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THE SECOND WORLD WAR

1939–1945

ROYAL AIR FORCE

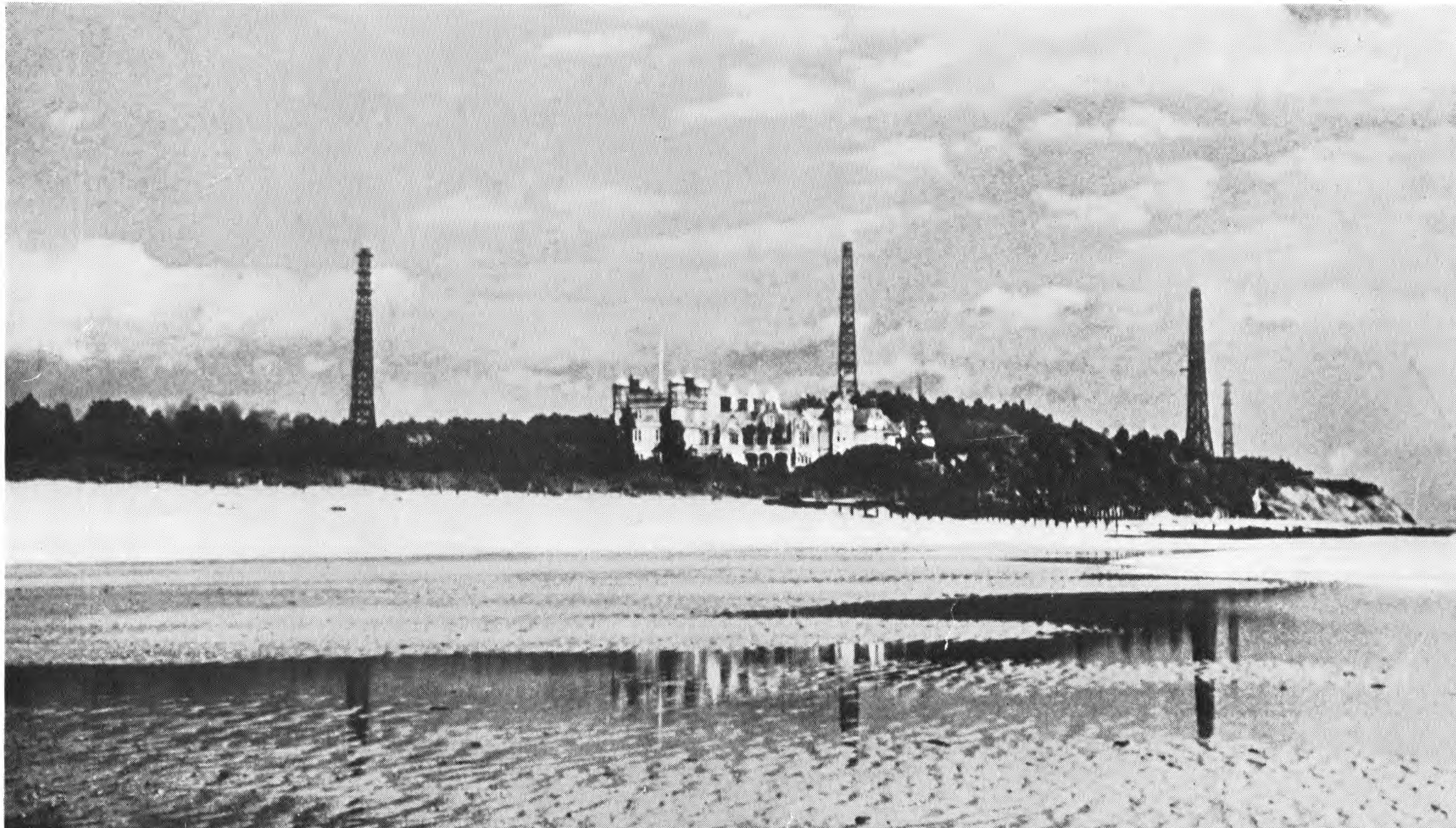
SIGNALS

VOLUME III

AIRCRAFT RADIO

ISSUED BY THE AIR MINISTRY (A.H.B.)

1956



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Promulgated for the information and guidance of all concerned.

By Command of the Air Council,

ISSUED BY THE AIR MINISTRY (A.H.B.)
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Preface

DURING the war a large number of radio navigation and blind bombing systems were developed, together with systems to assist aircraft to home to and land on airfields when weather and visibility were poor. Many were developed for particular types of aircraft or to suit particular operational conditions, and were not, therefore, suitable for wide adoption in the Royal Air Force as a whole. While operational requirements of individual commands, or of forces used in different tactical roles, were often conflicting or contradictory, the only limitations on production of equipments to meet the varying requirements were those of inventiveness and manufacturing capacity. There was, therefore, no urgent need for standardisation or close co-ordination of requirements, and many aircraft radio systems were developed to fulfil certain limited requirements. The development of radio for fighter aircraft is narrated in Volume V of the Royal Air Force Signals History, for the detection and location of enemy submarines and surface vessels in Volume VI, and for employment in radio counter-measures in Volume VII. This monograph deals with the development, production and operational use of aircraft wireless and radar equipment not covered by the more specialised volumes, and includes an account of the pre-war development of wireless direction-finding and aircraft communication systems.

AIRCRAFT RADIO

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Introduction

Aircraft radio systems were extensively used by the Royal Air Force during the Second World War to enable all types of aircraft to be operated effectively by day and night in practically all weather conditions. Although radio was well established as a means of providing assistance to air navigation before the war, the available systems suffered from very serious limitations. These were largely overcome during the course of the war by developments in radio technique. Many new aircraft radio devices, systems, and methods were evolved and applied for the specific purposes of different types of aircraft. Outstanding improvements were made in aircraft radio communications and new radio systems were developed for aircraft direction and position finding. Entirely new aircraft radio systems were designed and developed for a large variety of specialised aircraft functions, including aircraft interception, target location, precision blind bombing and the detection and location of shipping and submarines. Numerous other important applications of radio, which were made as a result of wartime experience of radio requirements for operations, included means for providing warning of approaching aircraft and automatic aiming and firing of aircraft guns. New radio systems were also introduced to give better facilities for aircraft 'homing' and more reliable assistance in approach and landing.

These systems, and many other notable innovations in the radio sphere, have endowed the Royal Air Force with enormous increases in its effective operational capabilities and striking power. They enabled aircraft to be operated, and to deliver their attacks, in adverse weather conditions which had previously restricted their full and effective use, provided means for detecting and locating unseen targets on land, in the air and at sea, and for improving the accuracy, timing and concentration of air attacks. Aircraft radio thus enabled air power to be applied, during the Second World War, with greater accuracy, precision and economy, than ever before. It also greatly extended the scope and frequency of air operations. These achievements led inevitably to the conclusion that aircraft radio had become a vital factor of air power.

CHAPTER 1

PRE-WAR DEVELOPMENT TRENDS

There can be no better way of appreciating the influence of radio on air power, and of understanding the functions of aircraft radio, than by studying development which led to the provision of the radio systems used by the Royal Air Force in the Second World War. The advances made in the two distinct and separate sciences of aeronautics and radio were unrelated ; progress in either or both did not necessarily represent a development in aircraft radio. It was only when developments in radio technique were deliberately applied to specific purposes in aviation that real progress was achieved in the sphere of aircraft radio. Whilst this may appear to be obvious in retrospect, it was certainly not evident until compelling circumstances, from time to time, resulted in the development of various applications of radio for installation in aircraft to increase the effectiveness of aircraft as weapons of war. The development of aircraft radio was thus, right from the start, directly dependent on fundamental developments made in both aeronautics and radio. It so happened that wireless communication and powered flight were both demonstrated as practical propositions at the beginning of the twentieth century. From then onwards, remarkable progress was achieved in both fields. It was, however, the combination of the two separate lines of progress which was to be of vital importance in war.

Inception of Radio and Aircraft

The origins of radio may be assumed to date from the important theoretical demonstration of electro-magnetic waves given by James Clark Maxwell to the Royal Society in 1864. This theory impelled scientists in many countries to conduct research and experiment to produce the waves described by Maxwell. It was not until the year 1887, however, that Heinrich Rudolf Hertz, of the University of Bonn, published the results of experiments in which he had succeeded in producing wireless waves by means of oscillating currents, thus confirming what Maxwell had discovered and proved mathematically.[1] In 1889, Professor Oliver Lodge was able to measure electrical radiation and, four years later, Edouard Branley invented the coherer, to receive Hertzian waves, which he described to the British Association at Edinburgh in 1893. In the same year, Nikola Testa published the results of his researches on high frequency currents and this contributed much to later work on wireless telegraphy. Also, in the year 1893, Hertz had shown that both light and electro-magnetic energy could be reflected in the form of a beam by means of concave mirrors. He made use of parabolic mirrors about two metres high and one metre wide and obtained successful results using a wavelength of about two-thirds of a metre. Such mirrors and their reflected beams were to be the radar scanners of the Second World War. In 1895, William Rutherford set up apparatus, in the Cavendish Laboratory, by which he received signals transmitted from an oscillator over a

[1] H. Hertz, *Electric Waves*, English translation, 1909.

distance of half a mile. During 1897, Professor F. Braun invented the cathode ray tube, for use as a laboratory instrument.[1] It is interesting to note that the firm of A.C. Cossor was manufacturing cathode ray oscillographs in 1902. Marconi was the first to demonstrate the practical utility of wireless telegraphy by establishing communication between Poldhu in Cornwall and St. Johns in Newfoundland in 1901. From the year 1899 onwards there were many new inventions in connection with wireless, particularly for the screening of wireless aerials in certain directions and for reflecting wireless waves. The object of using reflectors and screens was to prevent the wide dispersal of the energy in all directions and to concentrate it in a desired direction. It thus became well established that radio waves were reflected by material objects, and especially by metal reflectors of suitable dimensions. Wire screens and reflectors were used instead of parabolic mirrors since high power could only be generated on very long wavelengths and it was not practicable to make mirrors to suit such wavelengths. Mirrors were thus discarded until some thirty years later when they were used by the G.P.O. for beaming very short wavelength radio telephony communication across the Bristol Channel between Weston-super-Mare and Cardiff.[2] The development of wireless aerials and reflectors attracted the attention of many experimenters to the directive properties of certain types of aerials.[3] Consequently, between 1899 and 1906 there was a spate of patents taken out for directional types of aerials, including open spaced aerials, closed loops, and frame aerials. Some of them enabled the direction of incoming wireless waves to be determined when the aerial was arranged so that maximum signal intensity could be determined in a wireless receiver. The directional properties of the conveniently handled frame aerial were soon well understood and applied on many ships. In 1907, a method was introduced by E. Bellini and A. Tosi which avoided the need for rotating large spaced aerials in order to find the direction of incoming waves, and this device became known as a radiogoniometer. Its development resulted in the famous Bellini-Tosi direction finding stations which were used by the Royal Air Force for many years. One of the most important advances ever made in wireless technique was the invention of the thermionic valve in 1904 by J. A. Fleming. This enabled continuous waves to be generated, detected and amplified. Eventually, it enabled spark transmitters and coherer receivers to be superseded by valve equipment.[4]

Wireless was thus in its first stages of development as a means of communication and direction finding in 1903 when the Wright brothers' first power-driven aeroplane was flown for a distance of half a mile. Six years later, when, in 1909, they had greatly improved their aircraft and complied with the terms of a United States Government specification for a flying machine, wireless was already being used by many ships although it was still little more than an experimental novelty. The Royal Navy had set up a wireless section

[1] *The Cathode Ray Oscilloscope in Radio Research*, H.M.S.O., April 1933.

[2] A demonstration of beaming very short wavelengths across the English Channel was given by the Standard Telephones and Cables Company in 1930. Equipment made by this firm was used in October 1932 when a V.H.F. radio telephone link was opened by the G.P.O. for public service between Weston-super-Mare and Bristol with the radio terminals at Hutton and Dinas Powis. The wavelength used was approximately 5 metres.

[3] R. Keen, *Wireless Direction Finding*, 4th edition.

[4] It was decided in 1919 that in future all Royal Air Force wireless apparatus should be designed to reduce interference caused by the spark system. (A.H.B./IIA/1/53. D. of Plans Folder, Wireless.)

in H.M.S. *Vernon* and, in 1907, the 1st Wireless Company of the Royal Engineers had been formed at Farnborough, where it was assisting the R.E. Balloon School '. . . to devise wireless communication between balloons and the ground . . .' The first experiments were made in a captive balloon.

One of the earliest reports of wireless communication between air and ground stated that '. . . In May 1908, a free run was made in the Army balloon Pegasus in which a receiver of wireless had been installed. When the balloon was over Petersfield very good signals were received from the Aldershot wireless station which was 20 miles distant. . . .' During the same month some success was also achieved in the sending of wireless messages from the balloon. Experiments were also made at this time with wireless transmitters and receivers in aircraft, but reception was not possible. One pilot reported that the vibration and noise in the aircraft made it difficult to hear anything other than the aircraft engine and he reported that the problem of reception was complicated by '. . . the risk of fire, the splashes of oil and the rush of air . . . .' On 27 January 1911 the Army airship Beta went up from Farnborough equipped with wireless apparatus and many messages were sent from the airship to the ground up to a range of 30 miles. For a short time, while the airship engine stopped running, it was found possible to receive messages from the ground.[1]

In 1912, the first R.N.A.S. aircraft was fitted with wireless. This was the Short hydroplane S.41 known as H.M.S. *Amphibian*. The W/T equipment consisted of a 30-watt spark transmitter and a small crystal receiver and the range obtained was from three to five miles. For the Army manoeuvres of 1912 the airships Gamma and Delta were fitted with wireless equipment. The Delta broke down but the Gamma was an unqualified success. Her signals were received loud and clear at a distance of 35 miles. Also in 1912, M. Lucien Rouzet invented a light-weight engine-driven transmitter which he brought over from France and demonstrated in England. A number of these sets were purchased for the naval and military wings of the Royal Flying Corps. By 1913, 26 seaplanes had been equipped with Rouzet sets and the aircraft were engaged on W/T communication trials; reception experiments were also carried out with crystal receivers. Shortly before the Army manoeuvres in 1913 Lieut. B. T. James, piloting a B.E. aeroplane, succeeded in receiving wireless signals with his engine running at full power in the air. This remarkable success had been achieved by screening the wireless receiver from engine magneto interference by enclosing it with a thin iron box and by screening all the leads by wrapping them with copper tape. Also, the received signals were strengthened with relays invented by S. G. Brown.[2]

It had already been established by 1913 therefore that, whilst aircraft and wireless offered, individually, novel and rapid means of transport and communications, in combination they would provide a new means for reconnaissance in war. The Royal Naval Air Service and the Royal Flying Corps had been formed from the naval and military flying wings of the R.F.C. before war broke out in 1914, and the role of aircraft fitted with wireless had already been decided and tested during exercise manoeuvres on land and at sea. The aircraft of the R.N.A.S. were to be used for maritime reconnaissance

[1] Raleigh, *The War in the Air*, Volume I, Oxford University Press, 1922.

[2] A.H.B./IIE/246. *History of Wireless Telegraphy in the R.N.A.S., R.F.C., and R.A.F., 1914–1918.*

and naval co-operation. The Royal Flying Corps would be engaged on spotting for the gunners so that artillery fire could be made more accurate and effective. The R.F.C. was also to carry out reconnaissance overland and report on enemy dispositions and movements. The first function of aircraft radio was thus to provide communication between aircraft and ground stations for naval and military purposes.

When war broke out on 4 August 1914 wireless had been installed in several types of R.N.A.S. aeroplanes, seaplanes and airships, and in 16 aeroplanes of the R.F.C. The two R.N.A.S. airships Astra Torres and Parseval patrolled the English Channel during the passage of the Expeditionary Force whilst reporting ship movements by W/T. When the R.F.C. was mobilised in August 1914 a headquarters flight wireless section proceeded to France with Headquarters R.F.C. and a wireless flight also accompanied No. 4 Squadron R.F.C. The latter had at its disposal three early type B.E. aeroplanes. The two wireless sections left Farnborough about 12 August and met at Amiens aerodrome a few days later, whence they moved to Maubeuge on the frontier shortly before the Battle of Mons. The aircraft were used for daily reconnaissance flights and communicated with a wireless station which was installed in a wagon. After the Battle of Mons the wireless stations were brought back in stages and later they met again at the aerodrome at Fere-en-Targenois during the Battle of the Marne. It was during the Battle of the Marne that Lieutenants James and Lewis of the R.F.C. first worked in conjunction with field artillery. They devised a W/T reporting code to provide the information required by the gunners without unnecessary details. The value of aircraft in spotting for the guns was quickly appreciated and this resulted in ever-increasing demands being made for more aeroplanes fitted with wireless, and for ground stations with wireless mechanics to accompany almost every field battery commander.[1]

The method used by the Allies for directing artillery fire against hostile batteries and other targets by means of wireless telegraphy in aircraft was so successful that the Germans soon followed suit. They also quickly developed improved aircraft and anti-aircraft guns and this changed the conditions of spotting and of aerial reconnaissance. Faster and specialised types of aircraft were rapidly developed by both sides. These included small types for scouting and fighting patrols and larger aeroplanes for reconnaissance and bombing. The need for longer ranges of reconnaissance resulted in aircraft being designed with increased radius of action and thus the requirement arose for wireless sets to give greater ranges of communication. The early months of the First World War gave great impetus to the improvement of aircraft design and performance and also to practical developments in all branches of wireless. Demands from the front for large numbers of aircraft fitted with wireless sets for spotting made it necessary to establish the foundations of a radio industry to meet requirements within a short period.

The struggle for air superiority took a new turn when the aircraft of both sides were equipped with guns. Formation flying was adopted so that aircraft could give each other mutual support. Wireless telegraphy in the Morse code proved to be too slow for aircraft intercommunication, and radio telephony

[1] A.H.B./IIE/246.

was developed at the R.F.C. Experimental Wireless Section and was demonstrated in 1916. Radio telephony was introduced experimentally in two squadrons in France in 1917 and large numbers of aircraft were equipped during the following year. With experience improvements were made in the apparatus, and the careful fitting of flying helmets was recognised as one of the most important needs for efficient R/T working. The facility of direct speech by radio telephony between aircraft and base, and between pilots in formation, was only of limited tactical value at first since the quality of reception was poor. Various factors militated against the success of radio telephony in aircraft, amongst the more important being the use of a trailing aerial which was an encumbrance to fighter aircraft and which had to be dropped when enemy aircraft were sighted; the discomfort caused by head telephones, which was eventually overcome by including trained helmet fitters in squadrons; the high degree of concentration required to send and receive messages successfully; the high incidence of equipment unserviceability which could not be remedied until a completely efficient servicing organisation had been developed. In June 1918 radio telephony was introduced in the United Kingdom Home Defence system for purposes of passing raid information and directing the movements of defending aircraft towards interception of the enemy.

In the war at sea, all airships and aeroplanes were fitted with wireless for their duties on naval co-operation both in home waters and abroad. In March 1915 a small S.S. type airship, which consisted of an aeroplane fuselage with a gas envelope above it, was designed, and was used largely in searching for submarines. By July 1915 several of these airships were engaged on regular patrol work around the coast of the British Isles and by August their W/T ranges to base and to H.M. ships were often as much as 50 miles. R.N.A.S. aircraft fitted with wireless were also used for spotting during naval bombardments. In December 1915 orders were issued by the Admiralty to the naval coastal direction-finding stations to listen-in for aircraft wireless transmissions, and a procedure was adopted which afforded aircraft position-fixing facilities. The need for aircraft to be able to find their way to their destination and to return without disclosing their position led to development work on aircraft D/F installations. One of the earliest forms of aircraft direction-finder used a loop which was capable of being rotated on a vertical axis inside the fuselage. This enabled aircraft to take a bearing on a ground transmitting station without making a transmission or altering the aircraft heading. Such loops were made as large as could be accommodated in the aircraft, in view of the very low gain of the early wireless receivers. As soon as the gain of receivers was increased and amplifiers were introduced a satisfactory D/F service was provided for the slow aeroplanes of those days. Meanwhile, in order to obtain a greater signal pickup on transmitting stations at greater distances and thus increase homing ranges a wing loop aerial system was developed. This consisted of a loop of wire stuck on by doped bandages around the edges of the mainplanes and the outer inter-plane struts of biplanes. When the aircraft was heading towards the transmitting station signals of minimum strength were received, and the device was used for homing. This was improved by an invention of Captain J. Robinson who added separate loops having their planes at right-angles to the main loop and depending on the maximum pick-up of signal to determine the heading of the ground transmitter.[1] All loops were, however, subject to quadrantal errors due to the asymmetry of the metal parts of aircraft. The inherent and variable errors of this method of aircraft D/F were not understood at that time.

At the fifth meeting of the Technical Sub-Committee of the Air Board, which was held at the War Office on 10 November 1917, proposals were considered by the Director of Air Services for '. . . aerial navigation by W/T directional apparatus. . . .' The proposal was for three high-power transmitter stations to transmit at pre-arranged times so that bearings could be taken with directional aircraft W/T apparatus without the necessity for aircraft W/T transmissions to be made.[2] The advantages and disadvantages of the method and its value for use by enemy Zeppelins and submarines were considered in great detail. In reviewing the various systems of wireless direction-finding which had been developed up to the end of 1917, it was noted that the Germans were experimenting with a revolving directional W/T transmitter, by which bearings could be taken in aircraft if an accurate stop watch was carried.[3] At the seventh meeting of the Technical Sub-Committee of the Air Board on 7 December 1917 it was decided that four high-power W/T stations should be used for the proposed air navigation system and each station should transmit for five minutes once an hour.[4] The beacon service was required for the new Handley Page long-distance night-bombing aircraft which had been ordered by the Air Board in 1917 and of which the first hundred were expected to be available on or about 1 May 1918. At the end of the war only a small variety of types of wireless sets was available for general use in Royal Air Force aircraft and they were comparatively simple in design. The successful developments included the T.21 transmitter and Tf receiver, used in conjunction with the Type 57 ground transmitter for reconnaissance and general aircraft communication purposes. The T.21/Tf installation formed the basis of the R.A.F. aircraft communication system for many years after the war. No. 1 Sterling spark transmitter was used for short-range artillery co-operation. A receiver was not normally carried in the aircraft for these duties. For long-range artillery co-operation a spark transmitter Type 52*a* was carried in the aircraft, together with a 3-valve aircraft wireless receiver, Type Mark III. Wireless telephony was in a state of active development and several squadrons had already been fitted with equipment which consisted of the standard wireless telephone transmitter and the Type Mark III receiver coupled to the No. 12 R.A.F. amplifier. Up to the time of the signing of the armistice on 11 November 1918 wireless telephony had been used for training pilots in formation flying, and for passing reconnaissance reports to appropriate formation headquarters. No. 8 Squadron experimented with the use of R/T for communication with tanks but this was not very satisfactory owing to the difficulty of fitting a tank with an aerial suitable for use with the standard aircraft receiver Type Mark III. Long-range Type 7 and Mark II transmitters were fitted in seven squadrons before the end of the war for the purpose of passing reports direct to squadron headquarters during night bombing raids.[5] The increasing use of wireless in aircraft during the war is revealed by the

[1] A.M. File Air/02792/1917.

[2] A.M. File MR/1184.

[3] A.H.B./IIA/1/53.

[4] R.N. Air Department File Air/02772/1917. The high-power W/T stations selected for the beacon system were Ipswich, Poldhu, Stonehaven, and Rinella, operating on 2,650 metres.

[5] A.H.B./IIE/246.

quantities of apparatus purchased. During 1914 and 1915 aircraft wireless sets were ordered in small quantities of one or two dozen at a time at a cost of only a few hundred pounds. During 1917 expenditure on wireless apparatus for the year reached a figure in the region of £150,000. In 1918 aircraft wireless sets were being ordered in thousands, many from workshops and factories which had never previously undertaken wireless or instrument work, and expenditure on contracts amounted to several hundred thousand pounds.

General Development of Aircraft Radio 1919–1939

The First World War had greatly accelerated the development of aircraft and wireless. A comparatively large proportion of the population had been brought into contact with the two new sciences and a widespread interest had been created in both subjects. The main types of aircraft had been evolved for their specific tasks and included bombers, fighters, army co-operation aircraft, flying-boats and seaplanes. The advantages of wireless communication with aircraft had been recognised, and the value of wireless direction-finding as a complementary aid to dead-reckoning air navigation had been established. As a result of the widespread attention which had been attracted to the potentialities of aircraft and to wireless, the period immediately following the war saw research and development in both of those fields devoted chiefly to the exploitation of the new techniques for peace-time purposes. They were, however, of fundamental importance to the design of the vast number of radio devices which were used by the Royal Air Force during the Second World War. In order, therefore, to appreciate the apparently slow development of practical radio means for improving the operational efficiency of aircraft, it is essential to consider the main wireless developments during the period between the wars.

At the end of the war the attention of scientists working for the British Government in the wireless section of the National Physical Laboratory and in the research departments of commercial organisations was turned to investigations of radio wave propagation. Various unexplained errors had been detected in the practice of direction-finding. It was soon discovered that there were direct ground rays from wireless transmitters and also waves which were reflected from the upper atmosphere. The main evidence of this came from the closed loop direction-finder which had been devised as a practical instrument before the war and which was used chiefly as an aid to marine navigation. During the war, the development of the method was rapid and its application had become widespread. Its limitations were beginning to be understood in so far as the observed bearings of fixed transmitting stations were found to vary considerably during the night and the transition periods at sunrise and sunset. Similar effects were noticed when bearings were taken on transmissions from aircraft. It was this phenomenon that inspired F. Adcock in 1919 to devise his system of direction-finding. His conception of the main cause and cure of direction-finding errors was so complete that no fundamental change had been made in the technique of the Adcock direction-finder even by the end of the Second World War.

The introduction of broadcasting in 1923 was to have an ever-increasing effect on the development and expansion of the radio industry and resulted in the continual improvement of wireless transmitter and receiver circuit design. In particular, many new types of wireless valves and other components were produced by the rapidly expanding industry. New valves, having improved characteristics, made it possible to operate wireless services on the higher radio frequencies in the short-wave band. The short wave-lengths were soon found to give improved communications, when far less power was used, over much greater distances than were previously obtained using medium and long-wave frequencies. In the short-wave band there were more frequencies and less congestion and static interference than in the long-wave bands. The development of short-wave wireless made it possible to construct highly directional aerials which had to be of dimensions proportional and resonant to the wave-length, and radio beams were produced which concentrated the energy in a relatively narrow path, in the right direction, thus avoiding wasteful dispersion.

In 1920, rotating loop wireless beacon transmitters, devised by the Germans, were introduced, so that bearings could be taken in aircraft whilst the necessity for two-way communication with D/F ground stations was avoided. The beacons made use of a large loop aerial, connected to a ground transmitter, rotating completely through one revolution every minute. Characteristic signals were transmitted when the loop was pointing due north and a continuous note radiated during the remainder of the revolution. The D/F operator in the aircraft obtained his bearings in degrees from the beacon by timing the interval between the due north signal and the instant when zero signal fading occurred, and by multiplying the number of seconds by six.

At about the same time the radio range was introduced in the U.S.A. It had been invented in 1907 by O. Scheller, of the German *Lorenz* Company, who devised and patented the equi-signal wireless guidance system, later used as a basis for beam approach, which he called a ' course setter '. This defined a straight path over the earth's surface by using a radio beacon which radiated alternately on two adjacent beam aerials which were set at an angle to each other. The signals transmitted in Morse code were the letter A on one beam and B on the other. The signals were interlocked so that a continuous note was heard when both signals were received at the same strength. The radiation pattern of the beams overlapped and the line of equal signal strength from the two aerials was determined by a radio receiver, the output of which could be fed to head-set telephones or to an instrument in the cockpit. An extensive system of medium-frequency radio tracks was installed in the U.S.A. for the use of continental long-distance civil airlines. The radio range was not adopted by the Royal Air Force because the system lacked flexibility and security, and because the medium-frequency wave-band was congested in Europe, as well as being subject to variable errors and static interference. The most severe atmospheric interference usually occurred when the assistance of the system was most urgently required. Another aspect was that pilots were inclined always to ' ride the beam ' and if the system failed in bad weather they quickly became lost if their D.R. navigation was not accurate. Topography also affected the accuracy of the beams.

Improvements in the range and performance of bomber aircraft, and also of large civil aircraft, which were regarded as potential bombers, gave rise to the introduction of high-performance interceptor fighters in 1932. For their efficient tactical control improved radio-telephony equipment was produced. The requirements for radio communication systems for use with the new types of long-range aircraft made it necessary to introduce improved aircraft transmitters and receivers and there was also an insistent demand for better radio direction-finding facilities. None of the direction-finding methods used in the 1914–1918 war was as accurate as the D/F ground station method whereby bearings were taken on aircraft transmissions. The loop aerial proved to be the most useful of the aircraft devices and was used as the basis of the radio compass in which the loop was automatically orientated towards the selected radio beacon. This gave a continuous indication of its bearing to the pilot of an aircraft whilst the beacon was within range. An improved type of rotating beam medium-frequency radio beacon was installed at Orfordness in 1929 and another at Tangmere. The bearings of the beacons could be determined in aircraft by using the wireless receiver and a stop watch. After five years of trial and consideration they were finally abandoned in 1935, chiefly because the system was insecure, subject to interference, and capable of being used by enemy aircraft in time of war. When metal-framed mainplanes were introduced, the loops were no longer effective and heavy gauge copper wire loops were then stretched on supports outboard of the mainplanes. The provision of D/F loops for monoplanes presented considerable difficulties and eventually a small outboard loop above or below the fuselage was used. Certain types of small ring loop were made retractable. They were used with radio compasses which enabled a set course to be steered by keeping a central zero dashboard instrument in the zero position. To overcome icing troubles they were enclosed inside a streamlined casing in which the loop could be rotated freely in all conditions.

Since the early days of aircraft a great deal of thought and research had been devoted to possible applications of radio to give assistance to pilots when approaching to land in conditions of low visibility. This function of aircraft radio was first demonstrated when the German *Lorenz* system made its appearance in 1933. This was adopted by the Royal Air Force on an experimental basis in December 1938 and was later adopted, in a modified form, as Standard Beam Approach. The main approach beam of the *Lorenz* and S.B.A. systems depended on the equi-signal path defined by two overlapping radio beams.

The annual air exercises of the Royal Air Force held in the summer of 1934 revealed the weakness of the United Kingdom air defence system. A detailed analysis of the results showed up clearly what was already more than a mere suspicion. There would be little chance of our fighter aircraft intercepting enemy bombers by night and even daylight interceptions would only be possible in favourable conditions.[1] Standing patrols of fighters would be costly and uneconomical. Moreover, they would be quite impracticable on the scale required to provide anything like a defence in height and depth against the new and improved bomber aircraft. Pilots of single-seater fighter aircraft flying in or above cloud during bad weather and at night had no means of navigation other than their flying instruments and a magnetic compass, and they had to rely on extremely rough-and-ready dead-reckoning without an accurate knowledge of the wind speed and direction. They could not be given any navigational assistance by radio since there were no facilities available in the high-frequency wave bands used for fighter R/T. Therefore, in conditions of poor visibility and at night, when fighter pilots could not fix their position by seeing the ground, there was no system by which they could be given instructions accurately enough to direct them to intercept enemy raiders. Another difficulty was that the position and track of enemy raiders could only be estimated very

[1] A.M. File S.34808.

approximately in bad weather and at night. The Observer Corps reports of aircraft movements depended on visual and aural methods. Against high-flying raiders little raid intelligence of real help to the defending aircraft could be made available.

The development of radio communication systems operating in short-wave bands had been rapidly advanced between 1923 and 1931 and a great deal of attention had been given to the development of high-frequency direction-finders. H.F. D/F stations, developed at the Royal Aircraft Establishment, were installed at Hornchurch and Biggin Hill in 1931/1932 for Service trials. The trials took place in 1933/1934 when tests were made during daylight and at night with successful results. Following a series of homing trials and demonstrations during the autumn of 1935, it was decided at the Air Ministry in March 1936 that H.F. D/F installations were to be provided at all fighter sector airfields. In August 1936 methods of homing and fixing fighter aircraft were practised in a series of exercises at Biggin Hill. Fighter positions were fixed by the triangulation of bearings from H.F. D/F stations at Northolt, North Weald, and Biggin Hill. The fixes were accurate within a distance of about three miles but the time taken to obtain and pass the position to the fighter aircraft by R/T averaged about one minute.[1] It was soon apparent that one H.F. D/F station in each sector was quite inadequate to permit fixing to be a recognised function of the H.F. D/F stations.[2] In July 1936 it had been decided that experiments should be made to develop a fighter interception technique, and to find out what period of warning and accuracy of positioning were necessary. The experiments were guided by the Committee for the Scientific Survey of Air Defence, which had been set up at the end of 1934.[3] Considerable success was achieved, and the immediate result was a demand for additional H.F. D/F stations to provide more rapid and accurate facilities for fixing the position of fighter aircraft.

These new H.F. developments of the old D/F technique represented a small but nevertheless important contribution to the solution of a big problem. It still remained to devise means for obtaining warning of the approach of enemy raiders, tracking their positions, and directing the fighters to the best position for attacking them. The H.F. D/F system could at least assist the operations staff to keep track of our own fighter aircraft and that represented one finite factor amongst the unknown quantities in the problems of air defence.

It was known by the Air Ministry in 1934 that Germany was expanding its aircraft industry and building up a powerful force of modern aircraft. These facts served to emphasise the vital importance of improving the air defence system, and helped to clarify the nature and magnitude of the three-dimensional problems to be solved in order to achieve a really effective improvement. In this instance, as so often happens, the understanding of the problems represented progress towards their solution. It remained to apply to the problems of air defence scientific radio principles which had already been evolved by Professor E. V. Appleton and his colleagues in their investigations of the ionosphere. An important radio phenomenon which was to give more than a clue to the solution of the air defence problems was provided by radio engineers of the General Post Office. During tests carried out on the Very High Frequency R/T experimental link, on a wavelength of 5 metres, between the G.P.O. research stations at Dollis Hill and Colney Heath on 16 December 1931, it was observed at the latter

[1] A.M. File S.39190/1. [2] A.M. File S.34961. [3] A.M. File S.38638.

station that beats were often being received on the tone transmission from the Dollis Hill transmitter. In all instances when this occurred, an aeroplane was heard and seen in the neighbourhood. The only possible explanation which could be given for the phenomenon was that interference was set up between the directly received radio waves and those which were re-radiated from the aircraft. During the period between 16 December 1931 and 5 February 1932 observers recorded, in the Colney Heath station log, details of such radio reflections from 83 individual aircraft. Two copies of the report were sent to the Air Ministry on 5 September 1932, three to the Radio Research Board, and one to the Wireless Division of the National Physical Laboratory.[1] The Radio Research Board had been set up in 1920 by the Department of Scientific and Industrial Research, and its programme of work included investigation of the ionosphere and study of the propagation of radio waves, under the direction of Professor E. V. Appleton, at the radio research stations at Slough and Peterborough and at King's College, London. The work was undertaken with a view to the long-term improvement of radio communications. In 1924 Appleton had devised a method of frequency modulation of continuous waves for measuring the height of the Heaviside Layer. This method of measuring distance by means of radio waves did not prove as useful as had been anticipated, although it was later used in radio altimeters. Also in 1924, the American scientists, G. Breit and M. A. Tuve, had invented the pulse technique or group-retardation method for obtaining an echo or reflection of radio energy from the conducting layers of the upper atmosphere, but they did not develop it. A combination of the pulse technique with cathode-ray tubes and linear time-bases was developed by Professor Appleton and his colleagues from 1930 onwards. This development greatly aided quantitative study of the ionosphere and its effect upon wireless propagation and was certainly the most striking development which eventually made possible the detection of aircraft by radio.

By the end of 1934, the increasing strength of German air power, the more aggressive foreign policy being adopted by Hitler, and the inability of the British air defence system to meet the threat of bombing, caused the Air Ministry to consider the possibilities of science for solving the problems of air defence. In November 1934, at the suggestion of the Director of Scientific Research, Mr. H. E. Wimperis, the Air Ministry set up a committee composed of eminent scientists under the chairmanship of Mr. H. T. Tizard '. . . to consider how far recent advances in scientific and technical knowledge can be used to strengthen the present methods of defence against hostile aircraft. . . .' The committee soon appreciated that the major problem was '. . . to effect the engagement of fighter aircraft with hostile bombers . . .' and they immediately turned to the radio field for means to achieve that object. In January 1935 the C.S.S.A.D. received a proposal for the detection and location of aircraft by radio. On 26 February 1935 a demonstration was given to the committee of radio echoes being reflected from an aircraft flying in the main beam of radiation of a radio transmitter at the B.B.C. station at Daventry. The committee was at once convinced of the possibility of developing the method. Mr. R. A. Watson Watt, who had presented the original proposals and arranged the demonstration, was at that time the Superintendent of the

[1] G.P.O. Radio Report No. 223 dated 3 June 1932, Part 5 : 'The Further Development of V.H.F. Transmitters and Receivers '. Distribution records held by the Wireless Planning Section, Radio Branch, E.-in-C.'s Office, G.P.O. Headquarters.

Radio Department of the National Physical Laboratory. He presented to the C.S.S.A.D. a memorandum dated 27 February 1935 on '. . . the detection and location of aircraft by radio methods . . .'[1] Within a few months, early experimental work at Orfordness had proved the practicability of the location of aircraft by radio waves. Thereafter, further research and development continued rapidly on the installation of the first few ground stations of the Home Defence radar system.

The original proposals for the construction of a chain of ground radar stations to give early warning of the approach of enemy aircraft also referred to the need for identifying our own aircraft and discriminating between them and enemy aircraft. This proposal was recognised as being an essential feature of the radar defence system if abortive fighter sorties were to be eliminated and incidents in which fighters attacked our own aircraft were to be avoided. The idea was therefore developed during 1935 and 1936 but research work on the aircraft radar identification system was not begun at Bawdsey Research Station until the latter part of 1937. The first experimental models of the radar equipment for identification of friend from foe, I.F.F., were encouraging from a technical stand-point, but the excrescence of the additional radar aerial system was a serious drawback to the adoption of the system.

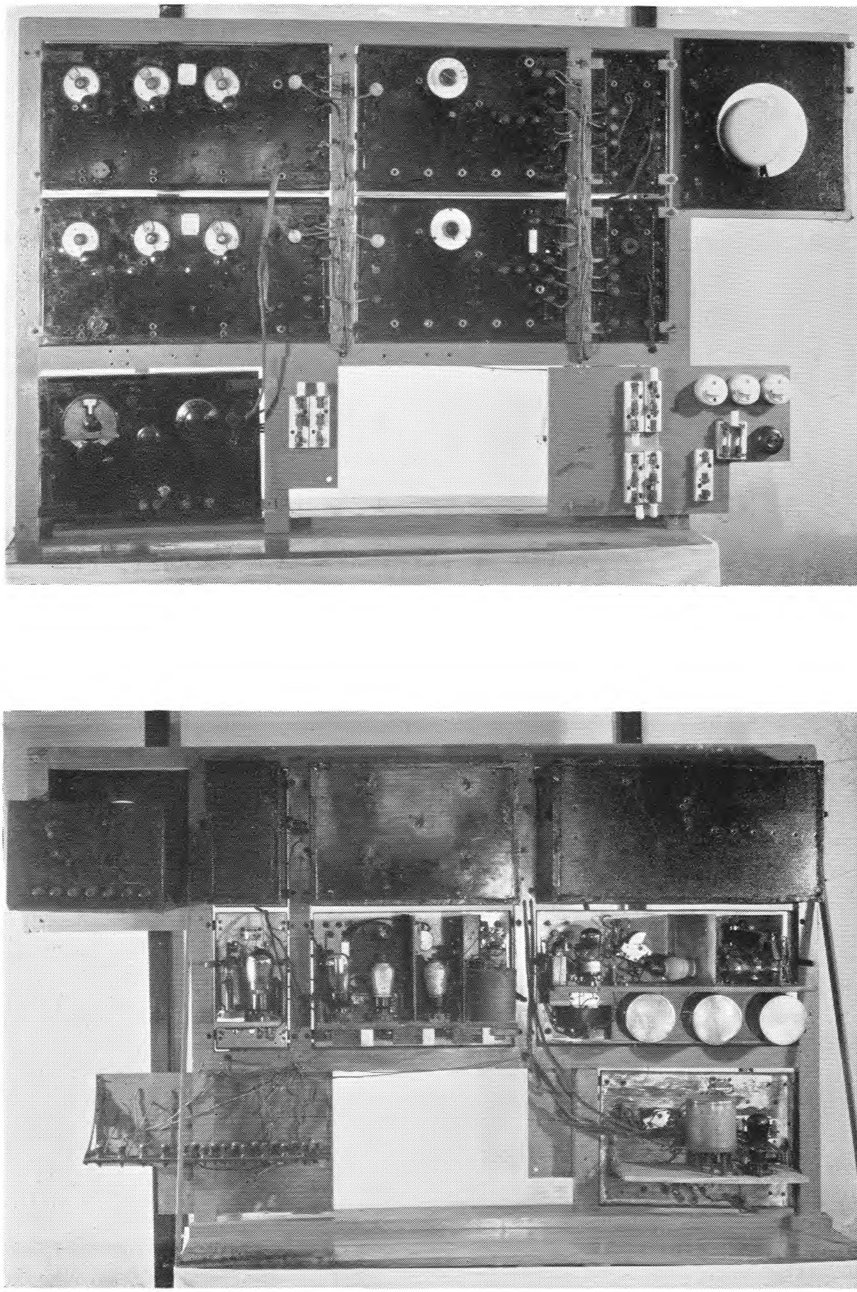
In the Home Defence exercises of 1938 the M.F. D/F system was used for the identification of friendly bomber aircraft but the method proved to be unsatisfactory and Headquarters Fighter Command was convinced of the need for a radar system for identifying aircraft. This had the effect of stimulating official interest in identification experiments and an improved method was proposed in which aircraft carried a small radar receiver and transmitter known as a transponder. The equipment was developed and successfully demonstrated in March 1939. Special efforts were made to produce a small number of sets within a few months and during the air exercises in August 1939 it was decided that the I.F.F. system for the identification of friendly aircraft should be adopted, and preparations were immediately made for large-scale production.[2]

Great possibilities of expanding the functions of aircraft radio to provide new and improved facilities for aircraft were foreseen during the early development of the radar defence system in 1935. The Committee for the Scientific Survey of Air Defence agreed to proposals made in February 1936 for a radar system to be developed and installed in fighter aircraft to enable them to locate and attack enemy aircraft.[3] There was only a relatively small scientific staff available at Bawdsey, however, and development of the aircraft equipment could only be undertaken at the expense of the more urgent tasks

[1] Radar was originally known as radiolocation and for security reasons was referred to as R.D.F. until the term radiolocation was used in the first public disclosure of the system in June 1941. The term radar was introduced to conform to U.S.A. terminology in 1943, and was derived from its functions of radio detection and ranging.

[2] The development of the I.F.F. system and its introduction to Service use are fully described in the Royal Air Force Signals History, Volume V: 'Fighter Control and Interception'.

[3] Ground radar was known as R.D.F. 1 and aircraft radar as R.D.F. 2. In July 1936 the possibility of combining infra-red ray technique and television, to enable pilots to obtain a continuous view of ground otherwise obscured by clouds or fog, to facilitate navigation and blind bombing, was discussed at the Air Ministry. (A.H.B./IIA/1/53.)



Radio Receiver used in the First Radar Experiment—26 February 1935

[Facing page 12

of developing the long-range early warning stations. In spite of this, development was continued intermittently during the next eighteen months, and an experimental aircraft radar installation was completed by July 1937. The primitive radar transmitter and receiver were installed in an Anson aircraft at Martlesham Heath and on one of its first flights radar echoes were obtained from a small ship at a range of about five miles. On 4 September 1937 the Anson conducted a search in very bad weather over the North Sea for a small fleet of H.M. ships making its way to a combined exercise area. With the aid of the radar equipment the aircraft located H.M.S. *Rodney* and H.M.S. *Courageous*, unmistakable echoes being received at a range of nine miles. The practicability of using aircraft radio for search at sea was thus established but the main and urgent requirement was for an efficient air defence system, and little additional assistance could be spared for the development of R.D.F.2 in the maritime reconnaissance role. To enable the applications of aircraft radar to be distinguished, the names A.S.V. for Air to Surface Vessel and A.I. for Aircraft Interception were brought into use.[1]

During the development period following the success of the initial experiments, many improvements were incorporated which were subsequently to prove valuable in the development of A.I., on which work was concentrated after September 1938. The direction-finding properties of various aerial systems were tried, and the system adopted for early aircraft radar installations was the 'forward-looking' system, which was based on an application of the equi-signal wireless guidance beam. The transmitting aerial radiated a fan-shaped beam in front of and below the aircraft, and search was confined to that area. The direction of the target was determined by means of two receiving aerials. They were designed to have overlapping lobes, and their mounting on aircraft was so arranged that signals of equal strength were obtained in both aerials only when the target was dead ahead. The signals were compared by switching the receiver alternately from one aerial to the other. By appropriately changing the line of flight of the aircraft the signals could be equalised and the aircraft homed to the target.

Another method of direction-finding was developed during the latter part of 1938. This employed a rotating half-wave dipole aerial which was common to both the aircraft transmitter and receiver. A cathode-ray tube was used to display the impulse reflected from target aircraft and ships. The echo impulses were superimposed on a rotating radial time-base synchronised with the rotation of the aerial, and the afterglow of the tube gave the approximate bearing of the target.[2] This latter method was seen to hold great possibilities, but its drawback at the time was that airborne radar was operating on a wavelength of just over one metre. Since the rotating aerial, to be efficient, had to be half a wavelength long, it was not suitable for installation in aircraft and the lobe-switching method was adopted. The scientists concerned with the development of airborne radar realised that its potentialities would be greatly expanded if they were able to use wavelengths of a few centimetres. At the end of 1938, however, there were no valves available for operating at the very high frequencies which were necessary to achieve radio wavelengths of

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[1] *See* Royal Air Force Signals History, Volume VI : 'Radio in Maritime Warfare', for the development and use of A.S.V. by the Royal Air Force during the Second World War.

[2] This method was later used in centimetric wave technique.

a few centimetres. Although Hertz had, in laboratory experiments, generated such waves by spark excitation of small resonant circuits, he had only managed to generate minute quantities of power on such very short wavelengths.

The early experiments with A.I. and A.S.V. were made with installations designed to use valves which were already in existence. Valves for operating on a wavelength of about 17 centimetres had been developed for an experimental G.P.O. cross-channel radio teleprinter service in 1930, but they could handle only a small fraction of the high-power pulse energy which had to be radiated for the operation of airborne radar.[1] The Admiralty Signal School had designed and produced suitable high power silica valves for the ground radar stations but they were not suitable for the very short wavelengths required for airborne radar. In any event the total output of valves from the School was barely sufficient for ground radar stations and naval communication transmitters at the time of the crisis in September 1938.

There was an urgent operational need for valves which would operate on higher wavelengths at the end of 1938. The maximum range achieved with A.I. at this time was no greater than the height of the aircraft above the ground, and this severe limitation could only be overcome by the use of a very narrow beam which demanded an aerial small enough for fitting in aircraft. The need for a narrow beam arose because with broad beam radiation power was dispersed and echoes of varying strength were received from many directions depending largely on the contours of the ground. So far as A.S.V. was concerned, the detection of ships at ranges good enough to develop an attack depended on the use of the largest possible ratio of effective height of aerial to the wavelength. With radar aerials on aircraft this meant that the wavelength had to be as short as possible. It had also been determined that the accurate measurement of direction would be greatly facilitated if centimetric wavelengths could be used. Whilst the advantages of centimetric wavelengths had thus been appreciated, they had not been pursued owing to the great pressure of work on other applications of radar and because, at the beginning of 1939, there were no valves which would handle the necessary pulse power at the required frequency.

The first type of valve specially designed for pulse transmission was produced early in 1939, and was a small metal and glass valve called the 'micro-pup'. It was constructed with a copper anode which was also part of the envelope. It was much smaller than previous valves and could be used at shorter wavelengths. It made possible the design of A.I. for night fighters where small size was essential. A number of modified versions of the valve were soon introduced and they were found to be suitable for use on decimetre wavelengths, which were also used for the early versions of A.S.V. equipment. However, it was soon apparent that the valves could not be operated efficiently on a wavelength of less than about one metre.

The operational need for the full exploitation of radar, particularly for aircraft equipment, was known to be dependent on the development of valves

[1] This micro-wave equipment is described by Macpherson and Ulrich in 'Electrical Communications'—April 1936. The V.H.F. radio teleprinter service operated between Lympne and St. Inglevert. The beam was concentrated by the use of parabolic reflectors directed towards the receiving station. The beams provided straight line transmissions to obviate interference, including static, and to produce a steady signal for teleprinter working. This service was provided for civil aviation purposes and the cost was borne by the French and British Air Ministries.

for working on centimetre wavelengths. In the autumn of 1939 it was therefore decided to devote increased resources to the development of such valves, and research teams at the University of Birmingham and at the Clarendon Laboratory, Oxford, started a research programme. Subsequently the research laboratories of several British commercial organisations were also co-opted. The co-ordination of valve development had been controlled since 1938 by the Co-ordination of Valve Development Committee, which proved to be a most successful example of inter-Service and industrial collaboration. It included the expert advice and assistance of leading physicists from the Cavendish Laboratory at Cambridge and the Clarendon Laboratory at Oxford. An offshoot of the C.V.D. was the '10-Centimetre Committee' which was set up early in 1940.

The result of this co-ordination and concentration of development was the production of a new type of magnetron valve which had a power rating of about ½ kilowatt at a wavelength of 10 centimetres. This great achievement was the result of the adaptation of the split-anode magnetron for use with cavity resonators. It was due to the work which had been entrusted to Professor J. T. Randall and Mr. H. A. H. Boot, and thus became known as the Randall-Boot magnetron. G.E.C. Research Laboratories then produced a new design of this valve (E.1189) which had a pulse output of some 10 kilowatts at a wavelength of 10 centimetres. In the meantime the design of receiving valves to operate on centimetre wavelengths had been developed by the Clarendon Laboratory, the Admiralty Signals Establishment valve development team at Bristol University, the research laboratories of the firms of Electrical and Musical Industries and Standard Telephones and Cables, and the A.M.R.E., as the result of which suitable oscillators and detectors were produced.[1] The culminating point in the basic phase of centimetric development was reached at the T.R.E. at Worth Matravers, Dorset, on 13 August 1940, when echoes were obtained from an aircraft at a range of about six miles with the use of an experimental installation on the ground. All that remained was '. . . to put it in an aeroplane . . .'[2]

The development of various valves for centimetric radar was undoubtedly the most important in the whole course of wartime technical radio developments. It was due to the scientists' appreciation of the tactical possibilities of pulse technique and their realisation, at an early stage in the development of radar, of what could be done on shorter wavelengths at a power which had not previously been generated. The Randall-Boot cavity magnetron was working within three months of the problem being given to the inventors, and eighteen months later centimetric radar was in daily use by both the Royal Navy and the Royal Air Force.[3]

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[1] Radio Board Memorandum—Radio (45) 26; 20 September 1945.

[2] The A.M.R.E. became the T.R.E. in May 1940.

[3] The early methods of using centimetric wavelengths made use of two metal parabolic reflectors, one for transmitting and one for receiving the radar reflections. At very short wavelengths it was possible to make the mirrors a convenient size, but for aircraft it was necessary to use one mirror for both purposes if possible. This was achieved in June 1941, as a result of collaboration between the research sections of the T.R.E. and a team at the Clarendon Laboratory, by the use of a gas-filled cavity resonator. This led immediately to the development of centimetric A.I. and A.S.V. and subsequently H2S. The basic principle of operation of the three aircraft installations was the radar scanner which radiated a narrow beam of pulse energy and received back in the same reflector the radar echoes from aircraft, from ships, or from the ground, according to the particular application.

Between the First and Second World Wars, technical research on and development of aircraft radio for the Royal Air Force were conducted by the Royal Aircraft Establishment at Farnborough. From 1935 onwards the early developments in radar were chiefly carried out at Orfordness and in the Radio Department of the National Physical Laboratory at Teddington.[1] In 1936 provision was made for the establishment of the Bawdsey Research Station, later the Air Ministry Research Establishment for research on and development of radio detection and location of aircraft. Research and development of signals equipment, excluding R.D.F., was seriously restricted at the R.A.E. by the limited financial provision made for such work.[2] Moreover, the pay and conditions of service for the scientific and technical staff employed in the Radio Department of the R.A.E. did not attract sufficient personnel with the highest qualifications, and the establishment was inadequate for the research and development tasks in all branches of radio required for the Royal Air Force. On the other hand, full support and good provision were made for the development of R.D.F. and the Bawdsey Research Station from 1936 onwards. Even so, it was not until it was apparent that war was inevitable after the Munich crisis of September 1938 that a great sense of urgency pervaded the whole field of radio development. Then the era of financial stringency in the development of aircraft radio came to an end, and it became possible for increased attention to be devoted to the requirements of aircraft radio and other types of signals equipment. In particular, activity in the development of aircraft radar search and identification equipment at the Bawdsey Research Station was greatly increased. By October 1938 contracts had been arranged with the firm of Cossor for the production of receivers and with that of Metropolitan-Vickers for the associated transmitters of the first aircraft radar installation, which was known as A.I. Mark I. The rapid deterioration in the political situation during the spring of 1939 brought an even greater sense of urgency to the further development and exploitation of radar. Greatly improved receivers were developed on the basis of the Pye television receiver.[3] Effective radio frequency switches were devised to give precise direction-finding in two dimensions by switching from one aerial to another for both port and starboard and up and down 'lobe-switching'. An important step forward in the design of aircraft radar transmitters was made possible by the General Electric Company valve Type V.T.90, which had a greatly increased pulse power output rating at the frequencies then in use.

Demonstrations with an experimental aircraft radar installation made during the latter part of 1938 and the early months of 1939 showed that coastline, towns, and railways could be distinguished by the pattern and types of radar echoes which were received and indicated that the functions of aircraft radar could be made to include entirely new methods of air navigation and bombing.[4] In December 1938 Headquarters Bomber Command

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[1] The Radio Department of the N.P.L. was formed on 1 May 1933 to amalgamate the Wireless Division of the N.P.L. and the Radio Research Station at Slough, with Mr. R. A. Watson Watt as Superintendent. *See* report of R.R.B. for period 1 January 1932 to 30 September 1933. (H.M.S.O., 1934.)

[2] A.H.B./IIA/1/53.

[3] The first public television service in the world was started in England in 1936.

[4] Squadron Leader R. G. Hart, who was the senior R.A.F. officer concerned with the development and operational use of radar at the Bawdsey Research Station, flew on several of these demonstrations during the latter months of 1938. He observed most distinctive echoes from railways, and also noticed reflections from the cranes on the quayside at Harwich. His personal observations were later to influence the decision to develop blind bombing equipment (H2S) when he was Director of Radar at the Air Ministry in December 1941.

submitted a list of its problems and requirements of aircraft radio for consideration by the Committee for the Scientific Survey of Air Offence in which was stressed the need for the development of aircraft radar in its application to bombing. Prospective functions had, however, to take second place in view of the overriding necessity for the improvement of the air defence system. The main features of this were the ground early warning system, aircraft interception, and identification. All available resources were concentrated on the extension of the early warning system and the development of A.I. was given priority over all other aircraft radar functions. In June 1939 a practical A.I. installation was demonstrated to the Air Defence Committee, of which Mr. Winston Churchill was a member. A.I. production was started in July 1939 and on the night of 3 September a Blenheim aircraft equipped with A.I. Mark I was flying in the London region with a member of the Bawdsey research team acting as observer. Two other aircraft had also been fitted with the equipment. The development of A.S.V. for locating ships at sea had to be deliberately slowed down in favour of development of A.I. for night fighters. Production of the A.I. equipment itself was inevitably delayed because of the priority which had to be given to create the ground early warning, location, and reporting system, during 1937 and 1938. Improvement of the radar equipment of the main early warning stations had also to be deferred until a rudimentary system gave the essential minimum of early warning. Thus, when war broke out, although the ground radar early warning system had been developed to a practical state of efficiency, the development of aircraft radar was far less advanced.

The aircraft radio systems in use in the Royal Air Force before the war provided means of communication between the ground and aircraft for assistance in navigation and landing and also for emergency and rescue purposes. The aircraft communications service enabled aircraft to receive instructions and to report as necessary, whilst the radio direction-finding facilities provided a rough check on the basic system of air navigation by dead-reckoning. Additional checks on the accuracy of air navigation were available to aircraft in suitable conditions by map reading and by astronomical observation. The art of air navigation could not, however, be absolutely precise since the normal concomitants of D.R., radio direction and position finding, and all visual observation, were variable errors which could not be entirely eliminated and which were usually aggravated by indeterminate variations in wind speed and direction. In good weather air navigation was accurate enough for all practical purposes, but in bad weather, especially at night in war conditions over enemy territory, air navigation was hardly accurate enough to enable aircraft to be operated with good prospects of success.

In radio direction-finding one or more D/F ground stations took bearings on a radio transmission from an aircraft which was then told its bearings from the station. Alternatively, the plotted position of the aircraft could be passed to it when this was determined by two or more D/F stations having taken simultaneous bearings. Another method of radio direction-finding, installed in a few of the larger types of aircraft before the war, used a D/F loop installation for taking bearings of ground radio transmissions. Both methods suffered from serious errors and severe limitations. The main disadvantages were due to the inherent unreliability of the medium and high-frequency wavebands, which had to be used before the war. The accuracy to be expected from M.F. and H.F. D/F stations in 1939 was a possible error of between two and three degrees in radial bearing, whilst aircraft loop D/F errors were often about four degrees. Unfortunately the errors were not consistent owing to natural factors such as coastal refraction, sky wave reflections and aircraft quadrantal errors. Also, by 1939 the medium and high-frequency wavebands were greatly congested in Europe. A high level of natural static interference, particularly on the medium waves, was also present. The range of the ground D/F system was between 200 and 300 miles but good bearings with loops could not be expected at ranges over 120 miles.[1]

Pilots and navigators of aircraft therefore regarded a position or fix obtained by radio direction-finding with reasonable scepticism, and aircraft radio was treated as an aid only, complementary to dead reckoning, map reading, and astronomical navigation. It could not be relied upon to provide precise information of bearing or position at any considerable range, and in any case, in the event of failure of aircraft radio equipment during a sortie, whilst the flight plan might be continued or abandoned it was always necessary to be able to navigate the aircraft safely to a base. These facts were generally well understood at the beginning of the war, and indeed throughout the war years dead-reckoning was always regarded as the essential basis of air navigation.

The first proposal for using pulse transmission to assist aircraft navigation was made in 1938 by Mr. R. J. Dippy, a member of the staff of the Bawdsey Research Station. No requirement for such a system had been raised at the time, but he was aware of the shortcomings of the methods by which it was intended to navigate in time of war. Although the use of radar had been adopted to assist Fighter Command when the pre-war exercises revealed the deficiencies of air defence, little thought was given to its use for aircraft of Bomber Command. It was a small force, as befitted the needs of a non-aggressive nation according to the strategic concept of those times, and its problems were considered to be negligible compared with the overriding needs of defence. No opportunities for realistic exercises existed during peace-time as there was no practical way of combining night-fighter attacks, blacked-out towns, enemy anti-aircraft fire, high-powered searchlights and decoy fires, which made even approximately accurate bombing an impossible task during the early days of the war, even in good weather. In any event, the general opinion was that a bombing offensive, when mounted, would be carried out in daylight, and no difficulty in identifying and hitting a target was anticipated. Mr. R. J. Dippy's proposal was consequently rejected by the Air Ministry and Headquarters Bomber Command.

The operational requirements of war and the conditions of flying in bad weather at night over blacked-out enemy territory, or over the sea, with the constant possibility of being attacked by enemy night fighters and ground anti-aircraft defences, led to a modification of the pre-war concept that aircraft radio was no more than an aid to navigation. The pressing needs of hostilities necessitated aircraft being operated in bad weather which made impossible the standard and primary systems of air navigation by visual observation outside the aircraft. Also, aircraft navigators not only needed to find their way to the target area, often after long periods of evasive action, but to locate and identify

[1] A.M. File S.5997.

the target on the ground, at sea or even in the air, and to deliver an accurate attack. These requirements provided a compelling influence on the development and introduction of radio systems to air warfare. In this situation radio was found to be the only practicable method for aircraft crews to fix their position, to detect an enemy, and to locate the target in all conditions. Thus radio came to be regarded as an essential primary equipment of operational aircraft. Nevertheless, the older and approximate systems of air navigation by observation continued to hold their important place in meeting the needs of the Royal Air Force beyond the range of the new radio systems, and always in providing for the inevitable electrical and radio equipment failures in aircraft.

CHAPTER 2

H2S MARK I

The pre-war conception of operating bomber aircraft against enemy territory envisaged their proceeding to target areas either independently or in small units during the hours of daylight. It seemed reasonable to assume that in the majority of instances the target would be found and identified with the aid of existing navigation facilities. Experience with prediction systems other than those controlled by radar suggested that the risk from anti-aircraft defences would be slight and it was believed that the bombers, despite their lower performance, would generally be able to evade fighter attack. Early in the war it became obvious that, with the types of aircraft available, daylight bombing could not be maintained without prohibitive losses. The development of early warning radar systems enabled fighters to be deployed sufficiently early to ensure interception of approaching bombers, which were too lightly armed to defend themselves effectively. Both the enemy and ourselves were forced to bomb at night as a matter of expediency. It soon became clear that navigation and target identification at night presented problems which were beyond the capacity of the aircrews of the rapidly expanding Bomber Command to solve without the aid of aircraft radar. In March 1942 the introduction of Gee resulted in an immediate improvement in the efficiency of bombing operations but its use was confined to attacks against targets within its clearly defined limitations of range, it was vulnerable to jamming, and it was not sufficiently accurate to ensure that bombing was concentrated on the target when visual identification of the target was impossible. With Gee, and later Oboe, it was possible to concentrate raids both in space and time, and the accuracy of bomb-aiming was vastly improved. Also these aids enabled bomber aircraft to be routed so as to avoid heavily defended areas. But without H2S the bombing of Berlin and many other large towns deep in Germany would not have been a practicable proposition.

Early Research and Experiments on Aircraft Radar

Research on the problems of developing airborne radar to work in conjunction with ground radar as a means of intercepting enemy aircraft was begun in 1936 by Dr. E. G. Bowen and a small team of scientists.[1] The most obvious difficulty was that presented by the dimensions of the various units of a radar installation of that time. All the early radar equipment was very large and required high power input. It worked on the comparatively long wavelength of 13 metres, and therefore aerial systems were too cumbersome for aircraft installation. Consequently it was first of all essential to reduce the size of radar equipment and to shorten the wavelength on which it was operated. The second of these tasks was the harder and the research team was forced to experiment at the limit of the available radar technique, and the performance of the resultant

[1] A. G. Touch, R. Hanbury Brown, F. A. Hibberd. *See* Royal Air Force Signals History, Volume IV : ' Radar in Raid Reporting ', for details of early ground radar research and development.

equipment was consequently critical and unreliable. Another less obvious but nevertheless important factor in the problem was the non-availability of important components such as flexible coaxial cable for use at a high frequency of 200 megacycles per second, and a suitable means of providing an adequate high-frequency power supply. Because of the lack of coaxial cable the scientists had to use open-wire transmission lines for their experimental transmitters, and the transmitter of the first Anson installation was fitted in the tail of the aircraft so that the length of the transmission lines to the Yagi array on the tailplane might be reduced to a minimum.[1] The installation was therefore inaccessible, the fire risk was high, and performance was affected by violent and continuous vibrations. In an attempt to avoid the same feeder difficulty the transmitter of the experimental Fairey Battle installation was built into the leading edge of the tailplane. The absence of a suitable power supply enforced the use of 50-cycle power packs, which were very bulky and entailed using a motor generator which overloaded the aircraft electrical systems, then of small capacity in all types of aircraft. Another great difficulty was created by the fact that the research team had to use rather fragile components which had been designed for laboratory bench experiments and were never intended for aircraft installations, a consequence of trying to pioneer a new radar waveband with an aircraft as a laboratory. Amongst the components were the cathode ray tubes, which were quite unsuitable; aircraft vibration set up vibrations of the deflecting plates which caused the tubes to defocus very noticeably at certain engine speeds. Similarly, some of the essential valves were not appropriate. In particular the transmitting valve TY/150, upon which great reliance had to be placed, vibrated internally to such an extent that on many flights the anode dropped off, whilst the delicate acorn types of receiving valve repeatedly failed. In their experiments with airborne radar the research team had not only to contend with the difficulties of aircraft vibrations but also with those caused by the effects of high altitude, such as extremely low temperatures, and although the purely theoretical side of the task was accomplished at the Bawdsey Research Station, the practical installation work was carried out at Martlesham Heath where there were no suitable facilities.[2]

In spite of the many problems, by December 1936 a radar receiving system had been installed in a Heyford aircraft, and early in 1937 a small transmitter was also installed and flight trials were begun. Although the receiver was not sensitive enough for its planned function of aircraft interception, responses were obtained from coastline, harbour installations and ships at sea.[3] After further development it became possible also to discriminate between responses obtained from open country and built-up areas although the differences were not so marked as those between land and sea echoes. Squadron Leader R. G. Hart flew with Dr. E. G. Bowen on one of the flights and was able to distinguish clearly the position of railway lines at Harwich. This was to prove important when, a few years later, the need for an equipment to facilitate target location became urgent and the possibilities of airborne radar were discussed at the Air Ministry. Such possibilities were first indicated in December 1937 when

[1] *See* Royal Air Force Signals History, Volume VI: 'Radio in Maritime Warfare', for further details of early experiments with airborne radar.

[2] Narrator's interview with R. Hanbury Brown.

[3] *See* Royal Air Force Signals Histories, Volume V: 'Fighter Control and Interception' and Volume VI: 'Radio in Maritime Warfare', for details of subsequent development of A.I. and A.S.V.

Dr. E. G. Bowen summarised the possible application to 'ground and contour mapping' as follows: '... Suppose an aircraft flew a steady course along a coastline and radiated a beam broadside to the line of flight. The echo pattern received would consist of a direct ray, a ground reflection, and echoes from the coastline and from objects inland. If the signals were placed on the cathode ray tube and a photographic film moved slowly past the tube, a map would be obtained showing details of coastline, of ships offshore, and of buildings, embankments and the like onshore. The kind of record which would be obtained when flying overland cannot be predicted so easily, but it is certain that towns and villages would show up from the surrounding country, that hedges, trees, and possibly railway lines and power lines would also be in evidence ...' The most urgent requirement at that time was, however, an effective long-range early-warning ground radar system, and development of airborne radar was allotted low priority compared with that given to the development of ground radar.[1]

Research and experiment had yielded valuable information, and the scientists anticipated that eventually it would be possible to use airborne radar for detecting and locating ships at sea and other aircraft in the air. Effectively long ranges could not be obtained because of the low power characteristics of the valves available for operating on the very short wavelengths required for airborne radar. Two main factors limited the wavelength. For aircraft only small aerials could be used because aerial arrays dangerously increased aerodynamic drag, and the minimum range of detection had to be as short as possible in order that accurate information might be obtained during the final stages of approach to a target.[2] The minimum range requirement placed a rigid upper limit on the wavelength that could be used, and the choice of wavelengths was inevitably restricted, whilst detection at long ranges called for high power output, which was possible only on the longer wavelengths; the minimum range requirement and aerodynamic considerations both demanded the use of a very short wavelength. The trend of subsequent development of early airborne radar installations was therefore determined largely by the compromise which had to be made in the selection of the wavelength to be used.[3] Limitations in performance had to be accepted until the right type of valve became available. During the first seven months of 1938 the small amount of scientific resources that could be spared for work on airborne radar was directed mainly towards the elimination of electrical interference in aircraft and the development of aircraft aerial systems for A.S.V. With the growth of international tension from September 1938 until the outbreak of war, the development of A.S.V. was regarded as being of less importance than the development of A.I. and work was concentrated on the improvement of the air defence system.

Operational Requirement for Aircraft Radar in Bomber Aircraft

The potential value of a radar installation in bombing aircraft was not entirely forgotten. In December 1938 the Commander-in-Chief, Bomber Command, submitted to the Air Ministry, for consideration by the Committee for the Scientific Survey of Air Defence, a number of operational requirements,

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[1] A.M.R.E. File D.2153.

[2] Minimum range was defined as the point at which a returned echo emerged completely from the direct signal between transmitter and receiver.

[3] The wavelength eventually used for A.S.V. Mark I and A.I. Mark I was $1\frac{1}{2}$ metres.

and emphasised the need for an early application of airborne radar to the solution of some of his problems.[1] The matter was referred to the Superintendent of the Bawdsey Research Station, A. P. Rowe, who, after consultation with the airborne radar research group, outlined the specific needs of bomber aircraft which might be met by one suitable installation. He was of the opinion that any improvement in the effectiveness of bombing operations which could be brought about by radar was no less important than its application to the air defence system, and requested permission from the Air Ministry to begin investigation of the problem of air navigation for a bomber force.[2]

Such a programme of research and development would have involved the withdrawal of men and resources from the more urgent task of increasing the efficiency of air defence, about which uneasiness existed at the Air Ministry and Headquarters Fighter Command, and was therefore not approved. However, the ambition to make it possible for aircraft to be navigated at night and in bad visibility by means of an independent radar installation remained with Dr. E. G. Bowen. In the summer of 1939 he was flown from Martlesham Heath to the west coast of Wales in a Battle aircraft equipped with a modified A.I. Mark I installation. On landing he was able to give his pilot an accurate description of the terrain over which they had passed from observation of the echoes displayed on the cathode ray tube during the course of the flight. He continued his experiments on a wavelength of 1½ metres, using aircraft based at St. Athan in Wales, and on 20 February 1940 again surveyed, in a letter to A. P. Rowe, the uses to which airborne radar might be put by bomber aircraft. He suggested that an installation, based on the design of A.S.V. but with different aerial arrangements and different methods of displaying information to the pilot and navigator, might be made to radiate downwards instead of forward or sideways, and be used as a navigation system.[3] With it, a navigator could be given a continuous record on a tape of contour sections of the terrain over which he flew, when conditions were such that visual observations and map reading were not possible. When over comparatively hilly country, accurate fixes, and consequently accurate wind velocities, would be obtainable by comparing the tape record with the appropriate map. Some measure of discrimination between open country and built-up areas could be made but would require skilled interpretation and probably a shorter wavelength.

Owing to the urgency of the A.I. and later the A.S.V. production and installation programmes, active interest in the proposal lagged until 1941, when the ineffectiveness and inaccuracy of night bombing became only too evident. Even then the teething troubles being experienced with A.I. in the fight against the night bomber and with A.S.V. in the anti-U-boat campaign were of greater moment, and the large-scale bombing offensive was still a thing of the future. At the Air Ministry and at the T.R.E. the possibility of using centimetric wavelength radar or modified A.I. for navigation had been

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[1] Bawdsey Research Station File BRS/4/4/208.

[2] Sir Henry Tizard noted in his diary on 17 February 1939 that '. . . Bowen and all concerned are now very keen on using a form of R.D.F.2 as an aid to navigation . . .' and on 28 February informed Mr. A. P. Rowe that '. . . one objection to the navigation device is that it necessitates radio transmissions over enemy country. This may turn out to be no more than a paper objection, but it is to be borne in mind . . . .' A.M.R.E. File D.2153. R.D.F.2 was the name given to aircraft radar.)

[3] A.M.R.E. File D.2153.

discussed, but it was considered that the early experiments on a wavelength of 1½ metres had met with but scant success, and the optimistic reports of raids in which targets had invariably been successfully found and bombed had tended to obscure the real and pressing need.[1]

In July 1941 Headquarters Bomber Command expressed satisfaction with the general trend of navigation aids but drew attention to the fact that there was no satisfactory means of calculating drift at night. However, Lord Cherwell, the scientific adviser to the Prime Minister, who considered that the whole question of target location had been neglected, asked for an investigation of inaccurate navigation during operational flights. Attempts had been made to heighten the standard of air navigation generally and of astro-navigation in particular, and various means of improving existing radio navigation aids had been suggested.[2] Experience obtained during leaflet raids over Germany during the first few months of the war had shown that navigators were not able to calculate astro sights accurately in the air in conditions of extreme cold and when they were tired after a long and arduous flight. The violent evasive action customarily taken by bombers made the possibility of obtaining accurate results from astro-navigation and astro-bombing even more remote. The desirability of installing in bomber aircraft an additional navigator-operated direction-finding aerial was being urged by Headquarters Bomber Command, who had also asked for the provision of cathode ray direction-finding ground stations. It was realised that airborne radar similar to A.S.V. would confer many advantages, a principal one being that it did not rely in any way on the use of ground stations and was not therefore limited as a navigational system by distance from base. As a result of Dr. E. G. Bowen's experiments it had seemed possible that a form of A.I. or A.S.V. might be used to enable an aircraft to be navigated throughout a flight by following contours or characteristic features of the ground. It was thought, however, that such a technique would be impossible if evasive action to avoid enemy ground defences and night fighters had to be taken.

A statistical analysis was made from photographs taken on night operations between 2 June 1941 and 25 July 1941 in order to determine the proportion of sorties which actually reached their objectives, and to examine possible ways of improving the effectiveness of bombing raids. Some 650 photographs relating to 28 targets, 48 nights, and 100 separate raids were studied.[3] Nearly half the photographs had been taken independently of bombing, but as in every instance the position believed to have been photographed was named, all were equally useful as a check on the accuracy of navigation. The summarised conclusions arrived at were that of those aircraft recorded as having attacked their targets, only one in three got within 5 miles; against French ports the proportion was two in three, over Germany as a whole one in four, and against targets in the Ruhr only one in ten. During the full moon periods the overall proportion was two in five, and when the moon was new only one in fifteen. An increase in the intensity of anti-aircraft fire reduced the number of aircraft

[1] On 15 February 1940, at the 7th meeting of the Committee for Scientific Survey of Air Warfare, Professor P. M. S. Blackett suggested the use of A.S.V. or radio altimeters for the identification of towns, coastline and mountains as an aid to navigation. The Assistant Chief of the Air Staff thought that trials should be undertaken but the proposal was not supported.

[2] A.M. File C.51721/52.

[3] A.M. File C.32357/46.

to arrive within 5 miles of a target in the ratio of three to two. The statistics were related only to aircraft which claimed to have attacked the targets. The proportion of the total number of sorties which got to within 5 miles was less by one-third; of the total sorties only one in five were arriving within 5 miles of the selected target. The number of photographs studied amounted to approximately 10 per cent of the sorties carried out during the period under review and might not therefore have been wholly representative, and the weather conditions during June and July 1941 were exceptionally bad. Nevertheless, the conclusions reached emphasised the urgent need for a great improvement in navigation and target location. The general bombing problem could be divided into four distinct parts; navigation to and from the target area, identification of the target, calculation of the bomb release point, and approach to the release point. Although during training great emphasis had been placed on a navigator's ability to calculate accurately the bomb release point, the approach for the bombing run had usually been made in ideal conditions, and the problem of navigation to, and identification of, the target in total darkness had not been fully appreciated.

The Prime Minister was informed of the results of the investigation, and, appreciating the seriousness of the situation in view of the approaching winter, demanded that urgent action be taken to improve it. '. . . It is an awful thought that perhaps three-quarters of our bombs go astray . . .' he minuted the Chief of the Air Staff on 15 September 1941, '. . . If we could make it half and half we should virtually have doubled our bombing power . . .' The Chief of the Air Staff regarded the results as '. . . not nearly good enough . . .' and informed the Prime Minister that '. . . although much has been accomplished in the past, much more must be done to improve the accuracy of our night bombing. I regard this as perhaps the greatest of all operational problems confronting us at the present time . . .'.[1] Acting on the assumption that ultimately it would be possible to use A.S.V. over enemy territory, he ordered that an investigation be made of the possibility of using A.S.V. for finding and bombing a target after navigation with Gee had taken an aircraft to within a short distance of the objective.[2] Hitherto the aim of experiments with radar in bomber aircraft had been to provide an accurate system of navigation, but the requirement was now changed to target location and identification.

In October 1941 the Deputy Chief of the Air Staff decided to form the Radio Aids to Navigation Committee to examine and report upon all radio aids to navigation and to advise him regarding their suitability for operational use, to co-ordinate radio and non-radio aids to navigation, to initiate development of new methods of air navigation by radio means, and to report on the progress made in providing the Service with radio aids to air navigation.[3] Headquarters Bomber Command prepared a paper on the problem of navigating to, locating, and bombing a target by night, for discussion by the committee at its second meeting on 5 December 1941. It stated that dead-reckoning was the fundamental method of navigating an aircraft and that there were three other means of determining the position of an aircraft, map reading, astro

[1] A.H.B./ID3/1791 C.A.S. Folder, Navigational Aids.

[2] A.H.B./ID/12/193. Aids to Target Finding.

[3] A.M. File C.51721/52. At the first meeting on 7 November 1941 the title of the committee was changed to 'Radio Aids to Air Navigation Committee.'

navigation, and radio position-finding, all of which were subject to certain limitations.[1] The limitations were described, and the possibilities of pulse transmission, or radar, systems were mentioned. At that time Gee was still being developed and was known to have definite limitations in range, whilst Oboe was little more than an untried idea. The conclusion reached was that in average conditions it could be taken that the standard of navigation had been high if at the end of a flight of 500 miles the position error was not more than 10 miles. Such a result could only be obtained if all the available aids to navigation were used judiciously in conjunction with accurate dead-reckoning calculations. The crux of the problem appeared to be that however accurately an aircraft was navigated, the ultimate location of the target within the last 10 miles, and bombing accuracy, depended upon visual search and observation. The navigator, having accomplished the difficult task of navigating the aircraft to within bombing approach distance, had a still more difficult one of obtaining a visual fix of either the target itself or some nearby identifiable landmark from which he could make a bombing run by dead-reckoning. The search entailed remaining in the area for sometimes as long as one hour, and as the enemy night defences improved, was often unsuccessful. Frequently crews thought that they had found the target when actually they were some miles from it, and in the absence of photographs taken as the bombs were dropped independent checking was not possible. Very few cameras for night photography were then available, and they were used only by the most efficient crews, so that Headquarters Bomber Command was frequently misled by reports of the degree of success achieved. A means of navigation and blind bombing was required that would ensure a position error of only 500 yards in a flight of 1,000 miles in all conditions, that would be free from enemy interference, and that would enable positions to be fixed instantaneously. Amongst the many suggestions put forward were fire-raising with pyrotechnics, the use of large numbers of reconnaissance flares, of marker bombs, of parachuted homing beacons, of homing aircraft, and of A.S.V. to identify a built-up area. With the exception of A.S.V., the suggested means were subject to one common limitation; it was essential that one or more aircraft should first locate the target accurately. A means of effectively locating and recognising a target was an urgent requirement and the possibility of using a form of A.S.V. could not be overlooked.

The acceleration of production of fighter aircraft during the Battle of Britain had delayed production of the four-engined heavy bomber aircraft on which reliance was placed for an effective bombing offensive. The smaller aircraft used by Bomber Command were already loaded up to capacity and every pound-weight of radar equipment installed meant a pound less of high explosive with which to hit a target. However, on 28 October 1941 the Prime Minister minuted the Chief of the Air Staff '. . . We are making great efforts to increase the production of bombers, using a high proportion of our resources to do so. It is therefore vital that we should press on with all measures to increase the numbers of them that bomb their targets . . .'.[2] As a result of the Prime Minister's intervention and the investigations many of the earlier projects of using radar in bomber aircraft were resurrected, but meanwhile important developments of radar technique had taken place at the T.R.E., and were eventually to be applied to the solution of Bomber Command's problem.

[1] A.M. File CS.11402. R.A.A.N.C. Paper No. 3. [2] A.H.B./ID3/1791.

Experiments with Centimetric Wavelength Radar

The $1\frac{1}{2}$-metre wavelength technique which had been employed in A.I. Marks I to VI imposed a common disadvantage on them ; it was impossible to prevent the pulses reflected from the ground obliterating all other indications on the cathode ray tube at ranges greater than the distance between the aircraft and the surface of the earth.[1] Attempts were therefore made in 1940 to develop an installation which could be operated effectively at low altitudes. One way of preventing the pulses from reaching the ground was to focus all the radiation sharply into a narrow beam in front of the aircraft, but the size of an aerial array capable of producing a narrow beam on a wavelength of $1\frac{1}{2}$ metres was far too large for an aircraft installation. Consequently a method of producing radiation of sufficient power was sought among the shorter wavelengths for which correspondingly smaller aerials could be used. Whilst experiments were being conducted on different wavelengths, the development of the Randall-Boot cavity magnetron valve, improved and produced by the General Electric Company, firmly stabilised the airborne radar experiments on a wavelength of 9·1 centimetres, and work on what became known as 10-centimetre, or centimetric, radar was begun.[2] The basic phase was completed when, at the T.R.E. Worth Matravers, Dorset, on 13 August 1940, echoes were obtained from a Battle aircraft up to a range of 6 miles when centimetric equipment was used on the ground. In March 1941 the first experimental centimetric A.I. installations underwent flight tests in a Blenheim aircraft.[3]

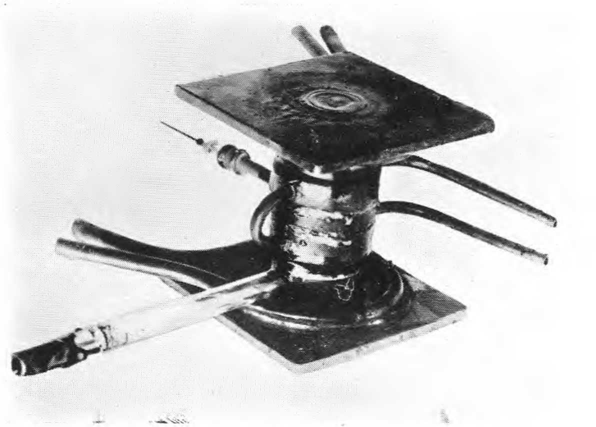
Throughout 1941 trailers containing 10-centimetre equipment were sited for experiments in a field adjoining the stables of Leeson House in which the T.R.E. was accommodated, which were used as a laboratory. The site was an ideal one since it overlooked, from a height of 250 feet, the town of Swanage two or three miles distant, and a 20-mile stretch of sea, frequently used by shipping, to the Isle of Wight. The scientists working on the experiments became quite accustomed to observing returned signals received from the various groups of buildings in Swanage, but the main purpose of the experiments was the development of A.I.[4] The application of the phenomenon to assisting a bombing offensive was therefore not seriously considered, although the possibilities of air navigation by means of centimetric radar technique were sometimes discussed. The experimenters were generally misled by optimistic press releases of effective bombing raids on which the targets were nearly always successfully found, and the comparative lack of success which had attended the early experiments with metric wave airborne radar discouraged immediate action. However, when, in October 1941, the urgent operational requirement for aircraft of Bomber Command was made known to T.R.E. scientists, the employment of centimetric radar was at once suggested. There followed quickly a series of discussions. Professor H. W. B. Skinner and Mr. J. R. Atkinson, as a result of the trailer experiments, were certain that buildings could be identified against general ground returns. The immediate problem to be solved was whether centimetric radar would enable adequate discrimination to be made between responses from

[1] *See also* Royal Air Force Signals History, Volume V : 'Fighter Control and Interception'.

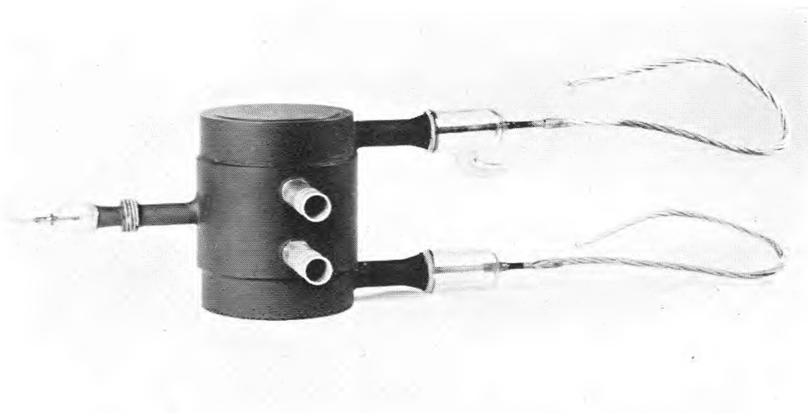
[2] *See* Royal Air Force Signals History, Volume IV : 'Radar in Raid Reporting', Appendix No. 8 for further details of the development of the magnetron valve.

[3] *See* Royal Air Force Signals History, Volume V : 'Fighter Control and Interception'.

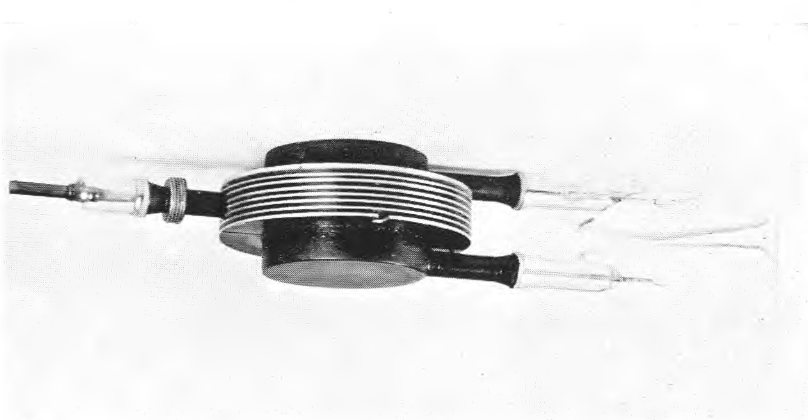
[4] A.H.B./IIE/187. A.G. Touch Papers on Airborne Radar.



Randall-Boot Cavity Magnetron—April 1940



Cavity Magnetron as developed by the G.E.C.—June 1940



Cavity Magnetron as developed by the G.E.C.—July 1940

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open country and built-up areas, as the angle of viewing from the air would be more nearly vertical as compared with the practically horizontal viewing from the ground. Methods of scanning with beams narrow both in azimuth and elevation were suggested, and eventually it was decided to use a wide beam in elevation and to scan in one dimension only, using plan position indicator presentation as had been proposed for A.S.V. Fortunately the Blenheim aircraft which had been equipped with an experimental centimetric A.I. equipment and a helical scanning system was available at Christchurch because for A.I. helical scanning had been replaced by the spiral scanner or radial time-base.[1]

Early Development of H2S

The proposed technique was given the name BN, for blind navigation, by the T.R.E. and arrangements were made for experiments to be conducted under the auspices of Professor D. I. Dee and Dr. A. C. B. Lovell. The Blenheim installation was suitably converted and on 1 November 1941 the first flight was made with the radiation beam rotating at 300 revolutions per minute and tilted towards the ground instead of towards the front of the aircraft. Isolated responses were quickly observed, and as the aircraft approached Southampton an echo which almost certainly represented the town appeared on the screen. Further flight trials were made during which the equipment was used to home to various towns and to identify military camps and other built-up areas on Salisbury Plain. Some of the isolated responses observed were identified as large towns, and at an altitude of 8,000 feet the maximum range at which the responses were obtained was about 35 miles. A notable feature of the presentation was, as had been the case with metric wavelength equipment, the discrimination between land and water, coastline being clearly displayed. A factor which raised doubts, however, was that the responses observed were comparatively numerous, and it was evident that many objects other than towns were producing echoes. The experiments were of the utmost importance in that they demonstrated that centimetric airborne radar could obtain individually distinct returns separately from general ground returns and thus overcome the failing of previous installations.

The attention of the Controller of Telecommunications and Equipment was drawn to the possibilities evinced by the flights, and he thought them sufficiently promising to be brought to the notice of the Secretary of State for Air and the Chief of the Air Staff. On 20 November 1941 the latter informed the Prime Minister of the results of the experiments but pointed out that a decision to install centimetric radar in operational bomber aircraft could only be made after most careful consideration of the effects of losing the equipment to the enemy. If the Germans were able to obtain possession of an installation and later use the technique against us we might lose more than we had gained in the interval by more accurate bombing.[2] He referred at the same time to unfavourable reports received on the application of metric A.S.V. to the identification of built-up areas, trials of which had been conducted after the instruction issued by him in September 1941. It appeared that no useful purpose would be served by further investigation of the possible uses of metric A.S.V. in Bomber Command. The Prime Minister at once showed a keen and lively interest in

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[1] *See* Royal Air Force Signals History, Volume V: 'Fighter Control and Interception'.
[2] A.H.B./ID3/1791.

the new experiments, an interest which was to characterise the subsequent development and production of H2S.[1] The first name, BN, indicated that T.R.E. scientists thought of the installation as being primarily a navigation system and, in fact, throughout the development of H2S, they felt that much of its potential value would be lost if its possibilities for navigation were ignored.

On 23 December 1941 the Secretary of State for Air convened a meeting to discuss the possibilities of H2S, at which Lord Cherwell raised some important points.[2] Having first stated that H2S was '. . . intended for use next autumn and . . . likely to be very successful . . .' he said that it was necessary to consider which of the two centimetric wavelength transmitting valves, the magnetron or the klystron, was to be used, and to decide whether it might not be desirable to use a simplified form of H2S as a device solely to ensure the identification of a built-up area as the required target rather than as a general navigation system. At the T.R.E., replacement of the range/azimuth presentation by a plan position indicator, to give a map display of the ground over which an aircraft flew, was being considered. Lord Cherwell was inclined to the view that the requisite scanning system was too complicated and would take too long to perfect, and suggested that a simpler installation, a split aerial system with left/right display for homing to a target echo, would be adequate and could be developed more quickly. Aircraft could be navigated to the target area by astro-navigation and dead-reckoning to within 10 or 15 miles of the target and H2S would then be used primarily as a blind bombing device. Since the existing equipment and scanner system were equally suitable for both roles, navigation and blind bombing, the argument would have been unrealistic but for the fact that it was linked with the use of the magnetron valve over enemy-held territory. The magnetron was the main basis of centimetric airborne radar technique, and its employment was essential, because of its high power pulse output, in A.I. Marks VII and VIII and in A.S.V. Mark III which were then being developed. The secrets of the cavity magnetron were known only to the Allies, and because it was practically indestructible its use over enemy territory was forbidden, although it could be used over sea areas since in such circumstances the possibility of its being captured by the enemy was remote.[3] The klystron had already been fully described in the scientific press of the world. For the proposed P.P.I. version of H2S the magnetron was almost essential but it was probable that the simpler left/right display could be achieved with the well known, less efficient, and more easily destructible klystron. However, the klystron had been developed only as a local oscillator, and existing models could only produce a small amount of power. Urgent measures to develop a suitable klystron had been undertaken, but the valves were not available in quantity and although the Ministry of Aircraft Production undertook to investigate the possibility of beginning their production, the Secretary of State for Air ruled that any klystron production should be treated as an additional project. Nothing was to be allowed to retard the production of magnetrons or the development of equipment along lines which

[1] For security reasons a name that meant nothing at all was required. 'Stinker' was suggested, and its obvious derivative, H2S, was adopted.

[2] A.H.B./IIE/6/60. H2S, Minutes of Meetings.

[3] Details of the magnetron were disclosed to the U.S.A. government by the Tizard Commission which went to the U.S.A. in August 1940. *See also* Royal Air Force Signals Histories, Volume V: 'Fighter Control and Interception', and Volume VI: 'Radio in Maritime Warfare'.

involved their use. Since doubts existed whether H2S responses could unambiguously be related to specific targets, further experimental flights were to be made immediately '. . . to determine whether the signals obtained could be definitely associated with specific ground objects . . .'

More detailed operational requirements for H2S were formulated by the Air Staff, and on 6 January 1942 the T.R.E. was informed that a maximum range of 15 miles against towns would be acceptable. The Assistant Chief of the Air Staff gave instructions that, in order to avoid delay, an order for the manufacture of at least 1,000 equipments was to be placed at once, and arrangements were to be made for H2S to be taken into operational use when delivery from production reached 100 per month.[1] The installation was not required as a navigation system, but was to be used solely as a means of identifying and homing to built-up areas within a range of 15 miles. The klystron was to be regarded as an integral part of the system. The possibility of using H2S in conjunction with suitable ground beacons for the purpose of homing bomber aircraft to their bases was also discussed in January 1942. As a result the Air Staff considered that if it was possible to include the facility in a simplified H2S installation it was desirable to do so, but if its provision was likely to cause delay in development and production, it was to be left until more comprehensive equipment was later evolved.

On 21 January 1942 the Chief of the Air Staff informed the Prime Minister that '. . . Progress has been so satisfactory that it is now possible to lay down the lines on which development should proceed. At first a simpler form of the equipment is to be developed as quickly as possible and will be accepted as soon as a maximum range of 15 miles can be achieved from an aircraft flying at 15,000 feet. Simple facilities for homing on to beacons at aerodromes will be included if their inclusion does not delay production. A contract for the equipment has already been placed in order to prevent any delay between the completion of development and the beginning of production. The Ministry of Aircraft Production has been asked to draw up a programme, with dates, for providing 1,500 sets and introducing the equipment into Service use as soon as possible. Later on a more elaborate form of apparatus, with greater range and with navigation and homing facilities, is to be developed. The Halifax will be the first aircraft to have the new equipment, and an experienced captain and navigator from Bomber Command will be at the disposal of T.R.E. . . .'[2]

By the end of January 1942 it was becoming increasingly important that a decision be made as soon as possible regarding the type of transmitter valve to be used in H2S; the planned production of magnetrons had not taken into account any possible demands for H2S as distinct from A.S.V.[3] If klystrons were definitely to be used it was important that one standard type should be developed. At a meeting held on 26 January 1942 the T.R.E. was requested to conduct experiments, which were likely to take two or three weeks, to obtain

[1] A.M. File C.30305/46.

[2] A.H.B./ID3/1791. Group Captain W. E. Theak, Wing Commander G. P. L. Saye and Flight Lieutenant E. J. Dickie acted as liaison officers with T.R.E. and T.F.U. during the development of H2S.

[3] T.R.E. File D.1738. The firms of B.T.H. and M.O.V. had each been requested to plan for an annual production of 25,000 magnetrons. B.T.H. expected to begin production in July 1942 and M.O.V. in December 1942.

definite information. The T.R.E. was to develop magnetron H2S units, whilst the firm of E.M.I. was to develop and produce klystrons and base the design of its H2S equipment on them. The Controller of Telecommunications and Equipment felt that '. . . a gamble should be taken on the klystron proving satisfactory . . .'

Meanwhile attention was focused mainly on the introduction of Gee into operational use, but on 13 February 1942 the Secretary of State for Air held another meeting to discuss H2S, and the T.R.E. representative was asked to report progress made since the first meeting.[1] Further experiments had indicated that magnetrons would not be essential for operations over Germany as klystrons were proving to be satisfactory. Flights on which the equipment had been used for the whole of the navigation had been accomplished with great success. The alternative system, the split aerial suggested by Lord Cherwell, was being examined and it was hoped to hold trials approximately three weeks later. The C.T.E. reported that in January 1942 a contract had been placed with the firm of E.M.I. for 1,500 H2S equipments, the first 200 of which were being regarded as development models.[2] It was appreciated at the Ministry of Aircraft Production that there was an element of risk of wastage in ordering so large a quantity initially, but in view of the potential value of H2S it was felt that the order was justified. The Secretary of State for Air was assured that H2S was being treated as a matter of the highest priority, and that so far no complication had arisen. Subsequently the split aerial system might be easier to produce and to install than the scanning system, but meanwhile the processes of research and development gave promise of being equally, if not more, complicated. Further research work was required before that could be decided. The Chief of the Air Staff stated that in choosing between the two methods the Air Staff would be mainly guided by two considerations. The first was that the system should be accurate enough to ensure that bombs would fall within the industrial or other areas selected as targets, and the second was that, if possible, the system should enable bombs to be dropped on any agreed spot inside such a target area if and when required. If only the first requirement could be met an advance in bombing accuracy standards would have been made. He proposed therefore that a thorough investigation should be made of both systems and a final choice made when it was known what the production and installation problems were likely to be.

Progress in the development of H2S suffered a setback later in February 1942 when, as the result of a taxying accident, the undercarriage of the Blenheim which was equipped with the experimental A.I. installation and was being used for H2S trials, collapsed, and the aircraft was seriously damaged. Eventually another Blenheim was equipped with the electronic components taken from the first, and with an improved scanning system. Flight trials were recommenced in the third week of March 1942.[3] The second aircraft was fitted with a perspex nose enclosing a parabolic mirror 28 inches in diameter which rotated continuously about a vertical axis, the beam of radiation being approximately 15 degrees wide with its axis at about 10 degrees from the

[1] A.H.B./ID3/1791.

[2] Contracts for the production of scanning systems had also been placed ; with Metropolitan Vickers for an electrical system and with Nash and Thompson for a hydraulic system.

[3] T.R.E. Report No. 12/106, dated 23 April 1942.

horizontal. The coverage in azimuth was limited to plus or minus 60 degrees by the nose structure. Range/azimuth presentation was used during the trials, and returned signals appeared as bright spots on the screen of the cathode ray tube. The installation had, however, been especially designed to fulfil an A.I. role and was not very suitable for the H2S function. It became increasingly evident that a scanning system providing all-round looking, and a plan position indicator display, were very desirable.

The first flights were made to determine what objects on the ground would produce recognisable signals. Large towns, such as Southampton, Bournemouth and Wolverhampton, were easily detected at distances up to 35 miles from a height of 8,000 feet, and the results were approximately the same from all angles of approach. Airfields with hangars produced responses as big as those from large towns, typical examples being Boscombe Down and Yelverton. Flights at heights of 3,000, 5,000 and 10,000 feet towards the Black Mountains in South Wales and towards the Malvern Hills produced no identified responses, but mining towns, such as Pontypool, situated on hillsides, gave good signals. Numerous homing runs to a selected target were successfully made. On one, Yelverton airfield was identified at a range of 30 miles and the pilot was directed towards it. Although poor visibility made it impossible to see the airfield until it was less than two miles distant, the headings given to the pilot enabled him to fly directly over the hangars. Flight trials were also made to determine the useful range of the installation with the overall sensitivity reduced to correspond with that which would be obtainable if a klystron were used instead of a magnetron. The results indicated that the consequent reduction in range was not sufficient to impair the effectiveness of H2S.

About 20 flights were made with the split aerial system, using A.I. Mark VII equipment with the addition of a linear time-base and a switch for presenting signals alternately to the left and to the right of the time-base. An experimental P.P.I. presentation was also used on some of the flights. Results indicated that a simple split aerial system could be designed to enable towns of medium size to be detected at ranges up to 12 miles when used with a magnetron transmitter. At that range P.P.I. presentation could be used to obtain a bearing on a target. The system would be of only slight assistance to navigation, and it was not possible to identify an objective unless the aircraft were navigated by other means to within three miles ; if the navigation was inaccurate neighbouring towns could easily be mistaken for the one selected as a target. The electronic equipment required was substantially the same as that used with the scanning system, but if it was essential to use a klystron the efficiency of the split aerial system would be seriously impaired as the ranges obtained with a magnetron were near the operational minimum.[1]

In April 1942 the Air Staff evaluated the two techniques. With the split aerial system the possibility of successful selective bombing within a target area was slight although its use would certainly reduce considerably the bombing of open country. The scanning system offered the likelihood of successful target selection and accurate location with some possibility of selective bombing within an area. Employment of the split aerial system would not obviate the risk of bombing decoy targets, but such a risk was negligible with the scanning system because it enabled the terrain surrounding the selected target to be

[1] T.R.E. Report No. 12/106, dated 23 April 1942.

identified. Also, should it become necessary to use only the klystron and not the magnetron, the range of the split aerial system would be too small to be effective, whilst the scanning system could probably be developed and produced with alternative components so that it could incorporate a klystron for the role of target location and blind bombing, or a magnetron for A.S.V. The only advantage of the split aerial system lay in its simplicity and the smaller aerials, but even this was considered unlikely to make any difference to the speed of production of H2S on a large scale because it appeared that the electronic equipment would present the major manufacturing problem. The scanning system had considerable operational advantages both in range and in the assistance to navigation that it offered. On 30 April 1942 the Air Staff directed that no further work on the split aerial system was required, and that further development of H2S was to be undertaken only with the scanning system.[1]

Meanwhile the development of A.S.V.S., the 10-centimetre wavelength version of A.S.V., had reached the stage at which a development and pre-production contract had been placed with the firm of Ferranti in March 1942.[2] During that month the T.R.E. suggested that the functions of H2S and A.S.V. might be fulfilled by one installation. It seemed obvious that such a combination would eliminate duplication of effort during development and production and would render unnecessary any competition for components and materials otherwise inevitable once production stages had been reached. The construction of a single complete equipment suitable for both applications seemed to be the ideal method since the cupola, scanner and scanner drive arrangements which constituted the major problem of aircraft modification could, it was thought, be made identical. However, the main difference between H2S and A.S.V. was that use of the magnetron was essential for the latter function. The performance to be expected from the H2S equipment being developed was only slightly, if any, better than that of metric A.S.V., when a klystron was used. Because use of the magnetron over enemy and enemy-held territory was forbidden, another method had to be sought. The Minister of Aircraft Production on 15 March 1942 agreed that a proposal to use one firm, that of E.M.I., which was developing H2S, to manufacture both H2S and A.S.V., with as many components as possible common to both, should be put into effect. The T.R.E. and E.M.I. together evolved a possible system for putting the plan into practice.[3] The cupola, scanner, magslip and cabling could be made common by changing only the aerials of the H2S system already being developed by E.M.I. The power unit, receiver and timing circuits, control box, and indicator unit could be made common to both roles by modification of the units already designed for H2S by the same firm. A.S.V. required three additional special units, a magnetron transmitter, modulator, and another power unit ; H2S, one, a combined klystron transmitter and modulator. During detailed discussion of ways and means of putting such a system into effect with a minimum of delay, the fact was stressed that it had not yet been definitely established that a klystron installation would be operationally satisfactory ; it might prove to be necessary to use the magnetron for H2S in spite of the security policy. The Gramophone Company, associated with

[1] A.H.B./ID/12/193.

[2] *See* Royal Air Force Signals History, Volume VI : 'Radio in Maritime Warfare', for further details.

[3] T.R.E. File D.1738.

the firm of E.M.I., was given a contract to design and develop the combination known as H2S/A.S.V., and E.M.I. undertook the engineering of 15 pre-production models based on A.I. Mark VIII components.[1] In March 1942 the original production contract for 1,500 H2S was changed to one for 1,500 H2S/A.S.V. equipments.[2]

During January 1942 the A.S.V.S. prototype Wellington was used for H2S experiments before it reverted to the group of scientists working on A.S.V.[3] The installation incorporated P.P.I. presentation, and although the experiments did not meet with any great success, experience gained with the Blenheim during the early trial flights indicated that P.P.I. presentation was desirable, and it was therefore incorporated in the Blenheim installation. At the end of April 1942 Flight Lieutenant E. J. Dickie, one of the Bomber Command liaison officers with T.R.E., made two flights in the Blenheim. He reported that the rotating scan line was apt to be disconcerting and there appeared to be insufficient afterglow on the cathode ray tube.[4] Signals faded between each revolution of the scanner so that at no time was the whole picture visible. Even though it was not difficult with a little practice to identify objects on the screen and to home to them by keeping the signals dead ahead, the picture was considered to be insufficiently clear for general Service use. The vertical datum line, through the centre of the cathode ray tube screen, was taken as the fore and aft axis of the aircraft, and responses from targets ahead of the aircraft appeared as blips vertically above the centre of the screen. The arrangement was considered to be fundamentally unsound because navigators of Bomber Command were not so much interested in the position of the source of an echo in relation to the line of flight of an aircraft, but in the relative positions of both the source and the aircraft on a plotting chart. Dickie suggested that true north and south should be represented by the vertical datum line, and the centre of the P.P.I. display should represent the position of the aircraft. Then the picture or maps of echoes would be observed drifting across the screen and little imagination would be needed to consider the picture as the stationary terrain over which a flight was being made, and the centre of the screen as the aircraft flying across it. The aircraft track could be seen at a glance and could be measured directly from a fixed azimuth scale.

The T.R.E., Headquarters Bomber Command and E.M.I. generally agreed that the principle was sound. It was decided that the motive power for orientating the display could be obtained from the repeater of the master unit of the distant reading compass by causing one of the stator coils to move so that it always pointed north. The D.R. compass was gyroscopically operated and was usually situated at some point in the tail of the aircraft well away from masses of metal, such as engines, which would be likely to affect the magnetic bearing. The position of the compass bearing relative to the heading of the aircraft could be displayed on dials in other parts of the aircraft. Electrical currents were used to operate the distant reading dials. One coil or magslip was fixed to the top of the rotating scanner. Each time the transmitter sent out a pulse a voltage was induced in one or both of the two stator coils connected to the plates of the cathode ray screen, which, when charged,

[1] A.H.B./ID3/1791. [2] A.M. File C.30305/46.

[3] *See* Royal Air Force Signals History, Volume VI : ' Radio in Maritime Warfare '.

[4] T.R.E. File D.1738.

controlled the movements of the spot of light. As a safeguard against failure should the compass become unserviceable, and to make possible installation in aircraft in which a D.R. compass was not fitted, Flight Lieutenant Dickie recommended that an alternative manual control be provided, to be operated by the navigator. The modifications were adopted and became an integral part of H2S/A.S.V.

Trial Installations in Halifax Aircraft

When at the end of 1941 the decision to install H2S in bomber aircraft was made, it became necessary to find out which of the types of aircraft used in Bomber Command would be most suitable for a prototype installation. Lancaster, Stirling and Halifax aircraft were examined, and on 5 January 1942 the Halifax was selected as the type in which H2S could most easily be installed. The siting of the cupola for the scanner was decided with the makers of the aircraft, Handley Page, but during January 1942 progress with the necessary modification to the fuselage was slow mainly because official instructions had not been received from the Ministry of Aircraft Production.[1] Until they were received no constructional work could be started and no arrangements made with sub-contractors. The requisite contract action was completed in February 1942, but further delay was caused by a failure to provide certain condensers ; it was essential that all necessary components were made readily available before real progress with an aircraft prototype installation could be made. At the beginning of March it became necessary to decide the type of radio navigation system to be used in the Halifax prototype since it was essential that accurate fixes were obtained during flight trials of H2S. V.H.F. R/T was originally fitted but, in order that greater accuracy might be obtained and to avoid the complication imposed by the need to use the ground V.H.F. R/T organisation, arrangements were made for substituting Gee, then about to be introduced into operational use. Two trial installations of H2S were to be made and the aircraft for the first, Halifax V.9977, was landed at Hurn on 27 March 1942 and was fitted there with T.R.E. experimental equipment based on the magnetron. A fixed perspex cupola, about 8 feet long, 4 feet wide, and 18 inches deep, had been fitted in the position normally occupied by the underturret, and enclosed an hydraulically driven scanner mirror about 3 feet wide and 18 inches deep. In order to determine as quickly as possible whether the scanning system would operate successfully at the operational height of the Halifax, 20,000 feet, experimental flights were made at that altitude with a Beaufighter equipped with A.I. Mark VII modified by the addition of a 40-mile linear time-base. The Blenheim installation could not be used at heights over 10,000 feet because the experimental components it contained were unsuitable. Good results were obtained at the required ranges with the Beaufighter, and as its aerial gain was approximately the same as that of the Halifax system, it was concluded that the scanning system would be satisfactory.[2]

The first trial flight was made with the Halifax prototype during the evening of 16 April 1942 and was unsuccessful. During the following morning, however, another flight test met with more success, and ranges of 4 to 5 miles were obtained against towns from a height of 8,000 feet. Further flights produced results

[1] T.R.E. File D.1738.

[2] T.R.E. Report No. 12/106.

which were disappointing after the success which had attended the Blenheim experiments, even although a magnetron was used. This was mainly because the tests were made at higher altitudes, and it became apparent that the scanning system required to be redesigned and repositioned. The problems of the scientists were growing larger because as more and more heavy bombers were becoming available for Bomber Command and the prospects of a real bombing offensive during the coming winter became brighter, more and more was expected from H2S, and they found it difficult to settle down to a logical sequence of experiments. Entangled with the problem of development was that of production. The intention was that E.M.I. should manufacture 200 equipments entirely by hand, using every advantage that the granting of highest priority conferred. This went beyond the stage of ordering off the drawing board since, when the decision was made, H2S was barely on the drawing board. The Gramophone Company did not believe that the sets could be made in the allotted time and thought that only 15 at the most could be completed by Christmas 1942. In their opinion it would not be possible to begin quantity production before June 1943.[1] According to the programme drawn up by the Ministry of Aircraft Production the first three prototype H2S equipments manufactured by E.M.I. were to be delivered in August 1942, and 200 hand made pre-production equipments by the autumn. It had been expected that if no major setbacks were encountered quantity production was likely to begin early in 1943. However, no date for the commencement of the main production programme could be given until the final design of H2S was accomplished. Many influential people doubted whether H2S would ever provide the satisfactory solution, which was so urgently required, to the problem of Bomber Command. The doubts were encouraged by reports that experiments in ' town detection ' being conducted in the U.S.A. were also meeting with but little success. This was mainly because nearly all evidence in the U.S.A. was obtained from flights made at low altitudes with aircraft equipped with A.S.V. The operational requirement in the U.S.A. was for a very accurate bombsight, and not so much for discrimination between built-up areas and open country as for the identification of particular targets within a built-up area.

The sceptical attitude led to a review of the situation at a meeting convened by the Assistant Chief of the Air Staff (Operations) on 19 May 1942.[2] As a result the Air Staff re-affirmed its faith in the possibilities of H2S in the role for which it was initially developed, that of the blind detection of built-up areas. The operational requirement was again defined. The system was to be accurate enough to ensure that bombs would fall within an industrial or other area selected as a target. The Air Staff would be satisfied in the first instance if the range of H2S enabled aircraft to home to a built-up area from 15 miles at 15,000 feet. Subject to there being no delay or interference with development of the installation and its introduction into the Service in a form which fulfilled those requirements, it was agreed that details in design to enable H2S to be used as a navigation system could be incorporated during the later stages of development and operational trials. In order to ensure that there should be no alteration of the primary purpose of H2S, and no delay in achieving its final design, the Air Staff ruled that it was essential for the T.R.E. to be kept in close and continuous touch with its development and trials and that all suggestions for modification

[1] A.M. File CS.15536.

[2] A.H.B./ID3/1791.

of the design were referred to the T.R.E. as quickly as possible. Every effort was to be made to arrive at the final design during June and July 1942. However, nine days after the meeting the Under Secretary of State for Air was warned by the Minister of Aircraft Production not to be too optimistic about an early introduction of H2S, '. . . the instrument being only in the early stages of development . . . and we are at this period overloading our aircraft with all the numerous gadgets which the inventive genius of our scientists produce . . .'[1] The Prime Minister, who in April 1942 had directed that '. . . offensive radio equipment must take precedence over defensive equipment . . .' was very disturbed when he was made aware of the amount of time which would probably be required before full production of H2S could be started. At the beginning of June 1942 he stressed that the production quantities forecast '. . . did not begin even to touch the fringe of the problem . . .' and gave orders that sufficient installations were to be completed to enable targets to be illuminated by the autumn even if it were not possible to fit the equipment in all the bombers, '. . . nothing must be allowed to stand in the way of this. . .' Sir Robert Renwick was instructed to make a personal effort to accelerate production of the electronic and ancillary equipment. The policy, as defined by the Prime Minister, was '. . . The main thing is to hit the target and this we can do with H2S. All other items are, of course, useful, but nothing like so urgent . . .'[2]

The encouragement and support thus given to those responsible for the development of H2S was badly needed in June 1942. The flow of experimental work was disturbed with the move of the T.R.E. from Worth Matravers because of the danger of German commando raids, and on 7 June 1942 a major disaster occurred when Halifax V.9977 crashed in South Wales. Five, about half, of the comparatively small group engaged on H2S development were killed.[3] The loss of the installation was unfortunate enough, but the loss of so great a proportion of the personnel with experience and detailed knowledge of H2S was almost overwhelming. During the weeks that followed, however, increasing pressure was brought to bear on speeding development, and on 3 July 1942 the Prime Minister reviewed the situation and ordered an all-out effort to be made to equip two squadrons of heavy bomber aircraft by October 1942. Trials were being flown with the second Halifax, in which had been installed what could be regarded as functional prototype equipment, and a replacement for V.9977 had also been equipped. However, even when the magnetron was used, H2S performance continued to be very unsatisfactory. The outlook was far from cheerful, and even as late as the end of August 1942 the commander of the newly created Pathfinder Force expressed his doubts about the operational usefulness of H2S in its existing form.[4] A great drawback was the display obtained with the cathode ray tubes then available ; one type of screen had far too long, and the other far too short, an afterglow. No great improvement was likely to be effected by a new type of screen. Certain aspects of the H2S problem were defined as 'laws of nature' at the T.R.E., where it was considered that technical methods could not produce improvement beyond a natural limit.

[1] A.H.B./ID/12/193.
[2] A.H.B./ID3/1791.
[3] A.H.B./ID/12/195. H2S and H2S/A.S.V. A. D. Blumlein, E. Blythen, C. O. Browne of E.M.I., G. S. Hensby of the T.R.E., and Pilot Officer C. E. Vincent, attached to the T.R.E.
[4] T.R.E. File D.1738.

Perhaps the greatest difficulty encountered was that of reducing the gaps in the field of radiation of the H2S aerial system. The magnetron pulse transmitter energised a horizontal dipole aerial which was placed in the focal plane of the paraboloid mirror or reflector. The properties of the dipole and mirror assembly resulted in the production of a wedge-shaped beam of radiation. The mirror and aerial were rotated so that the beam swept over the region under the aircraft approximately once every second. Because built-up areas reflected more energy than areas of open country, and open country more than stretches of water, some energy was reflected back to the aircraft, the actual amount depending on whether the aircraft was over a town, open country or water. The dipole and mirror assembly was used for reception as well as transmission, and some of the reflected energy was collected by the mirror, and, after passing through an amplifier, was displayed on the cathode ray tube screen as an echo or blip. Because of faults in the dipole and mirror system, gaps occurred in the radiation beam in such a way that no signals were received from built-up areas at certain ranges. By September 1942, although various modifications had been made to the Halifax aerial system, no complete solution to the problem had been found by the T.R.E. Only a compromise had been effected as a result of which the gaps occurred at a minimum range of 4 to 5 miles, or could be moved out to a maximum of 10 or 12 miles at 10,000 feet.[1] No flight trials had been made at 15,000 feet but it seemed highly probable that in the maximum position the gaps would occur at slightly more than 15 miles. Although this held obviously serious implications the Superintendent, T.R.E., considered that H2S would still most likely meet the operational requirement of the Air Staff and Headquarters Bomber Command '. . . to enable an aircraft to home to a built-up area from 15 miles at 15,000 feet . . .' Efforts to eradicate gaps were continued energetically, but no date or guarantee of early success could be given, and the possibility that early production equipments would still contain flaws had to be accepted.

Substitution of Magnetron for Klystron

By June 1942 it had become evident that insistence on the employment of klystrons for H2S would make impossible the attainment of even the minimum operational requirement in spite of the intensive efforts that had been made to produce a suitable type of klystron. On 10 June Professor D. I. Dee formally recorded his doubt whether the klystron modulator would give sufficient power for H2S, and on 23 June 1942 the Controller of Communications and Equipment asked for reports to be made on comparative trials of the klystron and magnetron.[2] Professor D. I. Dee stated that with the klystron the maximum range had been only 10 miles even when the installation had been operated by experts, whilst the Blenheim magnetron installation had produced ranges of 35 miles against big towns. However, plans had been made for a large output of klystrons for use in H2S, and although no difficulty was expected in supplying magnetrons for the first 1,500 H2S/A.S.V. equipments from the production ordered for A.S.V., the extra output that would be required afterwards entailed a probable delay of about one year. The original estimate of the number of magnetrons required had been 20,000, and this had later been increased to 50,000 to allow for contingencies. Complete substitution of magnetrons for klystrons meant

[1] A.M. File CS.13548. [2] T.R.E. File D.1740.

an increase to 100,000.[1] The klystron was generally considered to be technically unsuitable, and it was thought to be certain that the substitution of magnetrons would enable H2S to be introduced into the Service at a much earlier date than would otherwise be possible. It was a reasonable possibility that sufficient magnetrons could quickly be made available to enable the Prime Minister's directive that two squadrons were to be equipped by October 1942 to be complied with, but the chances of producing suitable klystrons in time were remote. However, before a decision could be made other considerations had to be studied. One was the effect of the substitution on the A.S.V.S. production programme, and another was the important question of security. Eventually, on 15 July 1942, it was agreed that major development and production plans for the klystron should be cancelled ; a final decision whether or not magnetron H2S should be employed on operations during the coming winter was to be made later.[2] In the meantime every precaution was taken to ensure that aircraft equipped with magnetron H2S were not flown in any areas where there was the slightest possibility that the installation might be captured by the enemy.

The decision to use the magnetron for H2S meant that the problem set by its indestructibility had, if possible, to be solved. The problem was considerable and the difficulties encountered during the many unsuccessful attempts that were made to develop a satisfactory destructive system encouraged a belief that the klystron would eventually prove to be more suitable for the H2S role. Experiments conducted at the Royal Aircraft Establishment revealed that the minimum amount of high explosive required to destroy a magnetron was two ounces, and as such a charge would cause great damage to an aircraft, it was necessary to contain the explosive in a box.[3] Several types of boxes were tried but no effective solution was found. Trials made with thermite were disappointing in that the quantity required weighed five times as much as the apparatus itself, and the degree of destruction which even this amount effected was much less than that which resulted from the use of high explosive. In addition to the difficulties created by the weight of destructive devices and their danger to aircraft and crews, there was always a probability that the magnetron could fairly easily be reconstructed from its fragments. Methods of ejecting them from the aircraft simultaneously with destruction were tried, but they involved a large recoil which could easily endanger aircraft. The use of powerful acids was also considered and experiments in burning out the valve by means of an electrical charge were made. In September 1942 efforts to achieve complete destruction were abandoned, and it was agreed that the best, although incomplete, solution, was the provision of two small detonators which rendered the magnetron unusable.[4]

Permission to use the magnetron for H2S very considerably eased development and production difficulties. A crash programme was initiated ; E.M.I.

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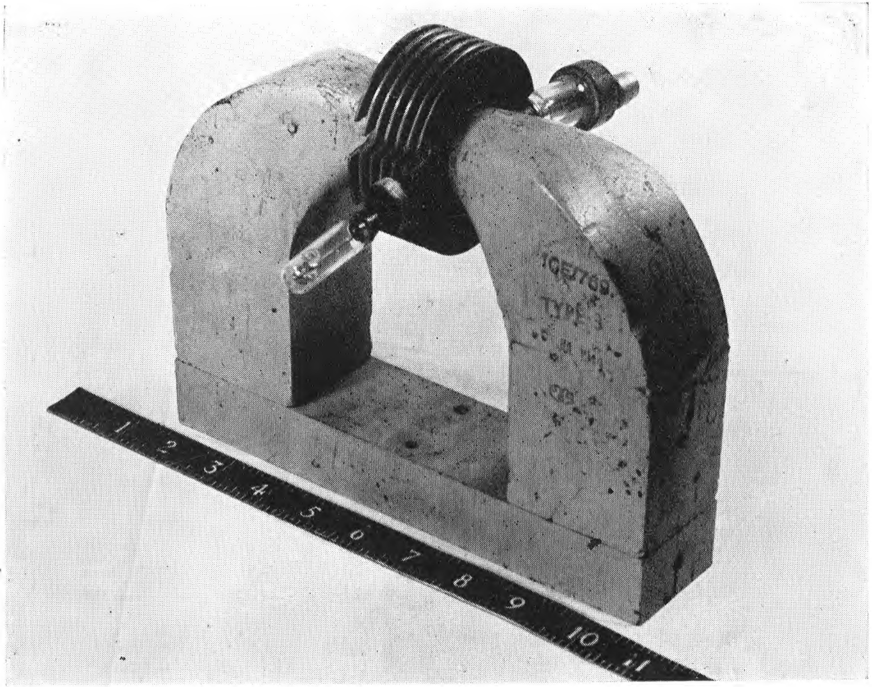
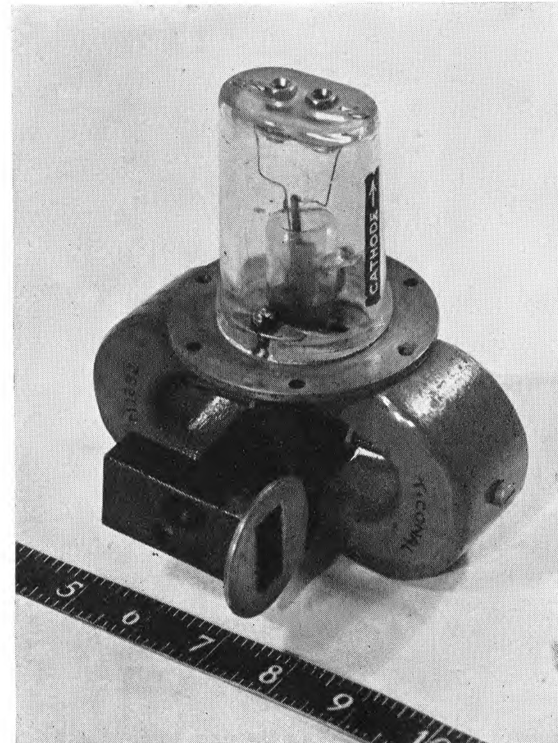
[1] Within one year the large number of differing types of magnetron which were required for centimetric radar equipment led to a serious decrease in total production because of the special tools and test equipment involved. *See also* Royal Air Force Signals History, Volume VI : ' Radio in Maritime Warfare '.

[2] A.H.B./IIE/6/60. *See also* Royal Air Force Signals History, Volume VI : ' Radio in Maritime Warfare '.

[3] The result of one of the most successful experiments was that a 10-foot hole was blown in the side of a *Junkers 88* aircraft, and even then an expert was able to gauge the dimensions of the magnetron from its fragments. (A.M. File CS.15549.)

[4] T.R.E File D. 1738.





Later versions of Magnetron

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undertook to manufacture 50 hand-made equipments by Christmas 1942, and the Research Prototype Unit was brought into the production plan. It was to manufacture the remainder of the required 200 equipments by the same date, using as a basis the E.M.I. development models rather than the experimental T.R.E. design as the former were well engineered and some 60 per cent of the essential drawings had been completed. This decision involved limiting the activities of the R.P.U. to H2S work only; additional personnel were recruited and plans for the extension of existing premises were made.[1] At the instigation of the Prime Minister all production arrangements were made the responsibility of Sir Robert Renwick and the Air Staff agreed to allow work on other development projects to be stopped if necessary in order that the commitment should be fulfilled.

First H2S Installation Programme and Service Trials

It had now become possible to plan an installation programme. As far back as February 1942 the Director of Bombing Operations had suggested that trial installations of H2S should be cleared for all types of bomber aircraft which were likely to be used for operations from September 1942 onwards.[2] The Deputy Chief of the Air Staff supported the proposal but in the following month the ruling was rescinded for all aircraft other than the Halifax until such time as more knowledge of the nature of the modifications involved had been gained. When, by the end of April 1942, installation in a Halifax of pre-prototype equipment had been completed, the Director of Radar urged that the layout for other types of bomber aircraft should be investigated. This proposal was made impracticable by the difficulties encountered with the scanner system, and all other trial installations were postponed until designs for the scanner and cupola had been completed, the beginning of July 1942 being set as a target date. On 15 July 1942 it was decided that Halifax, Stirling, Lancaster and Wellington aircraft should be equipped in that order of priority.

Arrangements were made for 24 Halifax and 24 Stirling aircraft to be equipped at Defford for two squadrons of Bomber Command by 31 December 1942.[3] An installation plan was made on the assumption that scanners and radar equipments would be made available from the manufacturers according to their agreed production programmes. The output of magnetrons for all purposes, including A.I. Mark VIII and A.S.V. Mark III, was expected to be 30 in August and 60 in September; bulk production was scheduled to begin in October at the rate of 200 per month.[4] The estimated output of fitted aircraft from Defford was one per week in September, three per week in October, and four per week in November and December 1942. On 15 August 1942 the programme was amended to include 24 Lancaster aircraft which were to be fitted when the Halifaxes and Stirlings had been completed.

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[1] A.M. File CS.13548.

[2] A.M. File C.30305/46.

[3] A.M. File CS.13548. The aircraft were also to be equipped with Gee.

[4] The centimetric A.S.V. installation was known as A.S.V.S. during its development stages. When pre-production development had been completed, and quantity production begun, the installation was to be given the nomenclature of A.S.V. Mark III.

The T.R.E. undertook the training of personnel required for the installation programme and for servicing the first two squadrons to be equipped. Twelve signals officers of Coastal Command were reporting to the establishment on 2 August 1942 for a three weeks course on Gee, and of them four were to be selected for training on H2S, Monica and I.F.F. Mark III.[1] Two of the four were to remain at Defford for work on the fitting programme until 17 October 1942 when they were to join the first squadron of aircraft equipped with H2S; the other two were to remain at Defford until the programme had been completed and were then to join the second squadron. H2S servicing courses for radio mechanics of Bomber Command were arranged on the basis of one flight sergeant, one sergeant, three corporals and sixteen aircraftmen for each of the two squadrons. It was also agreed that the T.R.E. Service Liaison Section should assist with the servicing of H2S on its introduction into operational use.[2]

Gradually the installation programme began to lag behind schedule. In September 1942 the Research Prototype Unit reported that a major labour problem had arisen in that unit. Great difficulty was being experienced in training new employees and little progress had been made with new buildings because, although steel had been delivered to time, deliveries of timber had been delayed. Its output of equipment was also affected by a shortage of components caused by a misunderstanding, which was subsequently cleared up, with the Gramophone Company. Also, the aircraft manufacturers, Handley Page, were seriously short of H2S connectors for the Halifaxes. The connectors were required for incorporation on the assembly lines and unless they were made available aircraft production would have to stop or aircraft would have to be delivered incomplete. The contractors manufacturing connectors could not begin production until midway through September 1942, and the requirements of A.I. Mark VIII clashed with those of H2S. The T.R.E. alleviated the situation by manufacturing some additional connectors, but delay in the installation programme was inevitable. The projected rate of installation involved the arrival at Defford of one Halifax per week from the Handley Page factories during September, and an intake of Stirlings from the aircraft assembly lines from the middle of November 1942. At the end of August 1942 it appeared that only one set of equipment, from E.M.I., would be available during September 1942. The situation grew worse in October 1942 when Handley Page decided to deliver six aircraft per week instead of three as had been planned. The T.R.E. requested that the surplus aircraft be diverted to be called for as required when sufficient equipment would eventually become available. The position in general, and the prospect of heavy bomber aircraft being left idle in storage, caused great concern. Bomber Command urgently needed every heavy bomber aircraft it was possible to obtain for operations over Germany, and H2S was urgently required for two squadrons of the Pathfinder Force for an offensive to be carried out during the winter months.[3] An immediate decision, no matter how unpalatable, was

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[1] Monica was a radar tail-warning device installed in bomber aircraft.

[2] *See also* Royal Air Force Signals History, Volume VI: 'Radio in Maritime Warfare', for details of the Post Design Service, as Service Liaison Sections were subsequently known.

[3] The formation of the Pathfinder Force coincided with German jamming of Gee in August 1942. The pathfinder squadrons therefore were without an effective means of locating targets.

essential. Before the end of September 1942 the installation programme, then more than six weeks behind schedule, was revised to allow for the fitting of 14 Halifaxes and 24 Stirlings by the end of December 1942, and of a further 11 Halifaxes and 4 Stirlings in January 1943.[1] The H2S installation had to be accepted with its existing faults and without further development. Arrangements were made for Service trials to be started right away.

Originally it had been intended that the pre-prototype Halifax installation should be given Service trials at the Bomber Development Unit, but in view of its unreliability, and because it became necessary to contemplate acceptance of H2S as it was, without further development, it was decided to send instead the first Halifax to be equipped at Defford. Installation of H2S in a Stirling aircraft was proving to be more difficult than had been anticipated because the equipment displaced the centre of gravity aft beyond the safety limit, and consequently completion of a trial installation was delayed. The first Halifax arrived at the Bomber Development Unit on 29 September 1942, and shortly afterwards a Stirling was also made available for H2S trials for short periods, by arrangement directly between the B.D.U. and the T.R.E. whereby scientists continued their development work on the aircraft.[2] No one was very satisfied with the equipment or confident that it would be satisfactory in operational conditions, and the results of the trials were eagerly awaited. Experience of the initial attempts of trained scientists to interpret the display had shown that a considerable amount of operational training was required before successful results could be obtained, and it was felt that early failure would prejudice the chances of H2S being introduced into Service use.

The first report, made by the B.D.U. in November 1942 on the preliminary trials, was reasonably reassuring.[3] Headquarters Bomber Command informed the Air Ministry that H2S, when competently operated, would fulfil requirements in so far as its use would ensure that bombs could be dropped within a built-up area selected by the navigator, and that the range was sufficient to enable aircraft to home to a built-up area from 15 miles at 15,000 feet.[4] A fully trained H2S navigator could navigate throughout a flight in 'blind' conditions to a selected target, but it was found that if H2S was used only after dead-reckoning navigation had been employed to take an aircraft to a point estimated to be 15 miles from the target, there was considerable risk of the wrong target being attacked. It was therefore recommended that H2S should be used for navigation to the target area. However, the standard of H2S serviceability was low, an average of about three hours flying per failure having been attained. The failures were mainly caused by breakdowns of transformers, both pulse and filament, and of condensers. Headquarters Bomber Command considered that they were the inevitable teething troubles and could be overcome, but proposed that, if the faults could not be cleared, the use of H2S would have to be limited to the target area only. The trials had made obvious the fact that extensive training and constant practice were necessary before a navigator would be able to use H2S effectively, and that unless he had the requisite aptitude he might never become competent. Permission was requested for the Pathfinder Force to operate with H2S as

[1] A.M. File CS.13548. [2] A.M. File CS.13548. [3] A.M. File C.30305/46.

[4] A built-up area was defined as one not less than one mile in diameter.

soon as one squadron was equipped, for '. . . H2S will be invaluable for the location and effective bombing of targets in all conditions of visibility . . .' After further trials Headquarters Bomber Command, on 2 December 1942, reported that '. . . the accuracy of bombing with H2S in blind conditions will produce a concentration of bombs about the aiming point comparable with the best results that can be achieved at present by crews in perfect visibility . . .' The outstandingly successful results that had been obtained were considered to be largely due to the considerable experience gained at the B.D.U. of the installation, servicing, and operational use of H2S ; '. . . such experience is an essential foundation for the effective training of squadron personnel . . .'[1] In the opinion of the Commander-in-Chief, Bomber Command, the results clearly indicated that if aircraft of his command were equipped and his crews trained with H2S, any target within flying range could be located and successfully attacked irrespective of the degree of visibility obtaining over enemy territory.

First Operational Use of H2S

As a result of the satisfactory reports from the B.D.U., and the recommendations of Headquarters Bomber Command, the Chief of the Air Staff minuted the Secretary of State for Air on 30 November 1942 '. . . the time has now come, I think, to decide when we should first use H2S in operations . . .'[2] It was not a simple decision to make. Investigation had revealed that there was little hope of Coastal Command being equipped with A.S.V. Mark III before the spring of 1943, and the employment of search receivers in U-boats had made urgent not only an improvement in A.S.V. performance but also a radical change in wavelength.[3] In September 1942 appeals for assistance made to the Chief of the Air Staff by the Chief of the Naval Staff and the Commander-in-Chief, Coastal Command, were answered by a ruling that 40 H2S installations were to be diverted from the crash production programme, as an emergency measure, to Coastal Command for employment in an A.S.V. role. There appeared to be no logical reason why the installation should not prove to be satisfactory, although it did not completely fulfil all operational requirements, and the arrangement was described as '. . . a justifiable gamble . . .' The implications of the new plan were discussed at a series of conferences convened by Sir Robert Renwick during the last week of September and early in October 1942, when the programmes for production of H2S and A.S.V. were reviewed and reorganised.[4] The real urgency of the need for centimetric A.S.V. caused its acquisition to be regarded as being equally important to that of H2S, and revived practical interest in the possibility of a universal system.

For the last few months the predominant requirement had been a radar blind bombing system, and the application of H2S/A.S.V. in a purely maritime role had been pushed into the background. The T.R.E. undertook to complete the final design of a universal H2S/A.S.V./A.I. system by the end of 1942, and estimated that quantity production could be started in August 1943. It seemed probable that the total Service requirements for H2S/A.S.V. would

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[1] A.M. File C.30305/46. [2] A.M. File C.30305/46.

[3] *See* Royal Air Force Signals History, Volume VI : 'Radio in Maritime Warfare'.

[4] A.M. File CS.17067.

be for some 3,000 installations by the end of 1943. In view of the forecast made by the T.R.E. it appeared reasonable to ensure that the current production of H2S was continued until August 1943, especially since it seemed likely that H2S would, once certain modifications had been incorporated, prove to be satisfactory in an A.S.V. role. That resolved the provisioning problem to one of obtaining a further 1,000 equipments by the end of 1943. The Ferranti contract for 200 sets of the equipment, which was to have been A.S.V. Mark III, was cancelled and the firm was given instead a contract to produce the additional 1,000 H2S/A.S.V. equipments. The policy of substituting an increased H2S/A.S.V. production for A.S.V. Mark III production was approved by the Assistant Chief of the Air Staff (Operations) on 28 October 1942, and the production of a single design of radar and scanning units common to both Bomber and Coastal Commands, first visualised in March 1942, was begun.[1]

The question of the date on which H2S could be introduced into operational use by Bomber Command had thus been complicated by the emphasis placed on its value in the anti-U-boat operations of Coastal Command. On 4 September 1942 the Chief of the Air Staff had informed the Chief of the Naval Staff of the progress made with the development of magnetron H2S and explained that although experiments were being conducted with a view to incorporating self-destruction devices, it was realised that the decision to use the magnetron over enemy territory was a very important one which would affect all three Services.[2] In fact, it had recently been ruled that before radar equipment working on a wavelength of 10 centimetres or below was used in areas where it might possibly fall into enemy hands, the matter was to be referred to the Radio Policy Sub-Committee who would, if necessary, obtain a ruling from the Chiefs of Staff Committee.[3] A ban on the use of centimetric radar over enemy territory was agreed to by the governments of the United Kingdom and the United States of America. On 8 October 1942, when the allocation of H2S to Coastal Command was being planned, the Chief of the Naval Staff requested reassurance that the policy still held good in view of the fact that the success of centimetric A.S.V. depended to a large extent on its ability to defeat German search receivers, and surprise was, in consequence, an important factor.[4] The position was further complicated when on 28 October 1942 the United States Army Air Force announced its firm intention of bringing centimetric airborne radar into immediate use in the Alaskan area. Until then it had appeared that the Combined Communications Board intended to reserve to the Combined Chiefs of Staff Committee the responsibility for making a decision regarding the date on which centimetric equipment might be used in circumstances involving risk of capture. However, on 28 October 1942 the Board recommended to the Committee that '. . . (*a*) Until centimetric equipment is available in quantities permitting large-scale tactical employment its

[1] A.M. File CS.17067. *See also* Royal Air Force Signals History, Volume VI : 'Radio in Maritime Warfare'.

[2] Although emphasis was placed on the need to destroy the magnetron, the scanning system used in H2S/A.S.V. indicated that a centimetric wavelength was being used. Salvage operations in June 1942 on the wreckage of Halifax V.9977, which had burnt and disintegrated, showed that the scanner system remained sufficiently recognisable to permit the wavelength to be deduced approximately. (T.R.E. File D.1738.)

[3] A.H.B./ID/12/195.

[4] A.M. File C.30305/46.

disclosure would enable the enemy to develop countermeasures and would lose us the element of surprise . . . (*b*) Until 1 March 1943, or any earlier date when non-restricted use is announced, it should not be used over heavily defended territory or in circumstances involving risk of capture unless the tactical or strategic advantage warrants it and special precautions are taken for destruction . . .'[1] It appeared likely that the recommendation would result in the delegation of authority on the matter to local Commanders-in-Chief, and the employment of magnetron equipment on minor operations before it was used on major operations. A firm decision was clearly desirable since the question was shortly to be discussed by the Radio Board.[2]

On 8 December 1942 the Secretary of State for Air convened a meeting, attended by the Chief of the Air Staff, Lord Cherwell, Sir Stafford Cripps, Sir Henry Tizard, Sir Robert Renwick, the Commander-in-Chief, Bomber Command, and other representatives of the Air Ministry, Bomber Command and the Ministry of Aircraft Production, to discuss the operational use of H2S in the bombing offensive. It was first of all necessary to confirm that it was intended to use H2S in the pathfinder squadrons only initially, and not in aircraft of the main force. The Commander-in-Chief, Bomber Command, was very definitely in favour, as, in his opinion, it would be unwise to defer the employment of H2S in the hope that the Germans would not learn of it by the time it became possible to build up a large force of aircraft equipped with H2S. The Chief of the Air Staff, whilst in favour of using the equipment for the pathfinders, thought it desirable to know what action the enemy could take to counter its use if they managed to get hold of an installation soon after its introduction into operation. He was informed that H2S was very difficult to jam and could only be countered by the use of very large decoys. Since it would be necessary to erect them around the place that might be chosen as a target, and because they were comparatively ineffective, it was considered unlikely that the Germans would be able to produce countermeasures to H2S for some considerable time. After further discussion the meeting agreed that at first H2S should be used only by pathfinder aircraft. The prospects of equipping, training, and servicing Nos. 7 and 35 Squadrons of the Pathfinder Force in time to allow H2S to be used before 1 March 1943 were then studied. It was thought that, with existing arrangements, by the end of 1942 12 Halifax installations would have been completed, and that 24 Stirlings would shortly afterwards be delivered to Bomber Command. The whole of the installation programme for January 1943 was scheduled for aircraft of Coastal Command. The Secretary of State for Air suggested that, to provide a reasonable number of replacement aircraft for the Halifax squadron, six Halifaxes should be substituted for six of the Stirlings. This plan presented difficulties but it was finally proposed that arrangements should be made for the additional Halifaxes to be fitted by personnel of Bomber Command. If the aircraft, once they had been equipped with H2S, were not used straight away on operations, they would have to be left in storage, and the loss of two squadrons for two months of winter when the nights were longest held serious implications for Bomber Command. Also, the navigators being trained for H2S bombing would have to be screened from operations, for the normal casualty rate would otherwise involve another training commitment, and, since they possessed a fairly detailed

[1] A.M. File C.30305/46.

[2] Formerly the Radio Policy Sub-Committee.

knowledge of the equipment, capture of the navigators endangered the security of H2S. It was agreed that it was possible to visualise operations beginning in January 1943, and that authority to make 1 January 1943 the starting date should be sought from the Radio Board.[1]

The Radio Board accepted the possibilities that the enemy might already be developing centimetric radar themselves, and that they might already be aware of the employment by the Allies of centimetric technique for ground radar. It considered that the use of H2S by two pathfinder squadrons during January and February 1943 would undoubtedly be of great value to Bomber Command, and that the capture of H2S a month or two earlier than might otherwise be possible would not be of great help to the enemy. The Admiralty, however, felt that the two months were very important in relation to the anti-U-boat campaign, and considered that the use of H2S should be deferred until after 1 March 1943. Reference to the Chiefs of Staff was postponed until some agreement could be reached. The Admiralty viewpoint was that, whilst it might take the Germans some time to develop and produce measures to make H2S less effective as a bombing system, the production and installation in U-boats of a suitable search receiver was a comparatively simple matter. The Radio Board was asked to re-examine the technical aspects of the situation as a matter of great urgency and to determine the probable effect on the war at sea if an H2S installation was lost to the enemy in the first week of January instead of in the first week of March 1943. The members of the board, directed by Sir Stafford Cripps, studied a detailed appreciation made by Sir Robert Watson Watt, and decided that the loss of an H2S installation in enemy territory would to some extent accelerate the use of countermeasures and would shorten the period of maximum effectiveness of centimetric A.S.V. by some two months.[2] On 22 December 1942 the Prime Minister presided over a meeting of the Chiefs of Staff Committee at which the findings of the Radio Board were discussed.[3] The Chief of the Air Staff outlined the advantages to be gained by the use of H2S in the Pathfinder Force during January and February 1943, and the Chief of the Naval Staff gave reasons for the anxiety felt by the Admiralty, who considered that U-boat warfare was fast approaching a crisis and wished to avoid compromise of the equipment until the last possible moment. After the various implications had been discussed in detail, the Prime Minister summed up. He considered that assessment on a quantitative basis of the results of the earlier release of H2S was not possible, but were the scales in balance he would have tipped them in favour of the war at sea. It seemed to him, however, that the advantage to be gained by Bomber Command if H2S were used as soon as possible would be of greater benefit to the general war effort than would be the probable advantage to be gained by Coastal Command if the operational employment of H2S were deferred. The majority of the committee were in agreement with him, and their conclusions were submitted to the Combined Chiefs of Staff Committee in the United States of America, who, on 8 January 1943, sanctioned the immediate employment of H2S over enemy and enemy-occupied territory.[4]

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[1] A.M. File C.30305/46.

[2] *See* Royal Air Force Signals History, Volume VI : 'Radio in Maritime Warfare', for further details.

[3] A.H.B./ID3/932A. H2S and A.S.V. Fitting Programmes.

[4] A.H.B./ID3/932. A.S.V. and H2S.

When permission to go ahead was received from Washington, the Chief of the Air Staff, on 10 January 1943, directed that arrangements were to be made immediately for the operational use of H2S on a bombing raid. However, this was not to be the straightforward process that had been hoped, and the situation was such that on 13 January 1943 the Director of R.D.F. reported to Sir Robert Renwick that '. . . the H2S/A.S.V. position seems to grow grimmer daily . . .' and at the end of the month the Chief of the Air Staff stated that '. . . the Ministry of Aircraft Production programme has been far too optimistic . . .'[1]

By 13 January 1943 ten Halifaxes of No. 35 Squadron and 13 Stirlings of No. 7 Squadron had been equipped with H2S. The achievement of even that limited number of installations had been made possible only by abandoning the policy, which the Signals Staff had found by experience to be necessary with new equipment accepted without thorough Service trials, of providing one spare set of equipment and a number of replacement components for each fitted aircraft. No. 35 Squadron held two unserviceable and one serviceable, and No. 7 Squadron two unserviceable, spare equipments. No more aircraft could be equipped until equipments had been received from the contractors. E.M.I. had delivered 61 of the 63 equipments promised by that firm, but many of them had necessarily been allocated for training, testing and research purposes. The R.P.U. had not begun production, and it seemed that even when it did begin, output would be limited, mainly by a lack of testing facilities. Arrangements had been made for the firm of Siemens to manufacture the test gear associated with H2S/A.S.V. but, until it was available, the production and installation programme were dependent on the small quantity of test gear which could be made by the T.R.E. The installation programme had fallen seriously behind schedule mainly because of delay in the production of equipments, but that was not the only factor which prevented the squadrons from using H2S on operations as soon as permission to do so was granted. There had been technical failures in the equipment, and setbacks with the aircraft. There was a shortage at the operational airfields of such necessary items as petrol bowsers, towing tractors and mechanics' tool kits; those shortages combined had reduced the amount of training which could be undertaken in the air in periods of good flying weather in order that crews might be ready to undertake H2S operations. In addition, the squadrons, No. 35 Squadron especially, were manned below establishment in personnel including other than radar tradesmen.[2]

As a result of the very appreciable delays in the production of equipments, it became necessary to revise continually the installation programme, and the main features of the progress made with the introduction of H2S Mark I into general Service use were the constant struggles to overcome the difficulties created by shortages and the problem of priorities of the requirements of Bomber and Coastal Commands.[3] During that period the Bomber Command Service Liaison Group of the T.R.E. performed invaluable services. A team of scientists went to the B.D.U. in September 1942 to train navigators and mechanics and to service the installations during the early trials, whilst others at the T.R.E.

[1] A.M. Files CS.13548 and CS.17067.

[2] A.M. File CS.13548.

[3] The nomenclature H2S Mark I was given to the early production equipments manufactured by the firm of E.M.I. and by the R.P.U. Later equipments which incorporated beacon facilities were known as H2S Mark 1A.

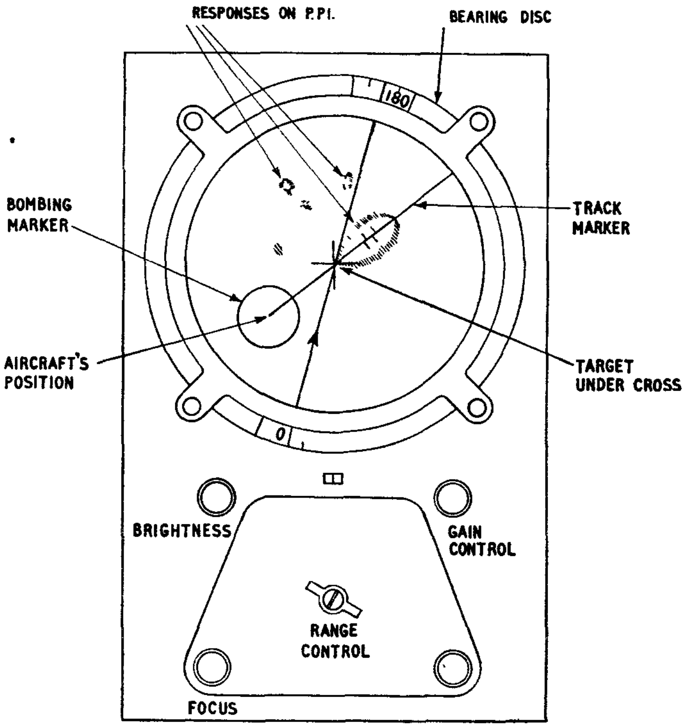
and at Defford did all they could to organise the supply of spares and to provide training for mechanics. The shortage of equipment made the task of training very difficult ; at one stage 47 men were being instructed at one bench set. Teams were also attached to Nos. 7 and 35 Squadrons, and very hard work was necessary in view of the arrival of aircraft equipped with H2S at R.A.F. stations where no repair workshops had existed before and where the entire organisation for maintaining a complicated radar installation had to be worked out from the very beginning. The inevitable teething troubles were experienced with the few equipments which had been manufactured, and the persistent lack of reliability caused grave misgivings to be felt. At the most difficult period a flying time of less than two hours for each failure was obtained, and it was feared that successful use of H2S was going to be imperilled by the number of failures which might be expected during an operation. Improved types of filament and pulse transformers were incorporated, but a major cause of unserviceability was the carbon pile in the voltage control panel, and modification recommended to increase the number of flying hours per fault included the addition of a stabilising device to the carbon pile, and the incorporation of improved condensers and transformers. Because a satisfactory type of transformer was not immediately available an alternative was adopted as a temporary measure, but after an initial provision supplies unaccountably ceased.[1] Until the technical defects of the equipment had been completely cleared the pathfinder squadrons could not operate satisfactorily unless an adequate number of spares was made available.

In January 1943 the Air Staff proposed that no more aircraft should be fitted until the squadrons were provided with one spare equipment, and an adequate range of the components which were causing failures, for each aircraft already equipped, and that such provision should be made for each installation to be completed. On 20 January 1943 the War Cabinet Anti-U-boat Warfare Committee, who were very perturbed about the failure to equip aircraft for Coastal Command, had to decide whether fitting should be continued in accordance with the agreed programme and the need to provide spares ignored, or whether a much smaller number of aircraft, each provided with a spare set, would be acceptable. It was eventually agreed that the six Wellington installations then in hand for Coastal Command should be completed, and thereafter equipments were to be allocated alternately to Bomber and Coastal Commands until such time as the number of aircraft delivered were accompanied by half as many spare installations. It was, however, stipulated that the decision did not in any way imply that the approved policy of 100 per cent spares had been permanently amended.

As the spares position improved and many of the teething troubles were overcome, the earlier despondency gave place to a feeling of confidence and towards the end of January 1943 Nos. 7 and 35 Squadrons were made ready to include H2S in their pathfinding technique against targets in Germany. During November and December 1942, as fitted aircraft were being delivered to the squadrons, crews were given specialised training both in the air and on the ground, whilst trials were being conducted at the B.D.U., and blind bombing techniques for using H2S and Oboe operationally were devised. They were developed from the ' Illumination ' method of attack in which pathfinders laid sticks of flares over the target, thus allowing the main force to identify and

[1] A.M. File CS.13548.

bomb it visually, and were used according to the forecast weather conditions. ' Paramatta ' was used when thick cloud was extensive enough to prevent the main force from identifying the target visually but allowed crews to observe ground marker bombs dropped on the aiming point with the help of H2S. ' Wanganui ' was employed when the amount of cloud was such as to prevent positive identification of ground detail, and the main force was guided to the bomb release point by coloured sky-marker flares released on H2S plots. The bombing aircraft had to approach the target on a given heading to release bombs at the point marked.[1]



H2S Indicator Unit

H2S was first used by the Pathfinder Force for a bombing attack against a target in Germany on the night of 30/31 January 1943, just one year after the initial production contract had been placed for the original klystron installation which at that time was in the research and experimental stage. Hamburg was selected as the target because of its importance as a U-boat base, its size, and its proximity to the coastline. From an H2S operator's point of view Hamburg was an ideal choice as its features were more easily interpreted on the P.P.I than would have been those of a target further inland, although in fact the weather was more suitable in other parts of Germany.[2] Six Halifaxes and seven Stirlings were detailed as H2S target markers. Four of the Halifaxes returned to base before they had reached the target because of technical troubles

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[1] A.H.B./II/69/215A. H2S.

[2] Over Hamburg cloud varied from two-tenths to ten-tenths and the wind at bombing height, 18,000 feet, was 100 miles per hour.

not connected with H2S. The installation functioned satisfactorily in the other two Halifaxes and in four of the Stirlings. Three Stirlings experienced difficulty with their H2S equipments and returned to base early, one did not work at all, one worked intermittently, and one failed to work on the outward journey, but was satisfactory on the homeward flight. The first aircraft to mark the target dropped ground marker bombs on an H2S plot ; the crew reported that they fell exactly at the aiming point, which was the southern end of the Binnen Alster. A good concentration of bombs was built up around the markers. The target then became obscured by cloud and other H2S aircraft changed from ' Paramatta ' to' Wanganui ' and dropped their flares at the appropriate release point. The pathfinders and the main force were able to change smoothly from the one method to the other during the attack. The Officer Commanding, Pathfinder Force reported that ' . . . the operation was, in the light of the prevailing weather conditions, a brilliant success . . . '[1]

In this first operation the crews differed in the manner in which they operated the H2S equipment. Some kept the sets switched on continuously from the time they crossed the enemy coast on the outward journey until they crossed it again on the return journey, whilst others switched it on and off intermittently. Less trouble was experienced by those who kept the equipment working continuously and orders were given that on subsequent operations all operators were to follow that procedure. The responses obtained throughout the operation contained a number of surprises. Wilhelmsburg, for instance, which was expected to give a clear response, did, in fact, give a particularly poor one, whilst other towns and landmarks which were not expected to be outstanding gave extremely good responses. Hamburg itself responded exactly as had been anticipated, and the performance of the equipment at a height of 18,000 feet was much better than had been thought possible.

Change in Operational Requirements

By 9 February 1943 H2S had been used by the Pathfinder Force on a further three raids, including one against Turin. Technical reliability had rapidly improved, and on the most recent operation all eight installations employed were switched on for an average of seven hours without a failure. Operational effectiveness was described as ' . . . surpassing expectations . . .' and navigators confirmed that they were able to identify towns at ranges of 20 miles.[2] Although Headquarters Bomber Command reported that ' . . . H2S in its present form fully meets Air Staff requirements . . . ' recent attacks had demonstrated the advantage to be gained from operating at heights above 20,000 feet in certain circumstances, particularly when a blind bombing technique was employed. The Halifax had been made capable of flying, with bombload, at heights above 20,000 feet, and the Lancaster was able to reach even greater heights with a full bombload. Consequently, on 2 February 1943, Headquarters Bomber Command raised an operational requirement for H2S to be modified to enable it to function efficiently at heights up to 22,000 feet and, if possible, to 25,000 feet. Arrangements were made for the B.D.U. to undertake experiments, with the aid of the T.R.E., in an attempt to reduce the gaps obtained above 20,000 feet, more particularly with the Halifax installation than with the Stirling, and the T.R.E. was requested to redesign the scanner system. H2S had been designed on the assumption that 15,000 feet would be its operational ceiling, and

[1] A.H.B./ID/12/195. [2] A.M. File CS.15545.

the faults in the display at that height were aggravated at 20,000 feet. The problem divided itself into two parts; that of removing gaps which occurred at about 15 and 6 miles, and the clearance of gaps and heavy ground returns which spread out to a range of about 4 miles. The T.R.E. had been seeking a solution to the first problem for some time by modifying the dipole aerial feed, and the results of tests were encouraging. The second problem was much harder to solve in that it was fundamental in character, and it was extremely unlikely that any radical improvement could be effected without the introduction of a new Mark of equipment and new scanner system, possibly working on a new wavelength.[1]

By 21 February 1943, when the strength of Bomber Command aircraft equipped with H2S was 12 Halifaxes in No. 35 Squadron, two Halifaxes in the B.D.U., and 15 Stirlings in No. 7 Squadron, Headquarters Bomber Command considered that sufficient operational experience with H2S had been gained to establish its value, not only as a blind bombing device, but also as an accurate all-weather navigation system, and raised a requirement for its installation in all heavy bombers not only to increase the destructive power of the command but also to reduce the restrictions imposed on its operations by adverse weather. It was appreciated that a well trained navigator was able, with the assistance of H2S, to navigate across Europe without recourse to ground stations and without limitations of range. The navigation aspect had become very important because of the lack of other aids on the Continent. In September 1941 there had been indications of German broadcast stations being operated in synchronised groups except when the enemy required to use them during operations, and one year later the waveband of enemy-operated medium-frequency beacons was narrowed to one not covered by the wireless receiver then in use in Bomber Command.[2] However, the P.P.I. display was not easy to interpret, particularly when over industrial areas, and only very few exceptionally capable navigators were able to combine dead-reckoning navigation and H2S interpretation. A new aircrew member, the bomb-aimer, usually a qualified navigator, had been brought into the aircrew of heavy bomber aircraft to relieve the navigator of the task of identifying the target visually, and he was made responsible for operating the H2S installation. The navigator worked along normal lines and notified the bomb-aimer when it became necessary to search for the next landmark. The bomb-aimer watched the P.P.I. and endeavoured to identify landmarks independently. If at any time a particularly definite landmark was recognised, the navigator was informed and a fix was taken.

Review of Installation Programme

Although Headquarters Bomber Command in February 1943 proposed that H2S should be regarded as standard equipment in all Halifaxes and in all Lancasters except those fitted to carry 8,000-pound bombs, by the end of the month it became only too obvious that a considerable gap existed between the predictable production and installation facilities and the existing fitting programme.[3] It became necessary to examine closely the needs of Bomber and Coastal Commands in relation to the installation facilities which could probably be made available, and when the requirements could not be met, to

[1] A.M. File CS.15545.

[2] *See* Royal Air Force Signals History, Volume VII : ' Radio Counter-Measures '.

[3] A.H.B./ID/12/195.

modify them and evolve a definite order of priority. The Directorate of Bombing Operations at the Air Ministry maintained that the priority of allocations to Bomber Command should be increased at the expense of Coastal Command; the great need of the bomber force of nearly 50 squadrons was concentration of attack and H2S enabled the pathfinder squadrons to locate targets and concentrate attack against them in an effective manner that had not before been possible. To ensure effective marking in sustained operations a minimum force of four squadrons equipped with H2S was required. Six squadrons were considered desirable to extend the period of marking throughout the entire attack and to ensure that there were enough markers at any time to reduce the effect of individual aiming errors and thus to provide a pattern of markers the centre of which would be on or near the aiming mark. For those reasons it was contended that the provision of H2S on a scale sufficient to equip immediately six pathfinder squadrons would be of a value out of all proportion to the number of equipments involved, whilst in Coastal Command, it was argued, each equipment could have but a limited value. However, at a meeting held on 12 March 1943 under the chairmanship of the Assistant Chief of the Air Staff (Operations), at which the general policy of installing H2S/A.S.V. in aircraft of both commands was discussed, it was finally agreed that they should be equipped as follows:—[1]

Date	*Bomber Command*	*Coastal Command*
By 31 March 1943	2½ squadrons	3 squadrons
By 30 April 1943	3 squadrons	3½ squadrons
By 31 May 1943	4⅓ squadrons	6 squadrons
By 30 June 1943	5⅙ squadrons	6 squadrons + 1 overseas
By 31 July 1943	7½ squadrons	7 squadrons + 2 overseas
By 31 August 1943	10⅔ squadrons	9½ squadrons + 2 overseas
By 30 September 1943	13 squadrons	11 squadrons + 2 overseas

With this order of priority as a guide allocation of the weekly output of equipment was governed by a number of fluctuating factors, examined each week by the Director of R.D.F. and Sir Robert Renwick, which included:—

(*a*) Casualties, losses, and technical breakdowns during the previous week.

(*b*) Output of aircraft available for fitting.

(*c*) Ratio of serviceable to unserviceable sets held by squadrons both in aircraft and as spares.

(*d*) Progress already made with aircraft at the installation unit.

(*e*) Progress of training on unit.

(*f*) Availability of spare components.

The percentage of equipment required to be held as spares for fitted aircraft had continued to be the subject of many discussions, and remained so until the end of the war. At the end of February 1943 the Director of R.D.F. contended that the holding by squadrons of a 100 per cent reserve of equipment was a wise policy which had been amply proved by experience with new equipment such as A.I. Marks IV and VII and A.S.V. Mark II, and he considered the difficulties which constantly arose with the installation programme were mainly due to the disregard for that need. In practice the percentage was rarely achieved but aiming at its maintenance usually resulted in a reasonably adequate number of spare sets being held. Relaxation of the rule inevitably resulted in

[1] A.H.B./II/69/215A.

a limitation of training and operational employment. At a meeting held on 4 March 1943 to discuss the scale of provision of spares the Chief of the Air Staff suggested that the ideal arrangement was one in which, instead of an arbitrary percentage being fixed, just sufficient serviceable sets were made at any one time to enable aircraft to operate with no equipment left over ; serviceable sets kept on the ground were wasted sets.[1] He wanted a reduction made in the number of equipments and components held as spares in order that an increase might be made in the number of aircraft equipped from the limited production. The Commanders-in-Chief of Bomber and Coastal Commands agreed to study the problem and to estimate their essential requirements. As a result of these investigations both stated that they would be able to operate satisfactorily with less than a 100 per cent holding of reserve equipments. Headquarters Coastal Command considered that 25 to 30 per cent would probably be sufficient but lack of operational experience with A.S.V. Mark III made accurate assessment impossible.[2] Bomber Command squadrons were holding just over 50 per cent in reserve and were managing with great difficulty to maintain a serviceability standard of about 75 per cent. Although it was doubtful whether the standard could be raised to 100 per cent unless one serviceable equipment was held in reserve for every one installed in an aircraft, the command was willing to operate with between 50 and 60 per cent spares in view of the difficult circumstances. The aircraft of Bomber Command were more vulnerable to casualties and damage than those of Coastal Command, and it was essential to get the maximum number in the air on every good bombing night. It was therefore natural that a higher proportion of spares should be required, and the Commander-in-Chief Coastal Command expressed his willingness to transfer to Bomber Command any spare equipments he was holding over the bare minimum required. Both commands had one great difficulty in common. Technical failure of H2S/A.S.V. occurred most frequently in certain components, and the faulty components could only be replaced through the process of 'cannibalising' serviceable equipments, obviously a wasteful procedure, or by applying to the T.R.E., who controlled such spare components as existed and helped whenever they could. The state of the production programme precluded extra components being readily available, and it was not worth while merely to manufacture an increased number of the components which were recurrently defective ; their design was fundamentally faulty and complete redesigning was necessary. It was only where the equipment had been in Service use for some time and, with the incorporation of modifications and refinements, had attained its approximate final form, that independent production of specific components could be made a practicable proposition.[3] Until then it was inevitable that spare components would generally be held as complete spare sets. The Chief of the Air Staff agreed that the holding of a large number of unserviceable equipments would have to be accepted temporarily, but ruled that the ratio of serviceable spare equipments to fitted aircraft was to be kept as low as possible in order that the number of completed aircraft installations might be quickly increased. Before the end of March 1943 the percentage of spare equipments held in Nos. 7 and 35 Squadrons had been reduced to about 30 per cent but it was clear that the empiricism would require very careful supervision.

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[1] A.H.B./ID3/932A.

[2] A.S.V. Mark III was the nomenclature given to the Coastal Command version of H2S/A.S.V.

[3] A.H.B./ID3/932A.

Installation Programme for Lancaster Aircraft

The number and type of aircraft equipped with H2S Mark I held on the strength of Bomber Command on 31 May 1943 were 26 Stirlings in No. 7 Squadron, 26 Halifaxes in No. 35 Squadron, nine Halifaxes in No. 405 Squadron, seven Lancasters in No. 156 Squadron and six Lancasters in No. 83 Squadron, all part of the Pathfinder Force. In addition, there were four Halifaxes at the B.D.U., and five Halifaxes and six Stirlings in the P.F.F. Training Flights.[1] The T.R.E. had been notified in August 1942 that installation of H2S in Lancasters would be required, as the planned rapid expansion of Bomber Command was to a great extent reliant on the large-scale production programme of Lancasters, in which ' shadow factories ' were employed. The production of Stirlings, Halifaxes and Lancasters had originally been planned on similar scales, but in 1942 it was decided to change over Stirling production to Lancaster. However, the type of Lancaster to be used as a prototype could not then be decided. Aircraft coming off the assembly lines were fitted with bomb-bay doors which were flush with the fuselage, but they were being superseded by blister bomb doors to allow for the carriage of 8,000-pound bombs. The modification necessitated a fairing along the underside of the fuselage, extended aft of the under-turret, which precluded the fitting of an H2S scanner cupola in a position similar to that used for the Halifax and Stirling installations.[2]

The Halifax had been selected as the first aircraft in which to make a prototype installation because the scanner system could, without major modification to the aircraft, be accomodated in a cupola fitted in place of the under-turret immediately aft of the bomb doors. This was a satisfactory arrangement for aircraft engaged solely on target marking duties and not required to carry large bombs.[3] In September 1942 the trial installation in a Lancaster was postponed until towards the end of November, when more information of the Halifax and Stirling prototypes would be available, especially regarding gaps in the radiation beam.[4] At the same time Headquarters Bomber Command stressed the urgency of the requirement for an improvement in performance and reliability of the intercommunication and radio telephony systems in Lancasters. Whilst the importance of H2S and Monica was clearly recognised, the highest priority was to be given to the incorporation of a low impedance inter-communication system, upon the efficiency of which depended to a large extent the tactical effectiveness of aircraft radar installations. H2S was required initially only in Lancasters intended for the Pathfinder Force, and the prototype installation was therefore to be made in an aircraft with the original type of bomb doors although it was appreciated that the problems posed by the blister bomb doors would eventually have to be tackled. A requirement was stated for H2S to be installed in 48 Lancasters ; 24 were to be completed by 1 January 1943 and four per month after that date to cover estimated wastage.[5] The order of priority for radio modifications and installations in Lancasters was stated to be :—

(*a*) Repositioning of blind approach units and vertical aerials.

(*b*) Low impedance inter-communication system, TR.9 and TR.1196.

(*c*) Monica.

(*d*) H2S.

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[1] A.H.B./IIE/248/2/1. Fitting progress of H2S aircraft. [2] A.M. File CS.15551.
[3] A.M. File CS.15550. [4] A.M. File CS.13548. [5] A.M. File CS.15551.

(*e*) Direct inter-communication system with gliders when aircraft used as towing tugs.

(*f*) Radio altimeter Type 5.

In October 1942 the Director of R.D.F. pointed out that the target date of 1 January 1943 was impracticable in the light of the delay in the Halifax and Stirling installation programmes and that if suitably modified Lancasters were delivered to Defford from the aircraft contractors by that date they would have to stand idle whilst awaiting fitting, especially since the rate of production of Lancasters would be high.[1] The fitting parties at Defford would be unable to accept Lancasters in any quantity until February 1943, and therefore on 7 December 1942 a revised programme was agreed. Six Lancasters were to be delivered to Defford by 28 February 1943 and 22 during March. The trial installation was to be completed for acceptance by the T.R.E. by 31 January 1943.

From the time when it was first decided to install H2S in Lancasters the possibility of fitting the scanner system in the aircraft nose was the subject of many discussions, and was closely allied with the bomb load to be carried. Before the decision was made, arrangements had been completed for all factories manufacturing Lancasters to incorporate in them the blister bomb-bay doors, which included the use of different jigs and materials. When the introduction of the H2S scanning system in the ventral position was planned, the Air Ministry asked for an alteration to the programme to ensure that all except approximately 10 per cent of the Lancaster output would retain the original bomb-bay doors. Two of the biggest contractors were, however, already so far committed in their preparations for changing to the new type of doors that about 30 per cent of the total Lancaster production for 1943 would be equipped with them, and the percentage was likely to increase to 40 per cent in 1944.[2] In January 1943 Headquarters Bomber Command considered it to be highly desirable that all Lancasters should be capable of carrying one 8,000 or two 4,000-pound bombs. Such a project was impracticable if H2S was also required unless the scanner system was installed in the nose of the aircraft. The Royal Aircraft Establishment was developing an 'ideal' navigator/bomb-aimer aircraft nose which was to incorporate an internally housed scanning unit, and a Lancaster was to be used for an experimental nose installation. Early experiments indicated that, with it, the forward-looking range of H2S would be improved but the efficacy of backward-looking would be impaired. Consequently, although the installation might be more effective for target location and identification, it was probable that it would be less satisfactory than the ventral installation as a navigation system, since all-round scanning was likely to be adversely affected. If all-round scanning were to be considered essential, a 'chin' design would have to be adopted, and that might mean a reduction in speed. The current tendency was to do everything possible to increase the speed of bomber aircraft, and the development being undertaken at the R.A.E. was aimed at producing an aircraft nose which was aerodynamically acceptable.[3] If Headquarters Bomber Command, in order that eventually all Lancasters could be fitted to carry large bombs, were to agree to accept the limitations imposed by scanning in a forward direction only, incorporation of a suitable scanning installation

[1] A.M. File CS.15551. [2] A.M. File CS.15551. [3] A.M. File CS.13548.

would take some six to eight months to implement, would involve the engagement of additional labour, and would cause further dislocation of the plans made by the aircraft contractors. If, on the other hand, it were agreed that the provision of H2S in 60 per cent of Lancasters, and of large bomb doors in 40 per cent, was satisfactory, the Ministry of Aircraft Production would be enabled to stabilise the aircraft production programme.

On 27 February 1943 Headquarters Bomber Command stated an official operational requirement for H2S to be installed in all Lancasters except those modified to carry the 8,000-pound bomb.[1] Although the production plans for Stirlings were not certain, the probable output figures indicated that a number of squadrons would continue to be armed with them for some 12 to 18 months, and the order of priority of Bomber Command requirements was given as:—

(*a*) Six Pathfinder Force squadrons (three Lancaster, two Halifax, one Stirling).

(*b*) Main force Lancaster squadrons other than those carrying 8,000-pound bomb.

(*c*) Main force Halifax squadrons.

(*d*) Main force Stirling squadrons.

In March 1943 the projected delivery of H2S equipments from October 1943 onwards was estimated at 400 per month. The requirements of Bomber Command, Coastal Command, and, a new factor, the United States Eighth Air Force, were calculated in conjunction with the anticipated output of the aircraft factories. The calculations indicated that it would be possible to equip 130 Lancasters and 85 Halifaxes per month for Bomber Command, and that those numbers fitted in with the requirements of the command and with the number of aircraft that would be delivered from the factories. For, as long as the production of H2S equipments did not rise above 400 per month, such a programme would not involve the delivery of more H2S sets than could be installed in aircraft. On 26 March 1943 the Air Member for Supply and Organisation was able to settle the complicated matter of Lancaster production with the Controller General of the Ministry of Aircraft Production.[2]

Although the Lancaster trial installation had been accepted, subject to minor modifications proposed by the S.I.U. at Defford and agreed to by Headquarters Bomber Command on 28 January 1943, delivery to squadrons of Lancasters equipped with H2S was tardy. The Chief of the Air Staff, the Commander-in-Chief Bomber Command and the Secretary of State for Air all expressed concern at the situation, and at the end of April 1943 the Prime Minister asked the Minister for Aircraft Production to state his proposals for accelerating the fitting of H2S, particularly in Lancasters. The Minister for Aircraft Production attributed the delay mainly to the special bombing operations against the Mohne and Eder dams and to the various other radio modifications and installations required by Bomber Command. The dam operations involved preparation at the Avro factory of 20 Lancasters, which precluded delivery to the fitting parties at Defford of suitably modified aircraft, and the other commitments were said to involve work on the aircraft assembly lines which adversely affected the speed with which H2S modifications could be incorporated. The projects causing delay were stated to be, amongst

[1] A.M. File C.30305/46.

[2] A.M. File CS.15551.

others, TR.1196, Monica, A.S.V., aircraft modifications in connection with use by airborne forces, A.R.I. 5043 and other radar equipment, Mark XIV bombsight, and dual control.[1] On 5 May 1943 the Prime Minister asked the Secretary of State for Air if those requirements could be foregone or postponed in order that H2S might be installed more quickly. Although it was doubtless that some of the items, particularly TR 1196 and the Mark XIV bombsight, may have interfered with the progress of H2S modifications, but only in either the drawing office or trial installation stages, others had never had any real effect. The inclusion of A.S.V. referred to two projects. The first was a proposal to install the Mark II A.S.V. bombsight in 15 aircraft, but this had been abandoned in August 1942 as unlikely to be successful. The second was the prototyping of a Lancaster with a view to the possible employment of Lancasters in Coastal Command. That project had been given low priority in or about March 1942, and, as far as was known, no work had been done on it. A.R.I.5043 was an A.I. ground beacon and the Air Ministry could not discover any possible connection between it and Lancaster aircraft.

The Lancaster H2S installation programme was given top priority, and the Secretary of State for Air assured the Prime Minister that '. . . no interference with this programme will be permitted . . .'[2] Delivery to squadrons began in May 1943 and it was confidently expected that Bomber Command would receive 265 aircraft by October 1943, in time for the winter offensive. The first 300 Lancasters were to be accepted with the scanning cupola fixed in the position usually occupied by the under-turret, but after that number the cupola and the under-turret were to be made interchangeable in order to satisfy the requirement for the employment of Lancasters in an airborne forces' role or on daylight operations.[3]

Review of Operational Use of H2S Mark I

By the end of May 1943 the Pathfinder Force had used H2S on 27 raids. The number of aircraft equipped with H2S despatched on each operation averaged 12, and ranged from 18 to 5. An average of 60 per cent of the aircraft were able to use H2S effectively in the target area; in 30 per cent the H2S installation failed before the target was reached; 10 per cent were abortive for reasons not connected with H2S. Reliability had increased, the percentage of aircraft failing to reach the target with serviceable H2S being 13·5 in April, 35·5 in March, and 29 in February.[4] Delivery to squadrons of Lancasters equipped with H2S did not begin until May 1943 and consequently only Halifaxes and Stirlings were used during the first four months of H2S operations. With them it was not possible to achieve a high degree of accuracy in timing because their airspeed at operational heights was not flexible enough, and on some occasions the main force was unable to take advantage of H2S marking. Also, not enough aircraft were equipped with H2S, and in consequence insufficient target indicators were burning at any given time. In the earlier raids some bomb-aimers did not rely on their H2S equipment but aimed their indicators at whatever they could observe visually. As soon as this was discovered, crews of the Pathfinder Force were instructed that they were not to aim visually, and, if their H2S was not working satisfactorily, they were

[1] A.M. File CS.15551. [2] A.M. File CS.15551. [3] A.H.B./IIE/6/60.
[4] A.H.B./II/39/1/1. Bomber Command O.R.S. Reports 'S' Series.

not to drop markers. Special target maps for use with H2S had been prepared but they were not always up to date. On the night of 19/20 February 1943 the Pathfinder Force mistook a new suburban area in Wilhelmshaven, which had not been marked on their maps, for the actual target area. As a result all target maps were revised by comparison with the most recent air photographs of the areas. The majority of the earlier raids were not very successful, but later, when improved pyrotechnics were used and more experience of H2S had been gained, much better results were obtained and many of the operations would not have been possible without it. Although H2S had originally been projected as a blind bombing device to meet a comparatively simple requirement, that of enabling Bomber Command to avoid dropping a high proportion of bombs ineffectively on open countryside, the advent of Oboe marking in March 1943 had set completely new standards of bombing accuracy, by which the effectiveness of H2S was assessed. During the period under review it was, of course, used only by the Pathfinder Force, and the most effective of the earlier bombing attacks were made when it was used to enable flares to be released over the target, which was then identified and marked visually by following aircraft known as 'backers-up.' With that technique it was possible, by the employment of very few aircraft equipped with H2S, to mark the target so that up to 50 per cent of the main force were able to bomb it with some degree of effectiveness. Assessment of the efficiency of the operations ranged from failure to considerable and serious damage, the average probable bombing error being assessed at about two miles.

By April 1943 the Pathfinder Force had developed a standard H2S marking technique which, with small modification, remained in use until the end of the war. An attack was begun with a group of H2S aircraft all of which dropped target indicators and illuminating flares at the same time. They were followed about two minutes later by a small number of aircraft which identified the target visually in the light of the flares and marked the target with indicators of another colour. After them came 'backers-up' which aimed more target indicators, at intervals of one or two minutes throughout the attack, at the indicators dropped by the visual markers. If the visual markers had failed to identify the aiming point and had not therefore dropped their indicators, the 'backers-up' aimed indicators at what they considered to be the main point of impact of the markers dropped by the H2S aircraft. A drawback of this technique was a tendency for the focus of the bombing to shift slowly from the aiming point in the direction from which the main force aircraft made their bombing runs. A large proportion of the 'backers-up' and main force bomb-aimers persistently undershot the aiming point because they saw the indicators from an angle as they approached, and did not judge the centre of the group of markers accurately. As a navigation system H2S proved to be satisfactory. Its effectiveness in that role was reduced to some extent by incorrect identification by navigators of landmarks, faulty recording of range and bearing, and by attempts to obtain fixes at excessive ranges and on towns which were too large. In general H2S fixes were reliable and position errors were less than two miles. Apart from technical failures, the main difficulties experienced with the H2S Mark I installation were poor definition, gaps at or near bombing range, scan distortion at close range, and the effects of evasive action on the P.P.I. display. Development by the T.R.E. of a wave-guide fed scanner was well advanced, and it was expected that its introduction would narrow the beam width to improve definition, remove clutter from the display, and fill the gaps. Experiments were also being conducted with roll stabilisation of the scanner to make the P.P.I. display easier to interpret whilst evasive action was being taken.

Until August 1943 the majority of the attacks made with the help of H2S were against targets in the Ruhr, but with the approach of the long winter nights preparations were made for the bombing offensive to be carried deeper into Germany, when the effectiveness of H2S would be severely tested. Before then, however, in July 1943, H2S was used very successfully for raids against Hamburg, the target chosen for its first operational use. During the night of 24/25 July about 700 aircraft attacked and standard H2S marking was employed by the Pathfinder Force.[1] Great fires, which lasted for more than 24 hours were started, and two nights later the attack was repeated, and for the first time 'fire-storms' resulted from the accurate and heavy bombing. The target was again attacked in force during the night of 29/30 July and even more areas of Hamburg were devastated. The city was practically wiped out, and in the words of the Commander-in-Chief, Bomber Command '. . . The destruction of Hamburg was, and remained, the greatest success gained by the use of H2S; by itself, it would have more than justified the time and labour spent on developing equipment . . .'[2]

[1] 'Window' was used for the first time on this raid. *See* Royal Air Force Signals History, Volume VII: 'Radio Counter-Measures'.

[2] 'Bomber Offensive' by M.R.A.F. Sir Arthur Harris.

CHAPTER 3

H2S MARKS II AND III

The production of H2S in quantity, as distinct from the crash programme of hand-made installations, was begun at Ferranti and the Gramophone Company in May 1943, and the installation manufactured on the main programme was given the nomenclature of H2S Mark II. The aircraft installation programme was made the responsibility of Headquarters Bomber Command and H.Q. No. 43 Group, and fitting began at once, the Pathfinder Force having priority.[1] During the period of production and installation of H2S Mark I, and as a result of experience gained during its operational use, the development of many improvements had been started, and these were eventually incorporated as modifications to H2S Mark II. However, the governing factor was the ease with which proposed modifications could be introduced. Before any change could be considered it was essential to ensure that no large-scale production of new units for the main H2S equipment was involved, and that the changes required did not involve major structural airframe alterations. A number of units remained common to both H2S and A.S.V., and means had to be devised so that the requirements of Bomber and Coastal Commands were met with a single unit. This was usually done by means of an internal switch which was set to the appropriate position when the unit was being installed.

Improvements Incorporated in H2S Mark II

The first addition to the installation was that of Lucero. When the wavelength of airborne radar was changed from 1½ metres to 10 centimetres as the result of the development of the magnetron valve, aircrews using the centimetric equipment were at first denied the use of ground radar systems for blind approach, of radar beacons, and of I.F.F. facilities, which had been built up on the metric wavelength. An interrogation system known as Lucero was therefore developed. It consisted of a transmitter working on a wavelength of 1½ metres which was capable of interrogating beacon and identification systems, and the local oscillator and first two I.F. stages of a receiver. The transmitter was triggered by a pulse from the main airborne radar equipment so that returned signals from Lucero were in phase with responses obtained by the main equipment. The returned signals, after passing through the two stages of I.F. amplification in the Lucero unit, were mixed with the I.F. signals of the main equipment and then passed through a common amplifier and detector channel; they appeared on the P.P.I. whenever a responder was within interrogation range. Lucero worked with an aerial system, independent of the main installation, mounted so that all-round cover and azimuth direction finding, were possible. In order that H2S might be made quickly available as a target-location system, the Air Staff had, in January 1942, stipulated that H2S Mark I should be made as simple as possible. A

[1] T.R.E. File D.1738 Part II.

proviso was added that later versions should include navigation and homing facilities. In order to fulfil that requirement the incorporation of Lucero in H2S Mark II was begun shortly after the main production programme had been started.

From the beginning of development of H2S Mark I the T.R.E. had grappled with the problem of reducing the gaps in H2S coverage, and whilst experiments and tests were being conducted, improvisations were employed. In order to overcome the limitation imposed by the gaps occurring at a range of 4 miles, which prevented H2S Mark I from being used effectively in the final and all-important stage of an aiming run, the Pathfinder Force devised a procedure in which the range marker was set at 5 miles. At that range the target could usually be clearly identified. The direction of the attack, and the airspeed at which it was to be carried out, were known factors. It was therefore possible to calculate the time which an aircraft would require to cover the distance from the 5-mile marker to the point at which flares or indicators were to be released. The time was given to the crews at briefing and target markers were dropped at the calculated interval after the target appeared on the 5-mile range marker. The system entailed a straight and level run in of about one minute's duration, which was not always possible, and was also subject to errors in the forecast wind velocity.[1]

During the spring of 1943 trials were conducted with a new type of wave-guide-fed scanner. The results showed that a great reduction in gaps had been effected, and H2S could be used right up to the aiming-point instead of only to the 5-mile marker. The new type of scanner made identification of the target easier, increased the effective range of H2S, and to some extent improved its degree of definition. In June 1943 Headquarters Bomber Command expressed satisfaction with trials carried out at the B.D.U. and raised an operational requirement for the modification to be included in H2S Mark II. A crash programme for 300 modification sets was initiated, and arrangements were made for main production to begin at the end of August 1943. Installations which incorporated the waveguide-fed scanner were given the nomenclature H2S Mark IIA. The modification not only improved the effectiveness of H2S, but made easier the task of training, an important factor because employment of H2S by main force aircraft was planned for the bombing offensive during the winter of 1943/44.

When, early in the war, Fighter Command aircraft were being equipped with A.I., it was realised that the enemy would eventually use a similar installation to assist in the interception of bomber aircraft, and countermeasures against enemy A.I. were discussed at a meeting of the Interception Committee on 28 November 1940.[2] Headquarters Bomber Command considered that early warning of the approach of enemy fighters was of the utmost importance, and detailed operational requirements on 20 July 1941, as a result of which the T.R.E. was asked to investigate the matter. A development contract for 24 sets of equipment known as Monica was placed with the firm of Cossor in December 1941. Monica was a small airborne radar installation which worked on principles similar to those of A.I. The field of radiation was to the rear of

[1] A.H.B./IIE/6/60.

[2] A.M. File CS.14215. *See* Royal Air Force Signals History, Volume V: 'Fighter Control and Interception', for further details of A.I.

the aircraft and covered the direction from which attacks were usually expected and were normally made. Design was not made final until July 1942, and production was delayed because of the changes in design and a shortage of essential components. Although by the end of May 1943 nearly 300 Halifaxes had been equipped retrospectively, it was not until then that Lancaster and Halifax aircraft began leaving the aircraft assembly lines modified for the installation.[1]

Meanwhile, from about March 1942, the enemy had been using fighter tactics at night which caused a small but steady rise in the casualty rate of Bomber Command and which reached its peak in the summer of 1942. The enemy night fighter aircraft climbed steeply until it was under the tail of a bomber aircraft when it opened fire at close range and continued to fire and to climb yet more steeply until it stalled. Air gunners were repeatedly taken by surprise for it was very difficult to observe another aircraft against the dark background below the tail. It became necessary for bomber aircraft to be banked repeatedly whilst the area below was searched, and a cork-screwing flight was developed as a means of taking evasive action, but German night fighters continued to be a serious menace. Boozer, a search receiver, was produced in October 1942, as a tail warning device. Its purpose was to inform the crew of a bomber aircraft when enemy radar was being used against it, and in its original form was a receiver which lit a warning lamp when the aircraft was within the field of radiation of an enemy radar transmitter so that the pilot could take evasive action until the lamp went out. While this appeared to be an immediate solution of many of the difficulties, the situation was complicated by the fact that Boozer and Monica caused interference to each other. With the advent of H2S, Fishpond was developed to enable some form of warning of the approach of aircraft to be obtained without the need for a separate and complete system, and without interfering in any way with the normal operation of H2S. As the H2S scanner rotated and radiated a beam underneath the aircraft, the area between the aircraft and the ground was illuminated in much the same way as it would have been by an all-round looking A.I. system. In the absence of any aircraft in the vicinity of the bomber no echoes were received between the time of the transmitter pulse being radiated and the return from the ground immediately below the aircraft. If there was another aircraft beneath the bomber, and at a slant range of less than the height of the bomber above the ground, an echo was received. Fishpond consisted essentially of an indicating unit using a P.P.I. display on which such echoes were shown, their bearing relative to the bomber being indicated. The choice of the name Fishpond came from the method of displaying the echoes ; the ground returns showed up as a bright fringe around the edge of the P.P.I., and blips of other aircraft showed up as 'fish' within the 'pond.' Originally it was expected that Fishpond would be an interim measure and would eventually be displaced by a system giving greater coverage and having a presentation much easier to interpret. This influenced the design of Fishpond in that especial modification to the H2S equipment itself could not be tolerated, and Fishpond had therefore to be as simple as possible. In May 1943 Headquarters Bomber Command reported that flight trials had been satisfactory although a number of limitations prevented the full value of the equipment from being assessed, and they considered that its use would have

[1] A.M. File CS.14125.

a good psychological effect on bomber aircrew.[1] In June 1943 Fishpond was made an official requirement on the basis of one equipment in each bomber aircraft fitted with H2S. Preliminary reports of further trials indicated that it would meet the needs of Bomber Command for the detection and location of other aircraft in the area beneath a bomber and up to 10 degrees above the horizontal. It was to be regarded as an essential part of H2S in the same way as Lucero.

By October 1943 the operations of Bomber Command were being carried out with such a high density of aircraft that enemy fighters were not the only danger. Successful evasion required more than warning of the nearest approaching aircraft, which was all that Monica Mark I provided.[2] All adjacent aircraft were required to be kept under continuous observation in order to distinguish an approaching hostile fighter from surrounding bombers, to enable effective corkscrew tactics to be employed, and to improve the air gunners' chances of obtaining hits. However, it had recently been suggested that Fishpond should be withheld until A.G.L.T. was ready for operational use for the reason that once the enemy determined the characteristics of Fishpond, fighters would carry out attacks from above the bomber aircraft, and no warning would be received by the bomber crew.[3] In addition, it was thought that the disadvantages inherent in the narrow beam of A.G.L.T. would be greatly reduced if it were used with Fishpond. The arrangements made for the introduction of Fishpond and A.G.L.T. were such that the former might be introduced in the Lancaster production lines in October 1943 in phase with the installation of H2S in aircraft of main force squadrons, whilst A.G.L.T. was not expected to be ready for operational use before the spring of 1944. The interference of Window with enemy A.I. was forcing the Germans to employ day fighters at night, and if the tactics were successful, the value of Boozer would be diminished since it was useful only against fighters equipped with A.I., and the value of Monica was more moral than real. If the enemy began using the tactics of attacking from the area above the bombers, his fighters would find greater difficulty in aiming effectively whilst the crew of a bomber aircraft would have a better chance of observing the fighter. It was therefore decided to use Fishpond as soon as it was ready, and H2S installations incorporating the equipment were given the nomenclature of H2S Mark IB. By 23 October 1943 25 Lancasters and six Halifaxes had been equipped.

Meanwhile the Royal Aircraft Establishment had made progress with the development of an H2S nose installation in a Lancaster and flight trials were undertaken in October 1943. Photographs were taken of the P.P.I. display, showing different targets at various ranges.[4] Maximum range appeared to be good, towns showing up at 30 miles, but a gap, extending from 0 to 7½ miles, was observed in a dead-ahead position. Various modifications were tried, but the most successful flights showed a gap from 4 to 7½ miles when the aircraft was at 20,000 feet, and the backward looking range was only 4 miles. Headquarters Bomber Command considered that all-round looking was essential to give tactical freedom during operations, and a range of at least 15 miles at 10,000 feet was required for viewing to the rear of the aircraft.

[1] A.H.B./IIE/6/60. [2] A.M. File S.15385. [3] A.M. File S.15385.
[4] A.M. File CS.15551.

However, the ideal nose offered many advantages in other ways. With it aircraft performance was markedly improved, and there was everything to gain from the aerodynamic aspect in having such a nose incorporated. The bomb-aimer's view and the layout of his instruments were good, and in November 1943 the Directorate of Operational Requirements (Navigation) decided that the merits of the nose installation generally outweighed the limitations imposed by the lack of all-round scanning. It was made a firm requirement for the new Mark of Lancaster, Mark IV, and arrangements were made with the firm of A.V. Roe for it to be incorporated on the aircraft production lines.[1] Neither the Director of Radar nor Headquarters Bomber Command was satisfied with the arrangement and the reasons for its adoption. It had been assumed that the backward-looking range would be 7 miles at 10,000 feet and 17 miles at 25,000 feet, but the T.R.E. continued to insist that it was not possible to guarantee any backward range at all. It was realised that the installation would seriously reduce the effectiveness of Fishpond, but it had been assumed that A.G.L.T. Mark III would be introduced early in 1945. In January 1944 it became apparent that A.G.L.T. Mark III would not be ready for operational use before the end of 1945, and Headquarters Bomber Command expected that the war against Germany would continue until after that time. There was no reason to believe that Lancaster IV aircraft would be operated in any manner different from that in which other heavy bomber aircraft were employed. No great importance was attached to the provision of a gunner's turret in the ventral position, and good all-round H2S coverage was considered to be essential for navigation. It was finally decided, on 25 January 1944, to install the scanning system for Lancaster IV aircraft in the ventral position, to fit them with 4,000-pound bomb doors, and not to make provision for an under-turret interchangeable with the scanner but to provide for a single hand-held gun which could be fitted in place of the scanner if and when required. The specification for a nose scanning installation was therefore cancelled.[2]

The later trials of the nose installation had been made with a barrel type of scanner. Little experimental work had been done on scanning systems before August 1943, but reports were then received from the U.S.A. of successful trials of a barrel reflector. The design of the scanner in its original form was not entirely suitable for British aircraft because their cupolas were wider and shallower than those on American heavy bomber aircraft, so some alterations were necessary. The barrel scanner consisted of a single reflector fed by a waveguide horn and was larger than the scanner then in normal use. Some control over the field of radiation was obtained by varying the flare of the horn and its position and angle relative to the reflector, which was a truncated paraboloid. The results showed a satisfactory increase in the extent of coverage and a reduction in gaps. The scanner was developed and produced as Scanner Type 63 and was incorporated in H2S Mark IIC, an installation which also included the addition of roll stabilisation and scan distortion correction.

The effects of evasive action on the P.P.I. display of H2S had quickly become apparent during the early Pathfinder Force operations. To make H2S really effective it was important to maintain an even distribution of energy over a wide range of angles of elevation, but with the scanner fixed to the aircraft as

[1] A.M. File CS.22828.

[2] A.M. File CS.22828.

it was with H2S Marks I, II, IIA and IIB, the even distribution was completely upset if the aircraft departed from straight and level flight. Since evasive action, involving corkscrewing, violent banks and steep dives, was an essential part of operational sorties, it was very desirable that the efficient operation of H2S should not be restricted to those periods when the aircraft was flying straight and level. This meant that the distribution of energy over the ground should be maintained by having the scanner fixed relative to the ground and not to the airframe ; in other words the scanner was required to be stabilised. To this end the scanner was detached from the airframe and mounted in a gymbal ring which was in turn suspended in the airframe so that it could rotate about its axis in the fore and aft line of the aircraft. This did not allow for any correction to the position while the aircraft was diving or climbing, but was confined to roll stabilisation. Because of the space and weight limitations imposed on the scanner by aerodynamic requirements, it was necessary to restrict rotation of the gymbal ring to plus or minus 30 degrees from the symmetrical position, but the Operational Research Section of Bomber Command established that with such correction a recognisable picture could be obtained during a large part of any sortie.

Early experience with H2S had also shown that the P.P.I. display was distorted at close ranges. The indicators in use employed linear scan. Consequently the distance of an echo from the centre of the P.P.I. was proportional to the time taken for the response from an object to travel the return distance, and was therefore proportional to slant range and not to the horizontal distance between the object and a point directly beneath the aircraft. A town was consequently shown on the P.P.I. as a foreshortened version of its actual shape. For purposes of navigation this was not very important, but since distortion increased as the range was closed, it was a great disadvantage from the bomb-aimer's point of view. He was usually given a feature of the target to be attacked to use as an aiming point, and identification of that point on the P.P.I. was not always possible. As, with the development of H2S, gaps in the radiation field were reduced and other drawbacks thus eradicated, it became necessary to improve presentation. A new indicator, using rotating scan, was required, but limitations on design were imposed by Service requirements that it should be completely interchangeable with the existing type of indicator ; size, weight, power supplies and cables were all to remain unchanged. Many of the earlier attempts to provide an indicator were successful in so far as results were concerned, but were ruled out because of weight and space considerations.

At the beginning of October 1943 the T.R.E. reported that development of a new indicator, Type 184, which included scan distortion elimination, and a roll stabilised scanner, had been completed. Twelve models of the indicator were being made at the T.R.E., and an experimental roll stabilised scanner had been flown with successful results. Headquarters Bomber Command was anxious to have the modification introduced into the main H2S production programme as soon as possible and asked for crash programmes to be arranged in the interim. Contracts for indicator Type 184 had been placed but at the beginning of November 1943 the Gramophone Company had not completed the drawing office stage, and type approval of the General Electric Company production model was not expected before February 1944. It was suggested that the addition of roll stabilisation and scan distortion elimination should be carried out in two phases. No difficulty was envisaged with the introduction of indicator Type 184, which could be installed on squadrons once modification kits were made available, but the supply position of gyros and motor generators made the production of roll stabilised scanners an uncertain proposition. The firm making the gyros, Henry Hughes, could undertake only limited production, and a crash programme was impracticable, as the firm was heavily committed to the production of Sperry Gyros and Mark XIV bombsights. No development contract had yet been placed with the Gramophone Company specifically for development of the electrical units of H2S Mark IIC as a whole. Whilst it was decided that the production line of H2S Mark IIB equipment should be changed over to H2S Mark IIC as soon as the arrangements could be made, as an interim measure indicator Type 184 was to be incorporated in H2S Mark IIB, and the resultant installation was given the nomenclature H2S Mark IID.[1]

Limitations of H2S Mark II

By the middle of August 1943, 840 H2S equipments had been manufactured, and it was estimated that the monthly output would rise from 240 in that month to 600 in February 1944. A shortage of suitable connectors was still a limiting factor in the number of aircraft that could be modified for the installation of H2S, and it was hoped to increase the production of connectors by substituting a new design of cable form for the enamel wire which was causing the major difficulties and delays. Another shortage which made the installation and servicing of H2S and associated radar equipment increasingly difficult was that of radar mechanics. The immense amount of effort which had been devoted to development and production of aircraft radar would largely be wasted if more mechanics were not obtained. The manning in Bomber Command was 30 per cent below establishment. In August 1943 Headquarters No. 60 Group offered to release a number of ground radar mechanics for attachment to the command for as long as the grave shortage existed. The proposal was accepted and the necessary specialised training on airborne radar was given within the command.[2] Installation of H2S in aircraft of the main force was about to begin, and it was necessary to decide whether, when the equipping of sufficient aircraft had been completed, the pathfinder technique was to be adhered to or whether crews of the main force were to drop bombs on indications received in their own H2S equipments as had been intended when the equipment was first devised.[3] The importance of teaching bomber crews to regard H2S as a blind bombing device as well as a navigation system was fully appreciated, but Headquarters Bomber Command naturally preferred to adopt the method which would ensure the greatest number of bombs falling in the target area in all circumstances. It appeared that by retaining the P.F.F. technique the desired result could be obtained in 90 per cent of operations. The only exception was when the command attacked a target such as a small town of which the radius was about three-quarters of a mile or under from the aiming point, in ten-tenths' cloud conditions. The pathfinder technique involved bombing on skymarkers in such circumstances, and it seemed probable that better results would be obtained if crews bombed on their own H2S plots. However, the Air Officer Commanding,

[1] A.H.B./IIE/6/60. The requirement for roll stabilising platforms was cancelled in May 1945. (A.M. File CS.16458.)

[2] A.H.B./IIE/6/60.

[3] A.M. File CS.21346.

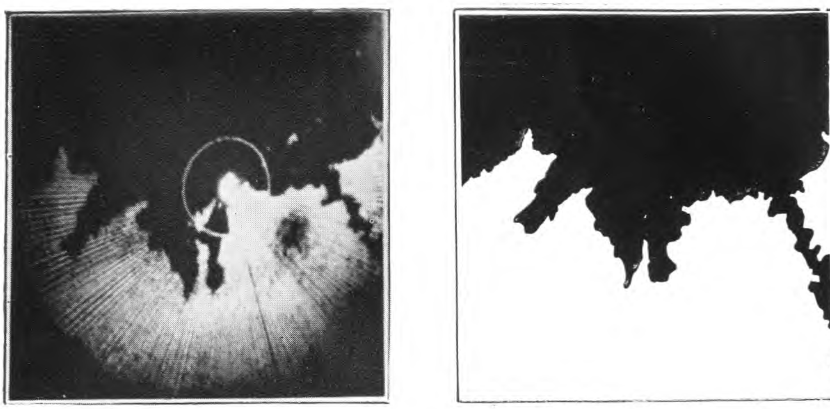
Pathfinder Force, contended that greater accuracy would be obtained if sky marking continued to be used, and it was agreed that against small targets the main force aircraft would use H2S for navigation and target approach but would aim visually at the estimated centre of skymarkers.[1] The procedure for the use of H2S by the main force was to be reviewed when the squadrons had gained more experience with the equipment. On the night of 17/18 November 1943 aircraft of the Pathfinder Force carried out an experimental blind bombing attack against Mannheim and Ludwigshafen. No markers were dropped and all crews were instructed to bomb only on H2S indications. It was estimated that 60 per cent of the bombs were dropped in the target area, and 50 per cent within a mile and a half of the aiming point. However, all the crews were highly trained and experienced in the interpretation and use of H2S, which would not be so with main force crews, and it was decided to continue using the pathfinder technique and sky marking during the winter of 1943/44.

By 12 October 1943 the number of aircraft which had been fitted with H2S and delivered to Bomber Command totalled 255 Lancasters, 155 Halifaxes and 70 Stirlings, and of these 50 Lancasters, 70 Halifaxes and 29 Stirlings had been lost. The number of aircraft modified for H2S but not yet equipped was rather high. 26 Lancasters were in operational use in No. 5 Group and could not be spared in order that installation might be completed and flight trials undertaken, 16 were in the hands of Bomber Command fitting parties, and 15 already equipped were not available for use in squadrons because bad weather had interfered with flight tests. Nos. 7, 83, 97, 156, 405 (Lancaster) Squadrons and No. 35 (Halifax) Squadron of the Pathfinder Force were equipped with H2S Mark IIA, and 20 Lancasters, 20 Halifaxes, and 22 Stirlings of the main force with H2S Mark II.[2] Headquarters Bomber Command was able to report from operational experience that the introduction of waveguide-fed scanners had eliminated the gaps which had previously made the run in for the bombing approach so difficult and had noticeably increased the definition ; it was possible to identify coastlines and built-up areas much more readily.[3] Generally, isolated towns approximately two miles in diameter, and coastal towns, were the best targets for H2S bombing. Towns in congested industrial areas, such as the Ruhr, were very difficult to identify since definition was still not sufficiently good to enable each particular built-up area to be separated. Very large cities, although easier to identify, could not be bombed accurately with H2S, because bomb-aimers experienced great difficulty in selecting a specific aiming point in the built-up area. Responses entirely filled the P.P.I. screen so that no recognisable shape could be seen, and open spaces such as parks and squares could not be pinpointed. The inability to recognise with certainty particular parts of a large target was especially significant in the case of Berlin. Although its importance as an industrial centre alone made it a worth-while target, its political prominence made effective attacks even more desirable from the Allied point of view. The city housed 5 per cent of the total population of Germany and was the chief administrative centre. The Russians attached great importance to its being bombed. Because of its distance from England it could only be attacked during the winter nights, when heavy bombers were able to fly outward and homeward during the hours of darkness, and from whatever direction the attack was made at least four hours' flying over very heavily

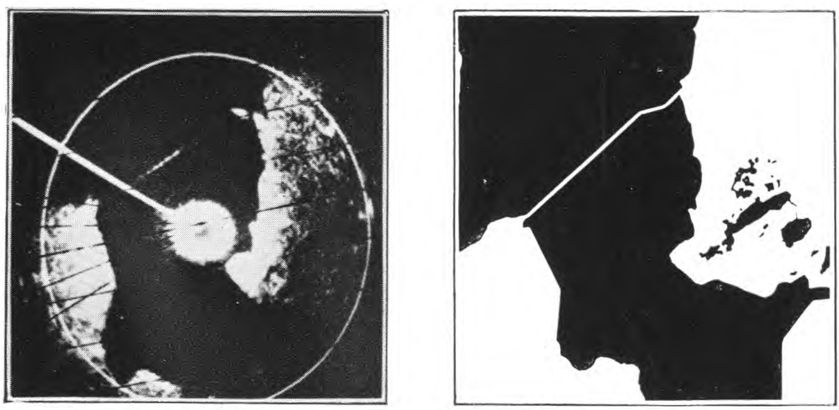
[1] A.H.B./IIE/6/60. [2] A.H.B./IIE/248/2/1. Fitting Progress of H2S aircraft.
[3] A.M. File CS.15545.

Photographs of Cathode Ray Screen

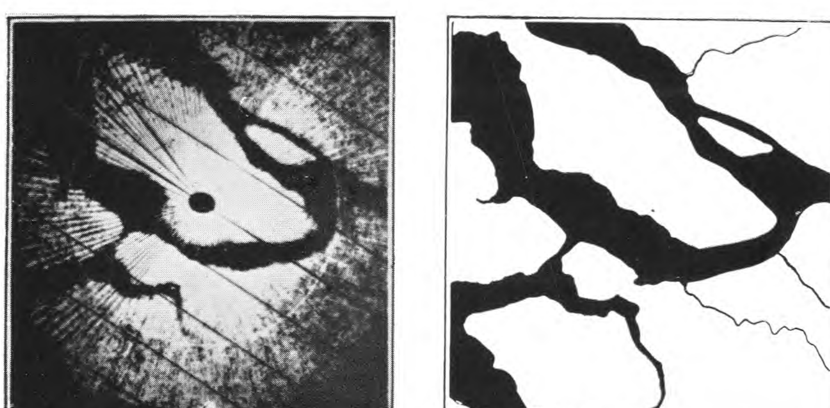
Synthetic Tracings from Maps



Cap Frehel to St. Malo—11/12 August 1944



Zuider Zee Dam—14/15 January 1944



Overflakee Holland—20/21 December 1943

TYPICAL H2S INDICATIONS

defended areas was involved. The ground defences of Berlin were heavier than anywhere else in Germany, and its night fighter defences were well concentrated. Heavy losses attended attacks in December 1941, and none were carried out in 1942. In January 1943 haze and snow prevented the Pathfinder Force from identifying the aiming point visually, and again operations against Berlin achieved little success but heavy losses. The city was well outside the range of Gee and Oboe and it was hoped that the introduction of H2S would improve the prospects of concentrating bombs on specific targets within the built-up area. Although by March 1943 it was getting near the time when Berlin would be out of range of heavy bombers during the hours of darkness, three attacks with H2S marking were planned. On the first the pathfinders found it impossible to identify the aiming point, and it was decided that for the following operations timed runs would be made from prominent landmarks outside the city which would give good H2S responses. Suitable points were few however, and for the second attack a lake, the Muggel See, was used as a landmark and identified visually in the light of flares. The main force was prevented by bad weather from arriving in time to use the markers, and for the third operation the markers were wrongly placed. After the success of the offensive against Hamburg, it was hoped that a similar result with Berlin would have a decisive effect on the war. The city was subjected to three attacks in ten days at the end of August and beginning of September 1943. In the first the pathfinders tried to obtain an H2S fix, from which to fly to the real aiming point in the centre of Berlin, on a feature which showed up very clearly in an air photograph. It was a built-up area projecting outwards from the main part of the city in the shape of a hook; theoretically it should have been easy to distinguish on the P.P.I. screen but in practice it was not. The pathfinders tried the same technique for the second operation when the main force failed to arrive in time, and for the third operation the method of a timed run from the Muggel See was employed. Again the attack was not made against the real aiming point, which escaped damage. A higher degree of discrimination was essential if H2S was to be of real value, and it was expected that an installation working on a wavelength of 3 centimetres, generally known as X band, would meet the requirement. On 4 July 1943 the Prime Minister had informed Sir Robert Renwick that '. . . as we extend our main radius of operations beyond range of Oboe, H2S will become more and more important. I am anxious you should spare no pains to speed up improved H2S . . . if extra staff is required it should be obtained, even should this mean slowing up work of lower priority . . .'[1]

Development of X-Band H2S

The invention of the magnetron had made possible the development of H2S by enabling a rotating aerial system, capable of radiating a narrow beam through 360 degrees, to be installed in an aircraft. On the 10-centimetre wavelength the beam was, however, about 8 degrees wide. When, as the scanner rotated, the beam was directed to within 4 degrees of an object, the echo was displayed on the P.P.I. screen, and remained there until the scanner had rotated through another 8 degrees. Rotation of the time-base was synchronised with that of the scanning mirror, and the echo appeared on the display as an arc of 8 degrees. The shape of a collection of reflecting objects, such as a

[1] A.H.B./ID/12/195.

town, was therefore falsely displayed because the objects on the fringe were presented through an extra 4 degrees, and the width of the town was extended by the width of the beam. At 5 miles slant range this amounted to three-quarters of a mile. Similarly, echoes from the land immediately surrounding a lake or river extended over the water area by half a beam width at both sides. Thus a lake or river three-quarters of a mile wide would not be shown on the P.P.I. screen at slant ranges greater than 5 miles. Consequently, in order to obtain improved definition, it was necessary to reduce the beam width. This could have been achieved by increasing the size of the scanner mirror, but that method was not immediately practicable because of the increased aircraft drag involved. In the 3-centimetre technique reduction could be effected by increasing the transmitter frequency from the 3,000 megacycles per second of H2S Mark II to 9,000 megacycles per second. This reduced the beam width to approximately 3 degrees with a consequent improvement in the fidelity of the display.

From the beginning of development of H2S eventual employment of the 3-centimetre wavelength had been anticipated at the T.R.E., where A.S.V. Mark XI was being developed for the Fleet Air Arm, and design of H2X had been started on the assumption that it would become an operational requirement.[1] Experimental work on Stirling and Halifax installations had been envisaged in October 1942, but could not be carried out until essential units had been made at the T.R.E. or by contractors.[2] After setbacks and delays caused mainly by the technical difficulties involved in the development of a valve to work efficiently on the new wavelength, the first pre-production 3-centimetre equipment developed for the Fleet Air Arm was installed in a Swordfish in February 1943, just after the first operational use of H2S, and flight trials were successful. A production and installation programme of the new installation, known as A.S.V. Mark XI, was arranged, but to meet Admiralty requirements only.

During March and April 1943 reports of Bomber Command operations in which H2S was used for marking reached the Royal Air Force Delegation at Washington, U.S.A.[3] They showed clearly that H2S held promise in spite of comparatively poor ranges and serviceability. At about the same time good reports of the serviceability and performance of A.S.G.1 (A.S.V. Mark V) were beginning to arrive, and the United States Navy was using a 3-centimetre installation, A.S.D., with which a high degree of definition was being obtained. The Royal Air Force Delegation studied ways and means of assisting the Bomber Command H2S programme for the winter of 1943/44, and approached the British Air Commission, who showed immediate interest in the possibilities of converting A.S.G.1 into 3-centimetre equipment by incorporating the R.F. units of A.S.D. The Ministry of Aircraft Production was informed of the proposal, the essence of which was that well-tried equipment already in production would be used, so that little development and no research work was required. Modifications were to be kept to a minimum since each change would involve delay, and it was considered that a simple ASG/ASD hybrid would be an improvement on H2S. It was envisaged that the number of equipments produced would be no more than 200 so that the required parts of A.S.G. and A.S.D. could be diverted from current production ; a larger number would necessitate a special production programme. The Lancaster was considered to be the only suitable type of aircraft likely to be employed in the

[1] *See also* Royal Air Force Signals History, Volume VI : 'Radio in Maritime Warfare' H2X was the name given to H2S on 3-centimetre wavelength.

[2] T.R.E. File D.1738.

[3] A.M. File C.28982/46.

Pathfinder Force, and on 27 April 1943 the British Air Commission suggested that a Lancaster should be sent over from the United Kingdom for prototype installation. The ideal arrangement was thought to be that the aircraft should be one already equipped with H2S so that it could be used to stimulate interest in the U.S.A.A.F., which at the time had no urgent requirement for H2S since its strategic bombing was carried out by day. The Lancaster, when ASG/ASD had been substituted for H2S, would be used for flight trials and after their satisfactory completion would be returned to the United Kingdom, where a special installation unit could be formed. It was emphasised that there would be no need for changes to be made on the Lancaster production lines and that the work of the installation unit would not be complicated. Other advantages of the proposed plan were that servicing personnel were already being trained on the two basic equipments, and spares and test equipment were already being made available. The operational performance was expected to be much superior to that of H2S. Ranges would be greater because power output was higher, and serviceability was expected to be that of A.S.G., an average of about 180 flying hours for every failure in the air. The improved presentation would simplify considerably the training of operators.[1] During the first five months of 1943 250 A.S.G. equipments were delivered to the British Air Commission, and production had been as high as 70 in one week. A request for 200 in addition to the existing A.S.V. allocation could be met by monthly deliveries until December 1943. About 400 A.S.D. equipments had been manufactured, and a production rate of 40 weekly had been planned and reached, although not maintained; the additional 200 required could be obtained by monthly allocation between June and the end of the year. The United States Navy was willing to make arrangements for modification of up to 200 equipments since the commitment could be undertaken by a small sub-contractor without interference to existing programmes.

In May 1943 Lord Cherwell, during a visit to the U.S.A., flew in an aircraft equipped with the experimental 3-centimetre equipment and was impressed with the performance and the P.P.I. presentation.[2] At a meeting held by the Secretary of State for Air on 31 May 1943 to consider the development and production of scientific equipment, he suggested that the installation of American H2X equipment in aircraft of Bomber Command would increase the effectiveness of the bombing offensive, and that the possibilities of an installation programme being carried out before the autumn should be examined as a matter of urgency. The Secretary of State for Air agreed that there was an immense need for improving as much as possible the efficiency of the bombing offensive and thought that if the installation prospects were reasonable it might prove worth while to equip two squadrons.[3]

Meanwhile, progress had been made with the development of H2X in the United Kingdom. Early in the year a Stirling H2S installation had been modified to work on 3 centimetres by using the R.F. unit of the Swordfish installation, and trials of the equipment in an H2S role were undertaken. The results of the trials were not very promising insomuch as the ranges and coverage were poor and the equipment failed at high altitude, but in May a requirement was stated for the conversion of a limited number of H2S Mark II

[1] A.M. File C.28982/46. [2] A.M. File CS.23288.

[3] A.H.B./IVA/33 Part II. *Minutes of Scientific Equipment Progress meetings.*

installations to H2X and for 200 H2X equipments to be developed and produced on high priority with a view to fitting three squadrons of Bomber Command by 1 January 1944.[1] As an interim measure, until H2X was ready, Headquarters Bomber Command required ASG/ASD to be installed.

A.S.V. Mark III had been introduced into operational use by Coastal Command in March 1943 as a countermeasure against the employment by the U-boat Command of metric wave search receivers. The early introduction of search receiver operations on the 10-centimetre waveband was anticipated, and the preparation of suitable countermeasures was required.[2] One of the proposals was that sufficient equipments from the H2X crash programme should be diverted to Coastal Command for installation in one squadron of Wellingtons by October 1943 and that the projected production of 200 ASG/ASD equipments should be installed in 100 Liberators for use as A.S.V. by 1 January 1944.[3]

At the beginning of June 1943, therefore, it became necessary to decide the relative claims of Bomber and Coastal Commands to H2X and ASG/ASD. The Air Ministry wished to avoid equipping British bomber aircraft with American radar equipment unless its performance was so superior to that of British equipment that forsaking an accepted policy was justified. It appeared reasonable to assume that H2X could be made available as soon as, if not before, ASG/ASD, and that performance would be similar. Consequently it was decided that the ASG/ASD hybrid equipments should be installed, in the U.S.A., in Liberators for Coastal Command. The remaining issue to be decided was whether the bombing offensive would benefit more if Bomber Command received the total output of H2X in view of its higher degree of discrimination, or whether the importance of the anti-U-boat campaign justified the allocation of H2X to Coastal Command. Eventually, on 8 July 1943, it was decided that because of the improvement in definition which was expected to result from the introduction of waveguide-fed scanners in H2S Mark II installations, the comparative merits of H2S Mark IIA, H2X and ASG/ASD were to be determined by trials before a definite decision was made.[4] On 9 July 1943 the Chief of the Air Staff provisionally agreed that, subject to the outcome of the trials, the H2X output should be allocated for installation in three squadrons of Pathfinder Force Lancasters, and in one squadron of Coastal Command Wellingtons, by the end of 1943. He added a proviso that the programme was to be reviewed later in the year and confirmed or changed according to the strategic situation at the time. There was much to be said for confining the use of 3-centimetre equipment to Coastal Command for some time after its introduction into the Service. The change of wavelength might prove to be of considerable importance in the war against U-boats, and its loss over the Continent before it had been used operationally over the Atlantic and the Bay of Biscay would enable the enemy to produce a suitable search receiver in time to neutralise its value.[5]

However, the inability of the Pathfinder Force to identify aiming points during the attacks against Berlin early in September 1943 emphasised strongly the urgent need for an improvement in the definition of H2S. A special crash

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[1] A.M. File CS.23288.

[2] *See* Royal Air Force Signals History, Volume VI : 'Radio in Maritime Warfare'.

[3] A.M. File CS.23288.

[4] A.M. File CS.23288.

[5] T.R.E. Report No. T.1636.

programme to install H2X in six Lancasters of the Pathfinder Force by 1 November 1943 was put into force immediately on high priority. Although this meant freezing the basic features of the design when it was in a promising state of development, it also assured the T.R.E. of extra manpower, a good supply of experimental scanners, and adequate aircrews and aircraft for test flights. Rapid progress was made and the experience gained lessened to some extent the delays which were to occur with the main programme and provided a basis for future development.[1] A Type 63 scanner was used, and the scanner rotating mechanism was essentially the same as used with H2S, as were most of the components of the electronic equipment other than the 3-centimetre H.F. unit, although the receiver had to be modified. During trials an average maximum range of 24 miles and a minimum range of 2 miles were obtained at 20,000 feet. Definition was estimated to be six times as good as that of H2S Mark II and three times that of Mark IIA.[2]

The comparative trials were planned to be held in October 1943. Lancaster ED.605 left Defford on 25 July 1943 for the United States of America, equipped with H2S Mark IIA, Fishpond and Monica, to stage demonstrations of the equipment and to acquaint authorities in the U.S.A. with operational experience gained by Bomber Command. Demonstration flights were made in various parts of the U.S.A. and Canada during August, and in September the aircraft was equipped with ASG/ASD and experimental equipment similar to Fishpond, with which satisfactory tests were made at a height of 20,000 feet.[3] Meanwhile, however, the situation regarding H2S had changed considerably in the U.S.A. When the ASG/ASD project had first been raised there was no pressing requirement for H2S or its equivalent in the U.S.A.A.F. ; optical bombsights for precision bombing had been developed and operations in which they could not be used had not been envisaged. When the United States Eighth Air Force began operating over Europe it was found that reliance could not be placed on the bombsight for the majority of operations because of weather conditions. As a result some Liberators and Fortresses were equipped with H2S Mark IIA and plans were made to effect an immediate improvement in the effectiveness of bombing of the U.S.A.A.F. There was a demand for more radio aids to navigation and blind bombing, especially for systems of the H2S and Oboe type.[4] The comparatively simple ASG/ASD installation was used as the basis for development of an advanced H2X called AN/APS 15, and production lines were set up for manufacturing complete equipments.[5] In the circumstances the United States Navy was unable to sponsor the manufacture of the simpler hybrid in case an attempt to do so should seriously conflict with the major production programmes, and the output of AN/APS 15 for the first few months was to be allocated to the U.S.A.A.F. There was therefore no longer any point in evaluating the merits of American H2X for Bomber Command, and in any event Lancaster ED.605 was unable to return to the United Kingdom until the end of 1943.[6]

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[1] T.R.E. Report No. T.1636.

[2] A.M. File C.28982/46.

[3] A.M. File C.28980/46.

[4] A.M. File CS.23288.

[5] *See* Royal Air Force Signals History, Volume VI : ' Radio in Maritime Warfare ', for further details of AN/APS 15.

[6] A.M. File C.28980/46. In 1945 pathfinder Liberators equipped with AN/APS 15 were in service with the R.A.F. in overseas theatres. The installation was given the nomenclature H2S Mark V.

Conflicting Requirements of Bomber and Coastal Commands

In October 1943 the Commander-in-Chief, Coastal Command, informed the Air Ministry that there was strong evidence to support the belief that the enemy was employing a search receiver on the 10-centimetre wavelength, and unless suitable alternative equipment to A.S.V. Mark II were made available quickly the success of the anti-U-boat offensive in the Bay of Biscay would be hopelessly prejudiced. He pointed out that 10-centimetre A.S.V. had been used in Coastal Command for over nine months, and countermeasures to German search receivers had become '. . . a matter of immediate practical importance after a period of grace considerably longer than we had any right to expect . . .'[1] The plan to equip one squadron of Coastal Command had not, of course, been put into effect although the contingency which it was intended to meet had become a matter of certainty. The Commander-in-Chief considered that at least two squadrons should be fully equipped by the end of the year, and strongly urged the adoption of special measures to accelerate production.

The relative urgency of the need for H2X installations in aircraft of Bomber and Coastal Commands was considered at meetings of the Anti-U-boat Warfare Committee and at the Air Ministry during October, in order that the extent to which requirements might be met from the crash programme of 200 equipments could be decided.[2] No further orders had been placed and a setback had occurred in the planned production schedule, the principal cause being a lag in production of the 3-centimetre H.F. units.[3] A more realistic possibility was 100 equipments by the end of the year, 50 in January and 50 in February 1944. A limiting factor was still likely to be the supply of H.F. units in which CV.108 magnetron valves were used, and the supply of CV.108 valves was insufficient to meet the demand. In addition, the useful life of the valve was much less than had been anticipated, 20 to 30 hours instead of 200 hours, so that production was likely to lag even further behind requirements. American 3-centimetre magnetron valves Type 725A were in good supply but were of different external dimensions and could not be used in the H2X units. The T.R.E. therefore began an immediate investigation of the possibility of modifying the equipment so that American magnetrons could be used.[4] If it was assumed that the immediate requirement of Coastal Command was the 50 installations for which provision had been made in the crash programme, it would be scarcely possible to equip three squadrons of the Pathfinder Force. Even that could only be accomplished at the risk of giving them insufficient spare equipments to enable them to operate for more than three months ; a major disadvantage since quantity production of H2X equipments was not likely to be effective for at least another year.

The implications were momentous. Headquarters Bomber Command, after ten months' experience of H2S, estimated that its use afforded good results on only one raid of every four, and confidently expected that the improvement

[1] A.M. File CS.16766. *See also* Royal Air Force Signals History, Volume VI : 'Radio in Maritime Warfare'. American 10-centimetre A.S.V. equipment was in use before A.S.V. Mark III.

[2] A.M. File CS.16766.

[3] A.H.B./IIE/6/60.

[4] In February 1944 Headquarters Bomber Command was asked not to increase the number of main force squadrons to be equipped with H2S because of the difficult manufacturing problem created by a general shortage of magnetron valves. (A.H.B./IIE/6/60.)

in definition to be obtained with H2X would enable an average of at least two good raids in four. As the number of heavy bombers had increased, so had bombs become more effective, and it was of greater importance that attacks against large targets at long range, in particular Berlin, should be more accurate and concentrated. Acting on the assumption that only 200 H2X equipments, but no less, would be available, the Commander-in-Chief, Bomber Command, had planned to install the total output in aircraft of three squadrons of the Pathfinder Force, instead of in the six squadrons which he considered to be the actual requirement, so that H2X could be maintained in operational use throughout 1944. Speed in equipping the squadrons was essential since it would be during the winter months that they would be employed to the fullest possible extent and advantage. In the circumstances the Commander-in-Chief, Coastal Command, decided that he would ask for no more than one of his squadrons to be equipped. It was therefore recommended that the output of the H2X crash programme should be allocated so that one pathfinder squadron could be equipped, to be followed by one Coastal Command squadron, and then the remaining equipments were to be installed in aircraft of another two pathfinder squadrons.[1] However, the Air Staff, after further study of the proposal, considered that, in view of the uncertainty of supply of sufficient spare equipments to maintain in service for any length of time so many equipped aircraft, and in view of the urgent need to provision for spares over a period of twelve months until equipments would be available from a quantity production programme, it would be in the common interest to allocate the whole of the output of H2X to Bomber Command. The anticipated improvement in the accuracy of target marking, and the consequent increase in concentration on the target of bombs dropped by the main force would, it was urged, be of direct assistance in anti-U-boat warfare. It had been calculated that as a result of the bombing offensive during recent months the production of U-boats had been reduced by 40 to 50 per cent. Even if the estimate was over-optimistic, it was thought likely that the value of a considerable increase in the effectiveness of the bombing offensive would outweigh that which could reasonably be expected to result from equipping one squadron of Coastal Command. The main advantage to be gained from H2X lay in the value of a change of wave-length, and that would be only temporary and was possibly illusory; it was quite possible that the search receiver used by the enemy to monitor 10-centimetre A.S.V. emissions might also be effective on 3 centimetres. The Chief of the Air Staff decided that, in the circumstances, it would be unwise to allocate any H2X equipments to Coastal Command. The Chief of the Naval Staff and the Commander-in-Chief Coastal Command did not dissent, but were most anxious that higher priority should be given to the production and installation of High Power 10-centimetre A.S.V., A.S.V. Mark VI, which was another means of defeating the U-boat search receiver, and the Deputy Chief of the Air Staff immediately initiated the necessary action to that end.[2]

During November 1943, however, it became clear that the production programmes for both the H2X and A.S.V. Mark VI installations were falling seriously behind schedules. Unless drastic measures were taken, only 10 aircraft would be fitted with H2X, and it was doubtful if as many as 25 with

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[1] A.M. File CS.16766.

[2] A.H.B./IIK/12/5(B). *See also* Royal Air Force Signals History, Volume VI: 'Radio in Maritime Warfare'.

A.S.V. Mark VI, before the end of the year. The two programmes were inter-dependent in so far as essential components for scanning systems were concerned, and the production of scanning units for A.S.V. Mark VI was stated to be conflicting with the satisfactory production of scanning units for H2X.[1] In addition, the limited capacity of the Special Installation Unit at Defford was strained to such an extent by the two installation programmes that its output was adversely affected. It had been arranged that whilst the special installations were being made by the T.R.E., S.I.U. personnel would at the same time be trained in H2X installation. Then the S.I.U. personnel were to install at Defford 10 H2X equipments from the crash programme, meanwhile training P.F.F. and No. 32 Maintenance Unit personnel, after which the maintenance unit would be responsible, in conjunction with Headquarters Bomber Command, for the remainder of the installation programme.[2]

Meanwhile progress had been made with the special programme to equip six Lancasters with H2X. Although, because of exceptionally bad weather conditions, it had not been possible to carry out necessary flight tests in time to hand over the aircraft by the target date of 1 November 1943, the installations had been completed. The first three Lancasters were delivered to the Pathfinder Force on 13 November and the other three on 17 November 1943.[3] The Commander-in-Chief, Bomber Command, had, after the failure to hit the centre of the city in the September raids, postponed any further attacks against Berlin until H2X was available. On the night of 18/19 November 1943 the Battle of Berlin, which lasted until the middle of March 1944, began. The Pathfinder Force included two Lancasters equipped with H2X, or H2S Mark III as it was named. The results obtained with the installations were described by the Deputy Chief of the Air Staff as ' . . . most outstanding . . . '[4] Target definition was very good and the accuracy and concentration of bombing was a great advance on that obtained with 10-centimetre H2S. Headquarters Bomber Command and the Air Staff considered that if H2S Mark III could be installed in an adequate number of pathfinder aircraft, the bombing offensive could be made increasingly effective against Berlin and other targets at long range even when weather conditions over enemy territory were very adverse. Only bad weather at home bases, and severe icing conditions would be limiting factors, and it was felt most strongly that full advantage should be taken of the long winter nights immediately ahead. In the event, the Battle of Berlin was fought in the most appalling weather conditions, and scarcely an aircrew ever caught a single glimpse of the objective. Photographs showed nothing but clouds. Not until after six attacks had been made was it possible for a photographic reconnaissance aircraft to obtain confirmation that the target was being fairly accurately and devastatingly bombed. Then the weather again closed in and not until March 1944 was it possible to make any assessment of the damage.

The Director-General of Signals considered that it was important to give active support to the bombing offensive and on 29 November 1943 recommended that the Air Staff should focus effort on the Bomber Command programme even at the expense of delaying yet further the introduction of A.S.V. Mark VI

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[1] A.H.B./ID/12/201. 3-centimetre A.S.V.
[2] A.H.B./IIE/6/60.
[3] A.M. File C.28979/46.
[4] A.H.B./ID/12/201.

into operational use in Coastal Command. He estimated that it would be possible to complete installation of H2S Mark III in about six aircraft by 4 December 1943 and four aircraft each week thereafter if the H2X programme were given the higher priority until the middle of January 1944. By then No. 32 Maintenance Unit would be able to undertake its installation. The lag in the production of scanning units for A.S.V. Mark VI would be increased and its installation in aircraft of Coastal Command at the S.I.U., Defford, would have to be postponed until the maintenance unit took over the Bomber Command commitment.

The plan would enable the Pathfinder Force to be equipped by the end of the year with the minimum number of H2S Mark III installations required to increase the effectiveness of the offensive. The Air Ministry therefore felt justified in asking the Admiralty, after discussing the strategic situation with the Commander-in-Chief, Coastal Command, to agree to the delay in the A.S.V. Mark VI programme. The U-boat Command had adopted a safety-first policy. U-boat commanders were rarely exposing themselves to the risk of air attack and shipping losses were comparatively low.[1] The bombing offensive appeared to be reducing the rate of production of U-boats and was obviously of immense value to the air offensive as a whole and to the maintenance of air supremacy which was so essential. A defensive policy had been forced on the *Luftwaffe*, and the German aircraft industry had been diverted to the production of fighter instead of bomber aircraft and guided bombs. Even that production was being much reduced by bombing raids, whilst fighter losses increased. Consequently, although faced with the prospect of receiving only about six aircraft fitted with A.S.V. Mark VI by the end of January 1944, the Commander-in-Chief, Coastal Command, and the Admiralty, agreed to the modified installation programmes.

Installation and Further Development of H2S Mark III

The last heavy attack against Berlin was made on the night of 24/25 March 1944. By then H2S Mark III had been installed in some 55 Lancasters of the Pathfinder Force, of which 17 had been lost, and H2S Marks IIA and IIB in about 800 Lancasters, 490 Halifaxes and 85 Stirlings, of which 339 Lancasters, 216 Halifaxes and 30 Stirlings had been lost. The Stirlings had been replaced in operational squadrons by Lancasters, and were being used by the Heavy Conversion Units in a training role. Not all the equipped aircraft were available for operations on any one night, however, because of the shortage of fully trained crews. All five Lancaster squadrons of the Pathfinder Force contained aircraft equipped with H2S Mark III, and the remainder of the pathfinder aircraft were equipped with H2S Mark IIB, which was then being installed in aircraft of the main force to replace H2S Mark IIA. The aircraft of the main force equipped with H2S were distributed amongst 18 squadrons, and aircraft of an additional 10 squadrons were being fitted.[2]

The large-scale installation programme had not been accomplished without setbacks. The main force programme had been held up in the latter part of 1943 by a shortage of scanners, waveguides, and connectors, and the installation of H2S Mark III by difficulties in obtaining an adequate supply of suitable magnetrons Type CV. 108, which were hand-made, primarily to meet Fleet

[1] *See* Royal Air Force Signals History, Volume VI : 'Radio in Maritime Warfare'.

[2] A.H.B./ID/4/175A and A.H.B./IIE/248/2/1.

Air Arm requirements.[1] About one-third of the total production were rejected because they were far below standard, and probably no more than 50 per cent of those accepted were suitable for use in H2S because their power output was too low to permit required ranges to be obtained, although they were more or less satisfactory for A.S.V. Mark XI.[2] The supply position of magnetrons Type CV. 108 improved in January 1944, when magnetrons Type CV. 208 were introduced. Although the latter had a better performance and a longer working life, they were by no means satisfactory. Since the design of H2S Mark III involved employment of the British types of magnetron, it was decided not to make arrangements for quantity production of the equipments, but to rely on crash programmes until H2S Mark IV was available for Service use, and the original crash programme had been increased from 200 to 300 in November 1943.[3] By 12 February 1944 35 Lancasters had been fitted with H2S Mark III by the Special Installation Unit at Defford. The plan to begin an installation programme at No. 32 Maintenance Unit could not be put into effect until the first week of February, and then, once the usual difficulties associated with a new project had been cleared, a shortage of scanners held up output.[4]

The design, development, and production of scanners for airborne centimetric radar operating on a wavelength of 3 centimetres and below was a major problem. the crux of which was the manufacture in quantity of complicated and finely-adjusted mechanism and the delicate limits of tolerance of the reflectors which did not lend themselves to mass production methods. The real nature of the problem only came to light as improvements in scanner design were attempted. and with the use of shorter wavelengths, which made more evident the effects of slight distortion. Even when reflectors were manufactured exactly to the required dimensions, the type of material used generally caused the dimensions to alter within a short period of time so that H2S performance was adversely affected. The provision of new materials and methods to overcome the difficulty was treated as a matter of urgency. Ultimately, as more experience was gained, it became possible to design scanning systems which not only fulfilled the technical requirement but were also a practical proposition when production in quantity by industrial methods was planned, and at the beginning of 1945 the firm of Rose Brothers, Gainsborough, successfully employed die-casting for the manufacture of reflectors. A major requirement for H2S scanning systems was an increase in the degree of definition required at various heights. The scanner used for H2S Mark III was a modification of that used for H2S Mark IIC, and was designed to obtain maximum range at one operating height, 20,000 feet. It was necessary, however, for the scanning system to be sufficiently flexible in performance to allow reasonable ranges to be obtained down to 10,000 feet. Such flexibility had been comparatively easy to achieve with equipment working on a wavelength of 10 centimetres, but lower wavelengths involved an additional complication in the design of the scanner reflector, or the incorporation of adjustable tilt control. Experimental versions of the latter, designed during the development of H2S Mark III, were introduced in the design of H2S Mark IV.

In March 1944 the policy for installation of H2S in aircraft of Bomber Command was that all heavy bomber aircraft were to be equipped with

[1] A.H.B./IIE/248/2/1. Fitting progress of H2S aircraft.

[2] A.M. File C.28978/46.

[3] A.M. File C.28978/46. Increased to 500 in February 1944.

[4] A.H.B./IIE/248/2/1. Fitting progress of H2S aircraft.

3-centimetre installations, but its implementation was dependent on delivery from the U.S.A. of gyros and magnetrons Type 725A. They were required not only for H2S Mark IV but also for two variants of H2S Mark III, in which the American magnetrons were to replace the British. Tentative plans were made for the quantity production of H2S Mark IV, which was to be the main 3-centimetre installation in the command, but it was not expected to begin until early in 1945. The crash programme for H2S Mark III was therefore extended to provide an output of 35 sets of H2S Mark IIIA per month until 31 December 1945.[1]

The development of H2S Mark III known as H2S Mark IIIA incorporated roll stabilisation, scan distortion correction, and automatic setting of the drift line as used in H2S Mark IV. The operation of the equipment for bomb-aiming was the same as with previous installations except that the drift line appeared automatically on the P.P.I. instead of being set by the bomb-aimer on the azimuth scale, thus allowing the release point to be more accurately determined. This modification was an important one. With H2S Marks IIB and III the bomb-aimer calculated the drift and estimated the amount by which he had to 'aim off' to hit the target, in addition to calculating the ground speed. Statistics had shown that bombs were dropped, on an average, about half-a-mile downwind because of a somewhat natural disinclination to 'aim off'. In October 1943, however, the successful development and production of roll-stabilised scanners appeared to be a matter which would require some months to complete, and it was decided to add the scan distortion correction modification to H2S Mark III as soon as possible and call the resultant equipment H2S Mark IIIB. On 5 November 1943 Headquarters Bomber Command requested that priority should be given to the incorporation of the Indicator Unit Type 184 for scan distortion correction in H2S Mark IIIB before it was introduced in H2S Mark IID for aircraft of the main force.[2]

Review of Operational Use of H2S Marks II and III, 1943/1944

By the end of the 1943/44 winter bombing offensive, during which 93 per cent of Bomber Command sorties had used H2S for navigation and target marking, a great deal of research, development, and industrial manufacturing effort and resources had been expended in producing the best possible forms of H2S in large quantities. It had been necessary to make considerable sacrifice in other directions, particularly in the provision of A.S.V. for maritime aircraft. It was therefore important to ensure that the very best use was being made of H2S and the greatest possible value extracted from it. For some time there had been a growing feeling at the Air Ministry and at the T.R.E. that in spite of the wider introduction of H2S Mark III, and the greater number of aircraft of the main force equipped with H2S Mark IIB, proportionately better results were not obtained on bombing attacks. The Battle of Berlin had cost considerable casualties, and although large areas of the city had been devastated and many valuable targets had been hit, the concentration achieved was thought to be relatively ineffective. The introduction of H2S Mark IIIA to the P.F.F. and H2S Mark IIC to the main force was imminent, and it was thought that a careful analysis should be made of the manner in which H2S had been employed so that there would be no doubt that the new and improved installations would

[1] A.M. File C.28978/46.

[2] A.H.B./IIE/6/60.

be utilised by both the Pathfinder Force and the main force in such a manner that the fullest possible advantages were obtained in future bombing operations. The Air Staff thought that the subject was one of outstanding importance and of far-reaching repercussions, since it challenged the tactical employment, organisation and the aircraft equipment policy of the whole of the bomber force.[1]

Until early in 1944 the Pathfinder force had been employed not only for marking the aiming point over the target area but also for dropping route markers for the main force to follow on the way to the target area. From December 1943 until March 1944 there was a distinct rise in the loss rate of bombers, because fighters were no longer encountered only at the target area, but during the flight to it. The enemy had greatly improved his system of controlling night fighters and controllers were directing them to the bomber stream. There they used the route markers as a guide, tactics which had been expected by Headquarters Bomber Command. As more and more squadrons of the main force were equipped with H2S, the use of route-markers was abandoned, and the main force relied on H2S for navigation to the target. For targets beyond Oboe range the Pathfinder Force had found that the ' Newhaven ' method was the most effective for marking the aiming point. Flares were dropped over the target by aircraft equipped with H2S, and the aiming point was then marked visually, in the light of the flares, with coloured indicators. ' Backers-up ' then kept the aiming point marked as accurately as possible whilst the main force bombed.

Scientists of the T.R.E., who had been requested to place emphasis on the blind bombing aspect of H2S during further development, felt that there was a need to investigate, during actual operations, as had previously been done in November 1943, the possibility of better results being obtained if H2S was used by the main force for the purpose for which it was originally intended, blind bombing, rather than for blind marking by the P.F.F. and only for navigation by the main force. If, on the other hand, it was necessary to continue using the pathfinder technique, then, they contended, better results might be obtained by employing few aircraft using only H2S Mark III or IIIA, rather than by using aircraft of several squadrons using H2S Mark IIB and H2S Mark III together, since the value of the greater definition obtained with the latter was probably being wasted. Also, if the main force was not to use H2S for blind bombing, then the large-scale production of H2S involved by the policy of equipping every bomber aircraft should be reviewed ; the resources freed by a reversal of the policy might be better employed in devising and producing improved equipments to be used solely by blind marking aircraft of the Pathfinder Force.[2]

The Air Staff considered that the problem could be summarised as a search for answers to two questions :—

(*a*) What was the ideal method of marking and subsequently bombing a target with the aid of H2S when the ground was visible ?

(*b*) What was the ideal method of marking and subsequently bombing a target with H2S when the ground was obscured by ten-tenths' cloud ?

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[1] A.M. File C.28978/46.

[2] On 30 April 1944, of the heavy bombers in use, about 740 were equipped with H2S. (A.H.B./IIH/241/10/36(C). Bomber Command File—H2S fitting—Policy.)

Many factors other than technical performance of an equipment had a direct bearing on the answers, including morale of the aircrews, the extent of their experience with the H2S technique, the effect of the casualty rate on that experience, and the availability of H2S training facilities. The Air Staff, considering the first question, were of the opinion that experience had shown quite conclusively that visual bombing on a precise aiming point, either a marker or a ground feature, was the most accurate form of bombing outside Oboe range. The need was, therefore, to work out the best method of finding an aiming point and keeping it marked throughout an attack, and it was suggested that about 30 specially selected crews, highly trained in the use of H2S Mark III, would be adequate for marking as accurately as possible and for maintaining that accuracy throughout an attack. The Air Staff found it more difficult to decide which was the better answer to the second question; the whole force bombing blind, or selected crews dropping sky markers on which the main force bombed. If a high standard of H2S training could be achieved throughout the whole command it would be better to use H2S for blind bombing. On the other hand, if the standard was low, it would be better for the main force to bomb on sky markers dropped by the Pathfinder Force. The main conclusion reached by the Air Staff was that the employment in the Pathfinder Force of a small number of really expert crews in aircraft equipped with H2S Mark III would enable the bomber force to achieve better results than it was getting. The low standard of efficiency with which H2S was generally operated was thought to be mainly due to lack of sufficient training facilities caused by the shortage of ground training equipment and qualified instructors, and to the high casualty rate which reduced very noticeably the overall experience in the Pathfinder Force. A decrease in the casualty rate would enormously increase the general efficiency of H2S operations. A casualty rate of 5 per cent, and in the Battle of Berlin it had been 6·4 per cent, meant that the average crew completed only about 20 sorties. The casualty rate of Mosquito aircraft over the first three months of the year was 0·31 per cent, which meant that only one crew in seven would not complete a tour of 45 sorties. The Air Staff considered in consequence that if the Pathfinder Force could be composed entirely of Mosquito squadrons the efficiency and experience of the crews employed on target marking would be extremely high, and the disappearance from the force of Halifaxes and Lancasters would mean a decrease in the complications of training, armament, and servicing. However, the standard Mosquito was not equipped with navigation devices such as the air position indicator and the D.R. compass, and it remained to be seen whether it could be fitted with the most effective version of H2S. The layout of other equipments would have to be built around the H2S installation, and every possible ancillary equipment deleted or relegated to a position of secondary importance.[1]

By February 1944 the Pathfinder Force included five Mosquito squadrons. Those aircraft which were not equipped with Oboe were used on spoof raids, for decoy route-marking, and for harassing or ' nuisance ' raids when visibility was good and in moonlight periods.[2] Their provision with navigation and blind bombing equipment which was not limited in range by the use of ground stations was considered by Headquarters Bomber Command to be important

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[1] A.M. File C.28978/46.

[2] A.M. File CS.21410.

in order that the operational employment of the Mosquito squadrons in those roles might be made more effective and less dependent on weather conditions. Gee-H had been tried but was only partially satisfactory because of its range limitations, which made it ineffective beyond the Ruhr area. By December 1943 a trial installation of H2S Mark II had been completed, incorporating a scanner system specially modified by the T.R.E. On flight tests the results obtained below 15,000 feet were poor, large gaps in coverage occurring, but from 20,000 to 25,000 feet the maximum range was 25 miles with a minimum effective range of 4 miles.[1] Discrimination of detail was good but coverage was restricted to forward-looking only, the field of radiation being limited to a sector of 200 degrees ahead of the aircraft. That was considered to be sufficient for the purposes of blind bombing and of great value for navigation. The internal layout of equipment was re-arranged to accommodate a Gee installation, which created difficulty with the aircraft power supply because the alternator and voltage control panel were common to both installations. The difficulty was eventually cleared, and in December 1943 Headquarters Bomber Command raised an operational requirement for 12 aircraft of No. 139 Squadron to be equipped with H2S Mark II retrospectively by Pathfinder Force personnel, and for three aircraft per month to be equipped against wastage.[2] The requirement was officially approved on 2 January 1944 and no difficulty was anticipated except with the provision of scanners and connectors. The T.R.E. undertook production of special connectors and suitably modified scanners for the first four installations. A Mosquito equipped with H2S Mark II was first flown on operations on 12/13 January 1944, when it was included in the force which attacked Bremen ; it operated at 23,000 feet and the crew reported that the equipment had a satisfactory performance with a degree of definition superior to that usually obtained with H2S Mark II.[3] By the middle of February three installations had been completed and a fourth was in hand ; further progress was dependent on the provision of scanners Type 76, which were especially designed for mounting in front of the bomb-aimer's compartment, scanning through the perspex aircraft nose. The indicator, switch, heading control and modulator units were positioned so that the navigator had easy access to adjustable controls, whilst the remainder of the units were mounted in the rear of the fuselage. Because of the high altitude at which Mosquito aircraft operated, up to 30,000 feet, a considerable number of insulation breakdowns occurred and modifications were frequently required. By the end of March 1944 six Mosquito aircraft of the Pathfinder Force were equipped with H2S Mark II.[4]

On 22 April 1944 a meeting, known by the T.R.E. as ' The March on London,' was held in the Air Council room to ' . . . provide an opportunity for those responsible for the design and development of H2S and those responsible for its operational employment to discuss freely and frankly the methods by which it might most effectively be employed . . . ' and was attended by senior representatives of the Air Staff, Headquarters Bomber Command, the T.R.E. and the Ministry of Aircraft Production.[5] Headquarters Bomber Command

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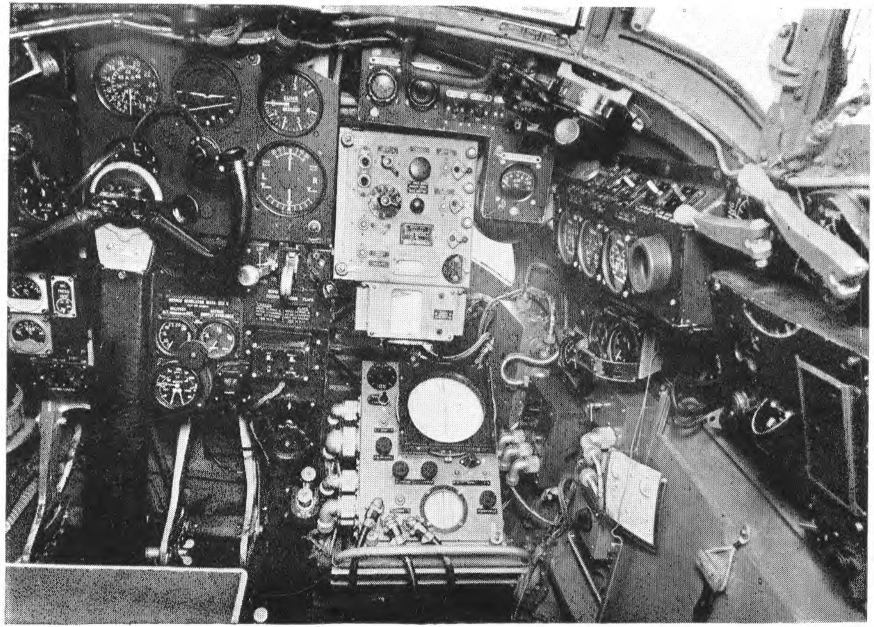
[1] Bomber Command File BC.52724/13.

[2] A.M. File CS. 21410.

[3] Bomber Command File BC. 52724/13.

[4] A.H.B./IIE/248/2/1. Fitting Progress of H2S aircraft.

[5] A.M. File C.28978/46.



H2S Installation in Mosquito Aircraft

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stated that with the existing equipment the best method of locating, marking and subsequently bombing a target beyond Oboe range when the ground was visible was without doubt by means of the Newhaven technique. It was agreed that ideally the marking force should be a small one with selected crews using only the latest equipment, but it was pointed out that such a force was likely to suffer a high casualty rate and would consequently be difficult to maintain. It was essential that the force should be fairly large so that a plentiful supply of trained and experienced personnel would always be available to replace casualties amongst those crews selected to carry out the initial marking stages of an attack. There was also another factor, not mentioned at the meeting, which influenced the requirement for a larger force. The increasingly effective tactics employed by the enemy night defences made it necessary to avoid, whenever possible, sending a single force of heavy bombers to attack targets deep in Germany. The diversionary attacks by Mosquito aircraft were having little effect, and comparatively large forces were used for diversions, whilst the main force was divided to attack more than one target, or to attack the same target at different times. The question of how best to bomb a target through ten-tenths cloud was divided into two ; bombing when cloud was low, and when it was high. Headquarters Bomber Command felt that with existing equipment the best method, when cloud was low, was the use of either ground markers or low-bursting sky markers, dropped blind by selected crews using 3-centimetre H2S. The centre of the pattern made by the markers then became the aiming point for the main force. There were considerable difficulties in judging the centre, and they increased proportionately with the height of the top of the clouds. The T.R.E. suggested that the enemy technique of defence would inevitably improve, and it was conceivable that Bomber Command would be forced to abandon altogether the use of markers and be compelled to restrict bombing operations solely to times when the weather was bad. It was therefore important that the whole bomber force should be capable of bombing blind with H2S. Headquarters Bomber Command was well aware that the system of bombing on markers was not ideal, and was conscious that it complicated the organisation and tactics of raids, but thought that with the equipment available it was the most effective method. The T.R.E. was not satisfied that H2S Mark III had been used to the best advantage in the Battle of Berlin. In the early stages the comparatively few aircraft fitted with the equipment had been given a special role, but later, when it became available in more aircraft, this had not been done. The representatives of the T.R.E. were of the opinion that the aircraft should be concentrated in one or two special squadrons and should be regarded as the spearhead of the Pathfinder Force with a highly specialised role, from which they should in no circumstances be diverted. Headquarters Bomber Command stated that, so far as was possible, H2S Mark III was provided for only the very best crews in pathfinder squadrons, and they were employed in the van of the attack. All other marking aircraft were regarded as 'backers-up'. The equipment had certainly been divided among a number of squadrons, because of the undesirability of forming with all the best crews of pathfinder squadrons a *corps d'élite'* within a *corps d'élite*, but it was agreed that the proposal should be further examined. In answer to a statement that the main force crews were using H2S Mark II equipment equally as efficiently as the crews of pathfinder squadrons, suggesting that the training of the latter could be improved, Headquarters

Bomber Command replied that the limitations of the H2S Mark II series precluded any great advance in proficiency after a certain stage had been reached. A major difficulty being experienced in the command was caused by the fact that there were more aircraft equipped with H2S than there were trained crews to use them. The position was steadily growing worse as the production of equipments was speeding up more rapidly than had been anticipated. Hastening of the supply of training equipment was required. The command had received 31 of the total requirement of 100 H2S ground trainers. There had been some allocations to other than Bomber Command, notably to the United States Eighth Air Force, but in May, June and July the command was to receive the full production of eight per month. A rearrangement of production to provide H2S trainers at a faster rate could be made, but only by reducing the delivery of A.S.V. trainers to squadrons in Coastal Command; priority was given to Bomber Command.

As a result of the meeting it was decided that:—

(*a*) All available Bomber Command aircraft equipped with H2S should carry out a blind bombing attack against a suitable target at the earliest opportunity when weather conditions permitted. Marker flares were to be used but only to ensure that crews bombed the right target.

(*b*) The policy of equipping all aircraft of the main force with H2S Mark IIC should be continued, but H2S Mark IIC was to be replaced by H2S Mark IIIA as quickly as the equipment became available. H2S was considered to be indispensable for the main force, both for navigation and as a warning device.

(*c*) Very great advantages might be found in the employment of Mosquito aircraft equipped with H2S as pathfinders for target-marking. The T.R.E. was therefore to examine the possibility of installing 3-centimetre H2S with all-round scanning in Mosquito aircraft.

On 16 May 1944 Headquarters Bomber Command informed the various group headquarters in the command that an operational trial of H2S would be made at an early opportunity. Certain conditions were necessary for the operation, among them being that it should be carried out on a cloudless night and that all aircraft should photograph results of the bombing.[1] No target indicators or flares were to be dropped. The command was, however, heavily engaged between April and September 1944, under the command of the Supreme Allied Commander, in bombing targets directly related to the land war in France, and the H2S operation was delayed. On 3 August 1944 the Deputy Chief of the Air Staff requested that, since the increasing hours of darkness permitted deeper penetration into Germany, and if it were consistent with any directions given by the Deputy Supreme Commander, the command should consider carrying out the blind bombing trial. The Commander-in-Chief Bomber Command decided that Berlin would be the target. This was changed to Brunswick on the advice of his operations staff as they thought that Berlin would most certainly be cloud covered and the required photographic verification would not be possible, and in any event it would be difficult to assess damage caused by an attack on an already heavily damaged city such as Berlin.

[1] Bomber Command O.R.B. Appendices Volume 4, August 1944.

The raid was made on the night of 12/13 August 1944. The force was composed of 373 Lancasters and Halifaxes equipped with H2S. Bombsights were made inoperative and no markers or flares of any sort were dropped. Crews were briefed that if H2S became unserviceable they were to bomb by the best means possible. Routeing was arranged to give all aircraft the same run in to the target from a point about 50 miles W.S.W. of the target, and the attack was timed in three waves to last just under 15 minutes. Of the aircraft despatched 317 claimed to have attacked the target; seven were equipped with H2S Mark III and the remainder with H2S Marks IIA or IIB. The seven H2S Mark III aircraft and 234 others reported that they had bombed blind, 18 had used H2S with visual checks, and 58 had bombed visually, 48 because H2S was unserviceable. The target area was covered with ten-tenths cloud, so that it was not possible to observe results visually, and only six photographs showed ground detail. From what evidence could be collected over the next few days it was estimated that about 50 aircraft dropped bombs within 3 miles of the aiming point, and about 50 in the area of the Hermann Goering Works at nearby Hallendorf. The H2S responses from that area were almost as equally bright as those from Brunswick itself and that fact may not have been sufficiently well known to all the crews taking part. It was not possible to determine exactly whether the comparative failure of the attack was due primarily to the inaccuracy of blind bombing or to a failure to identify the correct target. The evidence indicated, however, that the latter factor had a considerable influence on the results, which were considerably below those normally obtained by main force crews during training. This was no doubt partly because little or no blind bombing training had been possible for some time owing to intensive operations, many of the crews had little or no experience of attacks against German targets, the direction of approach to the target was not the best from an H2S aspect but was necessitated by a high wind, and nearly 25 per cent of the crews who claimed to have attacked bombed on the glow of fires seen on the cloud although the percentage of unserviceable equipment was only 15 per cent for the whole force; the other 10 per cent presumably had little faith in the equipment.[1] Headquarters Bomber Command considered the results as confirmation of the view that interpretation of H2S Mark IIA and IIB was not sufficiently easy for average bomb-aimers to bomb blind with any degree of accuracy; its great value lay in its use as a navigation system. The main factor determining the success of an attack was weather, and when that was bad, radar was essential. It was important that all bomber aircraft should be equipped with H2S of sufficient accuracy and ease of interpretation to make blind bombing a practical proposition, and the Commander-in-Chief, Bomber Command, emphasised the need for accelerating the provision of H2S Marks IIC and IIIA for the main force whilst the highest priority was given to the production of H2S Mark IV. The Air Ministry was of the opinion that the lack of success with the operation could be attributed in part to the fact that it was not carried out in accordance with the plan agreed on 22 April 1944 when it was stated that '. . . marker flares were to be used but only to ensure that crews bombed the right target . . .' It was considered that further operations should be arranged in order that the possibilities of blind bombing might be more accurately assessed and essential experience gained.[2] However, in September 1944, the German forces were driven out of France, the enemy lost the benefit of much of his early warning

[1] A.M. File C.28978/46.

[2] A.M. File C.28978/46.

system, and his air defences rapidly deteriorated. The Allies were able to set up ground stations on the Continent and the range of Gee, Oboe and Gee-H was greatly extended. Targets requiring precision bombing were attacked, in daylight and at night, by Bomber Command. H2S marking was used for long-range objectives, but the long nights were not used mainly for deep penetration into Germany as in the previous winter. H2S Mark III proved to be quite effective against the smaller targets when used by experienced pathfinder crews, but the need for greater accuracy was increased, and the requirement for the main force to use H2S for blind bombing receded into the background. No more trial operations were undertaken.

Installation Programme for Mosquito Aircraft, 1944/1945

In April 1944 it had been agreed that, because the low casualty rate of Mosquito operations resulted in crews achieving a much higher level of experience and training than was the case with heavy bomber crews, Mosquito aircraft were to be more generally used in the Pathfinder Force for target marking, especially since a considerable increase in their production was expected in the near future. It seemed that H2S Mark III could be fitted without undue difficulty if the limited H2S coverage afforded by the existing H2S Mark II installation would still be acceptable with the new equipment, and the T.R.E. was already making an experimental installation with a scanning system similar to that used with H2S Mark II. In May 1944 the Air Officer Commanding No. 8 Group stated that all-round looking and roll stabilisation were not required, but scan distortion correction was desirable. The existing H2S coverage, about 140 degrees forward of the aircraft, was acceptable, and a nose scanner would therefore be considered satisfactory. The bomb-aimer's position would not be used and equipment could be located in that compartment.[1] The Air Staff, however, considered all-round looking to be a requirement, and the T.R.E. agreed to begin development of a trial installation with a ventral scanning system, and anticipated that it could be completed before August 1944.

On 11 June 1944 Headquarters Bomber Command stated an operational requirement for Mosquito aircraft of the Pathfinder Force to be equipped with H2S in three stages. The first entailed completing the installation of H2S Mark II in all aircraft of No. 139 Squadron. When that had been done, conversion of the squadron to, and installation in a second squadron of, H2S Mark III with nose scanning, was to be started. On completion of that programme, both squadrons were to be changed to H2S Mark III with ventral scanning and all-round looking. The T.R.E. was overburdened with development projects and it was suggested that Headquarters No. 8 Group could undertake the introduction of the installation with nose scanning in a limited number of aircraft if the requisite components, including scanners and scanner mountings, could be made available to No. 8 Group Mosquito Servicing Unit. It was considered that before the end of the year there would probably be a need to equip more Mosquito squadrons with H2S Mark III and the position was therefore to be reviewed in four to six months' time. No. 139 Squadron had, between 6 and 13 June, carried out very accurate H2S marking for small but effective Mosquito bomber forces, including three attacks against Berlin, and their operations were not restricted by the hours of darkness or weather

[1] A.H.B./II/69/215B. H2S (Archives).

conditions which might limit the operations of heavy bombers. It was realised that an H2S Mark III installation programme for Mosquito aircraft would necessarily mean the diversion of equipment from the heavy bomber programme, but 94 Lancasters had already been equipped, and the diversion was acceptable.[1]

Trial installations of H2S IIIB, the original equipment with scan distortion correction incorporated, one with nose, and one with ventral scanning, were officially requested in June 1944, when the former was given the higher priority. On 11 July 1944, however, the priorities were reversed, and the development of a ventral scanning installation was regarded as an urgent requirement. Both installations were to be made in a manner suitable for fitting to be carried out eventually on the aircraft production lines.[2] An experimental nose installation had been made by the P.F.F. and two more aircraft were to be completed, and provisional Service trials were to be made with them, while the T.R.E. continued development of a system suitable for incorporation by the aircraft makers. The Type 76 scanner, being used for the H2S Mark II and the first H2S Mark III nose installations, was in short supply, and the design of a Type 89 scanner for the ventral position was given highest priority. Only 36 scanners Type 76 had been ordered for the initial H2S Mark II installation programme and arrangements were made with the R.P.U. to manufacture an additional 24. Although Headquarters Bomber Command had stated a definite requirement for all-round looking, the effectiveness of a scanning system in the ventral position was not known, and the final requirements were therefore made dependent on comparative trials. Meanwhile, duplication in provisioning was inevitable, and on 22 July 1944 it was agreed that 160 scanners Type 88 for the nose and 160 Type 89 for the ventral positions should be ordered. Delivery of Type 88 scanners could not be started before January 1945, and the reflectors incorporated in them posed a difficult manufacturing problem. The resources of the makers, Nash and Thompson, were badly strained, and the provision of additional Type 76 scanners would delay even more the provision of scanners Type 88.

Meanwhile a further complication had arisen. The U.S.A.A.F. had been allocated Mosquito aircraft with which to arm a photographic reconnaissance wing, and they asked the Air Member for Supply and Organisation if 12 of the aircraft could be equipped with H2S Mark III, in order that a small force able to take photographs of the P.P.I. display over selected targets might be formed. The photographs were to be used to improve the briefing of crews engaged on daylight operations and to ensure quicker recognition of the targets by formation leaders.[3] The request received the full support of the Air Staff since it had been agreed that the R.A.F. would also use the information obtained. Although the development of a suitable H2S Mark III installation for R.A.F. Mosquito aircraft was being undertaken by the T.R.E., and it was intended that the project for the U.S.A.A.F. should be the responsibility of the Special Order workshop at the De Havilland factory, the requirements were closely connected. In May 1944 it was agreed that six aircraft installations would be made at the rate of two per month but by the end of August 1944 only four had been delivered. The U.S.A.A.F. stated that the success

[1] A.H.B./II/69/215C. [2] Bomber Command File BC.52724/13.
[3] A.M File CS.21410.

achieved in H2S operations was largely due to the work of the Mosquito aircraft. During the design and experimental stages, work on the H2S installations had interfered with the production of standard Mosquito aircraft and the development of the Hornet, Vampire and Comet aircraft because the firm's drawing offices and experimental shops were overloaded. However, in September 1944, it was agreed that five additional aircraft would be delivered as quickly as possible.

In August 1944 technical approval was given to the H2S Mark III nose installation made in No. 8 Group. Flight trials had been carried out satisfactorily, and arrangements were made for draughtsmen of the T.R.E. to prepare drawings. The installation had been made in a Mosquito XX, production of which was to stop in December 1944 to make way for the production of Mosquito XVI aircraft, with which the squadrons were to be armed. The Mosquito XVI was intended for operations at high altitude, and the aircraft were therefore being pressurised. However, the performance of the H2S Mark III installation fell away progressively at heights above 20,000 feet, and it was suggested that fitting the equipment would decrease the potential value of the aircraft. The T.R.E. would not take any responsibility for the experimental installation made by No. 8 Group, and it was decided that a final decision should be made when trials of a ventral installation had been held. The prototype ventral installation in a Mosquito XVI was completed by the T.R.E. in August 1944, and after preliminary flight trials at Defford, minor modifications were made and the aircraft was sent to No. 8 Group for further trials. In the meantime there was no option but to continue with efforts to evolve a satisfactory nose installation since failure to do so might jeopardise the supply of replacement Mosquito XVI aircraft when stocks of Mosquito XX were exhausted. Little progress was being made with the development for production of scanners Type 88 and Type 89, although the T.R.E. had made a few models of the former for experimental purposes.[1] Service trials of the ventral installation were conducted in November 1944. Although the results were encouraging from a technical point of view, operationally the installation was unsatisfactory. The cockpit layout needed redesigning completely to facilitate operation by the navigator, in his cramped position, of all instruments and controls, the D.R. compass was made unusable by interference from the H2S transmitter and required repositioning, and the location of the scanner precluded the fitting of a vertical night camera, which was an operational requirement.

By December 1944, No. 139 Squadron was still the only Mosquito squadron equipped with H2S in Bomber Command. The strength of the night bombing force of Mosquito aircraft was about to be increased to 10 squadrons, and it was expected that the force would be called upon to attack up to four targets each night. Such a programme would involve a heavy strain on the target-marking resources of one squadron. On 10 December 1944, therefore, Headquarters Bomber Command asked for a second squadron to be equipped with H2S Mark II. However, the estimated time required for the provision of additional scanners Type 76 was two months, and it was hoped that the scanner Type 88 would be available before then ; the Air Ministry therefore suggested that the second squadron should be equipped with the installations

[1] A.M. File C.16041/44.

discarded as No. 139 Squadron was equipped with H2S Mark III. On 31 December 1944 Headquarters Bomber Command proposed a new Mosquito installation programme. No. 139 Squadron was to be equipped with H2S Mark IIIB as soon as scanners could be made available. If it were not possible to equip No. 162 Squadron similarly at the same time, then the H2S Mark II installations previously used by No. 139 Squadron were to be fitted in aircraft of No. 162 Squadron as a temporary measure. Nose installations were required for both squadrons, and the requirement for an H2S Mark III ventral installation was cancelled. As soon as it became available H2S Mark IV was to be installed in No. 139 Squadron, and then No. 162 Squadron, with scanners in the ventral position, but the drawbacks of the H2S Mark III ventral installation were to be eliminated. The contract for scanner Type 89 was cancelled and Headquarters Bomber Command urged '. . . that all possible action be taken to remedy the unsatisfactory state of affairs existing with H2S scanners, the shortage of which is having an adverse effect on the operational effort of the command, and threatens to have serious repercussions on the entire H2S programme . . .'[1]

Installation Programme for Main Force Aircraft, 1944/1945

The preliminary Service trials of an H2S Mark IIC installation in a Lancaster were conducted in March 1944 and the performance obtained was a great improvement on that of H2S Mark IIB. However, its early introduction into the Service was threatened with delays likely to be caused by a shortage of power drive units and gyro controls, and the order of priority for incorporating the main modifications was decided as the roll stabilised scanner Type 63, the indicator unit Type 184, and then the roll stabilised scanner platform.[2] The changeover to a roll stabilised scanner from a waveguide-fed scanner could, if necessary, be made without the platform. Arrangements were made for production of the equipment for aircraft of the main force to begin in August 1944.[3] In order that H2S Mark IIC might be introduced on the aircraft production lines in September a monthly output of 180 equipments was required, the first 20 of which were to be delivered by 1 September 1944. By July 1944 it became obvious that the introduction of H2S Mark IIC could not be achieved as early as had been anticipated, and in that month fresh plans were made for the provisioning of equipments to meet the operational requirement for its installation in all aircraft of the main force, and the subsequent conversion of H2S Mark IIIA. According to the information available then, all manufacturers of heavy bomber aircraft expected to be able to begin fitting H2S Mark IIC by January 1945, when the introduction of H2S Mark IIIA would begin on the Lancaster IV assembly lines. Other factories hoped to begin making the changeover by May 1945. The conversion of H2S Mark IIC to H2S Mark IIIA had become closely linked with the policy for introducing A.G.L.T. into Bomber Command.[4] Many difficulties were encountered in the production of satisfactory scanning units and stabilised platforms for H2S Mark IIC, and in October 1944 it was evident that the

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[1] A.M. File C.16041/44. In January 1945, 53 of the order for 60 scanners Type 76 had been delivered, and a contract for an additional 50 was placed, so that fitting of H2S Mark II might be continued.

[2] A.M. File C.28978/46.

[3] A.M. File C.16040/44.

[4] A.M. File C.16038/44.

installation was not likely to be incorporated on all aircraft assembly lines until March 1945. Meanwhile nearly all heavy bomber aircraft were being delivered equipped with H2S Mark IIB, and the possibility of converting from H2S IIB to H2S Mark IIIA without waiting for H2S Mark IIC was investigated.

After the meeting at the Air Ministry on 22 April 1944, Headquarters Bomber Command, impressed with the superior performance of H2S Mark IIIA compared with that of H2S Mark IIC, had requested that the changeover might be made as soon as possible.[1] Arrangements were made for a main production programme of H2S Mark III receiver and R.F. units to begin in September 1944, and the urgency of the need for obtaining financial approval and placing official contracts quickly was stressed. The acquirement of the necessary items of electronic equipment was facilitated in May 1944 when 1,700 R.F. units became surplus to the stated Fleet Air Arm A.S.V. requirements, and again in August 1944 when a further 900 R.F. units became available from the same source. Scanners Type 63 were to be replaced by scanners Type 71, and the original contract for 3,600 of the former was to be allowed to run out. During that process part of the scanner production resources was to be turned over to the manufacture of scanners Type 71, and it was estimated that the resultant combined production would be over 800 per month. A crash programme for 300 pre-production models of scanner Type 71 was initiated, and, on the assumption that type approval would be readily obtained, it was anticipated that main production would begin with 500 in December 1944. The provisioning plan was based on the existence of a requirement for units peculiar to H2S Mark IIC until August 1945 and the availability of units peculiar to H2S Mark IIIA from January 1945 onwards. A fitting programme was to begin at No. 32 Maintenance Unit in January 1945 and to be continued until the equipment could be incorporated on the various aircraft assembly lines.[2]

However, the aircraft firms were unable to change their production line arrangements as had been planned, and revision of the programmes for the manufacture of aircraft made it necessary in January 1945 to review completely the H2S requirements for the main force, and to adjust contracts accordingly. The introduction of new Marks of H2S was governed by the ability of the makers of aircraft to incorporate the requisite modifications. Contractors drawing offices were being overloaded by the very large number of modifications to Lancaster and Lincoln aircraft which were being called for. Lancasters I, II and III were being produced and fitted with H2S Mark IIB by the firms of A. V. Roe, Metropolitan Vickers, Armstrong Whitworth, Vickers Chester, and Austin. A. V. Roe had begun fitting H2S Mark IIC, and the changeover on the production lines was scheduled to be completed by the middle of February. It was expected that 330 aircraft could be completed by September 1945 when the firm was to finish making Lancasters I, II and III. Armstrong Whitworth and Metropolitan Vickers could not effect a changeover until March, and Vickers Chester and Austin until April 1945. They would then have to deliver about 100, 14, 160 and 170 aircraft respectively before production ceased. The firms producing H2S equipment were therefore committed to providing H2S Mark IIB for installation in aircraft until April 1945, and for maintenance purposes for some months afterwards. Since, however, the

[1] A.M. File C.16458.

[2] A.M. File C.16038/44.

original production plans envisaged a changeover to H2S Mark IIC in the autumn of 1944, it was not surprising that stocks of units peculiar to H2S Mark IIB were almost exhausted.[1] They were indicator Type 162, power unit Type 280, control unit Type 218 and scanner Type 3. There were no stocks of indicator Type 162 and current production covered only the requirements of the A.S.V. programme. Indicator unit Type 184A, tuning unit Type 207 and switch unit Type 207B were being produced for H2S Mark IIC and could be used instead of indicator Type 162 if slight modifications were made to aircraft. The power unit Type 280 was scheduled to be converted to Type 280A for H2S Mark IIC, the modification consisting of taking out one valve and a few components. Production of control unit Type 218 was ending, and in H2S Mark IIC was superseded by Type 446 which could be used with H2S Mark IIB if minor modifications to connectors were made. The existing stock of scanners Type 3 was about 870 which would meet requirements for some time to come. Proposals had, however, been made to convert them to Type 63 for use with H2S Mark IIC, and provided that in their new form they were suitable for use with H2S Mark IIB, the position would be satisfactory. It was therefore possible to convert H2S Mark IIB to H2S Mark IID, which would have all the improvements planned for H2S Mark IIC except roll stabilisation. Arrangements were made for the change from H2S Mark IIB to IID to be carried out at No. 32 Maintenance Unit and by Bomber Command units in the maximum possible number of aircraft.

It was assumed that if the requirement for a changeover from H2S Mark IIC to H2S Mark IIIA on the Lancaster aircraft production lines were insisted upon, it would not be met before September 1945. At that time only three firms would be producing Lancasters ; A. V. Roe and Vickers Chester 10 each in September, and Austin 15 in September and 6 in October ; a total of 41 aircraft. It was therefore decided to cancel the requirement, and as an insurance the manufacture of 500 H2S Mark IIC/IIIA conversion kits was proposed, so that Lancaster aircraft could be converted retrospectively if the need arose. The few Halifax aircraft still being made were mostly being equipped with H2S Mark IIC but the numbers were rapidly dwindling. At the best a production line change to Mark IIIA would not be effected before April or May 1945, when only three firms would be making the aircraft, Rootes, Fairey and English Electric. It was extremely doubtful if, in fact, the firms could change over, and in any event the small number of aircraft made such a course impracticable. It was therefore decided that should conversion from H2S IIC to Mark IIIA be required in Halifax aircraft for operations in the Far East the production of conversion kits similar to those for Lancaster aircraft would be undertaken. Lincoln I and II aircraft were being delivered equipped with H2S Mark IIC and instructions had been issued for H2S Mark IIIA to be fitted on the production lines as soon as possible. A. V. Roe expected to complete a trial installation during March 1945 and to turn over the whole of their production line during July 1945, whilst Metropolitan Vickers, Armstrong Whitworth and Austin anticipated producing Lincolns fitted wth H2S Mark IIIA in September. Conversion kits were to be prepared for retrospective modification of those aircraft delivered before September 1945.

There were two main difficulties connected with the production of H2S Mark IIIA equipment. One was the receiver peculiar to that equipment. Its

[1] A.M. File C.16038/44.

production was scheduled to begin in March 1945 to supersede the receiver used in H2S Marks IIB, IIC and IID, and both receivers could not be produced concurrently under existing arrangements. Since the Mark II series was to be in use for several months it was essential that ways and means be found of manufacturing both in quantity. The second difficulty was the type of scanner to be used. As a result of a T.R.E. request being misunderstood, it had been assumed that scanner Type 69 could be used for both H2S Mark IV and H2S Mark IIIA, and plans had been made to abandon production of the scanner Type 71 then being used for H2S Mark IIIA and to produce scanners Type 69 for all 3-centimetre H2S installations to be used in heavy aircraft of Bomber Command. At the beginning of 1945 it was learnt that scanner Type 69 was not easily interchangeable for H2S Marks IV and IIIA, its use with the latter equipment entailing certain changes. The major difference between the two scanners was that Type 69 incorporated a mechanism whereby tilt of the beam could be controlled over a wide range of angles of depression from the navigator station, a very desirable feature. The reason for the request by the T.R.E. that Type 69 should be used instead of Type 71 was to enable that feature to be made available for H2S Mark IIIA. The T.R.E. never intended that an assumption should be made that the Type 69 could be immediately used instead of the Type 71 for H2S Mark IIIA, but that, as soon as the state of production of Type 69 permitted, H2S Mark IIIA scanners incorporating variable tilt could be obtained by having the production line of Type 69 divided at the final wiring stage for modifications to be introduced into a proportion of the output. In that way the manufacturers would have, in effect, only one production line of scanners for both H2S Mark IIIA and H2S Mark IV, instead of two in parallel, and variable tilt would be included in the former installation.[1] Urgent action was necessary, and contracts for scanner Type 71 not already cancelled were kept in being.

The Commander-in-Chief, Bomber Command, agreed to modify retrospectively to H2S Mark IID Lancaster aircraft equipped with Mark IIC at units within the command if a supply of the necessary items of equipment was maintained at a suitable rate, but was certain that the programme would very much overstrain manpower resources and that a serious decrease in the standard of radar servicing would inevitably follow. The programme was to include only Lancasters; Headquarters Bomber Command did not intend to modify Halifax aircraft. Many difficulties, both technical and otherwise, were still being encountered in the manufacture of the stabilising platforms and stabilised scanners for H2S Mark IIC, and there was a distinct possibility that in the spring aircraft modified by the contractors for H2S Mark IIC might be delivered deficient of one or of both those items. It was quite impracticable for retrospective fitting to be undertaken within the command, and arrangements were made for notifying Headquarters Bomber Command in advance of the serial numbers of such aircraft so that they could be allotted to squadrons which did not use H2S. In view of the requirements for an improved version of H2S in aircraft to be used for operations in the Far East, it was necessary for retrospective conversion of Lancaster and Lincoln aircraft to H2S

[1] A.M. File C.16064/44. Scanner Type 69 was to be so designed that the sine potentiometer for the rotating time-base unit, with its mounting casting, could be replaced by a magslip mounted as on scanner Type 71, and a plug which took an eighteen-way cable replaced by five plugs required for H2S Mark IIIA.

Mark IIIA to be undertaken, and Headquarters Bomber Command estimated that a total of 1,000 modification kits would be required initially with an additional quantity for wastage. It was emphasised that if H2S Mark IV could not be expected before the autumn of 1945 then the modification kits would have to contain items which would permit conversion up to H2S Mark IIIF.[1] The Commander-in-Chief urgently requested that every opportunity would be taken to avoid using Bomber Command resources for the entire retrospective fitting programme, and that arrangements would be made for substantial assistance to be afforded by maintenance units or special fitting parties. Whilst all possible assistance would be willingly given, the role of the command was an operational one, and it was considered most unsatisfactory that it should be put in the position of having to undertake the work of manufacturers and maintenance units in order to make available in its aircraft equipment which was known to be essential to the efficient performance of its operational role.

In March 1945 the Air Ministry informed Headquarters Bomber Command that production of H2S Mark IV would not begin at the Gramophone Company until April or May 1946, and as R.P.U. production would be inadequate to meet the requirements of aircraft production line fitting, it was clear that such fitting could not begin until after the spring of 1946. The provisioning of H2S Mark IIC/IIIA and IIC/IID conversion kits for Lincolns and Lancasters had been initiated, and every effort was to be made to relieve Bomber Command of as much as possible of the retrospective fitting task.[2]

Thus, during the final winter bombing offensive of the war, in spite of the very great amount accomplished in research, development, and production, aircraft of the main force of Bomber Command operated with H2S installations on which experimental development had been completed by the summer of 1943 and which embodied principles of design formulated in 1942. It was estimated that during that winter the probable average error obtained by the Pathfinder Force with H2S Mark IIIA was 1·27 miles and by the main force with H2S Mark IIB, 2·22 miles.[3] Analysis of available plots indicated that there had been a progressive slight decline in the accuracy of H2S Mark IIB, which might have been caused by an increasing concentration on pathfinder tactics. Such concentration caused the various groups of Bomber Command to devote what little time was available for H2S training to the navigational rather than blind bombing application of H2S. Whilst a higher standard of training than was obtainable in wartime might have been reflected in a higher standard of accuracy, it was considered that substantial improvement could only have been achieved with the introduction into operational use of the new and better Marks of H2S which were being developed.

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[1] H2S Mark IIIC was H2S Mark IIIA with 6-foot scanner.

H2S Mark IIID was H2S Mark IIIA with improved T.R. unit.

H2S Mark IIIE was H2S Mark IIID modified to obtain improved definition and incorporating indicator Type 216 using a magnetic C.R.T.

H2S Mark IIIF was H2S Mark IIIE but using unstabilised 6-foot scanner.

H2S Mark IIIG was H2S Mark IIIB with improved T.R. unit and extended time-base.

H2S Mark IIIH was H2S Mark IIIB with improved T.R. unit and indicator Type 216. Fishpond and scan distortion correction were not incorporated.

[2] A.M. File C.16038/44.

[3] A.H.B./II/69/215D.

Improvements Incorporated in H2S Mark III

By the first week of August 1944 about 135 Lancasters of the Pathfinder Force had been equipped with H2S Mark III, of which 80 had been lost.[1] In No. 35 Squadron five Lancasters were fitted with H2S Mark IIIA, and 13 operational sorties had been made with those aircraft. As a result of the experience gained Headquarters Bomber Command on 11 August reported on the performance of, and technical difficulties encountered with, H2S Mark IIIA.[2] On the 10-mile scan the P.P.I. display contained defects similar to those characteristic of H2S Mark III. In particular, an annular gap occurred between the ranges of 6 and 8 miles. Contrast between built-up areas and open country was comparatively poor, and interpretation of signals at, or near, the centre of the P.P.I. was very difficult because of excessive ground returns in the centre of the display and the breaking up of signals at close range. It was emphasised that responses of clear and equal intensity at both distant and close ranges were essential and their achievement was an important requirement. The faults of the H2S Mark IIIA display were considered to be due to inferior scanning, and it was felt that every effort should be made to improve and standardise production models of scanners. Incorrect gearing had been used in the first four scanner Type 71 installations to be delivered to the squadron with the result that the heading marker invariably became decentralised with the orientation of the P.P.I. display after a major alteration of aircraft heading. The scanner motor supplied with the scanner Type 71 had insufficient initial starting torque. In order to start the scanner rotating it was necessary to set the scanner speed control to maximum before switching on the scanner, and sometimes to rotate it initially by hand. Other faults were also reported, most of which had been present in the prototype installation that had been given Service trials by the B.D.U. a few weeks previously. The introduction of H2S Marks III and IIIA into operational use with the Pathfinder Force had, however, been hastened through on a crash programme basis. It was the policy of the Air Ministry with all crash programmes to insist on the production of equipment at the fastest possible speed and to avoid the incorporation of modifications which were likely to reduce output except when they were essential to permit operational use of the equipment. The output of H2S Mark III and IIIA from the limited crash production facilities of the R.P.U. was barely sufficient to maintain requirements for aircraft wastage, and had already proved to be inadequate to re-equip all squadrons of the Pathfinder Force as had been requested by Headquarters Bomber Command. It was therefore essential that removal of the shortcomings was not allowed to affect production in any way, unless a reduction in the rate of flow to the command of H2S Mark III and IIIA installations was acceptable.[3] It was fully appreciated that the P.P.I. display required considerable improvement and that the fundamental cause of the defects was inefficiency of the scanners. Immediate action was taken to endeavour to ensure that reliable scanners, fully meeting the design specifications, were made available with the minimum of delay compatible with maintained output rates. Such action, it was hoped, would lead to the production in quantity of scanner Type 69. The cause of the de-synchronisation of the

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[1] A.H.B./IIE/248/2/1. Fitting Progress of H2S aircraft. [2] A.H.B./II/69/215C.
[3] A.M. File C.16064/44.

heading marker was traced to a manufacturing error, whilst the low-power motors had only been used because a higher-powered version was not immediately available.

As the use of H2S Mark III became more widespread, the question of training procedure as compared with that employed for H2S Mark II arose. Fundamentally the training problem was identical for both installations, but H2S Mark III contained characteristics which required special consideration. Because of the shorter wavelength and consequent narrowing of the scanner beam width, small areas of landlocked water previously undetectable on the display became visible, and built-up areas gave much clearer responses. Evidence obtained from assessment of bombing results during the winter of 1943/1944 indicated that greater accuracy resulted from the use of H2S Mark III against Berlin than against any other target. This was considered to be due to the fact that lakes and airfields within the Berlin area provided recognisable H2S landmarks which were used as reference points, and it was believed that development of a reference point bomb-aiming technique would lead to a further increase in accuracy. The training programme for H2S Mark III therefore paid special attention to the use of small lakes as check points both for navigation fixes and aiming points, and the technique of aiming bombs directly at built-up areas was practised.[1] Experience had shown that the quality of track-keeping was directly proportional to the frequency with which fixes were obtained, and the taking of a fix at least once every 5 minutes was recommended. Navigators were instructed to check carefully with D.R. navigation so that errors caused by a confusion of responses were avoided. The efficient use of H2S as a blind bombing system required considerably more practice than could be obtained on cross-country navigation exercises, and special flights against towns in the United Kingdom judged to be suitable targets were undertaken. Infra-red targets were located in many of the towns so that photographic evidence might be available. It was of the utmost importance that the accuracy achieved in blind bombing training was kept continually under review, and all photographic assessments of trial bombing runs were analysed by the Operational Research Section. Photographs of the P.P.I. display, known as ' Y ' photographs, became of increasing importance. Those taken at the instant of release permitted a fairly accurate assessment of the point of impact when no other means of obtaining the information existed, they provided valuable intelligence about the nature of the response pattern to be expected from various target areas in enemy territory, and they provided information about prominent and reliable landmarks. It was essential therefore that practice was obtained in the technique of P.P.I. photography. The elementary manipulation training was quite effectively carried out with a ground synthetic trainer, although a set of bench equipment was a better medium for practice in tuning.

In December 1944, when about 140 aircraft were equipped with H2S Mark III, there was a serious shortage of scanners Type 65. Although H2S Mark III was being replaced by H2S Mark IIIA, the rate of change was very slow because of the shortage of scanners Type 71, and it was evident that Mark III would remain in operational use for some months. In view of the introduction of H2S Mark IIIA, however, production of scanners Type 65 had been stopped, and Headquarters Bomber Command suggested three choices

[1] A.H.B./II/69/215C.

of action to prevent the possibility of a number of installations being rendered unusable because of a lack of scanners. The first was an immediate provision for the production of 48 scanners Type 65 at the rate of six per month. The second was a limited programme of converting H2S Mark III already installed in aircraft to Mark IIIA in order to make available for spares a limited number of scanners. The third was provisioning action for enough scanners Type 71 to cover normal wastage of both types of scanners.[1] Arrangements had already been made to cancel contracts for Type 71 in favour of Type 69 scanners, but the commander of the Pathfinder Force had arranged, through local purchase procedure, with the engineering firm of Rose Brothers at Gainsborough to produce an experimental form of scanner reflector in which die-casting was used. Normally reflectors were hand-beaten and they varied widely even though they were modified and improved as far as possible in accordance with T.R.E. instructions. Headquarters Pathfinder Force reported that the die-cast reflector produced a performance equal to that of the best scanner yet seen in service, and that in all the scanners Type 65 in which die-cast reflectors had been used the performance was uniform. Therefore, in January 1945, the possibility of initiating a major replacement programme, and the likelihood of improving the relatively poor production figures for scanners by the adoption of cast reflectors which were comparatively easy to manufacture, was investigated. A contract had already been placed for 50 reflectors for scanners Type 65, and an immediate increase was requested.[2] On 26 January the Air Ministry reported that the T.R.E. had given verbal approval of the cast reflector for scanner Type 65 from the electrical aspect, and had successfully tried it with a Type 71 scanner incorporating a stabilised platform, an essential test because the cast reflector weighed about 20 pounds whilst the existing aluminium reflector weighed about five pounds. The firm of Rose Brothers contracted to make a total of 150 Type 65 and 400 Type 71 at the rate of 50 per week beginning with the week ending 3 February; 15 Type 65 and 35 Type 71. Output was to be increased to 100 weekly when arrangements for placing a contract for an additional 1,500 Type 71 reflectors were completed, and another Gainsborough firm, Marshalls, became sub-contractors. Contracts were also placed with Rubery Owen of Darlaston and their sub-contractors, Boulton Paul of Wolverhampton. Their output was estimated as likely to be just over 20 per week from the beginning of February until the end of March, and it was hoped that when tooling-up had been completed, the output would be 125 weekly. Other methods of manufacture, including moulding of resin-backed plywood sprayed with metal, were also investigated, although difficulty in finding suitable material that would not become distorted with age was anticipated. Scanner manufacturers delivered their products without reflectors, which were fitted at No. 32 Maintenance Unit and at Bomber Command units. Meanwhile, the performance of H2S Marks III and IIIA was improved by a modification to existing scanners which entailed fixing a strip of perspex, one-sixteenth of an inch thick, to the reflector. This had been made necessary because the very close tolerances required could not be satisfactorily achieved by the original manufacturing methods.

On 16 December 1944 it was decided that, as an interim measure pending the introduction of H2S Mark IV, Lancaster aircraft of the Pathfinder Force should be equipped with an improved version of H2S Mark IIIA, and a

[1] A.M. File C.16458.

[2] A.M. File C.16064/44.

requirement was raised for provision on a crash programme basis of 100 H2S Mark IIIE or IIIF installations, both of which had a considerably improved performance. The main requirement was for H2S Mark IIIF to be fitted in two squadrons, but H2S Mark IIIE was to be used until scanners were available for IIIF, when arrangements would be made for conversion. H2S Mark IIIA was modified to become IIIE by modification of the receiver and switch units, introduction of a new type of waveform generator, and by substituting indicator Type 216 for indicator Type 184.[1] As new methods of making possible a higher degree of definition were evolved, so it became necessary to ensure that the advantages were not impaired by the system of presentation used. Scan distortion correction had to some extent been achieved by the indicator Type 184, but its design had been affected by the limitations of other components in use at the time. With indicator Type 216, in which a magnetic tube was used, the scale of the display was kept constant at all operating heights, and bomb-aiming accuracy was improved. H2S Mark IIIE was converted to IIIF by substituting scanner Type 97 for scanner Type 71. The effectiveness of H2S for blind bomb-aiming depended to a large extent on the degree of definition obtained, and a high degree of definition was achieved by narrowing the beam width. That result had been brought about in H2S Mark III by reducing the wavelength of H2S from 10 to 3 centimetres However, the width of the beam was not only directly proportional to the wavelength, but also inversely proportional to the width of the horizontal aperture of the aerial system. An increase in the width of the aperture involved the use of a large scanner, a difficult proposition because of its adverse effect on aircraft drag. The Type 97 was a six-foot scanner on which the T.R.E. had been working since February 1944. With H2S Mark IIIF, not only was a more accurate picture obtained over the target, but long ranges for the purposes of navigation were made possible.

In January 1945 the operational requirement was increased to 150 H2S Mark IIIE and 100 Mark IIIF installations for the Pathfinder Force. By the middle of March, when 112 Lancasters had been equipped with H2S Mark IIIA, 31 of which had been retrospectively converted from H2S Mark IIC, provision of the necessary components for H2S Mark IIIE, except the waveform generator Type 52, was proceeding satisfactorily. Contract action for the generator had been initiated, but it had not been possible to give type approval, and no H2S Mark IIIE trial installation had been made. However, it was anticipated that, once the design of the generator had been cleared, it would be possible to provide two complete IIIE installations every four days. Difficulties were being experienced with the development of a perspex nacelle. The T.R.E. had constructed a framework and were awaiting a scanner in order that tests might be made ; until they were completed it could not be decided definitely whether a new nacelle would be required. The design of the scanner Type 97 had been completed, and it was hoped that the first model would be ready by the end of the month. Further development work was required in order to make possible quantity production and arrangements were made to facilitate that production by reducing the existing orders for scanner Type 69 by 1,000 and to place instead orders for 1,000 scanners Type 97. Delivery of the first H2S Mark IIIE installations from the T.R.E., where they were being manufactured with the assistance of Bomber Command

[1] A.M. File C.16458.

personnel, began in mid-April 1945. On 22 August 1945, when hostilities had ceased, it was considered desirable, in the interests of economy, to reduce the number of Marks of H2S likely to be in Service use before the introduction of H2S Mark IVA. Production contracts for H2S Marks IIIH, E and F were therefore cancelled, and arrangements were made for the installation of H2S Mark IIIG in Lancasters and Lincolns until Mark IVA became available.

Revival of Interest in Nose Installations for Heavy Bomber Aircraft

At the time, January 1944, that the decision was made to cancel the specification for a scanning installation in the nose of Lancaster aircraft, it was expected that Lancaster IV aircraft would be employed as night bombers over Germany for some considerable time after their introduction into the Service. The possibility of using Lancasters on sustained daylight operations was thought to be remote, but in June 1944 nearly 40 per cent of Bomber Command sorties over France were made in daylight. Installation of an under-gun in aircraft of main force squadrons had begun in April 1944. The gun had first been considered as a definite operational requirement when there was considerable evidence that the enemy was delivering his fighter attacks from underneath bomber aircraft. It occupied the same position as the H2S scanner, but the general opinion of the operational groups in Bomber Command was that H2S should not be discarded in favour of the gun, especially as operations were still mainly carried out at night. However, by the summer the prospect of the continued use of heavy bombers for daylight sorties over Europe, and later in the Far East, was a real one. There was considerable feeling that by discarding the mid-under defence position the command was binding itself, when deep penetrations over enemy territory were contemplated, to a policy of night sorties and evasive tactics generally, irrespective of any new strategy which the course of hostilities might dictate. The suggestion was therefore made that, rather than rely on evasive tactics when warning was received of attacks developing underneath aircraft, it might be advisable to provide a mid-under turret and the Directorate of Bombing Operations requested that consideration of the advantages to be obtained from fitting a scanner in the aircraft nose be renewed.[1] The original Lancaster trial installation was still available if further trials were proposed but only two prototypes of Lancaster IV aircraft were in existence, and it was not practicable to employ one of them for testing an experimental installation which would take some time to complete, although such a course seemed desirable.

The situation resolved itself to a question of whether, when planning for the operation of a bomber force in the Far East, the H2S installation arranged for Lancaster IV aircraft, to which the Air Ministry was already committed, was one to provide the best results, or whether conditions in that theatre of war were so different from those obtaining in Europe that a new approach to radar requirements was needed. If a change was required, it was necessary to decide quickly, for it would take at least one year to bring it into effect.

The geographical and climatic conditions of the two theatres of war differed widely. It was possible that heavy bomber aircraft required not so much one general purpose radar installation such as H2S, providing good navigation,

[1] A.M. File CS.22828.

fair blind bombing, and indifferent tail warning facilities, but separate equipments providing a highly accurate radar bombsight, navigation systems such as Loran for position-fixing and Rebecca for homing and landing, and effective tail warning. The advantages bestowed by a nose installation could possibly be of increased importance. It was more suitable for the role of target location, the H2S layout did not interfere or compete with any other equipment, H2S and the mid-under gun turret could be used simultaneously, and it placed no limitations on the number and size of bombs to be carried. Before a decision could be made, various factors required study. They included the extent to which Lancaster IV aircraft were likely to be used for daylight operations against Germany and Japan; the radar requirements for operations in the Far East, where conditions varied widely from those in Europe; the extent to which reduced H2S performance would be acceptable in order to obtain an improvement in armament; and the extent to which H2S performance could be restricted to permit greater flexibility in bomb load. The question was also closely linked with possible development in the near future of gun-laying devices and the co-ordination of bomber aircraft armament.

Daylight operations' policy was discussed at a meeting held at the Air Ministry on 25 April 1944, when it was agreed that '. . . as a general principle it was felt that 360 degrees of H2S cover was preferable for both day and night bombing operations . . .' It was, however, also considered that something less than 360 degrees coverage might be accepted in the Far East theatre of war if material advantages in defensive armament resulted. However, as only a ventral scanner could give the all-round looking which was a requirement of Bomber Command, the question of a nose installation was dropped until it was brought up again in November 1944 in connection with Lincoln aircraft.[1] It had been decided that all Lincolns should be fitted with a ventral installation but were to be equipped so that a hand-operated F.N.88 under-gun could be substituted for the scanner at short notice at the discretion of the commander in the field. The scale on which the F.N.88 components should be supplied had not been fully considered, but it was proposed that as a provisional estimate sufficient gun equipment to enable at least two-thirds of the Lincoln force to be deployed in operational units should be provided. When the desirability of a nose installation was once more suggested in connection with the development of an ideal aircraft nose the Director of Radar pointed out that something more than a new nose would be required to make possible a satisfactory installation in other than the ventral position, even if coverage of less than 360 degrees was acceptable, and that structural alterations to parts of the airframe other than the nose would be necessary. The Assistant Chief of the Air Staff (Operations) decided that the question of whether or not an operational requirement for a nose installation should be raised officially depended on the amount of difficulty involved. If nose scanning could be incorporated conveniently then it was clearly desirable as it would do much to solve the vital problem of defence beneath the aircraft, and a new nose to provide accommodation for a Type F turret with a gyro gunsight and the Mark XIV or S.A.B.S. bombsight was already projected.[2]

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[1] A.H.B./II/69/215D.

[2] A.H.B./II/69/215D. The Type F was a turret developed for use in heavy bomber aircraft fitted with an 'ideal' nose, to be operated from the bomb-aimer position. The S.A.B.S. was a stabilised automatic bombsight. *See* Royal Air Force Armament History, Volumes I and II.

An investigation was therefore made of the difficulties likely to be encountered in the provision of such a new nose without H2S, or with a scanning installation giving 360 degree coverage, or with one giving less than 360 degree coverage. During January and February 1945 the project was discussed with the chief designer of A. V. Roe, and representatives of the T.R.E., R.A.E., D.O.R., D. Armament R., D. Armament D., D.T.D., and Boulton and Paul.[1] The introduction of the G.G.S. would in any event necessitate a major redesign of the Type F turret, and even with a redesigned turret including the G.G.S., major structural alterations would have to be made to the nose in order to obtain the necessary sighting angle. The bombsight and the bomb-aimer's position would have to be relocated, and it was quite obvious that even with the simplest scheme major modifications were involved which would, although given the highest priority, take more than one year to incorporate in production lines, whilst a more satisfactory nose would be obtained only by lowering the floor some eighteen inches and introducing a new empennage. The T.R.E. was of the opinion that a nose scanning installation would impose very definite limitations on the future development of H2S. However, it was appreciated that the reason for moving the scanner forward was to improve the defence of the aircraft, and the T.R.E. considered that it would be unprofitable to cater only for existing scanners; a scanner nacelle six feet in diameter would be required in the near future. It would be impossible to obtain all-round looking without locating the scanner below the fuselage, and the aircraft designer thought that a new empennage would be required, together with considerable modification to the bomb doors in order to obtain reasonable fairing and to reduce undesirable aerodynamic effects. Such a scheme would involve as much as 12 to 18 months' design and development work, and practically a new aircraft would have to be built. The original type of Lancaster nose installation was also considered but even that, as an interim measure, would involve a large amount of redesigning and tooling, and in the view of the T.R.E., would be unacceptable because of poor H2S performance. In addition, a great deal of other equipment would have to be moved from the nose and repositioned elsewhere. If it were finally decided that it was essential to transfer H2S to the nose and provide an under-gun turret, the system used in the Lancaster trial installation offered the only reasonable method which could possibly be put into production during the next 18 months using existing aircraft design and existing H2S equipment, and with it only forward coverage would be provided. The major alterations otherwise required indicated that the Lincoln, although it was not brought into operational use before the end of the war, was fundamentally out-of-date as a heavy bomber aircraft because of its inability to accommodate the most modern equipment.

Revision of Aircrew Duties and Training

In July 1943 the formation of a navigation team, consisting of the navigator, bomb-aimer and wireless operator, was approved in principle by the Air Ministry, because the operational conditions encountered by aircrews of Bomber Command made revision of aircrew duties necessary to ensure the satisfactory navigation of bomber aircraft. The bomber force was then facing increased opposition which made it necessary to fly at increased heights, and when possible, at higher speeds, often for long periods above cloud, and on circuitous

[1] A.M. File CS.22828.

routes, to avoid the main defence areas. The introduction of H2S and other navigation and bombing systems had also increased the demands made on the navigator's time and ability. Not only, therefore, had the work of the navigator been considerably increased, but also greater accuracy was required to enable the main force to keep on a planned track and maintain the desired concentration. The Pathfinder Force had adopted the navigator team principle at the end of 1942, the navigator and the bomb-aimer sharing the duties of navigation. In the revised scheme, the navigator remained the key member of the team, but the bomb-aimer and wireless operator supplied him with information obtained by map-reading, astro-navigation, or from H2S and other radar systems. It was intended that, with the observations thus provided, the navigator would be able to fulfil his duties with a high degree of precision.[1]

By October 1943 alterations in the training programme of all three members of the team had been arranged, but obviously the main effect of the changes would not be felt for about six months, when a notable increase in efficiency was expected. However, investigations made during March 1944 revealed that the standard of navigation was not meeting the exacting requirements of bombing operations. In fact, navigation errors were so numerous that it was considered to be practically certain that a much higher proportion of Bomber Command losses were directly attributable to faulty navigation than had previously been suspected.

In the navigation team, the bomb-aimer was the H2S operator, and as such was required to keep a navigation log and plotting chart. To be competent he required a sound knowledge of dead-reckoning navigation, and the standard of navigation training for bomb-aimers was raised accordingly. The technique of H2S operating was not easy to master. In the hands of good operators H2S was of great assistance to precise navigation, but for blind bombing an even higher standard was required, and few bomb-aimers attained that standard. It was essential not only that training should be intensified, but that as H2S was further developed its operating sequences should be simplified. H2S training was normally carried out during the Heavy Conversion Unit course, but in May 1944 consideration was given to the inclusion of H2S training at the previous stage of instruction, the Operational Training Unit. Experience had shown that position-fixing by relating the responses to dead-reckoning navigation was the bomb-aimer's greatest difficulty and with the advent of the reference point bombing technique improvement was essential. Proposals for synthetic means of providing training other than the issue of complete H2S trainers, considered to be an uneconomical measure, were made, but in July 1944 it was decided that no benefit was obtained from H2S training at operational training units. During that month H2S Mark IV was made an operational requirement for all heavy bomber aircraft, and Headquarters Bomber Command proposed alterations to be made in the layout of the navigator station in conjunction with its introduction. Since the system of a navigator team was first adopted the wireless operator had been responsible for operating Gee, but he was no longer required to be a direct contributor to navigation, and Gee, or Loran, was in future to be operated by the bomb-aimer. In order that the navigator might easily take the maximum

[1] Bomber Command O.R.B., July 1944.

advantage of the facilities for finding wind velocity which were incorporated in H2S Mark IV, he was made responsible for the operating of H2S, whilst the air-bomber was required to keep a simplified log and to be responsible for dead-reckoning navigation and plotting.[1] The proposals culminated in the design of a single radar station for Lincoln aircraft, but during the winter of 1944/1945 the Pathfinder Force included two navigators in each crew in order to improve the accuracy of navigation and target-marking. In September 1944, when the use of H2S had become general in the majority of operational squadrons, it was decided that the responsibility for H2S training policy and supervision should be transferred from the Radar to the Training branch of Headquarters Bomber Command.[2] Such a step was in accordance with the general policy in which specialist branches were responsible for the early training on new equipments until such time as they had been brought into general use. The training branch took over the responsibility of allocating H2S trainers and sets for training, the allocation of training hours both in the air and on the ground, the methods of instruction, and the training and categorisation of instructors.

Use of H2S for Reference Point Bombing

The earlier methods adopted for the tactical use of H2S for blind bombing and target marking were based upon the assumption that an aiming point could be accurately selected from the responses obtained from a built-up area. When the target was small and compact, attacks were usually concentrated and successful, but difficulties arose when the methods were applied to large and scattered areas, and they could not be employed for precision bombing or against targets which gave no identifiable response on the P.P.I. display. P.P.I. photographs showed that certain physical features in enemy territory, particularly stretches of water, provided readily identifiable landmarks by which it was possible to fix the position of the aircraft with a high degree of precision. The Operational Research Section of Headquarters Bomber Command therefore suggested in May 1944 that whenever the target selected for attack was situated within range of identification by H2S of such a landmark, a potentially accurate method of bombing was possible by using the landmark as a reference point and homing to a pre-calculated release point.[3] The release point could be determined by knowledge of the true air speed, height, track, wind velocity and bomb ballistics. Two obvious objections were the loss of tactical freedom caused by the necessity for adhering to a given track, airspeed and height, and the probability of bombing error caused by the use of an incorrect wind velocity. However, with the current bombing methods it was already necessary to keep to a pre-determined track on the approach to the target, and it was thought that the likely errors in calculation of the wind velocity would not appreciably increase except when conditions were very unusual. It was estimated that the overall accuracy of bombing, if the reference point system were adopted, would be such that 50 per cent of bombs would fall within a circle of a radius of not more than one mile and possibly much less, and it was emphasised that the area of the circle would be independent of the size, shape, and degree of dispersion of the target, in contrast to the results of current bombing methods. Once the position of the release point with reference to the selected landmarks had been determined, it would

[1] A.H.B./II/69/215C.
[2] A.M. File C.16073/44.
[3] A.H.B./II/69/215C.

be necessary to set up the information in a manner which could be conveniently used by the bomb-aimer during the run-in to the target, and some modifications of the H2S installations in current use were required for two of the three ' offset ' methods proposed.

For the first, in which no modification was required, the distance of the reference point from the release point was set up on the range marker ring, and a chinagraph line was drawn on the track marker plate to indicate the bearing of the reference point from the release point, the track marker having been previously set on the track required at the target. The aircraft then had to be flown along the required track in such a manner that the reference point passed through the intersection of the range marker ring and the chinagraph lines, at which instant bombs or markers were released. The second method required a modification to include a simple mechanical device with which to measure off and mark the range and bearing of the reference point from the release point, whilst the third method was more or less a refinement of the second. The main modification required was one to enable the whole P.P.I. display to be offset from true centre before the bombing run was started. Then the aircraft was flown so that the planned reference point appeared to move in towards the centre of the P.P.I. display.

Immediate interest was shown in the possibilities of the system, and Headquarters Bomber Command placed three aircraft at the disposal of the Bomber Development Unit for extended trials, whilst Bomber Command groups included it in their training programmes. The possibilities of the technique for mine-laying from high altitudes were recognised, and trials of various mine-laying applications were included in the B.D.U. programme. Previously mine-laying had only been carried out successfully in enemy coastal waters when weather conditions were favourable.[1] It was necessary for navigators to pinpoint a coastal land feature near the release point, and mines were laid after a timed run had been made from the selected landmark. The method demanded good visibility and an absence of low cloud, and, because landfall had to be made as near as possible to the release point, usually at low altitudes, aircraft were invariably flown within range of enemy ground defences. The unmistakable H2S responses obtained from coastline and the comparative ease of interpretation of bearing and distance from prominent coastal features made it possible to release mines on H2S plots from heights up to 15,000 feet, irrespective of low cloud and poor visibility. The approach to the release point was selected to provide maximum assistance from H2S, whilst avoiding as much as possible heavily defended areas. P.P.I. photographs were taken at the moment of release on a number of sorties and provided a valuable means of assessment of the methods employed. The method generally used was to mark on the P.P.I., before take-off, the pre-calculated position of the reference point relative to the required release point. The aircraft was then flown so that it followed the planned track to such a position that the response from the landmark coincided with the mark on the P.P.I., when mines were released. However, with H2S Mark II it was not always possible, because of poor definition, to pinpoint accurately on the P.P.I. the reference point, but analysis revealed that 34 per cent of mines fell within one mile, 53 per cent within one and a half miles, and 69 per cent within two miles of the aiming point.

[1] Bomber Command File BC.52724/60.

The B.D.U. report on the trials was promulgated in November 1944, but the information gained from them was too scanty to enable any precise conclusions to be drawn because most of the data proved to be unsuitable for scientific analysis. However, the causes and effects of inaccuracies in the measurement of the bearing of a response, unimportant as they were for general navigation but of considerable importance in the reference point technique, were determined. Amongst the recommendations made for their eradication was one that the T.R.E. should investigate the possibilities of incorporating an electronic bearing marker in existing and future Marks of H2S.

During the winter of 1944–1945 the reference point technique was successfully used and developed by Bomber Command for target marking on bombing operations. The markers were dropped on a reference point sufficiently distant from the target to be clear of smoke, and bombsights were offset in such a way that although the main force aimed on the markers, bombs fell on the target. When the technique was first used against tactical targets in France the Master Bomber made calculations which he broadcast to the main force to ensure that bombsights were corrected. Such a procedure took some time and the inevitable delay caused rather heavy casualties as the main force waited for the markers to be placed and for the Master Bomber's instructions. The procedure was therefore modified for employment against well-defended targets in Germany. The actual target was first illuminated and marked by use of H2S. In the light of the flares the crews of between five and nine aircraft identified a previously chosen marking point which was anything from 1,000 to 2,000 yards distant from the centre of the area to be attacked, and dropped indicators whose accuracy was continually checked by the Master Bomber. Eventually each aircraft of the main force could be given a separate heading on which to approach the target area from the marking point, and a different interval of time at which to bomb after the marking point appeared in the bombsight.

At the T.R.E. it had been realised for some time that H2S should be developed so that, however invisible the real target might be, a clear-cut sighting on a neighbouring feature at a known bearing and range from the target would result in accurate bombing.[1] The value of the reference point technique as a countermeasure to jamming was also appreciated. In the design of H2S Marks VII and VIII two possibilities were covered by providing for two types of offset bombing. One was for use when a suitable reference point could be chosen before an operation; the radar reference point controlling the reference point target marker was pre-set and translated into position information to cover bombing of the real target. The other was for use when a correction was required in the target area. It involved rapid off-setting to meet local surface wind conditions for flare and ground marker bombing and to correct for cross trail of low terminal velocity bombs. Facilities for offset bombing were also included in H2S Mark IV.

Restrictions on Operational Use of H2S Marks II and III

Full technical knowledge of H2S was gained by the enemy when a comparatively intact installation was recovered from an aircraft which crashed near Rotterdam in March 1943. Five possible courses of action to counter the use of H2S were presented by that knowledge; development of a similar

[1] A.H.B./II/69/215D.

installation for use in bomber aircraft, jamming, the use of decoy targets, development of a homing receiver, and development of a raid-tracking organisation to obtain information from H2S emissions.[1]

Although *Berlin* centimetric A.I. equipment was developed from H2S, the majority of German bombers were twin-engined aircraft which were considered to be too small to accommodate effectively a form of H2S, and in any event at that period of the war the enemy requirement was for fighter rather than bomber aircraft. In addition Allied bombing raids against industrial areas and factories seriously restricted all forms of radio, including valve production, and little progress was made with an H2S project. The difficulty of jamming highly-beamed centimetric radar emissions was appreciated, and it was decided that all that could be done to jam H2S was to attempt to defend a few vital targets. The first target chosen for such a defence was the *Leuna* works. Transmitters, known as *Postklystron*, were positioned on eight sites around *Leuna*, and began operating about March 1945.[2] It was claimed that when a jammer was directed against an aircraft equipped with H2S, normal responses on the P.P.I. display were obliterated at a range of 25 miles. Plans were also made to employ a second type of jammer, making use of the *Roland* transmitter manufactured by *Siemens*, but its development was abandoned in March 1945 as it was considered to be ineffective. Experiments were also made in ground camouflage with the aid of corner reflectors but they were unsuccessful. It was originally planned to use the reflectors to disguise prominent landmarks, such as lakes, but too many were needed to make the scheme practicable, and it was also necessary for them to be fixed in one particular orientation to produce any effect. In particular, a number of decoy buoys were sited in the harbours of Kiel and Wilhelmshaven. The buoys were of two kinds, and were arranged as if to attempt to reproduce the outline of the docks. One consisted of a small boat with a corner reflector mounted on top, and in the other the reflector was supported by three rafts lashed together. There were at least 50 or 60 buoys at Kiel and 300 at Wilhelmshaven, laid at a density of about 60 per square mile. P.P.I. photographs taken by Allied bomber aircraft at the moment of bomb release over both locations showed no consistent false echoes, and none were observed at any other targets, either coastal or inland.[3] Consideration was also given to the use of metallic powder, having high reflectivity characteristics, in the construction of decoy targets but the amount of powder required was found to be prohibitive. The only two countermeasures which proved to be effective were homing receivers and radar intercept stations.

Immediately the nature of H2S was realised, an operational requirement was raised for a receiver capable of homing to H2S emissions to be installed in night fighter aircraft. Homers for use on metric wavelengths had already been developed but the enemy considered that free-lance tactics by specialist homing aircraft were incompatible with the system of direct ground control of fighters which was the essential basis of German air defence. When that system had to be abandoned because of the Allied use of Window, the practicability of homing operations was accepted. But the problem of homing to the source of emissions radiated on centimetric wavelengths was technically and tactically much more difficult because of their characteristics. Eventually

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[1] *See* Appendices Nos. 1 and 2. [2] A.H.B./IIG/29. A.D.I.(K) Reports.

[3] A.H.B./69/215D. Air Scientific Intelligence Report No. 29, dated 5 December 1944.

a receiver known as *Naxos* was designed, but early development models gave no indication of range and bearing and were ineffective as homers. Modified versions of the earlier *Naxos* equipment were installed in U-boats from September 1943 for employment as a warning system against centimetric A.S.V., and further development of the receiver for homing was continued until in December 1943 final Service trials were conducted.[1] An installation programme for an operational unit, *Gruppe II*, was completed in January 1944, but because of the technical difficulties which had been experienced and the lack of success which attended the early operational use of *Naxos*, aircrews had not much confidence in the equipment and comparatively little use was made of it. Fighter aircraft could not be homed to individual aircraft equipped with H2S unless they were isolated at some distance from the main bomber stream, for there were inherent difficulties in solving the problem of homing to one aircraft situated in a concentration of others all emitting similar radiation. *Naxos* did, however, facilitate making contact with the stream itself, and when the aircrews of *Gruppe II* were considered to be adequately trained in its use, their aircraft were usually positioned as near as possible to the estimated track of the main bomber force to act as pathfinders for the remainder of the fighters.[2] On 8 April 1944 all the *Naxos*-equipped aircraft of *Gruppe II* were destroyed on the ground at Quakenbruck by a bombing raid carried out by the U.S.A.A.F., but by July 1944 replacements were made available for operations.

Meanwhile, radio countermeasures against the ground radar elements of the German air defence system had been so effective that the enemy was denied information of the approach and intentions of bomber forces by that means, and an extensive raid tracking organisation or listening service was set up in order to gain that vital information by means of intercepting aircraft radar emissions.[3] A network of radar intercept stations using *Korfu* receivers, an elaboration of *Naxos* with directional aerials, was spread over all probable areas of approach of bomber forces and was used for plotting H2S emissions on the 10-centimetre waveband. Early warning of raids was received at long range, and as the system became more highly developed the enemy was able, to some extent, to analyse bomber tactics and thus possibly to distinguish main raids from diversions. With the adoption of free-lance night fighter tactics the listening service grew in importance, and by July 1944 the entry of *Naxos*-equipped aircraft into the main bomber stream was very much facilitated. On the night of 25/26 July 1944 the bomber force was plotted, by means of its H2S emissions, whilst it was still in the Peterborough area, and its subsequent heading was followed as the aircraft flew south to the English Channel.[4] The tracks plotted then divided, some going to targets in France whilst the main force went on to the Stuttgart area. The maximum range of early warning thus obtained by the enemy was 150 miles, which compared favourably with that which had previously been made available by the coastal radar stations. In addition a reasonably accurate estimate of the number of bomber aircraft engaged was made; 300 to 400 as compared with the 500 actually employed against Stuttgart.

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[1] *See* Royal Air Force Signals History, Volume VI: 'Radio in Maritime Warfare', for details of use of *Naxos* in U-boats.

[2] *See* Royal Air Force Signals History, Volume VII: 'Radio Counter-Measures', for further details of *Naxos* and its tactical use.

[3] *See* Royal Air Force Signals History, Volume VII: 'Radio Counter-Measures'.

[4] A.H.B./II/69/215C.

In July 1944 it became evident to Headquarters Bomber Command that the enemy was not necessarily relying entirely upon his ground radar system for early warning, and it was strongly suspected that effective use was being made of emissions from radar equipment carried in bomber aircraft for that purpose and for homing fighters to the bomber stream, if not to individual aircraft.[1] It was also evident that, if the facts were true, the only way to deny the information to the enemy was to prohibit all radar emissions from bomber aircraft.[2] However, H2S was of very real value to Bomber Command, and without it the efficiency of the bomber force would be very much reduced. The homing threat had two aspects. Homing to the bomber stream only was considered to be an acceptable risk since there were many ways other than by making use of H2S emissions by which the enemy could accomplish such homing.[3] Homing to individual aircraft, however, constituted a risk which was by no means acceptable. The task of assessing the degree of success achieved by the enemy was most difficult. At that period of the war German air activity was confined to the Continent and it was not possible to obtain enemy aircraft so that equipment could be examined. Fortunately, on the night of 12/13 July 1944, because of an error in navigation, a *Ju. 88* landed at Woodbridge. Although the aircraft was not equipped with *Naxos* its crew definitely established the use made of H2S. It became apparent that, in order to increase the security against attack of the bomber force, H2S and other radar equipment would have to be kept switched off, at least until the aircraft were within effective range of German ground radar.

The decision to enforce H2S silence was not to be made easily, however, and was the subject of considerable discussions and controversy. It was argued that H2S was the main system of navigation and blind bombing beyond the range of Gee, and any suggestion that it was a potential danger would very likely cause loss of confidence amongst aircrews with a consequent loss of efficiency; if a high standard of efficiency was to be attained, the maximum use of H2S was necessary. In addition, the overall casualty rate was low and investigation had revealed that it was no greater for aircraft fitted with H2S than it was for aircraft not so fitted.[4] A technical difficulty also existed. If H2S was not to be used until late on the outward journey, the H.T. and L.T. circuits were switched on as usual after take-off, but the modulator remained switched off until the prearranged position was reached. At high altitudes, especially during the winter months, flash-over was very likely to occur, with a consequent great increase in unserviceability of H2S equipment. Moreover, the average bomb-aimer or navigator required at least 15 to 20 minutes to re-tune once the modulator had been switched on, so that if the installation was to be used for navigation it would be necessary to bring it into use at an appreciable distance from the enemy coast.[5] It was therefore suggested that there was not sufficient justification for curtailing its operational use, although the possibility of long-range plotting and homing to the stream existed, as the advantages of retaining the employment of H2S outweighed the disadvantages.

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[1] A.H.B./IIE/76. 'War in the Ether'.

[2] A.H.B./IIE/77/73. Air Scientific Intelligence Report No. 73, dated 13 July 1944.

[3] *See* Royal Air Force Signals History, Volume VII: 'Radio Counter-Measures'. I.F.F. and Monica emissions were used by the enemy.

[4] A.H.B./IIE/69/215C.

[5] Bomber Command O.R.B., August 1944.

Those who considered that the use of H2S should be restricted, principally the Radar Staff, maintained that the enemy, by using H2S for long-range plotting in areas where Gee cover was available, was deriving more benefit from H2S in those areas than were the aircraft of Bomber Command. The Germans were obtaining vital and essential information whilst the bomber aircraft in those areas were using H2S only because of the training factor, and because of technical difficulties which could be cleared eventually by modification. H2S could not be considered an operational requirement in any area when Gee was unjammed, and that extended as far as the Rhine. Although the overall casualty rate was low, it included sorties against targets not in Germany. For the month of July 1944 it was 1·6 per cent, which was acceptable, but against targets in Germany alone, it was 4 per cent, which was too high. Whilst the enemy use of *Naxos* might threaten no danger to individual aircraft, the bomber force as a whole could be endangered by H2S emissions acting as a beacon for night fighters which, having used *Naxos* to home to the stream, could use their A.I., then unjammed, for intercepting individual aircraft which might or might not be equipped with H2S. The proposal that H2S should not be used whilst aircraft were within Gee cover could not affect the accuracy of bombing, which was the main consideration ; the improvement of bombing accuracy was the prime reason for the development of H2S. The training aspect was considered to be not important enough to justify the use of H2S in conditions which could be dangerous to the bomber force, particularly as the return flight from a raid offered opportunities for practice. In the matter of the loss of confidence amongst aircrews it was felt that if the difference between the plotting hazard and the homing risk was clearly explained, there would be no reluctance to use H2S operationally.

The opposition to imposing restrictions on the operational use of H2S was considerable, and whilst many of the opinions expressed were biased and uninformed, the issues at stake were well understood at Headquarters Bomber Command. The possibility that the command might, in effect, lose the benefits conferred by H2S if crews were to regard it as a source of danger was fully appreciated, but at the same time it was imperative to deny the enemy the ability to plot the tracks of bomber aircraft at long range. It was essential to reach a rational compromise whereby H2S could be used when necessary and not merely when convenient. The problem was examined and re-examined, for it was of the utmost importance that all the implications should be fully realised before a decision was made, until 22 July 1944, when the Chief Signals Officer of Bomber Command recommended to the Air Staff that H2S, Monica and A.G.L.T. should not be switched on until the bomber force was within 40 miles of enemy territory.

On the night of 28/29 July 1944 the restriction on the use of H2S was ordered for the first time for an operation against Hamburg. Radar silence was to be observed up to 0600 degrees East, and the height at which the Channel was to be crossed was restricted to 4,000 feet. Unfortunately, some aircrews did not obey the order and the experiment was to all intents and purposes a failure. H2S silence was also ordered for operations against Stettin and Kiel on the night of 16/17 August 1944, until points 0500 degrees East on the route to Stettin, and 0400 degrees East on the route to Kiel, were reached. The indications were that no early appreciation was made of the intentions of the forces, and the reaction of German fighters was late, Bomber Command losses being comparatively low. Opposition to the restriction still remained.[1] As a result of the free circulation amongst crews of information from both British and American Intelligence sources on the use of *Naxos* as an H2S homer there was considerable uneasiness, and the Air Staff was warned by Bomber Command groups that confidence in H2S was being rapidly lost. As a result, on 13 October 1944, Headquarters Bomber Command sent to headquarters of groups a full and detailed appreciation of the situation, with instructions that all aircrews were to be acquainted with it.[2] It was pointed out that the liberation of France, Belgium and part of Holland had brought about a considerable change in the war situation with regard to the strategic bombing of Germany. The enemy had lost the use of the extensive and highly efficient radar network and G.C.I. organisation which had been set up in France and the Low Countries. The majority of night fighter squadrons had been withdrawn well into Germany, and the parts of the bomber force approach during which they could engage the bomber force were very restricted, since they were not allowed to fly over territory occupied by the Allies in case the equipments they carried were captured. The results were to be observed in the greatly reduced loss-rate of Bomber Command, and it would have been surprising if the enemy failed to take advantage of any method which held a promise of modifying the situation in his favour. The obvious thing to do was to make use of radar emissions from bomber aircraft. The ability of the Germans to take full advantage of H2S emissions for plotting at long range was obviated by relying for navigation on Gee, the cover of which was being extended by setting up stations on the Continent. It was still not known whether *Naxos* could be used for homing to individual aircraft, but there was evidence to indicate that it was not being done. The comparative casualty rate of aircraft fitted with H2S and those not fitted when attacking similar targets was being carefully watched, and on the whole the rate of loss of those fitted with H2S was slightly less than that of those not fitted. The use of H2S within the existing restrictions might be allowing a proportion of fighters to enter the bombing stream, but was by no means necessarily helping them to home to individual aircraft, whilst it was practically certain that the Germans possessed no means of homing to H2S Mark III. The extreme importance of every air crew implicitly obeying every instruction regarding radar silence was strongly emphasised.

Doubts about the wisdom of the attitude of Headquarters Bomber Command persisted, and it was agreed that Professor D. I. Dee of the T.R.E. should be permitted to make an independent investigation of the matter. His findings were a complete vindication of the policy adopted, and proved that much, if not all, of the criticism was based upon lack of knowledge of the subject.[3] In fact, it was the aircrew of *Gruppe II* who, in October 1944, began rapidly to lose confidence in the effectiveness of *Naxos*, for they were obtaining very few contacts and suspected the use of a new wavelength for, or the complete disuse of, H2S.[4] However, the degree of success achieved with radio silence was dependent on the standard of discipline amongst aircrew, and it became obvious that a proportion of aircrews in Bomber Command either failed to

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[1] A.H.B./IIE/76.

[2] *See* Royal Air Force Signals History, Volume VII: 'Radio Counter-Measures', Appendix No. 16, for copy of letter.

[3] A.H.B./IIE/76.

[4] A.H.B./IIG/29.

understand the importance of radio silence and other radio countermeasures, or were guilty of a criminal disregard for the needless danger to which they exposed not only their own but all the other aircraft participating in an operation. For instance, on the night of 30 November/1 December 1944 a force of 576 aircraft attacked Duisberg, and radio silence until 0530 degrees East was ordered, in addition to a height restriction of 6,000 feet until 0400 degrees East.[1] Whilst the main force was *en route*, a radio countermeasure force employed Window, Mandrel, Dinah, Drumstick, Jostle, Corona, Special Tinsel, and A.B.C.[2] If instructions had been obeyed, the enemy would have been denied all information of the intentions of the force until about half an hour before the attack was timed to begin. Actually, however, the enemy was heard passing bearings and plotting positions 66 minutes before the attack, when the main force was still over the English Channel. Strong indications that the early warning was obtained from H2S emissions were substantiated the following night by a test carried out by No. 100 Group, when aircraft used H2S for six minutes in the same area. The enemy was again heard to pass bearings and as soon as H2S was switched off the bearings ceased and the aircraft were reported as having disappeared. Further investigation revealed without doubt that some bomber aircraft had disregarded both the radio silence and height restriction orders, with the result that six fighter *Gruppen* were airborne or at readiness to meet the attack. Instances of similar disobedience were still being reported in March 1945, although repeated efforts were made to emphasise the fact that the use of H2S was dangerous only when aircraft were within the radio silence zone, since long-range plotting and not *Naxos* homing was considered to be the main threat. With the revival by the enemy of night intruder tactics over Bomber Command airfields, the use of H2S was not only restricted on outward flights but also during return flights before the end of the war.[3]

Removal of H2S Mark II from Main Force Aircraft of No. 5 Group

During the summer and autumn of 1944 No. 5 Group developed a marking technique in which the target was illuminated by flares dropped by pathfinder Lancasters, and the aiming point was marked by low-flying pathfinder Mosquitos, principally against undefended targets in France. In October 1944, when Headquarters Bomber Command made S.S. Loran an operational requirement for Mosquito and Lancaster aircraft not fitted with H2S but used for target-marking in Nos. 5 and 8 Groups, Headquarters No. 5 Group asked for an allocation of an additional 200 sets of equipment to enable aircraft used for main force bombing also to be equipped.[4] Authority was requested to limit the number of No. 5 Group squadrons equipped with H2S to five, in order to release sufficient radar mechanics to install and service Loran. Headquarters No. 5 Group considered that with the development of *Naxos* the operational value of H2S in main force squadrons had been greatly reduced, and probably did not justify the heavy commitment of servicing personnel, except for squadrons equipped with 3-centimetre H2S or engaged on minelaying

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[1] A.H.B./IIH/241/3/612—Bomber Command File TS.32130.

[2] *See* Royal Air Force Signals History, Volume VII : ' Radio Counter-Measures '.

[3] Between midnight and 0400 hours on the night of 3/4 March 1945 about 80 enemy aircraft intruded under cover of returning bomber aircraft and made a number of attacks.

[4] A.H.B./IIH/241/10/77. S.S. Loran Policy.

operations. Although the results achieved by No. 5 Group squadrons had been excellent, their bombing attacks had generally been made in reasonable weather conditions and H2S may not have been essential, especially since many of the targets were within Oboe range so that initial identification of the target area had been simplified.[1] Headquarters Bomber Command emphasised that H2S, in spite of the employment of *Naxos* by the enemy, was still of great operational value beyond Gee range, and would be of vital importance for accurate navigation and therefore effective bombing when attacks against long-range targets were again undertaken in adverse weather conditions during the winter months. There was no reliable evidence that the use of *Naxos* was in fact a serious menace. The loss-rate of aircraft fitted, and those not fitted, with H2S, showed no significant difference, and total losses over the past few months were only one-third of those sustained during the equivalent period in 1943. Although the Continental chains would extend the effective coverage of Gee, it was by no means improbable that the extent of such coverage would be considerably reduced by enemy jamming. Moreover, Loran was undoubtedly easy to jam and it was expected that, sooner or later, the advantages of the system might well be denied to bomber aircraft operating over Europe. H2S was the only effective navigation and blind bombing system covering all ranges to which the bomber force might be required to penetrate, and if thick cloud was unexpectedly encountered over the target area, H2S made an effective concentration of bombing possible when visual marking was ineffective. It was considered most important that the command should not be intimidated into imposing restrictions on the use of H2S beyond those designed to deny to the enemy early warning of the approach of a bomber force. Approval to the request to remove H2S from aircraft was therefore not given. The Ministry of Aircraft Production had embarked upon an enormous programme to equip all aircraft of Bomber Command with H2S at the expense of development and production of other aircraft radar systems. Its removal would adversely affect the standard of H2S training, which, should both the Gee and Loran systems be rendered ineffective by jamming, would seriously impair the efficiency of bombing operations. However, in order that early operational experience of the performance of the S.S. Loran chain might be obtained whilst production line installation was awaited, authority was granted for the installation of Loran instead of H2S in all No. 5 Group aircraft not already fitted with H2S, if the retrospective fitting programme could be carried out within the group. When, in March 1945, the use of H2S on homeward flights from bombing raids was restricted because of the risk of enemy intruder aircraft entering the bomber stream, Headquarters No. 5 Group ordered the removal of H2S Mark II from aircraft of all main force squadrons in the group.[2]

[1] A.H.B./II/69/215D.

[2] No. 5 Group File 5G/57/Air.

CHAPTER 4

H2S MARKS IV, VI AND VII

When more advanced development of H2S Mark III had been stopped in order that the special programme for installing it in six Lancasters, and the crash production programme, might be started, an approach to the achievement of more effective equipment using the wavelength of 3 centimetres had already been made. From the beginning H2S had always been developed on a crash programme basis, and in order to allow quantity production to be started as soon as possible, complexity of the equipment had been reduced to a minimum. In particular, the P.P.I. presentation arrangements were simple and straightforward. The various versions of H2S had used units which were basically of similar design, and when new ideas, and improvements of old ones, were introduced, they were developed along lines which enabled them to be readily fitted in with existing equipment.

Development of H2S Mark IV

H2S Mark IV was conceived as an entirely new version of H2S, and its design, except in relation to such standard components as modulator and power units, was not required to conform, either physically or electrically, to the technique used on the earlier systems. The operational requirements were of course fundamentally the same as before, navigation and blind bombing, but the emphasis was on the latter. It was intended that new ideas, which lack of sufficient time had prevented from being incorporated in earlier equipments, together with major improvements found desirable as a result of operational experience with the H2S Mark II series, should be introduced, and it was planned that the equipment should be suitable for large-scale production.[1] Two specific requirements were made however. Where standard units could be used, they were to be those developed for the T.R.E. universal units programme, and the equipment was to be linked with the Mark XIV bombsight with the object of presenting on the P.P.I. display all the information required for blind bombing.[2]

At the beginning of October 1943 the T.R.E. made known the main improvements to be expected with H2S Mark IV. They included not only roll stabilisation, but possibly also pitch stabilisation, which allowed for correction of the position of the scanner when an aircraft was diving or climbing, if it was required. Scan distortion correction was automatic with changes of aircraft height. Bomb-aiming would require no action by the bomb-aimer other than to place the normal settings on the bombsight, and setting of the range markers and the drift line were also automatic. The equipment included an electrical

[1] A.H.B./IIE/6/60.

[2] The Mark XIV bombsight was introduced into general operational use in Bomber Command during 1943 and by January 1944 the majority of heavy bombers were equipped with it. It incorporated a computor which was automatically self-adjusting for alterations in height, course and airspeed, but the bomb-aimer applied corrections for errors found in the forecast wind velocity, which was preset.

position indicator which enabled the bomb-aimer to stop the response given by a town ahead of the aircraft from travelling in towards the centre of the P.P.I. as range was closed. The centre of the P.P.I., representing the position of the aircraft, together with the drift line and predicted bombing marker, moved out across the P.P.I. to meet the stationary response. By this means the aiming point could, if the contrast and appearance of the town response at the bombing angle was unstable, be marked when the town was several miles distant, and then no further attention need be given to the response. Against large targets the aiming point could be marked when the whole town was visible on the 20-mile scan. The facility was achieved by changing the latitude and longitude on the air position indicator to electrical voltage, and, with a voltage representing the wind vector, the information was used to control the movement of the predicted bombing marker and drift line across the P.P.I. screen.[1]

Headquarters Bomber Command had stressed that an ability to bomb at all heights and in all weathers was essential for bomber aircraft and that, accordingly, a fundamental objection to the projected installation was that it was based upon employment of the Mark XIV bombsight, which already was considered to be an out-of-date device in view of the scientific knowledge gained since the sight was first designed, and which could not be operated with accuracy above 20,000 feet. The sighting line of the sight at 20,000 feet was accurate within 200 or 300 yards. It had not been designed for use above 20,000 feet, and because of the inadequacy of the height computing mechanism, the sighting error increased by 30 yards for every additional 1,000 feet above that height. The bombsight contained inherent disadvantages but was the most precise instrument available, and was more accurate than H2S itself. Development of a new bombing computor mechanism was envisaged, but a development period of at least two years was required. It was expected that H2S Mark IV could be made ready for production by the middle of 1944, and the Mark XIV would be the best bombsight available then.

In October 1943 the decision was therefore made to develop H2S Mark IV so that it could be used in conjunction with the Mark XIV bombsight, and the T.R.E. was asked to investigate the possibility of including other refinements. The Pathfinder Force had reported that during a recent operational flight wind data had been obtained near the target area by the use of H2S, and that its accuracy was about plus or minus 3 knots and 5 degrees, a higher standard of accuracy than had been achieved by any other means. Incorporation in H2S Mark IV of an automatic wind recording device was therefore required. Photography of targets from the air at night for purposes of verification involved using bomb flashes and clockwork fuses, and their employment was undesirable. A camera mounting, attached to the indicator unit in such a way that photographs of the P.P.I. display might be taken, was another requirement. The photographs would not only be useful for checking that bombs had been dropped on the right target, but would also be invaluable for briefing and target recognition purposes.

The first development model of H2S Mark IV was received for type approval in February 1944 from the Gramophone Company, and the T.R.E. began work on an experimental installation in a Lancaster I.[2] In July 1944 a series of

[1] A.H.B./IIE/6/60.

[2] A.H.B./IIE/6/60.

demonstrations and flight trials were conducted at the T.F.U. Defford, and Headquarters Bomber Command reported to the Air Ministry that the performance of H2S Mark IV was much superior to that of the Marks of H2S then in service. The contrast between open country, water, and built-up areas was very sharp, and the definition of built-up areas was a great improvement at both long and short ranges. Ranges of 30 miles, compared with 18 to 20, were obtained, scan distortion correction was effective and made ground ranges accurate, and full H2S coverage was available up to the bomb release point. The installation made available for the first time navigation and blind bombing facilities which gave greater scope for reference point bombing. They included automatic wind speed and direction finding, and a link with the Mark XIV bombsight computor enabled the relative movement of target responses and the aircraft to be reversed, making it possible to track the aircraft out to the target, thus permitting greater tactical freedom. Blind bombing could be accomplished more accurately because the range marker automatically changed size with variations of air speed and altitude. The positions of the aircraft and target responses could be moved to any position on the display, which enabled the aiming point to be selected and maintained before the responses broke up at very close ranges. This was facilitated by a cross marker at the centre of the P.P.I., under which the aiming point within a target area could be positioned ; when the target responses broke up, accurate bombing runs could be achieved by homing the aircraft to the cross marker. The controls were very much simplified, thus making operation of the equipment easier and reducing to some extent the need for long and intensive training.[1]

A crash programme for the production by the R.P.U. of 300 equipments, to be followed by an output of 50 per month, had been arranged, for installation in Lancaster III aircraft of the Pathfinder Force. During February 1944 the decision not to extend H2S Mark IIIA into quantity production had been confirmed and the policy of initiating a main production programme for H2S Mark IV during 1945 agreed, the actual dates being dependent on delivery from the U.S.A. of gyros and magnetrons.[2] It appeared that it would be a requirement for Lancaster IV aircraft, and that possibly two aircraft production lines, those of Metropolitan Vickers and Armstrong, would be changed over, leaving introduction on the lines at A.V. Roe until a later date. No final decision could be made, however, until the whole question had been examined in detail and production estimates were available.

Operational Requirement for H2S Mark IV

On 15 July 1944 the question of whether or not a requirement existed for the installation of H2S Mark IV in aircraft of the main force was considered at Headquarters Bomber Command. The crash programme for the Pathfinder Force had been agreed, but it had been suggested that when the replacement of H2S Mark IIC by H2S Mark IIIA in aircraft of the main force was completed, an installation programme of H2S Mark VII should be initiated. It was most likely that H2S Mark VII, also known as ' Liontamer ', would be even more efficient than H2S Mark IV, but the equipment was still very much an unknown quantity, whilst H2S Mark IV had reached the type approval stage of development, and its capabilities were known. It was doubtful whether H2S Mark VII

[1] A.M. File CS.22828.

[2] Bomber Command O.R.B., July 1944.

could be made available for some considerable time, and it was not improbable that H2S Mark IV could be introduced into the main force at least one year earlier.[1] The Commander-in-Chief, Bomber Command considered that, whilst further development of H2S to obtain even greater improvement was very important, such development should not be allowed to interfere with an early and rapid introduction of H2S Mark IV, which on 20 July 1944 was made an urgent operational requirement for all heavy bomber aircraft.[1] He requested that action be taken on the highest priority to provision for its installation in all heavy bombers of the Pathfinder Force on a crash programme basis following the introduction of H2S Mark IIIA, and in all heavy bombers of the main force on the aircraft production lines, also after the introduction of H2S Mark IIIA. The possibility of installing H2S Mark IV in Mosquito aircraft was to be considered later.

The implications of the request for a main force installation programme were extensive, and had to be considered in relation to their effect on current H2S programmes and on the development and production projects of K-band, or 1½-centimetre, equipment. It was necessary to estimate as accurately as possible the date on which full-scale production could be started, the availability of test gear, and the dates on which installation on aircraft production lines could begin. In addition, a requirement for altering the layout of the navigator station in conjunction with the introduction of H2S Mark IV had been raised, and needed close study. The T.R.E. felt that, as H2S Mark IV had received type approval, the installation programme would not substantially affect other H2S development work, but would have an adverse effect psychologically on the development of H2S Mark VII, which the T.R.E. considered should be the next Mark of H2S to be fitted in heavy bombers. If arrangements were made to change over aircraft production lines as soon as possible, it would be at the direct expense of the H2S Mark IIIA programme and would probably also affect the start of H2S Mark IIC fitting. The production of one set of H2S Mark IV equipment required 40 per cent more man-hours than the production of one set of H2S Mark IIC or IIIA. To maintain the output of H2S equipment at the current rate would mean taking over additional production resources then engaged on meeting the demand for other urgently required airborne radar equipments. However, if an official requirement for the introduction of H2S Mark IV was raised immediately and given overriding priority, it was possible that fitting in Lancasters might be started in September 1945.[2] The desirability of the alterations to aircraft layout proposed by Headquarters Bomber Command was agreed, but their adoption in conjunction with the introduction of H2S Mark IV would involve abandoning the H2S Mark IIIA programme for the main force and noticeably delaying the introduction of H2S Mark IIC. The T.R.E. intended to have an H2S Mark VII installation ready for demonstration by the middle of October 1944 and anticipated that it would be ready for type approval by July 1945. If those plans were fulfilled, the production of equipment and installation on the aircraft production lines could probably be started in April 1946. All the other necessary improvements could be incorporated in aircraft, and the H2S Marks IIC and IIIA programmes would not be adversely affected. At a meeting held at the Air Ministry on 9 August 1944 it was therefore decided that for the time being the H2S Mark IIC and IIIA programmes

[1] A.M. File CS.22828.

[2] A.M. File CS.22828.

should proceed as planned, and that the need for a changeover to H2S Mark IV or H2S Mark VII should be referred as a matter of urgency to the Air Staff for an immediate decision. The radar requirements for operations in the Far East, the question of a nose or ventral installation, and the incorporation of improvements in the layout of the aircraft all required very careful consideration.

At about the same time Headquarters Bomber Command urgently requested approval of the H2S Mark IV project in order that programmes for air and ground crew training might be planned, and formulated requirements for modifications to be made based on experience gained during flight trials conducted at Defford with the T.R.E. experimental installation in a Lancaster I. With the existing arrangement for automatic wind velocity finding, the speed and direction were given in terms of rectangular or cartesian co-ordinates. The task of the bomb-aimer was thus made more complicated, and a modification to enable the wind velocity to be given in polar co-ordinates was required, together with a remote control for feeding wind velocity information to the Mark XIV bombsight computor. The maximum time that could be used with the set as designed for finding the velocity was 5 minutes, and it was considered that at least 10, and possibly 15 minutes, were required, and an extension of the time period was an urgent need. Arrangements for the provision of a suitable camera mounting which could easily be swung away from the front of the P.P.I. screen when it was not in use were also asked for because P.P.I. photography was becoming an essential feature of H2S operations. The type of shift controls used caused the display to move across the screen in small jumps, and the headquarters recommended that the method should be changed so that the movement was smooth and continuous. The bomber force was being increasingly employed on daylight operations, when observation of the P.P.I. was difficult and the provision of a visor essential. A positive form of identification of the track and heading markers, so that they were easily distinguishable, was required, and modification to enable responder beacons of the B.G.X. type to be used with H2S Mark IV was regarded as essential. When the installation had been demonstrated, and for flight trials, a Type 71 scanner was used, although the equipment had been designed to work with a Type 69 scanner. The latter had many advantages. It incorporated automatic tilt which enabled it to be used in three positions at the will of the bomb-aimer. The upward tilt was designed for use at low altitudes so that maximum range could be obtained at 10,000 feet. The medium tilt was approximately the same as that of the Type 71, and was suitable for operational heights of about 20,000 feet, whilst the lowest tilt position was designed to enable the most sensitive part of the beam to be concentrated on the target during the bombing approach in order that maximum definition might be obtained. The scanner included facilities which allowed the heading marker to be adjusted and set up for accurate wind velocity finding. The Commander-in-Chief considered that the very considerable improvements provided by the Type 69 scanner made it an essential requirement for H2S Mark IV and requested confirmation that it would be introduced at the same time. He emphasised that although the recommended modifications were considered to be essential, they were not to be incorporated at the expense of an early and rapid introduction of the H2S Mark IV system.[1] After the failure of the experimental

[1] A.M. File CS.22828.

blind bombing raid in August 1944 he again stressed that the aim should be to equip every bomber aircraft with H2S of sufficient accuracy and ease of interpretation to make entirely blind bombing a practicable proposition, and called for the acceleration of the H2S Mark IIC and H2S Mark IIIA programme in addition to an early introduction of H2S Mark IV.[1]

In September 1944 the Air Ministry informed Headquarters Bomber Command that no aircraft production line fitting of H2S Mark IV could begin before 1946, and that no Mark of H2S other than IIB or IIC was likely to be installed in main force aircraft before the end of the war in Europe.[2] The future policy for fitting H2S in main force aircraft was therefore to be determined by the requirements for operations in the Far East. For operations over Europe it had been possible to introduce H2S and improvements of it into Bomber Command by means of crash programmes and retrospective fitting programmes. That would not be possible in the Far East. Assuming that a bomber force of 40 squadrons would be sent, it was essential that the force should be equipped with H2S which was an aircraft production line installation of a type for which adequate spares, test gear and 'pipe-line' reserves were available, and which was standard throughout the force. Those conditions could only be met by adherence to the current policy of installing H2S Mark IIC on the production lines between September 1944 and March 1945, and H2S Mark IIIA after March 1945. The size and organisation of the Pathfinder Force for the Far East had not been decided, but it might prove to be possible to equip four squadrons with H2S Mark IV if the difficulties of maintenance could be overcome. However, until more was known of the plans for the Pathfinder Force no details could be determined; it was, for instance, essential to know whether there would be one self-contained force or whether pathfinder aircraft would be included in each bomber squadron. On 25 September 1944 Headquarters Bomber Command agreed that the proposed policy was the only satisfactory one to meet the requirements of the command in the existing circumstances. It was, however, considered possible that the war in the Pacific might last long enough to make a changeover to H2S Mark IV worth while at a later stage, since '. . . it would be indefensible to use obsolete equipment if we could, in fact, replace it during the course of the war with the most up-to-date device . . .'[3] A strong recommendation was therefore made that consideration should be given to the possibility of substituting H2S Mark IV for existing Marks of H2S in replacement aircraft for the Far East, as and when production conditions permitted, and that as the installation would in any event be a requirement in peacetime, tooling for production in quantity should be arranged immediately. However, it was not by any means certain that H2S Mark IV would be a peacetime requirement. The equipment was linked with the Mark XIV bombsight, which was already obsolescent, and H2S development was very closely bound with the development of new navigation and armament devices. By the time that an installation programme could be started H2S Marks VI and VII would be available and might be considered preferable; it was evident that main production could not begin before March 1945, and it was expected that practical comparisons with Marks VI and VII could be made about June 1945. If a decision were postponed until then, and if H2S Mark IV were selected as a result, production and installation

[1] A.M. File C.28978/46. [2] A.M. File CS.22828. [3] A.M. File CS.22828.

could probably be started about September 1946. On the other hand, whilst it was possible that the advantages of H2S Mark VI or Mark VII might prove to be so great that an urgent requirement for main production and fitting programmes would be raised immediately, there were indications that considerable development work might still be necessary, especially in order to prevent serious interference by cloud formation, which would delay quantity production for some time. Therefore, although it was not possible to state a firm requirement for production of H2S Mark IV in quantity, it was decided in October 1944 that the Gramophone Company should begin the 'tooling-up' processes.[1]

Trial Installation of H2S Mark IV

In September 1944 the Commander-in-Chief, Bomber Command expressed his dissatisfaction with the rate of progress being made with the provision of H2S for the Pathfinder Force. '. . . The problem appears to be a lack of priority . . . it is apparent that the priority for radar research and development is totally inadequate . . . while it is quite probable that labour has not been diverted from the radio industry, it is obvious that sufficient increases in labour for that industry have not been made to meet its vastly increased commitments. I would suggest that this is a gross oversight when we know full well that radar is an essential to every operation of war . . .'[2] However, the Air Staff felt that delivery from a crash programme by February 1945 would be very commendable in view of the many difficulties associated with production of new equipment, and stated that '. . . no priority question is being allowed to interfere with meeting H2S requirements which have had priority over all other urgently needed equipment . . .' By the end of the month the development stages of the various components of H2S Mark IV had been completed, and the first production drawings of scanner Type 69 were expected to be ready in November 1944. The equipment did not incorporate interrogator facilities for centimetric wavelength beacons, and arrangements were made for Rebecca Mark II to be used until Rebecca Mark VI was introduced.[3] As a Lancaster IV was not yet available, a trial installation was to be made in a Lincoln as quickly as possible, and later, in a Lancaster I or III if it was found that Lincolns would not be delivered from the aircraft factories and accepted by the Service in time for employment in the Pathfinder Force. One month later the possibility of being able to begin equipping the Pathfinder Force in February 1945 had disappeared. Because of the uncertainty regarding the date of acceptance by the Royal Air Force of Lincoln aircraft, a decision on the re-arming of pathfinder squadrons with them was not possible, and an aircraft could not be obtained for a trial installation. The firm of Nash & Thompson, who had been given a development contract for three models of scanner Type 69, envisaged that detailed drawings would be ready at the end of December 1944 for use by the firm of Reynolds, who in September accepted a contract to make 50 scanners on a crash programme to be followed by quantity production.[4] The production of equipment on the crash programme was unlikely to begin at the R.P.U. before the end of March 1945, the limiting factors being a heavy load on the drawing offices and

[1] A.M. File CS.22828.
[2] A.H.B./ID4/175A.
[3] A.H.B./IIE/15. H2S Meetings and Notes.
[4] A.M. File CS.23241.

a shortage of tool makers, and it was evident that scanners and stabilising platforms were unlikely to be available before May 1945. The introduction of the *Schnorchel* device in U-boats had made the need for improvement in A.S.V. very urgent, and required an increase in research, development and production resources. It became necessary to consider once more the relative priorities for aircraft of Bomber and Coastal Commands, and to determine if the requirements of the anti-U-boat campaign at sea would have serious repercussions on the H2S programmes. It was established that there was no justification for any relaxation in the development of H2S and A.G.L.T. whilst the needs of Coastal Command were being met.[1]

The first prototype scanner Type 69 was delivered to the T.R.E. in January 1945 for type approval, but did not pass the tests. Modifications were required, and in March 1945 it was expected that approval would be given to the scanner by the middle of the following month. Meanwhile six scanners Type 71 were being modified for use with H2S Mark IV. Although they would not incorporate all the refinements of Type 69, they would at least enable flight trials to be conducted when the equipment was ready. By the middle of May 1945 the firm of Nash & Thompson had not been able to supply a satisfactory scanner, and it seemed that it would be necessary to rely on scanners produced on the Reynolds crash programme, with the T.R.E. ensuring that the necessary modifications were included for the Pathfinder Force aircraft. The scanners were fundamentally the same as the development models made by Nash & Thompson, and it was anticipated that ten could be made available in May and 40 in June. Bulk production was expected to begin in October 1945. A trial installation in a Lincoln, which had been allocated to the T.R.E. late in March, had recently been cleared, and a Lancaster trial installation had been completed in No. 8 Group.[2] The Special Installation Unit at Defford had begun installing H2S Mark IV in six Lincolns, and Service trials were to be undertaken at the B.D.U. as soon as the aircraft were accepted by the Service. The supply of H2S Mark IV units from the R.P.U. crash programme varied; 400 transmitters and 50 receivers had been manufactured, but difficulties were being experienced in the production of indicators Type 187, and none were completed. Development contracts had been placed for units peculiar to H2S Mark IVA, which combined the advantages of H2S Marks IIIF and IV, the main differences between it and the latter being the magnetic indicator, wire-wound potentiometers in place of the stud type to improve the movement of the P.P.I. display, and the introduction of a six-foot scanner. The T.R.E. trial installation Lincoln was sent to the B.D.U. for trials in May. Immediately after arrival it was grounded whilst the propellers were changed, and then for engine-bearing modifications.[3] It had not been flown when in July 1945 the Air Staff raised a requirement for H2S Mark IVA to be installed in Lincolns on the aircraft production lines from March 1946 onwards, and it was not until October 1945 that Service trials could be started.

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[1] *See* Royal Air Force Signals History, Volume VI: 'Radio in Maritime Warfare'.

[2] In March the radar layout for the Lincoln was changed from one which enabled H2S to be operated by the bomb-aimer, wireless operator, or navigator, as required, into a single radar station consisting of one crate on its own independent anti-vibration mountings, in which could be installed the H2S, Gee, Loran, and Rebecca indicators, together with control panels. The radar station was located between the back of the pilot's seat and the navigator's table. (A.M. File CS.23241.)

[3] A.H.B./II/69/215D.

When, in July 1944, H2S Mark IV had been made an operational requirement for heavy bomber aircraft, it was decided not to ask for a trial installation in Mosquito aircraft until the effectiveness of H2S Marks II and III in the smaller aircraft had been proved on operations. In December 1944, in view of the success of Mosquito operations and of the proposed expansion of the Mosquito night bombing force, Headquarters Bomber Command requested that a trial installation in a Mosquito XVI be undertaken without delay, and that consideration be given to equipping at least one squadron if the installation was successful.[1] The equipping of a second squadron with H2S Mark II had recently been requested, trial installations of H2S Mark III with both nose and ventral scanners had been completed, and an experimental installation of H2S Mark VI was in progress. The Air Ministry pointed out that the rate of production of H2S Mark IV was not likely to be high, and that therefore its installation in Mosquito aircraft might only be possible at the expense of Lincoln aircraft, and requested that, in order that provisioning might be straightened out, the H2S requirements be restated. Information was required on the extent to which the H2S Mark II installation programme was to be continued, whether the nose or ventral installation of H2S Mark III was preferred and to what extent it was to be installed, whether there was a need for linking H2S Mark IV with the bombing computor, and to what extent the projected H2S Mark IV installation programme was regarded as a replacement of previous programmes. The situation was clarified when Headquarters Bomber Command explained that H2S was required for two squadrons. H2S Mark II was to be provided until it could be replaced by H2S Mark III with nose scanning. H2S Mark IV, with ventral scanning, was eventually to be substituted for H2S Mark III in the two squadrons, and its linking with the computor of the Mark XIVA bombsight was considered to be essential. However, complication was added by a proviso that, as a result of trials made with the ventral installation of H2S Mark III, it was considered necessary for H2S Mark IV that cockpit layout should be redesigned to facilitate operation of the H2S controls, that the distant reading compass should be repositioned in order that interference from the H2S transmitter might be avoided, and that a new location for a vertical night camera should be planned.[2]

Arrangements for a trial installation were initiated in January 1945, but the problems set by the limited space and the variety of equipment to be carried required careful study, and work could not in any event be started until H2S Mark IV was available and the Lincoln installation had been completed. Suitable locations had to be found for Gee, tunable S.B.A. receiver, V.H.F. radio (TR.1430), separate intercommunication amplifier, I.F.F. Mark III, Mark XIVA bombsight computor, distant-reading compass, F.24 camera, P.P.I. camera stowage and mounting, A.P.I./A.M.U., Monica Mark VII, and a six-way bomb distributor, in addition to H2S.[3] The size of bomb doors had also to be decided, but the T.R.E. anticipated that adequate ranges would be obtained if large doors were fitted ; if flight trials proved otherwise it would be possible to substitute small doors without complication. The layout of the H2S Mark III installation had been strongly criticised because the location of the indicator and control unit made it necessary for the navigator to spend most of his time on his knees. It was very desirable that the units should both be easily accessible and at eye level so that strain and parallax were

[1] A.M. File CS.22828. [2] A.M. File CS.22828. [3] A.M. File CS.24230.

avoided. The T.R.E. suggested that one way of overcoming the difficulty was to arrange the layout so that the navigator faced aft, and Headquarters No. 8 (P.F.F.) Group agreed that there was no apparent reason why such an arrangement should not be successful. The ventral scanner would occupy the normal camera position, so that it was necessary to find a suitable location for the F.24 camera, and it was thought that the position used in aircraft employed on photographic reconnaissance might be adopted. However, in April 1945, the Air Officer Commanding, No. 8 (P.F.F.) Group learnt that the effect of a ventral scanner blister on the speed of a Mosquito was more serious than had been envisaged. The reputation of the aircraft had been built up mainly on its performance and anything which reduced that performance could only be countenanced if very definite advantages were to be obtained in return. He considered that adequate H2S range and scanning up to 140 degrees on either side of dead ahead could be obtained if the scanner were fitted in a perspex nose and located further forward than was done with the H2S Mark III nose installation. A similar installation had been carried out by the De Havilland Aircraft Company for the U.S.A.A.F., and the T.R.E. confirmed that a nose fairing of better aerodynamic shape could be designed and fitted in the same way. The requirement was therefore changed on 1 May 1945 from a ventral to a nose installation, and work on a mock-up layout was begun on the highest priority. In June the trial installation was placed on very low priority, and on 24 August 1945 was cancelled.

Modification of H2S for Tactical Reconnaissance

The possibility that employment of suitably modified radio sono-buoys might be a means of enabling tactical reconnaissance to be made effective at night and in poor visibility was investigated in October 1943.[1] Although the technical difficulties did not appear to be insuperable, it was considered that the development programme involved in making such a system practicable would be too extensive, and it was by no means certain that the outcome would be successful. Early in 1944 therefore the Chief Signals Officer of No. 2 Group, which provided tactical air support for land forces, asked the T.R.E. to examine ways and means of using airborne radar for determining the density of traffic on roads over a fairly wide area. He visualised the use of an H2S system with a high degree of definition, which would enable roads to be observed during the hours of darkness, and which would enable the amount of traffic using them to be resolved.[2] Such a system was not, however, within immediate reach, although current experiments with K-band, or 1¼-centimetre equipment, indicated that one might be developed at some future date. The T.R.E. therefore considered other means of meeting the immediate requirement, and by May 1944 had made progress with the development of H2D. It consisted essentially of an H2S Mark II installation in which the scanner was locked in the dead-ahead position, and ground returns were displayed on a Fishpond indicator unit using a linear time-base. Experimental flights proved that the presence of traffic moving along roads could be detected by a characteristic 'beating' response on the time-base. The beating effect was present because the frequency of the pulse reflected from the road itself differed slightly from the frequency of the pulse reflected from a vehicle moving on the surface of the

[1] A.M. File CS.23248. *See* Royal Air Force Signals History, Volume VI: 'Radio in Maritime Warfare', for details of radio sono-buoys.

[2] A.H.B./ID/12/204. H2D.

road. The area kept under observation was triangular in shape, approximately four miles long and one mile wide at the base. There were a number of limitations. Since the maximum beam width was about one mile, the aircraft had to be flown not less than half a mile to one side or the other of the road being patrolled. Interpretation of the beating signals was difficult and required a great deal of skill. Two or three cars travelling at high speed gave a response similar to that obtained from a slow-moving convoy tightly packed over the same distance. It was necessary for the aircraft to be flown straight and level, as during a turn ground returns were modulated in the manner characteristic of the indications given by moving traffic. Therefore, even if the H2D responses could, after some experience had been gained, be correctly interpreted, and the number of vehicles moving along a road correctly assessed, there still remained the difficulty of flying an aircraft by night or in very poor visibility with such accuracy that it was never more than half a mile from the road.

Two problems had to be solved before the operational employment of H2D could be contemplated; that of the correct interpretation of responses, and that of very accurate navigation. Short-term development was completed at the T.R.E., and arrangements were made to install H2D in three Wellington XIV aircraft, in May 1944, when the best way of using the aircraft to find a solution to the problems had to be decided. In view of the forthcoming operations in Normandy it was not practicable to allot the task to operational squadrons and, in any event, it was improbable that such squadrons were manned with aircrews sufficiently skilled and experienced to make a rapid and true assessment of the potentialities and limitations of H2D. It was therefore agreed that initial trials should be undertaken by the Fighter Interception Unit and, if necessary, subsequent operational trials by the School of Army Co-operation. Higher priority was given to the H2D trials before the end of June 1944 when, because the Allied air forces had gained complete air superiority, the enemy was forced to restrict the movement of troop-carrying and armoured vehicles to the hours of darkness and to periods of poor visibility; an aircraft radar system for night reconnaissance became an urgent operational requirement.

In order that an assessment might quickly be made of the possibilities of H2D, the F.I.U. concentrated on tests of performance, accuracy, and ease of operation, and an appreciation of the training commitment involved, rather than on an investigation of the tactics involved and the navigation problem. Flights were made in daylight along selected stretches of fairly straight road, and it soon became apparent that it was necessary to keep the aircraft, by means of visual observation, within 300 yards of the road. In those circumstances an H2D operator was able to detect movement of single vehicles with an accuracy rated at about 60 per cent, but was unable to distinguish between single vehicles and groups of vehicles. It was obvious that the results to be expected in operational conditions, at night, would be very much inferior. H2D could not be greatly improved technically, and was of no value in its existing form. In July 1944 the project was therefore dropped, but the importance of the operational requirement was again emphasised. The T.R.E. proposed that it might be met with modified H2S Mark III used in conjunction with a six-foot scanner, and recommended that a Lancaster equipped with H2S Mark III should be sent to Defford in order that experiments might be started.

The Air Ministry was not immediately convinced, however, in view of the disappointing results achieved with H2D, and required more information of the probable operational limitations and of the date by which operational trials were likely to be completed. In addition, the wisdom of using a Lancaster for the purpose was questioned. It was assumed that the reconnaissance aircraft would be required to fly at low altitudes over the battle area, and a Mosquito appeared to be more suitable. The T.R.E. thought it most unlikely that the modification of H2S Mark III, to be known as H2D Mark II, could be installed in a Mosquito, and because of the urgency of the need to provide a solution to the problem of the Tactical Air Force, a Lancaster fitted with H2S Mark III was transferred from the Pathfinder Force to Defford for experimental work in August 1944. At the same time Headquarters Allied Expeditionary Air Force asked the U.S.A.A.F. to undertake immediately trials in the U.S.A. with the Magnetic Anomaly Detector and Eagle.[1] The employment of magnetic detection devices held several disadvantages. The limitations of range necessitated flying at a very low operational height, detection covered a narrow area only, responses were not associated with geographical position, the lack of range and indication of bearing made location of a detected target very indefinite, and responses from magnetic disturbances such as power cables and railways were likely to be the same as those from vehicles. Information about the technical performance of Eagle was promising, and the operational requirement had become so urgent and so vital that H.Q. A.E.A.F. urged that adaptation of Eagle and development of a suitable British installation should be undertaken concurrently on very high priority. Production was not a major factor because only a small number of suitable installations would be required.

The airframe alterations required for an Eagle installation were considerable and complicated. The aerofoil had to be fitted to the fuselage in such a way that structural and aerodynamic requirements were met, whilst ground clearance, the area of fire of aircraft armament, and other facilities, were not adversely affected, and pressurising and de-icing connections were required in addition to electrical connections. It was unlikely that the U.S.A. War Department would undertake the engineering commitment on aircraft built in the United Kingdom, so in February 1944 the British Air Commission had arranged for a trial installation to be made in one of the Liberators allocated to the R.A.F.[2] In August 1944 it was expected that the trial installation would be started during the following month, when two U.S.A.A.F. Fortresses equipped with Eagle were to be sent to the United Kingdom for H2S trials.[3]

The first Fortress arrived in the United Kingdom in October 1944. Trials with Eagle for the detection of armoured fighting vehicles had already been conducted, with disappointing results, in the U.S.A., but as the T.R.E. was meeting with but little success in experiments with H2D Mark II, arrangements were made for further Eagle trials to be undertaken in the United Kingdom. However, technical difficulties were experienced with the installation, which

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[1] A.M. File CS.23248. *See* Royal Air Force Signals History, Volume VI : 'Radio in Maritime Warfare', for details of M.A.D. Eagle, or AN/APQ.7, was an airborne radar equipment designed to be used in an H2S role at high altitudes. It worked in conjunction with a large aerial system, enclosed in a special aerofoil located on the underneath of the fuselage, which scanned with a very high degree of definition a section of 60 degrees ahead of the aircraft.

[2] *See also* Royal Air Force Signals History, Volume VI : 'Radio in Maritime Warfare'.

[3] A.M. File CS.23264.

was still not working satisfactorily late in November 1944, when the Fortress was urgently required for trials of Eagle in the role of H2S for which it was designed and intended. The tactical reconnaissance trials had therefore to be postponed indefinitely until such time as the Liberator fitted with Eagle became available. Meanwhile, although the operational requirement still existed, the course of land warfare in France had considerably reduced its immediate urgency, and the T.R.E. reported that very promising results had been obtained from experiments with K-band equipment.

Development of H2S Marks VI and VII

Experiments with K-band equipment were begun at the T.R.E. in 1943. Research and development were guided by the aim to evolve an installation which would markedly increase the accuracy of bombing and navigation and reduce considerably demands on the skill and attention of H2S operators. An important principle underlying the design was that the accuracy attainable would ensure that, even if all lattice and beacon navigation systems were unusable, an economical bombing policy could be pursued. For that purpose, navigation had to be accurate enough to enable the tactics of extreme concentration to be maintained. For the necessary high standard of bombing accuracy, a reference point facility was to be provided so that an identifiable response, in the neighbourhood of and at a known distance from the selected target, could be used to define the release point with precision. At the same time a generous latitude for change of airspeed during weaving, climbing and diving, and of direction of approach, was to be permitted to the pilot. The three main parts of the H2S function, an accurate and detailed display of responses, navigation computing, and bombing computing, were to have a unified design so that all data could be readily and automatically interchangeable. H2S Mark IV contained the disadvantage of being designed to fit in with navigation and bombing equipments which were already in existence and were not themselves designed to link up with H2S. The new navigation computors and bombsights were being designed to fit in with each other and with new H2S developments, the first of which was known as Liontamer until eventually it was given the nomenclature H2S Mark VII.

In order that operational experience of K-band equipment might be obtained as quickly as possible, and because it was considered that in many circumstances a considerable improvement in bombing accuracy could be achieved with the existing computing devices if a higher degree of definition could be obtained on the P.P.I., an experimental and interim installation known as H2S Mark VI, in which the computing and bomb-aiming arrangements were much the same as in H2S Mark IIIA, was developed. In order to minimise the time taken for development and production, as much use as possible was made of components, such as modulators, power units, control and switch units, which had already been put into production for earlier Marks of H2S. Little or no work had been done in the United Kingdom on the design of a K-band R.F. head because research resources were sufficient only to deal with a certain number of projects at one time, and it was realised that in consequence any short-term British K-band project would be entirely dependent on the supply from the U.S.A. of sufficient heads. The R.F. head contained the transmitter and its modulation transformer, T.R. and anti-T.R. cells, crystal mixers, local oscillator and A.F.C. circuits and their power supplies, all the I.F. amplification stages, one video stage and a cathode follower output. The whole unit was pressurised for operating at high altitudes with provision for maintaining the pressure by means of a barometrically controlled electric pump.[1] As the degree of definition was increased it was essential that its value should not be impaired in the method of presentation, and a new display system was therefore designed, whilst a three-foot scanner with a beam width of 0·75 degrees, based on Types 63 and 71 and including several refinements, was developed. Concurrently, to meet a Pathfinder Force requirement for an increase in the degree of definition obtained with H2S Mark III, a six-foot aerial system known as Whirligig was being developed.

Progress made with K-band development was reviewed on 22 February 1944.[2] The T.R.E. reported that it had been possible to achieve an increase in the sensitivity of the equipment during the previous three months and thought that ranges up to 20 miles would be obtainable, although no firm promise could be made. The stage of development already reached made a crash programme practicable, since the British Air Commission had been able to obtain an allocation of 60 R.F. heads, the first of which were due to leave the Radiation Laboratories on 25 February 1944 and most of which would, it was thought, be delivered by late autumn. It was considered that if the early models proved to be up to expectations it would be possible to obtain further deliveries if more were required. That the incorporation of Whirligig would improve the performance of 3-centimetre equipment was not doubted, but if it were required to form part of the H2S Mark VI installation the extra research work involved was likely to create a conflict of priorities at the T.R.E., as the group already working on the three-foot K-band scanner would have to handle it. The stabilisation and simultaneous rotation of Whirligig involved difficult problems, as extreme accuracy, both electrically and mechanically, was required, and complete and satisfactory overcoming of difficulties might take six months. The aircraft manufacturers were unable to gauge the effect of Whirligig on the aircraft performance of Lancasters without wind tunnel tests, which might take as much as six weeks. Two schemes were being considered; in one the aerial would rotate in a cupola and in the other it would be located outside the fuselage. In order that priorities might be allotted the potential value of K-band equipment and Whirligig were investigated. No comparison of performance could be made although it appeared that H2S Mark VI would give approximately half the range obtainable with 3-centimetre equipment and Whirligig. The Air Officer Commanding, Pathfinder Force, considered range to be very important particularly when heavily-defended areas had to be avoided. The range limitation of the K-band technique was salient, and it was thought that eventually a hybrid system of X and K-band might be necessary, but it was decided that the continuance of K-band development was essential in order that more information of its potentialities might be gained. Work on both H2S Mark VI and Whirligig was to be undertaken on equal priorities, with the proviso that if the T.R.E. met with any great difficulty in consequence, the matter would again be reviewed. Provisional arrangements were immediately put in hand for a crash programme of H2S Mark VI installations in Lancaster aircraft to be completed during 1944.[3]

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[1] A.H.B./II/69/215D. [2] A.M. File CS.15536. [3] A.M. File CS.15536

Trial Installations of H2S Mark VI

In March 1944 the allocation of R.F. heads was increased, and provisioning action was taken for a crash programme of 100 complete sets of H2S Mark VI. By June 1944 preliminary flight trials had been undertaken. The best performance was achieved at a height of 10,000 feet with a maximum range of 10 miles, and it was estimated that the elimination of known faults after further development during the next few months would probably enable ranges of 20 miles to be obtained at 20,000 feet. There were still many problems to be solved, and the equipment was not really out of the research stage. Estimates of the ranges likely to be obtained during the next six months could not therefore be made with any certainty. The crash programme was more or less an expression of faith in the eventual value of the K-band technique and had already stimulated additional research in the U.S.A. ; it was important, however, that hopes were not pitched too high. There was a likelihood, which had to be faced, that scatter would occur in thunderclouds, and that would have the effect of noticeably reducing range, although no evidence had yet been found to indicate that undue difficulty would be experienced with ordinary cloud formation in temperate zones. Ranges were, however, likely to be inadequate until many improvements had been incorporated in the R.F. head. Meanwhile, it had become doubtful whether the U.S.A.A.F. would employ K-band H2S in the European theatre of war, and the R.F. heads being manufactured by the American firm, Sylvania, had only a British application. It was essential therefore to maintain American interest in the project and T.R.E. scientists were attached to the responsible laboratories. It was not practicable to contemplate design, development and production in the United Kingdom of an R.F. head. In any event American valves would have to be used, and past experience had shown that it was easier to obtain equipments containing valves from the U.S.A. than the valves alone. The requisition order was increased to 500 heads, 200 from the Sylvania company, and 300 of a more advanced design from the firm of Philco.

Flight trials with a three-foot scanner were continued, and during August 1944 it was agreed that the output of the crash programme should be installed in Lancaster IV aircraft equipped with A.G.L.T. and Monica or Fishpond.[1] Trial installations in a Lancaster III to be followed by a Lancaster IV were ordered, and it was hoped to have one P.F.F. squadron equipped by the end of the year. At the end of September 1944 the T.R.E. experimental installation was used to give demonstrations to representatives of Headquarters Bomber Command and to the Air Officer Commanding, Pathfinder Force.[2] The Commander-in-Chief, Bomber Command thought that the installation already showed promise of becoming sufficiently effective to warrant serious consideration of its introduction into the Service on a limited scale, and stated a formal requirement on 5 October 1944 for a crash programme for the Pathfinder Force. To meet the requirements of a heavy bomber installation it was essential that ranges of at least 20 miles at 20,000 feet could be obtained, but during flight trials the effects of cloud absorption had been indicated. Responses faded when flights were made in the vicinity of ten-tenths cloud and reappeared when near gaps. It was apparent that cloud conditions might seriously affect the effective use of H2S Mark VI, and further investigation on the highest priority was requested. Mosquito aircraft were being used for low-level target marking and it was suggested that H2S Mark VI might have great value in that role

[1] A.H.B./IIE/15.

[2] A.H.B./II/69/215C.

when cloud reduced its effectiveness at normal operational heights if ranges of 15 miles at 2,000 feet could be achieved.[1] A trial installation in a Mosquito was therefore made an immediate requirement, and, in addition to the Lancaster squadron, six Mosquito aircraft were to be equipped; if possible, three or four were to be made available in December 1944. Although three-foot scanners would be acceptable with the early installations, development of a suitable six-foot scanner was given the highest priority.

It was expected that, subject to the satisfactory production of scanner units, six Mosquito installations would be completed by the end of January 1945, but it had first to be decided which of the various types of Mosquito was to be used.[2] Headquarters Bomber Command wanted the installation to be made in a Mosquito B Mark XX, but investigation revealed that it was not possible because of its effect on the centre of gravity of the aircraft. H2S Mark VI could be installed in a Mosquito XVI, but only if certain restrictions were accepted. 4,000-pound bomb doors could not be fitted, or, if already fitted, would have to be removed, because otherwise the forward H2S coverage would be very adversely affected. To help correct the centre of gravity the H2S installation would have to be installed in the nose compartment, which would thus be denied to the bomb-aimer. If B.A.B.S. and beacon facilities were required, a Rebecca interrogator would be necessary, and that could only be provided at the expense of the API/AMU. Headquarters Bomber Command confirmed in October that the change of aircraft type and the restrictions were acceptable. During the following month, at the request of the command, the aircraft requirement was changed from Mosquito XVI to Mosquito IX, which was not fitted with bomb doors and was not pressurised, because the pressurisation of the Mark XVI would be redundant in a low-level role, and the installation of API/AMU was preferred to that of Rebecca.[3] By then, hopes of using H2S Mark VI in the Pathfinder Force by the end of the year had disappeared. The firm of Nash and Thompson expected to complete the prototype scanner, Type 82, and stabilising platform, by the end of the month and to deliver six crash programme models by the end of December and a further nine by the end of January 1945, whilst the R.P.U. reported that the maximum number of complete equipments that could be made in 1944 was five.

A Lancaster trial installation with a six-foot scanner was completed and given preliminary flight trials early in December 1944. The clarity and definition of the display deteriorated at heights of 5,000 feet and above because of cloud effect and excessive ground returns, and the installation was of no use for operations above 10,000 feet, but at low altitude excellent results were obtained. It was very doubtful whether H2S Mark VI installed in a Lancaster would be of value to the Pathfinder Force, and the Chief of the Air Staff suggested that the equipment might have an important application in a tactical role. Although the possibility of detecting and identifying hidden armoured vehicles was slight, H2S Mark VI appeared to offer assistance for ordinary tactical reconnaissance and for low-level bombing because of its exceptionally accurate and detailed definition of ground objects. It was also considered that it might be of value, when suitably modified, for operations against *schnorchel* U-boats, and trials were being undertaken, although the indications were that equally good if not better results would be achieved with the improved version

[1] A.H.B./II/69/215C. [2] A.H.B./II/69/215C. [3] A.M. File CS.23802.

of A.S.V. Mark VI about to be installed in Coastal Command aircraft. The most promising feature about the equipment was the high degree of definition achieved at low altitudes, but it was doubtful if the operation of Lancasters at those heights would be a practical proposition. The six-foot scanner could not be fitted to the Mosquito, for which a three-foot scanner would have to be used, and as a result there was likely to be a great difference in performance. The T.R.E. felt that the results obtained were so revolutionary that it was not worth while to lose 50 per cent of the efficiency of the equipment by installing it in Mosquito aircraft for the tactical role, but the Air Staff considered that it was not possible to judge without further investigation to what extent H2S Mark VI would be useful if installed in Lancasters. Three immediate applications of H2S Mark VI were possible; low-level marking of strategic targets by No. 5 Group, low-level marking and attack of tactical targets in army support, and low-level tactical reconnaissance in army support. Before a firm decision could be made it was necessary to find out if the less well-defined display afforded by a Mosquito installation would be operationally useful. If it were not, then the practicability of operating Lancasters over a battlefront at less than 5,000 feet would have to be assessed. If Lancasters could be employed in such a role, a choice between allotting them to the Tactical Air Force or to No. 5 Group would have to be made. Neither the air crews nor the ground crews of the Tactical Air Force were experienced with H2S or its test equipment, and if it were decided to use Lancasters in the tactical role, two possibilities would be presented; that of operating the aircraft from advanced landing grounds on the Continent and basing them on airfields in the United Kingdom where the assistance of the T.R.E. could be made more readily available, or of basing them on the Continent.[1] Until answers to the various questions could be found, the crash programme for Bomber Command was held in abeyance, but arrangements were made for six Lancasters and six Mosquitoes to be fitted as quickly as possible in order that trials in different applications, particularly that of army support, might be undertaken in Bomber Command where the benefit of past experience could be applied and where T.R.E. scientists would be able to maintain close supervision.

Restrictions on Operational Use of H2S Mark VI

In October 1943 the Chiefs of Staff Committee in the United Kingdom considered the advisability of restricting the operational use of K-band equipment in order to avoid premature disclosure to the enemy, and strongly recommended that it should not be employed over enemy territory in any circumstances without the consent of the Combined Chiefs of Staff.[2] However, the Chiefs of Staff in the United States of America did not agree, and in December 1943 informed the War Cabinet that they took the view that the advantage to be gained by the use of such equipment when required would outweigh any advantage to be gained by withholding its use until it was available in large quantities. They therefore proposed that all area and theatre commanders should be informed of the secret character and special value of K-band equipment, that it embodied techniques believed to be unknown to the enemy, and that it was to be employed only when, in the opinion of a commander, the advantage to be gained justified the risk of compromising it, when they were to inform immediately the Combined Chiefs of Staff that it

[1] A.H.B./II/69/215D.
[2] A.H.B./ID4/175A.

had been used. The Chiefs of Staff in the United Kingdom remained convinced that the unregulated use of the equipment at the discretion of area and theatre commanders would not be to the advantage of the Allies, and adhered to their original views. The matter was discussed again in Washington where, on 7 January 1944, it was agreed to defer a decision until 1 April 1944 unless accelerated development and production made an earlier date desirable, and at the beginning of June 1944 the decision was postponed until 1 September. In November 1944 the Chiefs of Staff in the U.S.A., after further consideration, propounded their original views, and, after inviting the Radio Board's comments, the Chiefs of Staff in the United Kingdom on 28 November 1944 agreed that the time had arrived when the decision to use K-band equipment could be delegated as suggested.

On 25 March 1945 Headquarters Bomber Command requested authority to use H2S Mark VI over Germany, but before granting permission the Air Ministry required an appreciation of the operational advantages likely to be gained which could not be obtained by the use of current Marks of H2S. The employment of H2S Mark VI in the war against Japan, after the conclusion of the war with Germany, was being contemplated, and it was felt that its loss over the Continent would seriously affect its operational value, especially since it might well prove to be the basis of post-war blind-bombing equipment. The Commander-in-Chief, Bomber Command considered that the employment of H2S Mark VI would permit effective attacks to be made against certain important strategic targets, such as the remaining major oil objectives, in bad visibility and in spite of smoke screens, when raids using other systems would be quite impracticable. The Air Staff, however, considered that in view of the successful and rapid advances being made by the Allied land forces, with the unlikelihood of the establishment of any strong line of defences, and the consequent reduction in the number of possible strategic targets, there was only a small need for the employment of H2S Mark VI. The chain of Oboe stations had been extended so that strategic targets as far east as Berlin could be bombed with precision, and within a few days the requirement stated by the Commander-in-Chief had been made less urgent. The scope and nature of strategic bombing operations in the Far East were by no means certain. It was likely that there would be suitable targets in Japan itself, but it was debatable whether the advantages of H2S Mark VI over Mark III series were sufficient to constitute overriding operational urgency for its use. The balance was between operational urgency and security because, given time, there was little doubt that suitable opportunities would occur for effective attacks to be made against small targets with the assistance of equipments already in operational use. It was still not possible to define the potentialities and application of H2S Mark VI in the army support role, and they could only be determined by comprehensive tactical development trials which had not been possible because the number of aircraft equipped with the installation was limited. K-band was the last band of frequencies through which aircraft radar equipment had progressed during the war, and it was likely that it would be the shortest wavelength operationally usable since below it, and possibly within it, propagation and other difficulties such as reflection from clouds and rain impaired effectiveness. If it were not used operationally, the advantages of the technique would be reserved to the United Kingdom and the United States of America for future purposes. If it were certain that the equipment would be used against Japan in either the strategic or tactical role there could be no cogent argument for not employing it for operations immediately, and the long-term security aspect was therefore the critical factor. During the war incompletely developed equipment had often been introduced, in small quantities, into operational use, but on each occasion the result had been an immediate operational advantage and an intensification of development in return for the early disclosure of a new technique. The benefit of rapid development depended chiefly upon the opportunities for intensive use in war conditions. Such conditions no longer existed in the war with Germany. The possible operational use of H2S Mark VI was limited and its immediate introduction would not contribute any decisive operational advantage, whilst its potential value was largely speculative.

On 3 May 1945 the Chiefs of Staff informed the Joint Services Mission in Washington that they considered it undesirable and unnecessary to risk compromise of security by the use of airborne K-band installations against both Germany and Japan but thought that the advantages of using it in ships were great enough to outweigh the very slight risk of ship-borne equipment being captured by the enemy if all proper safeguards were enforced. They recommended that the Chiefs of Staff in the U.S.A. should be asked to agree to the cancellation of the authority previously accorded to theatre commanders, and that no use should be made of K-band equipment, other than in American or British warships, without the prior agreement of the Combined Chiefs of Staff. In view of the technical implications involved, the matter was first discussed by the Combined Communications Board in Washington. The American members of the board made it quite clear that they were unwilling to limit the powers of theatre commanders in the Pacific theatre of war regarding the use of such valuable equipment, and it was unlikely that the Chiefs of Staff would disagree with the advice given them by their advisers. The C.O.S. Committee in the United Kingdom therefore decided that, unless the Air Staff had any strong objections, it would be pointless to restrict the use of K-band equipment in the hopes of preserving its secrecy. On 4 June 1945 the Joint Services Mission was informed that, as it appeared that airborne K-band equipment was likely to be used by the Services of the U.S.A., the R.A.F. would continue to train crews and equip aircraft with H2S Mark VI for the Far East theatre of war, and on 28 July 1945 the Chiefs of Staff in the U.S.A. were told that it was intended to use the equipment operationally in the last three months of 1945.

Operational Trials of H2S Mark VI

By the beginning of February 1945 a number of experimental flights had been made with both a Lancaster and a Mosquito aircraft. Although it was too early to draw firm conclusions, it was possible to make an intelligent guess at the potentialities of H2S Mark VI and to suggest probable operational uses and the nature of the trials still to be completed. The greatly improved discrimination, which enabled topographical features such as woods, railways and rivers to be detected, was about twice as good in the Lancaster as it was in the Mosquito. However, in order that the great advance in clarity and definition might be exploited, it was necessary for the aircraft to be flown at heights below 5,000 feet, and it appeared that heights of 500 to 1,000 feet would probably be the most effective. The employment of heavy bomber aircraft such as the Lancaster at those heights over heavily-defended targets would obviously be hazardous and would only be justified if the results to be obtained were likely to achieve a quick and substantial dividend not obtainable by current tactics with existing radar installations. Mosquito aircraft had, however, already been successfully employed for low-level marking. H2S Mark VI might therefore be more properly used in that type of aircraft, except in conditions where the nature of the target and the surrounding country called for the higher degree of definition provided by the Lancaster installation. The danger of loss of Lancasters in such circumstances might possibly be reduced by the provision of tactical support in the form of low-flying Mosquito bomber and fighter aircraft to distract enemy defences and to draw off fire from the heavy bombers. In accordance with the importance attached to enemy oil production by the Combined Chiefs of Staff, the Air Staff considered that the targets meriting first claim to such a specialised form of attack were the major oil installations in Germany. In addition to the probable ability of aircraft equipped with H2S Mark VI to mark such difficult targets even when a smoke-screen had been laid, the accuracy of marking was likely to be far greater than that achieved against targets beyond the range of Oboe by methods possible with existing equipment. The Minister of Aircraft Production had been asked to ensure that three Lancasters and three Mosquitoes equipped with H2S Mark VI were delivered to Bomber Command by the middle of February 1945 so that they might be used against major objectives as soon as possible.

One of the outstanding features of the Lancaster H2S Mark VI installation was that it enabled bridges over sizeable rivers to be detected at night and when visibility was poor, a factor which was likely to be important at that stage of the war. Baillie bridges spanning rivers more than 70 yards wide had been detected quite clearly, and it was probable that gaps in bridges which had been destroyed could also be observed. As the German land forces were driven westward, it was likely that the permanent bridges spanning the Rhine would be destroyed by Bomber Command, and the enemy would be forced to rely on pontoon or other temporary bridges and ferries. It was improbable that the river would be so spanned during the hours of daylight or when visual reconnaissance by aircraft was feasible because of the danger of air attack. The enemy would thus be forced to take advantage of bad weather and darkness, and in those circumstances H2S Mark VI might well deprive him of the tactical advantage he hoped to gain. It would be possible to locate the presence of pontoon bridges or regular ferry services with great accuracy and it might be possible to pass the information to a strike force of heavy bombers as a reference point, so that the target could be attacked by means of Oboe or Gee–H when direct observation of the ground or ground markers was impossible. Similarly, it might be possible to mark cross-roads or villages through which the enemy was passing, in order to cause a ' bottleneck '. The experimental flights had shown that in certain circumstances concentrations of tanks or vehicles in open country could be detected by H2S Mark VI, but only when the approximate location of the concentration was known. Because of the mass of other detail which appeared on the P.P.I. it was improbable that an H2S operator would succeed in determining with certainty whether a particular response was caused by such a concentration or by objects such as small buildings. It was possible to detect convoys on roads not lined with trees, but there were only a few such roads on the Continent. It was possible, however, that information of the movement of road convoys could be derived from a close study of P.P.I. photographs. The area covered by H2S Mark VI at a height of 2,000 feet was approximately a circle of 5 miles radius, and a path about 10 miles wide could therefore be swept by one aircraft. If regular flights were made nightly over a battle area, especially in bad weather and when there was no moon, which, it could be assumed, would be the periods when the enemy was most likely to increase the movement of his forces, only a very small force of aircraft would be required. Since the value of such reconnaissance depended on the regular and intelligent interpretation of P.P.I. photographs, it might be necessary to operate from advanced landing grounds where the photographs could be developed and examined without delay. It was appreciated that the work involved in assessing the value of H2S Mark VI for low-level reconnaissance would take a considerable time, and would probably necessitate the compilation of a P.P.I. mosaic for careful study and appreciation. It was therefore thought advisable that further trials in that role should be undertaken only after the completion of those required for strategic and tactical bombing.

Three Lancasters equipped with H2S Mark VI and six-foot scanners were delivered to Bomber Command at the end of February 1945, when three more aircraft were expected to arrive within a few days.[1] A special flight was formed within the organisation of No. 3 Group with the object of determining the best way of using the reference point marking technique against oil targets so that the aircraft could avoid flying over heavy defences, and of training air and ground crews with H2S Mark VI. Delivery of Mosquitoes did not begin until the first week of March when technical difficulties experienced with the installation had been only partially cleared, and they were not yet ready for operational use. They were allotted by Headquarters Bomber Command to a No. 5 Group station, where training was concentrated on endeavours to exploit the potentialities of the aircraft installation for low-level target marking. On 1 March 1945 Headquarters 2nd Tactical Air Force stated an urgent operational requirement for two or three Mosquitoes equipped with H2S Mark VI. It was considered that they would be of great value on night reconnaissance to determine enemy activity on the approaches to, and the crossings of, the Rhine. The possibility of withdrawing the aircraft from Bomber Command was examined, but the Mosquitoes were suitable only for training purposes at that time. It was, however, expected that additional aircraft could be made available early in April for allotment to the Tactical Air Force. The wisdom of dividing the few aircraft equipped with an entirely new installation between three separate formations so that each could develop its own operational methods was questioned. Much of the preliminary work was bound to be common to all three, and there was a danger of overlapping and a lack of mutual consultation. Proposals were made for all the aircraft to be operated from one airfield as an experimental unit, to which could be attached representatives of the various users, in order that flying and training resources could be more economically applied. When the degree of usefulness in the various roles had been assessed, the requisite number of aircraft and

[1] A.H.B./II/69/215D. The first aircraft arrived on 15 February and the sixth on 14 March 1945.

trained crews could be transferred to the operational command or group concerned. By 8 March 1945 the Allied land forces were on the west bank of the Rhine, and enemy forces had already crossed, or were crossing, the river, so the immediate value of H2S Mark VI to the Tactical Air Force was already much reduced, whilst it was uneconomical and impracticable for the command to develop the equipment because of a lack of facilities and experience. However, the Air Ministry considered that, although a special development flight would be ideal, it was not practicable because manpower limitations precluded the formation of new units and because Headquarters Bomber Command was unlikely to agree to the proposal. Arrangements were made for all further development and training to be undertaken within Bomber Command, but Headquarters No. 5 Group was to transfer one Mosquito to No. 3 Group, to which Tactical Air Force aircrew and servicing personnel, and Army officers, were to be attached, whilst Headquarters No. 3 Group was to transfer one Lancaster equipped with a three-foot scanner to No. 5 Group to facilitate the training of navigators. When personnel of the Tactical Air Force were considered to be adequately trained, and if H2S Mark VI was thought to be of use operationally, aircraft were to be flown to the Continent.

Meanwhile, further development of the installation to enable it to be used effectively at higher altitudes was continued at the T.R.E. because the limitations were believed not to be fundamental, but efforts to meet the specifications laid down by Headquarters Bomber Command were unsuccessful, and modifications were incorporated to improve performance at low altitudes in spite of the fact that they made the installation unusable at high altitudes, and the low-level version was known as H2S Mark VIA. In the Lancaster installation a second P.P.I. display with camera mounting was made an operational requirement so that continuous P.P.I. photography could be achieved. By the beginning of April there were eight equipped Lancasters in No. 3 Group and six first-class specially selected crews had been fully trained, and three equipped Mosquitoes and six fully trained crews in No. 5 Group. The stage had been reached when training and trials had been completed and the group commanders felt that no further useful development work could usefully be done without operational trials over Germany.[1] However, until permission was obtained, the equipment could not be flown over enemy territory.

By the middle of May the Lancaster Flight contained nine aircraft fully equipped with H2S Mark VI, and 10 crews had been fully trained. Nearly 800 hours flying had been accomplished on trials and training in the strategic and tactical target marking and bombing roles, and results showed that the best performance was achieved at 2,000 feet. Below that height more detail was obtained but the display was confused by radar shadows, an effect which was of special importance when a built-up area formed the target, because the shadow of one building hid another and broke up the outline. At 3,000 feet the strength of responses deterioriated and at 5,000 feet only the strongest echoes were observed. The optimum height for operations with the installation was necessarily a compromise between tactical considerations and the height at which responses were sufficiently clear and detailed to be effective, and that appeared to be 3,500 feet. At that height an improvement in performance was effected by tilting the scanner four degrees downwards. The average range

[1] A.H.B./II/69/215D.

at which landmarks could be clearly identified was from three to seven miles, depending on the nature of the response source. Trials showed that the installation could be used to locate and bomb accurately such small targets as villages, isolated factories, railway stations, and ships, and any one of such targets or even the corner of a wood could be used as a reference point to bomb map-reference positions which gave no response on the P.P.I. Early bombing results showed average errors of 200 yards with a tendency to overshoot, but after modifications had been made, average errors were reduced on some occasions to as little as 70 yards, and with further modifications to eliminate certain known errors, it would be possible to improve accuracy appreciably. An excessively long approach run was not essential, and it was considered that if certain factors were taken into account when operations were planned, H2S Mark VI compared favourably with any other system. The greatest limitation in the planning of an attack was the necessity to avoid flights over targets which were heavily defended, especially with light anti-aircraft guns, but it was possible that offset bomb-aiming might enable that to be achieved. In July 1945 it was considered that maintenance of the Lancaster flight at its existing strength was no longer justified, and four aircraft and six crews were added to the establishment of the Bomber Development Unit. Full-scale tactical trials were authorised on 31 August 1945.

In May 1945 an operational requirement was stated for H2S Mark VIA to be installed in ten of the Mosquito B XXXV aircraft included in the low-level marking force for the Far East, and on 26 May Headquarters Bomber Command requested approval for the formation and official establishment of a training and development flight. In view of the requirements for the projected operations against Japan intensive training and further trials in the bomber role were considered essential, and trials in the army support role were still to be completed; authority for the formation of a special flight of six Mosquitoes was therefore granted in June. The Tiger Force intended to use one Mosquito fitted with H2S Mark VIA to mark the target from low-level for a bombing attack, instead of several aircraft carrying flares and indicators. It was expected that not only would greater accuracy be obtained, but also that a greater weight of bombs would thus be dropped, since the normal ' backers-up ' would be able to carry a full bomb load. The effectiveness of the attacks would depend entirely on the accuracy of the marking, and intensive training was therefore essential.[1] When hostilities ceased and work on preparing Tiger Force was stopped, seven of the ten Mark XXXV aircraft were nearly completed. Arrangements were therefore made for the installation programme to be continued, although further production was stopped, and the aircraft were stored until the policy for the future was decided. In October 1945 two of them were transferred to the Bomber Development Unit for extended trials.

Projected H2S Development

H2S Mark VI was of greater potential value to the scientist than to an operational user, because of its limitations in range and height, and the essential requirement was an installation that would afford a very high degree of definition with no restrictions on height and range. Although H2S Mark VII was designed to incorporate the Philco type of R.F. head, all orders for the components were cancelled, since it was considered that the expense was not justified for

[1] A.H.B./ID/12/115. K-band H2S.

further experiments on the 1¼-centimetre wavelength.[1] The major development programme to be undertaken at the T.R.E. was on an installation, tentatively known as H2S Mark IX, for the projected Canberra bomber, which was being undertaken on a new K-band wavelength, 2¼ centimetres, and on X-band, until trials revealed which provided the best solution. For experimental work H2S Mark VIII, working on the wavelength of 3 centimetres, which was very near the new wavelength, could be used. The greater power possible with X-band, and the much smaller amount of attenuation caused by atmospheric absorption, enabled much greater ranges to be obtained. With H2S Mark VIII ranges of 60 to 80 miles against coastline, and of about 100 miles with X-band beacons, at heights up to 35,000 feet, were expected.[2]

In addition to the normal requirements of simplification, weight reduction, and an increase in reliability, which were common to all forms of airborne radar equipment, the further development of H2S contained many possibilities at the end of the war.[3] One of the most important, perhaps, was the need for increased accuracy in reference point bombing. Results had indicated that compass errors caused by periods of weaving had contributed to bombing inaccuracies. There were fundamental difficulties which prevented the improvement of the compass itself during such periods, and alternative methods were required. One proposal was the use of two suitably situated reference points and the elimination of compass error by matching both on the P.P.I. display to two markers by feeding in a correction to the compass input. Another, on the same basic principle, which showed distinct promise, was to superimpose on the normal P.P.I. display a radar picture of the target area previously obtained by a reconnaissance sortie. A higher degree of definition was still required. For the ranges needed in high-level bombing a very short wavelength could not be used alone because of atmospheric attenuation, but a very narrow beam width was clearly advantageous. The design of a hybrid installation, using a very short wavelength for definition and a longer one for range, was therefore being considered. A common modulator and scanner reflector was obviously possible, and with care in design, many other components could be made common so that the additional weight and complexity involved need not necessarily be prohibitive. With the existing systems of navigation and bombing, one of the most likely causes of operational error, as distinct from instrument error, was the need for finding wind velocities. If the speed of the aircraft could be automatically determined by the radar system, improved accuracy and ease of operation would result. The use of doppler beats from the ground echoes enabled speed to be measured. Tests had shown that an accuracy on track of half a degree could thus be obtained, and experiments were being made on X-band which might enable complete automatic doppler navigation to be effected. The design used an H2S system with a special scanner which could, however, also be used for producing the ordinary P.P.I. display. As neither doppler navigation nor H2S needed to be operated the whole time, it appeared very likely that the same equipment could be used for both functions. Although not of major importance, the use of a two-coloured cathode ray tube with suitable gain switching, so that built-up areas appeared blue, open country orange, and water black, was being considered.

[1] A.M. File CS.22830.

[2] X-band responder beacons had been developed and were expected to be in Service use before the end of 1945.

[3] A.H.B./II/69/215D.

The factor dominating all projected developments was the improvement of H2S performance coupled with, if possible, a reduction in weight and an increase in simplification and reliability. If proposed advantages implied increased weight and complexity, a careful appreciation was required. Additional complexity involved a greater likelihood of breakdown, increased difficulty in servicing, greater delay in manufacture, higher initial cost, the provision of a larger number of spares, and perhaps most important of all, a higher standard of aircrew and training. H2S was to some extent vulnerable to jamming and homing, but the latter danger could be countered by intermittent use for short periods, whilst the narrow moving beam relying solely on reflections from the ground was very difficult to jam. When used for navigation the equipment scanned downwards, and jamming resources would therefore have to be very widespread, whilst jamming at the target could be overcome by judicious choice of an approach route and the use of the reference point bombing technique.

Bomber Command Requirements at the End of the War

At the end of the war, amongst the many radar requirements stated by Headquarters Bomber Command to be necessary to enable the command to fulfil its future operational commitments, was one for a navigation and blind bombing system independent of ground transmitters, and therefore unlimited in range, but incorporating facilities for using beacons.[1] Many features and specifications were to be made common to all the airborne equipments required. The existing aircraft radar installations, almost without exception, had, through force of circumstances, not been fully engineered. Little change in design had been effected between a laboratory model and an equipment eventually installed in an operational aircraft, with the result that in many instances installations were clumsy and bulky, unsatisfactory from the point of view of both the air operator and the ground radar mechanic. Miniaturisation was required to the fullest possible extent in order that weight and size could be reduced to a minimum. With the advent of jet engines for aircraft, operational heights would be very much increased, and equipments were required to be completely pressurised, and since it was essential that bomber aircraft should be capable of operations anywhere in the world without modification of radar equipment being involved, completely tropicalised. In order that the provision of requisite space, whilst design of a new aircraft was still at the drawing board stage, could be simplified, standardisation was required. The ideal was that every aircraft radar equipment should be completely contained, apart from aerials and in some instances indicators, in a standard unit which could be installed in, or removed from, any aircraft quickly and easily. External cabling was required to be reduced to a minimum, and the terminations to be robust, reliable and easily accessible. As the dimensions of aerials were likely to increase, it was important that development should be aimed at fitting them within the fuselage or wings of aircraft. It was also important that the main electrical power supply should not be affected by variations of engine speed, as otherwise the performance and serviceability of airborne radar equipment was impaired, and the provision of an auxiliary power supply was essential. Universal equipments and indicators which combined several functions were considered to be unnecessary for heavy bomber aircraft. They possessed the serious

[1] Bomber Command O.R.B., October 1945.

limitation that any unserviceability might involve the loss of more than one radar system, and inevitably tended to be less efficient in performance than were equipments specifically designed for one purpose only. It was considered that the combination of miniaturisation, standardisation, and good engineering would result in a reduction of weight and dimensions adequate for large aircraft, but in view of a possible requirement for small bomber aircraft in which the saving of space was essential, there was a requirement for the development of universal equipment. All installations were to be designed to be as immune as possible to effects of interference and countermeasures. The development and production of test equipment was required to be undertaken simultaneously with the development and production of the main equipments so that there was no time lag between the introduction into Service use of the two, and such introduction was to be preceded by that of the appropriate ground trainer.

The specific requirements for H2S included an accuracy of about 100 yards average radial error at all bombing heights, which were to range from 500 to 50,000 feet. Presentation was required to be of high definition and unaffected by cloud, showing clearly and accurately the main features of the terrain over which an aircraft was flown, with facilities for obtaining precise navigation fixes. Ranges of 200 miles for beacons, and 100 miles for ground detail, were required, with a high standard of discrimination of detail at the shorter ranges. A variable sweep delay was to be incorporated to permit magnification of a portion of the presentation on any of the scales, which were to range from one in two million to one inch to the mile, and the plan position indicator was to be at least 10 inches in diameter to enable the large scales to be fully utilised. The bombing indicator was to be separate from that used for navigation, and was to be developed solely as an efficient radar bombsight. In order to facilitate the building up of a high-definition picture of a target, stabilisation was to be incorporated, and the equipment was required to be linked to the navigation and bombing computor so that data could be fed continuously to the computor. A pilot's track and release indicator was also to be fitted, and it was to be possible for the P.P.I. display to be automatically photographed and recorded, continuously or as required, without interference with the H2S operator's presentation.

CHAPTER 5

GEE MARK I

The first proposal for using radar-type pulse transmission as an aircraft navigation system was made in 1938 by Mr. R. J. Dippy, a member of the staff of the Bawdsey Research Station, but the main emphasis was, at that time, on daylight precision bombing and no special navigation problems were envisaged. Before the end of 1939, however, the severity of our losses in daylight attacks against German naval units compelled the Royal Air Force to adopt a policy of night bombing and the question of accurate navigation and the location of targets in darkened Europe became of paramount importance. The idea of a radio aid to navigation was discussed by the Committee for Scientific Survey of Air Warfare and its sub-committee on radio research in the spring of 1940, and Air Marshal Sir Philip Joubert de la Ferte, the Assistant Chief of the Air Staff (Radio), visited the Air Ministry Research Establishment and informed the scientists of the urgent need of Bomber Command for a device which would enable bomber aircraft to reach a point within five miles or so of a target in face of enemy defences and the hazards of bad weather.[1] On 24 June 1940 Mr. R. J. Dippy submitted a scheme for assisted navigation, similar in principle to his 1938 project, but with the additional advantage of target-finding by grid reference as well as homing back to base. Four days later Sir Philip Joubert de la Ferte requested the Directorate of Communications Development to initiate experiments with the system as a matter of urgency.[2] The code name 'G,' short for the grid or network of position lines which were laid over a specific area, was adopted in July 1940 and later changed to 'Gee' for security reasons.[3] The object of Gee was to provide a means of navigation by which the pilot of an aircraft could obtain information of his position in the area served by the system.[4] The system consisted of the reception in an aircraft of pulse transmissions from three transmitters situated as widely apart as practicable, one acting as a master station and transmitting pulses of a particular shape at regular intervals, while the two slave stations transmitted simple pulses. The slave stations were locked by radio means to the master so that the transmission of the pulses coincided in time, and by reading off the distance between them on the time-base of a cathode ray tube in the aircraft and comparing the results with co-ordinates on a specially prepared lattice chart, it was possible to find the geographical position of the aircraft.[5]

[1] T.R.E. File D.1666. The Air Ministry Research Establishment became the Telecommunications Research Establishment in May 1940.

[2] T.R.E. File D.1235. [3] M.A.P. File SB.9314. [4] A.P. 2557.

[5] Mr. Dippy anticipated that three transmitters placed in line about 100 miles apart would cover a sector of 100 degrees on either side of this line extending to 350 miles range. The accuracy of this positioning would then be in a diamond of about 3·5 miles in length and one mile wide at the extreme range, being correspondingly smaller at shorter ranges.

Early Development of Gee

On 28 June 1940 a transmitter and receiver were allocated to the T.R.E. Swanage, and a programme of work on Gee was drawn up. The T.R.E. was to build a small-scale model of the proposed system in order to provide data on which a decision might be made about the actual operational requirement for Gee. At the same time investigations were to be made into an additional system termed ' H ' which was similar to Gee but involved radiation from the aircraft. Besides the normal laboratory work on the equipment, flight tests were to be made to discover the probable range of the system, and from the results of these trials a decision could be made on establishing the full-scale Gee method. A Blenheim aircraft was accordingly fitted with a receiver operating on 22·7 megacycles per second with a cathode ray tube presentation unit, and on 27 July 1940 a flight was made from Hurn to discover the range at which a pulsed transmission could be recorded.[1] The back radiation of the C.H. station at Worth Matravers was used, and signals were received at a height of 10,000 feet over Newcastle-on-Tyne, approximately 300 miles away. Having checked the range possibilities, the next step was to try out a two-station chain in operation. Sites were selected, at Hurn and Worth Matravers, giving a base-line of about 20 miles. The transmitters worked on 51·9 megacycles per second and a power output of 50 watts was fed into simple aerial systems on 70-foot masts. New airborne receiving equipment was built to correlate the transmissions from each ground station and was installed in an Anson aircraft, which soon resembled a flying power house. Excluding the rather large power source of 50-cycle alternating current, the equipment measured five feet by two feet by two feet.

The first flight using a two-station Gee chain was made on 19 October 1940, and, with the aid of a pre-calculated lattice chart made up of hyperbolas of the phase difference between the two stations, the aircraft position was fixed, and it was found possible to home along the position lines. The only weakness was found to be the airborne filter, which was disturbed by interfering signals, causing the time-base to come out of lock frequency. This filter was later replaced by a crystal oscillator, and on a flight in December, the equipment appeared to be satisfactory; an outstanding performance was the reception of both signals at a range of 111 miles at a height of 5,000 feet. Various meetings had been held between representatives of Headquarters Bomber and Fighter Commands, the Directorate of Communications Development and the Telecommunications Research Establishment, to consider the relative possibilities of the Gee and H systems and at a C.T.E. conference on 17 October 1940 it was decided that work should continue on Gee although at that time there was no demand for H. A signals officer and a navigation officer from Headquarters Bomber Command visited the T.R.E. on 14 October 1940 and gained their first experience of Gee when they made a flight in the Anson on 15 November. They were very favourably impressed with the results of this trial and considered that Gee would provide the answer to many Bomber Command navigation problems if the claims made for it in regard to range and accuracy could be substantiated, and if its stability in aircraft could be ensured. At that time, however, the T.R.E. could give no guarantee of ranges or accuracy until further trials had been carried out in varying atmospheric conditions at different times of the year.[2]

[1] T.R.E. File D.1666.

[2] A.M. File S.7515.

The Air Officer Commanding-in-Chief, Bomber Command, on the strength of the reports, recommended on 22 November 1940 that the provision of Gee should be treated as a matter of great urgency.[1] He realised, however, that some considerable time would elapse before aircraft could be fitted in quantity and he therefore suggested that a small number of hand-made sets be produced immediately in order that some benefit might be obtained from them during the coming winter. He visualised the use of a few specially equipped aircraft to locate targets and start fires for the guidance of the following bombers, a technique similar to that used by the enemy. To minimise maintenance and training problems, the sets could be allocated to one squadron only. The proposal was agreed to and the Telecommunications Research Establishment was instructed on 2 December 1940 to begin the construction of 12 aircraft equipments for use in a Wellington squadron of Bomber Command.[2] The number was increased to 24 later in December 1940 although it was realised that it would mean delaying completion of the programme until April 1941.[3] In February 1941 the Director of Communications Development asked for a ruling on the future operational use of Gee, as without one it was impossible to plan further requirements. There were two schools of thought on the use of Gee in the event of trials proving successful.[4] The equipment could either be installed in a limited number of aircraft only for specialised use as fire-raisers, thus enabling its introduction to be speeded up, or it could be installed in all bomber and maritime aircraft, involving a considerable delay in its introduction into operational use.

As an exponent of the first view the Director of Signals considered that because of the experimental state of the whole system it was necessary to assess the performance of Gee in short Service trials before coming to a conclusion about its use, even at the risk of seriously delaying extension of the system to other squadrons. If this were not done and it were found that a great many modifications were needed then there would be a quantity of useless equipment left on hand.[5] Opposed to the delay was the Superintendent of the Telecommunications Research Establishment who on 16 June 1941 urged the Director of Communications Development to take a chance on the success of Gee and to drive ahead with installation in a large number of aircraft.[6] No one knew how long it would be before the enemy could counter it, and it was therefore very important that full use should be made of Gee in the limited time before it was rendered useless by jamming or interference. He felt that the proposal to install Gee in only a few aircraft was very dangerous, as one or more installations were fairly certain to fall into the hands of the enemy, and he considered that the story of the tank in the First World War was analogous.

Meanwhile, by the end of 1940, sites for the first chain of Gee ground stations had been chosen to give eastward cover over Germany, particularly the Ruhr area. In a choice between the Daventry and Rugby British Broadcasting Corporation transmitting stations, Daventry was selected to be the master station because of the high voltage gradient at the top of the Rugby masts. The two C.H. stations at Stenigot and Ventnor were adopted as sites for the slave stations and in February 1941 it was arranged for the chain to be monitored from Great Bromley C.H. station.[7] The sites were not decided

[1] A.H.B./IIE/24. Memo. on the introduction of TR.1335 into Bomber Command.
[2] T.R.E. File D.1235.
[3] A.M. File S.9515.
[4] A.M. File C.30486/46.
[5] A.M. File C.30486/46.
[6] T.R.E. File D.1235.
[7] A.M. File S.8135.

upon without opposition. Headquarters Bomber Command thought that a more forward base-line should have been chosen in order to obtain maximum range from the equipment.[1] The T.R.E. considered the sites to be highly unsatisfactory from a technical point of view.[2] The frequency of Gee had been fixed at 53·7 megacycles per second in order not to interfere with the B.B.C. broadcast wavelength but this would cause the second harmonic of one of the Stenigot frequencies to interfere with the locking of the Gee stations. Ventnor was considered to be far too vulnerable to enemy attack. Any additional equipment installed at an A.M.E.S. site would always tend to increase the risk of attack, and would possibly prejudice the technical performance of the stations. The objections were, however, overruled at a conference at the Ministry of Aircraft Production on 21 December 1940. They were considered to be of less importance than the advantages gained, the most important of these being speed. The four sites were to be employed unless the transmitters could be moved to new positions before the 24 aircraft sets were ready, but, whatever transpired, the Director of Signals required the ground installations to be completed by 31 March 1941.[3]

The Gee system as a whole was under the operational control of Headquarters Bomber Command through Headquarters No. 3 Group, although technically the ground stations came under the control of Headquarters No. 60 Group.[4] By 9 June 1941, two months beyond the target date, two receivers were ready to be despatched to the slave stations, transmitting aerials had been completed, but no transmitters had arrived because of delay in obtaining valves, and the buildings were not finished. Nevertheless, despite the incomplete state of the ground stations, it was decided at a conference at the Air Ministry on 9 June 1941 that Service trials should begin in the first week of July.

First Service Trials, and Postponement of Operational Use

A programme for Service trials had been drawn up in May 1941. An experimental full-powered transmitter was erected looking north from Worth Matravers, the aerials being mounted on a 350-foot tower and the aircraft equipment, now powered by a 1,000-watt generator and considerably smaller in size, was installed in a rather ancient Wellington. During the first flight, which took place on 15 May 1941, signals from Worth Matravers were received 20 miles south of Dundee at a height of 10,000 feet. This was equivalent to a range of about 400 miles and showed an increase of 50 miles on the previous experiments.[4] However, an unforeseen obstacle threatened to delay the Service trials. It was the provision of suitable detonating apparatus for the destruction of airborne Gee equipment should it be likely to fall into enemy hands. Headquarters Bomber Command wished to forge ahead with the trials and considered that if detonating equipment could not be produced immediately, it was worth while operating without it and accepting the risk of capture.[5] A meeting was called at the Air Ministry on 14 July and the question was raised whether Gee

[1] A.M. File C.30486/46. [2] T.R.E. File D.1235. [3] A.M. File C.30486/46.

[4] A.M. File S.8135. Headquarters No. 60 Group was to arrange the erection of aerials and transmission lines at Stenigot, Ventnor and Great Bromley (T and R arrays at the first two and R array only at the last) and was to be responsible for the maintenance of all technical equipment. All ground personnel at the C.H. stations were administered by H.Q. No. 60 Group through the Signals Wing Headquarters, the B.B.C. providing servicing personnel.

[5] A.M. File C.30486/46.

was to be regarded as a navigation aid or as a means to assist aircraft captains to locate targets. If the former, then there would be no need for aircraft to fly over enemy territory during the early stages of the trials. The answer to this could only be given when some idea of the range and accuracy of the system was obtained. The T.R.E. was prepared to guarantee a minimum range of 200 miles with aircraft flying at 15,000 feet. Positioning accuracy at those ranges would be an area approximately 1·5 miles by 0·6 miles with correspondingly greater accuracy at reduced ranges. It was impossible to state the maximum range to be expected. Experience of V.H.F. propagation indicated that the maximum range varied according to the seasons of the year and the conditions of ionospheric density. It was decided that trial installations should be made in various types of bomber aircraft and that the Director of Armament Development should be asked to devise an interim destruction equipment within two weeks,without which no Gee-fitted aircraft was to fly over Germany.[1]

Before a final decision on operational policy could be made the production angle had also to be considered. Each aircraft receiver was equivalent to three A.S.V. receivers as far as components were concerned. Mass production of receivers to provide one for each bomber aircraft was held up because of the great difficulty in manufacturing one of the valves (Type E.50) in sufficient quantity. There was no capacity in the U.S.A. for producing the valve and Mullard was the only firm in Britain who had succeeded in making it. Other firms had tried and failed. This meant that maximum mass production could not possibly be reached in under 12 months. The outcome of the conference was that production of 300 hand-made sets was to be started at once.

The Gee ground stations were completed by 9 July except for the receivers at Great Bromley. Personnel were available and telephone lines had been connected. Two aircraft of No. 115 Squadron, Marham, were fitted with Gee and four more were scheduled to be ready by 14 July. Ground training had started on 7 July, air training was about to begin on 14 July, and the trials were to start three days later. The trials actually began on 17 July 1941 with four Gee aircraft from No. 115 Squadron flying over the North Sea. Over a period of ten days the trials showed that the ground equipment was not yet giving results reliable enough to make Gee the principal means of navigation during operational flights. Detailed examination of the results obtained up to 23 July 1941 were made by Headquarters Bomber Command, and while it was proved that extremely accurate fixes could be obtained with ease when the system was working satisfactorily, it was also shown that out of 17 flights made only six were completed without a breakdown of the ground stations. The flights were of short duration compared with sorties into Germany on which, it could be assumed, a higher percentage of failures would have occurred. For three consecutive days no flying was possible owing to unserviceability of the ground stations. Investigation of their poor performance showed that most of the failures could be tracked down to power supply troubles, failure of rectifier valves, and weak radio links between Daventry and Ventnor. Once these were dealt with there was considerable improvement in the performance of the ground organisation.[2]

[1] Only the heavier types of bomber aircraft were considered to be suitable and the following were selected for trial installations.

Stirling.	Wellington.	Manchester.	Liberator.
Halifax.	Lancaster.	Warwick.	Albemarle.

[2] A.M. File C.30486/46.

Operational trials began in the first week of August although all the 24 aircraft sets had not yet been delivered. For these trials hyperbolas of the ground transmissions were projected on to the navigator's maps by means of a film in a modified astrograph. On 2/3 August 1941, four flights were made over the North Sea up to a distance of approximately 180 miles from Marham, all four aircraft navigating by Gee, without the use of W/T. In each instance the pilot described the accuracy as uncanny. On the night of 11/12 August two Gee aircraft operated over the Ruhr and obtained fixes which were very accurate indeed. Both aircraft found Munchen Gladbach, which was their target area, and bombs were aimed accurately by the use of Gee co-ordinates for establishing the release point. On the following night, two aircraft operated over Hanover and one failed to return. This led to a major change in Gee policy, but not before a third raid had been made by two Gee aircraft on 14/15 August, again over Hanover, both returning safely.

It had been hoped to put the Gee system into general operational use as soon as possible, but with the loss of the Wellington over enemy territory the Gee policy was immediately reviewed. At an emergency conference on 18 August 1941 the Chief of the Air Staff ruled that all tests—operational, technical or training—were to be stopped at once.[1] No operational use of aircraft equipped with Gee fittings was to be made until all traces of the installation were removed, and the great need for secrecy was to be impressed on all persons who had been connected with Gee.[2] At the request of the Chief of the Air Staff, Sir Henry Tizard held a meeting on 20 August 1941 to collect advice on the future use of Gee.[3] The meeting was told that it was impossible to say from Intelligence sources whether the enemy would learn anything from the missing aircraft. No signals had been received from it and no one had seen it go down. As for the chances of the Gee equipment being destroyed, there were ten detonators which could be set off by the pilot, wireless operator or navigator. Mr. Dippy had attached great importance to the destruction of the crystal, and detonators had been provided accordingly. The aerial itself would give nothing away, but although the R.A.E. had made destruction tests on separate parts of the equipment, none had been made on the complete assembly in an aircraft. Sir Henry Tizard thought that it could not be assumed on those grounds that destruction would be adequate to prevent the enemy obtaining any knowledge of the system, and that the obvious attempts to destroy some part of the aircraft would incite the German Intelligence branch to trace the meaning of the installation from every possible source.

As it was possible for the enemy to locate the three ground stations by means of direction-finding systems, the meeting agreed that they should be unlocked, the double pulse removed from Stenigot, and the stations closed down one at a time, Daventry to be the last, after faked failures, the actual taking off the air to occur during bomber operations.[4] Further meetings were to be arranged to discuss jamming and spoofing. It was anticipated that when Gee was introduced into the Royal Air Force its useful operational life would not be more than five or six months at the maximum. It was not likely that Gee would be jammed over the United Kingdom ; more probably attempts would be made to jam it near its normal limit of range, in which case Gee would still be effective for homing

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[1] A.M. File C.30486/46.

[2] The aircraft were actually allocated to O.T.Us.

[3] A.M. File C.30486/46.

[4] A.H.B./IIE/100. Gee and Oboe.

back to base and for part of the way towards target areas. After weighing up the arguments for and against the immediate use of the few Gee sets available, or waiting for an increase in supply, the conference decided that no more operational flights were to be made until the first 300 sets were ready, and that a meeting should be held a few weeks before that date to reconsider the position. It was hoped to create a general impression meanwhile that the lost aircraft had been an isolated experimental one and that further tests had been stopped as the system had proved a failure.

Although Gee was officially ' dead ', work continued on plans to reintroduce the system at an appropriate future date. No. 115 Squadron produced a very comprehensive report, in conjunction with the Operations Research Section, Bomber Command, on 23 August 1941 showing that as a navigational aid Gee was undoubtedly far in advance of any other system then in operation in the Royal Air Force. The report was discussed at a meeting held at the Air Ministry on 26 August 1941, which had originally been arranged to consider the results of the operational trials made by Bomber Command and to consider the future policy of operational use.[1] It was decided to hold the meeting despite the change of plans in order to reconcile the new policy with the action in hand at the Ministry of Aircraft Production, which was working on the requirement formulated by the Chief of the Air Staff on 18 August 1941 when he stated that eventually all aircraft of Bomber Command were to be fitted with Gee on aircraft production lines, after which the needs of Coastal Command and of night fighter aircraft were to be considered.[2] Fifty hand-made models of the original design were to be completed by the end of October, and a further 250 by 1 January 1942, with a follow-on of 50 per week.[3] Mass production was to start in May 1942, a figure of 300 per week being aimed at, as it was estimated that 1,200 to 1,500 sets per month would be needed to meet the Bomber Command programme alone.

Ground Station Organisation

With a promise of 300 aircraft equipments being made available by 1 January 1942, the target for beginning Gee operations was set at that date. The Gee ground system, in August 1941, consisted of a chain of three stations, which would be used for operations early in 1942, the location of additional ground stations naturally depending to a great extent upon the outcome of the operations. Meanwhile, a short-term policy, to be effected as quickly as possible, was for Daventry and Stenigot to be duplicated and Ventnor to be resited and duplicated at some position on the mainland, the reserve stations to be in operation by January 1942. The most important work on the ground stations for immediate action was refinement of the existing equipment including the strengthening of aerial arrays where possible. In September 1941 the first reserve site, for Daventry, was selected at Sharman's Hill, 3½ miles distant on the main Banbury road. A reserve site was chosen for Stenigot between Wragby and Alford at Tetford, about 4½ miles south-east of the original site, and on 23 October 1941 a site was found at Gibbet Hill, on the Hog's Back, for a duplicate of the Ventnor station.[4] Originally it was planned to use

[1] A.H.B./II/69/210. Gee. [2] A.M. Files C.30486/I, S.7515.

[3] Production estimates were : 200 receivers from Dynatron by 31 December 1941 ; 300 receivers from Cossor by 31 January 1941 ; 50 per week thereafter from Cossor up to a total of about 1,000.

[4] A.M. File C.30468/46.

Gibbet Hill as a reserve for Ventnor but the latter's technical performance and vulnerability gave rise to some concern, and as Gibbet Hill consisted of a main and a reserve installation it was decided in December 1941 that as soon as the new station had been running satisfactorily for one month the Isle of Wight station should be taken off the air completely.

The question of providing further Gee coverage was considered in September 1941.[1] The first chain was to give coverage about 400 miles to the east of England, but this left out the whole of the Lincolnshire and Yorkshire areas. The Air Officer Commanding-in-Chief, Bomber Command was particularly anxious about this lack of cover.[2] He pointed out to the Air Ministry on 25 September 1941 that if the heavier types of bomber aircraft were to be used in operations involving the use of Gee the number of suitable aircraft bases within the existing Gee coverage would be insufficient for the planned installation programme of 300 aircraft and consequently squadrons from Nos. 1, 4 and 5 Groups in Yorkshire and Lincolnshire would have to be fitted. Although the primary function of Gee was to assist in target finding it also provided a very accurate homing service within the coverage and he accordingly recommended that the erection of an additional chain of stations should be started at once so that it would be available for use in January 1942. The Director of Telecommunications indicated that a fourth station for the first Gee chain was to be sited near Shrewsbury and would provide coverage over the areas lacking it, and also, coverage to the south. The building of a complete new chain could not be envisaged before 1942, and therefore the Air Officer Commanding-in-Chief, Bomber Command had to be satisfied with the method proposed for meeting his immediate requirements. The ground organisation appeared to need more co-ordination, and on 28 October 1941 the R.D.F. Chain Executive Committee (B) met for the first time. With Sir Robert Renwick as chairman the committee had been formed to organise and co-ordinate all works production, erection, and installation services of the Gee stations, which in future were to be known generally as Type 7000 stations.[3] Despite the efforts to complete the ground station programme the target date for Gee operations receded further into the distance as 1941 drew to a close. Two main factors delayed the operational introduction of Gee. One was a matter of security, and concerned the provision of lattice navigation charts, the other was the delay in the aircraft installation programme.

Preparations for Operational Use

When Gee was first used experimentally, and during the operational trials of August 1941, a film of the lattice was used in an astrograph. Although the method was satisfactory for general navigation it suffered from many

[1] A.M. File C.30461/46. [2] A.M. File C.17185/44.

[3] A.M. File S.8135. Each individual station was to have a four-figure number. The hundreds indicated the number of the chain to which the station belonged, the tens the type of station, whether master, slave, monitor, or reserve (1, 2, 3 and A), and the units the individual number of the station. Thus the numerical designations of the first chain were :—

Daventry, master station	7111A
New Daventry, master station (to be the main station)	7111
Ventnor, slave station	7121
Stenigot, slave station	7122
Gibbet Hill, proposed slave station	7123
Clee Hill, proposed slave station	7124
Great Bromley, monitor station	7131

disadvantages when compared with the use of charts on which the lattice was printed in two colours and which were numbered and drawn in a special way designed to simplify as far as possible the task of the navigator.[1] At conferences between those concerned unanimous agreement was reached that the use of printed charts was the only means of interpreting Gee readings which ensured the highest degree of efficiency and the least likelihood of errors on the part of the navigator, and the decision was confirmed at a meeting presided over by the Deputy Chief of the Air Staff on 18 October 1941.[2] The question then arose of how security of the charts could be safeguarded in view of the danger that, should one of them fall into the hands of the enemy, the latter could produce countermeasures which would considerably reduce the effectiveness of Gee. Opinion varied about the degree of risk involved, but it was eventually decided that every possible precaution should be taken to ensure destruction of the charts by the provision of destructor boxes, and by insistence on the most stringent training and discipline in their use. There was no time to evolve complicated equipment which would take months to produce, for already the original target date of 1 January 1942 had been overshot. The destruction system had to be completed and installed by 1 February 1942, the revised target date for the first operational use of Gee.[3] The date of introduction into operational use was dependent on the aircraft installation programme, and that caused even more delay than the security problem. On 5 November 1941 the Chief of the Air Staff informed the Prime Minister that development of Gee was going along as fast as was possible, and that he hoped its operational use by aircraft from the majority of bomber bases in the United Kingdom would begin early in February 1942.[4] The Prime Minister pressed for an earlier date, but the supply and installation situations, aggravated by the transfer of three Wellington squadrons to the Middle East, made it necessary to postpone the commencement of Gee operations until after 15 February 1942. It was then left to the discretion of the Air Officer Commanding-in-Chief, Bomber Command, to defer their start until he was reasonably certain of a spell of fine weather.[5]

Meanwhile, although research had been made into the theoretical accuracy likely to be obtained with Gee, it had been impossible to forecast with any certainty the probable error. It was of vital importance that this should be discovered before operations began in order that they might be planned economically to provide maximum concentration in the minimum time with as few aircraft as possible. There was no time to carry out a long series of trials, but flights by two or more aircraft making as many runs as possible over a selected target during three or four days were considered sufficient to produce information upon which accurate planning might be based. It had therefore been decided to form No. 1418 Flight at Marham with four Wellington III aircraft to carry out special duty flights for the development of Gee from 10 January 1942.[6] The flight was stationed at West Freugh on the north-west coast of Scotland, and an army G.L. set was installed in the neighbourhood to check the position of the aircraft as they carried out performance tests over the Mull of Galloway. Fixes obtained both on the ground and in the air were collected for analysis. From 12 January 1942 accuracy trials were carried

[1] A.M. File C.30486/46. [2] A.M. File C.30486/46.

[3] The first 400 destructor canisters were ordered by 10 January 1942: 250 had to be available at maintenance units on 21 January 1942.

[4] A.H.B./ID/12/193. [5] A.M. File C.30486/46. [6] A.H.B./II/69/210.

out for five days, but because of initial technical difficulties only the results of the last two days were considered. It was found that there were three main errors which fundamentally affected the accuracy of Gee. They were caused by incorrect operation, limitations of the monitoring equipment, and discrepancy between calculated and observed co-ordinates of Great Bromley.[1]

The first source of error was overcome by the issue of detailed instructions on the operation of Gee ground stations, prepared by the Telecommunications Research Establishment and passed to Headquarters No. 60 Group for distribution to the operators. The problem of the limitation of monitoring equipment was passed by the Operations Research Section, Bomber Command, to the Telecommunications Research Establishment so that the possibilities of producing equipment which would allow increased accuracy in the phasing of slave stations could be investigated. In view of the seriousness of the limitation, improvement of the monitoring equipment was given the highest priority, and every effort was made to install it in the shortest time possible. The third error was found to have occurred because the co-ordinates of the new Daventry station, which was not yet in use, had been provided for the trials by mistake. It was also recommended that slave stations should always be phased to give the correct reading at Great Bromley and this was taken up with Headquarters No. 60 Group.

Following exercises carried out by No. 3 Group in February 1942 to test operational techniques, a decision was made that flares should be used as a fundamental principle of Gee attacks and a method was devised, called the 'Shaker' technique, for using three task forces in the following order :—[2]

(*a*) Flare-carrying force.

(*b*) Incendiary-carrying force.

(*c*) Main striking-force.

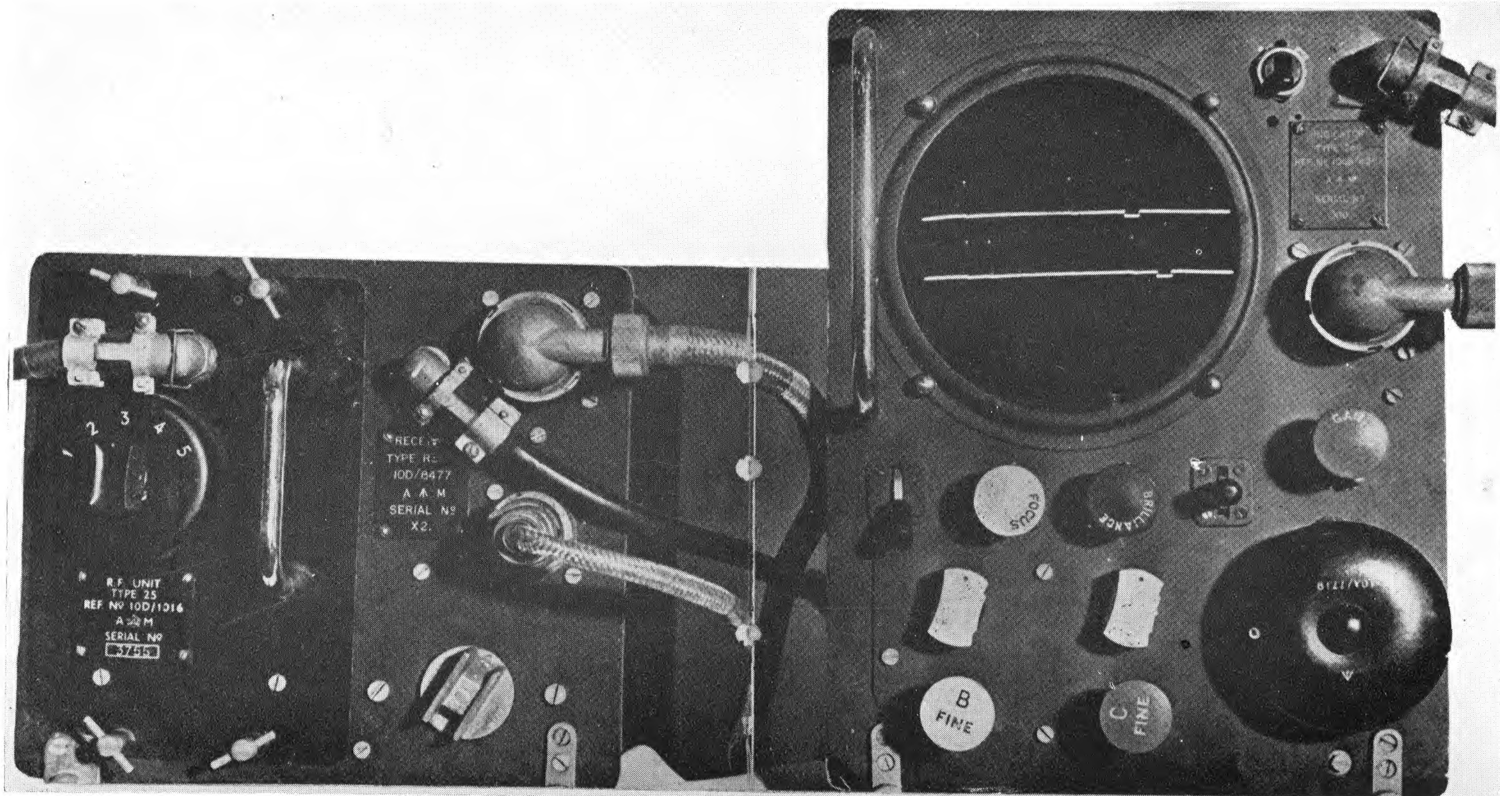
The sequence of a raid allowed for only small margins of error in the time of attack. The flare force aircraft, navigated to the target by means of Gee, were detailed to arrive continuously at two-minute intervals, and the incendiary force within a period zero to zero plus 13 minutes. The main force not equipped with Gee had wider scope, but were required in 15-minute waves, that is, zero to zero plus 15, zero to zero plus 30. The timing requirements made a more exacting demand upon navigational accuracy than had previously been called for, but were considered to be justified in view of the proved accuracy of Gee. It was expected that the system would enable an aircraft to bomb a selected area in or through ten-tenths' cloud and thus to increase the average number of effective operational nights per month from about three to possibly 20 or more.[3] Although it was realised that the accuracy to be obtained from Gee in that part of Germany lying within its range might not be quite as high as that obtained during Service trials over the United Kingdom, a provisional estimate made by the Air Warfare Analysis Section suggested that 47 per cent of bombs would fall on Essen in ten-tenths' cloud, and that Gee should therefore be regarded as a blind-bombing device and not merely as a navigational aid.[4]

[1] A.M. File S.8135.

[2] A.H.B./IIM/AI/3a, Appendix B1919, 5 April 1942.

[3] Air Ministry D.B. Ops. paper on Area Attack employing Gee. 16 January 1942.

[4] A.W.A. Report B.R.A./3.



Aircraft Gee Receiver/Indicator

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First Operational Use

When at last there seemed a reasonable prospect of a spell of fine weather, the first Gee operation was launched, although the number of aircraft available was still below that originally required by the Chief of the Air Staff with which to begin Gee operations. The night chosen for the first raid was 8/9 March 1942 and 211 sorties were made against Essen, of which 82 were made by aircraft fitted with Gee, receiving pulses from the Daventry master, and Stenigot and Gibbet Hill slave stations. The operational results of the first raid were disappointing. Photographic evidence showed that although there was little doubt that the majority of aircraft equipped with Gee flew over the target, and although built-up areas were sighted and bombed, in many instances the main objective of Essen was not attacked, proving the bombing to be far less accurate than had been expected from the trials carried out in the United Kingdom. Technically, however, the Gee equipment was far from disappointing, only nine of the 82 receivers being reported as faulty. Transmissions from the ground stations were kept accurately phased for the whole of the operational period, and although there was little doubt that over the Ruhr the A (master) pulse was the weakest, even this was received satisfactorily by the majority of aircraft. In the remaining few aircraft poor reception was caused mainly by incorrect adjustment of receivers. The slave station Stenigot became unlocked because of weakness of signals from Daventry just before the first aircraft was about to take off at 2340 hours but it was rephased by 2352 hours, and at no other time did the ground transmissions become unlocked. On one or two occasions slight interference was reported by the ground stations, but this was certainly not as intense as had been anticipated.

The first raid and a second attack against Essen on the following night formed the basis of discussion at a conference called by the Air Officer Commanding--in-Chief, Bomber Command, on 13 March 1942, to which he invited the commanders of the bomber groups using Gee.[1] The meeting agreed that Essen had been a poor choice for an initial target. It was at the extreme range of the equipment, and the aircrews taking part had no previous experience of the use of Gee at such a range. In addition, the accuracy of the system was seriously diminished over that particular area because of the acute angle cut given by the lattice lines at that distance. The operational technique tried out had not fully solved the problem of leading a main force to the target. In one instance a flight commander saw the flares when 80 miles away but on arrival he found that the flares were no longer in a concentrated mass and he had to discriminate between a number of groups of dispersed flares. With few exceptions crews could not be certain that they were in the Ruhr area, and had to content themselves with attacking the biggest fires they could find. In short, flares were not maintained in the right place for a long enough period to assist later arrivals. It was suggested that, as a remedy, all aircraft should approach the target on one lattice line and that this line should be selected by navigation and planning staffs of Headquarters Bomber Command. As a further aid, a release height of flares was to be specified together with definite fusing orders so that all flares would ignite at 3,000 feet above ground level.

During the following weeks, to the end of April 1942, 27 major operations were carried out by Bomber Command against targets in Germany and the occupied countries, a fair proportion of aircraft equipped with Gee being used

[1] A.H.B./II/69/210.

in all raids.[1] The sorties gave the general impression that the use of Gee would eventually result in greatly improved accuracy of navigation, especially for targets within the coverage, which was about 400 to 500 miles from Daventry. However, several factors still prevented Gee from being as great a success as had been confidently considered possible. There had been little planning to discover the best means of employing Gee other than the belated trials in January 1942. In February the Director of Bomber Operations had asked if the G.L. set might be retained in Galloway as the data obtained and analysed from the experiments had been so valuable that it was hoped to include such flights in the training programme of future crews.[2] There were practical difficulties, however, in the use of a G.L. station for training Gee navigators and later it appeared that the data was of great academic interest but of less operational value. The final method of using Gee had therefore to be determined by trial and error on operational flights ; it was one of the first problems to be settled before the Gee system could achieve a full measure of success.

A shortage of bomb-aimers added to the difficulties of the Gee planners.[3] During the initial raids of March and April 1942 very few crews carried trained bomb-aimers as they were not available in sufficient numbers, and many of those in the squadrons were lacking in experience. Second pilots, who had been trained in Gee operating when the squadrons were being fitted with Gee, were now needed for pilot duties elsewhere. Navigators were therefore compelled to use Gee solely as a navigational aid to reach a point a few miles from the target, and then to move to the bomb-aimer position for the final run up to the target. Consequently there was a danger that no one would be able to operate Gee at the critical stage in the operation, so that it could not be used to keep the aircraft on track or as a check on target identification, and the navigator was unable to give the signal to release the bombs blindly on Gee indications when ground detail could not be seen. In addition, it was considered that observation of the cathode ray tube spoiled the navigators' 'darkness adaptation'. Eventually, when sufficient bomb-aimers were available for all aircraft equipped with Gee it was essential that very close co-ordination was maintained between the pilot, the bomb-aimer, and the navigator, and a suitable drill was needed. This took time to work out and much practice was necessary. Every effort was made to overcome the limitations but until the programme of conversion to Gee was completed and each crew contained an experienced bomb-aimer who was trained in map-reading and target location as well as in the use of the bombsight, it was impossible to expect maximum success. The correctness of that assumption was confirmed by the results of raids against the Ruhr area and the Rhineland. Aircraft using Gee were less successful than unequipped aircraft during March 1942, but more successful during April, doubtless because of the development of an operational technique and because of the increased experience of aircrew.

Some concern was felt over the possibility of Gee taking the place of the normal methods of navigation, but it was used as an adjunct to those and not as a continuous plotting device. As soon as aircraft reached operational height, navigators attempted to determine the wind velocity by flying on a steady course and taking Gee fixes. They then navigated by dead-reckoning using

[1] A.H.B./IIM/A1/3a, Appendix C, O.R.S. Report No. S.46, 15 May 1942.

[2] A.H.B./II/69/210.

[3] Bomber Command O.R.S. Report No. S.54.

Gee occasionally to check position. By this means navigators were able to follow the specified route and to arrive at the turning point for the run into the target at approximately the correct time. On the homeward journey navigators were encouraged to practise normal navigation, using Gee only as a check on other fixes. It was often used to home an aircraft to its airfield, its value for this purpose being shown by a comparison of the number of aircraft landing away from base during April 1942 ; those carrying Gee 1·2 per cent, those without Gee 3·5 per cent.

Operations against Targets within Gee Coverage

After the first two weeks of Gee operations a procedure for approaching targets within the coverage of Gee was formulated by Headquarters Bomber Command. The available force kept its original three divisions, flare-dropping, incendiary, and main striking forces, but the first, consisting entirely of Wellington III aircraft fitted with Gee, flew over the target along a lattice line and dropped a stick of flares about six miles in length, the centre of the stick being aimed at the target. In order to avoid the danger of being misled by decoys, the stick of flares was laid blindly on Gee plots and therefore the most experienced Gee crews were detailed for the task. The flares illuminated an area about six miles by one mile, the length being parallel to the lattice line and nearly parallel to the major axis of the ' error ellipse '. In this way it was almost certain that the flares would light up the target although they might not have been dropped directly on to it. Sufficient aircraft were detailed for this work to enable the illumination to last for the ' flare period ', which varied from 15 to 45 minutes. The incendiary force, consisting entirely of aircraft equipped with Gee, attacked during the flare period, approaching along the same lattice line, and thus flying over the illuminated strip of territory, which provided an accurate target for the incendiary bombs which in turn caused fires to act as beacons to the main striking force.

By the use of this technique, raids were made successfully against targets regardless of the state of the moon. Such a raid took place on the night of 13/14 March 1942 when Cologne was attacked in complete darkness through drifting clouds. Although Gee was still suffering from its teething troubles, 58 per cent of the photographs successfully taken covered the target area, and later daylight reconnaissance flights confirmed direct hits on industrial centres in the city. Nothing approaching this success had been achieved before except on one occasion, in July 1941, when the moon was full and the weather perfect, and then 60 per cent of photographs covered the target area. The average percentage for all other raids against Cologne since that occasion had been about 10 per cent. So far, Gee had been used as a navigational system and as an aid to target location, but accuracy trials had indicated that Gee held promise as a blind-bombing system, and on 22/23 April 1942 an experimental blind-bombing raid was made against Cologne in very poor weather.[1] Crews were instructed to release their bombs on Gee fixes alone and not to make any use of visual identification. It was practically impossible for navigators to disobey the instructions as the weather was far too bad to enable ground observations to be made. For this reason very few photographs were taken but of the five which showed ground detail, four were plotted, two being within five miles of the target and two slightly more distant. From an

[1] A.H.B./II/69/210.

analysis of photographs taken during this raid and all other operations when flare-carrying aircraft released blindly, it could be seen that results achieved by blind bombing would be superior to those obtained visually in poor weather but inferior to those obtained in medium or good weather. Research was continued with a view to reducing the errors sufficiently to make blind bombing effective, as some method was badly needed against such targets as Essen, which were difficult to recognise because of the prevalence of industrial haze.

The ' thousand-bomber ' raids of 1942 were planned on the assumption that Gee could be used for accurately locating targets without visual observation. In the highly successful raid against Cologne on 30/31 May 1942 the flare-dropping technique was not used because the weather was clear and there was a full moon. Nevertheless a large proportion of the aircraft leading the attacks used Gee, dropping full loads of incendiary bombs at or very near zero hour, thus enabling the main force to find the target. The use of Gee facilitated recognition of the target without the necessity to conduct a search visually, and errors in identification and delay in starting fires were consequently avoided, two factors which contributed considerably to the success of the operation. In July 1942 the Chief of the Air Staff asked that the possibility of increasing the efficiency of intruder and other aircraft employed on similar duties by fitting them with Gee should be investigated.[1]. The De Havilland Aircraft Company quickly made an experimental installation in a Mosquito Mark II and the Fighter Interception Unit carried out trials. At the same time, Gee Mark I was installed by No. 26 Group at Stradishall in six Mosquito Mark IVB aircraft, in preparation for use by No. 109 Squadron on special operations. On the results of the trials depended the fitting of No. 2 Group Mosquito bomber aircraft. However, shortage of Gee installations prevented the introduction of Gee into Fighter Command until mid-June 1943, when a number of squadrons were fitted for intruder and ranger operations.[2]

During 1942, when Headquarters Combined Operations was planning for the Dieppe raid, various small raids were carried out, each one accentuating the need for very accurate timing. This problem came to a head during the rehearsal when parts of the force failed to make landfalls with anything like the necessary accuracy because of the difficult tide conditions in the English Channel. Gee had already been tried out by Headquarters Combined Operations in motor gunboats and was judged to have distinct possibilities for the type of raid. Trials had shown that the signal could be held for a good distance although neither maximum range nor accuracy had definitely been established. Nevertheless, it was decided to rely upon Gee as the only system likely to achieve the necessary accuracy for the Dieppe raid. Additional ships and aircraft were accordingly fitted and personnel trained in its use, with the result that during the raid on 18/19 August 1942, Gee proved of very great value. In some quarters reports were received of the inaccuracy of the system, but this was mainly because the installations were put in at the last moment and without adequate testing. In addition, the two lattice lines available off the French coast were not fully suitable to enable accurate fixes to be obtained, especially as inaccuracies in reading Gee indications occurred through weakness of the signals. As the raid moved eastwards up the Channel the error became

[1] A.M. File S.7515.

[2] A.H.B./II/69/210.

greater—up to as much as two miles. Despite the limitations, the success of Gee in the Dieppe raid led to a comprehensive installation programme for Combined Operations' ships and craft and this was later extended to nearly all naval ships and craft operating in areas covered by Gee chains.

Operations against Targets beyond Gee Coverage

For targets beyond the normal cover, Gee was used primarily as an accurate navigation system, fixes being taken every 10 to 20 minutes.[1] By this means it was possible to calculate the wind velocity reasonably well and to maintain an accurate track over the greater part of the distance to the target. As for targets within its coverage, use of Gee enabled accurate timing to be attempted and facilitated accurate routeing of aircraft to avoid heavily-defended regions. The targets outside Gee range which were attacked during the first months fell into two groups, ports in north Germany and inland towns in south-west Germany. Against the ports Gee was extremely useful in enabling accurate tracks to be flown across the North Sea so that landfall could be pinpointed after flying over some 300 miles of sea. Beyond this point map-reading was usually possible, and as accurate navigation had been maintained over the first part of the journey it was possible for concentrated attacks to be made against targets over 500 miles from the United Kingdom.

The most successful operations carried out in the north-easterly direction were directed against Lubeck and Rostock. In both instances aircraft equipped with Gee led the attack, and there was little doubt that the accurate navigation obtained with Gee on the first part of the route enabled the leading aircraft to arrive at the target on time and to light a beacon which was of great assistance to following aircraft. On another occasion, however, when Warnemunde was attacked on 8/9 May 1942, although the leading aircraft arrived on time at the target, accurate bombing was difficult because of extremely effective German searchlight defence. Against inland towns in southern Germany, Gee was very useful for navigation over most of the route, but conditions near the objective usually very much reduced the accuracy of map-reading so that great difficulty was experienced in finding the actual targets. Gee was also installed in a large number of minelaying aircraft. At the low altitudes at which mine-laying operations were usually carried out Gee coverage was limited, but the equipment proved to be invaluable as an aid to accurate navigation. It was used primarily for the initial stages of a sortie only, but occasionally fixes were obtained as far distant as Denmark when aircraft were flying at comparatively low altitudes.

Need for Expansion of Gee Coverage

Throughout March, April, and May 1942 the ground stations of the Eastern Chain gave very good service.[2] A remarkably small number of interruptions occurred during operational flights and those occurring during periods of attack were negligible. Of the few faults most were of short duration, the average being about 30 seconds, while the longest was 16½ minutes. It was never necessary to use any of the reserve stations, and accuracy of phasing was maintained to a high degree. Any changes from the normal programme

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[1] Bomber Command O.R.S. Report No. S.54.

[2] Bomber Command O.R.S. Report No. S.54.

of operations were graded and users were informed by the controllers.[1] The work at the ground stations was, for the most part, of a tedious nature, and to stimulate interest and to maintain the morale of ground operators certain most secret items of operational news were made available at the headquarters of the Gee chain, while outstations were brought into the operational picture to some extent by means of a ' flower code', the wistful forget-me-not implying air/sea rescue, and the flaming red-hot poker nuisance raids.[2] During the first month, reception of the Daventry master station over the Ruhr was frequently inferior to reception of the slave stations, a fair proportion of aircraft on several nights reporting weak A pulses in spite of the fact that the Ruhr was well within coverage. On 31 March 1942 a number of aircraft took off to attack Essen by day, making use of cloud cover and relying on Gee for navigation to the target. Unfortunately the pulses faded over Holland, and this technical failure of the system was later attributed to the peculiar meteorological conditions prevailing at the time.

As it had been impossible to estimate an accurate maximum range limit for Gee from theoretical calculations, it was subsequently calculated from the records of last and first fixes obtained by navigators during raids against targets beyond the coverage of Gee. Apart from variations due to changes of height there were considerable differences between individual aircraft, possibly because of variations in tuning or because of varying skill of the navigators. The ' probable range ' at any height was therefore defined as that distance from the master station at which half the navigators had obtained fixes at that height. For purposes of comparison between various nights, ranges obtained at various heights were corrected to 12,000 feet, the resulting probable range being taken as the standard. The average probable range at 12,000 feet on the route to Heligoland was about 385 miles, but this varied from night to night by approximately plus or minus 25 miles. In the direction of Mannheim, the average range was 420 miles, varying again by about 30 miles either way.

Range was not the only limitation of the Gee system. The operational area was also restricted to north-west Germany by the original layout of the ground stations. A Southern Chain had first been proposed in December 1940 when Mr. Dippy pointed out the need for giving bomber aircraft a navigation aid to enable them to find the advanced base airfields of the enemy in occupied France, which were difficult to discover because of camouflage and lack of landmarks.[3] Further consideration of the idea was postponed by the Director of Communications Development in February 1941 until data was available from trials of the experimental Gee equipment.[4] In July 1941, Headquarters Bomber Command proposed a Southern Chain to increase Gee cover but had to be content with a fourth station added to the original Eastern Chain.[5] A long-term policy of establishing additional chains was examined in October, and in the following month the T.R.E. decided that sites could be chosen fairly easily for Southern, Western and North-Eastern Chains but the provision of

[1] The grades were :—Grade A—Operations in progress.
Grade B—Normal transmissions.
Grade C—Not for use in the air.
Grade D—Stations closed down.
Grade Z—Transmissions totally unreliable and may be off tune.

[2] *See* Appendix No. 3 for details of Flower Code.

[3] T.R.E. File D.1235.

[4] T.R.E. File D.1235.

[5] A.M. File C.17185/44.

adequate locking between sites in the north and north-west, that is, in the Shetland and Orkney Island area, would present great difficulties.[1] In November 1941 it was decided that the order of priority for subsequent chains should be :—

(*a*) Southern.

(*b*) North-Eastern.

(*c*) Western.

With work on the first two proceeding simultaneously if possible, the Southern Chain was to be available by May 1942 and the North-Eastern by July 1942.[2]

Southern Chain

In December 1941 the T.R.E. began prospecting for Southern Chain sites. The cover to be provided by the chain was to fit on to the existing cover of the Eastern Chain (or 7100 as it was then termed) and to extend over France including its west coast as far south as possible. The greatest possible accuracy was needed on the French coast between Dieppe and Brest. From experience of the Eastern Chain it had now been decided that distances between the slaves and master stations could not be less than 80 miles in order to maintain accuracy at long ranges, and should not greatly exceed 100 miles in order to have adequate locking signals, an angle of 120 degrees being needed between the 'legs' to give a fair amount of accuracy immediately in front of the system. Because of the existing facilities at early warning radar stations, those sites were to be used wherever possible, C.H. stations being preferred to C.H.L., but the latter were to be used in preference to an entirely new site. The only C.H. stations which could possibly be considered suitable for master stations were Ventnor and Worth Matravers but Ventnor had already proved to be too vulnerable and Worth Matravers was rejected because it was screened by the Purbeck Hills and also because it was impossible to obtain a reasonable angle between the legs to the slaves. A new site was finally chosen at Bulbarrow Hill and was found to be an excellent choice technically. No suitable C.H. station existed in the area required for the eastern slave as they were all sited on low land near the coast. The choice therefore fell upon Truleigh Hill C.H.L. station and the risk of any possible overcrowding was felt to be justified in view of the difficulties involved in alternative sites. The C.H. station at West Prawle in Devon was found to be quite suitable for the western slave.

The problem of finding a monitor station for the new chain was much more difficult than the siting of the chain itself. The main reason was that as the stations were so close to the coast it was impossible to find a site in front of them at reasonable distances from the master without going much too far from one slave. Sites far behind the chain were out of the question as there would have been too much screening from the hills, so it became clear that a site relatively near the master would have to be used. This had two disadvantages ; the signal strength from the master would be vastly greater

[1] A.H.B./II/69/210. These were final-phase proposals submitted by the T.R.E., consisting of four systems to cover the whole British Isles, of which two systems covering the north and west would operate on the common frequency and two systems covering the east and south would have separate frequencies and alternatives.

[2] A.M. File C.30486/46.

than that from the slaves, which was technically undesirable, and ground reflections from nearby hills came in at strength comparable with the slave signals and so would confuse the picture. It was also stipulated that a monitor station should be sited near a main telephone cable because of the great number of lines required from that type of station. However, no suitable site existed near a cable route and finally a site was found at Brandy Bay, Dorchester, excellent from a technical point of view but five miles from a main telephone route with no easily accessible power supply. Despite the fact that the site was not approved until the middle of February 1942, and installation of equipment for the whole chain did not begin until 10 April, all stations except the monitor were ready by 15 May 1942 for operational tests with No. 1418 Flight, and Truleigh Hill acted as slave-monitor until Brandy Bay was ready.[1]

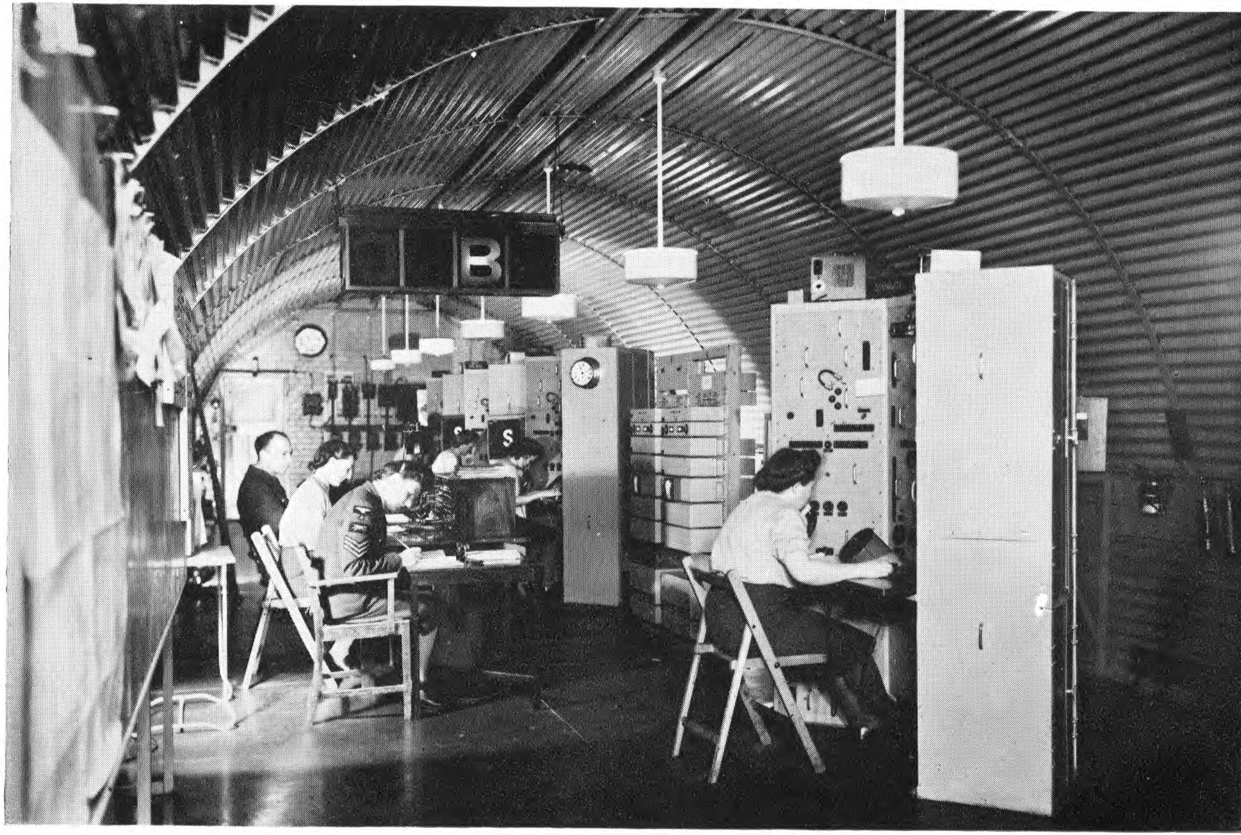
In January 1942 the Director of Telecommunications had stated that he wished to make certain that the Eastern and Southern Chains could work simultaneously on one frequency without causing confusion to aircraft navigators, as the general introduction of a Gee Mark II aircraft installation with its two frequency channels was not expected before October 1942.[2] He was assured that although the two chains would be working on the same radio frequency, they would have a different pulse recurrence frequency and any interference which might be expected would consist of a faint background haze on the cathode ray tube which would be insufficient to affect the reading of the signals in any way. In April 1942, however, the T.R.E. carried out tests with ground trainers representing two chains on the same radio frequency using different pulse recurrence frequencies, and it was agreed that the average navigator would have great difficulty in using the system satisfactorily.

The Southern Chain became fully available on 20 July 1942, on a frequency of 44·9 megacycles per second, but as it could only be used as an alternative to the Eastern Chain, Headquarters Bomber Command arranged that it should operate two days per week or when required in an emergency, on the instructions of Bomber Command Operations Room to the controller at Great Bromley.[3] Reports from the bomber groups showed that the forward coverage of the chain was good and the accuracy was judged, from visual observations, to be excellent. Numerous fixes had been obtained by aircraft flying as low as 2,000 feet just north of Bordeaux, and homing was possible down to 3,000 feet.[4]

South-Eastern Chain

In June 1942 the Admiralty stated a requirement for better Gee coverage in the English Channel with improved fixing at sea-level.[5] As speed was essential, it was decided to erect a D slave for the Southern Chain. This station was to provide accurate position lines for naval craft in the Straits of Dover and as far west as Fécamp where the A pulse of the Southern Chain might not be visible. Canewdon C.H. station was chosen as a possible site and an MB2 transmitter was set up on 44·9 megacycles per second, locked to Truleigh Hill. In tests between Newhaven and North Foreland, with two motor gunboats fitted with Gee Mark I, it was found that sufficient signals

[1] A.M. File C.17185/44. [2] A.M. File C.30486/46, Part III. [3] A.M. File C.17185/44.
[4] Bomber Command File BC./S.25906. [5] A.M. File C.17185/44.



Gee Monitoring Station Barkway

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were received for fixing, so a permanent type of station was set up at Canewdon, the two stations becoming known as the South-Eastern Chain.[1] Unfortunately this subsidiary chain was not completed in time for the first major Combined Operations raid against Dieppe.

Northern Chain

Although the southern and eastern parts of Britain were the more important operational areas in 1942, the north had not been forgotten. It had been placed second in the list of priorities and it had been hoped to bring the Northern Chain along in parallel with the Southern Chain, but by the time the latter was practically completed in May 1942, work had not started on the former.[2] There were two reasons for the delay ; every effort had been put into improving the Eastern Chain and constructing the Southern, and it was quite impracticable to begin siting or constructional work in the north of Scotland or on the Islands during the winter months. The position was reviewed in April 1942 when Headquarters Bomber Command seemed doubtful whether a Northern Chain was really an operational requirement, and it was the officially recorded view that Headquarters Coastal Command was not interested at all in Gee.

This had been the case when the subject was discussed with Headquarters Coastal Command in November 1941, as the lack of range at low heights had led to a preference for A.S.V. beacons.[3] However, that view was modified and the Air Officer Commanding-in-Chief, Coastal Command asked for installations to be made in two squadrons to test the possibility of Gee

[1] The chains then worked as follows :—

Chain.	Master.	Slave Stations.	Users.	Frequency in mcs.
Eastern (Virginia)	Daventry	Stenigot Gibbet Hill Clee Hill	Bomber and Fighter Commands U.S. Army Air Force and Combined Operations	48·75
Southern (Virginia)	Bulbarrow	Truleigh Hill West Prawle	Bomber and Fighter Commands U.S. Army Air Force and Combined Operations.	48·75
Southern (Carolina)	Bulbarrow	Truleigh Hill West Prawle	Coastal Command and Combined Operations	44·90
South-Eastern (Carolina)	Truleigh Hill	Canewdon	Combined Operations	44·90

Although the Eastern and Southern (Virginia) Chains could not radiate simultaneously, the Southern (Carolina) Chain could operate with the Eastern Chain, and the South-Eastern Chain could radiate simultaneously with any other chain. As Combined Operations were the only users of the latter chain it could be brought up or closed down at their request without reference to any other users of Gee.

[2] A.M. File C.30486/46, Part III.

[3] Bomber Command experience of Gee at low heights (below 5,000 feet) was that the average range was 250 nautical miles. Only about once in 20 times were ranges of less than 150 miles recorded. Up to a height of 5,000 feet there seemed to be no consistent change of range with height. Even at 500 feet or 100 feet range was, in the few instances recorded, about the same as at 5,000 feet. As height was increased above 5,000 feet the average range increased slowly to about 350 nautical miles at 20,000 feet. The variations of range appeared to be due to the fluctuating effects of atmospheric refraction although they had not yet been correlated with weather conditions. There seemed to be no consistent difference of range over land and over sea. (O.R.S./C.C./8/5.)

fulfilling the command's operational requirements. An officer from the Directorate of Telecommunications had also visited Headquarters Coastal Command, and confirmed that there was a need for Gee coverage in the North Sea towards Norway and between the Hebrides and the Faroes, although the Air Staff of Coastal Command was dubious about pressing its claims until some experience of the equipment had been gained. However, the Director of Telecommunications decided that such a Gee chain would be of great value and wished, in view of the climate and inaccessibility of the sites, to see work started in the spring of 1942 so that full advantage might be taken of the summer weather. It was hoped to have the chain completed before October 1942. Several combinations of sites were inspected, and after complications of inaccessibility had been weighed against operational suitability, a combined master and monitor was chosen at Burifa Hill, with three slaves at Scousborough, Windy Head (Fraserborough) and Sango.[1] Work began on the chain in June 1942, with a target date of September 1942. Difficulty with road making and delay in the supply of electronic equipment deferred the completion date until 1 November 1942.

The Northern Chain, like the Southern Chain, could not be used operationally at the same time as the Eastern Chain until Gee Mark II was introduced into general Service use. By August 1942, when it became certain that the equipment would not be generally available for some months, Headquarters No. 60 Group requested that the opening date of the Northern Chain should be postponed until Gee Mark II was actually in use. However, Headquarters Bomber and Headquarters Coastal Commands both insisted on the original target date and the chain became operational on 14 November 1942, with very little hope of actually being used until the following year.

Precautions against Jamming

Increase of coverage had not been the only reason for the accelerated building of the Southern Chain—it was to be a ' second string ' in the event of enemy jamming. During the first month of operations casualty figures of Gee-equipped aircraft showed very little difference from those of non-equipped aircraft, but up to the end of March 1942 about 20 aircraft in which Gee was installed had been lost over Germany, and there was therefore every reason to believe that the Germans possessed some of the equipment.[2] This fact led Headquarters Bomber Command to ask if operational use might be made of 140 aircraft which had been delivered without lattice chart destructors and which were consequently grounded.[3] At that stage it seemed imperative that the maximum possible Gee effort should be made before the enemy could reduce the effectiveness of the whole system with interference. Approval was given although it was decided to continue using the destructors already installed so that, when additional stations were set up, the disclosure of their positions to the enemy could be delayed. However, in June 1942, development of a chart destructor was abandoned and the equipment was removed from all aircraft. To understand the plans made and precautions taken to counteract enemy jamming it is necessary to survey the several ways in which the Germans could either deny the use of Gee to aircraft or make use of the

[1] The master and monitor stations were originally named Dunnet Head but this title was altered to Burifa Hill as there was already a naval station and a proposed Type 271 station of that name.

[2] B.C. O.R.S. Report No. S.54.

[3] A.H.B./II/69/210.

equipment themselves. If sufficient Gee sets were captured then the enemy could salvage enough undamaged parts to equip a number of his own aircraft and to employ them on fire-raising tactics over Great Britain. To deal with that contingency, Gee transmissions were to be coded. Headquarters Bomber Command tested out a system designed to enable squadrons to change over to Gee coding with the minimum delay. Briefly, the method consisted of retarding the slave pulses so that the navigator had to subtract the code number from the Gee numbers obtained from his equipment before finding his position from the lattice charts. For simplicity, the coding was at first confined to whole Gee number changes as this was less confusing to navigators. The method could be made subtle by avoiding jerky changes. About 156 simple codings were possible and it was proposed to change the code to a pre-arranged schedule.

It was assumed that to deny the use of Gee to British aircraft the enemy would set up ground jamming transmitters which would be so designed to make indications on the cathode ray tubes in aircraft unreadable. In addition, he could send over Great Britain aircraft equipped with jamming transmitters which would interfere with the locking of the slave stations, or, alternatively, interfere with monitoring. It was generally believed that large-scale jamming of Gee was unlikely and it was anticipated that the enemy would only be able to set up transmitters which would jam the reception of Gee over a limited area covering suitable targets. Gee was more difficult to jam than the radar early warning chain as no reliance was placed upon reflected energy, which produced only a very small signal. To counteract ground jamming, the mass-produced aircraft equipment Gee Mark II (A.R.I. 5083) was to be capable of rapid switching to any of five spot frequencies in the band of 40 to 50 megacycles per second. A replaceable R.F. unit was also designed to give five spot frequencies in the band 20 to 30 megacycles per second. Thus if it were possible to avoid interference by changing to the 40 to 50 megacycles per second band this could be done, but in any case a changeover to the 20 to 30 megacycles per second band should be temporarily effective. Ground stations would work on one radio frequency in the 40 to 50 megacycles per second band and would be able to change to the 20 to 30 megacycles per second band within a few hours.

Jamming of the locking lines was not considered to be a really serious threat as it would require standing patrols of enemy aircraft over the United Kingdom. Nevertheless, the failure of locking lines could be overcome by the filter comparator oscillator which was to be installed in all slave stations and which would enable the stations to run for some time without radio-locking but would need rigorous monitoring and hand-phasing. There did not seem to be any complete answer to monitor jamming, but the monitor station was less liable to detection as it did not transmit. Finally, there was the danger of direct bombing attacks against any of the Gee ground stations with the possibility of damage to installations, telephone lines, or radio links. As a precaution against such action, at each site there had been installed both a main and a reserve station, sited approximately 400 yards apart, the reserve station containing all the essential equipment to carry on operations. Landline communications also consisted of main and reserve systems which were planned so that the main lines could eventually be placed underground. To safeguard the communications further, the possibility of installing V.H.F. R/T links was being investigated. Transmissions on reserve frequencies were limited to unlocked transmissions from single stations, except for the minimum transmissions necessary to test locking. No aircraft equipment was set up on the frequencies until they were brought into use, and when Gee Mark II became available spare channels were to be tuned to certain spoof frequencies on which Headquarters No. 60 Group planned to arrange vertically-polarised transmissions.

First Jamming Offensive

There is no record either in British or German documents of any immediate German interest being taken in Gee after the first aircraft was lost over Hanover on 12 August 1941 and it must be assumed that the aircraft was not found or else that the detonators had done their job sufficiently well to arouse no suspicion. Bad interference was first experienced almost one year later when, on 4/5 August 1942, 22 Gee-fitted aircraft took part in a raid against Essen and most of the crews reported losing Gee signals 10 to 20 miles from the target.[1] Most of the interference was attributed to static and electrical disturbances, and three aircraft engaged in minelaying near the Frisian Islands reported normal reception. On the following night eight aircraft attacking the Ruhr found that their signals were blotted out just beyond the Rhine, yet 36 minelayers over various sea areas from Heligoland to La Rochelle reported that reception was normal, except for three crews who reported much ' grass ' off the Frisian Islands.

On the evening of 6 August 1942, a Bomber Development Unit Mosquito aircraft was sent to Duisberg to check on the interference and it was found that the Gee signals were all weak, especially A, and considerable W/T interference was experienced. The pulses appeared to be suppressed, falling partly below the time-base, and the strobe time-base appeared as about nine lines dancing in a vertical plane. Later that night a force of 122 aircraft attacked the same target ; 12 crews reported that conditions were normal, 26 found that interference blotted out all signals in the target area, 46 were able to use the signals despite the interference, and the remainder reported that signals were weak or that they faded. On the following day the reports were discussed at a meeting of radar officers of the various groups in Bomber Command, and the possibility of enemy jamming was suggested, but it was agreed that the trouble was probably due to meteorological conditions. During the afternoon, a Bomber Development Unit Mosquito was again sent to Duisberg for accuracy trials and reported interference similar to that of the day before but not to the same extent. On the night of 9/10 August 1942 a strong force attacked Osnabruck, and all aircraft reported Gee to be ineffective east of the Zuider Zee. It was clear that Gee had been deliberately jammed between the Zuider Zee and the target, and investigation revealed that the time-bases had been split up into a number of wavy lines which blotted out Gee signals. An attack against Mainz was planned for the next night but was cancelled at the last moment in favour of minelaying in the Kattegat area and there were no reports of interference there. The night after, however, Gee-equipped bombers, accompanied by an investigating Bomber Command Development Unit Wellington aircraft, attacked Mainz, and enemy jamming was again successful, Gee becoming

[1] A.H.B./II/69/210.

ineffective over Belgium. The Wellington aircraft followed the same route as the striking force, at a height of about 20,000 feet. The first indications of jamming were observed at approximately 15 miles south-south-east of Ghent where there was slight thickening of the main time-base. This gradually increased in width until it became a band of noise which was more regular in structure than normal receiver noise. At first the pulses were clearly visible, their amplitudes being considerably greater than that of the interference, the A pulse becoming weaker while the B and C pulses remained strong. Finally fixing became impossible and no further readings were obtainable until the aircraft reached practically the identical position on the return journey. All signs of jamming finally disappeared 25 miles inside the Dutch coast.

German documents indicate that the existence and method of operation of Gee was first discovered in March 1942, but the decision to jam the system was not taken until August 1942. A jamming transmitter was hurriedly improvised from a standard ground transmitter used for R/T communication, modulated to operate on 150 to 200 kilocycles per second. Before the makeshift equipment was used, a Dr. Mogel had been experimenting locally with jamming transmitters for a short time, which probably accounted for the interference experienced in the first week of August. In the same month the Germans placed an order for a large number of jamming transmitters to counter Gee raids. They were ½-kilowatt *Heinrich* transmitters, the first coming into operation in November 1942. A considerable number of monitoring stations placed about 100 kilometres apart were erected around the coast of occupied Europe from Brest to Norway.[1] Each site had two *Heinrich* transmitting units, one operational and one spare, and these monitored all possible wavelengths. Changes of phase were also reported so that when German pilots flew with Gee equipment, they could be notified by W/T.

The effect of the jamming was not to destroy the accuracy of Gee working but to reduce the range at which fixes could be obtained, the range from Daventry being cut from about 400 miles to about 250 miles. As range limitation was one of the most important disadvantages from which Gee suffered, this was a serious setback and meant that all targets in Germany lay outside the coverage. Therefore, until means of overcoming jamming were available, Gee could not be used for locating the principal targets, but reverted to its original function, a navigation system only. It still overcame, however, one of the greatest difficulties of navigation, as it provided an accurate fix when the aircraft had attained operational height.

Although blind bombing and target approach by Gee were out of the question for a time, the possibility of successful anti-jamming measures was not overlooked and it was considered somewhat optimistically that training in the homing and blind bombing techniques should be increased rather than reduced in order that full use might be made of Gee as soon as such measures were available. These were quickly initiated and a simple modification, consisting of a filter in the rectified output circuit of the receiver, was made available to Bomber Command by 19 August 1942.[2] By 21 August 520 sets had been modified, and a greatly improved performance in the face of jamming was achieved. But gradually enemy jamming increased in effectiveness, and it was realised that further steps would have to be taken to ensure the uninterrupted use of Gee. The most obvious way was to introduce a change of frequency.

[1] *See also* Appendices No. 8 and 9.

[2] B.C. O.R.S. Report No. S.61.

CHAPTER 6

GEE MARK II

It had been hoped that Gee Mark II would be available for installation in operational aircraft when enemy jamming started, but although the prototype was completed by March 1942 production equipment was not ready until October 1942.[1] When the first of these equipments were used in trials they were very unsatisfactory because of faulty components and had to be sent back to the makers. In the meantime it was decided to confine Gee operations within the area covered by the Southern Chain. From the middle of October 1942 the Southern Chain was used exclusively for major bombing operations, which at that time were mainly directed against targets in France and northern Italy.[2] The first of these took place on 17 October 1942 against Le Creusot, with 94 Gee-fitted aircraft taking part. No jamming was experienced and the average range was 387 miles, comparable with that achieved on the Eastern Chain before the jamming started. On 3 December 1942 a raid was made against Turin, during which the average range was 488 miles while many fixes were obtained over the target, 730 miles from the master station at Bulbarrow Hill. These ranges were the greatest at any time recorded with Gee equipment except for a fix over Gibraltar, which meant a range of 1,000 miles at 2,000 feet, and was probably the result of freak conditions.[3] Operations with the Southern Chain continued into January 1943, raids during that month being made against Lorient, 222 miles from the master station. All aircraft were able to obtain fixes and no serious jamming was reported. In a further attempt to relieve the Eastern Chain from the continuous jamming which was becoming heavier and more effective, it was decided to operate it with main transmitters on a frequency of 44·9 megacycles per second and reserve transmitters on 48·75 megacycles per second. As a long-term policy, arrangements were made to install aerials as soon as possible to enable the Eastern Chain to operate on 20/30 and later on 50/70 and 70/90 megacycles per second.

The Eastern Chain used the frequency 44·9 megacyles per second for the first time on the night 30/31 January 1943 with the 48·75 megacycles per second frequency switched off, because it was found that there was a break-through from one chain to another. Unfortunately the new frequency had already been used by the Southern Chain for other uses than bomber operations and it was known to the enemy. This fact soon became painfully evident, for at 0215 hours the enemy, having discovered the change in frequency, began to jam it heavily and just as effectively as the old frequency.[4] The range of the Eastern Chain was reduced still further during February 1943 by enemy interference, and by a comparison of the figures for February with those for

[1] A.M. File C.30486/46, Part III.
[2] B.C. O.R.S. Report No. S.69.
[3] A.H.B./II/69/210.
[4] B.C. O.R.S. Report No. S.81.

November and December 1942 it could be seen that ranges on the Southern Chain had also deteriorated This indicated a stepping up in the enemy jamming which was corroborated by aircrew reports.

Introduction of Gee Mark II

It had been the original policy to delay as long as possible the date of using Gee Mark II operationally to stave off its possible capture by the enemy, but the increase in jamming of Gee Mark I made this no longer a feasible proposition, and during February 1943 the first Gee Mark II installations were brought into operation.[1] The main advantages of Gee Mark II over Mark I were its superior anti-jamming circuits and greater frequency flexibility. The latter was achieved by enabling navigators to change frequency while in the air and thus to operate on different chains.[2] The new equipment also allowed the ground stations to change from the jammed frequency. The target date for the changeover from Mark I to Mark II had been 13 February 1943 but although this was not met because of technical and production difficulties, installation proceeded fairly rapidly from that date. Although at first there were too few Mark II sets in use to enable any definite conclusions to be drawn about the performance compared with the obsolescent equipment, the operational range of the aircraft using the new sets did not appear to differ markedly from those using the old and, in general, the Mark II receiver was somewhat disappointing. There were fewer manipulation difficulties with the new set but the degree of unserviceability was higher, and when the anti-jamming controls were used the increase in discrimination seemed to be counteracted by a loss of sensitivity.

During March 1943 the number of Gee Mark II installations in operation gradually increased from 10 per cent of the whole force to approximately 60 per cent by the end of the month.[3] There was still little difference in the performance of the two sets, and in fact the average operational range for Mark I was greater than that for Mark II, probably attributable to lack of experience of navigators with the new equipment. By the end of the month the squadrons more experienced in the use of Gee had been equipped with Gee Mark II and as a consequence there was an immediate improvement in the range of operations of the equipment. Serviceability also improved with experience. During May the serviceability of Gee Mark II rose from 86 per cent to 90 per cent, with every indication of more improvement with further use of the equipment. Although the anti-jamming circuits in the new set cut out light interference they also reduced sensitivity to the extent that no real advantage was gained when reception was heavily jammed. In addition the enemy was quite definitely strengthening his jamming systems in the North Sea area, including the use of frequency modulation. A considerable increase or decrease in height brought some relief and ranges of 300 miles at 25,000 feet and over, and 340 miles at 100 feet, were obtained in jammed areas.[4]

[1] A.M. File C.30486/46, Part III.

[2] A.H.B./II/69/210. Frequency flexibility was achieved with four bands of frequencies by using interchangeable R.F. units, covering 20/30, 40/50, 50/70 and 70/90 megacycles per second. The R.F. unit which covered the frequency band in which it was desired to operate could be plugged into the Gee receiver while the aircraft was in flight. Storage space was provided for the three R.F. units not in use. Two of the units could be switched to five spot frequencies, and the other two had a tuning dial which could be used to select any frequency in their bands.

[3] B.C. O.R.S. Report No. S.87.

[4] A.H.B./II/69/210. The long range at 100 feet was obtained over the Ruhr dams, and was probably due to a ' skip ' effect.

In April 1943 a determined effort was made to counteract the increasingly effective enemy jamming. A new operational procedure, known as the target frequency scheme, was brought into use on 8/9 April. Aircraft used one of the normal frequencies on the way out, and just before the target was reached switched to a special frequency, termed 'XF'. The first few XF operations were not very successful mainly owing to general inexperience of the crews, but by the end of April operators had become accustomed to the new method and from 26/27 April some fixes were obtained in the target area for all Ruhr targets, although the mean ranges and the percentage of aircraft obtaining fixes in the target area were not so high as they had been before jamming started.[1] By the same date the replacement of Gee Mark I by Gee Mark II had been completed and every navigator then had the opportunity of using the target frequency, but the Germans started jamming the XF frequency in June 1943. On the night of 4/5 May a broader pulse was introduced in the Eastern Chain and, in general, navigators agreed that it was easier to pick out from the interference. On the other hand, it did not improve the efficiency of the anti-jamming circuits and interference often broke through, the pulse became distorted, and alignment of the pulses was therefore difficult. All the steps taken to alleviate the effect of enemy jamming proved to be temporary palliatives only, and there appeared to be no satisfactory method of reducing the vulnerability of Gee to jamming.

Western and South-Western Chains

Meanwhile Gee coverage was being extended to the west. Headquarters Coastal Command had, in April 1942, visualised a probable requirement for coverage over the Western Approaches, particularly in the southern sector, in addition to coverage in the north.[2] Although, despite jamming difficulties, Gee had proved its worth and reliability in Bomber Command, no very low-flying operations had yet been attempted, but it was considered that, by using a frequency of about 25 megacycles per second for the new chain and by using high sites, the effective reliable range would be over 400 miles at 5,000 feet. Two alternative solutions to the problem of range were considered. One was to wait for the American navigational system, Loran, which was similar to Gee but gave considerably greater ranges. The other was to apply the recent discovery that long ranges could be obtained by using the indirect ray from Gee on 22·9 megacycles per second; ranges from 500 miles up to 1,100 miles, irrespective of aircraft height, had been obtained with one station at Worth Matravers. In September 1942 the Air Officer Commanding-in-Chief, Coastal

[1] The following table shows a comparison between the results obtained in the pre-jamming, jamming, and XF periods :—

	1 Pre-jamming April–May 1942	2 Jamming Jan.–March 1943	3 XF May 1943
Mean range for targets beyond coverage (Routes across Holland in periods 2 and 3).	405	230	280
Percentage of aircraft reporting fixes in target area (Ruhr region).	75	None	12

[2] A.M. File C.30486/46, Part III.

Command made it clear, however, that neither of the proposals would solve his immediate problem, and he wished to have a Western Chain as soon as possible despite the limited range offered to him.

Sites were selected by the T.R.E., the master station on the topmost point of Snowdon, and slaves at Mulaghologa (in the Sperrin Mountains, Northern Ireland) and Tintagel (Cornwall).[1] The chain was to be self-monitoring with a check monitor at Bryn-Ffynon, a poor site technically, and the target date for opening was 1 May 1943. The chain was to work on 25·3 megacycles per second and it was hoped that the longer base-line would improve the accuracy because of the longer range over which adequate locking signals would be obtainable.[2] The slave sites were found unsuitable and work began on two new positions, one in County Antrim and the other at St. Juliot in Cornwall.

Meanwhile, the Coastal Command Operations Research Section indicated that it was not happy about the coverage that the Western Chain would give over the Bay of Biscay. A suggestion was made that two stations of each of the Western and Southern Chains should be used to cover the area, but it was impracticable at that time for any Gee chain based in the British Isles to give cover over the Bay, 400 to 500 miles from the nearest possible site. All that could be expected was that Gee would give the dead-reckoning plot an advanced springboard well to the south-west and provide reasonable homing facilities for the return journey. On 4 December 1942 all work was stopped on the Western Chain, and instructions were given for dismantling the sites. With the invasion of North Africa the strategic situation had changed. As the Western Chain was no longer considered suitable, Headquarters Coastal Command was again asked to review the need for a South-Western Chain. The Air Officer Commanding-in-Chief held the view that if Gee fixes could be provided as far as possible in a south-westerly direction from Lands End, the subsequent navigation errors of aircraft operating against U-boats and with convoys in that area would be appreciably reduced.[3] Furthermore, with the need for operating against U-boats irrespective of the weather in the area or at base, the provision of a Gee service for Coastal Command stations in South Wales, Devon, and Cornwall would greatly help aircraft navigating to and from weather-bound bases.

The building of such a chain was held in abeyance for a time pending the decision on whether Gee should be installed in Coastal Command aircraft. Finally, a legitimate need for Gee in Coastal Command was recognised, and plans were prepared for the building of a site which would give low-flying coverages from 2,000 to 5,000 feet over the South-Western Approaches and the best possible cover over the Bay of Biscay. To meet such a requirement, sites had to be chosen as far south as possible, with a D slave in Wales to extend the cover to the regions south of Ireland. It was made clear that as far as possible existing C.H. sites should be used to minimise the building effort. In January 1943 sites were suggested at Hawks Tor for the master, and at Worth Matravers, Sennen and Folly for the slaves, with a promise that such a chain could be erected in six to eight months. Ground transmitters and receivers had already

[1] A.H.B./IIE/113/6. R.D.F. Chain Exec. Committee B (Gee).

[2] A.M. File C.17445/44.

[3] A.M. File C.17445/44, and A.H.B./II/69/210.

been provisioned and could be supplied without prejudice to other projects. The site at Hawks Tor was soon abandoned because locking signals were not obtained at Worth Matravers and Sennen during tests, and a new master site was selected at Sharpitor, near Yelverton. Although a reduced-scale monitor station was to be used, two monitors were needed, one to monitor Worth Matravers and Sennen and the other to monitor Folly. This was arranged by using West Prawle to monitor the southern stations and the second C.H. channel at Trerew to monitor Folly.

The South-Western Chain was ready to operate by 17 July 1943, and Headquarters Coastal Command was anxious to start right away as 50 aircraft had been fitted with Gee by that date. The question arose, however, whether the operation of the chain on the new frequency band, 20/30 megacycles per second, should be delayed in order to give Bomber Command the first possible tactical advantage of using a new frequency in the area where jamming was most troublesome. Headquarters Bomber Command did not wish to use the new band until 1 August 1943, when the bombing of targets further afield than the Ruhr was to be started, and the decision therefore rested on the comparative operational value of immediate use of the chain to Coastal Command and a fleeting tactical advantage to Bomber Command. Jamming had become such a menace that it was finally decided to wait until 1 August 1943, when Bomber Command could use the new frequency in an area more liable to jamming than that in which Coastal Command aircraft operated. Meanwhile, in February 1943, an alternative to the South-Western Chain was proposed by Headquarters Coastal Command, to cover the North-Western Approaches. By this time, however, the preliminary arrangements for the South-Western Chain had progressed so that it could be completed in four months' time. On the other hand, a North-Western Chain would take at least eight months to build. In addition, it was now certain that a Loran navigational chain would cover the North Atlantic, and although it was impossible to say when this would be available as its development was the responsibility of the United States authorities, it was known that they were anxious to complete it as soon as possible.

North-Eastern Chain

By midsummer 1943 Gee had proved itself to be invaluable in aiding concentration of attacking aircraft over the target area, assisting in wind velocity determination, and in ensuring accurate tracking in order to avoid defended areas. In target location it was subject to limitations of range and also to an increase in possible errors with an increase in range, and it was too inaccurate for blind bombing. Much of its value for minelaying operations depended on whether or not the area to be marked was a restricted area in a channel, and also on the angle of cut-off of the lattice lines in the target area and their relations to the margin of error permissible in laying mines. The danger of homing and landing large numbers of bombers in a short time in indifferent weather was greatly reduced by the aid of Gee, and investigation into the effect of Gee on the casualty rate showed that it tended to reduce the number of aircraft missing and damaged probably because aircraft in which it was installed were able to maintain position in the main stream. It had also reduced appreciably the proportion of aircraft landing away from their own bases on return from operations.

By then four chains existed, covering practically the whole of the United Kingdom coastline.[1] The Northern Chain covered Norway, Denmark and as far south as the Frisian Islands, with a considerable backward cover over the north-east Atlantic. The Eastern Chain had two lobes, the main one covering north Germany, south Denmark, the Ruhr, Holland, Belgium and France as far west as a line from the Somme to Dijon. The second lobe, which was not of much operational value, covered the Cherbourg peninsula and the northern coast of the Brest peninsula. The Southern Chain cover extended over western France, the Bay of Biscay as far as the Spanish coast and some distance west, and, in good atmospheric conditions, north Italy, giving for some unknown reason much better results than the Eastern Chain. The South-Eastern Chain was a miniature chain entirely for the use of craft of Combined Operations and gave sea-level cover to the Eastern Channel and the Dieppe area of France. The South-Western Chain just coming into use covered the Bay of Biscay and gave extended cover over the east Atlantic. The chains thus provided navigational assistance to all equipped aircraft operating within roughly 300 miles of the shores of the United Kingdom.

After the Northern Chain had been in operation for a few weeks navigators reported a gap in coverage between the Northern and Eastern Chains.[2] In May 1943 Headquarters Bomber Command asked for test flights to examine the coverage between the two chains and a number of flights were made by the T.R.E. from the R.A.F. station at Wick in conjunction with the Coastal Command Development Unit between 31 May and 10 June 1943 to discover the limits of the gap.[3] The tests showed that there was a corridor in the middle of the North Sea extending from the coast near the Humber to the coast of Denmark in which Gee was inaccurate and where Gee signals for the most part were not received from either chain. If Gee was to be used in the middle of the North Sea it was evident that a North-Eastern Chain was essential. Unfortunately increasing demands in the Mediterranean theatre of operations arose at that time and resulted in the first heavy Gee mobile stations being deployed in Italy. Consequently the North-Eastern Chain programme was temporarily shelved as further equipment was not then available. In December 1943 the question of the chain was reconsidered at the request of Headquarters Bomber Command, who pointed out that such a chain would prevent wastage of operational crews and aircraft, and it was decided to

[1] A.H.B./II/69/210.

Frequencies were allocated as follows :—

Frequency in megacycles per second.	Code-Word.	Users.	Normal time of transmission.
43·0	Utah	Northern Chain	14·00–10·00
44·9	Carolina	Southern and South-Eastern Chain	17·00–08·30 and 09·30–13·00.
46·79	Indiana	Not yet in use	
48·75	Virginia	Eastern Chain and Southern Chain when Mark I receivers in use	09·30–05·30
50·5	Zanesville	Emergency frequency (XF)	

[2] A.M. File C.30489/46.

[3] A.M. File CS.19777.

allocate the second heavy mobile chain for the purpose, with a target date of 1 April 1944.[1] Sites were found which met requirements and the North-Eastern Chain was ready for testing on 25 March and became operational on 18 April 1944.[2]

Development of Mobile Gee Stations

The first proposal for mobile Gee, which was put forward on 6 November 1941 by Mr. Dippy, was thought to be impracticable. Siting of permanent stations was difficult enough but positioning of ground stations likely to be constantly on the move appeared to be impossible, involving as it would the production of lattice charts which required sites to be accurately located every time a unit moved.[3] Mr. Dippy, however, thought that it would not be necessary to calculate lattice curves for mobile Gee, since for a small number of targets the spot readings could be readily calculated and the reading for homing could be obtained immediately after becoming airborne. A proposed second method of obtaining the co-ordinates of a target was to carry out a calibration flight but it would only be necessary when either the exact position of the transmitter was not known, as in the desert, or the target was semi-mobile in nature.[4] He recommended two types of mobile equipment; one to act as a mobile standby, which could be rapidly installed at any of the permanent sites, and the other to be a bombing aid for use at an advanced base with an expeditionary force.

The Director of Telecommunications thought that a suitable lattice could be produced quickly, provided that such a high degree of accuracy was not insisted upon as for the permanent stations. He agreed that an alternative was to dispense with charts altogether and to log targets spotted by reconnaissance aircraft by taking readings of the pulses when over the target. With this information bomber aircraft could navigate to the spot at a later date although not necessarily by the most direct route. If the mobile stations were to remain in one place for any length of time the co-ordination of a number of targets and landmarks would be available, and if these could be identified with points on a map it would be possible to construct lattice charts of a rough nature on the spot. A further alternative was the use of two stations beamed on the target, the aircraft flying along the line of zero path difference. The disadvantage of this system was common to all beam systems, namely, the need for the aircraft to maintain a fairly steady course.

On 23 March 1942 the Director General of Signals put forward two distinct requirements.[5] The first was mobile Gee equipment which could be rushed to operational permanent stations which had been put out of action by enemy bombing, using either any towers left standing or suitable portable masts to give limited coverage while the permanent stations were being repaired. The second was a chain of mobile stations chiefly for use overseas. This would

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[1] A.H.B./II/69/210.

[2] A.M. File C.17329/44. The units were deployed as follows :—
Master Station : 7711—Richmond, Yorkshire.
B Slave Station : 7721—High Whittle, Northumberland.
C Slave Station : 7722—Stenigot, changed to Nettleton, formerly Caistor. During tests it was found that the signal at Stenigot did not reach the required average strength to ensure the right standard of accuracy.

[3] A.H.B./IIE/113/2. Gee Mobile Ground Stations. [4] A.M. File C.30489/46.

[5] A.M. File C.30489/46.

consist of a master, two slaves and a monitor, readily transportable and entirely self-contained with power supplies and suitable communications, and with a mobile printing press for preparing lattice charts. It was visualised that the chain would be brought into use a short distance behind the front line, giving 150 miles or more forward coverage. At that time the overseas model was to take priority over the higher-powered but less mobile version. A meeting was called at the Ministry of Aircraft Production on 15 May 1942 to discuss provision of the equipments. They were agreed to in principle, and instructions were given to the Telecommunications Research Establishment and the Royal Aircraft Establishment to complete a bombing reserve and a heavy mobile trial station by 1 September 1942. A third type of station was also discussed at the meeting, a light mobile for army co-operation work, consisting of a modified aircraft receiver and a modified A.I. transmitter installed in a small vehicle capable of being set up within twenty-four hours of arrival on site. The range from an aircraft at 5,000 feet was expected to be 150 miles and the accuracy similar to that of a fixed chain at 300 miles. The Air Warfare Analysis Section suggested a design for a mechanical device to construct simply, rapidly, and without any calculations, hyperbolic curves on a suitable graticule to provide navigators with lattice charts which could be used with this much more mobile type of Gee convoy.

It was considered possible to provide a chain of heavy mobile stations for employment overseas by the end of August 1942, as the stations would be constructed from equipment which had already been used in the permanent chains thus making it possible to produce a prototype in a comparatively short time. For the lighter and more compact equipment a completely new design was required and therefore the prototype would not be available until much later.[1] Nevertheless it was considered that a chain could be provided in nine months and a target date of February 1943 was set. At the end of November 1942 it was finally confirmed that one heavy mobile station was required for each Type 7,000 chain as a third line reserve and masts and aerials were to be provided on the assumption that four chains only would be needed. At a meeting on 24 May 1943, however, the T.R.E. again outlined the advantages of the light mobile Gee station, which hitherto had been looked on as merely a theoretical proposition which might one day be needed. It was pointed out that the assumed range of the equipment was only 20 miles less than that of a heavy mobile from a site at sea-level to an aircraft at 10,000 feet.[2] It needed less vehicles and less personnel to operate it and carried an oscillator serving the dual purpose of providing a check signal for Gee-H and a control for Gee work. The equipment was also designed so that when installed in an aircraft it could be operated as a Gee responder, repeating the Gee fixes of an aircraft both to the ground station or to any aircraft within its range. As the co-ordination of the pulses to the second aircraft would not have been distorted the system could be regarded as a Gee repeater. The meeting agreed to recommend the development of the light mobile station in view of the possibility of its being used as Gee and Gee-H simultaneously. In the meantime the heavy mobile station which had been installed in Crossley vehicles at the R.A.E. Farnborough early in 1943 was being tested at Gibbet Hill, operating in place of the main station for certain periods in the Type 7,100 chain. The trials held in May 1943 were satisfactory and it was decided to

[1] A.M. File C.30489/46.

[2] A.M. File C.30489/46.

build 12 similar sets, transportable rather than highly mobile, as an interim measure, in case a mobile form of Gee was required before the all-purpose light mobile stations were available.[1] The T.R.E. thought it would be a matter of six months before the heavy equipment could be completed.

In order to expedite the formation of the units Headquarters No. 60 Group was instructed on 3 August 1943 to prepare three Gee chains, each consisting of a master and two slave stations, using vehicles from existing M.R.U. programmes. The chains were to be used for three separate commitments. One was to provide a fully trained and fully equipped unit which could be held in readiness to move overseas at any time the occasion should arise. Another was to be sited on the Eastern Chain sites to give additional anti-jamming services for Bomber Command and the United States Eighth Air Force. The third was to provide a gap-filling North-Eastern Chain, and was given priority with a target date of 1 October 1943.[2] No provision was made for a monitor station, but an aircraft receiver was incorporated in the master station for general checking purposes. The chains were to operate on frequency bands 1 and 2 and were not to be fully tropicalised as the Gee-H light fully mobile stations would have that facility.

Gee in the Mediterranean Air Command

On 8 September 1943, immediately before the landings in Italy, the Air Officer Commanding-in-Chief, Mediterranean Air Command called the attention of the Air Ministry to the great need for early provision of radio aids to navigation as soon as the Italian front became stabilised.[3] Assuming that the operations were successful, the Allied air forces would shortly be in a position to operate from bases in Italy against targets in central and eastern Europe. Conditions would be a complete change from those previously experienced, and obviously there would be increased difficulty in navigation on both day and night operations. Aids for accurate navigation were essential, not only to assist crews to reach and locate their targets, but also for blind bombing. The Commander-in-Chief emphasised that the aids should be made available immediately if full benefit was to be obtained because the aircrews needed extensive training. He considered that a complete mobile Gee chain of a master and three slaves should be despatched right away so that it could be sited in central Italy, as soon as the territory was occupied by the Allies, to provide navigation and homing facilities for aircraft of the Strategic Air Force operating northwards from the Rome area and for aircraft of the Special Operations Executive operating eastwards from Foggia. Gee installations were required in all the heavy day and night bomber aircraft of the Strategic Air Force. Of the 160 aircraft in that force, 60 had already been wired, and a number of navigators had already been trained in the use of Gee, whilst all 25 aircraft of the Special Operations Executive were already wired.

The requirements were agreed to in the main by the Air Ministry on 13 October 1943 although it was decided that Gee was not to be supplied at the expense of Bomber Command and the United States Eighth Air Force who were fully engaged in the strategic bombing offensive against Germany, then reaching its peak. Gee equipment for installation in Fortress and Liberator aircraft of the

[1] A.M. File C.30489/46. [2] A.M. File C.30489/46.

[3] A.H.B./IIJ1/84/502. Mediterranean Air Command Navigational Radar Aids.

American component of the Mediterranean Air Command was to be provided in phase with the delivery from the U.S.A. of aircraft wired for Gee/Loran, the responsibility for ensuring that they were wired being that of the U.S.A. authorities. An installation programme for pathfinder aircraft was to be given priority, to be followed by programmes for night bomber aircraft, Special Operations Executive aircraft, and the Liberators and Fortresses. The proposal for a four station star Gee chain in Italy was considered impracticable as it was improbable that a radio lock could be obtained between stations straddling the Apennines. A plan was accordingly made for a chain of three stations to be sited along the east coast of Italy, to give accurate fixes over the Balkans, Hungary, and Austria as far north as Vienna.[1] This primary chain was to be operational by the end of December 1943 and was to be reinforced by a second chain as soon as possible, the latter giving fixing cover over the north Italian plain up to the Alps.[2]

An experienced siting party was sent out from England in November 1943 to assist in choosing the best locations and returned on 17 December, having made their decisions. As the fall of Ancona (which was to be the northern slave) still seemed far distant a temporary scheme was proposed by the Air Staff of Mediterranean Air Command involving the use of the original master and southern slave sites to give position lines covering the north and east, with a new third site just south of Foggia, the equipment on this site being phased up as a D slave station. This chain was expected to provide the same coverage except that line bearings only would be available at longer ranges. Accurate fixes would be provided over the central Adriatic and the airfields in southern Italy. Above all, good homing facilities would cut down the large number of aircraft failing to return to base.

The proposals for an interim chain were finally approved by the Air Ministry and a meeting was held on 30 December, the original target date for the first chain to become operational, to discuss the sites and the production of suitable charts for the stations, which were now named Lanciano for the master, Monte Saint Angelo for the second slave, and Ascoli as the sub-slave. Ancona was still to be regarded as the first slave and would be set up as soon as possible.[3] Arrangements were made to produce the lattice charts for the three stations by a new rapid system of computing, bringing along the final chart for the whole chain later by the slower but more accurate method. The temporary charts were to be completed as soon as possible, at the latest by 1 February 1944, and the permanent sets were to be completed some eight weeks later. However, the new method of computing proved to be a failure and the charts had to be prepared by the old system. Meanwhile, in view of the urgent need for Gee in Italy, an attempt had been made to despatch one station during

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[1] M.A.A.F. O.R.B. Signals Appendices, January 1944.

[2] The stations were to be sited as follows :—

Master station near Pescara.
Southern slave station on the spur of the 'Italian Boot'.
Northern slave station near Ancona.

The stations of the second chain were to be as follows :—

Master station on Monte Amiata.
One slave station on Island of Elba.
One slave station near Vicion.

[3] A.H.B./IIJ1/84/502.

September 1943, but the non-delivery of transmitter and receiver modifications made this impossible. After this delay every effort was made to get three stations off, one in October, one in November and the third in December 1943, so that the chain might become operational at the end of that month, but again months went by without the equipment reaching the Mediterranean Air Command.[1]

The first mobile chain was eventually formed, at Royal Air Force, Renscombe Down, under the control of Headquarters No. 60 Group, in October 1943, and following its completion, the convoys were sent on 8 November to the Eastern Chain stations for one week to carry out Service trials.[2] The trials were successfully completed on 22 November 1943 and the convoys were sent to Cardington for despatch overseas. Two stations reached Bari by January, and a third a few days later, and it was expected that the chain would become operational by mid-February 1944. It was controlled operationally by the Strategic Air Force of Mediterranean Air Command, who handled operational details, authorised operation, and co-ordinated requests for the service. The commanding officer of the master station was in charge of the chain and acted as adviser on the staff of Headquarters Mediterranean Allied Air Force on technical and operational details of the system, the chain being assigned to No. 205 Group for administrative purposes. To obtain full operational value from this equipment it was essential that the element of surprise was maintained. Therefore it was not used in training or for any other purpose until authorised by Headquarters Mediterranean Allied Air Force. The aircraft equipment could be installed for testing but was not in any circumstances to be flown on operational missions until the system was ready to be used. All conditioning run-ups of the ground equipment were carried out with the aerial system replaced by a dummy load, actual transmission only taking place for essential tests. This meant that no practical experience was gained by either air or ground crews, and when Gee eventually came into operation there was an interim period when both were feeling their way.

In March 1944 work began on the slave stations at Ascoli, Satriano, and San Giovannichio, but the master site was still under fire.[3] In April 1944 a new master site was chosen at Palata, 15 miles south-west of Termoli. Approval was obtained from Headquarters M.A.A.F. and the Air Ministry, and by 1 May 1944 the charts had been drawn locally and the new chain was undergoing tests. It was estimated that the accuracy of this chain, while being lower than that of the original interim chain, would be sufficiently good to give adequate homing facilities in the Foggia area and reasonably good position lines elsewhere. The chain was not put into operation, however, until it was proved that any inaccuracies were not large enough to be a source of danger to aircraft using the charts and that the accuracy of the charts was sufficient to be of definite use. As a result of air tests carried out it was decided that the chain was sufficiently accurate for the operational requirements of the aircraft of the Strategic Air Force and the chain became operational on the frequency of 22·9 megacycles per second.

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[1] A.M. File C.30489/46.

[2] The convoys consisted of one transmitter vehicle, one receiver vehicle, one aerial trailer, one winch vehicle and one power vehicle, and were fitted with W/T.

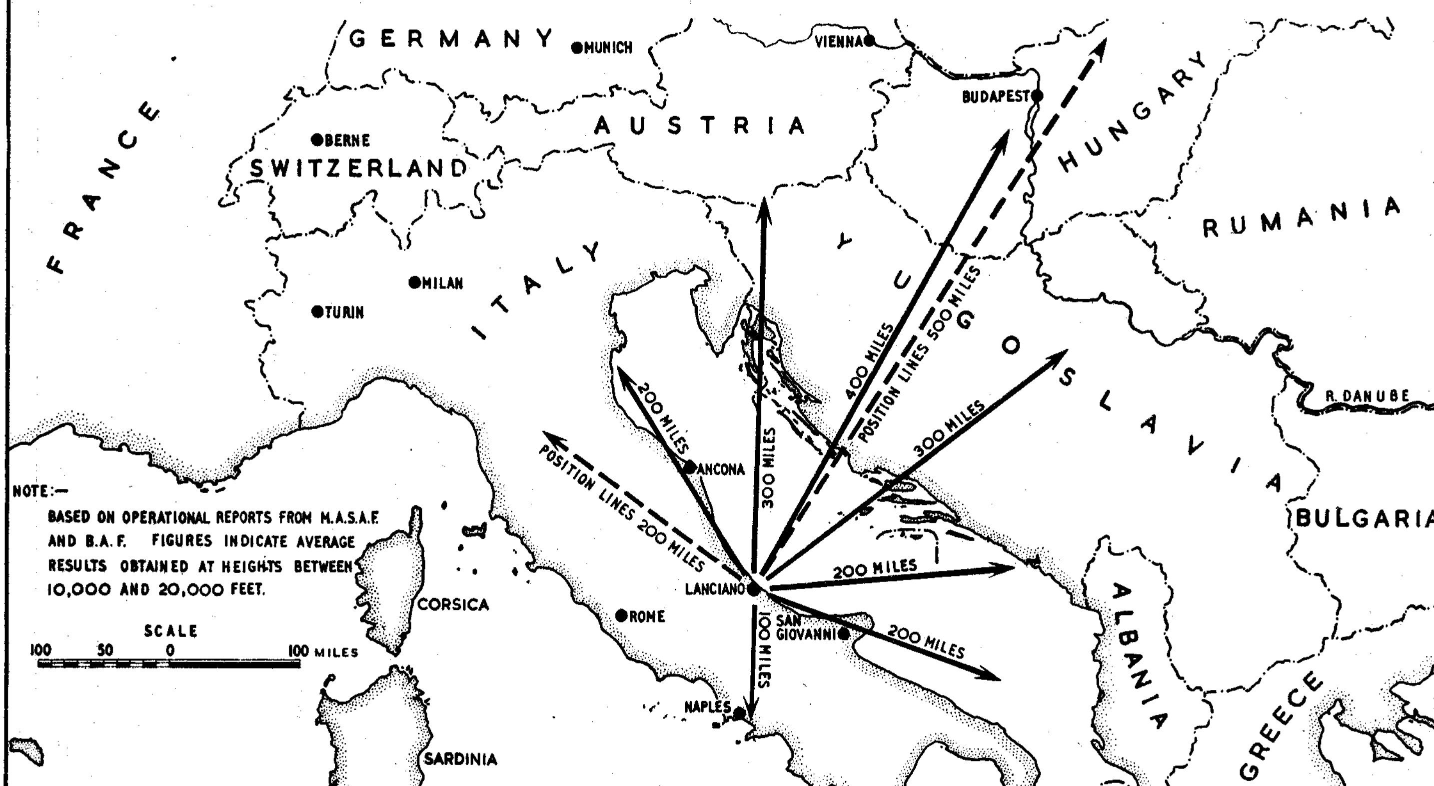
[3] M.A.A.F. O.R.B. Signals Appendices, 1944.

It was not a great success technically, difficulty being caused by the very high noise-level introduced into the chain telephone circuits by adjacent electrified railways, and interference was picked up from one of the Gee chains in England. This trouble was mutual and the Italian chain was ordered to change to 29·7 megacycles per second. Maximum ranges of 400 miles were obtained with consistent ranges of 250 miles, and signals were picked up at both Bizerte and Algiers. However, with the temporary sites and locally produced charts, accurate fixes could not be obtained beyond 125 miles from Foggia, although accurate homing to within 100 yards was reported in that area. Despite the various troubles with equipment, and the delays which were due to the fact that the front line moved forward only very slowly, the formation of the chain of ground stations had progressed relatively smoothly. On the aircraft installation side, however, questions of priority for men and equipment arose between Headquarters Mediterranean Air Command and Headquarters Bomber Command, and up to the end of April 1944 no British aircraft had been completely fitted with Gee although the ground stations were ready for operation by 1 May 1944. Then sufficient aircraft equipment was collected from the various maintenance units to enable a large part of the installation programme to be completed, and as a temporary measure radar mechanics were withdrawn from the Mediterranean Allied Coastal Air Force.[1] Gee was eventually brought into use, and the ground stations in Italy, now called the Adriatic Chain, became operational on a 24-hour basis on a frequency of 29·7 megacycles per second, on 24 May 1944. The system was very favourably received by aircrews and on many occasions was instrumental in enabling lost aircraft to find their way back to base in adverse weather.

During July 1944 the Gee chain was primarily concerned with the move of two of its stations from their interim site to the final area. The master station site at Lanciano was first inspected on 27 June 1944 and the B slave site at Ancona on 28 July 1944. A few days later the standby equipment from Ascoli and Palata was moved to the new sites, while the main equipment was left behind to continue transmission on Grade B. After some delay at the Ancona site the chain went on the air for test on 7 August 1944. The trials proved to be satisfactory and the final chain was opened up and the interim one closed down on 11 August 1944. The change was effected without a break in the Gee service despite the fact that one station had to move nearly 300 miles. During the three months of operation of the interim chain consistently reliable service had been given throughout, although it was used almost exclusively for homing. The locally produced charts proved to be accurate and the experience gained made it possible for Headquarters M.A.A.F. to produce charts at very short notice for a subsequent project. With the new chain, fixes were obtained regularly up to 380 miles in a north-easterly direction and in some cases up to 400 miles, position lines being obtained well beyond the fixing area. The reaction to the new chain by navigators was very satisfactory, for whereas the interim chain was used mostly for homing, the new chain was used as a navigation system practically all the way to and from the targets. Aircraft equipment gave but little trouble, and performance of the ground stations, except for the D slave at Ascoli, which was technically weak, was highly satisfactory.

[1] M.A.A.F. O.R.B. Signals Appendices, April 1944.

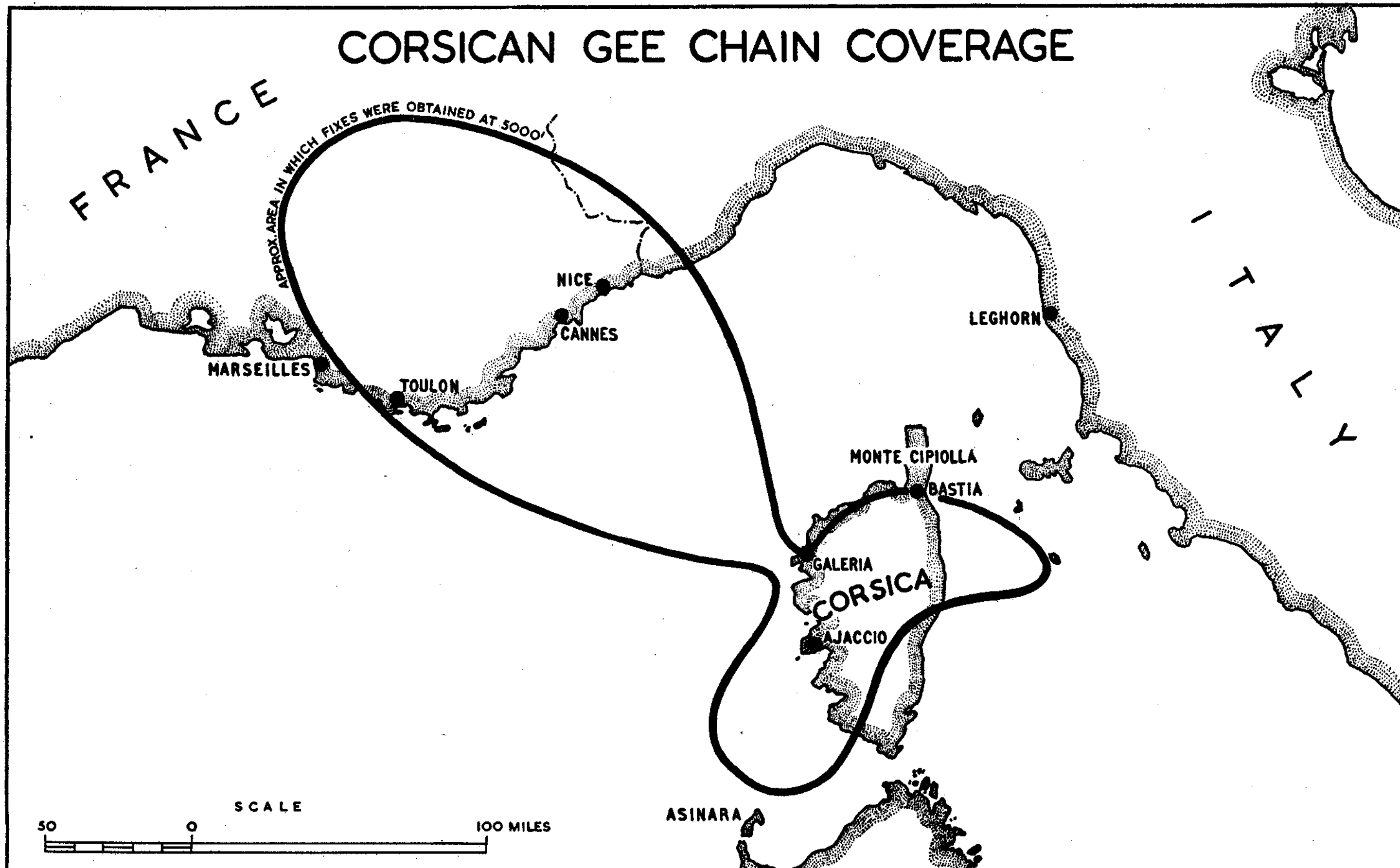
ITALIAN GEE CHAIN COVERAGE



On 22 July 1944 arrangements were made for Headquarters No. 60 Group to begin preparing three light transportable Gee units for transport by glider. It was proposed to drop equipment and crews for a complete light chain in the French Alps to provide cover for landings in the Toulon-Cannes region. Three experimental prototype Gee-H stations of No. 72 Wing built by the T.R.E. were chosen for the purpose.[1] The equipment was originally intended for use by the 2nd Tactical Air Force in Normandy and had just completed field and technical trials and had been found reasonably satisfactory for use with Gee. The three units were moved to Cardington where the technical equipment was split down as far as possible into units of 40 pounds or less, packed in light cardboard cartons, waterproofed in balloon fabric, and fitted with carrying braces. Only the masts and petrol electric generator sets could not be brought down to loads capable of being man-handled. Following a map survey of possible sites by No. 72 Wing it was decided that at least as good a cover could be provided by siting the stations at Asinara (off north-west Sardinia), near Galeria (north-west Corsica) and near Utelle (north of Nice, France). Apart from the risks of an airborne landing, optical locking paths were very difficult to find in the area north of Marseilles-Nice, and they were essential in that sort of terrain. Those that could be found were limited to 40 miles, giving a short base-line and consequent inaccuracy, and would have meant the master and western slave stations being sited in politically undesirable areas. In addition the alternative proposals had the advantage that in the event of the Utelle station being forced to destroy its equipment or being unable to reach its site, there would still be the Galeria and Asinara stations giving position lines. On 2 August 1944 the crews and their equipment emplaned for the Mediterranean in five Dakota aircraft provided by the Allied Expeditionary Air Force. When the parties arrived at Headquarters M.A.A.F. the revised proposals for the siting of the new chain were adopted.

On 6 August 1944 a siting party of four officers reached Corsica and went by road to the nearest point to the site near Galeria, chosen in the map survey for the master station. The site lay on a ridge 2,500 feet high, to the west of the Calvi-Ajaccio road south of Calvi, and was approached by foot, taking an hour to reach. On 7 August 1944 the party flew on to Alghero in north-west Sardinia and Asinara was inspected from the air. The site was reached after an hour's ride from the quay at Lassaretto but when the party arrived there they found that a U.S.A.A.F. V.H.F. D/F station was already in position. However a point slightly west of and screened from the D/F installation was chosen for the Gee station. A.M.E.S. Nos. 101 and 104 were installed in their respective sites at St. Catherines and Alghero by 11 August 1944 and arrangements were made at Algiers for A.M.E.S. No. 102 to be dropped to the Maquis. This plan once again fell through, however, and a map survey was carried out on a site on Monte Cipolla, near Cap Corse. It was 4,000 feet high, of which only 1,000 feet was covered by road. As with A.M.E.S. No. 101, mules were used to transport the equipment to the site, but in this instance the mules were unable to reach a point more than 3,500 feet high, and for the rest of the way the equipment had to be man-handled. On 14 August 1944 all three stations went on the air and were ready to become operational. The operation of the Corsican Chain during the landings on 15 August 1944 was,

[1] M.A.A.F. O.R.B. Signals Appendices, August 1944. The three units were A.M.E.S. Nos. 101, 102 and 104.


CORSICAN GEE CHAIN COVERAGE
FRANCE
APPROX. AREA IN WHICH FIXES WERE OBTAINED AT 5000'
NICE
CANNES
MARSEILLES
TOULON
LEGHORN
ITALY
MONTE CIPIOLLA
BASTIA
GALERIA
CORSICA
AJACCIO
ASINARA
SCALE
50
0
100 MILES

however, somewhat marred by the failure of the B slave at the last minute. Position lines were available from the other two stations and provided the troop-carrier pathfinder navigators with excellent check points for crossing the French coast. In October 1944 the mobile stations were sent back to the United Kingdom for use in northern France.[1]

Headquarters M.A.A.F. found, on the whole, that the prototype experimental equipment, which had been used for the Corsican Chain, was scarcely robust enough for use in the conditions encountered in the mountainous regions of that land. Duplicate standby equipment was needed, and, above all, more than three hours were required for ironing out teething troubles after installation. The climate of the Mediterranean theatre gave propagation conditions in the summer which made it well worth while using base-lines which, in the United Kingdom, would be considered dangerously large for light equipment. Provided that there was an optical path between sites, base-lines of 100 miles appeared to be fully practicable. It was also found that sufficiently accurate lattice charts could be produced in under five days in field conditions with a minimum of equipment.

Gee in the Liberation of North-West Europe

It was realised at a very early stage that the Gee system would be of immense value during the projected landings in Normandy and afterwards when the Allied forces crossed the Continent to Germany, and planning therefore started months before even the size of the air force to be used was known. There were two main problems which were discussed at length by the Air Ministry, Headquarters A.E.A.F., and Headquarters No. 60 Group.[2] These were the expansion of Gee coverage at home, and the supply of Gee during the Allied forces' advance across Europe.

The Southern Chain was obviously to play a vital part and would be used extensively both by air and sea forces. In order to strengthen its eastern section along the south coast, the South-Eastern Chain, consisting of Truleigh Hill and Canewdon, was to be merged into the main Southern Chain, the two stations acting as additional slaves. To increase further the usefulness of the Southern Chain it was decided to increase its frequency range. In November 1943 the chain had become operational on Band I so that it could run simultaneously on the 20/30 megacycles per second band and the 40/50 megacycles per second band. But the enemy was already aware of those frequencies and owing to the threat of jamming it was essential to bring as many frequencies into play as possible on this chain, using a fresh one as the previous one became jammed. The minimum number of frequencies needed to give reasonable security was three additional transmissions in the 50/80 megacycles per second band from four sites, requiring a total of twelve transmitters. This was achieved by installing the third heavy mobile type 7000 chain at the master and two slaves of the Southern Chain, the masts being used for Band III arrays.[3] This mobile chain was then itself expanded to provide the three extra frequencies needed, by the addition of two further sets of GL transmitters and receivers,

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[1] A.H.B./IIE/44. A.M. Signals Bulletin, October 1944, Section D.

[2] A.H.B./ID4/177. Radio Aids to Target Finding, Gee and Gee-H.

[3] T.R.E. File D.1235.

suitably modified to cover the Gee frequency bands. The target date set for completion of the task was 1 March 1944. Although the frequencies were actually available by this day only one was operated on 1 May, the other two being withheld until D-Day to effect the maximum surprise, and to delay enemy countermeasures.

The first step in the extension of Gee coverage to the Continent was to establish the Channel Chain as soon as the landings had been accomplished. It was to consist of a master station at Truleigh Hill, a B slave at Canewdon and a C slave near Cherbourg, and Headquarters No. 60 Group had prepared a plan for deploying the ground stations as the Allies advanced across the Continent.[1] The plan was divided into five phases and maps were drawn showing the proposed locations of the stations for each phase and estimating cover at heights of 5,000, 10,000, and 20,000 feet.[2] In general, the plan was designed to provide a steady improvement of cover, particularly at low altitudes, over both the presumed active areas of operations and also over possible airfield areas, but was not to impair in any way the Gee cover provided by the chains sited in the United Kingdom. As the position of the military front had to be assumed at certain dates the whole planning was liable to alteration in the light of subsequent events, and each phase would in fact be put into effect when and where the military situation demanded.

Gee was not the only navigation system to be used on the Continent, and, in order to manage the numerous ground stations which were to be employed under the control of the Air Ministry through Headquarters No. 60 Group, it was decided to form a wing to organise the stations in the field. With the reshuffle of signals wings in the north of Scotland, No. 72 Wing had become redundant and was reformed to take charge of the radio navigation aid (R.N.A.) stations on the Continent. There were many problems to be faced since although No. 72 Wing units were to be under the administrative control of Headquarters 2nd T.A.F., the stations could be deployed anywhere on the Continent, and the majority were to be in the American areas many miles from the 2nd T.A F. sphere of operations. The wing was to move to north-west Europe after the firm establishment of a beachhead and was mainly to provide an extension of R.N.A. cover. Day-to-day administration in the operational theatre was to be maintained by Headquarters No. 85 Group. A small equipment section was formed at R.A.F. Cardington to deal with the equipping of convoys and to act as a marshalling point prior to the calling forward of convoys into concentration areas. On formation, crews and convoys were sent to R.A.F. Renscombe Down for training and kitting prior to embarkation. When training was completed they collected their vehicles from R.A.F. Cardington and were dispersed to No. 60 Group outstations to await calling forward. The forward element of Headquarters No. 72 Wing was to proceed overseas with the first crews on or about 31 July 1944 according to the military situation. This forward element, together with A.M.E.S. 7921 (heavy-type Gee) and

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[1] A.M. File S.10512.

[2] A.H.B./ID4/177. The phases were :—
Phase A D + 60
Phase B D + 90
Phase C D + 150
Phase D D + 210
Phase E D + 330

A.M.E.S. No. 116 (light Gee-H), was to be set up in the vicinity of Anneville-en-Saire in the Cherbourg peninsula, and it was hoped to have a main headquarters forward between 31 August and 15 September 1944.

While plans were being made to give the best possible cover with Gee in the all-important north-west Europe campaign, an incident occurred which confirmed what had been anticipated early in 1941 and expected ever since Gee was first used in March 1942. On 24 February 1944 one of the German pathfinder aircraft shot down was found to have installed in it the remains of one of the latest British Gee sets.[1] If properly used with the British ground stations the set enabled the enemy to navigate with great accuracy to any point in a large area of England. It was therefore decided to introduce on 1/2 March 1944 the simple Gee coding which had been prepared soon after the idea of Gee had first been accepted. Coding was only to be used at night and initially was to be limited to the Southern and Eastern Chains. After four weeks use of coding it was found that the enemy could still intercept the code changes and could give his crews the code number in use before they became airborne. It was also apparent that coding was complicating the task of the navigator considerably. A method was therefore developed which enabled coding to be applied only during enemy activity over this country. Headquarters Air Defence Great Britain ordered the ground stations to bring in coding as soon as enemy aircraft approached the coast. ' Blinking ' of the master station transmission was introduced at the same time and continued during the period of coding so that the crews in the air would know that coding was being applied and would read the appropriate figures from the cards which were carried in the aircraft. Coding ceased as soon as the raiders recrossed the coast and interference to Allied users was therefore cut to a minimum. This method was proved operationally satisfactory and was introduced generally on the Eastern and Southern Chains on 1 April and on the South-Western and North-Eastern Chains on 15 April 1944. Phase coding was cancelled altogether during the period between D minus 2 and D plus 2 to ensure that crews of ships and aircraft had the simplest of Gee operating to perform at such a critical time.[2] It was particularly essential that this should be so for the airborne forces operations, when accuracy was of primary importance. It was suggested that the dropping of the coding on D minus 2 might lead the enemy to believe that ' Overlord ' was imminent, but the risk was thought to be lessened by the fact that a new frequency would be brought in on this day as though it were just a continuance of the policy of making every endeavour to combat enemy jamming.

The two remaining frequencies for the Southern Chain, withheld until D minus 2, were to be brought to life with the code-word ' Domino Double-six '. At 1500 hours on 3 June 1944 the code-word was received and the two new frequencies were brought into use. A few minutes after, the operation was cancelled for twenty-four hours because of the weather. It was too late by then to take the chain off the air but no harm appears to have been done as the plan was completely successful and the Germans utterly misled.[3] In addition to the surprise use of the five frequencies, the jamming stations were heavily bombed prior to the landings, and the disastrous effect of the bombardment

[1] A.H.B./ID4/177. [2] A.H.B./ID4/177. [3] A.M. File C.17185/44.

coupled with the skilful use of the frequencies completely silenced the German jammers, making Gee reception on D-Day perfect—to such an extent that some suggested that it should have been called G-Day.

Both British and American troops were accurately dropped in the chosen zones by Gee-navigated aircraft. British and American bomber formations used Gee to help both general navigation and location of the beaches, which they heavily bombed before the actual landings, and the sea-borne forces were able to use Gee to make accurate landfall on the selected beaches. No. 8 Group employed a combination of H2S and Gee to ensure that aircraft bombed their correct targets in northern France. In addition to its normal use of providing a navigation aid for all the air forces engaged in the operation, the Southern Chain was also used by the Allied Naval Combined Expeditionary Forces to direct the mine-sweepers which preceded the main force, and then to navigate the entire main force through the swept channels to the beaches.[1] The intricate navigation for the convoy simulation part of D-Day radio-countermeasures operations was carried out by No. 617 squadron with the aid of Gee. It took part in the diversionary operation ' Taxable ' in co-operation with the Royal Navy and used Gee lattice lines to enable a naval attack on Cap d'Antifer to be simulated. To ensure success the 16 aircraft were each fitted with two Gee sets and carried two navigators, the results making very worth-while the trouble involved.

Once a beachhead in Normandy had been secured the Channel Chain, consisting of a master and slave in the United Kingdom and a second slave in Cherbourg, came into force.[2] Originally the latter was to be a heavy mobile station shipped across on D plus 30, but because of the sudden break-through from the bridgehead it was not until 30 July that A.M.E.S. No. 7921 reached French soil. It travelled in the first convoy of No. 72 Wing along with the forward element of the headquarters and A.M.E.S. No. 116, landing on the beaches after a very easy journey. All three elements reached Anneville-en-Saire the following day and were sited adjacent to one another, A.M.E.S. No. 7921 becoming operational as the C slave of the Channel Chain on 23 August 1944. As soon as the chain became operational, the heavy mobile equipment used on the Southern Chain was withdrawn and renumbered to the Continental chain number series of 7900 and moved overseas to form the first Continental or Rheims Chain. With the break-through at St. Lo, and the collapse of all German resistance in northern France and in Belgium, modifications had to be made to the Gee plans and all but one of the five chains envisaged became redundant.

Rheims and Ruhr Chains

Headquarters No. 60 Group was the responsible authority for Gee on the Continent and had a very broad field of planning to cover. A scheme for moving the Gee stations was eventually roughed out at Versailles, taking the requirements of Bomber Command into consideration, and Headquarters No. 72 Wing was visited next to discuss the methods of achieving the plans produced. Here there was a large collection of maps from which a series of possible sites were chosen. When these had been whittled down to a minimum, No. 72 Wing

[1] A.H.B./IIE/159, Section XXIII. Air Staff S.H.A.E.F. Air Signals Report on Operation ' Overlord ' from assault to the cessation of hostilities.

[2] No. 72 Wing O.R.B., July 1944.

mobile siting parties went out to reconnoitre the positions selected. The parties consisted of one 15-cwt. truck carrying a radio transmitter and radio test gear for testing locking conditions. With the vehicles went a radar specialist with a flair for siting, a Directorate of Military Survey representative, and a sergeant. Gee coverage was needed most when the front line was fluid and it was therefore imperative that Gee chains could be rushed forward with as little delay as possible. To accomplish this it became the general principle to move the light mobile stations (Gee-H Type 100) up to the sites and then to bring the heavy mobile stations (Gee Type 7000) up later when the situation was stabilised. As the Tactical Air Force mainly flew at low altitudes Gee stations had to be sited on hill-tops to give the necessary range. When the front moved forward hill-tops were not always cleared up immediately and siting parties moved with the infantry, often carrying out their job under enemy fire. As soon as the site had been approved, the survey representative set to work and the co-ordinates were signalled back to Headquarters No. 72 Wing, and thence to Headquarters No. 60 Group, finally reaching the Air Warfare Analysis Section within 20 minutes of leaving the front line. Here a considerable number of computors worked to produce a preliminary issue of charts in seven to ten days, as opposed to the normal period of nine months. Thus a light mobile chain could be brought forward in a matter of two weeks. This, then, was the organisation under which a number of Gee chains sprang up throughout Europe to give valuable assistance to the supporting aircraft.

The plans for the first Continental Chain, which was to cover the Cologne—Stuttgart area, were radically revised and it became known as the Rheims Chain. A master station, two slaves, and a monitor, were on site by 4 October and operational by 5 October 1944 on a frequency of 83·5 megacycles per second.[1] Immediately after this chain became operational the master station caused very heavy interference to an American radio equipment, AN/TRC1, which was sited nearby. The problem was overcome by taking the Gee chain off the air until 11 October while the radar was resited outside the interference area. The D slave of the chain became operational by 24 October 1944, but although the Rheims Chain was fully operational, lattice maps were not available for some considerable time because priority had been given to map production for a second continental chain. By 2 November 1944 maps were finally available for the operational areas but there were still no charts for the base airfields in the Paris and Dijon regions.[2]

At the same time as the Rheims Chain was going into operation a second chain, to be called the Louvain Chain, was planned, primarily for the northern sector of the front line in the Lowlands. Its object was to give better cover over the Ruhr valley but because the battle had developed into almost a rout at this stage, the selection of sites was achieved by photo-interpretation and maps. Light mobile Gee-H stations (Type 100) were to be used and a master, A.M.E.S. No. 107, and a slave, A.M.E.S. No. 106, were sited and became operational on 9 October 1944. The Type 100 stations were to be replaced with

[1] No. 72 Wing O.R.B., October 1944. The stations were deployed as follows :—

Master station :	7912—Rheims
B Slave station :	7925—La Capelle
C Slave station :	7926—Ligny
D Slave station :	7924—Estissac
Monitor station :	7931—Mourmelon

[2] A.H.B./IIE/159, Section XXIII.

heavy mobile stations as soon as they could be brought up.[1] The enemy, however, eventually made a determined stand along the Moselle, the Germany-Belgium frontier, and in southern Holland. As the selected B slave site at Eindhoven was still well within German-held territory it became necessary to resite this equipment at Tilburg, after nearly all the maps for the chain had been produced. The revised chain became known as the Ruhr Chain and went into operation, using heavy mobile equipment Type 7000, on 23 October 1944, on a frequency of 80·5 megacycles per second.[2] Maps were produced on high priority and were in use while the Rheims Chain still had very few. On 18 November, to prevent breakthrough interference between the adjacent Ruhr and Rheims Chains, the frequencies were spread to 83·5 and 74·5 megacycles per second respectively. The B slave of the Ruhr Chain was not satisfactory technically and the Air Ministry suggested closing down the Channel Chain to make the C slave at Anneville-en-Saire available to take the place of the defective equipment at Tilburg. The United States Ninth Air Force did not agree to this proposal as the Channel Chain provided the only charted coverage in its base areas. As a result the Air Ministry suggested shipping a light Type 100 mobile station from the United Kingdom to replace the C slave at Cherbourg while the heavy mobile Type 7000 station was moved up to the B slave of the Ruhr Chain, and this plan was agreed to by the Air Staff of S.H.A.E.F.

However, shipping difficulties delayed the replacement and the Channel Chain had to operate without its C slave, thus providing only single ' line of position ' coverage from the master station at Truleigh Hill and the B slave at Canewdon for roughly the first half of November. This meant that there was no base area coverage for the United States Ninth Air Force until 13 November 1944, as the base area charts did not become available until that date. On 26 November 1944 S.H.A.E.F. finally agreed to closing down the Channel Chain as by then it had ceased to contribute useful cover over the Continent. The Chain went off the air on 2 December 1944 and the C slave, A.M.E.S. No. 101 a light Type 100, was moved to the Brest peninsula to become part of the South-Western Gee Chain in the United Kingdom.

Cologne and Saar Chains

In the middle of December 1944 the enemy staged a counter-attack against the steady progress of the Allies. The spearhead of his Ardennes offensive struck swiftly with the obvious intent of breaking through to the coast. Reports of considerable enemy activity east of Laroche had put No. 72 Wing on its guard and a close watch was kept on the possible trend of enemy movements. On 18 December 1944 the position became untenable and Laroche was evacuated at 0300 hours. This included the withdrawal of the C slave of the Ruhr Chain, A.M.E.S. No. 7922, and its standby equipment A.M.E.S. No. 106, to Florennes, which was an old R.N.A. site and fortunately had already been surveyed. The withdrawal was successful despite the tremendous volume of military traffic and the extremely bad road conditions due to frost and snow. No casualties were sustained by the two units, except A.M.E.S. No. 7922, which had to leave behind its two 105-foot masts.

[1] No. 72 Wing O.R.B., October 1944. The stations were to be deployed as follows :—
A.M.E.S. No. 107—Master at Louvain, to be replaced by A.M.E.S. No. 7911.
A.M.E.S. No. 105—B Slave, Eindhoven, to be replaced by A.M.E.S. No. 7923.
A.M.E.S. No. 106—C Slave, Laroche, to be replaced by A.M.E.S. No. 7922.
A.M.E.S. No. 108—D Slave, Axel, to be replaced by A.M.E.S. No. 7921.

[2] A.H.B./IIE/159, Section XXIII.

Resiting measures were immediately introduced to ensure adequate coverage of the entire area but some delay in perfecting the cover was inevitable owing to the fluid nature of the front. By 21 December some stabilisation of the situation had been achieved and the Florennes area then appeared relatively safe. A.M.E.S. No. 106 was set up as the C slave to the Ruhr Chain while A.M.E.S. No. 7922 was given a thorough overhaul. The chain was renamed the Cologne Chain and, pending the production of lattice charts, it was available for target fixes.[1] By 26 December 1944 it was apparent that there was little prospect of an early return to the Laroche area and A.M.E.S. No. 7922 was established as the C slave of the Cologne Chain, with A.M.E.S. No. 106 as standby. Lattice charts of the operational area in the Ardennes were produced on high priority and were available in the latter part of December. The improvised chain proved invaluable for night photographic work in the area of the enemy spearhead as well as for medium-bomber aircraft attacking communication centres immediately to the rear.[2]

Gradually the enemy penetration was reduced and towards the end of January 1945 the Laroche area was pronounced relatively clear and plans were made to re-establish the Ruhr Chain.[3] A.M.E.S. No. 120 (light Type 100) set off on 18 January to prepare the way for A.M.E.S. No. 7922. Heavy snowfalls, layers of mud three feet deep, minefields, and debris, made it impossible to site equipment and as every habitable dwelling had been destroyed during the short-lived German occupation it was decided to postpone sending any further units to the area until conditions had improved. A.M.E.S. 7922 returned to its former site at Laroche on 26 January 1945, where it became operational once again as the C slave of the Ruhr Chain on 28 January, with A.M.E.S. No. 120 as its standby.

Meanwhile, before the Ardennes offensive, planning had started on 3 December 1944 for the provision of a light mobile chain, to be called the Saar Chain, to meet an operational requirement of the United States Ninth Air Force.[4] The main function of the chain was to provide low cover for night photo-reconnaissance aircraft working in the Saar valley. Unfortunately the C slave site was near Saverne on a hill-top already occupied by an American AN/TRC–1 radio equipment. To effect a compromise on the site, interference trials with both equipments were carried out and finished early in January 1945, the results being helpful for later sitings in the area occupied by U.S.A. forces. During the enemy offensive in the Ardennes the work on the Saar Chain was held in abeyance for the more important task of withdrawing the C slave of the Ruhr Chain from its dangerous position. In addition, the remaining sites of the Saar Chain were in enemy-held territory and it was well into February before the chain became operational. On 14 February it went on the air using light transportable equipment working on 50·5 megacycles per second, a frequency in Band II which had so far not been pulse-jammed by the enemy, at sites which were considerably in the rear of those

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[1] No. 72 Wing O.R.B., December 1944.

[2] A.H.B./IIE/159, Section XXIII.

[3] No. 72 Wing O.R.B., January 1945.

[4] A.H.B./IIE/159, Section XXIII. The proposed sites for the Saar Chain were :—
Master station : St. Avold.
B Slave station : Diekirch.
C Slave station : Saverne.
D Slave station : Gondercourt.

originally proposed.[1] The performance of the C slave was poor at first, which was put down to the fact that it was the only unit which was operating with a 30-foot telescopic mast. When a 105-foot mast was installed it gave a considerably improved performance.

The formation of a Gee chain functioning exclusively on light mobile equipment was of interest in view of the decision to use the sets in forward positions with the minimum of delay. Early in 1945 there had been a steady flow of the light Type 100 units from the United Kingdom, making the provision of standby equipment for all Gee stations possible and enabling a 24-hour service to be available for all users. There followed a period of comparative stability of the ground forces which lasted until the beginning of March, when pressure against the enemy was renewed and preparations were made to launch the final offensive. No. 72 Wing was destined to provide essential support to this plan and units were moved rapidly eastwards into advanced strategic positions for further deployment. The light Type 100 units, which had been mostly used as standbys up till then, came into their own and proved to be outstandingly important in their new role providing highly mobile and immediate forward Gee cover for the ground forces.

Metz and Munster Chains

After some delay due to conflicting claims for sites the advanced Saar or Mainz Chain (later changed to Metz Chain) became operational with the Saar Chain light equipment on 21 March 1945.[2] Three days later, on 24 March, the heavy units of the Rheims Chain moved forward to replace the light equipment and the chain became fully operational with the D slave, A.M.E.S. No. 7924. Meanwhile the Rheims Chain, which was now of lesser importance, continued to function with light slaves and 105-foot towers, with A.M.E.S. No. 7931 modified to act as a master monitor.[3] The original Saar chain continued to operate until 3 April 1945 with its original standby units.[4] Early in March 1945, Headquarters 2nd T.A.F. put forward an operational requirement for a Gee chain to provide low cover for intruder Mosquitoes in the Munster area. After some consideration it was agreed that a Munster Chain would meet the general needs of all Allied air forces for improved Gee cover to the north-east of the Ruhr and would provide best possible Gee cover for Operation Varsity II, which was an airborne operation planned to secure a bridgehead across the Rhine at Wesel.

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[1] No. 72 Wing O.R.B., March 1945. The units were deployed as follows :—
Master station : A.M.E.S. No. 108—Commercy.
B Slave station : A.M.E.S. No. 106—Arlon.
C Slave station : A.M.E.S. No. 104—Remiremont.

[2] A.H.B./IIE/159, Section XXIII. The units were deployed as follows :—
Master station : A.M.E.S. No. 108—St. Avold.
B Slave station : A.M.E.S. No. 106—Diekirch.
C Slave station : A.M.E.S. No. 104—Saverne.
These later became :—
Master station : A.M.E.S. No. 7912 (standby 108).
B Slave station : A.M.E.S. No. 7925 (standby 106).
C Slave station : A.M.E.S. No. 7225 (standby 104).

[3] The Rheims Chain now stood as :—
Master station : A.M.E.S. No. 7931—Rheims.
B Slave station : A.M.E.S. No. 105—La Capelle.
C Slave station : A.M.E.S. No. 128—Ligny.
D Slave station : A.M.E.S. No. 124—Estissac.

[4] They were A.M.E.S. Nos. 127, 131 and 132.

The Munster Chain became operational with light mobile stations on 19 March 1945 and Varsity II was launched on 24 March.[1] The weather was ideal so that little difficulty was met with navigation. Two divisions of paratroops were carried across the Rhine in 1,300 gliders, the majority of the glider-towing aircraft using the Ruhr Chain, with which all operators were familiar, rather than the new Munster Chain, for which charts had only become available two days before the operation took place. Nevertheless the latter gave excellent cover up to Berlin and had been used by 2nd T.A.F. for special operations, using pre-calculated fixes before the lattice charts were produced. When the Ruhr Chain ceased operations on 3 April the light units of the Munster Chain were replaced by heavy units from it, thus improving the cover to Berlin.

Munich and Kassel Chains

In the last week of March 1945 the First United States Army broke out from the Remagen bridgehead and the Third United States Army crossed the Rhine at Worms. After the airborne crossing on 24 March, British and American forces started to outflank the Ruhr from the north, completing the encirclement of the Ruhr when they met on 1 April. Meanwhile British and American forces had been advancing to the north-east and east respectively. Activity in the air was reaching an unprecedented peak. On 23 March Gee chains were in continual demand, the largest operational use on any one day being recorded. Well over 7,000 sorties were flown by aircraft of 2nd T.A.F. alone and railways leading to the northern Ruhr were cut in at least 90 places.[2] At the beginning of April 1945 the Allied armies advanced to the Elbe and eliminated the Ruhr pocket. This was the most strenuous month that No. 72 Wing had yet experienced and ended with a promise of yet further activity to come. The military situation in Europe indicated that the final collapse of Germany was not far distant and all R.N.A. personnel were called upon to make every effort to provide and maintain the constantly varying coverage so urgently required by Allied air forces in their support of the ground forces.[3] On 11 March 1945 a meeting at S.H.A.E.F., at which the Air Ministry and Headquarters No. 60 Group were represented, considered the R.N.A. plans for assisting the final destruction of the German forces. Gee plans drawn up at the meeting had, however, to be considerably altered in the light of future events. Despite every effort there were two main causes of delay in the setting up of the Gee chains ; the military clearance, and the technical clearance, of sites.

It had been planned at the conference to put in a Frankfurt Chain just to the west of the Rhine but because the Allied advance had been so rapid it was decided to send the siting parties straight to the proposed Kassel and

[1] The units were deployed as follows :—

Master station : A.M.E.S. No. 7932—Roemand—later 7911.
B Slave station : A.M.E.S. No. 120—Nijmegan—later 7923.
C Slave station : A.M.E.S. No. 102—Euskirchen—later 7922.
D Slave station : A.M.E.S. No. 129—Louvain—later 7921.

A.M.E.S. No. 102 was the first 72 Wing unit to be deployed in Germany.

[2] No. 72 Wing File 72W/2196/Org.

[3] A.H.B./IIE/159, Section XXXIII.

Munich Chain sites.[1] Unfortunately two of the sites, Bad Homberg and Willingen, were needed as communication centres of the 12th Army Group, who would not allow an extra station to operate within 5 megacycles per second of the band 70 to 100 megacycles per second. Clearance was finally obtained to operate the master of the Munich Chain of 50·5 megacycles per second at Bad Homberg immediately, and agreement was reached that the Bad Homberg site should not be used for the Kassel D slave on 83·5 megacycles per second until 15 April, giving the Army V.H.F. communication units time to find alternative sites. It was also arranged to give the Allied air forces priority in an area within one mile of sites chosen in the R.N.A. Overlord/Eclipse plan, but if the site was changed this priority would not automatically cover any such revision. Consequently it was decided at a S.H.A.E.F. conference on 12 April to submit all planned sites to the Signal Division, S.H.A.E.F., so that reservation could be obtained from the Army. On the day following the conference, the immediate prospect of beginning operations with both chains brightened when the Supreme Commander ruled that No. 72 Wing units were to be given priority over all military Signals units, thus clearing the sites for the two Gee chains. The Munich Chain, using the light Type 100 units already released from the Metz Chain, became operational on 15 April, and the Kassel Chain on 17 April. The latter gave a particularly satisfactory performance, all signals at the ground stations being received at saturation level.

Nurnberg and Bremen Chains

On 27 April 1945 it was decided to proceed with an Innsbruck Chain in order to provide cover over Hitler's southern redoubt. This led to adjustments in both the Rheims and the Metz Chains, the light mobile standbys of the former being sent to Metz to release the latter's heavy units for Innsbruck. By the end of April, three of the heavy units had moved to Tothingen before going on to their final sites. Before the chain could become operational, enemy resistance collapsed and the Innsbruck Chain was no longer needed. It was decided, however, to maintain the chain as part of the post-war Gee organisation and the units proceeded to their original sites.[2] Owing to a technical difficulty over the length of the Fulda and Zinzenzell paths the functions of the slaves were interchanged with the effect that the chain then looked towards central Germany and was renamed the Nurnberg Chain, becoming operational on 26 April 1945.

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[1] For the Kassel Chain sites were to be at :—
Master station : A.M.E.S. No. 7932—Winterberg.
B Slave station : A.M.E.S. No. 120—Osnabruck.
C Slave station : A.M.E.S. No. 102—Gotha.
D Slave station : A.M.E.S. No. 131—Bad Homberg.

For the Munich Chain sites were to be at :—
Master station : A.M.E.S. No. 108—Bad Homberg.
B Slave station : A.M.E.S. No. 106—Fulda.
C Slave station : A.M.E.S. No. 104—Neustadt.
D Slave station : A.M.E.S. No. 127—Kempenich.

[2] The units were deployed as follows :—
Master station : A.M.E.S. No. 7912—Hesselburg.
B Slave station : A.M.E.S. No. 7925—Zinzenzell.
C Slave station : A.M.E.S. No. 7926—Munsingen.
D Slave station : A.M.E.S. No. 7924—Fulda.

The Berlin Chain was originally visualised to provide cover over north-west Germany but the rapid advance of ground forces had caused a change in plan and by 24 April it was evident that this chain would not be needed. Its units were held in reserve to form a more northerly chain to cover lower Denmark, and the Berlin Chain became the Bremen Chain. Sites were chosen and units moved to a staging point nearby. On 4 May 1945 five Gee chains, the Rheims, Munster, Metz, Kassel and Munich Chains, were fully operational, and both the Innsbruck and Bremen Chains were ready waiting for the order to become operational. The political situation suggested the possibility of a final enemy stand being made in Norway and with the capitulation of the Germans in the north the way was made clear for a chain to cover Scandinavia. The Jutland Chain came into being on 18 May, the need for its provision being emphasised by a request which the Allied Navy Command of the expeditionary forces had made regarding Gee cover over the sea for mine-sweeping operations off north Denmark.[1]

Jutland and Carcassone-Rhone Chains

After V.E. Day, there was a lull in activity while a great deal of rearrangement of convoys and crews went on. This was caused by the return of men due to leave the Services and the repatriation of Canadian personnel, leaving shortages which were later made good by taking men from Oboe and Gee-H stations and also by the change in the operational requirements of Gee. It could be used to serve the occupation forces and to aid transport aircraft operating over Europe, expecially those engaged on trooping to the Far East. Therefore work did not cease on Gee, and although the Munich and Munster Chains were closed down in July 1945, the Kassel Chain was revised and called the Central Germany Chain and two new chains were opened, the Jutland, on 25 July, and the Carcassone-Rhone Chain on 19 July 1945.[2] For the latter the siting and installation parties were faced with many novel situations. The high altitude of the sites, as well as severe inclines and bad surfaces of the roads, caused breakdowns and delays and led to man-handling of much of the equipment. It was estimated that winter conditions would be experienced from mid-September, and long isolation periods would be part of the units' daily life, so picked men, specially chosen from the physical and psychological aspect, were used to form the crews. The highest site was Mont Ventoux, estimated to be 6,000 feet above sea-level.

Final Jamming Offensive

It was the Germans' claim that before the Normandy landings Gee was of no use further east than 4 degrees latitude. They arrived at this conclusion by testing the effectiveness of jamming with captured Gee equipment and by questioning British prisoners-of-war.[3] After the landings the situation changed,

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[1] The units were deployed as follows :—
Master station : A.M.E.S. No. 7911—Ostbirk.
B Slave station : A.M.E.S. No. 107—Gislev.
C Slave station : A.M.E.S. No. 132—Lynvig.
D Slave station : A.M.E.S. No. 125—Glesborg.

[2] The units were deployed as follows :—
Master station : A.M.E.S. No. 108—Lodeve.
B Slave station : A.M.E.S. No. 106—Mont Ventoux.
C Slave station : A.M.E.S. No. 104—Prades.
D Slave station : A.M.E.S. No. 127—Rieutort.

[3] A.H.B./IIE/29. A.D.I.(K) Report No. 380/45.

and in August 1944 a jamming village (Stordorf) was set up on the Feldberg in the Taunus area. Equipment was installed at the beginning of August, and by September the first apparatus came into use, controlled and run by the *Reichspost Zentralle.* The countermeasures against Gee from the Feldberg site were of a different type from those previously employed. In addition to a number of normal *Heinrich* transmitters, three new types, of much greater power, were used to re-transmit received Gee transmissions with a very slightly different pulse recurrence frequency.[1] A keying arrangement was used to produce an imitation of the master and slave pulses. With this superior type of jammer the Germans expected that, in the immediate neighbourhood of the site, the pulse powers used would be so high as to jam completely the Gee cathode ray presentation screen. At greater distances, aircraft received on each frequency in use three or four false pictures on pulse recurrence frequencies which differed only slightly from those used by the British ground stations. The effect produced was one of false pictures which wandered very slowly over the true pictures so that it was difficult for an operator to tell which was the correct set of blips. At the outset an insufficient number of jammers were available to carry out spoofing of all Gee chains, but by January 1945 the site was fully equipped and the Germans were convinced of its success. With those at the Feldberg site the total number of jammers in Germany reached over 270 by the end of the war.

The first time that enemy jamming really seriously affected Allied operations was on 7 January 1945, and during February it became more intense, reaching its climax on 2 March 1945.[2] On this date aircraft of Bomber Command attacked Cologne and only the most experienced operators were able to make any use of Gee. However, by this time the Feldberg site had been located and recognised as a pre-war television station. On the same day fighter-bomber aircraft of XIVth Tactical Air Force carried out a very successful attack against the jamming station, blowing the upper three floors off the building. At the precise moment when the bombs were timed to drop, radar operators, monitoring the jamming at Type 7000 stations, had clear cathode ray tubes once again. Although the action was a complete success there had been some delay between the position of the jamming site being fixed by No. 72 Wing, the photographic reconnaissance, the interpretation of the photographs by the Air Ministry, and the strike action taken. It was decided that thenceforward photographic cover would be undertaken by home-based squadrons and the photographs would be sent direct to the Air Ministry for interpretation. It was stressed to A.D.I. Science, the department dealing with the reports, that speed of action was essential and that it was not necessary to be absolutely positive about the site of a jammer as sufficient strike effort was then available to attack sites classified only as 'suspicious.' Interference decreased as the Allied offensive progressed further and further into enemy territory, and organised jamming of Gee chains practically ceased with only occasional spasmodic efforts on specific raids. The presence of one enemy jammer, located between the mouths of the Elbe and Weser rivers, was confirmed by aerial reconnaissance but its success was far below that of the ill-fated Frankfurt jammer. The last effective instance of jamming was during a Bomber Command raid by 970 aircraft against Heligoland on 18 April 1945, when the Munster Chain was quite unreadable near the target.

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[1] The *Feuerzange* with peak power of 1 megawatt, the *Feuerstein* with peak power of 120 kilowatts, and a smaller transmitter, *Feuhilfe* (improvised by *Kothen*) with power of 30 kilowatts.

[2] A.H.B./IIE/159, Section XXIII.

Although Gee had been very vulnerable to it, jamming did not present an insoluble problem. When jamming was low-powered Gee could be used up to quite useful ranges, and when jamming was high-powered with consequent increase in range, it was not a difficult matter to locate the jammer and to have the equipment destroyed. Gee, in fact, had proved of considerable value during the campaigns in north-west Europe.

North-Western Chain

Within three months of D-Day the Southern and South-Eastern Chains had returned to their normal working conditions. Three of the five frequencies which had been made available for Operation 'Overloard' were withdrawn; the first on 19 August, followed by a second on 27 August, and a third on 9 September 1944. Together with the withdrawal of frequencies the heavy mobile equipment was removed for use on the Continent. The Southern Chain was left with one main frequency and one reserve, and Canewdon reverted to its role of slave for the South-Eastern Chain.

Gee operations settled back to normal until 20 October 1944 when Headquarters Coastal Command pointed out to the Air Ministry that there was no Gee or satisfactory Loran cover in the North-West Approaches.[1] It was feared that in the existing conditions of U-boat warfare the enemy, using *Schnorchel*, might well operate close in-shore against convoys. This would entail the provision of extensive patrols by both day and night to protect convoys in the approaches. The Loran cover was not satisfactory because the area lay on the extension of the Faroes-Hebrides pairs and they did not give accurate cuts. Moreover, Gee was much simpler to operate by day and night and did not need such a complicated training programme. It was suggested that the Gee gap could be closed by stations sited in the Northern Islands, using light transportable transmitters giving a maximum range of 150 miles.

On 10 November 1944 the Air Officer Commanding-in-Chief, Coastal Command informed the Air Ministry that '. . . Present trend of U-boats to operate close in-shore and in particular in the Northern and South-Western Approaches makes the immediate provision of Gee cover in the North-Western Approaches a most urgent operational requirement . . .'.[2] In addition to the immediate provision of Gee cover in the north-west an investigation was requested into the possibility of improving the south-west Gee cover, particularly for surface vessels, by siting a station of the South-Western Chain in Brittany. The Admiralty, too, had an immediate requirement for Gee cover in both areas to facilitate the accurate location of charted wrecks and so to allow effective Asdic hunts for U-boats to be carried out. A meeting was arranged between Headquarters Coastal Command, Headquarters No. 60 Group, the Admiralty, the T.R.E. and the Air Ministry on 25 November 1944 to discuss the provision of the new chain and the prospect of additional cover in the South-Western Chain. The technical equipment was due off production by December and the men to crew it were made available by the closing of the Channel Chain. Sites were provisionally chosen for three stations in the Northern Islands and one in Northern Ireland, the chain adopting the numbers of the cancelled Western

[1] A.M. File C.17549/44.

[2] A.M. File C.17549/44.

Chain.[1] The Admiralty was asked to help in transporting the siting parties and equipment, which it was willing to do only because the stations were of great importance. High-powered transmitters were to be used eventually but initially light equipment was to be sent to provide a service in the shortest possible time. The agreed target date was 31 January 1945 although every effort was to be made to improve upon it. However, because of siting difficulties, the plan was revised and a master station was provided at Saligo Bay, Islay, the B slave at Down Hill, and the C slave at Kilkenneth, Tiree. This meant a slight reduction in cover in a south-west direction from Down Hill because of shielding by the Donegal hills but it was hoped to overcome this disadvantage by providing high-powered transmitting equipment. The lack of cover was accepted by Headquarters Coastal Command and the Admiralty in their anxiety to bring the chain into operation. Difficulties with phasing and monitoring and the time taken to choose sites delayed the opening of the North-Western Chain until 23 March 1945. Trials were undertaken and it was found that coverage from the slave at Down Hill was satisfactory but the master station at Saligo Bay gave insufficient cover. The North-Western Chain was closed in October 1945 to release equipment for the more important peace-time projects.

The request for extra cover in the south-west had been answered by the deployment of a light mobile unit, A.M.E.S. No. 101, to St. Nic. The equipment was found to be satisfactory during trials but because of the delay in supplying new charts to ships, the station did not start operations until 1 May 1945.[2] Another light mobile equipment, A.M.E.S. No. 149, was sited at Burbage Moor in response to a request made by Headquarters Bomber Command in January 1945 for additional cover in the North-Eastern Chain to improve homing facilities, and the unit became operational on 10 April 1945.[3]

Gee in the Far East

It had been intended to ship a complete Gee chain of three stations to Air Command South-East Asia before the end of 1944 in order that experience in the use of the equipment might be gained in that theatre, so that formulation of a policy for any further requirement might be facilitated. There was also a proposal to use Gee to give cover for overland air transport routes to the Far East. However, the additional calls made upon the limited supply of equipment prevented the plans from being carried out, and it was not until January 1945 that a map survey of sites in the Karachi, Bombay, Bangalore and Calcutta areas was made for a Gee system intended primarily for use by Transport Command reforce and trooping aircraft. There was at that time no real operational requirement for Gee in the command as Loran would be used as the necessary long-range navigation system. On the other hand, if the Transport Command programme developed, and Gee facilities became extensive, the Air Staff of A.C.S.E.A. wished to take advantage of the Gee system and

[1] The sites chosen were :—
Master station : 7411—Mull.
B Slave station : 7421—Saligo Bay.
C Slave station : 7422—Barra.
D Slave station : 7423—Down Hill (Northern Ireland).

[2] A.M. File C.17323/44.

[3] A.M. File C.17329/44.

to this end asked for dual Loran/Gee installations to be made in several aircraft.[1] The usual problem of finding satisfactory sites was much greater in undeveloped Asian territory, and the Karachi Chain had to be resited when it was found that the positions chosen from maps were quite unsuitable. Headquarters A.C.S.E.A. kept impressing upon the Air Ministry the extreme difficulty and delay in all works services in the Far East and urged that work should begin as soon as any policy had been decided, particularly before the monsoon periods started. Hostilities ceased, on 15 August 1945, before little more than siting had been achieved.

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[1] South-East Asia Command O.R.B. Appendices, March 1945. The aircraft were transport, heavy bomber and multi-engined air, sea rescue aircraft.

CHAPTER 7

LORAN

Loran (Long Range Aid to Navigation) was an American system by which position could be obtained from measurement of two differences of distance, using hyperbolic lines, and the fundamental principles were similar to those of the British Gee system. There were two types of Loran, Standard and S.S.[1]

Standard Loran was a pulsed medium-frequency long-range system of hyperbolic navigation. Shore stations, synchronised in pairs by means of ground waves, provided lines of constant time-difference of arrival of the pulses from each pair. Aircraft navigators could select any two pairs to obtain a fix, reading the time-difference of one pair at a time. In the daytime, only ground waves were available, and were used over water out to 700 nautical miles or more. At night, ground waves were received only to 500 nautical miles because of the higher noise-level but, because of the stability of the lower ionospheric layer, fixes were available out to 1,400 nautical miles when single reflections from this layer were used. As many as eight station pairs could be operated on a single radio frequency, and pairs using a common radio frequency were identified by means of the different recurrence rates at which they operated. A pair of received signals was displayed on a double-trace oscilloscope pattern whose total length was about 40,000 micro-seconds. By the use of delay circuits two fast cathode ray traces were initiated at such times that one trace exhibited the master signal and the other the slave. The leading edges of the pulses were superimposed, and the amplitudes were made equal. When this final adjustment was complete, the time-difference was read by removing the signals and reading the relation between families of markers which were switched on to the traces. This time-difference established one line of position, and it was necessary to repeat the procedure with pulses from a second pair of stations to secure a second time-difference and line of position. The total time required to take and plot a fix in average conditions was about three minutes.

S.S., or Sky-wave Synchronised, Loran was a version of Loran used at night wherein two ground stations were synchronised by the reflection from the lower ionospheric layer. Baselines were from 1,000 to 1,400 nautical miles in length, the stations usually being disposed in a quadrilateral formed by two pairs. Navigators followed the same procedure as in Standard Loran except that only sky waves were used. Coverage over both land and sea was good, and signals were equally well received at all altitudes. Over most of the coverage area crossing angles were greater than 70 degrees, and the position lines of a pair were almost parallel. The system was used by the Royal Air Force for general navigation and for area bombing.

[1] C.R.B.48/1063. Loran, Long Range Navigation, Massachusetts Institute of Technology Radiation Laboratory series.

Research and Development

On 11 October 1940, more than one year before the United States of America entered the war, the American Army Signal Corps Technical Committee formulated a requirement for a ' Precision Navigational Equipment for Guiding Aeroplanes '. The system was required to guide aircraft to a predetermined point with the greatest accuracy obtainable, and to have a range of at least 500 miles at an altitude of the ceiling of the existing type of bomber aircraft, which was then 35,000 feet. In the same month, a pulsed, hyperbolic, radio grid-laying system for long range navigation was proposed to the Microwave Committee by its chairman. On 29 November 1940, the National Defence Research Committee approved the recommendations made by the Microwave Committee, and a sub-committee was established on 20 December 1940 which, in consultation with leaders of the American radio industry, placed contracts for the development of equipment necessary to enable operational tests to be made.[1] It was anticipated that most of the items would be available in time for tests to begin during the summer of 1941. It soon became apparent, however, that the new project was doomed to failure under the indirect control of an administrative committee and therefore, early in 1941, a group was formed within the Radiation Laboratory of the Massachusetts Institute of Technology to work on a system known at first as Project III and later as LRN.[2]

The frequency chosen for the project was in the 30 megacycles per second band and a very high-powered, high-precision system was envisaged, involving the use of accurately synchronised pulses transmitted from two widely separated shore stations. By the summer of 1941 the group had come to the conclusion that far greater ranges might be obtained from a medium-frequency system.[3] Accordingly two portable pulse transmitters capable of being tuned from 8·5 to 2·9 megacycles per second were hastily constructed and were set up at two abandoned lifeboat stations, one at Montauk Point, Long Island and the other at Fenwick Island, Delaware, forming a 290 nautical mile base-line entirely over water.[4] They were pulsed at $33\frac{1}{3}$ pulses per second from Bell Laboratory timers which had been installed for use with the still unfinished project III high-frequency transmitters. A set of receiving equipment was installed in a station vehicle which drove as far west as Springfield, Missouri. No attempt was made at synchronisation during the tests. As expected by the Radiation Laboratory group, the signals from the E-layer of the ionosphere were fairly strong and relatively stable. The stability of the first reflection was particularly encouraging. The lower frequencies produced the more stable signals at night, with the higher frequencies giving more stable sky-wave reflections by day. The tests tended to show that the medium frequencies

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[1] N.D.R.C. Division 14 Final Project Report, December 1945.

[2] The initials LRN stood for Long Range Navigation and eventually became corrupted to Loran.

[3] A number of factors were responsible for the change. The main consideration was the question of the most suitable frequency for a long range ground wave, since a hyperbolic navigation system depended upon a synchronised ground wave between the mast and distant slave station. Since there would be little bending over the horizon of the 30 megacycles per second radiation it held an obvious range limitation, and the greater ranges obtained with ground waves on the lower frequencies were emphasised. In addition, there was a need for an aircraft navigation system which would also have a sufficiently long range to make its employment by surface vessels effective. Although small navigational errors were not serious in peacetime, extreme accuracy was vital for wartime convoys, especially in the North Atlantic.

[4] C.R.B.48/1063.

might be used for a long-range navigation system although the potential accuracy could only be estimated at that time. They also showed that the circular sweep form of indicator could not be used satisfactorily for measuring the time-difference in the arrival of pulses at the navigator's position within an accuracy of one micro-second and, furthermore, that some form of two-trace indicator providing for a direct comparison of pulses would be necessary.

While the medium-frequency tests were being held in the United States of America the first concrete information about the Gee system was given to the Radiation Laboratory group during the late summer of 1941 by Dr. A. G. Touch, a member of the British Air Commission in Washington. Two important ideas were left in the minds of the American group, namely, that accurate measurements (to better than one micro-second) could be made with portable equipment, and that a multiple-trace indicator, providing a means of matching pulses in time on delayed sweeps, was a practical means of accomplishing this. In the meantime the main idea for the double line indicator had occurred independently to the American mid-western field party in September 1941. It was indeed a striking coincidence that this party returned with a strong recommendation for a two-trace indicator at the same time that the laboratory group had reached the same conclusion from the consideration of Dr. Touch's report.[1] Experiments with the new two-trace indicator technique were so successful that the same basic procedure was adopted for synchronising the shore stations. During the tests of the first two-trace indicator at Montauk it was found that the 5-kilowatt signals from Fenwick were ample for direct synchronisation, especially on the lower frequencies, and on these results it was decided to go ahead with the lower frequency system since no great advantage could be obtained from duplicating the British high-frequency system. The original project III was therefore finally abandoned.

In spite of many difficulties the medium-frequency stations were synchronised during December 1941 by means of the first experimental two-trace indicator located at a monitoring station in Manahawkin, New Jersey, where the two signals could be more easily compared as they reached practically equal amplitude. Several weeks later more carefully constructed receiving equipment was taken to Bermuda. Although the ground wave signals were not expected to, and did not in fact, reach Bermuda because the original low power variable-frequency transmitters were still being used, excellent sky-wave results were obtained. Frequencies of 7·7, 4·8 and 2·9 megacycles per second were used during the tests and not only was much excellent quantitative data obtained but the tests proved beyond a doubt the practicability of the Loran system and the assurance of its accuracy in the use of the new two-trace indicator. It was also found that night-time reflection was best at 2·9 megacycles per second. Consequently the Loran group decided to concentrate on developing a system near that frequency and to develop a more highly powered transmitter for further tests.

Work on 100-kilowatt pulse transmitters operating on several frequencies, begun during the latter part of 1941, was expedited during early 1942 in order that a full-scale demonstration of the new Loran system might be given. It

[1] The British and American indicators operated on the same principle basically but with Gee the two readings were made simultaneously while with Loran they were taken in succession.

was estimated that with such power the transmitters, working on a frequency of roughly 2 megacycles per second, would give ground-wave ranges of approximately 600 to 700 nautical miles over the sea and sky-wave ranges of 1,300 to 1,400 nautical miles by night. By June 1942 the first two high-power transmitters had been installed in the old Project III stations at Montauk Point and Fenwick Island, the first Radiation Laboratory timer had been installed at Fenwick, the slave station, and direct synchronisation had been established. The first test was carried out on a frequency of 2·2 megacycles per second but that channel was already being used in the Great Lakes area for a ship telephone system and the pulses began to ring telephones all over that area.[1] The radio channel of 1·95 megacycles per second, used by radio amateurs before the Japanese attacked Pearl Harbour, was available, and it was quickly claimed by the Loran group. The early tests of the Loran system and the ranges obtained had proved sufficiently satisfactory to interest the Services, and from January 1942 a number of conferences were convened by the United States Navy, United States Army, and the British Air Commission in Washington. Liaison with the Canadian National Defence Council and the Royal Canadian Navy was also established.[2]

In June 1942 the first American naval liaison officer for the development of Loran was appointed, resulting in close naval co-operation in trials and surveying of sites. On 13 June 1942 the first operational test of Loran was made when a United States Navy blimp took off from Lakehurst, New Jersey, carrying the first experimental airborne Loran receiver.[3] It was an improved model incorporating multiple recurrence rates and differential gain control. Although by later standards the set was crude, and only one set of position lines was available, the results were very encouraging. Later in the month arrangements were completed for the first sea trials to be held. A second receiver-indicator and observers were sent out on an extended long-range observation trip in the U.S.S. *Manasquan*, a coastguard weather ship. Frequencies of 1·95 and 7·5 megacycles per second were tested, the former giving the better reception. Although only one set of lines of position was still available, the results were so encouraging that immediate action was taken by Army and Navy authorities to plan the installation of a number of ground stations and shipborne receiver-indicators for Service trials in the north-west Atlantic.

Meanwhile the Air Ministry had become interested in 'American Gee,' the name given to Loran in despatches between London and Washington. It was thought that it might prove to be of great value for Coastal Command aircraft, since they normally operated at heights which imposed limitations on the effectiveness of Gee. In April 1942 the Air Staff asked the R.A.F. Delegation to forward full details of the system, and, in order that the aircraft installations might be made interchangeable, arranged an exchange of information on Gee development.[4] In May a member of the British Air Commission arrived in London with the latest technical details of Loran—which gave promise of enabling position to be fixed within about 10 miles at a range of 1,000 miles. The B.A.C. had already informally requested the National Defence Research

[1] C.R.B.49/1479J.
[2] N.D.R.C. Division 14 Final Project Report.
[3] C.R.B.48/1063. A blimp was a small airship used in anti-submarine search by the United States Navy.
[4] A.M. File C.30645/46.

Committee to arrange the provision of transmitters so that two ground stations could be set up in the United Kingdom and of receivers for installation in British aircraft and ships. At that time the United States Navy was showing more enthusiasm for Loran than was any other Service, because it would facilitate the accurate navigation of ships at long range. Consequently the B.A.C. made arrangements to ensure that the British Admiralty Division in Washington was kept fully informed.

In the U.S.A. the essential need for co-operation, if development of a hyperbolic type of radar navigation system was to be effective, was realised. The intention was to make it possible for the aircraft installation to be operated as either Gee or Loran by means of a double wave-band receiver. The design of Loran aircraft equipment was in a very early stage, and those responsible for it were eager to obtain full benefit of British experience with Gee aircraft installations. The N.D.R.C. accordingly made a request to the B.A.C. for help from someone with a knowledge of Gee. It was decided that, although he could be ill-spared, Mr. Dippy should be sent to the United States of America to try and bring about a completely common equipment for the two systems. He left for America in July 1942, and it was intended that he should spend a fortnight working with the Loran group at the Radiation Laboratory, M.I.T. In addition to supervising the development of mass-produced aircraft sets, to ensure sound engineering and interchangeability with Gee, he was able to contribute considerably to the design and development of the ground receivers and ground timing equipment; the latter was a critical unit, development of which had not been progressing too satisfactorily.[1]

The United States Army Air Corps and the N.D.R.C. were so impressed by Mr. Dippy's supervision of this work that they were reluctant to contemplate his departure because it might probably lead to errors and delays. The Air Ministry, on the other hand, was missing an able man, who as the Director of Telecommunications said '. . . was one of the few who had engineering common sense as well as scientific ability . . .'. It was decided that he was to be recalled. However, the B.A.C. had such faith in Loran and felt so concerned over the removal of Mr. Dippy that they persuaded the Air Ministry that it would be in the best British interests for him to stay in America. On 17 November 1942 it was agreed that he should be allowed to transfer to the M.I.T. staff for an indefinite period, but a few days later the Air Staff, although sympathetic with the American desire to retain Mr. Dippy's services indefinitely, recommended his withdrawal and he returned to the United Kingdom in January 1943. During his eight months in the U.S.A. he succeeded in bringing about the closest co-ordination between American and British work in the development of pulse hyperbolic navigation systems and by great perseverance ensured that Loran receivers and indicators would eventually be readily interchangeable with those of Gee.

North-West Atlantic Chain

As a result of proposals made at joint United States Army–Navy–N.D.R.C. meetings during the early summer of 1942 the Radiation Laboratory agreed to have four stations and three lines of position available for full-scale Service trials of Loran on 1 October 1942. Negotiations had already been opened in

[1] A.M. File C.17226/44.

the spring of 1942 with the Royal Canadian Navy and two suitable sites had been selected, by Radiation Laboratory engineers, at Baccaro Point and Deming Island, Nova Scotia. While the stations were being erected with the aid of the Royal Canadian Navy, three additional sites were chosen by a joint United States Navy, R.C.N. and Radiation Laboratory flying survey, at Battle Harbour, Labrador, Bonavista, Newfoundland, and Narsak, Greenland to provide maximum coverage of the north-west Atlantic coast.[1]

By 1 October 1942 the two Canadian stations were practically completed, although no standby equipment was available. A sufficient number of R.C.N. personnel had been trained by the Radiation Laboratory to make possible the inauguration of a regular service by the four-station (three-pair) chain for 16 hours daily. The first shipborne receiver/indicator was installed on the old U.S.N. battleship *New York* on 18 October 1942 and there were 45 such sets in use by the end of 1942.[2] In spite of every possible effort, the usual shipping difficulties and delays in providing equipment made it impossible for the three northern stations to be completed in 1942. An attempt to bring the Labrador station on the air was made in November 1942, but although the equipment was completed, personnel, permanent accommodation, and food were lacking. The station in Newfoundland was ready for synchronisation trials with Labrador in January 1943, but they were delayed because of a change made in recurrence rates and because of difficulty of communications. The building of the Greenland station was delayed by several unfortunate occurrences, including a storm which destroyed the station buildings. Fortunately no equipment was installed and the local inhabitants helped to put up spare buildings which the United States Navy had sent with the expedition. The station was put on the air during February but synchronisation could not be obtained immediately owing to the great distance between the Greenland and Labrador stations. After directional receiving aerial systems had been installed and the receivers made more sensitive the two stations were eventually synchronised.

The Loran system finally became fully operational in the spring of 1943 when charts were made available and about 40 ships of the U.S.N. Atlantic Fleet and a number of Canadian corvettes had been equipped with receiver/indicators. In the early summer of the same year the Loran coverage was extended northward and eastward when the Newfoundland, Labrador and Greenland stations began operating.[3]

North-East Atlantic Chain

When the North-West Atlantic Chain was being planned in September 1942, mention was made of a North-East Atlantic Chain. Dr. Touch, on a visit to the United Kingdom, gave a brief outline of the Loran system to a meeting at the Air Ministry on 17 September 1942 and indicated that he thought it was very likely that the Americans would soon be asking the British to erect and man two or three stations in the north-eastern Atlantic area.[4] The Royal Navy

[1] A.M. File C.30645/46.

[2] C.R.B.48/1063.

[3] This brief history of the early development of Loran in the U.S.A. is given to form a background to the story of the operation of Loran in the United Kingdom by the Royal Air Force.

[4] A.M. File C.30645/46.

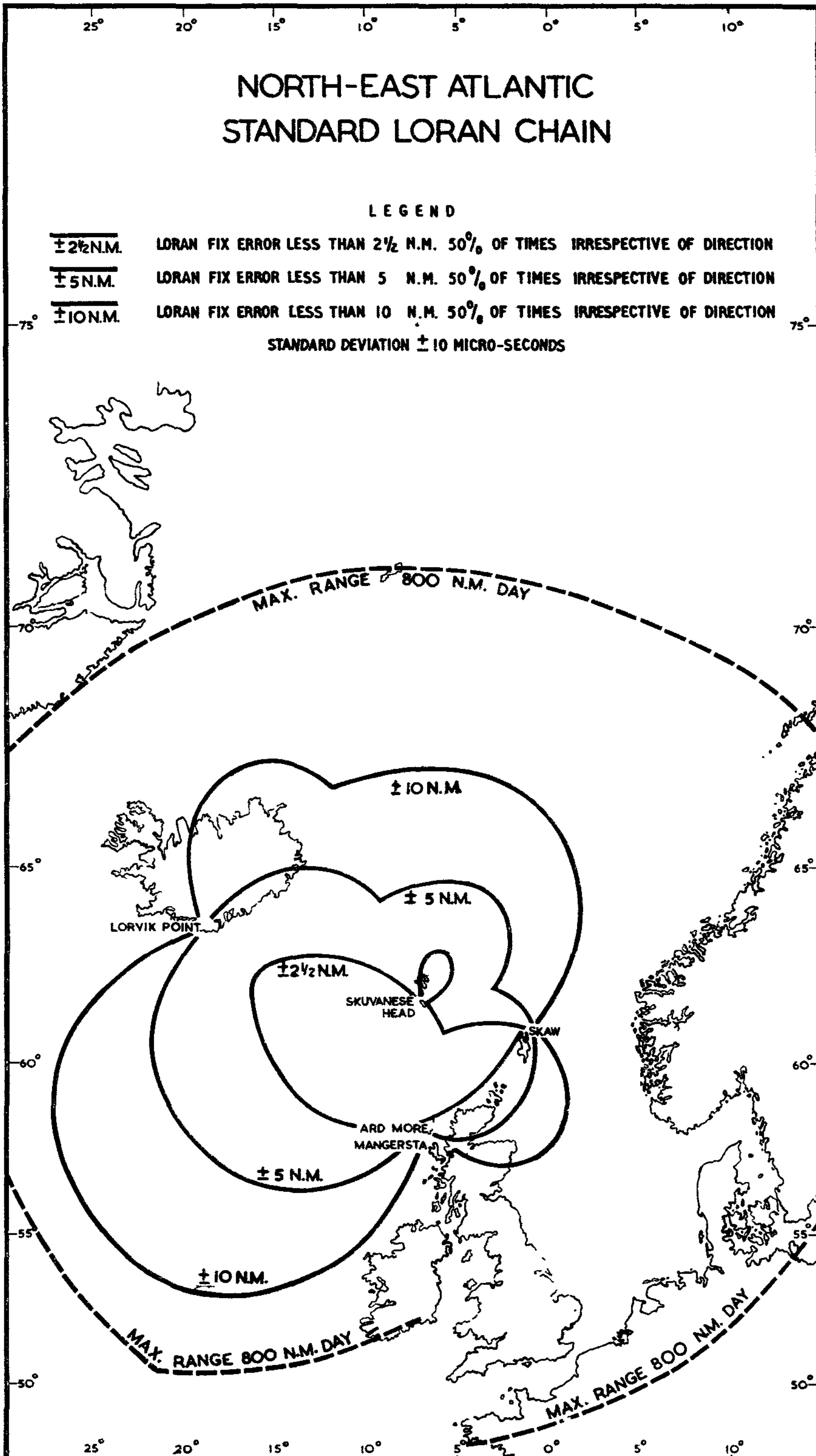
indicated its interest in the new system and suggested that the closest co-ordination should be maintained between the Royal Navy, the Royal Air Force and the U.S.A. Services. Accordingly a meeting was held at the Air Ministry on 20 November 1942 at which representatives of both British Services, the Ministry of Supply and the U.S.A. Services were present.

Sites suggested by the U.S.A. were discussed and it was agreed that the area covered would be useful to the Admiralty and might offer possibilities to both Ferry Command and Coastal Command. Ground stations had to be right on the water's edge with a clear path over sea in the desired direction. As there was no suitable seashore site in Northern Ireland, the proposed chain was altered to include stations in the Faroes, the Hebrides, and Islay, with two sites in Iceland as a U.S.A. commitment. The detailed selection of the sites was to be made by a party consisting of Admiralty, No. 60 Group, Air Ministry and U.S.A. representatives, but the Air Ministry was to erect the stations, and No. 60 Group was to install the equipment. It was not possible then to delegate responsibility for the manning and maintenance of the stations.

Since the existence of the system had by this time been revealed by the United States of America it was important that work on the North-East Atlantic Chain should be completed as quickly as possible to give it the maximum period of operation before the enemy could begin jamming operations. The United Kingdom scheme came third in the list of American priority of stations and was scheduled to be completed by the autumn of 1943, but there were several factors which led to delay in bringing the scheme to fruition. There had been delay in the production of satisfactory timers and delivery of them was not then expected before the end of April 1943. A change in the positioning of the stations occurred; the site on Islay was abandoned and an Icelandic site accepted as a United Kingdom commitment. In the meantime the B.A.C. had tentatively asked for an allocation of 60 ground stations and 1,000 sets of aircraft equipment from the United States production programme for 1943. On 26 February 1943, the British Admiralty Division complained to the Admiralty that no requisitions had been officially placed by the B.A.C. for any equipment and that no one could give adequate reasons why 60 ground stations had been asked for informally.[1] The Admiralty considered that the demand, with an additional 20 for Australia, was excessively high, particularly in view of the production rate of two per month and, after discussion, requisitions were made for three ground stations only. Amongst the 1,000 equipments provisionally ordered there was no shipborne equipment which could be interchangeable with Gee, and in addition, the whole of the existing order to cover naval requirements for the U.S.A., Canada and the United Kingdom only totalled 450 sets to be manufactured by the firm of Fada and 200 by the General Electric Company, 40 of which were to be made available to the United Kingdom.

It was agreed between the B.A.C. and the B.A.D. that in future the latter would obtain all ground stations and shipborne equipment while the former handled requirements for airborne equipment. The R.A.F. Delegation was perturbed and on 7 March 1943 warned the Air Ministry that the absence of a firm policy to use Loran in maritime aircraft was resulting in the aircraft not being modified for installation of the equipment, and in priority for ground

[1] A.M. File C.30645/46.


NORTH-EAST ATLANTIC
STANDARD LORAN CHAIN
LEGEND
±2½ N.M.
LORAN FIX ERROR LESS THAN 2½ N.M. 50% OF TIMES IRRESPECTIVE OF DIRECTION
±5 N.M.
LORAN FIX ERROR LESS THAN 5 N.M. 50% OF TIMES IRRESPECTIVE OF DIRECTION
±10 N.M.
LORAN FIX ERROR LESS THAN 10 N.M. 50% OF TIMES IRRESPECTIVE OF DIRECTION
STANDARD DEVIATION ± 10 MICRO-SECONDS
MAX. RANGE 800 N.M. DAY
±10 N.M.
±5 N.M.
±2½ N.M.
LORVIK POINT
SKUVANESE HEAD
SKAW
ARD MORE
MANGERSTA
±5 N.M.
±10 N.M.
MAX. RANGE 800 N.M. DAY
MAX. RANGE 800 N.M. DAY
25° 20° 15° 10° 5° 0° 5° 10°
75° 70° 65° 60° 55° 50°

equipment being given to areas other than the Atlantic. It was then decided that G.R. Halifax, Liberator, Catalina and Sunderland aircraft should be equipped with Loran and that lend-lease aircraft should be suitably modified in the U.S.A. for the installation of Loran. Finally it was agreed that the Admiralty should be responsible for the North-East Atlantic Chain and should also obtain 60 aircraft sets for use in aircraft of Coastal Command.[1] By the end of May 1943, sites for three stations had been selected at Lorvik Point (Iceland), Skuvanese Head (Faroes) and Ard More, Mangersta (Hebrides).[2]

With the prospect of the chain being in operation by the end of 1943, Headquarters Coastal Command pressed for an early supply of SCR. 622, the Loran aircraft set.[3] The equipment was not immediately available. The time taken to formulate a definite British policy had resulted in priority being given by the U.S.A. to production of equipment for employment in other theatres of war. In addition, there was a shortage of aircraft receiver/indicators owing to a change in the production programme.[4] Development work had initially been contracted out to the General Electric Company but had later been turned over to the Aircraft Radio Laboratory of the Signal Corps. The United States Army then requested the Radiation Laboratory to cancel the requirement for further development by the General Electric Company, even though the firm had already completed one excellent model, and the development contract was given to the firm of Philco. That decision set back development and production about one year, although it probably led to earlier large-scale production. When finally aircraft equipment started to arrive in the United Kingdom, Coastal Command was once again passed over in the bid for radar equipment because by that time a fresh commitment had arisen in Bomber Command. A change had occurred in the anti-U-boat war, and in view of the value that Bomber Command was likely to derive from a long-range navigation system during the following critical months it was given first call on the Loran system and equipment.

Development of S.S. Loran

While the problem of operating and using the standard Loran chain was being discussed, an important development was taking place in the United States of America. Mr. J. A. Pierce, leader of the Loran Operational Research Group, had suspected from the earliest days of the medium-frequency project that the probable errors of sky-wave observations over distances greater than a few hundred miles would be strikingly low and that transmission was remarkably stable over the longer distances. This led to an unofficial test on the night of 10 April 1943 in which the Fenwick Island station attempted to maintain synchronism by means of the sky-wave signal received from Bonavista, Newfoundland, 1,100 nautical miles distant. The results of the experiment revealed a line-of-position probable error of only 0·5 mile, and the idea of Sky-wave Synchronised Loran (known as S.S. Loran) was born. On 15 May 1943 a report was prepared by the American scientists outlining this method of accurately guiding night-bomber aircraft with the use of standard Loran transmitting and receiving equipment and with baselines that would straddle the enemy-occupied territories of Europe.[5] The report was sent to Great

[1] A.M. File C.30645/46.
[2] A.M. File C.17299/44.
[3] A.M. File C.30645/46, Part II.
[4] C.R.B.48/1063.
[5] A.M. File C.28851/45.

Britain in the same month. Dr. D. G. Fink, of the Loran Division, Radiation Laboratory, was sent over to supply further information and to assist in working out details of the plan should it appeal to the Air Staff.

A meeting of the Operations and Technical Radio Committee was held on 20 July 1943, at which Dr. Fink described the basic principles of the new system. Although S.S. Loran could be used only at night it made possible the use of base-lines 1,200 to 1,300 nautical miles long and it could be used nearly as well over land as over water. Experiments carried out from November 1942 to April 1943, involving some 25,000 observations of sky-wave propagation, had showed that the longer the distance at which the signals were received the smaller was the error. The probable explanation of the phenomenon was that at more oblique angles the penetration of the E layer in the ionosphere was less or, alternatively, alterations in height of the E layer had a smaller effect at more oblique angles.[1] At under 250 nautical miles the error was so great that the system was practically useless for navigation purposes, but between 250 and 1,600 nautical miles the system was effective.

At first it was proposed to site one pair of stations in Scotland and near Leningrad, and another in Scotland and North Africa. It soon became apparent, however, that it would not be easy or expedient to try to arrange for a station to be sited in the U.S.S.R. at that time, and it was therefore proposed to build one station in Scotland and three in North Africa. The great advantage of the S.S. Loran system was that the equipment in current production for standard Loran could be used, thus saving time and money and enabling chains to be set up without delay. Eight sets of ground stations, four operating and four standby, were required, and as the transmitting equipment was then in production at the rate of one to two transmitters a week and mass production of aircraft equipment was expected to begin in June 1943, no trouble was anticipated in going ahead with the project and it would not jeopardise any other Loran projects by more than one month at the most. Training of aircrews would take only a fortnight, including about ten hours in the air. Training of 30 men with previous radar experience for ground station personnel would take probably two months.

The frequency which had been most effective in experiments was about 2 megacycles per second. The Air Ministry thought there might be some difficulty in reserving a frequency but had no doubt that it could be overcome. It had been admitted in the Radiation Laboratory report that S.S. Loran would be vulnerable to enemy jamming, but it was considered that there would be a sufficiently long period of operational use, before the enemy could complete an entirely effective jamming programme, to warrant the adoption of S.S. Loran. It was difficult to estimate the useful life of such a system. Estimates of the time it would take the enemy to jam Gee had varied from one week to six months. It had in fact taken the Germans five months. However, because of its probable limited life-time the Radiation Laboratory urged that the system should only be used after a training and installation programme so large that

[1] Sir Edward Appleton was greatly interested in the experimental data and confirmed that the explanations were strictly in accord with the best theoretical views on the behaviour of the ionosphere. He was invited to furnish a scientific appreciation of the S.S. Loran system based on the existing knowledge of the ionosphere including data on the variations of the height of the abnormal E layer at night.

effective results would be obtained immediately. To this end it was decided to set up a full-scale system in the United States of America for test and training purposes and to transfer the system as a whole to the European theatre of war when training was complete.

A small panel under the directorship of Mr. Watson Watt was set up to consider plans for the operational use of the system, in consultation with Dr. Fink, and to report to the Operations and Technical Committee. On the understanding, obtained from Dr. Fink, that the U.S.A. authorities were prepared to let the Royal Air Force have nearly all the output of aircraft and ground equipment necessary for the Loran scheme, a target date was tentatively suggested as 1 January 1944, so that use could be made of the remaining long winter nights. It was intended to equip with Loran all bomber aircraft already fitted with Gee, including those based in the Mediterranean area. A comprehensive memorandum describing standard Loran and S.S. Loran, and comparing them with Gee, was formally submitted to the Air Staff on 24 July 1943 and the Chief of the Air Staff gave his approval to the scheme on 29 July 1943.[1]

Unfortunately, when the minimum requirements for a 24-hours' service were worked out, it was found that not only were they considerably above those ordered on 12 May 1943 but that there seemed very little chance of realising them. Although Dr. Fink had the backing of the U.S.A.A.F. and his services were greatly appreciated by all concerned, the U.S. Navy had fairly extensive plans for the use of much of the ground equipment and aircraft sets, and were loath to have them diverted. The B.A.D. reported on 22 August 1943 that the production of Loran equipment was very slow and that the estimates made by Dr. Fink did not appear to bear any relation to the anticipated production figures. A day later the Royal Air Force Delegation informed the Air Ministry that the requirement could only be met, even in part, by taking almost the total supply of ground transmitters and all aircraft sets expected to be available during the next few months.[2] The plain fact was that there was not, nor would there be in the next few months, sufficient Loran equipment to meet the needs of all the British and U.S.A. Services. Eventually the U.S.A. authorities decided that no action was to be taken on the S.S. Loran project until the results of practical trials had been obtained, and then the matter of priority would be laid before the Joint Combined Chiefs of Staff Committee.

This was the first hint that the target date of 1 January 1944 would not be reached, but it was still aimed at with the intention of operating as soon as the S.S. Loran ground system was completed and as soon as not less than 400 heavy bomber aircraft of Bomber Command could be fitted with Loran and maintained in operation. This was later cut down to the fitting of 156 Coastal Command aircraft to begin in October, to use with the North-East Atlantic Chain, and the fitting of 144 aircraft of Bomber Command. The figures were definitely the lowest acceptable to the R.A.F. and did not allow for installations in aircraft based in the Mediterranean area. In view of the sudden intensified interest in Loran and the keen competition for equipment, the Chief of the Air Staff called for a progress report on 10 September 1943. He was informed that the site for the ground station in Scotland had been chosen at Port Errol and that a siting party was in North Africa. The actual date of operation depended upon the accuracy of the production forecast, the British obtaining priority

[1] A.M. File C.28851/45.

[2] A.M. File C.28851/45.

of allocation after the S.S. Loran trials in the U.S.A., and priority for shipping of both ground and aircraft equipment. The target date for the ground stations becoming operational had already been moved to 1 February 1944 but it was thought unlikely that even that date would be met. In the event, by 1 February 1944, the United Kingdom ground stations were completed and ready for tests, but although sites for the Mediterranean stations had been chosen as far back as September 1943, and were now ready for installation, equipment was late in arriving from the U.S.A. and installation could not be completed before 1 March 1944, or even one month later.[1]

Service trials of S.S. Loran were held for three weeks during October 1943.[2] Equipment was assembled and modified to provide four transmitting stations. Two at East Brewster, Massachusetts, and Gooseberry Falls, Minnesota, were synchronised to provide an east-west baseline and two at Key West, Florida and Montauk Point, Long Island gave a north-south baseline. Night after night, U.S. Army, U.S. Navy and Royal Air Force aircraft flew through the eastern and central areas of the United States navigated entirely by S.S. Loran, the observers including high-ranking officers of all three Services. At the conclusion of the tests a report was prepared by the Royal Air Force Delegation showing that the average error over hundreds of navigational fixes proved to be between one and two miles. The results were considered to be excellent and of sufficient value to justify the diversion of much needed U.S. Navy ground-station equipment to the European theatre of war for use by Bomber Command. It had been found during the tests that the system could easily be jammed by a 75-kilowatt transmitter using noise modulation, but R.A.F. observers considered that sufficient use could be made of the system to justify its installation before the enemy could render it useless.[3] Relying upon this opinion, the United States Navy agreed that the system should be installed in Europe as quickly as possible and the equipment used for the trials was immediately dismantled and returned to the Radiation Laboratory for reconditioning.

Following the successful trials strong representations were made to the W/T Board for the allocation of the frequency of 1·9 megacycles per second, but no agreement was reached as the Admiralty complained that the use of

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[1] A.M. File C.28851/45. The S.S. Loran chain consisted of the following stations :—

A.M.E.S. No. 700 : Port Errol (Scotland)—Master } Pair No. 1.
A.M.E.S. No. 23001 : Bizerta (N. Africa)—Slave }
A.M.E.S. No. 23002 : Oran (N. Africa)—Master } Pair No. 2.
A.M.E.S. No. 23003 : Appollonia (N. Africa)—Slave }

Port Errol was given a number from the 700 series on security grounds in order that it would be dissociated from the sites in North Africa.

The Homing Loran chain consisted of the following stations :—

A.M.E.S. No. 710 : Danby Beacon—Slave.
A.M.E.S. No. 711 : Clee Hill—Double Master.
A.M.E.S. No. 712 : Worth Matravers—Slave.

Although originally it had been suggested that the homing stations should be sited at the Eastern Gee Chain stations, it was considered later that the selected sites would give better cover, and greater accuracy, because of longer base-lines. In addition, erection of a Loran station on the Daventry site would have produced technical complications owing to the resultant congestion of equipment.

[2] A.M. File C.28851/45 and C.R.B.48/1063.

[3] The United States Navy Department considered that Loran might well have been compromised as five naval ratings stationed at the Loran site on St. Matthew Island in the Bering Sea disappeared on 21 September 1943 and had presumably been made prisoners by the Japanese.

that frequency for S.S. Loran would completely disrupt certain essential naval and some army communication channels which were in operation. Naval communications in particular included those which were, among other purposes, used for control of convoys and offensive action against E-boats in the North Sea and English Channel. The Admiralty considered that it might be possible to accept the reduced interference if the Homing Chain were dispensed with and if the S.S. Loran station at Port Errol was resited in the Faroes. Both these suggestions were unacceptable to the R.A.F. Headquarters Bomber Command insisted that a homing chain should be available and not only was it impossible to resite a station if the chain was to be in operation by early 1944 but the range from the master station to the Faroes site would be 1,930 miles, which was unquestionably too great for satisfactory synchronisation.[1]

The Admiralty, however, was adamant in its refusal to allow the use of the frequency until tests had been carried out to discover to what extent interference might effect communications, and therefore tests were arranged to start in December 1943 using the North-East Atlantic Loran Chain stations, with Admiralty and M.A.P. observers.[2] Although the results were favourable, it was not until August 1944 that the difficulty was finally resolved and the W/T Board agreed to the allocation of 1·9 megacycles per second for use with the S.S. Loran system. Meanwhile it had been discovered that the Loran equipment failed when flown above 10,000 feet and this and other factors necessitated a postponement of the provisional target date for beginning operational use until 1 September 1944.

By September 1944 it was becoming apparent that methods of interpreting the Loran system were not being standardised, and, through lack of personal contact between those concerned with the use of the equipment, considerable duplication of effort was taking place. Since it was quite evident that the use of Loran facilities was becoming world-wide for both air and surface craft, it was considered essential that every effort should be made to obtain closer standardisation, to limit the variety of interpretation systems, and to effect a full exchange of information between the users. Accordingly, in August 1944, an Air Ministry Mission, under Wing Commander R. E. G. Brittain, was sent to the United States of America for discussions with the United States Army Air Force and Navy and with British Service delegations in Washington. As a result of a series of meetings complete agreement was reached on the various aspects of the requirements for Loran navigation charts, with particular emphasis on the air navigation side.[3]

Operational Use of Loran

The North-East Atlantic Chain came into operation on 6 March 1944 and two squadrons of Coastal Command began using it from 1 May.[4] The navigators found the system exceedingly useful.[5] Before they had time to become fully accustomed to its use, however, the chain was switched off by

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[1] A.M. File C.28851/45. [2] A.M. File C.26821/45. [3] A.M. File C.30524/46.

[4] A.H.B./IIK/54/1/3/(A). Coastal Command File Loran. Coastal Command squadrons equipped were :—

No. 59 (Ballykelly) .. .. 12 Liberator aircraft.
No. 518 (Tiree) .. .. 14 Halifax aircraft.

[5] A.M. File C.17532/44. A main disadvantage was instability of the aircraft installation.

the Admiralty just before D-Day for Operation Overlord and came back on the air again on 10 July 1944 at the request of Headquarters Coastal Command. The S.S. Loran Chain and the Loran Homing Chain came into operation on 7 September 1944, but no great operational use was made of either of them during September and October.[1] Most of the sorties attempted were in the form of operational trials, by P.F.F. Mosquitos *en route* to Berlin and by a P.F.F. Lancaster *en route* to Frankfurt. The results showed the Homing Chain in a very poor light. It had a severely restricted range and fixes could not be obtained at altitudes below 5,000 feet, despite the satisfactory preliminary tests which had been carried out. However, although the Homing Chain was unsatisfactory, the S.S. Loran Chain was producing very promising results.[2] Accuracy was normally within the plus or minus two miles claimed for the system, but difficulties had arisen in some areas owing to the confusing first and second E layer reflections. In those areas it appeared that a first E reflection was not seen at all or only at small amplitude. This confusion resulted in reports of inaccuracy in the system, which in turn led to the conclusion that consistent accuracy in the use of S.S. Loran entailed an extensive period of training of the navigator.

In November 1944 there was still insufficient data to give any precise estimate of the limits of S.S. Loran coverage over Europe. Lancaster aircraft of No. 5 Group carried out only three operations in which Loran was used to any extent. They took place against Hamburg on the night 11/12 November, Ladbergen on 21/22 November and Munich on 26/27 November. The Homing Chain was not accepted by Headquarters Bomber Command as an alternative to Gee and all aircraft using the S.S. Loran system were fitted with dual installations of Gee and Loran in order that the use of Gee for homing might be continued. Unfortunately the sites for the Homing Chain had been chosen to give coverage over south-eastern England at relatively high altitudes, and it was found that the stations were too far apart to provide satisfactory signals at the heights flown by aircraft returning to base. In most areas all three stations could not be received at the same time in an aircraft below 6,000 feet at night. Interference was very heavy and this, combined with the inherent difficulty that S.S. Loran provided only position lines, made the Homing Chain entirely unsatisfactory as an alternative to Gee. The Homing Chain was closed down on 30 November 1944. By the end of 1944 the lack of an operational requirement for Loran was becoming apparent. Fewer targets at long range were being attacked and short-range navigation systems, sited on the Continent, provided adequate cover.

Loran equipment was vulnerable to interference and, although the North-East Atlantic Chain was not jammed intentionally, operations frequently suffered from jamming by random H.F. transmissions. Enemy jamming of the S.S. Loran Chain, on the other hand, began in February 1945 and effective use of the equipment was seriously affected over northern Germany.[3] The discovery of Loran came as a great shock to the Germans because Professor von Handel had convinced himself that a long-range, comparatively long-wave, pulse system would be too inaccurate for employment as a means of navigation. Maps were captured in the middle of 1944 and ultimately a complete set was

[1] Bomber Command File BC./S.30408. [2] A.M. File C.28851/45.
[3] A.H.B./IIG/29. A.D.I.(K) Report No. 380/1945.

obtained from an American aircraft. By March 1945 noise jammers were in operation, transmitters to meacon the pulses were being built, and jamming of the synchronisation of the transmitters from the front line was being considered. A transmitter was actually taken to Thuringen but disruption of transport and communications prevented it from being used.

Extension of Loran Coverage

In July 1944 the Air Officer Commanding-in-Chief, Coastal Command had pointed out that although the North-East Atlantic provided excellent fixing cover for the Atlantic convoy routes, it did not extend far enough to the north-east and there were areas of ambiguity along the extension of the base-lines of the stations.[1] There were, therefore, serious limitations to the chain as a navigation system. Other means of navigation were also very limited in the northern waters ; weather conditions normally precluded the use of astro-navigation at operational heights and Gee cover did not extend sufficiently far north. The only W/T aids were M.F. beacons at the Faroes and on the Shetlands, and they did not provide adequate cover or accuracy.

The T.R.E. and the B.B.R.L. produced four alternative methods of extending Loran coverage in the north but, as it was impossible to build any new chains, it was finally decided to erect a Loran station on the remote reserve site of the C.H. station at Skaw.[2] It could then be arranged for the Shetlands station to have a different phasing from that on the Hebrides and for its pulse to be identified by slow rate interruption of transmission. Although the Joint Chiefs of Staff Committee approved the Shetlands project on 21 August 1944, it stipulated that equipment for it should not interfere with the U.S.A. programme for the Pacific. Therefore the only equipment immediately available was that earmarked for the Azores, but the United States Navy would not release this as they did not consider the Shetlands requirement sufficiently urgent. By mid-September 1944, the Homing Chain had come into operation and had given a most unsatisfactory performance. It was therefore decided, with considerable misgivings, to withdraw two reserve transmitters from the chain and install them with all possible speed in the Shetlands.[3] A.M.E.S. No. 713 at Shaw accordingly became operational on 7 November 1944, with its signal distinguishable from the Hebrides pulse on the lower trace, having a continuous identification blink distinguishable from the ordinary blink indicating unreliability.[4] Not only was this extension of the North-East Atlantic Chain of great value to Coastal Command but also for operations over the coast of Norway such as the attack on the *Tirpitz*, and it was used extensively by surface vessels escorting convoys to Murmansk.[5]

At the end of the war in Europe both the United States Services, as well as Coastal and Transport Command of the Royal Air Force, were anxious that the North-East Atlantic Chain should be kept in operation.[6] In August 1945 control of the chain was taken over by the R.A.F. Personnel establishments were brought up to strength by using redundant crews of the North Africa Loran stations which had been brought back to the United Kingdom for the East Atlantic S.S. Loran Chain, and by economies made amongst radar crews

[1] A.M. File C.23180/44. [2] A.M. File C.17496/44. [3] A.M. File CS.23180.
[4] A.M. File CS.23180. [5] C.R.B. 48/1063. [6] A.M. File C.17496/44.

in No. 60 Group. In February 1946 A.M.E.S. No. 713 at Skaw was placed on a care and maintenance basis and in June 1946 the stations in the Faroes and Iceland were handed over to the U.S.A., while the station in the Hebrides was transferred to the Ministry of Civil Aviation.

Loran in the Far East

The use of Loran in the Far East had first been considered as far back as the autumn of 1943, when a Loran system was proposed to provide navigation for the United States Army Air Transport Command route from India to China.[1] Among the several schemes for providing Loran cover over the Pacific the China-Burma-India theatre came second in a priority list drawn up by the U.S.J.C.O.S. in February 1944.[2] In May 1944, Headquarters A.C.S.E.A. requested standard Loran cover over the Bay of Bengal and neighbouring areas.[3] Four stations were suggested, sited at Cuttack, Sunderbans, Cocanada and Madras, to give day and night cover. The U.S.A. authorities were willing to supply equipment for the three northerly stations but considered that Madras gave insufficient additional cover to warrant the effort to construct, install and man a station there. The proposals for the East India Chain (as it was to be known) were therefore changed to three standard Loran stations at Cuttack, Sunderbans, and the Arakan coast.

The Joint Chiefs of Staff Committee approved the proposals for the chain in July 1944 and agreed that the U.S. Army Air Force would install and operate the equipment, on a frequency of 1,850 kilocycles per second. As the war progressed in the Far East, the sites were, however, again changed to Char Chapli, Puri, and Cocanada, with a monitor station at Vizagapatam. The frequency was changed to 1,750 kilocycles per second to assist long-range navigation by day over the Bay of Bengal, the Andaman Islands, and Rangoon, and by night to Bangkok and towards Singapore. By 15 April 1945 the Fourth Army Air Corps Signals Wing, A.A.F., had the chain in operation and on 1 July 1945 the system was turned over to the Royal Air Force on lease-lend terms. The home commands had provided a nucleus of highly trained and experienced Loran personnel who trained the remainder provided by A.C.S.E.A.[4] Flight reports indicated that excellent signals were obtained at ranges of 700 and 800 miles, and that errors were less than one mile for the favourable coverage areas. For the less favourable regions, those off the baseline extensions, errors were up to two and three miles.[5]

In November 1944 Headquarters A.C.S.E.A. stated that there was an urgent operational requirement in the Far East for navigation assistance east, south and west of Ceylon in order that reconnaissance commitments over most difficult terrain might be fulfilled, and Loran sites at Galle, Cape Comorin and Kelai were suggested.[6] However, owing to the difficulty of obtaining additional equipment the proposal for the chain was not approved by the British Chiefs of Staff Committee. In spite of that decision, in January 1945 the Supreme Allied Commander, South-East Asia, asked the Chiefs of Staff Committee to support a request for equipment to enable the East India Chain to be extended

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[1] C.R.B. 48/1063. 'Loran', a publication of the M.I.T., R.L. series, gives full details of the Loran chains in the Far East.

[2] A.M. File CS.23151. [3] A.M. File C.26818/45. [4] A.M. File C.26818/45.

[5] C.R.B. 48/1063 and South-East Asia Command O.R.B., Signals Appendix, July 1945.

[6] A.M. File C.26641/45.

to cover the area south of Ceylon.[1] The new Ceylon Chain was to have sites at Cape Comorin, and at Male and Addu Attoll in the Maldive Islands. This was considered a more reasonable request and was agreed to by the Chiefs of Staff in May 1945, and accorded sympathetic consideration by the United States Services. By July 1945, however, equipment which had been earmarked for the Ceylon Chain was diverted elsewhere by the United States Joint Chiefs of Staff Committee and it was decided to take the two slave stations earmarked for the Eastern Atlantic S.S. Chain, on condition that the United States supplied one complete double master station. This caused further delay, because the two stations had to be brought back to the United Kingdom from North Africa to be shipped to Colombo. By September 1945 it was improbable that any equipment would be obtained from the U.S.A. because the whole Loran policy was then under consideration in view of the end of the Japanese war and the cessation of Lease-Lend. On 10 October 1945, Headquarters A.C.S.E.A. informed the Air Ministry that in view of the diminished need for Loran coverage and the shortage of equipment, the command had decided to abandon the project entirely. The Ceylon Loran Chain was finally cancelled in March 1946, the stations having existed for the previous six months merely as paper establishments in No. 60 Group.

[1] A.M. File C.28855/45.

CHAPTER 8

OBOE MARK I

In November 1940 during the blitz against England it was discovered that one of the most important factors in the enemy bombing offensive was the use by the *Luftwaffe* of *Lorenz* beams which intersected over targets in the British Isles, providing both a navigation aid and a bomb release point for enemy bombers. Vital targets were seriously threatened by the use of the beams, and it became imperative therefore that, in addition to the development of radio countermeasures, the main beam installations on the French coast should be eliminated by precision bombing without delay. Scientists of the Telecommunications Research Establishment at Swanage realised the necessity for developing radar for use by Bomber Command in adverse flying conditions. While a preliminary investigation of possible methods was being made at the T.R.E., the first attempts at blind bombing were already being carried out at the Wireless Investigation and Development Unit, Boscombe Down, which was controlled by the radio countermeasures formation, No. 80 Wing, and was investigating the source and direction of the enemy beams. On 10 December 1940 the unit became a flight of the newly formed No. 109 Squadron of No. 3 Group.[1] The squadron consisted of one flight of Anson aircraft engaged on the development of radio countermeasures, and one flight of Wellington aircraft from the converted W.I.D.U. whose purpose was a full investigation of enemy methods of beam navigation and assistance in experimental blind-bombing trials.

Early Blind-bombing Experiments

During December 1940 and January 1941 the first attempts at blind bombing made by the Royal Air Force were carried out by the Wellington flight against the ' Ruffian ' transmitters at Cherbourg.[2] A rather crude method had been evolved whereby aircraft flew down the enemy beam until the cone of silence was reached and then released bombs whatever the visibility. The accuracy of the attacks was questionable, but they did prove that it was a simple matter to locate the sites of the transmitting stations and that accurate methods for radio-controlled bombing could be developed. The T.R.E. had been kept informed of these early attempts and the operational requirements which had given rise to them, and in December 1940 proposed that experimental flights using the normal CHL apparatus with a modified display system should be carried out over prominent landmarks. An observer in the aircraft signalled to the CHL station when he was vertically over the object selected as a target. Several experimental flights demonstrating the possibilities of the system were made, and by comparing the radar range with the actual range it was estimated that an accuracy of 80 yards had been achieved.

In January 1941 the CHL Group at the T.R.E., which had been carrying out the earlier range-measuring experiments, devised a new scheme called ' Howler Chaser ' which combined control in azimuth of aircraft with range

[1] No. 109 Squadron O.R.B., January 1941.

[2] *See also* Royal Air Force Signals History, Volume VII : ' Radio Counter-Measures '.

measurement. It was claimed that a CHL station by virtue of the horizontal 'split' could detect any deviations from the correct course, and it was proposed to modulate a remote high-frequency continuous-wave transmitter in accordance with the off-bearing indication obtained by the split method. The type of modulation proposed was that used on the blind approach systems in which the distance off track was indicated by the depth of modulation of dots or dashes according to which side of the mean track the aircraft had erred. Range was determined by modified CHL as in the earlier experiments, and it was estimated that the release point along the track could be defined with an accuracy of 80 yards up to a range of 70 miles.[1] The name Oboe which was given to the system was derived from the note emitted by the modulated continuous-wave transmitter used in the experiments, considered by one member of the research group to sound like an oboe. The name persisted and was applied to the very different system of control which was eventually developed from those beginnings.

By February 1941 it was known that the majority of the enemy beams ~~were~~ originated in the Cherbourg area, and that one of them lay directly over the CHL station at Worth Matravers. A requirement therefore arose in the same month for the destruction of the Cherbourg transmitters, and in particular of the station operating over Worth Matravers. It was proposed that aircraft of the Wellington flight of No. 109 Squadron should fly along the German beam in the direction of the transmitter, their range being measured accurately by the CHL station at Worth Matravers, and the instant of bomb release should be signalled from that station on the ordinary high-frequency communication channel. The range of the target was 60 miles from Worth Matravers and in order to be certain of obtaining reliable pulse returns from aircraft at that range it was decided to introduce a new ancillary device in the form of a 'repeater' to be carried in the aircraft. The repeater consisted of a receiver which picked up the radar pulse from the CHL station, amplified it, and re-radiated it, so that the pulse received on the ground was more powerful than the normal echo. In effect the repeater was a high-powered IFF set.[2] The chief difference, apart from that of power, between it and standard IFF lay in the strict attention which had to be paid to keeping constant the delay between reception of the ground station pulse and transmission of the magnified pulse since on this delay depended the accuracy of the ground measurements. This early airborne repeater apparatus, which was named 'Broody Hen', was the forerunner of that ultimately used in Oboe aircraft some eighteen months later. Although several sorties were made in March 1941 with this method of ground-controlled bombing, under the code-name of 'B.B.C.' (Blind bombing of Cherbourg), no serious damage was inflicted, and in April 1941 the scheme was abandoned in favour of radio jamming of the beams.

Development of Oboe

Although the early experiments were discontinued in view of the negligible amount of damage inflicted on the transmitting stations, the possibility of a similar but more fully developed system was under consideration. On 4 May 1941 Mr. A. H. Reeves assembled at the Telecommunications Research

[1] Paper by A. H. Reeves and J. E. N. Hooper on 'Oboe History and Development' in T.R.E. Journal of October 1945.

[2] *See* Royal Air Force Signals History, Volume V: 'Fighter Control and Interception'.

Establishment a small group of scientists known as the Oboe group. The aim of the group was the development of radio aids and techniques for blind bombing with particular application to the scheme which had already been labelled Oboe. In June 1941, the group submitted to the Air Ministry a proposal that experiments should be made to determine the position of an aircraft by cross-cutting accurate range measurements obtained from the use of two modified CHL stations with rotatable aerial systems.[1] In that way advantage would be taken of the ability of radar to measure range accurately, and it was estimated that individual bombs could be dropped in a target area of 200 feet by 600 feet up to a range of 600 miles. The general principles were that when near the target the bomber was to fly on a course at constant range from one ground station, signals from which would actuate a visual indicator. The pilot would therefore be able to maintain his heading with ease. The second ground station was to determine the ground speed of the bomber by plotting its track over approximately 10 miles and to send a bomb-release signal at the appropriate moment. The signals to the bomber would be sent on the same radio channel as that used for range measurement and consequently R/T or W/T communication between the bomber and the ground station was not necessary.

It was recommended in the original proposal that early development work should be carried out on a wavelength of 1½ metres since fairly large quantities of apparatus working on that wavelength were then available from existing stocks of A.S.V. equipment, and that the use of centimetre wavelengths should receive early consideration in order to counteract the possibility of enemy jamming. Unfortunately the scheme was complicated and, in order to obtain the required maximum range of 600 miles, involved flying a repeater aircraft on a set course between the bomber and the ground station, amplifying the signals sent out by the ground station to the bomber and vice versa. On 15 July 1941, however, the original proposal was modified, and a multi-channel control system was introduced so that it would be possible for two ground stations to control up to 20 aircraft simultaneously. In Oboe Mark I, 1½-metre equipment without repeater aircraft was to be used, whilst Oboe Mark IB was to operate on the same wavelength but with repeater aircraft. Oboe Mark II was to operate on centimetre wavelengths as was Oboe Mark III, which also included a multi-channel control system. On 17 July 1941 the Director of Communications Development reported the progress already made on those lines at the T.R.E. since the scheme was first proposed.[2] Although the proposals at first met with some criticism in the Air Ministry, the need for an accurate method of blind bombing was becoming ever more apparent and the Air Staff eventually agreed that the two CHL stations at Worth Matravers and West Prawle should be made available to the Oboe group for experimental work.

Whilst the subject was under discussion and initial experimental work on the scheme was proceeding at the T.R.E. certain operations took place which provided an argument against a previous criticism of a straight and level approach to the target and indicated that the risk to bombers operating under those conditions might not be as great as was anticipated. The operations, which were known as 'Trinity' operations, were directed against the *Scharnhorst* and *Gneisenau*, then lying in Brest Harbour. The ships were extremely well camouflaged and very difficult to bomb visually, so it was

[1] T.R.E. Journal, October 1945.

[2] T.R.E. File D.1459.

decided that a blind-bombing technique was necessary. A study of long-range narrow-beam radio technique had been undertaken by Headquarters No. 80 Wing and a scheme was proposed whereby aircraft could fly an accurate course on a radio beam to a range of approximately 200 miles. The beam which was suggested as suitable for the purpose was known as the Baillie beam, a device which was subsequently used to a very great extent for navigation purposes with the Oboe system. It was decided that the beam should be used in conjunction with the experimental Oboe station at West Prawle, on the south coast of Devon, which was designed to give the bomb-release signal. The Baillie beam, which was a 6-metre dot-dash split beam, was laid from a station at Helston in Cornwall to carry the bombing aircraft over the ships, and the responsibility for the installation, maintenance and operation of it was made that of Headquarters No. 80 Wing. The T.R.E. was responsible for transmission of the bomb-release signal by means of a 1½-metre pulsed transmission from West Prawle.[1]

Trinity operations commenced on 3 December 1941, and some 35 sorties were subsequently flown by Stirling aircraft of Nos. 7 and 15 Squadrons of No. 3 Group, using equipment working on 207 megacycles per second. The aircraft crews included an additional second pilot from No. 109 Squadron, an expert in beam flying, who took control of the aircraft in flight, and a special wireless operator, also from No. 109 Squadron, to manipulate the Broody Hen equipment. The aircraft picked up the Baillie beam at Helston and flew from there to the target in a straight line at a height of between 15,000 and 18,000 feet. Considerable interference was experienced by aircraft in detecting the note resultant upon the response of the IFF set to the Oboe station at West Prawle because of responses to other CHL and GCI stations in the vicinity, and it was found necessary to close down such stations for the duration of the operations.[2]

An analysis made by the T.R.E. on 14 January 1942 revealed that of the 35 aircraft used, 11 were considered to have completed their mission successfully in that they had dropped bombs in accordance with the plan.[3] Despite the rather high percentage of failures, experienced as a result of the inadequacy of the Broody Hen ranging apparatus, further exploitation of the scheme was considered worth while, and operations were suspended until an improved aircraft responder was developed. Although the Trinity operations caused some temporary diversion of scientific effort from Oboe development, some important, if negative, results emerged. Firstly, Broody Hen was shown to be completely unreliable, and consequently considerable impetus was given to the development at the T.R.E. of 'Peacock", a pulse repeater operating on 222 megacycles per second which by virtue of its higher power and greater sensitivity became the first airborne Oboe equipment.[4] Secondly, no aircraft was lost on the operation despite the necessity for straight and level flying over some 20 miles of

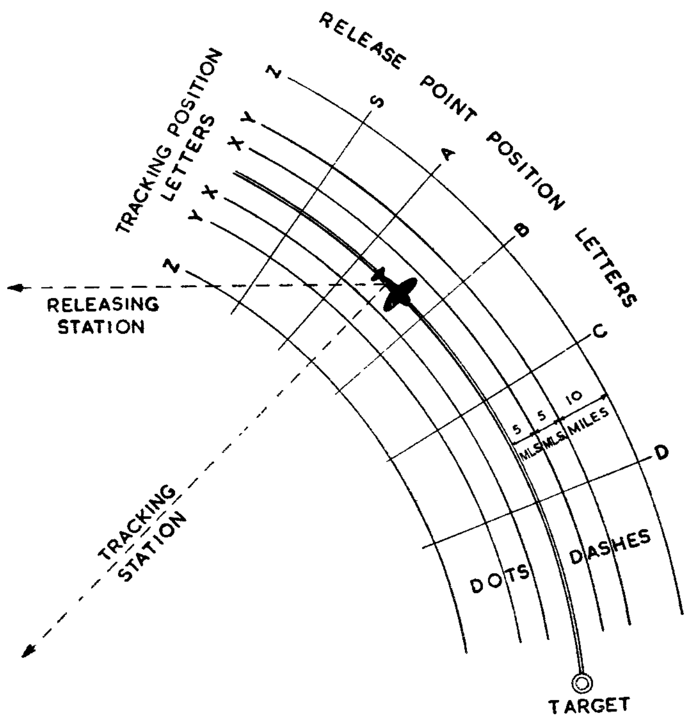
[1] T.R.E. File D.1709. [2] T.R.E. Journal, October 1945. [3] T.R.E. File D.1709.

[4] 'Peacock' was a pulse repeater with pulse peak output of 7–10 kilowatts. It consisted of a sensitive superheterodyne receiver connected by a suitable trigger circuit to a transmitter. Received pulses activated the trigger circuit and caused the transmitter to emit a pulse. The total delay between receiving and retransmitting a pulse was of the order of 4 micro-seconds.

The receiving and transmitting aerials consisted of centre-fed half-wave elements, mounted on the tail of an aircraft, and the feeder system was carried up to the apparatus, which was located in the navigator's compartment. The power supply was obtained from an 80-volt 1,000-cycle generator placed in the nacelle of the starboard outer motor. The receiver itself had two controls, one for volume and one for tuning, so that from an operating point of view the installation was made as simple as possible.

well-defended country, and thus a sound argument was provided against the critics who had originally opposed Oboe on the ground of such a serious limitation. The sorties were nevertheless very hazardous, most of the aircraft being damaged by anti-aircraft fire, which indicated that an increase in operational height was a further tactical requirement. The operations also focused attention on the urgent need for precision bombing methods. Headquarters Bomber Command submitted an immediate requirement and gave wholehearted support to the development of Oboe.

In a skeleton programme submitted by the Oboe group in January 1942 it was estimated that the 1½-metre project would be working by July 1942 and that the complete centimetric equipment would be available for operational use in January of 1943.[1] In fact it was impossible to adhere to the schedule, and Oboe Mark I equipment did not come into use until December 1942; Oboe Mark II did not become operational until October 1943, and Oboe Mark III until April 1944.



The Oboe Track

The Oboe system was one in which an aircraft was controlled by range measurements from two ground CHL stations.[2] The two stations transmitted pulses on the same radio frequency but on different pulse recurrence frequencies; the aircraft carried a pulse repeater to provide adequate signal strength of the return pulse at the ground stations. Theoretically the aircraft was required to fly on an arc, centred at one ground station (known as the 'Cat'

[1] T.R.E. File D.1637.

[2] *See* Appendix No. 4 for further details of the system.

or 'Tracking' station), of radius equal to the target range, and of length equivalent to approximately ten minutes' flying time terminating at the target. This 'track' formed the basis of the region of Oboe control and when the aircraft was exactly on the predetermined track the pilot received a steady continuous note in his headphones. Deviation from the track was defined by a series of dots and dashes, as in the *Lorenz* beam approach system, the dots representing a range less than the target range and the dashes a greater range. The dots and dashes were superimposed upon the steady note and so the deviation from track was indicated by their relative intensity and definition with respect to the note. The limit of this fine control represented a deviation of 175 yards on either side of the track ; when the limit was reached the steady tone disappeared completely, and clear dots and dashes were heard. At the second ground station (known as the 'Mouse' or 'Releasing' station) which was situated some considerable distance from the Tracking station, normally not less than 100 miles, progress of the aircraft along its track was followed and its ground speed measured. From that information, used in conjunction with a knowledge of the ballistic characteristics of the bomb and the pre-arranged height and air-speed of the aircraft, the point at which it was necessary for the aircraft to release its bombs was determined and an appropriate signal given to it. Instructions were transmitted to the navigator by means of a steady continuous note, which was keyed at intervals to denote progress of the aircraft along the track and to provide a warning of approach to the target before the actual bomb-release signal, the overall time of Oboe control being in the region of 10 to 15 minutes.[1] Signals to the pilot from the Cat station, and to the bomb aimer from the Mouse station, were transmitted on the same wavelength as that used for range measurement, and both stations were interchangeable for operative purposes.

In January 1942, although the work of the Oboe group was quite well advanced on the 1½-metre system, the scheme in its simplest form would only permit of a few aircraft operating in succession at intervals over any given target, and therefore was only applicable to a small force of aircraft operating against specially important targets suitable for limited attack, although it was considered that it could also be used for fire-raising operations which would allow for a follow-up attack by main force aircraft. The Oboe group itself had been split into two sections ; one section, situated at R.A.F. Hurn, was to carry out the centimetre research work, and the other, at R.A.F. Boscombe Down, to undertake all work on the 1½-metre technique. The assistance of the Wellington aircraft of No. 109 Squadron was made available at the latter unit.[2] On 16 February 1942 the Air Staff requirements for Oboe were consolidated into one statement which formulated the following principles.[3] Firstly, immediate effort was to be concentrated on the Mark IA system using modified CHL radar installations at Worth Matravers and West Prawle. A frequency of 222 megacycles per second was allocated for experimental work, and permission was given for bomb-dropping trials to take place over the Stormy Down sea ranges. A Lancaster aircraft was to be allotted to No. 109 Squadron for that purpose and every effort was to be made to conclude the experiments by April 1942. Secondly, an investigation was to be made of the

[1] The aircraft was navigated by a system other than Oboe to the 'waiting point' from which the Oboe operation began.

[2] T.R.E. File D.1459.

[3] A.M. File C.28852/45.

Mark IB repeater project using modified CHL equipment. Again, attention was to be focused on avoiding the necessity of keeping the repeater aircraft on track by using a beam installation. The same ground stations were to be used for experimental work, and when the system was sufficiently developed, bomb-dropping trials were to be carried out on the ranges at West Freugh. Finally, it was stressed that much more concrete evidence of the practicability of the Oboe Mark I system was required before any consideration would be given by the Air Staff to the development of Oboe Marks II and III. In February 1942 range accuracy trials were conducted over a camera obscura, with two Wellingtons of No. 109 Squadron which had been fitted with the Oboe repeater and pulse communication systems. The camera obscura was situated approximately 70 miles from the ground station at Worth Matravers and the results obtained with it indicated an average error of plus or minus 34 yards with a maximum error of 180 yards.[1] Two Stirling aircraft of No. 15 Squadron had also been fitted with pulse repeaters of the Oboe type so that they could be adapted for use in the full Oboe scheme, which it was hoped would be ready for use with repeater aircraft by midsummer 1942. It was anticipated that, with repeater aircraft flying at 32,000 feet and the bombing aircraft at 23,000 feet, the range covered would be in the region of 650 miles, thus enabling cities as far distant as Berlin and Munich to be attacked. Although work had continued slowly on the centimetre wavelength programme one experimental ground station had been constructed in a trailer situated near Swanage, and one Wellington aircraft had been fitted with a pulse repeater, pulse communication receiver, and visual indicator.

Flight Trials

Bomb-dropping trials, planned for mid-March 1942, were postponed at the beginning of the month in view of the delay caused by the frequency change from 207 to 222 megacycles per second, which necessitated modifications to the aircraft Peacock equipment. Eventually, on 24 April 1942, the first trial took place over the sea ranges at Stormy Down in South Wales, to be followed by further trials from 25 April until 21 May 1942. Ranges of the target from the ground stations at Worth Matravers (the Tracking station) and West Prawle (the Releasing station), were 90 and 80 miles respectively, and an angle of cut of 49 degrees was subtended from the two stations over the target. The trials were conducted in two series. The first, which comprised the runs made on 24 and 25 April and 1 and 3 May 1942, were made by a Wellington aircraft of No. 109 Squadron, flying at 10,000 feet in conditions of perfect visibility. Only one aircraft installation was available in this series, and was not satisfactory in operation due chiefly to the types of valves used, the trouble getting progressively worse as the trials continued. Modifications were made to the equipment and the second series of tests was carried out on 19 and 21 May, again by a Wellington aircraft of No. 109 Squadron in conditions of eight-tenths cloud between the aircraft and the ground.[2] Forty-nine practice bombs were dropped and an extraordinary degree of accuracy was obtained, 50 per cent of the bombs falling within an ellipse approximately 400 by 200 yards, the probable error therefore being plus or minus 200 yards along the major axis

[1] T.R.E. File D.1637.

[2] T.R.E. Report 4/R.103/JENH—Oboe Mark I Trials by Group 4, T.R.E.—dated 7 June 1942.

and plus or minus 100 yards along the minor axis. Further tests were then made, with a Lancaster aircraft flying at 22,000 feet, to determine the range of the system, and they showed that effective ground control could be maintained up to a range of 260 miles.

After the Stormy Down trials two papers were issued which were to be of vital importance in the subsequent adoption of Oboe. The first was a memorandum issued by the representative from the Directorate of Telecommunications who attended the trials, and the second was an analytical report drawn up by the Operational Research Section, Bomber Command, who had closely observed the progress and results of the trials.[1] The reports contained the first objective considerations of the Oboe system by personnel other than its originators or sponsors. Both reports emphasised the practicability and accuracy of the Oboe system, making no attempt to minimise the limitations, and the O.R.S.B.C. report concluded with the statement that '. . . It is recommended that the use of Oboe Mark I as an aid to the location of targets in the Ruhr should be put up as an extremely urgent operational requirement, and that, to this end, two ground stations should be set up, and six suitable aircraft fitted, on the highest priority . . .'. The most important point of all to emerge from the trials was that the direct range was about 270 miles when aircraft flew at about 23,000 feet, thus bringing all the important targets of the Ruhr within direct control of ground stations situated at the nearest points on the English coast. The question of the future of Oboe, and the immediate course of action to be adopted, became the subject of thorough examination by the Air Staff so that an indication could be given of the areas to be covered if the system was put into operational use immediately.

Preparations for Operational Use

On 19 June 1942 the Air Staff raised an immediate operational requirement for 1½-metre Oboe, without repeaters, to be used in attacks against the Ruhr area with Essen as the focal point. The project was assigned the highest priority, and it was decided that immediate arrangements were to be made by the T.R.E. for the use of ground station sites near Cromer and Hastings, about 260 miles from Essen.[2] It was considered that the quickest method of ensuring effective employment of the system was the formation of an Oboe squadron and on 23 June 1942 the establishment and function of No. 109 Squadron were modified for that purpose.[3] Attention was then focused on the most suitable type of aircraft for Oboe operations. The commanding officer of No. 109 Squadron had reported unfavourably on two aspects of the Wellington VI; the restricted view from the pilot's seat which made operations impossible when the weather at base was other than good, and the difficulty of exit. Strong recommendations were made to the Air Ministry by Headquarters Bomber Command in July 1942 that Wellington VI aircraft should not be used for Oboe operations, and that trial installations should be made in Mosquito IV aircraft which were then being taken into operational use. It was pointed out that the Mosquito IV was more suitable as its speed was greater than that

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[1] A.M. File C.28852/45 and B.C. O.R.S. Report No. 53 dated 16 June 1941.

[2] It was also decided to duplicate the stations on the sites to eliminate the risk of failure due to technical breakdowns and because two pairs of stations working simultaneously on different frequencies with two groups of aircraft would double the effective force.

[3] A.M. File C.28852/45.

of any other bomber aircraft, and its operational ceiling was 30,000 feet; providing not only a safeguard against interception by hostile fighters but also the maximum range with Oboe. Meanwhile, in the summer of 1942, the marker bomb, or target indicator, was produced. Earlier attempts to develop such a bomb had been unsuccessful, and incendiary bombs had been used for the illumination and identification of targets; a practice which had a great disadvantage in that it provided the enemy with an opportunity for starting 'spoof' fires. In addition, fires originated by incendiaries were frequently so scattered or obscured by smoke that they failed to direct bomb-aimers.

A requirement had accordingly arisen for a marker bomb which would illuminate the target in distinctive colours and burn for a prolonged period. Two types of indicators were evolved; 'Skymarkers' for use when heavy cloud obscured the actual target, and 'Groundmarkers' for use in clear conditions. The skymarkers were designed in the form of a floating 'candelabra' which burst at approximately 3,000 feet and remained suspended in the air for a period of approximately five minutes, and the groundmarker burned brilliantly in distinctive colours on the ground. The value of the indicators for use with Oboe was quickly realised since a technique incorporating their use nullified all existing objections to the scheme based on its low traffic-handling capacity. By dropping either version of the bomb an Oboe aircraft need only act as a pathfinder, and could mark the target accurately for following main force aircraft. The first marker bomb trials were held at Boscombe Down on the night of 2/3 July 1942 with two Wellington aircraft fitted with Oboe. Release was effected under Oboe control simultaneously with the release of a stick of eighteen bombs from a Stirling aircraft for comparison. The trials proved that by use of the marker bomb in conjunction with Oboe the whole of the main force of Bomber Command could be brought to bear against an enemy target instead of only the lesser effort of one specialised squadron.

Such a procedure was in line with the operational policy of using a pathfinder force to mark targets, and development and production of the bombs were taken up as a matter of urgency. This development also had an important repercussion on the type of aircraft in which Oboe was to be installed, as, although the bomb-carrying capacity of the Mosquito aircraft had been considered too small, it became a practical proposition when the load was to consist of only four 250-pound marker bombs. The only modification found necessary was shortening of the bomb-tail to enable them to be released with reasonable clearance in horizontal flight, in order that the ballistics were impaired as little as possible. Consequently, in July 1942, the Air Staff decided that a flight of No. 109 Squadron was to be equipped with Mosquito IV aircraft.[1] Arrangements were made for the first five to be equipped with Gee, V.H.F. R/T, V.H.F. beam approach, and Oboe, at Stradishall by special fitting parties from No. 26 Group.

In July 1942, two CD/CHL sites, one at Walmer, near Dover, and the other at Trimingham, a few miles from Cromer, were obtained from the War Office for conversion to two Oboe stations.[2] They were then duplicated; a second site was already available at Trimingham, and a hut in the compound of the CHL station at Swingate was converted to complete the second pair. The

[1] A.M. File C.28852/45.

[2] A.M. File CS.10741.

policy for maintenance and operation of the stations was formulated on 12 July 1942, and a target date for completion of the first pair of stations was set as 3 September 1942.[1] In August, centimetre Oboe was given top priority, and a large laboratory at Defford was taken over by part of the Oboe group for experimental work.[2] Progress with the Mark IB repeater scheme was held up owing to the pressure of work on the Mark IA direct control project, and it was considered impossible to carry out a demonstration of the repeater system before the end of September 1942. Although work had proceeded slowly on the centimetre project, it was hoped that a pair of stations would be available by the end of October 1942 so that the interim centimetre system could bridge the gap between the expected jamming of Oboe Mark I and the evolution of the final form of the system, Oboe Mark III. The first Oboe Mark II operation did not in fact take place until October of the following year. In the middle of August a conference was held at Headquarters No. 80 Wing when it was decided to provide two Baillie beams as a means of navigation to the vicinity of the target and also to facilitate accurate timing. Gee was later to be installed for this purpose.[3] The two beams were to intersect at a pre-determined waiting point at which stage the Oboe ground stations would assume control. Sites were chosen at Caister near Great Yarmouth and Oldstairs near Dover, and arrangements were made for Mosquito aircraft of No. 109 Squadron to be equipped with the Baillie beam receiver.

By the end of August 1942 work was well advanced on one pair of ground stations and the second pair was soon to follow. The Air Staff was asked to indicate, in order of priority, the first targets to be attacked during the trials with Oboe.[4] The exact locality, such as any one particular part of the *Krupps* works for example, was required to be assessed as accurately as possible in order that calculations could be made to determine the exact distance from the Oboe ground stations to the points selected. All targets had of necessity to be in the Ruhr area, or on the approximate line from East Anglia to the Ruhr, and not more than 260 miles from Dover, since with the existing arrangement ground stations were unable to work at greater ranges or in other areas. Plans had also been made for courses of instruction on Oboe equipment to be instituted at the T.R.E. for R.A.F. and civilian technical personnel, the first of which began on 20 September 1942, for the unusual nature of the equipment and the vital character of the operations demanded a high standard of efficiency.

The possibility that the enemy would quickly be able to initiate jamming measures against Oboe Mark I had been well to the fore in the thoughts of all those connected with its development and operational employment. The working frequency of the system was in close proximity to that of other radar systems in the 1½-metre wave-band, which had already been jammed by transmitters located in the Pas de Calais area. Stations in the Dover area had already been affected, and it was expected that coverage of the jamming transmitters would be rapidly extended to include Oboe frequencies. It was decided to erect special anti-jamming aerials at Walmer and Swingate, but it was considered, even in the most optimistic circles, that the effective life of Oboe Mark I would be of brief duration, and Headquarters Bomber Command was most anxious that special effort should be devoted to development of centimetric wavelength equipment.

[1] A.M. File C.28852/45. [2] T.R.E. File D.1459. [3] A.M. File CS.10169.
[4] A.M. File CS.15193.

The first Oboe site at Trimingham was completed by 3 October 1942, and the first site at Walmer, later to be called Hawkshill Down, was finished by the beginning of November. The second pair of stations was also practically ready by 18 November, and by then six Oboe controllers and ten pilots had been trained and were ready for operations. The completed ground stations were taken over by, and manned by personnel from, No. 60 Group, the formation fully responsible for their operation.[1] On 26 November permission was given by the Air Ministry for all four Oboe stations to transmit continuously, in order to convince the enemy that the transmissions were being radiated by normal CHL stations, the transmission characteristics being very similar.[2] They began at 0900 hours on 2 December 1942, and a daily two-hour break was made in staggered periods at all four stations for servicing purposes. The spoof transmission plan became a regular feature of the Oboe system, and served a double purpose since it kept the equipment working continuously to meet urgent operational calls. In addition, it was agreed by the Air Staff that any one of the four stations could be used as either a Tracking or a Releasing station according to the varying operational requirement for approach tracks to different targets; the responsibility for deciding the function to be fulfilled was vested in the Commander-in-Chief, Bomber Command.

At the beginning of December it became apparent that the target date for the first operation, 12 December, could not be met. Training had been seriously disrupted by the severity of interference experienced on aircraft equipment. Although appropriate action was taken to eliminate interference caused by Army G.L. transmitters, the trouble was not completely cleared. Training was again suspended whilst intensive air tests were carried out by No. 109 Squadron and No. 1474 Flight in conjunction with the T.R.E. to investigate possible sources and to check all transmissions made on frequencies in the band from 215 to 235 megacycles per second. It appeared that the interference was mainly caused by radiations from Monica, Eureka and Rebecca. Filters were fitted in the aircraft equipment, but although they were quite effective, it was decided that major modifications were necessary to obviate the possibility of random interference in the future. The decision resulted in the first major technical change in the Oboe system, a double frequency scheme introduced in 1943 and known as 'K-Oboe'.[3] On 7 December 1942 the Air Ministry gave Headquarters Bomber Command permission to begin Oboe operations.[4]

Operational Trials

On the night of 20/21 December 1942 Oboe was given its first operational trial. It was decided to attack a target on the Continent and to plot the resulting bomb-craters shown on P.R.U. photographs. The target chosen was Lutterade, a power station in Holland. Six Mosquito aircraft of No. 109 Squadron, each

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[1] The stations were given the following A.M.E.S. numbers :—

Trimingham I : 9121
Walmer (Hawkshill Down) : 9132
Trimingham House II : 9131
Swingate : 9122

Worth Matravers and West Prawle, as experimental stations, were not given A.M.E.S. numbers.

[2] A.M. File C.28852/45. [3] *See also* Appendix No. 5. [4] A.M. File C.28852/45.

carrying three 500-pound bombs, were detailed to attack at half-hourly intervals from a height of 26,000 feet. In the event, only three aircraft were able to attack. Hawkshill Down and Trimingham I acted as Cat and Mouse stations respectively. The P.R.U. photograph obtained on 23 December 1942 showed a large number of craters in the vicinity of the target, most of which were caused by bombs dropped inaccurately during a previous attack on Aachen in adverse weather conditions; it was therefore impossible to calibrate the system, and a new target was selected.

A large house near Florennes in Belgium was the second choice. It had the advantage of being a military objective, isolated, free from previous bomb craters, and suitable from the Intelligence aspect. Three aircraft from the same squadron were detailed for the sortie, to attack the target at intervals of twenty minutes from a height of 28,000 feet, each carrying three 500-pound bombs as before. The operation took place on the night of 31 December/1 January 1943 but the first aircraft developed technical trouble and the remaining two had bad runs due to the very poor weather and turbulent conditions which made accurate runs an impossibility. P.R.U. operations were given high priority but after six sorties no photographs had been obtained owing to the presence of ten-tenths cloud over the target. Reports were later obtained from Intelligence sources which showed that the two sticks of bombs actually fell about 1,150 and 250 yards from the aiming point. The error in the first stick was mainly range error, and in the second, one of the two bombs failed to explode.[1]

Whilst details of the results of the first Lutterade raid were awaited other attacks were carried out against steel works in the Ruhr, mainly with the object of completing the training of air crews. A fairly ambitious programme was continued and two series of operations were conducted. In the first series, twelve groundmarking raids were made between 22/23 December 1942 and 16/17 January 1943, 19 sorties being made by No. 109 Squadron aircraft at a height of 28,000 feet.[2] The ground stations reported three good and seven medium runs, but again the fundamental difficulty arose in assessing damage caused by small bombs from reconnaissance photographs of built-up and factory areas.

[1] The term 'range' refers to the bombing error according to normal usage and does not refer to the Oboe station.

[2]

Date	*Target*	*Sorties*	*Attacks*
22/23 December	Hamborn ..	2	1
	Rheinhausen ..	2	1
23/24 December	Essen	2	2
	Hamborn ..	1	1
	Rheinhausen ..	1	1
	Ruhrort ..	1	—
24/25 December	Essen	1	1
	Ruhrort ..	2	1
29/30 December	Essen	1	1
	Ruhrort ..	2	2
15/16 January ..	Aachen ..	2	2
16/17 January ..	Ruhrort ..	2	1
	Total ..	19	14

The second series consisted of nine skymarking raids with Essen as the focal point.[1] The attacks were carried out because bad weather prevailed over the target area and an opportunity was provided for the Pathfinder Force to try out the technique of leading the main force to a target in any weather by means of skymarkers, a method in which flares were accurately placed in the air at the required release point by an aircraft fitted with Oboe. The Oboe Mosquitoes each carried four bundles of three flares, and operated at heights between 27,300 and 28,000 feet. In order to prolong the marking period, and to lessen the inaccuracy caused by drift of the flares, a second Oboe aircraft, working on a different wavelength, was detailed to repeat the process about three minutes after the first, and aircraft of the main force bombed on whichever marker appeared most suitable. As an insurance against failure, reserve aircraft were sent whenever available.

Of the nine raids, that against Essen on 9/10 January was the only one of which useful night photographic evidence was obtained, the percentage of bombs falling within three miles of the target being 60. Post-operational analysis showed, however, that 11 of the 14 attacking aircraft had a calculated error of less than 450 yards.[2] The size of the main force rose from 8 aircraft for the first attack to 66 on the night of 13/14 January and, in all, 352 heavy bombers were led to their targets by Oboe aircraft, in the sort of weather which had hitherto rendered operations impossible. The main factor which impaired accuracy was the difficulty of the meteorologists in estimating wind velocities at high altitudes over the target. Although the Mouse at the ground station measured the ground-speed of the aircraft, it could only do so between certain limits of speed which were variable, and had to be set in advance in accordance with the estimated ground-speed of the aircraft. Unfortunately, little was known about wind velocities at the heights at which Oboe aircraft were required to fly, and on at least four of the nine occasions the wind speed and direction as forecast proved inaccurate.

During these training raids the Germans themselves gave evidence of the accuracy of Oboe. The Ruhrort steelworks was attacked on the night of 24/25 December by two Oboe aircraft, only one of which made a bombing run, classified as of medium accuracy. The next day the German radio system broadcast that '. . . Some British aircraft broke the peace of Christmas night and attacked western German territory. Among other objects several graves in a remote cemetery were destroyed by bombs . . .' The cemetery was

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1

Date	*Target*	*Oboe Aircraft* Detailed	*Oboe Aircraft* Attacked	*Total Aircraft*	*Main Force Claiming Attack on Markers*
31 December 1942/1 January 1943	Dusseldorf	1	1	8	7
3/4 January	Essen	2	2	19	12
4/5 January	Essen	2	1	29	17
7/8 January	Essen	2	1	19	14
8/9 January	Duisburg	3	2	38	26
9/10 January	Essen	2	2	49	28
11/12 January	Essen	2	1	72	48
12/13 January	Essen	4	3	52	43
13/14 January	Essen	3	1	66	41
		21	14	352	236

[2] B.C. O.R.S. No. S.78 dated 28 January 1943.

situated just south of the selected aiming point. Results of the raids were analysed in a report made on 28 January 1943 in which it was stated that '. . . it is considered that the accuracy is sufficient for groundmarking purposes and it is therefore recommended that such an operation be carried out at the first suitable opportunity on a clear dark night, against an important target in the Ruhr . . . . The results of night photographs obtained on the occasion of the sixth skymarking operations, with Essen as the target, indicate that the percentage bombing achieved is three times as great as the best percentage yet recorded on this target . . . ' Several other points of importance were raised in this report.[1] These were :—

(*a*) Indications showed that the operational accuracy to be expected was about 650 yards.

(*b*) 66 per cent of the 47 main sorties were successful.

(*c*) No Oboe aircraft had been lost.

(*d*) The ground stations worked well, and it was expected that the modification to Mouse, proposed by the Telecommunications Research Establishment, would increase accuracy.

The Commanding General of the United States Eighth Air Force asked for 12 sets of Oboe Mark I to be installed in Fortress and Liberator aircraft of his pathfinder force, but owing to a shortage of equipment, only one Liberator and one Fortress had been equipped by February 1943. Then four crews were trained with No. 109 Squadron, and during March and April flight trials were conducted over the Stormy Down ranges. However, as a result of an agreement made between the Chief of the Air Staff and General Eaker, the Oboe aircraft of the Eighth Air Force were not permitted, for reasons of security, to operate over enemy-held territory. Oboe was to be used by the Royal Air Force for heavy raids only, and its use on small-scale nuisance raids was discontinued. Its use over enemy territory in daylight was to be reconsidered when the Eighth Air Force had sufficiently built up its strength, to some 200 to 250 aircraft, to enable large-scale attacks to be made. General Eaker was, however, urged to assist with the development of Oboe Mark II as, apart from its being less vulnerable to jamming, its capture would not necessarily end the effective life of Oboe technique. Work on the repeater scheme which was being developed throughout the first three months of 1943 caused a further shortage of components, and in March 1943 Headquarters United States Eighth Air Force was informed that only eight Oboe Mark I installations could be made available. This, coupled with the security limitations, resulted in a lull in the progress being made in Oboe operational technique by the Americans until the situation was reviewed in June 1943.

By the beginning of June 1943 the United States Eighth Air Force had formed a pathfinder unit similar to that of Bomber Command and submitted a requirement for the fullest exploitation of Oboe when overcast conditions became prevalent towards the end of the month of September 1943. Two Liberator and two Fortress aircraft were equipped with Oboe Mark I and several crews had been trained in its use. General Eaker pressed for the supply of Oboe Mark I aircraft installations, as had been provisionally promised in March 1943, to be accelerated, and supplemented by 18 Oboe

[1] B.C. O.R.S. No. S.78—Report on Oboe operations up to 16/17 January. *See also* A.H.B./II/69/231A—T.R.E. Memorandum 'Some Comments on O.R.S. Report No. S.78'.

Mark II installations.[1] Although it had been expected that the first 10 Mark II aircraft equipments would be available for installation by July, and another 30 by September, difficulties had been experienced with the klystron valve Type PK.2, and completion of the programme was consequently much delayed. A crash programme for the production of another valve, Type PK.150, had been started, but no deliveries were expected before October 1943, and the T.R.E. suggested that experiments should be carried out with the transmitter and modulator of an American A.S.V. equipment, A.S.G.3.[2] The Air Ministry therefore informed Headquarters United States Eighth Air Force that it was unlikely that the request for Oboe Mark II installations could be met until early in 1944, but eight Oboe Mark I installations would be provided in August 1943. The comparatively small scientific staff of the T.R.E. was very hard-pressed, and therefore in August 1943 several American scientists were sent from the Research Department in Washington to help the Oboe group with the development of Oboe Mark II. The combined groups accelerated the progress of experiments with modified A.S.G. used in conjunction with the receiver already designed for the Mark II installation.

In August 1943 General Eaker again asked the Air Ministry to review the Oboe programme in respect of its use by aircraft of the U.S.A.A.F. Although the security factors which had made undesirable an earlier release of Oboe were fully appreciated, General Eaker felt that the risk was one that should be accepted in view of the limitations imposed on effective operational employment of the Eighth Air Force if such a radar system were not made available. The Prime Minister was anxious that the advantages conferred by such facilities as Oboe should be placed at the disposal of the U.S.A.A.F. and suggested that a time-table for the future distribution of equipment should be compiled by the Air Staff and the Eighth Air Force staff together. There followed a series of discussions on the release of Oboe to the U.S.A.A.F. during August and September 1943, when the primary consideration was the danger of equipment falling into enemy hands before the introduction of Oboe Mark II. The risk appeared to be greater in daylight operations than at night, and the chance of a Fortress aircraft being totally destroyed was much less than that of a Mosquito. However, it was decided on 28 September that the increased concentration of attack which the Americans could bring to bear with the use of Oboe outweighed the risk of loss of Oboe Mark I installations, and approval was given to the release in quantity of the equipment to the Eighth Air Force if adequate destructors were fitted.

The first operation to be carried out by the Eighth Air Force with the aid of Oboe equipped pathfinder aircraft took place on the night of 20/21 October 1943 against Duren. It was not very successful, nor were similar operations in the following six weeks, owing to the efforts of the enemy to jam the Oboe system, and by the end of 1943 the Eighth Air Force had abandoned the use of Oboe in favour of H2S. Nevertheless, the use of Oboe, and Gee-H, was continued by the medium-bomber aircraft of the Ninth Air Force, an intensive training programme with Marauder aircraft being started in January 1944.

Two types of marking technique were introduced into the operational trials; groundmarking known as 'Musical Parramatta' and skymarking known as 'Musical Wanganui'. The second method was used when it was expected that

[1] A.M. File C.28852/45.

[2] *See* Royal Air Force Signals History, Volume VI: 'Radio in Maritime Warfare', for details of A.S.V.

the target would be obscured by cloud. The track along which the main force was to approach the target having been decided, the positions at which flares were to be dropped and the heading to be used were calculated so that bombs aimed at the flares with no allowance for wind would hit the aiming point. The release-point flares were red or green emitting stars of the opposite colour; they burned for two and a half minutes only and had therefore to be supplemented by white flares, lasting approximately four minutes, released in salvo. To assist main force aircraft to run up correctly to the release point, other flares of distinctive colouring were dropped on track five minutes and two and a half minutes before the release-point flares.

The position at which a flare had to be dropped so that bombs aimed at it would hit a particular point was governed by the height, airspeed and heading of the bombing aircraft, the terminal velocity of the bombs, and the wind velocity at flare-dropping height. The release-point flares moved downwind continuously, and the point at which flares were dropped was normally calculated so that they would be in the correct position one and a half minutes after bursting, which was found to be the average time taken by an aircraft to run up on a flare. Variation in most of the factors and a difference between the actual and estimated wind velocities were inevitable; allowances could not be made for them by adjustment of the bombsight and therefore bombing on skymarking was unavoidably less accurate than that on groundmarking raids, even if the markers were dropped with equal accuracy. Since no allowance had to be made for drift, it was easier to run up on a flare which burst when expected than to aim correctly at a groundmarker, but the difficulties of timing were such that only about half of the main force was able to bomb the release-point flares on the ordered heading. Later, difficulty was added with the introduction by the enemy of decoy flares.

In the groundmarking technique, Oboe aircraft dropped primary target indicator markers on the aiming point at the shortest possible intervals.[1] Continuity of marking was provided by other aircraft dropping secondary markers of a different colour, aiming them visually at those released by the Oboe aircraft. The main force aimed at the primary markers if visible, or alternatively, at the centre of the concentration of secondary indicators. This system did not suffer from any of the disadvantages of skymarking attacks as the markers did not drift downwind and correct aim could be made at any speed, on any heading and from any height. On the other hand the accuracy with which the secondary markers were laid was considerably less than that achieved by the Oboe aircraft. The success of the Oboe groundmarking raids, as compared with other methods, was later to be attributed to the certainty with which primary markers could be placed within a fraction of a mile of the aiming points, thereby enabling the remaining aircraft to be instructed to aim at a single salvo of indicators rather than at the mean point of impact of several.

Operational Use of Oboe Mark I

In view of the decision made by the Combined Chiefs of Staff at Casablanca to give priority to the anti-U-boat war, and the resultant increase in the importance given to attacks against U-boat bases on the west coast of France, the establishment of Oboe stations to give coverage in that area was strongly

[1] B.C. O.R.S. Report No. S.102.

urged. A proposal for the formation of a Southern Oboe Chain was quickly approved by the Air Staff, and high priority was given to the building of two stations at Sennen and Treen, near Lands End, and two at Worth Matravers. The experimental prototype stations at Worth Matravers and West Prawle were discarded, and the new ones erected in record time, great assistance being received from working parties lent by the United States Army Air Force.[1] The Southern Oboe Chain carried out its first operation on 28 February 1943 when over 400 heavy bomber aircraft led by four Oboe aircraft bombed the U-boat base and port of Saint Nazaire. Severe and widespread damage was caused throughout the town and dock area, and the fires were still burning on the following day. Up to the end of February 1943 190 Oboe Mark I sorties had been flown and 71 targets had been attacked; a total in which Essen had figured 20 times, Dusseldorf seven times, and most of the Ruhr towns on one or two occasions. The majority of the attacks were in the nature of operational training in preparation for the planned heavy spring offensive against the Ruhr area, but they included 15 marking operations in which some 1,576 heavy bombers were led to their targets by Oboe aircraft. Two of the operations were particularly outstanding for the success achieved; the heavy raid against Cologne on 26 February, followed by that against Saint Nazaire on 28 February, when on each occasion 400 bombers were engaged. In the Cologne raid one of the Rhine bridges was so badly damaged that it was closed to all traffic until the end of the following month.

The long-awaited Ruhr offensive began in March 1943, and continued with increasing vigour until the end of June 1943. The first big Oboe-led groundmarking raid took place on the night of 5 March 1943 when eight Oboe-equipped Mosquito IV aircraft of No. 109 Squadron led a following force of over 370 heavy bomber aircraft in an attack against the *Krupps* factories at Essen. A second attack followed on 12 March when seven Oboe aircraft led some 400 bombers to the same target, and a third equally heavy raid was made in April 1943. Two pairs of ground stations and consequently two channels were available in the Eastern Chain.[2] The success of the attacks was outstanding, and most significant was the fact that groundmarking by Oboe brought the level of results achieved against Essen, which previously had proved most difficult to find, up to that obtained against easier and more vulnerable targets. In 1942, 14 major raids had been made against Essen, in which 3,530 sorties

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[1] Oboe, or Type 9000, stations in operation by 14 February 1943 :—

Station	*Height above sea level*	*Frequency in megacycles per second two channels*	
Trimingham I, Norfolk	250 feet	211,	228
Trimingham II, Norfolk	200 feet	228,	236
Hawkshill Down, Walmer	170 feet	228,	236
Swingate, Dover	350 feet	211,	228
Worth Matravers	400 feet	211,	228
Sennen, Lands End	300 feet	211,	228

[2] Eastern Chain stations used for the Ruhr offensive :—

	Frequency in megacycles per second		*Approx. line of shoot*	*Baillie Beam positions*
Trimingham I	211	228	090 degrees	Caister
Swingate	211	228		Oldstairs
Trimingham II	228	236	090 degrees	Caister
Hawkshill Down I	228	236		Oldstairs

Channel refers to pulse recurrence frequency, and pair to each two stations working on a common radio frequency.

were despatched and 179 aircraft were lost. This effort had, however, resulted in only a few scattered incidents of damage in the town and the *Krupps* works. The three Oboe-led groundmarking raids of March and April 1943, in which 1,245 sorties were despatched and 47 aircraft lost, had resulted in great devastation both in the town and in the works. In all, about 1,500 acres of the built-up area were seriously damaged. Nearly 25 per cent of the factory building of *Krupps* suffered some form of damage and it was estimated that the works lost the equivalent of three months' production solely as a result of the three raids.

During March 1943, Oboe was used in 45 attacks against targets which were mostly in the Ruhr area, the few exceptions being attacks on U-boat bases on the French coast made under the control of the ground stations in the newly formed Southern Chain. 84 Oboe sorties were flown and over 1,880 main force aircraft took part. In April and May the concentration of effort was built up; 50 Oboe sorties leading over 1,600 bombers were made in April, and some 78 Oboe sorties followed by nearly 4,000 heavy bombers in May. The heaviest attack took place on the night of 23 May, when 13 Oboe aircraft led 780 main force bombers in a raid against Dortmund. A raid of similar strength was made against Dusseldorf two nights later by a force of 670 aircraft, led by 12 Oboe aircraft, and on 29 May, Wuppertal was attacked, 11 Oboe aircraft marking the target on this occasion for some 630 bombers.[1] During the month of June 1943 the peak of the Ruhr offensive was reached. Dusseldorf was again raided heavily and it was reported that some buildings were still burning one week later. Heavy damage was caused to warehouses and store sheds in goods depots and the dock area and two-thirds of the central area of the town was destroyed. Other targets to suffer to much the same degree were Bochum, Oberhausen, Cologne, Krefeld, Mulheim, Gelsenkirchen and Elberfeld. At Krefeld alone, 900 acres of 1,100 acres of built-up area were devastated. Many of the attacks were made in weather which hitherto would have prohibited any serious offensive action. Up to the beginning of July 1943, 415 Oboe Mark I sorties had been flown; 140 operations had taken place involving about 13,000 sorties by heavy bomber aircraft.

A detailed examination of the raids, based on evidence from night photographs and the raid reports of individual crews, was made by the Operational Research Section of Bomber Command, and a complete analysis of the results was contained in a report submitted in August 1943.[2] The use of Oboe for groundmarking had trebled the proportion of the main force aircraft actually attacking the target and had enabled very successful attacks to be made against targets which had previously proved almost impossible to locate. The damage resulting from the raids was on a scale never before achieved by night bombing, and, from information then available, the systematic error appeared to be about 440 yards. There was no indication of deliberate jamming of the system. The main cause of such diversions of effort as had occurred were attributed to the gaps in the Oboe marking and to inaccurate marking by 'backers-up'. Improved main force results, both in skymarking and groundmarking attacks, would depend upon more frequent Oboe marking which in turn would entail the provision of more channels. It was apparent, therefore, that additional ground stations were necessary and it was estimated that a minimum of four

[1] *See* Table No. 5.

[2] B.C. O.R.S. Report No. 102, dated 31 August 1943.

channels would be required to ensure continuous marking. If, however, eight channels were provided it would be possible to dispense with 'backers up' and the bomber force could operate with maximum efficiency. Oboe aircraft enjoyed a very great measure of immunity from enemy action throughout the Battle of the Ruhr. Only one aircraft reported interception by enemy fighters, and although 19 were damaged by anti-aircraft gunfire in no case was the damage serious. However, two aircraft failed to return and there was always the possibility that some, if not all, of the Oboe equipment had fallen into the hands of the Germans. The possibility influenced to a very great extent the decision of the Air Staff to introduce Oboe Mark II at the earliest possible date.

K-Oboe and Latching

In the middle of March 1943 particular attention was paid to a repeater project about which technical opinion was divided; the soundness and practicability of the underlying principles were questioned. The repeater system was designed to increase the operational range of Oboe Mark I, which was no more than 270 miles from the ground stations when an aircraft was flying at about 28,000 feet. It entailed the use of a repeater aircraft, and it was anticipated that the maximum certain range between ground station and repeater aircraft would be 250 miles, and from repeater to marking aircraft, 400 miles. When allowance had been made for the repeater aircraft's 'beat' of 60 miles, an operational range of 590 miles was obtainable. At that time blind-bombing systems other than Oboe had reached an advanced stage of development; H2S had already been introduced into operational use and was expected to be installed in a large number of aircraft by the autumn, when Gee-H would also become available. The repeater project met with considerable opposition from Headquarters Bomber Command who contended that H2S would be available as the main system for marking targets beyond non-repeater Oboe range and that development should be concentrated on Oboe Mark II to accelerate the date of its introduction, since it was likely to remain an operational requirement only if it could replace Oboe Mark I within two or three months. However, progress was being made with the K-Oboe system for making Oboe Mark I less vulnerable to jamming, and development of the repeater system was continued until October 1943, when reasonably satisfactory results were obtained from operational trials, mainly over Emden, but the project was dropped by the Air Ministry in November 1943.

In the spring of 1943 the amount of interference experienced on Oboe Mark I became a serious matter. During an attack against Duisberg on 27 March 1943 six of the nine Oboe aircraft detailed for the operation were not effective, and it was confirmed that three of the failures were due to interference on the 228 megacycles per second frequency.[1] The source of the interference was the subject of some discussion, and at first it was not definitely established whether it was caused by enemy jamming or by one of the Allied radar systems. After many weeks of investigation Monica was stated to be the cause, and frequencies were reallocated. Many difficulties had been encountered, and although the Eastern Chain was ready for K-Oboe by 13 March 1943, trials with the modified equipment showed that its performance was inferior to that of standard Oboe, and it was clear that many improvements were necessary before it could be used for operations. The changeover to K-Oboe was eventually completed on 18 June 1943.[2]

[1] A.M. File C.16261/44.

[2] T.R.E. File D.1459.

For K-Oboe a second C.H.L. transmitter was added to each ground station. working on a frequency which differed from that of the main transmission by 8 to 12 megacycles per second. Both transmissions were driven by the same pulse from the control unit, but a two micro-second delay was introduced into the main transmission. A second receiver was included in the aircraft equipment to receive the second transmission. It incorporated an equal-delay circuit so that pulses from both ground stations arrived simultaneously at a subsequent gate valve. The filter and transmitter circuits were triggered by the coincidence of the two pulses and random interference was therefore rejected. The aircraft installation could only be jammed if the enemy obtained one complete with dipoles showing that two frequencies were in use. The system was, of course, no protection against jamming of the ground stations where there was only one receiver. Simultaneously with the introduction of K-Oboe a third channel was introduced by making use of the existing four radio frequencies. Operationally K-Oboe did not prove as invulnerable as had been hoped and the changes made in frequencies had in fact not erased the trouble but rather aggravated difficulties which had always been present. Investigation of the many failures which continued to occur after the system became operational showed that they were mainly due to interaction between aircraft transmitters which again it was hoped to overcome by a process known as 'Latching'.[1] Previously it had been proved impossible to use Monica and Oboe Mark I on the same operation but K-Oboe did permit both installations to be used in aircraft operating over the same target, although not in the same aircraft.

The success of the Ruhr offensive gave rise to an increasing demand on the part of Headquarters Bomber Command for more Oboe ground stations, with particular application to the future introduction of Oboe Mark II. Oboe Mark I was, however, continuing to meet its obligations satisfactorily, and so a decision was made in May 1943 to form a third Mark I channel at Winterton 2, to become operational by 18 June in conjunction with a third channel at Hawkshill Down. To obtain the necessary equipment quickly the installations at Treen and Worth Matravers 2 were withdrawn leaving only Sennen and Worth Matravers 1 operational on the Southern Chain. At the same time a requirement was put forward by the Air Staff for a method with a much higher traffic handling capacity to provide for the control of one Oboe aircraft over the target at two-minute intervals, and the Telecommunications Research Establishment was requested to accelerate development of Oboe Mark III or alternatively to hasten and extend the Oboe Mark IIA project.[2]

[1] The Latching system was introduced to cut down the interference by increasing the delay between the two transmissions from two micro-seconds to seven and a half micro-seconds. Later, when enemy jamming was definitely established, a further modification was necessary. In this, the aircraft transmitter frequency was made different from the ground station transmitter frequencies and thus the ground station had to operate three frequencies. The Brownless filter was specially designed to give optimum matching of the several frequencies into the one aerial system, and to eliminate inter-action between the transmitters. An improved version of the system which was highly efficient and trouble-free was eventually introduced.

[2] A.M. File C.28852/45. *See* Table No. 1 for details of Mark I stations.

CHAPTER 9

OBOE MARKS II AND III

In July 1943, a target date for the operational availability of the Mark II stations at Hawkshill Down 2 and Winterton was fixed for 7 August. They were to be duplicated on completion, the new stations being known as Hawkshill 4 and Winterton 3. Two mobile Mark II units were scheduled for the end of 1943 and the siting of the first pair of Mark III stations at Winterton and Hawkshill Down was under way. The Mark II fixed ground stations were later known as Oboe Mark IIF and the mobile stations as Oboe Mark IIM. The operational requirement for the Oboe mobile convoys, or Oboe Mark IIM, was formulated in September 1943. The method of operating one Oboe Mark IIM convoy, which originally consisted of one radio vehicle only, was similar to that for Oboe Mark I, but it was intended that an Oboe Mark II mobile site might include up to four convoys. To enable the area of Oboe coverage to be varied according to the current operational need, the convoy had to be capable of moving at twenty-four hours' notice. Consideration was also being given to the probable requirement for mobile stations overseas. In the following month approval was given for the provision of 20 mobile stations, making 10 pairs, to be used primarily in the United Kingdom but to be designed so that they could be easily diverted for employment abroad.[1]

Introduction of Oboe Mark II and Oboe Mark III

Development of an efficient airborne transmitter for Oboe Mark II was a slow and difficult process during the autumn months of 1943. The PK.2 klystron was still unsatisfactory, the average ranges achieved with its use being about 160 miles. Although pressure was exerted on the production of PK.150, which was of higher power, it was not expected to become available in any quantity before 1944.[2] Attention was therefore focused on the possibilities of the modified ASG.3 transmitter which used a tunable magnetron, and of which supplies were readily obtainable from the United States of America. After the initial difficulties were overcome, the hybrid installation of American transmitter and modulator, and British receiver, proved to be highly efficient and was eventually adopted as Oboe Mark II. Production of the klystrons PK.2 and PK.150 was stopped. The installation in which it was intended to use PK.2 had been given the code name Penwiper, and that with PK.150, Pepperbox. The combination of modified ASG with the Penwiper receiver and control units was known as Fountain Pen, and with those of Pepperbox, Album Leaf. The development eventually accepted as the final design was that of Album Leaf. The Oboe Mark II aircraft installation incorporated a filter unit Type 68 and could be converted to Oboe Mark III by the substitution of another filter unit, Type 166.[3]

[1] *See* Tables Nos. 2, 3 and 4 for details of Mark II and Mark III stations.

[2] A.H.B./248/1/3. C. of C. Oboe Meetings.

[3] A.H.B./ID/4/179.

However, by mid-September 1943, four Mosquito aircraft of No. 105 Squadron had been fitted with Penwiper, using the PK.2, and six flight trials were carried out with the first pair of Mark II stations. These were not very successful and no increase in range over that of Oboe Mark I was obtained. By October 1943, Album Leaf equipment was still unavailable, and the first Oboe Mark II operational sortie took place on the night of 3/4 October, the Penwiper installation being employed. On this occasion six Oboe aircraft attacked Aachen, but only two were successful owing to the poor performance of the transmitter.[1] The second pair of Mark II stations, also at Hawkshill Down and Winterton, became operational in mid-November, and a target date for trials with the first Mark III stations was arranged for 1 December 1943. These stations, pending the production of the Oboe Mark III filter, Type 166, could only operate on one channel.[2]

At the beginning of November 1943, Headquarters Bomber Command affirmed that although Oboe Mark I was continuing to give satisfactory service, signs of intentional enemy jamming had been perceived and more pressure was urged on a complete changeover to Oboe Mark II. All work had now been taken off the Oboe Mark I repeater project and every effort was being made to fit the new Album Leaf transmitters in all aircraft of Nos. 109 and 105 Squadrons. Towards the end of the month it appeared that Oboe Mark I was no longer effective. Its performance had become increasingly unsatisfactory, culminating in a complete failure of the system on the night of 19 November 1943 during operations against Ruhrort and Leverkausen.[3] The reasons for the failure could not be investigated at once but enemy jamming was suspected. Headquarters Bomber Command thereupon submitted an urgent requirement for three Mark II channels and a more speedy delivery of the aircraft equipment, stressing that the time had arrived for the conversion of the ground stations from Mark I to Mark II and the speedy production of the multi-channel Mark III scheme. In addition to the provision of complete Oboe Mark II cover over the Ruhr and north-west Germany, of which the range was to be increased at an early date by Mark II repeaters, the Air Staff had also an urgent need for Oboe cover in northern France, and a further Mark III station was sited at Worth Matravers to meet this commitment. This later became Tilly Whim I and II. The Album Leaf equipment was being produced on the highest priority and an output of 30 sets per month was anticipated. It was not, however, the policy to introduce the Mark II system until such time as supplies of both air and ground equipment were adequate or until the Mark I system was definitely pronounced 'dead'. The three pairs of Mark III stations which had been constructed at Cleadon, Hawkshill Down and Winterton, also giving Ruhr coverage, were additional to those supplied for the Mark II scheme but there was a considerable delay in the installation of their equipment.[4] Although operational use had decreased during the latter half of 1943, when there was a temporary lull in the Battle of the Ruhr, the period was important for the building up of technical resources preparatory to the destruction of V-weapon sites in northern France and the liberation of

[1] A.H.B./248/1/1. Oboe Fitting Reports.

[2] The aircraft equipments in Oboe Mark IIF, IIM, and IIIF differed only in respect of one filter unit. (F.U.69 for use with Mark IIF and IIM and F.U.166 for Mark IIIF.) The filter unit derived from the modulation the indications given to the pilot, which told him whether the aircraft was on track or not.

[3] A.H.B./II/69/231.

[4] A.M. File C.28852/45, Part II.

north-west Europe. At the beginning of July 1943 a requirement was submitted for Oboe coverage in the Pas de Calais and Cherbourg areas where the enemy V-weapon sites were under construction. It was decided that operations against the sites, and against targets selected in connection with the planned landings in Normandy, would be an important commitment for the Oboe system. The areas concerned were embraced within an arc centred at Dover passing through Le Treport to the Belgian coast and including the Cherbourg peninsula north of a line Isigny-sur-Mer to La Hay. The ground stations selected to cover the areas were:—

Pas de Calais	Trimingham I with Worth Matravers I.
Cherbourg peninsula ..	Swingate or Hawkshill Down with Worth Matravers I or Sennen and Worth Matravers I.

At the time, however, both Sennen and Worth Matravers were on a care and maintenance basis, and on 12 August 1943 instructions were issued that Worth Matravers was to be made available for operational use with Trimingham within four days. Two days later it was pointed out that since the pairs of stations chosen for attacking the Calais and Cherbourg areas both used Worth Matravers, targets in the two areas could not be attacked simultaneously. On 20 August, Worth Matravers I, Trimingham I and Swingate were ready for the launching of the attacks. The first operation took place on 30 August when five Oboe aircraft of No. 109 Squadron marked a target near Calais for 31 main force aircraft. The controlling stations were Swingate and Trimingham I, markers were dropped at the rate of one every ten minutes, and the accuracy obtained was estimated as being in the region of plus or minus 100 yards. During the operation flares released by Mosquito aircraft marking the target were actually observed visually from Hawkshill Down and Swingate as they burst over the target area. The main feature of Oboe operations in the winter of 1943/1944 was the renewed offensive against V-weapon sites in northern France. The second series of such operations began on the night of 16/17 December 1943, and those carried out in January 1944 were the heaviest made until June 1944 when the V-weapon offensive against London was initiated.

Extension of Oboe Coverage

At the beginning of 1944 much work was needed to prepare the Oboe system for its part in the liberation of north-west Europe. It was hoped to have eight channels available by April 1944, giving cover from Brest to Emden. but it was soon realised that the Mark III programme was at least six months behind schedule and that therefore only four channels would be available for coverage in the Ruhr area.[1] Nevertheless, in January 1944, a comprehensive programme was drawn up by the Air Staff in order to achieve the required number of channels and coverage by March 1944, and considerable effort was devoted to its execution. Priority of requirement was given firstly to the supply of Album Leaf equipment in reliable working order for use in the expanding Mark II system, secondly to the Mark III ground stations and the corresponding filter units for aircraft equipment, and finally to the Mark II mobile ground stations. Simultaneously the Telecommunications Research Establishment was directed to concentrate on those projects rather than upon other modifications to Oboe Marks I and II which were engaging its attention

[1] A.M. File C.28852/45, Part II.

at that time. The policy regarding the Southern Oboe Chain was formulated on 11 February 1944 and several alterations to the existing array of equipment were proposed. The concentration of Oboe Marks I, II and III installations in the Dover area was a weak point in the programme as all were within range of cross-channel gunfire and there was consequently considerable risk of their destruction. It was decided therefore to install two Mark II mobile stations at Beachy Head where they would be sufficiently remote from cross-channel shelling, and also capable of operating with either Worth Matravers or Hawkshill Down. This suggestion was supplemented by the immediate installation at Treen of the Mark I single-rack receiver made at the T.R.E.

Meanwhile the Air Ministry had decided that a crash programme was to be carried out at the T.R.E. for the installation of Oboe in four trailers.[1] Installation of the first two was to be made in two of the Mark III GL cabins and the second two in modified SCR.584 trailers. The mobile stations were to be designated Mark II SM, the display unit being specially modified so that the long and short time-bases were displayed on one cathode ray tube, and the corresponding equipment installed on one CHL rack instead of three. In both the Mark I and II systems the ground-to-air communication was carried out by space modulation of alternate pulses. In Oboe Mark IIM and Mark III, a new scheme using width modulation of all pulses was involved, but as this method had not been tried or proved operationally, Mark IISM, incorporating the use of space modulation in a mobile installation, was suggested and approved. The additional modification of placing the complete installation in one rack was solely to reduce the amount of equipment in the small trailers to a minimum. In order to distinguish the Mark IIIGL vehicles from the SCR.584 trailers it was later decided to adopt the following nomenclature :—[2]

Mark III GL. ..	width modulation ..	Mark II M
Mark III GL. ..	space modulation ..	Mark II SM
SCR. 584	width modulation ..	Mark II HM
SCR. 584	space modulation ..	Mark II HSM

On 18 February 1944 a meeting was held at the Air Ministry, under the chairmanship of Sir Robert Renwick, to discuss the progress of Oboe in the light of the requirements for the forthcoming offensive.[3] The Telecommunications Research Establishment was unable to guarantee that the Mark IIM or Mark III stations would be ready by 13 March in accordance with the Air Staff requirements. The following facilities were, however, available by that date :—

Southern Chain

Mark I	Two stations at Worth Matravers
Two channels	Two stations at Hawkshill Down
Mark II	Two mobiles at Tilly Whim
Two channels	Two fixed stations at Hawkshill Down
Mark III	One fixed station at Tilly Whim
Four channels	One fixed station at Hawkshill Down

[1] A.M. File CS.22484.

[2] It is of note that Mark II HM and Mark II HSM were not used operationally at home bases but underwent successful trials at Bawdsey.

[3] A.H.B./IIE/248/1/3. C. of C. Oboe Meetings.

Eastern Chain

Mark I .. .. .. Three channels	Three fixed stations at Winterton and Trimingham Three fixed stations at Hawkshill Down and Swingate
Mark II .. .. Two channels	Two fixed stations at Winterton Two fixed stations at Hawkshill Down
Mark III .. .. Four channels	One fixed station at Winterton One fixed station at Hawkshill Down.

Since it appeared unlikely that the mobile stations employing width modulation would be operational by the end of March 1944, the T.R.E. recommended that four mobile stations employing space modulation should be provided for a standby system. Efforts to put the Mark III system into operational use resulted in limited use being made of Hawkshill Down V and Winterton V at the beginning of April. Results were poor, however, because of difficulties inherent in the system.

The progress of development with Oboe Mark III was hindered to a great extent by the priority given at that time to the provision of the Mark II mobile convoys, and although successful operational trials were carried out on 11 and 12 April 1944, it was not possible to use the system extensively until July 1944.[1] As late as September 1944 only four Mark III channels were available at Hawkshill Down and Winterton, and to make even these operational each channel was given its own radio frequency. This was, in effect, a more compact equivalent of four Mark II ground stations. The Mark III stations at Cleadon were never used operationally and Tilly Whim only a few times during the Normandy landing operations. The second pair of Mark II stations, also at Hawkshill Down and Winterton, had two channels available by December 1944. They were used to a limited degree for operations during the early part of 1945. The obvious need for extended cover in northern France and Germany which arose in March 1944 did, therefore, come at a critical time, when every effort was being concentrated into producing Mark IIM trailers for rapid deployment on the Continent. The situation was mitigated to some extent by the installation of three mobile convoys at Tilly Whim, near Worth Matravers, and three at Beachy Head near Eastbourne, two of each working on space modulation and one on width modulation.[2] Headquarters No. 60 Group was made responsible for the upkeep and maintenance of both the Mark IIM and Mark IISM convoys, the T.R.E. providing such help as was required, and all effort was directed into the speedy production and operational availability of the mobile stations.

Although Oboe was used extensively by the strategic bomber forces prior to D-Day and after, and the necessary organisation had been set up to satisfy such requirements, it was found undesirable to rely on the installation of Oboe

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[1] A.H.B./II/69/231B. B. Ops. 2(a) folder Oboe.

[2] A.M. File CS.22487.

Nomenclature of the mobile stations was :—

Beachy Head 1—Westerly site—space modulation.
Beachy Head 2—Centre site—space modulation.
Beachy Head 3—Easterly site—width modulation.
Tilly Whim 1—Mark III fixed station.
Tilly Whim 2—Easterly site—width modulation.
Tilly Whim 3—Centre site—space modulation.
Tilly Whim 4—Westerly site—space modulation.

in all medium bombers of 2nd T.A.F. and the Ninth Air Force owing to shortages of equipment and the major expansion of the ground organisation entailed thereby. The Ninth Air Force obtained equipment from the Eighth Air Force, and by D-Day 24 Marauder aircraft were equipped to act as pathfinders for other Marauder formations. The strength of Oboe-fitted aircraft by that date had risen to an aggregate of 60.

Anti-Jamming Measures

Two additional considerations arose in connection with Overlord operations. The first was the problem of intensified enemy jamming and the second the actual accuracy of Oboe. Oboe aircraft operating over the Ruhr area had been experiencing severe interference which usually started immediately before the bombing run and made the timing of release signals difficult to distinguish. whilst the Oboe stations in the Dover area were also being jammed by enemy transmitters in the Pas de Calais area.[1] The interference was an extension of the normal jamming programme directed against CHL and other equipments in the 1½-metre wave-band.[2] By the end of January 1944 jamming had become so serious that the Director General of Signals decided that every effort must be made to design anti-jamming devices immediately. The Anti-Jamming Unit of No. 80 Wing had already proposed one method as a possible antidote so it was agreed that this unit should undertake the experimental work and that both Headquarters No. 60 Group and Headquarters No. 8 Group should co-operate with the installation of equipment and trials. By March 1944 the scheme had been formulated. Oboe information for the pilot and navigator of Oboe aircraft was to be passed on normal communication channels on the medium-frequency bands, positioning of the aircraft and the plotting of its course still being carried out by Oboe. It was believed that effective jamming of the medium-frequency waveband would be difficult and certain additional modifications to the Oboe equipment were made to afford even greater protection.

Tests with an M.24 medium-frequency transmitter made by the Anti-Jamming Unit at Mundesley in Norfolk had proved successful, and the project was undertaken as an immediate operational requirement. To maintain the high degree of security demanded, the scheme was only to be put into use when the Oboe controller at the ground station decided that jamming was interfering with the operation, and then only for the shortest duration possible. Furthermore, short spoof transmissions on the communication frequencies when no Oboe operations were in progress were introduced. An examination was also undertaken of the possibility of transmitting Oboe information on several Splasher transmitters which were being utilised for beacon purposes.[3] Arrangements were made in April 1944 for anti-jamming equipment to be installed at Hawkshill Down I and II, Worth Matravers I and III, Sennen, Treen and Trimingham I and Winterton II, and on 31 May 1944 authority was granted for the system to be brought into immediate use. At the same time the use of the Splasher beacons at Braintree in Essex and Templecombe in Dorset for spoof transmissions on their available frequencies was authorised.[4] Headquarters No. 80 Wing was

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[1] *See also* Appendix No. 6.

[2] No. 100 Group File TS.1207/1/5/Sigs.

[3] Splasher beacons formed a scrambled medium-frequency beam system consisting of a group of four beacons employing frequency switching. (*See also* Royal Air Force Signals History, Volume VII : 'Radio Counter-Measures'.)

[4] No. 100 Group File TS.1207/1/5/Sigs.

deciding the number of beacons to be made available after receiving a warning from Headquarters Bomber Command of the period when anti-jamming transmissions were required, and for ensuring that the beacons returned to their normal function when this period ended. However, by the time all the elaborate arrangements had been crystallised enemy transmitting stations in the Pas de Calais area had been heavily bombed, jamming had ceased, and the scheme was not required.

Improvement of Oboe Accuracy

In the early stages of Oboe development it was not envisaged that such a high degree of accuracy as 75 yards error would be required. However, the changing situation of the war in 1944 demanded such precision. Little information of the actual accuracy of Oboe was then available as few of the attacks had been made on virgin targets and it was impossible to distinguish bomb-craters arising from Oboe sorties from those of previous raids. On 4 January 1944, a report on the relative accuracy of bombing against objectives in northern France was submitted by the Operational Research Section of Bomber Command. Indications of a systematic error in Oboe were revealed, showing that the theoretical accuracy differed considerably from the actual accuracy, and calibration of stations was thereupon undertaken. A meeting was subsequently held at the Air Warfare Analysis Section on 24 January to discuss the problem.[1] Evidence available pointed to the conclusion that with the Mark I system, accuracy varied from 150 yards at 15,000 feet on the French coast to 500 yards at 28,000 feet over the Ruhr. Oboe Mark II accuracy was not guaranteed to be less than one mile. The major cause of inaccuracy was considered to be the necessity for weaving whilst attempting to fly on a theoretical circular track. A proposal for minimising such errors involved use of the Cat ground station for measuring not only the distance of the aircraft off track as in normal Oboe procedure, but also the rate of approach to or from the track. By means of signals transmitted from the ground station a pilot could be gradually homed on to track when he was within four miles of the target, and could be corrected as soon as he tended to turn off track, instead of only when he was already approximately 20 yards off, as was the case otherwise. In short, a pilot was practically guided on to track, and once there, was given a much more effective means of keeping to it. This method became known as the Delta or exponential system.[2]

Experiments with the new technique had been carried out by the T.R.E. in conjunction with the Oboe trainer at Marham as far back as November 1943, but it was not until the increasing demand for accuracy arose in January 1944 that consideration was given to the installation of Delta equipment for trials at Swingate and Trimingham. The changes could not, however, be made in time, owing to the period required for design, production, training and organisation. As a result, trials of Delta Oboe did not take place until February 1945. A target date of 21 April 1945 was fixed for the completion of Delta modifications on vehicles being prepared for use on the Continent, but the system could not be adopted in time to be of use operationally. It transpired later that the effects of the Delta technique were twofold. Once the initial changeover was made, the method of navigation on an Oboe beam was simplified and required considerably less training time and experience than non-Delta tracking.

[1] A.M. File CS.23140.
[2] B.C. O.R.S. Report No. 216.

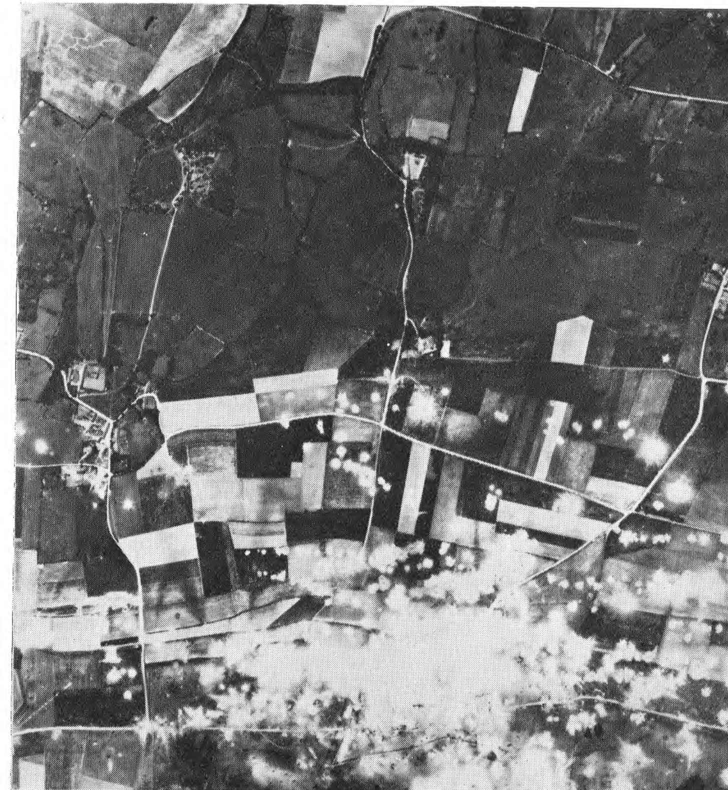
Secondly, it meant a reduction in flying errors, causing a considerable increase in bombing accuracy, especially at low angles of cut. Flying accuracy was increased and the average angle of weave of a Mosquito aircraft on operations was reduced from 1·1 degrees to anything below 0·66 degrees. During the Delta bombing trials conducted by the Pathfinder Force in January 1945 at Penrhos and Otwood one of the highly experienced pilots in the T.R.E. Test Flight obtained an average angle of weave of 22 minutes, and an average distance off track of 8 yards, as compared with a previous figure of 55 minutes with standard Oboe. The use of Delta Oboe therefore, at an average angle of cut, 34 degrees, and height, 29,000 feet, reduced the average bombing or marking error from 240 yards to less than 150 yards; the relative improvement in bombing accuracy between the new and the old systems, although applying under all conditions, was greatest at large heights and small angles of cut. The greatest value of the technique was evident when used for formation flying, as even a small improvement in the steadiness of the leader was strongly reflected in increasing bombing concentration. Delta Oboe operations theoretically lessened some of the tactical difficulties incumbent in Oboe formation flying such as the problem of getting on to track without upsetting the formation.

Operational Use of Oboe in D-Day Operations

Oboe, in common with other radar systems, was invaluable during the operations carried out immediately before the landings in Normandy, the assault phase presenting problems of target-marking for which it was well suited. The success of the landings depended upon the preliminary destruction and paralysis of as much of the enemy transport and communications system as possible. This entailed the bombing of a great number of marshalling yards and supply and ammunition dumps in France, Belgium and western Germany. Most of the Bomber Command effort was directed to attacks against those targets early in March, when the assault phase of the operation began. However, on a number of occasions it was found that the slight scatter of markers, together with loose markers caused by ballistic errors, gave the bombing force a selection of aiming points. This led to confusion, and, in some instances, to waste of effort. To counter this, a master bomber, who flew at low altitude if necessary to check visually, was introduced to assess the accuracy of Oboe markers and, if necessary, to re-mark the correct aiming point. Among the targets included in the offensive were Trappes, Le Mans, Amiens, Laon, Aubsoye, Courtrai, Villeneuve, Lille, Tergnier and Ghent, and in all the attacks against them between 100 and 200 main force aircraft were effectively led by Oboe pathfinder aircraft. During the latter half of May many gun batteries and radar and W/T stations sited along the French coast were successfully attacked, usually without the assistance of a master bomber since the targets were not sufficiently distinctive for visual identification. Striking proof of the accuracy of the Oboe system was provided on 3 May 1944 when a small number of Oboe aircraft destroyed more than half the ammunition stored at Chateaudun.

For many months before the landings the enemy had done everything possible to jam British radar stations and the radar navigation systems used by Bomber Command and the Eighth Air Force for long-range bombing

Beaumont Hague/Au Fevre after attack on 31 May/1 June 1944



Boulogne/Mont Couple after attack on 31 May/1 June 1944 operations.[1] It was therefore anticipated that during the assault phase of operation Neptune the enemy would make an intensive effort to nullify the usefulness of Allied radar. In consequence it was considered essential to employ the most effective protective measures which could be devised. The methods of jamming available to the enemy were classed in three main categories; the use of ground jammers, airborne jammers, and Window. A careful analysis of enemy ground jamming activity was made from records kept by the Anti-Jamming Unit of No. 60 Group, and the indications were that the enemy maintained a large number of jamming stations on coastal and inland sites covering a wide area from Norway to the Brest peninsula. It was suspected from direction-finding information that about 16 or 20 stations were sited on or near the French coast, the majority of which were believed to be concentrated in the Pas de Calais area. However, there was reason to doubt the accuracy of the D/F fixes, and in any event the pinpoints were not sufficiently accurate to enable direct attacks to be undertaken against the jamming installations on that evidence alone. Accordingly a detailed photographic survey was made of the areas in which the presence of jammers was suspected, as a result of which three jammers, the effective operation of which might have very seriously affected the success of the assault phase, were found. They were sited at Berneval le Grand, Cherbourg/Urville Hague. and Beaumont/Hague au Fevre, and their elimination was considered to be essential. The existence of a very large jamming installation at Mont Couple Fort in the Pas de Calais area was also revealed, and the Admiralty requested that it too should be rendered ineffective. Although it was deemed necessary that all the jammers should be destroyed, there was some difficulty in deciding the method of attack to be employed. The nature of the installations seemed to indicate that attacks by Special Air Service paratroopers was the only certain method, but finally it was decided to use heavy bomber aircraft in conjunction with Oboe. The operations were entirely successful, with the result that no interference was experienced from ground jammers during the assault phase and the weeks immediately following.[2]

Mont Couple contained about 60 transmitters. The first attack, made on 29/30 May, was unsuccessful, but on the night of 31 May/1 June, in an attack carried out by over 100 aircraft, at least 70 heavy bombs were placed on the target, which measured 300 yards by 150 yards. The installations at Hague au Fevre were attacked on the night of 31 May/1 June by about 120 aircraft. The main concentration of bombs fell just outside the target area but an effective number of bombs scored direct hits. The attack against Bernaval Le Grand, carried out on the night of 2/3 June, was completely successful. The majority of the eight or nine buildings, protected by blast-walls, received direct hits, and the remainder suffered so many near misses that the operational value of the installations was seriously diminished. Urville Hague, which was the centre of German Radio Intelligence, offered a target of a line of W/T masts running diagonally across an old fort, with headquarters buildings located 150 yards to the south. On the night of 3/4 June it was bombed by 99 aircraft, and remarkably successful results were obtained, the centre of a very neat bomb pattern coinciding almost exactly with the centre

[1] A.H.B./IISI/34/1. Air Signals Report on Operation Neptune.

[2] *See also* Royal Air Force Signals History, Volume VII : ' Radio Counter-Measures '.

of the target area. The cumulative effect of the successful attacks against jamming transmitters and wireless units became evident when the landing operations were begun. At no time from D minus 1 to D-Day were more than 18 per cent of the previously available enemy radio installations working, and for part of the time no more than 5 per cent, and the task of employing radio countermeasures against the remainder of the system was much simplified. The stage was now set and all preparations made. On the night of 5/6 June 1944, the Oboe stations at Sennen, Treen, Worth Matravers, Tilly Whim and Hawkshill Down were used in various combinations to attack coastal batteries in the ten major defence positions between Barfleur and Cherbourg which had been stated as a high priority invasion commitment in February 1944.[1] Fifty Oboe sorties were flown between 2300 hours on D minus 1 and 0500 hours on D-Day. Groundmarking was used for all the attacks and heavy aircraft of Bomber Command bombed on the target indicators. The total bomber force used was about 1,200 aircraft ; 5,000 tons of bombs were dropped representing approximately 500 tons per target. Forty-one of the 50 aircraft had serviceable Oboe ; two of the aircraft failures were not attributable to Oboe and an exceptionally high standard of serviceability was obtained.[2] In his despatch on the operations in north-west Europe Air Chief Marshal Sir Trafford Leigh-Mallory stated ' . . . The enemy did not obtain the early warning of our approach that his radar coverage should have made possible ; there is every reason to suppose that his radar-controlled gunfire was interfered with ; no fighter aircraft hindered our airborne operations ; the enemy was confused, and his troop movements were delayed . . . '

At dawn on D-Day, the United States Ninth Air Force sent out their formations led by Oboe-equipped Marauder aircraft to carry on the offensive. Bomber Command also maintained its concentrated effort during the day and again on the night of 6/7 June when 51 Oboe aircraft once more led the main force against nine major communication centres in France.[3] Oboe attacks

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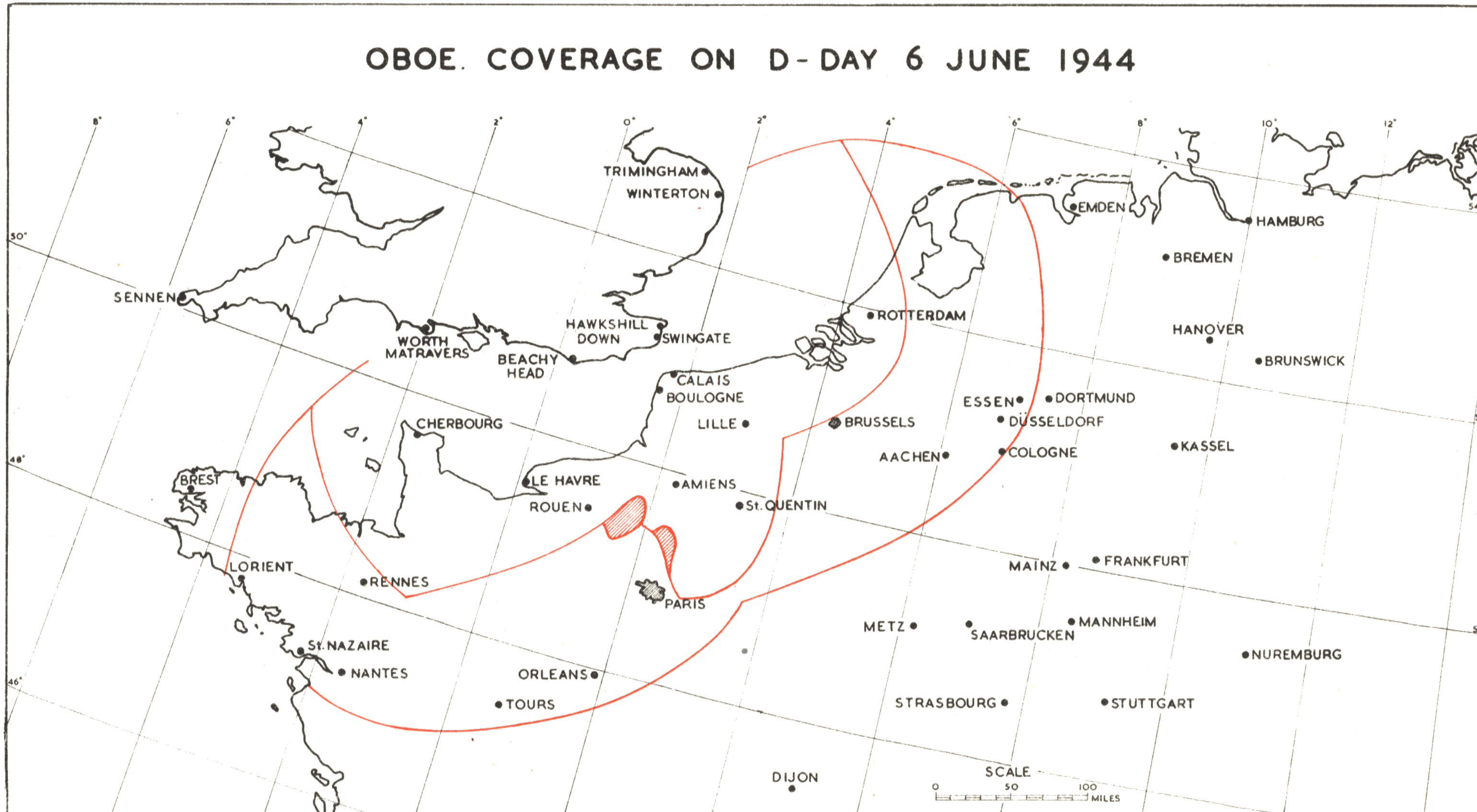
[1] Tilly Whim I and Hawkshill V, the Mark III stations, worked together. Worth Matravers I worked with Sennen, Worth Matravers II with Treen. The additional pairs were made up of the three mobile convoys at each of the Tilly Whim and Beachy Head sites, which were also capable of working with the Mark IIF stations at Hawkshill Down IV and II should targets arise in the areas covered by these pairs. Likewise the Mark III station at Tilly Whim could operate with that at Winterton, and the Mark I station at Worth Matravers with those at Swingate or Hawkshill Down.

[2] A.H.B./IIE/99. Oboe data for D-day Operations in France.

[3]

Target	Oboe Sorties		Main Force Sorties
	Detailed	Attacked	
Constances	5	3	132
Saint Lo	5	3	108
Vire Saint Puriere	5	2	107
Argantau	10	7	118
Lissieux	5	4	97
Conde Sur Noireau	5	2	115
Chateaudun	5	3	105
Acheres	5	1	97
Caen	6	5	124
	51	30	


OBOE. COVERAGE ON D-DAY 6 JUNE 1944
TRIMINGHAM
WINTERTON
EMDEN
HAMBURG
BREMEN
SENNEN
ROTTERDAM
HAWKSHILL DOWN
SWINGATE
HANOVER
WORTH MATRAVERS
BEACHY HEAD
BRUNSWICK
CALAIS
BOULOGNE
ESSEN
DORTMUND
CHERBOURG
LILLE
BRUSSELS
DÜSSELDORF
AACHEN
COLOGNE
KASSEL
BREST
LE HAVRE
AMIENS
ROUEN
St. QUENTIN
LORIENT
RENNES
MAINZ
FRANKFURT
PARIS
METZ
SAARBRUCKEN
MANNHEIM
St. NAZAIRE
NANTES
ORLEANS
NUREMBURG
TOURS
STRASBOURG
STUTTGART
DIJON
SCALE
0
50
100
MILES

continued from D-Day to D plus 30 against communication centres, airfields and marshalling yards. 119 Oboe sorties were flown in that period by the Ninth Air Force of which 40 aircraft failed, eight because of defects in the aircraft equipment, Oboe serviceability in the region of 64 per cent being maintained.[1]

Deployment of Oboe Ground Stations on the Continent

Oboe facilities in the United Kingdom had proved to be adequate for the opening phase of Operation Overlord but it was, however, desirable to implement Oboe coverage at the earliest possible opportunity by taking advantage of Continental sites. Unfortunately, all the available mobile equipment was deployed at home bases to provide the earlier and urgently required cover. Technical difficulties arose in connection with the equipment and the first convoys did not cross to the Continent until the third week in August.[2] While the assault phase of the operations was in progress, the future of all radar ground stations which were to operate in the campaign was under review, and, on 15 May 1944, Headquarters No. 72 Wing was formed within the No. 60 Group organisation to take over the responsibility for radar cover in the base area from mobile units of the A.E.A.F., thereby releasing those units for front-line support.[3] Eventually the wing was made responsible for the maintenance of all radar navigation ground stations in the operational theatre, amongst which was included six Type 9000 Mark IIM convoys.[4] Control of the ground reporting system was vested solely in groups of the A.E.A.F. Headquarters No. 60 Group retained control of major policy and of all details of a technical or operational nature, but day-to-day administrative control of the wing and its associated units on the Continent was maintained by the regional group of the A.E.A.F.

The early work of the wing was mainly exploratory, most attention being given to the preparations for its eventual deployment overseas. A small equipment section was formed at R.A.F. Cardington on 15 May 1944 to act as a marshalling point for the equipping of convoys before they were called forward into the concentration areas. Meanwhile, the first Oboe Mark IIM convoy was being deployed at Bawdsey preparatory to overseas working.[5] This convoy, designated A.M.E.S. No. 9432, moved to Cardington on 9 August 1944 to await calling forward and its place at Bawdsey was taken by a second Mark IIM convoy, A.M.E.S. No. 9441. Some ten days previously a forward element of Headquarters No. 72 Wing, together with A.M.E.S. Nos. 7921 and 116, had left England, arriving at Anneville-en-Saire on the Cherbourg peninsula on 31 July 1944. There it remained until 30 August 1944 when it advanced to Chateau Mathieu, some five miles north of Caen.

[1] H.Q. No. 60 Group History of Oboe.

[2] A.H.B./IIS1/34/1. Air Signals Report on Operation Neptune.

[3] No. 72 Wing O.R.B., September 1944.

[4] The basis of the Mark IIM convoy was the radio vehicle Type 434A, a trailer vehicle weighing some 10 tons and towed by Matador tractors. Two radio trailers and 16 other vehicles were allocated to each convoy, the establishment being 76 technical and administrative personnel with five controllers.

[5] In the original planning, one radio vehicle was to have constituted one Oboe or Type 9000 convoy, but later it was necessary to include two radio vehicles in the term convoy. Thus two convoys working as a pair included, amongst other equipment, four radio vehicles, and were capable of operating four Oboe control channels.

Initial plans for the extension of Oboe coverage over the Continent envisaged the establishment of two stations with two channels available at each, which would pair up with two corresponding stations in the United Kingdom. The Oboe technique required continuous voice contact between the controllers and the Cat and the Mouse stations during operations, which placed a heavy requirement on cross-channel communications; neither S.H.A.E.F. nor Headquarters A.E.A.F. were able to provide the facilities from the small amount of circuits which existed at that time.[1] By 23 August 1944, owing to the difficulty of maintaining landline communications across the English Channel, radio equipment and frequencies were provided and enabled a network to be set up for the control of Oboe missions. The efficiency of the system using radio channels was, however, much lower than that of the same system using landlines.[2]

On 22 August 1944, the first Oboe Mark IIM convoy, A.M.E.S. No. 9432, landed on the Normandy beachhead. This unit, the third mobile radar ground station to be deployed on the Continent, proceeded direct to a pre-selected site on Mont Pincon. However, owing to an alteration in plans necessitated by the rapid advance of the Allied armies, the convoy was instructed not to set up station but to proceed to the Paris area. On arrival at the new site, Les Alluets du Roi, the convoy began to prepare for action but this site was still too far in the rear for useful operations. Instructions were issued for the unit to prepare for an impending move into Belgium, and eventually the convoy arrived at Rosee, near Florennes, on 10 September 1944, when the station was set up, and operations in conjunction with Hawkshill Down began on 15 September 1944. By coincidence the first mobile Oboe convoy to operate on the Continent was sited at the place against which one of the very first Oboe raids had been carried out, the calibration raid on Florennes on the night of 31 December 1942.

On 26 August 1944 an Air Ministry plan for the deployment of the first continental Oboe pair was formulated, allowing for a two-channel station at Florennes in Belgium and a two-channel station at Commercy in France. A.M.E.S. No. 9441, which had been undergoing field trials at Bawdsey, was called forward, arrived on the Continent on 9 September 1944, and at Commercy on 14 September 1944. On the night of 25/26 September 1944, the first Oboe operation using the two stations was carried out.[3] Six Oboe aircraft were despatched and all failed. The failure was caused by a breakdown in wireless transmission at one of the stations rendering all control impossible as the two convoys were out of touch with each other. After W/T contact had been established a heavy explosion shook the convoy breaking a valve in the rectifier circuit which could not be repaired in time to complete the operation. Oboe did not, therefore, get off to a flying start on the Continent and the difficulties were manifold. Snipers operated in the woods between the two convoys, mines were located in the vicinity, and much work was still needed on the communication side.

The initial disappointments were, however, soon overcome, and the use of Oboe was continued, until the cessation of hostilities, in aircraft of No. 8 Group and in the pathfinder squadron of the Ninth Bomber Division (M), Ninth Air

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[1] A.E.A.F. File TS.15581.

[2] The ranges obtained with the mobile convoys were approximately 100 miles at 1,000 feet rising to 280 miles at 34,000 feet.

[3] A.H.B./IIE/248/1/6. Weekly Report on Oboe operations.

Force. In October 1944 a preliminary survey of a heavy increase in Oboe failures experienced after D-Day showed that they were in the main due to navigation errors resulting in aircraft, when called, being many miles away from the point at which they should have begun the Oboe run.[1] The errors were undoubtedly due to the absence of Baillie beam installations, and inadequate Gee cover. The Rheims Gee Chain, and the provision of radio track guides, later did much to overcome the difficulty, and an increase in the number of mobile signals units and frequencies assisted in removing the other obstacles.

As the ground forces advanced on the Continent so tactical targets passed out of range of the Oboe Mark I stations at Sennen, Treen and Worth Matravers. The last operation on which Worth Matravers, the most easterly of the stations, was used, took place on 28 September 1944, and all the stations in the Southern Chain were closed on the night of 6 November 1944, when dismantling instructions were issued. The Mark I stations at Trimingham and Swingate had ceased to participate in any operational sorties in April 1944, but they were maintained in use for training purposes until the middle of January 1945. Of the remaining two pairs of Mark I stations, Hawkshill Down I and Trimingham I ceased operations on 20 November 1944, and Hawkshill III and Winterton II on 14 January 1945. Thereafter all Oboe operations were carried out with either the Mark II or the Mark III centimetre equipment. Gradually, the operations controlled by the mobile units based on the Continent reached their peak as those controlled by the home stations diminished until even the most easterly Mark II and III stations in the East Coast Chain were no longer required operationally. On 29 April and 8 May 1945 Oboe aircraft using Mark II and III channels at Winterton and Hawkshill Down marked pinpoints in Holland to enable Bomber Command aircraft to drop food to the Dutch people. These, however, were to be the last operational Oboe missions controlled by stations in the United Kingdom and all the Mark II and III channels at Winterton and Hawkshill Down finally closed down on 8 May 1945.

As the need for cover from the United Kingdom diminished so the requirement for additional Continental cover increased, and at the beginning of September 1944 the four Oboe Mark IIM and the two Mark IISM units positioned at Beachy Head and Tilly Whim were also withdrawn for despatch overseas. Simultaneously, the siting of radar stations to extend radar navigation and precision-bombing cover from continental bases became the first priority commitment of Headquarters No. 72 Wing, and the rapid changes in the military situation entailed a programme providing great resilience. Although the rapid deployment of units in forward areas provided no difficulty, operational delays were frequent owing to the unfeasibility of obtaining ground surveys rapidly. Conferences to solve these difficulties were held at Headquarters 2nd T.A.F., and a system of aerial survey was adopted which was accepted subject to confirmation by ground survey. It was subsequently found that where aerial survey had been attempted the two surveys were in close agreement. A build-up of Oboe stations on the Continent then began, and by the end of November 1944 ten two-channel convoys had arrived in France; of these, eight were Mark IIM convoys and two Mark IISM. Four sites had been chosen,

[1] A.H.B./II/69/162. B.Ops.2(a) folder, Analysis of Losses.

and the convoys were deployed so that there were two complete two-channel Mark IIM units on each site with three operational and one standby channels.[1] The Mark IISM channels were split, one channel being deployed on each Type 9000 site. Meanwhile the transfer of Headquarters No. 72 Wing had been completed ; the first main headquarters established at Chateau Mathieu was moved to Caen at the beginning of September 1944, and forward to Mons at the end of that month. Here it was joined by the remainder of the wing headquarters on arrival from the United Kingdom on 11 October 1944. At the same time the assistance of No. 14 Air Formation Signals was made available to the wing for the establishment of landline and D.R.L.S. services : assistance of great value to a system such as Oboe, the effectiveness of which depended largely on an extensive operational communications network.

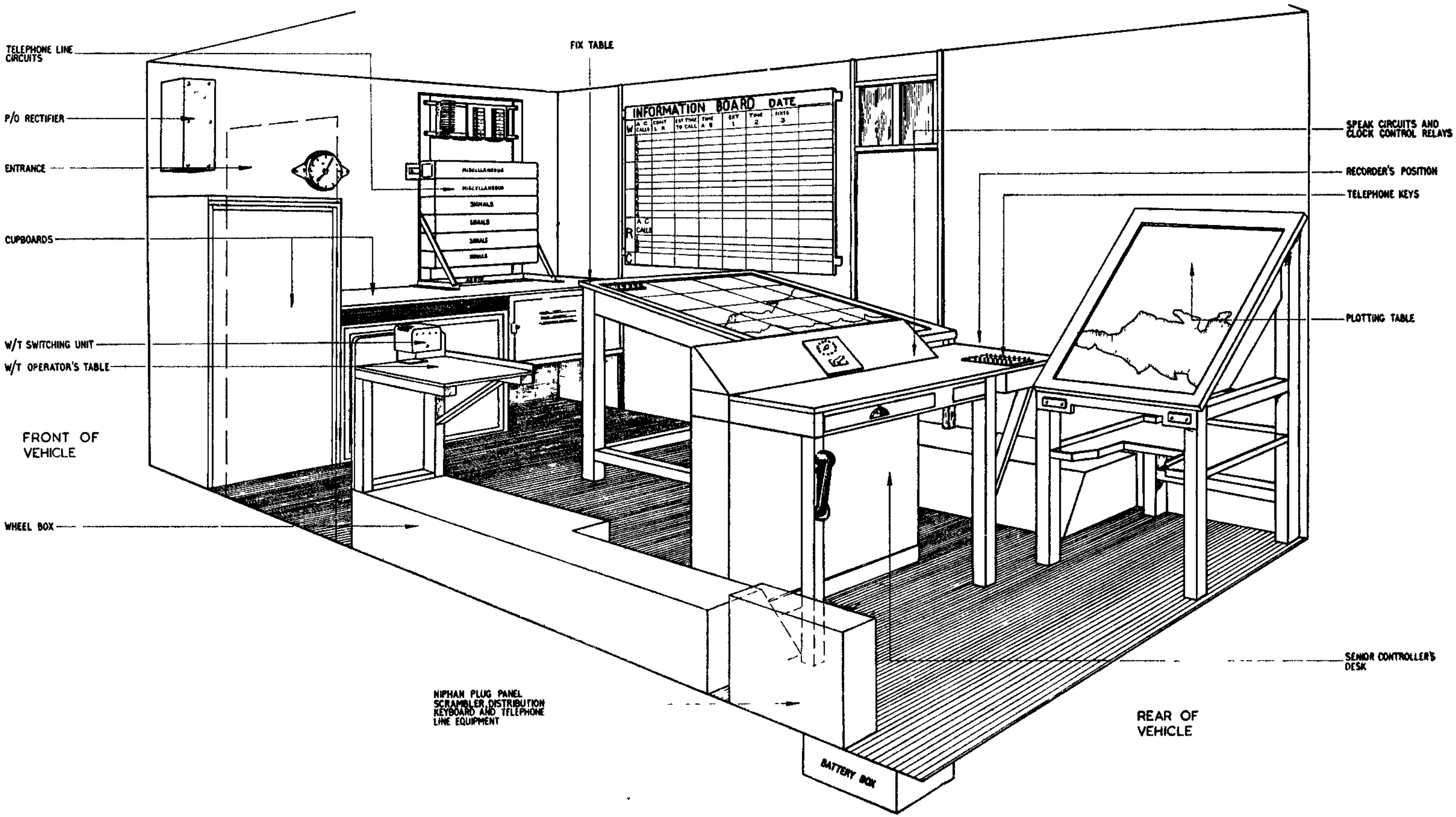
Early in December 1944 considerable re-organisation of the Type 9000 units became necessary in order to provide a complete four-channel convoy for deployment in the Strasbourg area, south of the existing mobile stations. In order to form this unit one Mark IIM channel was drawn from each of the Type 9000 sites at Florennes, Commercy, Laroche and Rips, together with one mobile workshop from both Florennes and Rips, and one controller's vehicle from Florennes. This convoy was assembled at Headquarters 72 Wing by 12 December 1944 ; on 14 December it left for the pre-selected site at Molsheim in France and become operational by 27 December 1944. The remaining Type 9000 sites were then left with three Mark IIM and one Mark IISM channels. The re-organisation of the convoys continued into 1945, and on 24 January 1945 all units as previously constituted were theoretically dissolved. Their convoy numbers were dropped and their personnel were posted to No. 72 Wing Type 9000 Section where they were re-assigned to units which were then designated Nos. 1 to 5 Type 9000 convoys.[2] Individual vehicles were simultaneously allotted cabin numbers. To maintain convoys efficiently in an area recently occupied by an enemy involves difficulties. The main problem was that of accommodation. It was difficult to find winter quarters, large enough to accommodate complete crews, which were near enough to the technical sites to make communications easy and rapid, and, at the same time, economical in transport services. In some instances good accommodation was available but was too widely dispersed. Nevertheless, the extension of Oboe coverage during this time enabled targets such as Stuttgart, Frankfurt, Schwemfurt, Ulm and Nuremburg to be brought within Oboe range.

In the middle of December 1944 a counter-attack against the hitherto steadily progressing Allied offensive was staged by the enemy with the obvious intention of breaking through to the coast. Despite earlier plans, aimed at affording maximum operational cover, which had been made with a view to the possible evacuation of forward areas in the event of such an attack taking place, the situation rapidly became critical, and for the first time the ability of No. 72 Wing to maintain cover in the face of rapid territorial changes was tested. Seven radar navigation ground stations in the Laroche area were endangered,

[1]

Convoy		*Station*
AMES Nos. 9432, 9452, 9412B	..	Florennes (Belgium)
AMES Nos. 9441, 9451, 9421A	..	Commercy (France)
AMES Nos. 9442, 9431, 9412B	..	Laroche (Belgium)
AMES Nos. 9411, 9422, 9412A	..	Rips (Belgium)

[2] No. 72 Wing O.R.B., February 1945.



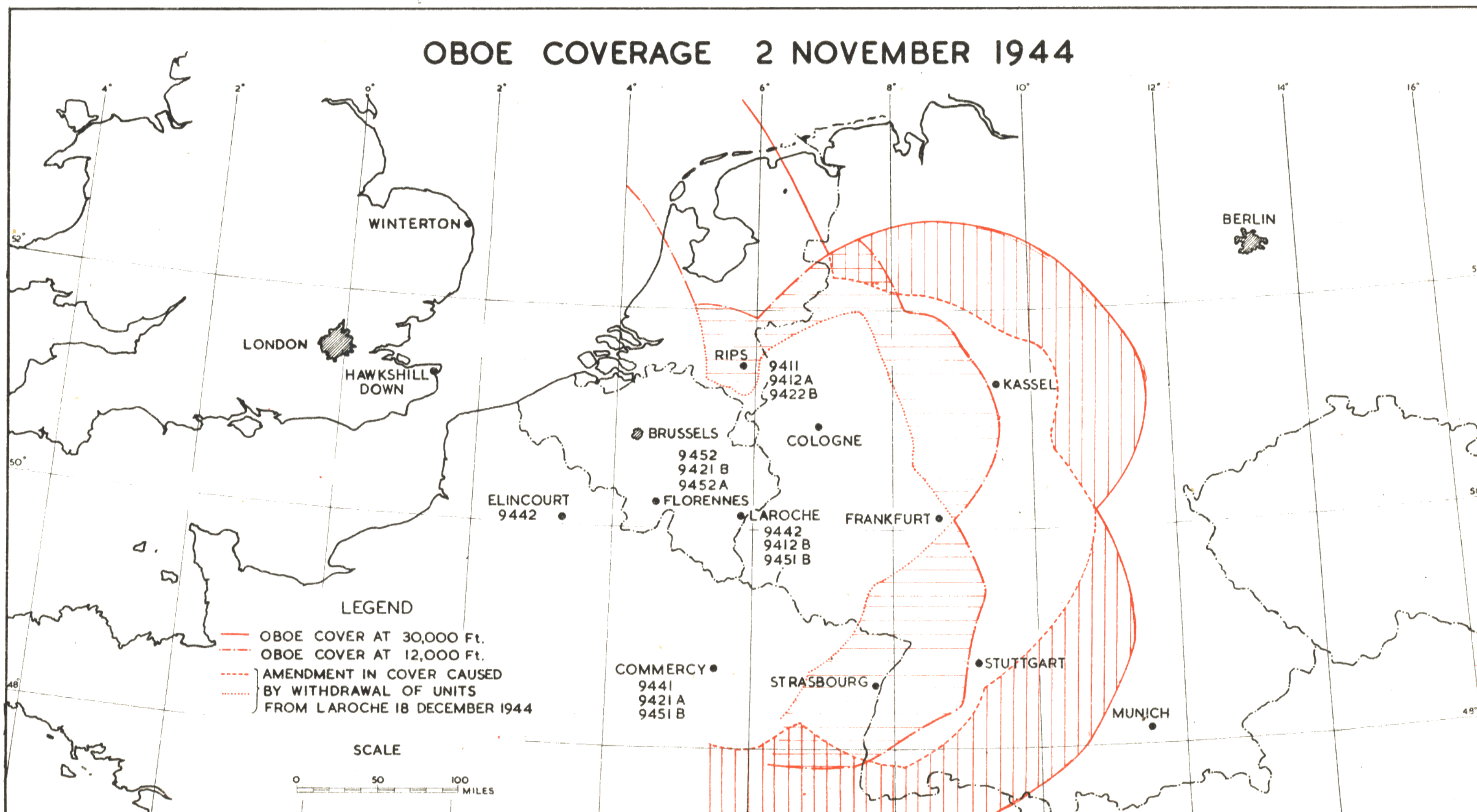
Type 9000 Station (Oboe Mark II) Operations Vehicle including three Oboe units, Nos. 9442, 9412 and 9431. As the enemy assault gained momentum, two aspects of the situation increased in significance. In the first place was the need for maintaining units in an operational capacity as long as possible to assist operations of the Allied air forces and to enable plans to be completed for replacement sites to the rear. Secondly, it was vital to ensure that technical equipment of either a useful or secret nature did not fall into the hands of the enemy. By 16 December 1944 pressure had increased to such an extent that the Laroche area was swiftly becoming untenable, and on 18 December evacuation instructions were issued detailing all radar navigation units to move to Florennes without delay.[1] The withdrawal began shortly after midday and, in spite of extremely bad road conditions resulting from a hard frost after a heavy fall of snow, coupled with the immense amount of military traffic, was successfully carried out. There were no casualties to wing personnel and nothing of a secret or documentary nature was left behind for the enemy. Only a few of more than 100 vehicles were lost, and they were set on fire by American demolition units at the last moment.[2] Resiting measures were immediately introduced, but some delay in perfecting cover arose as the depth of penetration seemed likely to involve the Florennes area, necessitating further evacuation. Reserve sites were chosen at Elincourt, and the three Type 9000 units involved in the withdrawal returned to Headquarters No. 72 Wing for re-fitting. Although the evacuation of Florennes did not take place, the first of the three Type 9000 units, A.M.E.S. No. 9442, to recommence operations did so from Elincourt on 4 January 1945, and radar navigation and precision bombing cover was re-established with the minimum delay.

In the new year the Molsheim area was also threatened by the enemy thrust beyond Strasbourg, and on 2 January 1945 the area commander signalled to Headquarters No. 72 Wing that a withdrawal was in progress and preparations to move had been instituted. The Officer Commanding, No. 72 Wing immediately gave authority for evacuation to be undertaken in emergency on the initiative of the area commander without further reference to wing headquarters. No risks were to be taken and all units were to withdraw to Commercy and await further orders. The order of retreat was specified, giving priority of movement to No. 1 Type 9000 convoy and its associated mobile signals unit. By 4 January the position had become no longer defensible and the withdrawal to Commercy began. Again weather conditions were to cause long delays but all equipment successfully arrived at its destination.

Mid-January saw the end of the German advance and the re-occupation of both the Laroche and Molsheim areas came under consideration. Although Laroche was clear of the enemy a vast number of mines had been sown in the area and all habitable accommodation destroyed during the short-lived German occupation. Weather conditions were severe and heavy falls of snow had made movement difficult, but by 26 January 1945 the radar navigation units were again on their way back. A.M.E.S. No. 120 had already moved on 18 January to prepare the way for the arrival of the other units. No. 2 Type 9000 convoy was the third unit to return to the environs of Laroche, arriving on 29 January 1945 at the site already prepared for it by A.M.E.S. No. 120 and

[1] No. 72 Wing O.R.B., January 1945.

[2] Field Marshal Von Runstedt subsequently disclosed that he had detailed an armoured unit for the specific purpose of capturing intact all No. 72 Wing units at Laroche, and that the Germans were at that time in possession of full details of the location, strength, and degree of mobility of the units.


OBOE COVERAGE 2 NOVEMBER 1944
WINTERTON
LONDON
HAWKSHILL DOWN
BERLIN
RIPS
9411
9412A
9422B
KASSEL
BRUSSELS
COLOGNE
9452
9421 B
9452A
FLORENNES
ELINCOURT
9442
LAROCHE
9442
9412B
9451 B
FRANKFURT
COMMERCY
9441
9421 A
9451 B
STRASBOURG
STUTTGART
MUNICH
LEGEND
OBOE COVER AT 30,000 Ft.
OBOE COVER AT 12,000 Ft.
AMENDMENT IN COVER CAUSED BY WITHDRAWAL OF UNITS FROM LAROCHE 18 DECEMBER 1944
SCALE
0
50
100
MILES

A.M.E.S. No. 7922, and becoming fully operational again on 5 February 1945. Meanwhile, plans to re-occupy the Molsheim area were under way, and on 18 January No. 1 Type 9000 convoy moved to a site near Baccarat to await clearance of its former site. On 5 February the convoy returned to Molsheim and on 12 February it again became operational.[1] The withdrawal from the sites, and their re-occupation, drove home many lessons, notable amongst which was that the lighter, mobile Gee-H equipment was better suited than heavy equipment for occupying forward emplacements, where it could be left on site for a longer period provided the necessary mobile defence forces of light armour and anti-tank weapons were available. The experience gained influenced the deployment of all R.N.A. units during the remaining months of the war in Europe.

By February 1945 the geographical structure of No. 72 Wing had been re-established as it was in December 1944, but of necessity time was required for recovery after the Ardennes offensive.[2] Nevertheless the Oboe stations were continuously used by aircraft of both Bomber Command and the United States Army Air Force and the number of aircraft operating with the system against tactical targets was increasing daily. A special technique, known as close-support attack, was adopted for sorties against vital targets close to the front line. On some occasions the targets were less than 1,000 yards in advance of forward troops and a high degree of accuracy was of major importance. Meanwhile a new method of assisting the navigation of Oboe aircraft, a rotatable radio track guide, had been installed at Juvincourt. This had first been employed experimentally with Oboe aircraft in January 1945 and had proved of considerable value despite the severe limitation imposed by its remoteness from the front line. The promising results obtained with the equipment led to an expansion of the system and track guides were provided in the neighbourhood of the three Oboe units at Laroche, Rips and Commercy. The arc of rotation varied between 000 degrees to 170 degrees for Laroche, 010 degrees to 170 degrees for Rips, and 010 degrees to 160 degrees for Commercy. The frequencies allotted were 34·0 megacycles per second for Laroche and 34·4 megacycles per second for both Rips and Commercy.[3]

The enemy was concentrating efforts on jamming Allied radar navigation and blind-bombing systems. At the beginning of January 1945 severe interference was encountered on the Gee system but only a few sporadic attempts at jamming the Oboe centimetre wavelengths were reported.[4] Jamming of Oboe began in earnest, however, in the early part of February, mainly during United States Ninth Air Force daylight bombing operations. First indications were the appearance of unlocked pulses having a fairly high recurrence rate. They overloaded the aircraft transmitter and resulted in poor repetition of the interrogating pulses, causing 'garbled' signals. Three main types of jamming followed, but as the ground equipment was in all instances triggered by pulses received in an aircraft and retransmitted by it, no signals were received directly

[1] No. 72 Wing O.R.B., March 1945.

[2] *See* Table No. 6.

[3] A.H.B./IIE/248/1/5. Radio Track Guides for use by Oboe aircraft.

[4] The system was rendered vulnerable to interference by the wide aperture of the aircraft aerial and the use of aural indication in the aircraft. In addition, the exclusive use on the Continent of W/T, with a code which was almost plain language, gave advance warning of operations, useful information regarding technique, and an immediate indication of the effect of jamming on ground stations.

at the ground stations.[1] The normal response seen on the ground station cathode ray tube was followed by one or more evenly spaced responses as the jammer and the aircraft transmitted back and forwards to each other. Little adverse effect on operations resulted.[2] At first it was difficult to determine whether the interference was caused by the enemy or by radiations of radar systems on adjacent frequencies, but a survey undertaken in March 1945 established it as deliberate jamming. Subsequently a technique for locating jammers was independently conceived by both Nos. 2 and 4 Type 9000 convoys and by a comparison of the logs of two stations carrying out an operation the approximate position of a jammer was determined.[3] A jammer near Mainz was excellently pinpointed in this way, but by the time the position was determined the Allied ground forces were over-running the area. Later, evidence was obtained of the location of jammers in the Ruhr area, and interference continued to be troublesome until the latter half of April 1944, when presumably the speed of the Allied advance caused a complete disorganisation of the enemy efforts. Documents captured from the *Luftwaffe* after the surrender substantiated earlier Intelligence reports that the enemy maintained an extensive organisation near the Ruhr valley whose sole function was the jamming of Oboe or, as it was known to the Germans, '*Bumerang*'. It also transpired that the enemy had gained considerable advance warning of Oboe sorties by monitoring the Oboe high-frequency radio control system.

The period of comparative stability which began in February 1945 ended in the opening weeks of March 1945 when the Allied armies initiated deep penetrations into enemy positions. Units of No. 72 Wing followed the territorial gains at maximum speed. The necessity for going as close to the advanced positions as possible in view of the rapid eastward movement led frequently to the existence of siting parties among the advanced units, awaiting the clearance of an earmarked area for immediate siting and survey. Requests for the deployment of Oboe stations in forward areas resulted in expansion of the system parallel with that of radar navigation cover. After the Allied crossing of the Rhine on 24 March 1945 the ground forces surged rapidly forward and the Type 9000 units began to move into Germany to keep pace with the military situation. No. 3 Type 9000 convoy, the first to arrive in Germany, left Florennes on 20 March and became operational at Kempenich on 24 March. On 10 April it again moved forward to Gotha from where operations began on 15 April. Nos. 4 and 6 Type 9000 convoys moved on top priority from Commercy and Tilburg early in April as they were no longer able to provide forward cover from those sites. No. 4 Type 9000 which was to proceed to a new site at Bad Homburg left the Rhine bridgehead on 3 April. Upon reaching the crossing, difficulties

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[1] The three types of jamming were :—

(i) Unlocked pulses of high pulse recurrence frequencies bearing no relation to the Oboe pulse recurrence frequencies.

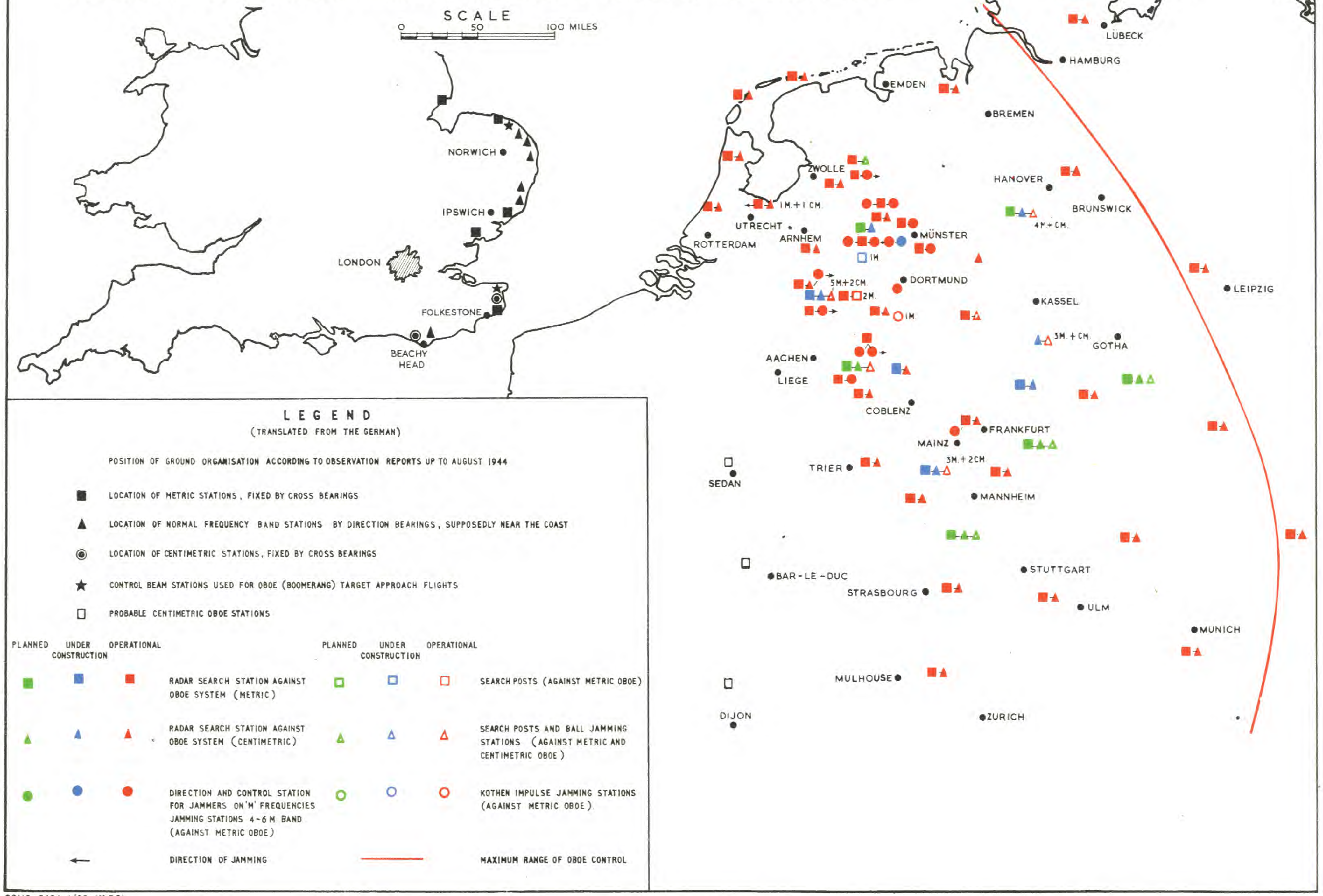
(ii) Unlocked pulses having a pulse recurrence frequency nearly equal to that of the Oboe channel.

(iii) Locked pulses sometimes combined with the first type.

[2] The jamming mainly affected the Mark IISM channels as the filter Type 166 used in the aircraft in the Mark IIM system accepted only incoming signals of the correct pulse recurrence frequency.

[3] Circles centred on the position of the aircraft and having radii equal to the spacing of the multiple responses were drawn. When the results of several sorties were superimposed, the jammers could be identified as the points of intersection of many range circles.

COPY OF ENEMY MAP SHOWING CHECK CONTROLS AND GROUND JAMMING UNITS AGAINST OBOE. AUGUST 1944



99115-8634-6/55-(M.F.P.)

were encountered owing to the amount of military traffic of higher priority, and the American authorities refused to allow the convoy to go through. A discussion between S.H.A.E.F. and General Anderson of the Ninth Bomber Division resolved the situation, however, and the convoy moved forward on 5 April to become the first of the No. 72 Wing units to cross the Rhine. No. 6 Type 9000 convoy, which was scheduled for a site at Munster, then followed on 7 April, its crossing taking place without hindrance at the Wesel bridgehead in the British sector. No suitable site was found at Munster and the convoy moved to, and was finally deployed some twenty-four hours later at, Horstmar. Both stations became operational on 8 April 1945 when they were used for marking operations over Berlin for the first time, with reasonably satisfactory results.[1] On 10 April No. 5 Type 9000 convoy ceased operating at Rips and moved to Barntrup where it became operational on 15 April. No. 2 Type 9000 convoy had been retained at Laroche to provide cover over the Ruhr area, but after the liquidation of the Ruhr pocket, the requirement ceased to exist, and on 16 April the convoy moved forward to Rottingen, becoming serviceable with the minimum of delay at the request of the United States Eighth Air Force. Only one Oboe convoy moved further forward, No. 4 Type 9000, which left Bad Homburg on 26 April, and was operating at its new destination, Erbendorf, on 30 April 1945.

Two operations were of particular note during this time, one which was successful and one which ended in complete failure. The first took place on 23 April when one of the largest Oboe attacks using continental stations was launched against Bremen. Nos. 5 and 6 Type 9000 convoys at Barntrup and Horstmar were employed and 40 aircraft successfully bombed the target with a high degree of accuracy. On the second operation 16 aircraft were detailed to attack Berchtesgarden on 25 April, using the Type 9000 convoys at Molsheim and Gotha. The target was hopelessly beyond the range of the unit at Molsheim, however, owing to the screening effect of the Black Forest, and the operation was completely abortive. Although Headquarters No. 8 Group was aware of the limitations, the attempt had still been considered worth while.[2]

Survey of Accuracy of Oboe

During the last year of operational use of Oboe a considerable amount of data was obtained on the accuracy of the system. The information was gained in various conditions ranging from marking operations over the Ruhr area at maximum heights and small angles of cut to the latest bombing trials in the United Kingdom. A comparison of the accuracy achieved with that of earlier operations showed that the fundamental accuracy of Oboe varied according to height, angle of cut and the type of target indicators used.[3] The average operational accuracy achieved in moderate conditions was shown to be in the region of 200 yards with low-burst target indicators, and 300 yards with high-burst target indicators. In severe conditions and with high-burst indicators the average radial error rose to 500 yards. A considerable increase in accuracy in severe conditions when Delta Oboe was used was revealed in trials held in the United Kingdom. Delta Oboe, by reducing the actual flying errors, considerably reduced the bombing errors, especially at height and when angles of cut were small. Insufficient data rendered impossible a comparison of the

[1] No. 72 Wing O.R.B., May 1945.

[2] No. 72 Wing O.R.B., May 1945.

[3] B.C. O.R.S. Report No. S.236.

results obtained between continental stations and those obtained with home stations but the continental units contributed to a reduction in flying errors by enabling much lower heights and better angles of cut to be used than would have been otherwise necessary. The photographic cover obtained on the Continent was poor and it was extremely difficult to allocate target indicators to specific Oboe channels. The only reliable evidence which could be obtained was from plots made of high-burst indicator photoflashes but there was every reason to believe that the results achieved with the mobile units based on the Continent were of a very satisfactory nature.

The predominant features affecting the accuracy of Oboe marking during the war years were :—

(i) The effect of flying inaccuracies, especially at great heights and small angles of cut.

(ii) Flare drift of high-burst target indicators due to errors in meteorological forecast of wind velocities.

The main physical limitations of the system were the errors introduced in lining-up aircraft equipment and setting up ground stations, the variations of delay in the system with signal strengths, the inaccuracy and drift of the crystal oscillators used as the basis of the measuring circuits at ground stations, the uncertainty introduced by variations of propagation conditions, and the geometrical errors due to siting and computation errors. In addition factors such as bomb ballistics, and the human element both on the ground and in the air, served to diminish accuracy from the generally assumed mean error of plus or minus 440 yards. Nevertheless, a considerable overall improvement was apparent from June 1944 to June 1945. A reduction of over 50 per cent was noticeable in the average radial error and both range and line errors were shown to have been eliminated completely. The early results obtained at long ranges on raids against Ruhr targets when home stations were used revealed a very significant undershoot of 230 yards but fortunately it was soon found that the bulk of the undershoot was due to the use of a wrong terminal velocity for the target indicator. At the same time it was discovered that some of the approximations used in the formulae for computing Oboe ranges were not justified at less than 150 miles. Final corrections to these errors were made in January 1945 after which date no further systematic errors were revealed in Oboe marking at either long or short ranges. Increased stick spacing of target indicators and the provision of the improved Type 60 computor reduced the gross errors considerably, and the ' boob ' rate fell as pilots and navigators became more skilled in Oboe technique. The urgent requirement to use all available Oboe equipment operationally prevented many accuracy trials from being carried out between December 1942 and the spring of 1945, but a further comparison of operational results obtained up to May 1944 with the results obtained during the T.R.E. and Pathfinder Force trials at Otmoor nearly one year later revealed an overall increase in accuracy.[1] The solution to the problem of flare-drift was the use of low-burst target indicators, but that was only possible when the loss of the distinctive cascade effect achieved with the high-burst target indicators was tactically acceptable. Any further development of the Oboe system as a target marking device obviously necessitated the parallel development of an improved target indicator.

[1] *See* Table No. 7.

The extent to which Oboe was used during the campaign in Europe is shown by a summary of sorties flown by No. 8 (P.F.F.) Group, and the pathfinders of the United States Army Air Force, between December 1944 and April 1945, under the control of ground stations based on the Continent.[1]

	Dec.	*Jan.*	*Feb.*	*Mar.*	*Apr.*
No. 8 Group :					
Sorties	72	158	336	364	537
Percentage Successful ..	52	66	60	65	71
Ninth Bomber Division (M) :					
Sorties	146	119	195	471	107
Percentage Successful ..	47	52	57	72	64

From 20 December 1942 until 3 May 1945 the Royal Air Force undertook 1,791 operations with Oboe-equipped aircraft, involving 9,624 Oboe sorties, and from 20 October 1943 until 1 May 1945 aircraft of the United States Army Air Force flew 1,663 Oboe sorties on 627 operations. To ensure accuracy in food-dropping operations over Holland the Oboe system was used from 3 May 1945 until 8 May 1945, when all home and continental Oboe ground stations were closed down.[2]

[1] Report on Assault Phase of Operation Overlord. The percentage of successes shown is a measure only of the correct functioning of the Oboe system and does not take into account failures of visual bombing or cancellation of sorties.

[2] The deployment of continental stations was then :—

No. 1 Type 9000	Melsheim.
No. 2 Type 9000	Rottingen.
No. 3 Type 9000	Gotha.
No. 4 Type 9000	Erbendorf.
No. 5 Type 9000	Barntrup.
No. 6 Type 9000	Hostmar.

CHAPTER 10

H SYSTEMS

Since the radar system of pulse transmissions could readily be used for measuring range to within an accuracy of a few hundred feet or better, a precision much higher than that of measuring bearings, it was particularly suitable for providing navigation fixes by measurement of the distance to two different and known positions. Such a method of using radar, in which airborne equipment measured the distance from the aircraft to two ground radar beacons, was known as H.

With the H system it was not necessary to employ directional aerial systems in the interrogating aircraft as measurement of range only was required, and the choice of radio frequency was not important if it was sufficiently high to permit use of the short pulses necessary for accurate measurement of distance. A transmitter and receiver were installed in an aircraft, and the only ground equipments required were two radar beacons which were so arranged to emit characteristic signals at a definite time after a signal had been received from the aircraft. By measuring the time interval between the original signal and the arrival of the answering signal from each ground station it was possible, in the aircraft, to determine the distance from the two beacons and thus to fix the position of the aircraft. A number of aircraft flying independently could obtain fixes by interrogating the same beacons, but the number was limited by differences in beacon design and the effects on aircraft equipment of beacon responses to other aircraft. Despite the apparent simplicity of the H system principle, computation of location from two observed distances, or advance computation of the two distances to a required location, was, in practice, laborious.

The principal H systems used by the Royal Air Force during the war were Gee-H, Rebecca-H, and Shoran.

Operational Requirement for Gee-H

The introduction of Gee in March 1942 resulted in a notable increase in the accuracy of navigation of Bomber Command aircraft, but the need for an accurate blind-bombing system persisted. Oboe, for use against targets within the range of its ground stations, and H2S, for use against targets at ranges limited only by the operational range of bombing aircraft, were developed and taken into Service use, but there remained a requirement for a system which would enable the main bomber force to attack accurately targets that were too small for the H2S technique to be employed, and which was not subject to the limitations of Oboe in controlling capacity.

In June 1940 the H system had been suggested by the A.M.R.E. as an alternative or a supplement to Gee. Although it appeared that H was simpler to put into operation than was Gee, and that positioning could be carried out

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more accurately, the system contained two main disadvantages. It could be used by only a limited number of aircraft at any one time and would always be vulnerable to deliberate jamming. The limitation in capacity was not considered to be a serious drawback at that time because the available bomber force was small, but the planned expansion of Bomber Command was such that it appeared that the H system would not meet requirements in the future. It was therefore decided on 17 October 1940 that Gee, and not H, was an operational requirement for aircraft of Bomber Command.[1]

The fact that Gee, Oboe, and H2S were not meeting in full the requirements of Bomber Command was made known to the T.R.E., where, on 23 July 1942, a project was suggested for using the Gee and H systems in combination to enable certain important targets in Germany to be effectively attacked as soon as possible.[2]

The possibilities of the combination, to be known as Gee-H, were quickly and somewhat lightly indicated in order that the Air Staff might be enabled to make an early study, but one month later the T.R.E., after discussions with Headquarters Bomber Command, produced a more comprehensive proposal, in which the advantages held by the Gee-H system as compared with Gee were emphasised, and its early introduction strongly urged. Work had been carried out to improve the accuracy of Gee but a conclusion had been reached that no great improvement could be achieved because of the limitations imposed by the radio and I.F. circuits of the aircraft receiver. Any attempts at re-designing the equipment would involve widening the frequency band and making the set even more vulnerable to interference, this in turn leading to the need for elaborate anti-jamming devices to be introduced. It was thought that, as an alternative, the desired accuracy would be obtained from the existing Gee receiver if it could be converted to work on the H system. It was estimated that, given ideal conditions, the accuracy of Gee over Essen would be 0·4 miles by 3 miles, and of the H system, 100 yards by 500 yards, using two ground stations 120 miles apart in the south-east of England. The accuracy to be expected in operational conditions would, of course, be less, but there was no doubt that the area of the fix would be 20 or 30 times less with H than with Gee.

Using similar aerial systems and similar frequencies, the ranges of H were liable to be 20 to 50 miles shorter than those achieved with Gee. In order, therefore, to retain in the Gee-H system the operational cover already being obtained with the Gee system, two changes were proposed. The ground stations were to be moved at least 40 miles nearer to the eastern and south-eastern target areas, and the radio frequency channel for the air-to-ground link was to be on a lower frequency of 29 megacycles per second so that the lower power of the aircraft transmitter was offset with a comfortable margin. It was anticipated that the overall coverage of Gee-H would be as extensive as that of the Eastern Gee Chain. The ground-to-air frequency was to be within the 40 to 50 megacycles per second range covered by the Gee Mark II receiver. Only minor modifications of the Gee aircraft receiver and indicator units were considered to be necessary to bring about the improvements.

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[1] T.R.E. File D.1235.

[2] T.R.E. File D.1979. The Air Ministry Research Establishment became the Telecommunications Research Establishment in May 1940.

The T.R.E. proposal included a time-table of the arrangements required, which, if adhered to, would enable 100 aircraft to be fitted with Gee-H and used on operations early in 1943. Ground station sites at the High Street C.H. station near Lowestoft, and at Beachy Head or on the Fairlight ridge near Hastings, were recommended, and it was planned that the installation of ground station equipment should begin by 15 August 1942. The design of aircraft equipment was to be completed by 1 September 1942 so that full details of the installation could be made available for contractors by 1 October 1942. The T.R.E. considered that the project entailed no great diversion of scientific effort since it could be regarded as merely a modification of the existing Gee development schedule. The installation of additional equipment in 100 aircraft involved a programme about equivalent to that of installing the first 100 Gee equipments, and the addition of the two ground stations required for H meant little when compared with the existing Gee ground station installation task. The proposal concluded with the statement '. . . It should be clearly understood that the T.R.E. is submitting with a full sense of responsibility that the above project should be undertaken at once, without trials, in the belief that the risk of failure is very small and that the operational benefit to be gained is very great, particularly if timed for early 1943 . . .'

On 9 September 1942 the Air Staff decided that Gee-H was to be installed in aircraft of the Pathfinder Force. Two hundred aircraft installations were to be made available as early as possible in 1943, and H ground stations were to be developed as mobile stations.[1] It was an unusual procedure, but it was felt that a good start would have been made towards getting the system into operational use should the experimental and development work prove to be as successful as was anticipated. A committee was formed, under the chairmanship of Sir Robert Renwick, to co-ordinate the various aspects of the project, and held its first meeting on 17 September 1942, when the Air Ministry representative explained that Gee-H was the first stage in the development of H–SBB.[2] The use of A.S.V. Mark II as a basis for Gee–H aircraft equipment had been considered, but it was decided to use instead 200 surplus A.I. Mark VI transmitters, and permission was obtained from the Air Staff to use the valve Type V.T.90 over enemy-held territory, as the Germans had already obtained some of the valves when they came into possession of A.S.V. equipment.[3] Aircraft already equipped with Gee were partly equipped for Gee–H, and aircraft equipped with Gee–H were able to make full use of Gee facilities, since the installation of Gee-H meant only the addition of three units, weighing about 120 pounds, and a separate aerial.[4] Headquarters Bomber Command suggested improvements to make the system meet operational requirements more completely, but considered that the value of the H system in aircraft not fitted with H2S promised to be so considerable that it was well worth while to go ahead with its development, in spite of the inherent shortcomings of the system, so that full use might be made of its advantages at the earliest possible moment.[5] It was therefore decided that modifications were to be incorporated only if no interference was caused with the production and general introduction

[1] A.M. File C.30474/46.

[2] H-SBB was Separate Band Beacon incorporating the H system.

[3] A.M. File C.30474/46.

[4] The additional power required was 400 watts.

[5] One shortcoming was the employment of the Gee time-base for the H system, for which it was not designed and not entirely suitable.

of Gee Mark II. In January 1943 trial installations in Lancaster, Stirling and Halifax aircraft were requested by Headquarters Bomber Command, but the Commander-in-Chief was asked to reconsider his decision to have the equipment installed in all the aircraft of four pathfinder squadrons and to confine installation to one type of aircraft only. By then it had become apparent that Gee-H would not be available for operational use before September 1943. It was anticipated that by that time a considerable number of Lancasters of the main force, other than those capable of carrying 8,000-pound bombs, in addition to Lancasters of the Pathfinder Force, would be equipped with H2S. Headquarters Bomber Command consequently decided that Gee-H should be installed in Lancasters modified to carry the heavy bombs, which could not be equipped with the existing H2S installation, and the Air Ministry requested that sufficient priority might be allotted to the requirement to ensure that a trial installation was completed by the end of March 1943; the requisite modifications were to be incorporated on aircraft production lines from 1 July 1943 onwards.[1] However, at the beginning of March 1943 it was decided that because a Gee-H installation was likely to reduce the radius of action of the modified Lancasters to 300 miles, and because Headquarters Bomber Command and the T.R.E. could not agree about the degree of accuracy likely to be achieved with the system, final decisions regarding the operational employment of Gee-H should be postponed until Service trials had been held.[2]

Development

After tests had been carried out to determine the extent to which interference might be expected from neighbouring C.H.L. stations, the sites for the first ground stations, High Street near Lowestoft, and Beachy Head, were selected to provide an Eastern Gee-H Chain with coverage similar to that of the Eastern Gee Chain.[3] Static stations, containing two sets of equipment, one for operational use and the other to act as a standby and to be used for training purposes, were planned, and on 20 November 1942 it was decided that the T.R.E. should set up a prototype at the High Street site, to be installed and manned by early December. Block numbers were allocated to Gee-H stations and arrangements were made for two technical officers and four radio mechanics to be attached to the T.R.E. for training. A second training programme was planned to begin in January to provide servicing personnel for the second station, and operators for both. On 26 November 1942 the Beachy Head site was rejected because it was too close to some vitally important wireless equipment, and a new site was chosen at Fairlight, which was then renamed Grangewood to avoid confusion with the existing C.H.L. station. By then it had become a matter of urgency that the site should be cleared as quickly as possible in view of the long delay experienced in the clearance of the original site.

The T.R.E. prototype equipment was made available for training and experimental purposes at High Street by January 1943. Tests indicated that Gee-H transmissions could interfere appreciably with C.H. operations but it was found that the interference could be completely overcome by the suppression

[1] A.M. File C.30474/46.
[2] A.M. File C.30474/46.
[3] A.M. File C.17209/44 and T.R.E. File D.2065.

of Gee-H transmission during certain phases. This required only the addition of a small unit to the Gee-H receiver and to each of the C.H. receivers, and the installation of a locking line between them.[1] By March 1943 the second prototype equipment was installed at Grangewood, and was used with its counterpart for tests and training until the fixed stations became available on 1 July 1943.

The frequencies required for Gee-H were in the 20 to 30 megacycles per second band for air-to-ground working, and in the 50 to 80 megacycles per second for ground-to-air. The Home Chain radiated in the first band, and although specific allocations were selected for Gee-H, it seemed probable that C.H. stations at close range might trigger the ground station equipment. In addition, the frequency band was already compromised as it had been used for Gee. Difficulty was experienced in obtaining a specific allocation within the 50 to 80 megacycles per second band for the ground-to-air link as the band was already largely used by G.L. transmitters, and its further use was projected for a highly-important communication system on the south coast. The wisdom of proceeding further with the Gee-H system consequently appeared to be doubtful, since the scope of its operational employment was likely to be limited by interference and jamming, and the shortest effective operational life that could be accepted was one month. In addition, the initial estimates of the T.R.E. regarding the provision of aircraft installations had proved to be too optimistic; the requisite modification of A.I. Mark VI entailed many more fundamental changes than had been anticipated, and the necessary components were not available. Although the two experimental ground stations were made ready by March 1943, the target date for operational use of Gee-H had to be altered, tentatively, to September 1943.

In the opinion of Headquarters Bomber Command the answer to the problem was a very early introduction into operational use within narrower limits, and on 16 March 1943 a memorandum was produced in which it was suggested that, instead of delaying the start of operations until 200 installations were available, probably not before October, the system should be employed only by pathfinder aircraft in a manner similar to that in which Oboe was then being used. In order to postpone for as long as possible the eventuality of the aircraft equipment falling into enemy hands, it was recommended that Gee-H should be installed in Mosquito aircraft of the Pathfinder Force. The success of a raid against Essen on 5/6 March had shown the value of using Oboe for accurate groundmarking when used in conjunction with 'backers-up' and a large main bomber force. It was considered that Oboe Mark I was likely to become ineffective at any time because of enemy jamming, and, since Oboe Mark II was unlikely to become available before August 1943 even at the most optimistic estimate, there might well be a gap during which the extremely promising Oboe technique would not be available. It was possible that the use of Gee-H could effectively fill the gap.[2] About 30 aircraft equipments were expected to be available by June, and the two temporary ground stations of the Eastern Gee-H Chain could be used for the training and employment on operations of a few aircraft. The introduction into operations of a small number of Gee-H Mosquito aircraft appeared to be a task of much less magnitude than that originally proposed.

[1] T.R.E. File D.2065.

[2] A.M. File C.30474/46.

If a frequency of 32 megacycles per second was used for air-to-ground transmissions there seemed little danger of Gee-H being compromised by Gee Mark II, which ranged no further than 29·7 megacycles per second. It was therefore suggested that the T.R.E. should be asked to make a trial installation of Gee-H in an Oboe Mosquito, in such a way that the equipment would be interchangeable with Oboe. At least one Mosquito was to be sent to the T.R.E. for fitting and subsequent use for trials at operational height, and for development of operational technique and training. The crews of No. 109 Squadron were to be trained in Gee-H as soon as equipment became available, so that very little time would be lost before groundmarking operations could be restarted once Oboe Mark I was jammed. The proposal was agreed to in principle on 25 March 1943, but permission to go ahead with it was not to be given until a detailed examination of the target-marking capabilities of Gee-H in its then existing form had been made.[1] A Mosquito was sent to Defford for trials on 20 April, but was found to be of such an early Mark that it needed some modification before the Gee-H installation could be begun. Other difficulties became apparent and in June 1943 it was agreed that all work on a Mosquito installation should be stopped.

Service and Operational Trials

Service trials with a Lancaster Gee-H installation were started by the Bomber Development Unit on 28 June 1943 with the object of determining the accuracy of the Gee-H system at long range. To begin with it was found that signals from High Street and Grangewood could not be received at the theoretical maximum range in the backward-looking area because of the existence of high ground between the ground stations and any points at which such signals should have been received. Eventually it was found that signals from both stations could just be received at a height of 15,000 feet when the aircraft was over the level crossing at Llandow, near Porthcawl, 225 miles from High Street and 196 miles from Grangewood. The first seven tests revealed a systematic error of approximately 250 yards. The cause of this was not apparent at the time but suitable allowance was made by adjustment at the ground stations. The random error, analysed by the B.D.U., showed 50 per cent of release points to be within 210 yards of the aiming point. After the first trials had been completed the B.D.U. reported that accuracy over Ruhr targets would probably be in the region of '. . . 50 per cent of bombs within 610 yards of the aiming point . . .' making allowance for possible systematic errors in early attacks over the Ruhr.

It was considered that before the system could be used operationally further trials would have to be carried out to determine the best technique to be used and to facilitate the formation of a nucleus of Gee-H instructors. On the basis of the accuracy of figures obtained from the trials it was considered that practice bombs might be dropped blind at Stormy Down range without interfering with the comfort of holiday-makers at Porthcawl, about four miles away.[2] Bad weather and unavoidable technical delays which beset the trials resulted in the target date being deferred once again until 8 October 1943.[3] Unfortunately, this coincided with the start of the long winter nights when the main targets

[1] A.M. File C.30474/46. [2] A.M. File CS.16572. [3] A.M. File C.30474/46.

of Bomber Command lay deep in German territory. Furthermore, it was the winter which heralded the Battle of Berlin and therefore there was no immediate use for the Gee-H system on a large scale.

Meanwhile, on 8 August 1943, Headquarters Bomber Command again recommended that, in addition to the Lancaster II squadrons being equipped with Gee-H, the Mosquito aircraft of No. 139 (P.F.F.) Squadron should also be equipped. It had become apparent that Oboe Mark II was unlikely to be available before 1944, and it was again probable that Gee-H would be required to fill the gap between the time when Oboe Mark I was effectively jammed and the introduction into Service use of Oboe Mark II. On 1 September 1943 the Air Staff agreed to the installation of Gee-H in one Mosquito squadron, but as no specific installation had been developed, it would necessarily have to be an improvisation of a Lancaster installation.[1] No. 139 Squadron began operational trials on the night of 4/5 October 1943 when one aircraft was despatched to bomb Aachen.[2] The Gee-H equipment was not actually used for bombing because, owing to confusion about which frequencies were to be employed, no signals were received.[3] The aircraft attacked on dead-reckoning from a Gee fix, and returned undamaged. A second attempt was made against Aachen by a Gee-H Mosquito aircraft on the night of 7/8 October and good signals were received in the target area but there was no evidence of the accuracy obtained. A Mosquito aircraft bombed Duren successfully with Gee-H on 8/9 October, producing a photograph which was plotted as being 500 yards from the aiming point. From the first night on which Gee-H was used on operations, until the first week in November, 11 sorties were despatched altogether on nine different occasions. On six of these technical trouble was experienced and on three the equipment was used for blind bombing. On two of the latter occasions weather was unsuitable for night photography, and on the other the attacking aircraft brought back a good picture of the aiming point.

On the night of 3/4 November 1943, 38 Lancaster aircraft from Nos. 3 and 6 Groups were briefed to attack the *Mannesmannvohrenwerke* factory on the northern outskirts of Dusseldorf, a range of 237 miles from High Street and 270 miles from Grangewood, the attack being timed to coincide with one by the rest of the main force on Dusseldorf itself. Twenty-nine Gee-H aircraft completed the raid, and of them, 50 per cent could claim success. Fifteen had no trouble and bombed without incident and 16 reported failures, three citing Gee-H failures, two Gee failures, three manipulation troubles, and six possible weakness in aircraft transmission caused by the omission of the modified modulator.[4] The ground stations reported satisfactory working and very strong signals were reported from both the air and ground, with a complete absence of enemy interference. Some trouble was caused at Grangewood by beam interference and a few aircraft had slight trouble with pulses from other aircraft. The results of the operation were very encouraging from the accuracy aspect.

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[1] A.M. File C.30474/46.

[2] Bomber Command O.R.B., October and November 1943. Night Raid Reports.

[3] The installation of Gee-H in No. 139 Squadron aircraft raised a serious problem regarding the training of navigators, as it was impossible to carry an extra navigator or instructor in a Mosquito. Owing to the complex nature of Gee-H equipment it was essential for new navigators to fly with an instructor, and the addition of an Oxford to the aircraft establishment of the squadron was requested. The training for, and operation of, Gee-H, were both more complicated than with Gee, but simpler than with H2S.

[4] Bomber Command O.R.B. Appendix, November 1943. Night Report No. 456.

All five photographs showing detail were plotted as well as three others showing fire tracks only; all the plots were within one mile of the aiming point, half of them being within a circle of radius just over half a mile. The crater plot similarly showed very good concentration, no fewer than 11 being attributable to H.E. bombs, and presumably to Gee-H aircraft. Damage to the factory appeared to be rather small but the result, nevertheless, was considered to be most promising.[1] The Bomber Command Operations Research Section was so impressed by the accuracy of Gee-H bombing revealed in the operation that it recommended that Gee-H aircraft should be ordered to use the system for bombing whenever the target was within coverage. It was also thought that consideration should be given to use of a Gee-H force against special targets and suitable spoof targets, and it was recommended that the possibility of target indicators being dropped by a selected aircraft of such a force for the benefit of any aircraft which might have Gee-H failures should not be overlooked. At that time the accuracy of Gee-H was considered to be far superior to that obtained by the use of H2S or Oboe. Although a maximum range had been obtained during training flights, it was important to find out the operational range of Gee-H, and Headquarters Bomber Command suggested that at the earliest opportunity a few Gee-H aircraft should be detailed to observe signal strengths while on a raid beyond Gee-H coverage at various places and heights *en route*. So far, four Gee-H Lancaster II aircraft had been lost over enemy territory. Assuming that the enemy found one of them in good condition, it was estimated that the ground stations could be jammed within one month to six weeks. It was not anticipated that jamming would affect aircraft operating at short range, against flying-bomb sites for instance. The main technical difficulty had been the lack of power in aircraft transmitters and this was soon remedied.[2]

It was this promising start in the operational life of Gee-H which led to the decision taken soon afterwards to strip all four Lancaster squadrons of the installation to prevent the unnecessary loss of equipment which would give the enemy the chance of preparing appropriate countermeasures before the new technique could be used in force. It was decided to conserve all Gee-H equipment until the trend of operations demanded its assistance and instructions were issued that the sets were only to be carried on operations when the aircraft were specifically detailed for Gee-H bombing.

Ground Station and Aircraft Installation Programmes

The accuracy of range determination obtained with Gee-H did not diminish as range increased as it did with the Gee System. The accuracy of a fix obtained with two Gee-H beacons depended on the angle subtended at the point of fix by the beacons, known as the angle of cut. Since no phasing or co-ordination was required between the two ground stations, the system could easily be resited to provide Gee-H cover over any selected area, if mobile instead of fixed beacons were used. On 9 September 1942 it had been agreed that H ground stations were to be developed as mobile stations. The decision was confirmed on 12 March 1943 when it was stated that development of mobile ground equipment was a matter of considerable importance.[3] On 2 April 1943 a proposal was made for

[1] A.H.B. ID4/177.

[2] A.H.B./IIH/222. Bomber Command Quarterly Review No. 11.

[3] A.M. File C.30474/44.

increasing the base-line of the two experimental stations at High Street and Grangewood by installing a third station at West Beckham or Winterton to be used in conjunction with Grangewood. It was considered that, for that purpose, the installation of a mobile station would be easier than that of a fixed station, and that it could make use of the existing C.H. aerial masts at West Beckham. It was later decided, however, that the work involved would considerably retard progress with the Gee-H programme and that it would be better to employ the extra effort on completing the final fixed stations.

In May 1943 it was decided that a light, mobile station, which had been described in November 1942 by the T.R.E. as a most suitable type for close-support operations in overseas theatres of war, and which could be used for both Gee and Gee-H, should be developed.[1] The T.R.E. claimed that Gee-H would enable blind bombing to be carried out with an accuracy of half-a-mile or less, and it was the purpose of the Gee-H light transportable equipment to enable such bombing to be possible when the choice of targets was governed by a swiftly moving battle-front. The equipment could be transported by road, or by air, or by man-handling methods, to the desired sites. With its aid, effective attacks against airfields, troop and tank concentrations, and other tactical targets of reasonable size would be possible in any visibility conditions. It could be used by 25 aircraft simultaneously and could provide normal Gee cover at the same time.[2]

Towards the end of 1943 Intelligence sources indicated that the enemy was about to use new forms of pilotless weapons against Great Britain. Immediately, the Air Staff stated an urgent requirement for increasing the cover provided by Gee-H ground stations to include all that part of France within 160 miles of London, from about 40 miles east along the coast from Dunkerque to the Cherbourg peninsula.[3] Two systems were suggested to extend the cover, a light transportable Gee-H unit used in conjunction with one of the existing fixed stations, or the use of two light transportable stations to be sited at existing ground radar stations, preferably Gee or Oboe. The latter proposal was chosen and two prototype light mobile stations, with reserves, were sited at Worth Matravers and Grangewood, using a ground-to-air frequency of 59·5 megacycles per second and air-to-ground frequency of 22·9 megacycles. The chain became operational from 5 January 1944, each station having a power output of 10 to 15 kilowatts, giving an estimated range of 240 miles for aircraft flying at 10,000 feet.[4] The chain had a handling capacity of about 25 aircraft simultaneously and with average operational conditions the accuracy in the neighbourhood of Le Havre was expected to be better than a 50 per cent bomb zone of plus or minus 500 yards.[5] In December, high priority was attached to the bombing of the V-weapon launching sites. Since the targets were extremely small their complete destruction called for precision bombing and, as a result, interest in employment of the Gee-H system for small-scale operations was increased.[6]

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[1] A.M. File C.30474/44. [2] T.R.E. File D.1979. [3] T.R.E. File D.1979.

[4] A.M. File C.30474/46. These stations were numbered A.M.E.S. Nos. 113 and 114.

[5] T.R.E. File D.1979.

[6] Little more than 50 single sorties had been made with Gee-H during the six months following its introduction and the attack against Dusseldorf was the only major raid on which the system had been used during that period. (A.M. File CS.16567.)

In August 1943 the Commander-in-Chief, Fighter Command (shortly to become Allied Expeditionary Air Forces) had asked for 100 sets of Gee-H with which to equip his light-bomber force, No. 2 Group, and for two complete chains of four light mobile stations for the sole use of that group. Sufficient equipment to enable an immediate allocation to be made was not available. In December the No. 2 Group requirement was confirmed ; Gee-H was to be used, by day and by night, against targets (mainly marshalling yards, factories and V-weapon sites in the Pas de Calais area), which called for precision bombing.[1] Shortly after the original request had been made by Headquarters Fighter Command, General I. Eaker, U.S.A.A.F., approached the Chief of the Air Staff in September 1943 with the suggestion that the United States Eighth Air Force should be included in the Gee-H installation programme.[2] The request was a relatively small one for eight aircraft installations with four spare equipments ; because the system was likely to be jammed shortly after introduction the U.S.A.A.F. wished to take advantage of its benefits quickly, concurrently with Bomber Command, and aircraft could be made available for a fitting programme by 15 September 1943. The Chief of the Air Staff agreed to the release of 12 installations, which were fitted in Liberators, to be used for marking on daylight operations when visual bombing was impracticable. An additional six installations, with test gear, for installation in Fortress aircraft, were then requested. It was decided, however, that in view of the widespread demand being made for the limited number of equipments then available, the Eighth Air Force could be supplied with only three sets until delivery of the second batch of 200 began.

Late in December 1943 the many conflicting claims for Gee-H installations raised a serious question of priority. The 200 equipments ordered initially had been produced and allocated, the majority to Bomber Command.[3] The three Fortress installations reduced the number held by Bomber Command to 145. Meanwhile, Headquarters Coastal Command had raised a requirement for 10 installations in photographic reconnaissance Mosquito aircraft, and a decision had been made to install Gee-H in three squadrons of Stirlings for operations against V-weapon targets. Delivery of the second batch of 200 equipments, which were being obtained by modifying the last of the available A.I. Mark VI equipments, was expected to begin in March or April 1944, whilst delivery from quantity production of 2,000 equipments was not expected before September 1944. Of the 200, three had already been promised to the U.S.A.A.F., 10 were required for Coastal Command, and 150 were required by Headquarters Bomber Command, whilst the Allied Expeditionary Air Forces' requirement was for 512 installations for use in connection with Operation Overlord commitments. The U.S.A.A.F. also wished to make more use of the Gee-H system for operations

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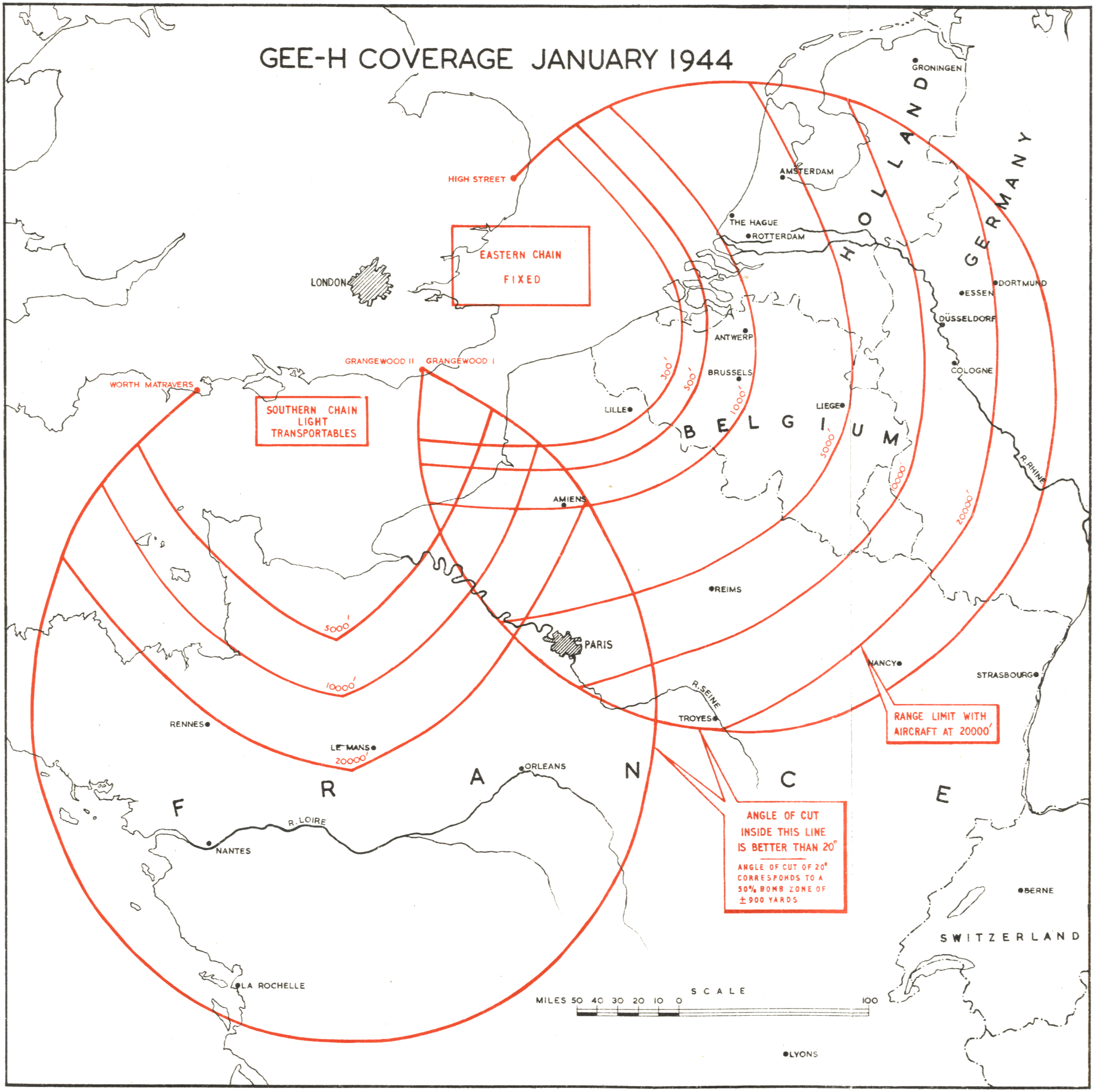
[1] A.M. File CS.16563 and A.H.B./ID/4/177.
[2] A.M. File C.30474/46.
[3] A.H.B./ID/4/177.

(*a*) Bomber Command :—	
Lancaster squadrons	80
Mosquito squadron	20
Spares held in reserve	48
(*b*) Lost on operations etc.	14
(*c*) Allied Expeditionary Air Forces	20
(*d*) U.S.A.A.F.	12
(*e*) Ministry of Aircraft Production	6


GEE-H COVERAGE JANUARY 1944
GRONINGEN
HOLLAND
GERMANY
AMSTERDAM
THE HAGUE
ROTTERDAM
HIGH STREET
EASTERN CHAIN
FIXED
LONDON
DORTMUND
ESSEN
DÜSSELDORF
ANTWERP
COLOGNE
BRUSSELS
GRANGEWOOD II
GRANGEWOOD I
WORTH MATRAVERS
SOUTHERN CHAIN
LIGHT
TRANSPORTABLES
300'
500'
1000'
LILLE
LIEGE
BELGIUM
5000'
10000'
R. RHINE
20000'
AMIENS
REIMS
5000'
PARIS
NANCY
STRASBOURG
10000'
R. SEINE
TROYES
RANGE LIMIT WITH
AIRCRAFT AT 20000'
RENNES
LE MANS
20000'
ORLEANS
FRANCE
ANGLE OF CUT
INSIDE THIS LINE
IS BETTER THAN 20°
ANGLE OF CUT OF 20°
CORRESPONDS TO A
50% BOMB ZONE OF
± 900 YARDS
R. LOIRE
NANTES
BERNE
SWITZERLAND
LA ROCHELLE
SCALE
MILES 50 40 30 20 10 0
100
LYONS

against the V-weapon targets, and it was obvious that all requirements could not be met. Re-allocation was therefore essential and was finally determined as 100 for Bomber Command, 87 for the Allied Expeditionary Air Forces, 10 for Coastal Command, and three for the U.S.A.A.F.[1]

Early Operational Use

The installation of Gee-H in 20 Mitchell aircraft of No. 2 Group had been completed, and the allocation of more equipment to the group was to be confirmed or cancelled after experience had been gained from operational trials during February and March 1944. A.E.A.F. started operations with Gee-H on 18 April 1944, and between that date and 3 May 1944 No. 226 Squadron of No. 2 Group carried out nine attacks, using the Southern Gee-H Chain, against V-weapon targets and Serqueux marshalling yards.[2] Ranges from Worth Matravers and Grangewood to the former were about 140 and 60 miles with an angle of cut of 56 degrees, and to the latter, about 150 and 60 miles with an angle of cut of 43 degrees. The operations were carried out in box formation, the leading aircraft being fitted with Gee-H operated by the same very experienced observer on all occasions except one. The release technique was planned to produce the maximum possible concentration, and to enable the craters or bursts of the bombs dropped by the leading aircraft to be distinguished since the operations might be carried out above cloud. The leader jettisoned his bombs at the release point while the other bomb-aimers released their bombs in the shortest possible stick-spacing on seeing the bombs leave the aircraft. Excellent strike photographs were obtained, many pictures providing crater plots of preceding attacks. Jettisoning was abandoned after the operations of 18, 19, and 20 April since the trajectory of 500-pound MC bombs in jettison was not reliable; on one occasion the bomb-aimer of an adjacent aircraft reported that the bombs were seen to be jostling. An analysis of the attacks showed the average bombing pattern to be an area measuring 450 by 190 yards, with the aiming point in the centre, which was consistent with the accuracy achieved by individual aircraft of No. 3 Group during the same period.[3]

The United States Eighth Air Force started Gee-H operations in strength on 28 January 1944, and 17 Gee-H operations were carried out between that date and 10 April 1944, all against tactical targets in north-west Europe, including marshalling yards, factories, and V-weapon sites in the Pas de Calais area. Six of the raids were believed to be representative and the results of them were analysed. An average pattern bombing error of 620 yards undershoot was revealed. The results showed that for targets of appropriate size, effective results could be obtained when Gee-H was used to determine the bomb-release point. The data did not imply that the accuracy of a Gee-H aiming point approached that of a visual bomb-sighting, but did support the doctrine that with a large formation bomb-pattern it was not possible to take full advantage of the accuracy of a visual bomb-sight.[4] If 500-yard accuracy

[1] A.M. File CS.16567.

[2] A.M. File CS.16572.

[3] A.M. File C.17209/44. When, just before the operations had been started, the programme of Gee-H training had been intensified, it was found that Gee-H cover over the No. 2 Group bombing range at Bristol was unsatisfactory because signals from Grangewood faded. It was impracticable, because of the distances involved, for aircraft of No. 2 Group to use the Bomber Command training area, so a light Type 100 unit was deployed to the Malvern Hills to work in conjunction with Worth Matravers, and was made ready by 1 April 1944.

[4] A.M. File C.17209/44.

could be achieved with Gee-H it should be possible to plan on the expectation of a group bomb-fall pattern of about 1,000 yards diameter, with almost maximum effectiveness, and it could be expected that results would continue to compare favourably with visual bombing when formations of 12 aircraft were employed. The limitation of the accuracy of Gee-H to about 500 yards became serious when small targets were to be attacked by squadrons or smaller units. It was therefore recommended that when planning the future use of Gee-H, particular care should be taken to find targets suitable for attack by groups of 12 to 18 aircraft. Visual bomb-aiming was to be used against targets suitable for attack by smaller formations.

When installation of Gee-H had been completed in a Stirling squadron Headquarters Bomber Command still felt doubtful about using the system against V-weapon targets as it was considered that there was insufficient evidence to show that it would be effective for operations on which extreme accuracy was needed. Accordingly, four experimental Gee-H operations were mounted in April 1944, the first to be carried out by Bomber Command since the raid against Dusseldorf.[1] Destruction of the target was not the primary object of the operations ; they were regarded as full-scale range and calibration tests, and aircraft therefore attacked independently. The first was carried out by 14 aircraft against Chambly, a marshalling yard near Paris, on the night of 20/21 April. During this trial the Southern Gee-H Chain was used for the first time by Bomber Command ; Grangewood, 139 miles from the target, acting as the tracking station, and Worth Matravers, 217 miles from the target, as the releasing station. Only four aircraft attacked successfully as general difficulty was experienced in receiving signals from the low-powered mobile ground station in use at Worth Matravers, and, whilst an analysis of results seemed to show that the tracking was satisfactory, there appeared to be an error of approximately 800 yards undershoot at the release point. This undershoot was hardly significant in one operation but, taken together with similar undershoots observed by aircraft of No. 2 Group when Worth Matravers was used, it appeared that there might be a systematic error at the beacon. Action was therefore taken to reduce the beacon delay until a fuller investigation could be made.

The second operation was carried out on 23/24 April 1944 by 12 aircraft against a signals depot at Vilvorde, near Brussels. The Eastern Gee-H Chain was used, Grangewood 166 miles, and High Street 156 miles from the target. Although the target was not actually hit, the grouping of the sticks was very satisfactory. Accuracy of release was particularly good, but there appeared to have been a tracking error to starboard, averaging about 300 yards, which was considered to be due to errors of heading at release. The radius of the 50 per cent circle was about 550 yards. The third and fourth operations were carried out against Chambly, on 24/25 and 26/27 April. The third raid once again demonstrated the inadequacy of a mobile ground station at ranges over 200 miles, but it was found that the alteration of the phasing at the ground station had eliminated the systematic error. The difficulty with the signal from Worth Matravers was overcome to some extent by reducing the limiter level at the beacon and improving the aircraft transmissions, and the results seemed to indicate that a cure might have been effected. The following raid,

[1] Bomber Command O.R.S. Report No. S.152.

in which 10 aircraft took part, showed that this was not the case however, since no signals from Worth Matravers were obtained, and after investigations had been made by the T.R.E. and Operations Research Section in conjunction with No. 218 Squadron and No. 84 Wing, it was decided to alter the air-to-ground frequency from 22·90 to 29·70 megacycles per second. Of the 40 aircraft used on the trials only one had an equipment breakdown, all the other failures being connected with poor range from Worth Matravers. This represented an equipment serviceability figure of 97·5 per cent.

Use in Operations Neptune and Overlord

Late in 1943 preparations were started for the extensive use of radar navigation and precision bombing systems before, during, and after the Allied landings in Normandy. Gee-H was to play a small but nevertheless important part. First of all it was necessary to strengthen the Gee-H facilities in the United Kingdom, mainly for use by Bomber Command. On 28 February 1944, Headquarters No. 60 Group took over the Southern Gee-H Chain, the T.R.E. retaining full responsibility for carrying out trials and for making any necessary modifications.[1] The accuracy tests made by the Bomber Development Unit had shown up the poor performance of the low-powered light Type 100 Units of the original chain in comparison with the fixed stations.[2] The maximum range from Worth Matravers had been 120 miles. The unsatisfactory results led to the substitution of heavy mobile stations, which consisted of normal fixed Gee-H equipment, with greater power supplies, housed in vehicles.

At first the Southern Chain was operated on a different frequency from that of the Eastern Chain to avoid interference, but the Director of Radar decided to fuse the two chains to form a trio of stations operating on the same frequency in order to obtain the best cover from the limited equipment available.[3] This rearrangement of the functions of each station was a source of contention between the T.R.E. and the Air Ministry, but its main advantage was that it was not necessary to retune aircraft transmitters when passing from the area of the Eastern Chain coverage to that of the Southern Chain. Grangewood II was dispensed with and Worth Matravers joined the two Eastern Chain stations on a frequency of 59·5 megacycles per second for ground-to-air, and 22·9 megacycles per second for air-to-ground, with the result that slightly improved cover was given in the Pas de Calais area.[4] With the combined system a Gee-H operator was able to use any two of the three beacons, distinguishable by suitable coding. On 28 April 1944 it was decided to establish two heavy mobile Type 100 stations within No. 60 Group for possible use overseas. The reserve equipment was removed from High Street, converted to a heavy mobile station, and numbered A.M.E.S. No. 115. The heavy mobile station at Grangewood was removed and made up to overseas scale, becoming A.M.E.S. No. 116. This unit was held at R.A.F. Cardington, but A.M.E.S. No. 115 was sent to the Lizard and became operational on 24 May 1944 at Kilter, working on the same frequency as the other three stations.[5] This fourth station was added to improve the Gee-H coverage

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[1] T.R.E. File D.2065. [2] A.M. File CS.16572. [3] T.R.E. File D.2065.

[4] A.H.B./IIE/160. Air Signals Report on Operation Neptune.

[5] T.R.E. File D.2065.

over the Brest peninsula. In the event of the limited number of Gee-H stations becoming swamped by too many demands, special phasing for particular targets was arranged by Headquarters No. 84 Wing. This system was put into practice by 17 May 1944 and was operated at the request of the command concerned, but No. 84 Wing treated requests for phasing according to a strict priority list which varied by day and night.[1]

During the assault phase prior to the Normandy landings, Stirling aircraft of No. 3 Group, using Gee-H, made several precision attacks against tactical targets in France and Belgium. The most notable of these was a raid against Chambly on 1/2 May, in which the main force of aircraft bombed on Oboe markers, but twelve aircraft of No. 218 Squadron used Gee-H for blind bombing independently of the markers. An analysis of the results showed that the bombs of seven aircraft fell within 300 yards of the aiming point, of three within 600 yards, and of two within 2,550 yards. One of the aircraft with the large error had swerved to avoid collision just before the release point. Bomber Command aircraft also made effective use of Gee-H in a minelaying role, off the north French coast and as far round as the Frisian Islands and the Baltic Sea. The United States Eighth Air Force confined its operations with Gee-H to daylight bombing of tactical targets, keeping to the technique of using leader aircraft to guide formations of about 18 Liberators or Fortresses.[2] In the first fortnight of June 1944 100 Gee-H sorties were flown against 49 targets, with excellent results.

It was a prime requisite of medium-bomber operations that they should not be governed by weather conditions over the target area by day, and that the effectiveness of attacks against precision targets at night should not be jeopardised by bad visibility.[3] The policy had been, therefore, to equip all aircraft of No. 2 Group with Gee-H equipment, but because the number of equipments available was limited only 30 Mitchell and 36 Mosquito aircraft were fitted by D-Day ; the remainder were fitted with Gee. No. 2 Group carried out 71 Gee-H sorties between 28 April and 4 June 1944.[4] Twenty-three were abortive and it was possible to isolate the bomb-fall of 28 of the remainder. The centres of pattern of the 13 sorties carried out before the night of 26/27 May had a significant systematic undershoot of 283 yards and 50 per cent of the bombs fell within 420 yards of the target. If this systematic error had been removed, the 50 per cent zone would have become 270 yards, thus more than doubling the efficiency of the equipment. On the 15 sorties carried out after 26/27 May, 50 per cent of the bombs fell within 560 yards of the target. The decrease in accuracy was thought to be due to three factors ; the use of a release point instead of a warning point, the use of non-zero second decimal co-ordinates, and the inexperience of No. 2 Group in operational night-flying at the altitudes necessary for Gee-H.

[1] A.H.B./IIE/160. The priority list was as follows :—

	By Day	By Night
First priority ..	A.E.A.F.	A.E.A.F.
Second priority ..	U.S. 8th A.F.	Bomber Command
Third priority ..	Bomber Command	U.S. 8th A.F.
Fourth priority ..	Coastal Command	Coastal Command

[2] A.M. File CS.16572.

[3] A.H.B./IIE/160, Section II.

[4] A.E.A.F. O.R.S. Report No. 21.

It was considered by the O.R.S. of the Allied Expeditionary Air Forces that accuracy would be improved if three conditions were fulfilled ; allowances made for the systematic error, zero second decimal warning points used, and a Mouse for measuring ground speed over the target used. Headquarters Bomber Command and the United States Eighth Air Force agreed, and a Mouse, the computor Type 56, was produced by the T.R.E.[1] Results of trials with the Mouse in August 1944 showed a substantial improvement, a reduction in the standard deviation along the track from 255 to 190 yards being effected, but they also showed room for further improvement, and trials were continued. In the meanwhile it was recommended that the equipment should be introduced into the Service as soon as possible. It was better and easier to handle than the warning point method. Wind-speed and direction errors, and airspeed indicator errors, were eliminated, and in their place only errors of measuring groundspeed by Gee-H were found.[2] The device was not produced in any large quantity by the end of the war, but a second Mouse, the computor Type 59 produced by the T.R.E., was installed in aircraft of No. 218 Squadron by February 1945.[3]

On D-Day, six aircraft of No. 3 Group equipped with Gee-H took part in a diversionary operation known as ' Glimmer '.[4] The aircraft flew in orbits across the English Channel towards the French coast at the same time releasing ' Window ' to simulate a large convoy approaching France at a regular speed of 10 knots. The operation was similar to ' Operation Taxable ' but as the target was Boulogne, Gee cover in the area was inadequate for the high degree of accuracy required. Precise positioning was essential throughout, and that this was provided by Gee-H was proved by the success of the operation, which caused a large number of enemy E-boats to be diverted against a wholly fictitious convoy. From D-Day until the end of August 1944, Bomber Command and the Eighth Air Force continued to use Gee-H against tactical targets just ahead of the Allied armies. Their chief aim was to disorganise the enemy supply lines, thus preventing speedy moves of reinforcements. At that time the enemy had also launched the VI and V2 weapons, and considerable effort was expended by all the Allied air forces on bombing the launching sites. Despite the comparatively small number of aircraft fitted with Gee-H, the system played its part in the success of the operations.[5]

No. 2 Group started night as well as day-bombing after D-Day. It had been originally intended to use both Mitchell and Mosquito aircraft for Gee-H operations, but up to 30 July only Mitchell aircraft were used while the

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[1] A.E.A.F. O.R.S. Report No. 25. The automatic computor Type 56 was an electrical Mouse. By measuring the time taken to fly between two points a predetermined distance apart, the computor established the groundspeed of the aircraft and automatically released the bombs.

[2] Bomber Command O.R.S. Report No. S.156.

[3] Bomber Command O.R.S. Report No. S.203. The computor Type 59 was composed of two modified Type 35 No. 20 camera controls.

[4] A.H.B./IIE/160, Air Signals Report on Operation Neptune. A full description of Operation Glimmer is given in Royal Air Force Signals History, Volume VII : ' Radio Counter-Measures '.

[5] A.M. File CS.16572. Approximate figures were :—

Bomber Command	100 aircraft
2nd T.A.F.	100 aircraft
Eighth Air Force	39 aircraft

Mosquitos were employed for low-level harassing attacks at night.[1] Because of the type of target allotted to No. 2 Group, Gee-H operations were divided into two categories; daylight formation raids led by Mitchells equipped with Gee-H, and individual night attacks by Mitchells in which target indicators or bombs were dropped. The first proved to be a most successful technique. Three 'boxes,' each of 18 aircraft, were normally employed, each box being led by a Gee-H aircraft. The whole operation was specially planned and the formations tracked in to the target on a Gee-H tracing co-ordinate. When cloud obscured the target each box released bombs on Gee-H indications, but if a break in cloud appeared at the right moment, leading bomb-aimers took over for visual aiming as soon as the target appeared in their sights. Generally speaking, both the Gee-H operator and the bomb-aimer found that their release points coincided. On one occasion, when clouds were patchy and one box bombed with a visual sighting and the remainder with Gee-H, it was the visual releases which were wide of the mark. The second category of operations consisted of target-marking sorties to help Mitchells and Bostons not equipped with Gee-H to locate targets, and straightforward bombing attacks in bad weather when the latter aircraft could not operate. Targets were mainly troop concentrations and de-training points. From D-Day until D plus 24, 774 sorties were flown in 22 effective operations, 13 of which were in the first category and the remainder in the second. Unfortunately results of the majority of attacks could not be assessed because photographic cover was unobtainable. One which had an important bearing on the battle for Caen was made on 10 June. Ground forces had achieved only slow and limited progress because of bad weather, delayed build-up of strength, and strong reaction by German armoured units in the Caen area, in which the enemy had substantial elements of three *Panzer* divisions in addition to considerable infantry, artillery, and anti-aircraft forces. It was known that the Germans were preparing a counter-attack, and there was some danger that they might be able to reach the sea and divide the Allied beachhead. In order that such preparations might be disorganised, bombing attacks against the headquarters of *Panzer* forces were arranged. 60 Mitchells bombed Headquarters *Panzer* Group West from 12,000 feet with great success, and put it out of action until 28 June. The main buildings were not badly damaged but the orchard in which vehicles were parked was saturated with direct hits and everything nearby was destroyed, whilst the Chief of Staff and several of his senior officers were killed.

Deployment of Ground Stations on the Continent

To meet the requirements of Bomber Command, 2nd T.A.F., the United States Eighth Air Force, and Transport Command, the heavy mobile Gee-H units were sent to Normandy as soon as the liberating forces had been established on the Continent.[2] The first Gee-H station, which it was planned to site near Cherbourg, was to have been sent on D plus 45 but shipping difficulties prevented A.M.E.S. No. 116 from landing in France until August. It became operational at Anneville-en-Saire by the end of the month, working with the United Kingdom Gee-H chains. The fourth station at Kilter was then closed down

[1] A.H.B./IIE/160, Section VI.

[2] A.H.B./IIE/159, Section XXIII. No. 38 Group, Transport Command, used Gee-H on a relatively small scale for troop-carrying and supply-dropping operations.

and A.M.E.S. No. 115 was sent to France.[1] As the Allies gained ground more speedily than had been visualised, great flexibility was needed in the siting programme of Gee-H convoys. By 4 August 1944 the Air Ministry had completed plans for deploying stations on the Continent up to D plus 330.[2] The plans visualised a total of three stations to be installed in France, but that number had been estimated for the steadily advancing front predicted in the overall Operation Overlord plan, and three stations were not sufficient during the rapid advance. Consequently three more heavy mobile stations were formed.

At the beginning of September 1944 precision-bombing cover was required over Stuttgart to the north of the Ruhr. On 7 September two siting parties left Headquarters No. 72 Wing to site A.M.E.S. No. 116 in the region of Florennes, in southern Belgium, to give the required cover.[3] On 13 September two light transportable units, A.M.E.S. Nos. 103 and 107, were deployed as reserves to the heavy units and a week later A.M.E.S. No. 103 was moved up to a site at Steendorp to extend H cover already given by the heavier stations. As soon as A.M.E.S. No. 116 had been established and was operating satisfactorily the heavy mobile station at Worth Matravers was withdrawn and made up to overseas scale to become A.M.E.S. No. 114, leaving only two operational stations in the United Kingdom, High Street and Grangewood I. By the end of September 1944 A.M.E.S. Nos. 115 and 116 were sited and A.M.E.S. No. 114 became operational on 17 October 1944 at Laroche.[4] To keep up with the fast-moving battle-front, units had to be moved forward very rapidly and at short notice. The move of A.M.E.S. No. 115 from Florennes to Bockel at the beginning of November was an outstanding feat of persistence and determination to set up a station with the minimum of delay.[5]

In October 1944 Headquarters VIII Bomber Command, United States Eighth Air Force, reported that poor results were being obtained from A.M.E.S. No. 103, the light transportable station in Belgium. The unit was later supplemented by a heavy mobile station which came into operation on 30 October, and its additional power increased the extent of effective cover. At the same time the provision of additional aircraft sets was also required but there was not sufficient to fulfil the need, as there had been no production for some months.[6] Production was due to start in November at a rate of 20 per week but the output would have to be divided between Bomber Command, 2nd T.A.F. and the Eighth Air Force, each of which would get roughly one-third of the equipments as they became available. Although there were then four Gee-H units sited on the Continent and two operating at home, the percentage of fitted aircraft in Bomber Command was insufficient to enable individual bombing sorties to be carried out.[7] Therefore Bomber Command Gee-H crews were trained to undertake marking duties for night attacks and to act as formation leaders for daylight raids, thus adopting the tactics already used by 2nd T.A.F. and the Eighth Air Force.

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[1] No. 72 Wing O.R.B., August 1944.

[2] A.H.B./IIE/159, Section XXIII.

[3] No. 72 Wing O.R.B., October 1944.

[4] Sites were :—

A.M.E.S. No. 115 : Florennes.
A.M.E.S. No. 116 : Commercy.
A.M.E.S. No. 103 : St. Nicholas.

[5] A.M. File CS.16572.

[6] A.M. File CS.16572.

[7] A.H.B./IIH/222.

Initially the Gee-H force of Bomber Command were employed mainly as bomb-aimers for daylight formation raids, and between October and November 1944 the force started its long list of successful attacks against a variety of objectives, including synthetic oil and benzol plants, marshalling yards, and certain tactical targets. In the first three weeks alone, nine daylight and two night attacks were made against targets in the Ruhr and Rhineland, and of the daylight attacks seven were carried out in completely overcast conditions. Amongst the first successes were some which ranked high in the list of the outstandingly successful attacks by Bomber Command: Bonn, Leverkusen, Bottrop, Solingen and, in particular, Koblenz, where 120 aircraft in formations of three, each led by a Gee-H aircraft, completely devastated approximately 250 acres of the built-up area attacked, or over two acres per aircraft.[1] On 18 October 1944, when Bonn was attacked, the releasing station experienced technical trouble which was not cleared until just two minutes before the zero-hour, with the result that while virtually the entire force tracked on Gee-H, only 50 per cent bombed blind, the remaining aircraft using the bombsight for release. The raid against Leverkusen was an early Gee-H attack through ten-tenths cloud in daylight. The damage was a little off-centre, mainly towards the south, but this was actually the first time that the target had been effectively hit. The results achieved by Gee-H aircraft in the early operations were highly satisfactory, the average error of 275 yards being about the same as that obtained during training exercises. In December 1944 the force continued to add to its successes and, despite weather conditions which hampered other bomber operations, it was able to maintain continuity of effort in one of the worst months of the year by operating on 15 days of the month.[2] Three attacks were in close support of the Army, during Rundstedt's breakthrough in the Ardennes, the first being undertaken in response to an urgent call for tactical support to which other air forces in the theatre were unable to respond because of the prevailing weather conditions. On this occasion an attack was made against Trier, when the target area was entirely fog-covered. The success of the attack in the conditions under which it was made drew the personal congratulations and gratitude of the Supreme Commander of the Allied Expeditionary Force.

The enemy's sudden counter-attack endangered the Gee-H unit at Laroche, A.M.E.S. No. 114, and although it was vitally important that the station should remain operational for as long as possible, it was also imperative that the equipment should not fall into the hands of the Germans.[3] By 16 December 1944 enemy activity east of Laroche had increased considerably and on 18 December the area was evacuated. A.M.E.S. No. 114, the Gee, and the Oboe stations, were instructed to go to Florennes and by the evening the Gee-H units had arrived intact despite bad weather and other unfavourable conditions. Some time elapsed before satisfactory cover was completed because of the need for deciding where replacement units should be located. The surprising depth of enemy penetration seemed likely to affect even the Florennes area, and reserve sites were selected at Elincourt against such a possibility. By 30 December 1944 A.M.E.S. Nos. 108 and 120 were deployed there as reserves. Gee-H cover was finally re-established with A.M.E.S. No. 114 operating at

[1] A.M. File 16572. *See* Tables Nos. 8 and 9.

[2] A.H.B./IIH/222. *See also* Appendix No. 7.

[3] No. 72 Wing O.R.B., January 1945.

Florennes by 23 December 1944 and A.M.E.S. No. 117 undergoing tests at the same time at Molsheim.[1] By the end of 1944 all six heavy mobile units were on the Continent in addition to 27 light mobile units which could be used for either Gee or Gee-H. When used for the latter they were saturated with 20 interrogating aircraft as compared with 80 for the heavy Gee-H station.

1945 began with threats of a further evacuation of technical units.[2] The Molsheim area was endangered by the enemy thrust beyond Strasbourg, and A.M.E.S. Nos. 117 and 102 were affected. On 4 January 1945 S.H.A.E.F. directed that all units at Molsheim were to be evacuated, and the heavy and light Gee-H units were ordered to Commercy, where they arrived late on 5 January. On the afternoon of 6 January S.H.A.E.F. decided that a light Gee-H unit could return to Molsheim, and accordingly A.M.E.S. No. 102 was instructed to go back to its old site. A.M.E.S. No. 117 was sent to a site near Baccarat to await further clearance of the Molsheim site. The heavier type of Gee-H mobile station was difficult to move over the very muddy and badly cut-up terrain. Similarly, although the Laroche area was by that time clear of the enemy, it was not possible to re-occupy it immediately because of the possibility of enemy mines. The first unit to return was A.M.E.S. No. 120, a light mobile Type 100, which was to function in an H capacity until released by the arrival of A.M.E.S. No. 114. Even the movement of the lighter equipment was retarded by hours because of the exceptionally difficult road conditions. When A.M.E.S. No. 120 became operational it did not give satisfactory service and A.M.E.S. No. 114 was finally brought up to the site on 8 February as a replacement. By the end of the month the last of the heavy equipments was in operation and the static condition of the front allowed the continued operation of the more efficient units.[3] Improvements were made to Gee-H coverage during the period of comparative stability which lasted until the beginning of March 1945. Then pressure against the enemy was renewed and preliminary preparations were made to launch an offensive to finish the war. No. 72 Wing played its part in providing essential support to this plan, and when extended cover was requested units were moved forward to meet the demands. Aircraft of No. 3 Group equipped with Gee-H made a major contribution during March to the successful Bomber Command offensive, inflicting severe damage on most of the targets attacked.[4] Raids against marshalling yards at Wanne-Eickel and an oil refinery at Salzbaerger were particularly successful, and an attack on Wesel helped to pave the way

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[1] By the end of December Gee–H units were deployed as follows :—

A.M.E.S. Nos. 103 and 107 : St. Nicholas.
A.M.E.S. Nos. 114 and 105 : Florennes.
A.M.E.S. No. 115 : Bockel.
A.M.E.S. No. 116 : Commercy.
A.M.E.S. No. 117 : Molsheim.
A.M.E.S. Nos. 108 and 120 : Elincourt.

[2] No. 72 Wing O.R.B., January 1945.

[3] These stations were deployed as follows :—

A.M.E.S. No. 114 : Laroche.
A.M.E.S. No. 115 : Bockel.
A.M.E.S. No. 116 : Commercy.
A.M.E.S. No. 117 : St. Avold.
A.M.E.S. No. 118 : St. Nicholas.
A.M.E.S. No. 119 : Croix.

[4] A.M. File CS.16572.

for one of the Rhine crossings in the Allied assault. No satisfactory explanation had, however, yet been found for the systematic error which frequently arose in Gee-H operations, which caused the bombing to undershoot or overshoot. In many instances good concentration had been achieved over the target, but the bombs had fallen up to 1,000 yards wide of their mark.

With the final rapid advance of the Allied armies during April 1945 the few strategic targets available for bombing were outside Gee-H range and as a result operations using the equipment were held up pending the forward movement of the ground stations. In the six weeks immediately before the capitulation, the six heavy Gee-H units made 11 moves. Each unit moved twice, except A.M.E.S. No. 119, their non-operational time varying from a few hours to eight days according to the distance and conditions of the move.

Limitations of Gee-H in Tactical Air Force Operations

Both Bomber Command and the United States Eighth Air Force had found Gee-H satisfactory for blind-bombing operations apart from the delays in obtaining sufficient aircraft equipment and the systematic errors which remained to the end of hostilities. It seemed to meet with less success in a tactical air force. The No. 2 Group requirement for a navigation system had been met with Gee, but the requirement for a blind-bombing system was more difficult to fulfil.[1] The targets were smaller than those of Bomber Command and therefore a system giving the highest possible degree of accuracy was essential. Oboe was considered but was unacceptable because of the need for complicated communications and it was therefore decided to use Gee-H. There were two reasons why the plan was not fully implemented; the shortage of aircraft equipment and the impracticability of fitting it in Boston medium-bomber aircraft. By D-Day nearly all Mitchell and Mosquito aircraft of No. 2 Group were modified for Gee-H installation but the shortage of equipment resulted in fitting being partly carried out during the campaign, whilst operations were in progress. Consequently it was not until September 1944 that adequate numbers were available throughout the group. The difficulty was overcome, however, by using box-formations consisting of six aircraft with a Gee-H leader. The number of qualified Gee-H air operators was so small that their operational tours would normally have been completed before others could be fully trained to replace them. Headquarters No. 2 Group foresaw this difficulty and made special arrangements for operators trained in Gee-H to form a reserve pool. The wisdom of this move became evident when operations were stepped up in February and March 1945.

Since Gee-H was also used by Bomber Command and the Eighth Air Force, the control of ground stations on the Continent was at first given to Headquarters No. 72 Wing of No. 60 Group, and Headquarters 2nd T.A.F. was responsible only for their administration.[2] Their moves and siting were co-ordinated under the direct control of the Air Ministry, and Headquarters 2nd T.A.F. had no control although it had the overriding right to veto a proposed move if the military situation made such a step necessary. Then it was decided to give Headquarters No. 2 Group four light mobile stations to

[1] A.H.B./IIS/88/2, Radar in 2nd Tactical Air Force.

[2] A.H.B./IIE/159. Section XXXIII.

have under its direct control. Headquarters No. 60 Group, however, under Air Ministry authority, produced a plan for the extension of Gee-H cover during the continental campaign and this appeared to be so complete that it seemed unnecessary for 2nd T.A.F. to retain four separate beacons. The units were therefore handed over to No. 60 Group on the understanding that they could be recalled if the need arose.

In the event, the Allied advance was so rapid that no preconceived scheme was capable of being implemented and Gee-H cover was inadequate to meet the demands of No. 2 Group. Consequently, on 3 September 1944, Headquarters 2nd T.A.F. requested that four light mobile stations should be assigned directly under its operational control.[1] Three light Type 100 units were recalled from No. 72 Wing, two of which were deployed solely for the use of the 2nd Tactical Air Force by the middle of November 1944. A month later they were joined by a third unit. Towards the end of the campaign No. 72 Wing had very largely overcome the difficulties of moving the mobile units, and as a result a better standard of cover was maintained in most areas. The light units were then used to fill the gaps in the area over which aircraft of No. 2 Group operated and which were not filled by the general Gee-H chains. The 2nd T.A.F. unit at Bladel was redeployed at Tilburg on 6 February 1945. The three units then remained static until six weeks before the final defeat of the enemy on the Continent. By 30 March they had moved forward, and on 28 April 1945, Headquarters 2nd T.A.F. requested that A.M.E.S. No. 110 be transferred to No. 72 Wing at a site at Nijverdal so that it could work with A.M.E.S. No. 118 at Papenburg to give cover over the Dutch islands.

The technical performance of Gee-H equipment was good and serviceability was very satisfactory. At one stage 89 per cent of all No. 2 Group missions, including close support, were briefed to use the system. In many cases it was possible to release bombs on visual sightings but in a high proportion the run-up was carried out on Gee-H. It could therefore be said that Gee-H was the factor which originally enabled medium-bombers to take part in close-support operations in conditions of bad visibility. As throughout the campaign in Europe the weather was far from ideal, the contribution of Gee-H to the success of No. 2 Group operations was material.

To sum up, the system performed a useful function in 2nd T.A.F. It was accurate enough for attacks carried out against area targets, but effective attacks against bridges and other similar small targets were generally beyond its capabilities as a blind-bombing system, although such targets had been attacked on occasion with success. Its disadvantages could be collectively described as lack of flexibility. Since flexibility was of first importance to a tactical air force, it had to be admitted that useful as it was, Gee-H was not the ideal blind-bombing system for such a force. The delays in obtaining cover compared very unfavourably with the speed with which Rebecca-H cover was obtained as a result of the beacons being directly under 2nd T.A.F. control and it was clearly necessary that a tactical air force should have its own Gee-H units. In addition, it was found that the use of Gee-H by light-bomber

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[1] A.H.B./VD/104. Report on Air and Administration Organisation in 2nd T.A.F. These stations were sited at :—
A.M.E.S. No. 109 : Heevlen.
A.M.E.S. No. 110 : Boom.
A.M.E.S. No. 121 : Bladel.

aircraft at night was inefficient since their bomb load was too small to give a reasonable chance of effectively hitting a target. Since their operations were mostly of a harassing nature, they could be performed without blind-bombing aids. Gee-H was therefore not used by them in operations on the Continent.

Operational Trials of Gee-H/H2S

In order to make possible accurate bombing of targets outside normal Gee-H range, but within range of one Gee-H beacon, it was proposed in December 1944 that blind marking should be carried out by the use of a combination of Gee-H and H2S. Lancaster aircraft of No. 514 Squadron were therefore equipped with H2S Mark IIIA in addition to the normal Gee-H installation. As the technique was untried, training flights were used as Service trials, and were undertaken in two forms; homing to a given position, and practice bombing. Although there was evidence of systematic beacon errors at both Biggin Hill and Sywell Gee-H stations the average deviation when homing was practised was less than 350 yards across and 510 yards along track. In bombing exercises the average error was 460 yards from the aiming point; it was estimated that in good conditions Gee-H/H2S marking could achieve the same accuracy as was obtained with Gee-H alone.[1]

The technique was used for a daylight attack against Hallendorf on 29 March 1945, when 130 Lancasters of No. 3 Group were detailed to bomb the benzol plant and coke ovens. Ten-tenths' cloud was expected over the target area and, owing to uncertainty that reception of the Gee-H release beacon at Bockel, 225 miles distant, would be possible, nine aircraft of No. 514 Squadron were briefed to lead the force and release skymarkers on Gee-H/H2S indications. The only suitable response for H2S in the target area was that of the target itself but because headwinds were expected and because the aiming point lay on the north-west side of the works, it was decided that the centre of the response was too close to the warning point for ranging to be reliable. Operators were therefore briefed to make a short timed run from a point on track 3·5 miles from the centre of the works, and were supplied with stopwatches and plots of times against groundspeed. The weather was worse than had been expected, and ten-tenths' cloud up to 22,000 feet effectively prevented photography, and thus detailed evidence of accuracy, of the attack. Individual raid reports indicated that bombing was probably scattered and it was unlikely that the skymarkers were effective since the first seen would be the furthest downwind. Of the nine aircraft of No. 514 Squadron only four used the Gee-H/H2S technique; Gee-H was unserviceable in one, H2S in three, and both H2S and Gee-H in one. The crews with serviceable equipment were confident that their marking was accurate.[2]

Development of Gee-H Marks II and III

Early in 1944 development of Gee-H Mark II aircraft equipment was begun. The original Mark I sets were modified A.I. Mark VI equipment, and the new apparatus differed from the old only by being designed and constructed specifically for the Gee-H function.[3] The circuits were therefore different and the Mark II units were tropicalised. Contracts were placed for 4,000 aircraft

[1] A.M. File CS.16572.
[2] Bomber Command O.R.S. Report No. S.221.
[3] A.M. File CS.16567.

equipments in July 1944 when plans for extending the Gee-H programme were made.[1] There were considerable delays in the production of Gee-H Mark II, however, because certain parts were not available, and an estimate was given for a weekly production of only about 20 sets by March 1945. In September 1944 it was decided at a meeting held by the Controller of Communications that the first 200 Gee-H Mark II equipments should be produced on a crash programme at the earliest opportunity, and they were expected to be ready for installation in aircraft between February and May 1945. In fact, replacement of Gee-H Mark I by Mark II began in April, but at a very slow rate.[2] Although Gee-H was proving successful it was still considered possible in December 1944 that the enemy might begin jamming it and in all probability the ground-to-air link would be the most seriously affected. The Directorate of Communications Development was therefore asked to develop a 10-centimetre ground-to-air link on high priority. This was to be considered as an immediate interim requirement and it was still necessary to proceed with the development of a centimetre Gee-H system as a long-term project. Development work was started, using, where possible, sets already developed and introducing modifications as required. Six ground stations and 20 aircraft equipments were to be modified for use immediately jamming became serious, and the first equipments were to be ready in two to three months' time. At the end of hostilities in Europe no development work had been completed on Gee-H Mark III and no production orders had been placed.

Disbandment of Stations in the United Kingdom

Until the units were established on the Continent the home-based quartet of stations was used for Gee-H operations. As the units were deployed overseas, and better cover was given in forward areas, so equipment was withdrawn from England. Kilter was the first home station to be closed, followed shortly by the heavy mobile station at Worth Matravers, leaving High Street and Grangewood I operating in the United Kingdom. As the Allied offensive moved eastward, the units on the Continent were able to follow to give the required cover in forward areas, and by the middle of November 1944 all available targets were out of range of the High Street and Grangewood pair. They were therefore relegated to training uses by Bomber Command.[3] In order to provide a single training channel which would satisfy all users and also to release equipment for a further two heavy mobile stations for the Continent, it was decided to resite the two light mobile units at Worth Matravers and on the Malvern Hills then being used by No. 2 Group for training. The units were moved to Sywell in Northampton and Biggin Hill in Kent, becoming operational by the middle of November 1944.[4] When this channel was operating satisfactorily, equipment was withdrawn from High Street and Grangewood I on 8 December 1944 and used to form two heavy mobile units, A.M.E.S. Nos. 118 and 119, for shipment to the Continent. The stations recently resited at Sywell and Biggin Hill had been run in the past on an experimental basis and had been manned by scratch crews. In view of the considerable increase in the demands being made upon them by Bomber Command, the Eighth Air Force, and 2nd T.A.F., it was decided to plan the stations on an official basis, under the control of Headquarters No. 60 Group, and they were then known as A.M.E.S. Nos. 137 and 138.

[1] T.R.E. File D.1070. [2] A.M. File CS.16567. [3] A.M. File C.30474/46.
[4] A.M. File C.17209/44.

In February 1945 reports were received that the stations were giving unsatisfactory results in some of the training areas, and they were therefore resited once again. The sites chosen were the C.H. stations at Stoke Holy Cross and Canewdon, and two new light Type 100 units, A.M.E.S. Nos. 134 and 133, were installed. Sywell and Biggin Hill remained operational until the two new sites had been tested and found satisfactory, and the original units, A.M.E.S. Nos. 137 and 138, were then moved to the new sites, becoming operational on 1 April 1945, with A.M.E.S. Nos. 134 and 133 as standbys.[1] They had not been operational for long before they were criticised for the lack of handling capacity, reduced range, and accuracy, compared with the heavier units. On 12 April 1945, Headquarters No. 60 Group asked if they could be replaced by production equipment, but as all available supplies were absorbed at the time by operational commitments, the situation was not improved until after the war had ended, and the stations were replaced in October 1945 by heavy mobile units, A.M.E.S. Nos. 116 and 117, which were withdrawn from the Continent. At the same time the remaining four heavy mobile units were disbanded.[2]

Operational Requirement for Rebecca-H

In the spring of 1943 informal discussions were held between the Telecommunications Research Establishment and Headquarters Army Co-operation Command on the possibility of developing an accurate fixing system for other than single-seater photographic reconnaissance aircraft of No. 34 Wing to make possible the taking of effective night flash-bomb photographs behind the enemy lines. Night reconnaissance was very important for ground forces because Allied air superiority during the hours of daylight was such that the enemy was forced to make his tactical dispositions by night. It was seldom possible for a pilot flying by night to know his location accurately enough for photographs to be taken without preliminary map-reading by the light of flares. This gave the enemy warning that reconnaissance was in progress and assisted his fighter and gun defences to engage reconnaissance aircraft. An additional disadvantage lay in the fact that only a strictly limited number of flares and flash bombs could be carried.[3] A fully mobile system was needed so that ground stations could be sited as near as possible to the front line and as wide a coverage as possible afforded of the country behind the enemy lines. The degree of accuracy required was that selected targets should be photographed from aircraft flying at 5,000 feet at a range of 100 miles from the ground station. The T.R.E. believed that the best way of meeting the requirements was by employing the H principle of fixing by means of two range measurements from mobile responder beacons, using Rebecca Mark II as a basis for both the aircraft and ground installations. On 8 March 1943 the Air Ministry agreed that the T.R.E. should proceed with the development of Rebecca-H for Ventura aircraft in Army Co-operation Command. On 18 March 1943 Headquarters Army Co-operation Command expressed a formal requirement for an equipment to enable photographic reconnaissance aircraft to be navigated with great precision at night when the ground was almost invisible. It was agreed that two ground beacons and twelve sets of aircraft equipment should be developed and constructed on the highest priority.

[1] A.M. File C.17209/II. [2] A.M. File C.30474/46. [3] A.M. File C.30523/46.

Development

Development of the new system was begun at the T.R.E. in March 1943. One Ventura aircraft was allocated to the T.F.U. for a trial installation in April 1943 and the necessary radar equipment was diverted from Rebecca production to the T.R.E. for modification.[1] The T.R.E. estimated that an accurate signal would be produced at ranges up to 100 miles and that the strobe unit would provide accurate measurements of range up to 100 miles. It was anticipated that in operational conditions an accuracy of range estimation of plus or minus half a mile would be achieved. The normal Rebecca aircraft installation was modified to provide transmission and reception in all directions from the aircraft and a strobe unit was added to the apparatus in order to produce a display suitable for accurate simultaneous range measurement from two beacons. The strobe unit, measuring 9 by 8 by 12 inches and weighing 17 pounds, incorporated a switch controlling the function of the equipment and also two delay-setting controls calibrated accurately in ten-mile steps. The usual Type 6E indicator unit, provided with a twelve-mile scale instead of the normal nine-mile scale, was used. The aerial changeover switch in the transmitter/receiver was employed so that a simultaneous display, on opposite sides of the time-base, of two beacon signals at different ranges, was obtained. Normal Rebecca homing aerials were retained for general homing and beam approach purposes and an all-round looking receiver aerial for H operation was added. A relay-operated switch effected the changeover from one type to another. The ground installation was also based on Rebecca Mark II but incorporated modifications to enable it to work as a responder instead of as an interrogator, and at first the ground beacons were mounted in two standard 12 cwt. vans. In the first tests an intermediate aerial system, consisting of a simple quarter-wave unipole with director, was used, but this was regarded only as an interim measure until the final aerial system had been developed. It was hoped that by using similar apparatus in the air and on the ground the multiple-frequency facilities would be preserved as a safeguard against enemy interference. The vehicles holding the ground beacon had to carry spares, test equipment and power supplies in addition. The aerial system was mounted on top of the body in such a way that it could be raised to a vertical position when in use and lowered to lie flat along the roof when in transit. A special vehicle became necessary because of the size and weight of the aerial system and the fact that the engine of the vehicle was required to drive the standby power supply. A new type of signals vehicle Type No. 440 was accordingly allocated. The method of presentation was that the beacons were first identified on the long time-base scale and then their range was measured with the twelve-mile scale and the strobe unit. The two ranges to the centre of the target area were computed and the pilot made his approach by keeping one range constant so that he flew along the arc of a circle passing through the centre of the target area. The distance from the second beacon at which photography commenced was chosen so that the centre of the series of photographs to be taken would, in the absence of errors, lie at the centre of the target area.[2]

Trials

By the end of June 1943 one aircraft installation and two ground beacons, using the interim aerial system, had been constructed. Experimental flight trials were held during which ranges up to 80 miles at 5,000 feet were obtained

[1] A.M. File CS.21556.

[2] A.M. File CS.22822.

and accuracies varying between two miles and seven miles in range measurement achieved.[1] In August 1943 the T.R.E. conducted operational trials of Rebecca-H. Two crews were detached from No. 140 Squadron for training in the use of the system and it was found that about ten hours' flying per crew was required before a good operational standard was attained. The beacons were situated on Defford airfield and the maximum range obtained was 75 miles at 5,000 feet. Later the beacons were placed approximately 20 miles apart, the ranges from the beacons to the targets being 38 and 40 miles; photographs showed a mean error of 540 yards. The beacons were then placed at Honiley and Little Rissington and the crews attempted to photograph the bombing range at Pershore by night. Results obtained indicated an average error of 432 yards. The trials proved that the equipment fulfilled the general requirement and the aircraft and vans were handed over to No. 140 Squadron for further trials at Hartford Bridge. By 10 October 1943, 105 photographs had been taken with the assistance of the system. The photographs were taken by day but the briefing of the crew was in terms of range only and did not include naming the target. The beacons were sited at Lasham and Hembury, approximately 31 miles apart. Four targets were used, spread fanwise in relation to the beacons. There were range errors in the early runs which were attributed to ground beacon delay variation and to inaccurate calibration of the aircraft equipment. The trials showed that, of 20 sorties with Rebecca-H, on 19 it was possible to take photographs accurately, without visual observation, of targets up to 40 degrees off the bisector between two beacons situated 30 miles apart, at a range of 60 miles.[2]

Production

It was considered that Rebecca-H met the operational specifications and on 28 September 1943 a formal requirement was raised for its installation in three squadrons of the Tactical Air Force, Nos. 4, 140 and 234, and for eight mobile beacons for Nos. 83 and 84 Groups. To enable 100 per cent reserves to be held an initial supply of 84 aircraft installations was required. The T.R.E. undertook to manufacture 12 equipments by hand, and in November six Rebecca Mark II sets were allocated to the firm of R.F. Equipment for development as Rebecca-H.[3] Later a production contract for 120 equipments was placed with the firm, and No. 1 Maintenance Unit was given the task of making an additional 20; Rebecca Mark II was to be used as the basis for modification and arrangements were made for the requisite number of equipments to be diverted from the Murphy Radio factory.[4] In February 1944 it was estimated that delivery of Rebecca-H would begin early in April 1944.[5] However, in April, the requirement was decreased to installation in one squadron only, No. 140, and the production contract was reduced to 60 sets. In August 1944 it was decided that no further development of Rebecca-H was required, and by December production had ceased.[6]

Operational Use

By July 1944 Rebecca-H was being used operationally by photographic reconnaissance aircraft of No. 140 Squadron. A high degree of mobility was required of the eight beacons which had been provided in order that coverage

[1] A.M. File CS.21556. [2] A.M. File CS.21556. [3] A.M. File C.39546/49.

[4] Ten from April production and 20 per month thereafter.

[5] A.M. File C.30523/46. [6] A.M. File CS.24135.

against rapidly changing military requirements might be maintained. The first two beacons were sited on the beach-head and were in operation by 5 July 1944; with the break-through they were moved rapidly forward into Holland and Belgium. To ensure adequate flexibility of the system the beacons were placed under the direct control of the headquarters of Nos. 83 and 84 Groups. The tactical advantage of high mobility was indicated when two beacons were quickly but temporarily returned to the United Kingdom for location on the Kent and Sussex coasts to provide cover for the Calais area when that could not be done from the Continent. With the crossing of the Rhine the beacons were again moved rapidly forward, their sites being changed frequently to maintain adequate coverage behind enemy lines. By 30 April 1945 the final disposition of the beacons was reached when all the 21st Army Group field of operations against Germany was provided with sufficient coverage. At the beginning of 1945 technical responsibility for the beacons was handed over to No. 34 Wing although their actual siting remained the responsibility of the Tactical Air Force. At first some difficulty was experienced in communication between Headquarters No. 34 Wing and the beacon sites and operating instructions often arrived at a beacon too late to be of any use. A Wireless Observer Unit post was consequently located at each beacon site and shared its W/T facilities; when W.O.U. posts were withdrawn the W/T establishments were added to those of the beacon parties. Originally five spot frequencies were allotted to the Rebecca-H system for communication purposes but, because of interference from other users, the allocation was later reduced to the exclusive use of two channels with common-user facilities on all but one of the remaining channels.[1]

Targets were chosen by the 21st Army Group General Staff (Intelligence) and the ranges for Rebecca-H were then calculated by the navigation officer of No. 34 Wing. Crews were briefed to use Rebecca-H for the final fifteen minutes only of a run so that the enemy received signals for as short a time as possible.[2] The operational use of Rebecca-H revealed weaknesses in the beacon which imposed certain limitations on its working. At ranges of less than 35 miles from the tracking beacon the curvature of the heading made tracking difficult, while at ranges greater than 35 miles the reduction in the angle of cut made releasing progressively difficult. The maximum operating range depended on such factors as the base-line between the beacons, operational height, and height of cloud base, and in practice varied from 65 to 85 miles.[3] The modifications that Headquarters 2nd T.A.F. considered to be necessary were the provision of a new coding unit, a rotatable aerial, a new power supply, and installation in a three-ton instead of 15 cwt. vehicle. The supply of ten beacons, modified in accordance with the recommendations, to replace the beacons already held, was requested. The Air Ministry was reluctant to accede to the request because the modifications entailed considerable development work and it had already been decided, in August 1944, that no further development of Rebecca-H should be undertaken. In addition, operational use of Rebecca-H was of necessity limited because only No. 140 Squadron was fitted with it, and Headquarters 2nd T.A.F. was asked to reconsider the request in view of the heavy demands being made on the radio industry for

[1] A.H.B./IIS/88/2. Radar in 2nd Tactical Air Force.

[2] A.H.B./IIE/167. Report on Radar Equipment for Tactical Air Force.

[3] A.H.B./IIS/88/2.

all types of equipment. The headquarters therefore agreed to carry out modifications within the command if three-ton vehicles and improved coding units could be made available.[1]

In spite of its limitations the Rebecca-H system was considered to be of value in night photographic reconnaissance operations. Headquarters 2nd T.A.F. estimated that the efficiency of the system in target finding was about 69 per cent from July 1944 to the end of February 1945. It was reckoned that of the failures to find the target only 21·6 per cent were attributable to technical deficiencies. The degree of accuracy attained was not high but was considered to be acceptable. A representative of the T.R.E. who visited the Tactical Air Force in January 1945 reported that it was estimated that when the system was correctly used the error was normally less than half a mile. More than 50 per cent of the photographs taken at 6,000 feet were useful.[2] Rebecca-H ceased to be of value when the war in Europe ended; it was not required in the Far East for its wartime operational use in night photographic reconnaissance and it had no peacetime application. On 25 June 1945 the Air Ministry declared it obsolete.

Development of Shoran

Shoran was developed in the License Laboratories of the Radio Corporation of America, and its whole process of development was sponsored by the Wright Field Radio Laboratory on behalf of the United States Army Air Force.[3] Unlike other H systems, it was not a modification of existing equipment, but was intended for use in its particular role from the initial research stages. As a result the development prototype was constructed for the most part from production drawings, and was not only well-engineered but required very little modification before production was started, which, however, was not until the war in Europe was almost over. Then, because of the time required to manufacture, deliver, and install equipment in sufficient quantity, and because of the limited range of the Shoran system, it was too late to be of value for strategic bombing. Had, however, the war been prolonged, it is highly probable that airborne repeater stations would have been used to increase Shoran range for strategic bombing in the Pacific. As it was, sufficient operational use was made of Shoran to indicate that it was a valuable asset to tactical air forces in that it enabled effective attacks to be made in bad weather against such targets as airfields, bridges, and lines of communication.

Shoran was similar in principle to the British H system. An aircraft interrogated two ground stations or beacons and, using its measured ranges from them, determined its position by triangulation. Since the actual ranges were measured, instead of the difference between ranges as in the Gee system, the position of the aircraft was determined by the intersection of two sets of circles. The aircraft installation, AN/APN3, consisted of three main units in addition to aerial arrays; transmitter, which included power supplies, timing unit, which included receiver and cathode ray tube display, and bombing computor. The aircraft was flown on a curved track at a constant distance from the 'drift' or 'navigation' station, the function of which was similar to that of the Cat station in Oboe, and its position on that curved

[1] A.M. File C.30523/46. [2] A.H.B./IIE/167.

[3] C.R.B. 44/4288. The name Shoran was developed from Short Range Air Navigation.

track was determined from the 'rate' or 'calculating' station, which enacted a role similar to that of the Mouse. In order that the ground stations could be identified, the aircraft transmitter radiated pulses on two different radio frequencies simultaneously by means of a commutator, which also switched the output of the receiver aerial and reversed the polarity of received signals. The returned pulses from the drift station pointed towards the centre of the display screen, which had a circular time-base, and those from the rate station pointed outwards. At the top of the display was a reference marker which corresponded to the instant of transmission from the aircraft. Transmissions were made at a fixed time, and by introducing a phase change, received signals could be made to coincide with the marker pulse. The amount of phase change required depended on the distance from a ground station, and by the manual rotation of two phase-change controls the drift and rate pulses could be moved around the circular time base until they were brought into alignment with the marker pulse. The distance from the ground stations could then be read, in miles, directly from a dial and a counter without the necessity for interpolation as in a pip-counting technique, and the position of the aircraft was easily determined. The radar equipment could therefore readily be used for navigation. A computor was added to the installation for the purpose of precision blind bombing. For a bombing run the aircraft was flown along a track in the form of an arc of a circle, passing approximately through the target, whose centre was the drift station. The computor, used in conjunction with the radar equipment, measured groundspeed and automatically released bombs when fed with the following requisite information for each bombing run, at each height, and for each type of bomb:—

(*a*) Distance from drift station to target, corrected.

(*b*) Distance from rate station to target, corrected.

(*c*) Magnetic bearing of ground track at 'no wind' release point.

(*d*) Angle between lines joining target to ground stations.

(*e*) Trail distance of bomb.

(*f*) Time of fall of bomb.

AN/APN3 was designed primarily for installation in Fortress aircraft, in which the large units could be fitted fairly easily. The receiving aerial was mounted on the top surface of the fuselage, behind the upper gun turret, and the transmitting aerial on the underneath surface below the tail gun turret. The positions were chosen to achieve omni-directional fields of radiation and to gain every possible advantage against deliberate jamming.[1]

The frequencies used were close to bands which had already been subject to enemy jamming, and the degree of probability of jamming being effectively applied to Shoran was studied by appropriate committees during its development. The conclusion reached was that jamming would be difficult and would entail the use of very high-power jammers. Shoran was operated for short periods only and it was probable that ground transmissions could be detected only from the air, depending on the distance of ground stations from enemy territory. The ground equipment could not be jammed from the ground. Jamming would have to be carried out from aircraft and would require a transmitter of high mean power, or entail flights over hostile territory, and the

[1] C.R.B. 44/1388. Quarter-wave wide-band vertical aerials were used.

frequencies could easily be shifted over a frequency band of 30 megacycles per second. By placing the receiving aerial above the fuselage the pick-up in a downward direction was considerably reduced, and ground jamming transmitters would therefore require very high power to be effective against aircraft. It was possible for up to 20 aircraft to interrogate simultaneously a single pair of ground stations. The pulse recurrence frequency of aircraft transmissions was scrambled, by means of the commutator, between the periods during which the transmitters were operating. Thus, although the ground transmitter replied to all aircraft on the same frequency, the pulses received by a particular aircraft, except those originated by its own transmitter, moved rapidly around the time-base. There was, therefore, no danger of confusion, and the unwanted pulses caused little interference.[1]

The function of a Shoran ground station, AN/CPN2, was to receive, amplify and retransmit pulses originated by aircraft, and its equipment consisted basically of a specially designed receiver and transmitter. As well as being amplified for retransmission, pulses were reshaped to overcome distortion and were transferred to a different frequency. Corrections were also made for the time-delay which pulses underwent during reception and retransmission, and a frequency check service was supplied so that air operators could set the master timing frequency on which the accuracy of distance readings depended. All units were designed so that they could be removed from their mountings and transported by air, and aerial masts and arrays could be erected by two men of no especial skill. The ground stations operated in the frequency band around 300 megacycles per second, and range was limited to just more than optical range.[2] Their siting was therefore strictly governed by the geographical location of the area over which it was planned that aircraft working with them should operate, and it was important to ensure that the aircraft would be within ultra-high-frequency radio range, at their operational heights, of both ground stations. It was also necessary to ensure that the drift and rate stations were so located that the angle from the aircraft to them was neither too large nor too small, the optimum being about 90 degrees, although for bombing it was practicable to work between 30 and 150 degrees. Ground station operators required but little training, and one person could manage a station which operated only intermittently. His work consisted mainly of switching the equipment on and off according to a pre-arranged schedule, servicing a generator, and carrying out simple tests and adjustments. The aircraft installation was more complex to service and to operate, and 20 hours' flying training was considered to be necessary before proficiency was attained.

Trials and Training

Flight trials were conducted in Florida in February and March 1944. The ground stations were first located at Boca Raton and Hendricks Field on very carefully surveyed sites. The base-line was approximately 130 miles, running roughly north and south. After initial tests had been carried out and operating experience gained, with aircraft flying at ranges between 50 and 80 miles, the ground station at Boca Raton was moved to Homestead Field for bombing trials. The target used was Memory Rock, a small piece of rock about 30 feet in

[1] C.R.B. 44/1388.

[2] Approximately 170 miles at 15,000 feet and 250 miles at 30,000 feet.

radius, situated 143 miles from Hendricks Field and 128 miles from Homestead Field, the angle of cut being 66 degrees.[1] Results indicated that the probable error in distances measured was not more than 50 feet, and 50 per cent of bombs were dropped within 225 feet of the target. The preliminary report on early trials stated that '. . . the results obtained in flight tests were extremely satisfactory and, it is believed, indicate that the equipments have greater precision than any previously employed for the particular tactical application . . .'[2]

Operations which necessitated conditions in which bombs could be aimed visually were severely restricted by bad weather during the winter months of 1943/1944 in the areas covered by the Mediterranean Allied Air Force. Although numerous attempts had been made to develop systems for bombing through overcast, none had been sufficiently accurate to meet tactical requirements.[3] Consequently, reports received early in 1944 of the progress being made with Shoran experiments aroused interest at Headquarters M.A.A.F., and in March 1944 a pilot was sent to Florida to observe the flight trials and demonstrations. As a result, in June 1944 the United States Twelfth Air Force requested the provision of sufficient Shoran equipment to enable the 42nd Bomber Group (M) to carry out operational trials in Corsica. At the same time Headquarters M.A.A.F. asked for 10 aircraft installations and two ground stations to be supplied on a crash programme basis for employment in operations should results of the trials prove acceptable. No signals personnel were available in the M.A.A.F. for training in Shoran, and sufficient technical assistance to enable the aircraft installations to be serviced was also required.[4] The requests were approved and arrangements were made for one Fortress equipped with Shoran and two ground stations to be sent from the United States in August 1944 so that preliminary training and trials could be undertaken in the Mediterranean theatre of operations, and delivery of the additional equipment and personnel in October 1944 was tentatively promised.

A Shoran demonstration unit, complete with equipment, arrived in a Fortress aircraft at Casablanca early in September 1944 and was sent to the 310th Bomber Group base at Ghisonnaccia in Corsica. One ground station was set up there on 11 October 1944 and preliminary flights to check coverage were made during the following day. The second ground station was set up at Lido di Roma in Italy on 17 October 1944, and two days later demonstrations and trials were staged. The bombing target was the Isle d'Affrica, a rock roughly 250 feet long in the Tyrrhenian Sea, 40 miles from one station and 122 miles from the other. Photographs taken of the fall and strike of bombs confirmed that of the first six dropped, three were direct hits and three were near misses, and it was considered that the immediate training of Fortress crews, in teams of pilot and bombardier, was more than justified.

At that time, however, a training programme in the midst of intensive operations presented a problem and it was essential that a training organisation for both air and ground operators should be set up in the United States of America as soon as possible. Training in the M.A.A.F. from October to December 1944 could only be carried out by allowing crews to use Shoran whilst under supervision of qualified personnel. When such training had been

[1] C.R.B. 44/1388. [2] C.R.B. 44/4288. [3] A.H.B./IIJ/11/18.
[4] M.A.A.F. O.R.B. Appendices, 1944.

completed, preparations were made for the operational use of Shoran. So that the first raid could be made against an undefended target the ground stations were resited, one at the tip of Cap Corse in Corsica, and the other about 25 miles north of Florence.

Operational Use by United States Army Air Force[1]

Shoran was first used operationally on 10 December 1944 when four formations of six Fortresses, each box led by an aircraft equipped with AN/APN3, bombed Fidenza railway bridge on the Bologna-Piacenza railway. In order that the potentiality of the system might be better demonstrated to the participating crews, an effort was made to time the raid so that the target would be clear of clouds. However, although visibility was good a few miles south of it, the weather over the target itself was completely overcast. The attack was a failure because each of the aircraft equipped with Shoran erred in one way or another on the initial bombing run.[2] One bombardier had used an incorrect rate, another failed to determine true altitude correctly, and signals from one of the ground stations faded during a run-in, a fault which could have been avoided if the aircraft had operated at a higher altitude. Not all the errors were large, however, and some hits were obtained. Photographs taken after the attack indicated that the bridge was '. . . possibly passable to single line traffic . . .'.

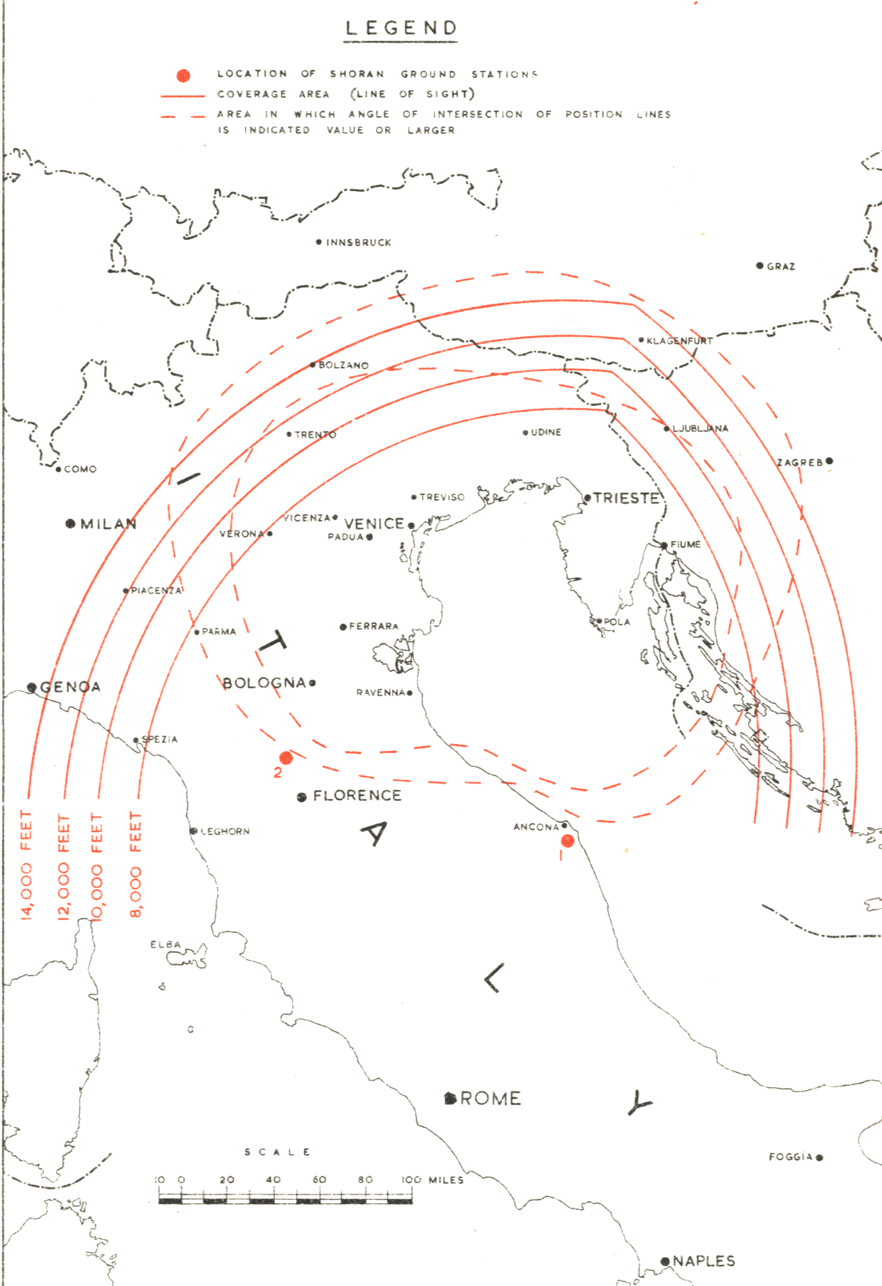
Action was taken to eliminate similar errors before the next attack, which took place on 14 December 1944 against a railway bridge at Parma West. Similar box formations were used and the performance of AN/APN3 was satisfactory in each of the four leading aircraft. Visibility over the target was variable, and the raid was successful. Results were much nearer those anticipated, four spans of the western end of the bridge being cut. During the next few days further sorties were flown against similar targets, and an ammunition dump at Bologna was hit by extremely accurate and well-concentrated bombing through ten-tenths' cloud on 15 December. The Cap Corse station was then resited just south of Ancona on the east coast of Italy in order to achieve coverage over the eastern end of the Po valley. An attack on 31 December 1944 against the Canale D'Isonzo bridge in north-eastern Italy provided the Shoran system with a serious test. In theory an increase in range should not have affected accuracy but in practice it had been found that beyond a certain distance accuracy deteriorated. On this occasion the range of 175 miles proved to be well inside the limit, and the approach to the important bridge was cut and one span completely destroyed.

Up to the end of December 1944 thirty-one sorties had been flown on ten operations, seven of which were considered to be successful. As with all new techniques, mistakes were made, and an acute shortage of equipment existed. It was considered that if errors could be eliminated to such a degree that results similar to those of the raid against the Parma West bridge could be consistently obtained, the effectiveness of tactical bombing could be notably increased. The advantages conferred by use of Shoran were already sufficiently apparent to ensure support of a proposal that all aircraft of the 57th Bomber Wing,

[1] This account of the use of Shoran by the U.S.A.A.F. is included so that its value as a blind-bombing system might be assessed. The R.A.F. was eager to exploit its many advantages but shortage of time and equipment limited its use to a few operations by the Desert Air Force.

[2] A.H.B./IIJ/11/18.

SHORAN COVERAGE ITALY
DECEMBER 1944



consisting of the 310th, 321st and 340th Bomber Groups, should be fitted with AN/APN3. With it, effective attacks against very small targets were not dependent on the extent of visibility over the targets. Losses were likely to decrease as the enemy anti-aircraft guns were forced to rely completely on radar control with the consequent lessening of their efficiency. Close support could be given to the Allied armies even when the sky was completely overcast, and enemy ground troops could be forced into inactivity in spite of what in the past had been helpful cover for them. Accurate bombing was possible at night. Navigation to and from, and identification of, the target was simplified, and the risk of bombing the wrong target was minimised. Aircraft of the 310th Bomber Group in which Shoran had been installed were allocated one to each squadron and were used as formation leaders. Against such small targets as bridges six aircraft released bombs when the leaders bombs were seen to fall, and against such targets as supply dumps 18 aircraft did the same. In order that greater concentration might be achieved radio directional bomb-control equipment was modified for use as an automatic radio-controlled bomb-release, by means of which the bombs carried by all the aircraft in a formation were released at the same instant as those of the aircraft equipped with Shoran, and an installation programme was completed as rapidly as possible. Other improvements were also made. A limitation of the Shoran technique was that approach routes to a target were limited to four directions, either way around each of the two circles, a factor which rendered diversion from heavily-defended areas more difficult. At that time the only remedy was the provision of more ground stations, although a computor was being designed to enable approaches to be made from any direction in any wind conditions.[1]

Two additional ground stations arrived in December 1944 and were located in Corsica, one at Ghisonnaccia and one at Cap Gorse. The four stations operating in suitable pairs provided good coverage over the entire Po valley. Air transport priority was given to another pair of ground stations and additional aircraft installations, and arrangements were made for another bomber group to operate with Shoran. However, at the end of January 1945, operational use of the system was stopped for two weeks after a run of unsuccessful sorties due mainly to a lack of trained crews. The timing and computor units had many associated controls and, despite the fact that many of them could be pre-set, failures were occurring because of operating faults. The remedy was, as had been found with H2S and A.S.V., constant and regular training.[2] A twelve-day period of intensive training from 2 to 11 February followed the cessation of operations, and targets were again successfully attacked on 12, 13 and 15 February.

By the time the final ground offensive was launched in April 1945 much thought and study had been applied to Shoran technique and the system had been considerably expanded. In addition to the tactical methods used for the early Shoran operations, a third method was used, in which the formation consisted of 24 aircraft, of which two carried AN/APN3 and acted as bomb-aimers for a flight of 12 aircraft. When all the factors of manoeuvrability, dependability, safety and efficiency were taken into consideration it appeared that the best tactical method was the employment of a minimum of two, and preferably three, aircraft equipped with AN/APN3 in a formation of 18 aircraft. During intensive operations carried out in the battle area by aircraft of the

[1] C.R.B. 44/1388.

[2] A.H.B./II/69/243.

57th Bomber Wing from 9 to 18 April 1945, Shoran was employed in approximately one-third of the raids made against enemy troop concentrations. Aircraft equipped with AN/APN3 led 443 sorties, and the results obtained clearly proved the value of the equipment.[1] Experience in Italy showed that with it a great increase in the scope of operations was made possible. In flat, open country it was often extremely difficult to find good identification and aiming points for visual bomb-sighting. With Shoran, aiming points could be selected solely for their value as targets, since it was not necessary to bear in mind the problem of identification. Also, it enabled targets to be attacked again very shortly after the completion of previous raids, when dust and smoke would normally have made aiming with visual bomb-sights very difficult, if not impossible. Although the accuracy of Shoran was such that bombing very near the Allied front line was possible, no attacks were made within two or three miles, and crews were briefed to bomb only when no doubt existed about the accuracy of the approach run. This policy was responsible for four operations being abortive, but considerably lessened the risk of bombing casualties being inflicted on Allied troops.

Attention was turned to the possibility of using Shoran in the North-West Europe theatre of operations shortly after the formation of the United States First Tactical Air Force. In the autumn of 1944 the lack of a navigation or precision bombing radar system for its 42nd Bomber Wing became a matter of primary importance, particularly in view of the approaching winter with bad flying conditions. By 11 November 1944 the First T.A.F. had formulated an operational requirement for Shoran on a basis of three aircraft installations per squadron and six ground stations. Meanwhile the United States Ninth Air Force, attracted by certain inherent advantages held by Shoran over Oboe, also planned a Shoran programme, which was finally formulated on 11 December 1944. The question of priority of supply of what little equipment was available immediately arose, and eventually it was decided that the First T.A.F. should be equipped first.[2] Equipment began arriving from the United States in the latter part of January 1945, and a training organisation for mechanics, ground operators, and bomber aircrews was set up in the south of France. Operations with Shoran were begun by the First T.A.F. in March, and by the Ninth Air Force, on a small scale, in early April.

Operational Use by Royal Air Force

In October 1944, Headquarters Desert Air Force, anticipating that weather conditions during the winter months would considerably curtail effective employment of medium-bomber forces, suggested to Headquarters Mediterranean Allied Air Forces that some form of radar should be provided to enable attacks to be made when conditions were such that, although operations were practicable, the target was partially or totally obscured by cloud.[3] The bomber component of the Desert Air Force was considered to be sufficiently powerful to justify equipping it with one of the more advanced radar bombing systems, such as Gee-H or Shoran, but the Air Officer Commanding D.A.F., acting on the assumption that such equipment would not be immediately available, had ordered that investigations should be undertaken into the possibilities of

[1] *See* Table No. 10.
[2] A.H.B./II/69/243 and A.H.B./IIE/159.
[3] A.H.B./IIJ1/122/83/6B. Employment of Light Bomber Force.

improvising radar equipment already in Italy.[1] Meanwhile, on 8 November 1944, Headquarters M.A.A.F. emphasised to the Air Ministry the extreme importance of providing the Desert Air Force with facilities to increase the effectiveness of tactical bombing. Experiments were being made with a modified SCR. 584, on loan from the U.S.A.A.F., in the control of tactical bombing at very short ranges by fighter-bomber aircraft, but there was no means of meeting requirements for light or medium-bomber aircraft operating at more than very short distances behind the front line.[2] The provision of Shoran was therefore requested, especially in view of the fact that it was also being asked for by the United States Twelfth Air Force, and it was obviously more practicable and economical for both air forces in the one theatre to use the same type of equipment. In addition, shortages and the need for meeting existing commitments made the supply of Gee-H to the M.A.A.F. very uncertain. Later in the month it was decided to install Shoran in Marauder aircraft of the Desert Air Force and 60 sets of AN/APN3 were allocated for the purpose, together with four ground stations. An installation programme to ensure that leaders and deputy leaders of bombing raid formations were able to use Shoran, whilst surplus equipments were held in reserve, was proposed.[3] However, the rate of production of AN/APN3 was slow, and the first two of the 60 equipments did not leave the United States until the beginning of February 1945.[4]

By then a re-allocation of equipment had been made, and only 12 installations were to be made available, in addition to the four ground stations, to the Desert Air Force because of the difficulties encountered during manufacture and the very urgent requirements of the United States Twelfth Air Force. Delivery was given high air transport priority and an installation programme for Marauder aircraft of No. 3 (South African Air Force) Wing was arranged. It had originally been planned that a limited number of R.A.F. personnel were to be given Shoran training in the U.S.A. but because of the urgency of the programme and the relatively small number of people involved, training was undertaken locally. An R.C.A. technician was attached to the Desert Air Force to assist with installation and servicing, and one officer and eight airmen attended the United States Service Command ground mechanics' training school. No. 3 (S.A.A.F.) Wing carried out tactical training in Corsica with the 57th Bomber Wing, and was placed under operational control of the latter on 2 April 1945.[5] On 16 April the wing flew on its first operation with Shoran. The raid was only partially successful, but direct hits were obtained on its second operation carried out on the following day when, according to Headquarters' D.A.F. reports, the target was totally destroyed. The raids were made against targets in the battle area of the 8th Army during a period when the front was beginning to collapse. On 19 April four Marauder aircraft, using Shoran, effectively attacked a road bridge, and four days later 12 aircraft attacked another road bridge at Sandon, but on that occasion completely missed the target. Another raid was forced to resort to visual bomb-aiming because the Shoran equipment failed. By 28 April the front line had become too fluid to enable radar control to be used for bombing near troop concentrations, and hostilities ceased before Shoran could again be used.

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[1] SCR. 584 and radar stations Types 14 and 15.
[2] A.M. File CS.24015.
[3] A.H.B./IIJ1/122/83/6B.
[4] A.M. File C.25601/45.
[5] D.A.F. O.R.B. Signals Appendices, January–April 1945.

In February 1945 it had become obvious that the enemy was trying to jam the Oboe system and as an insurance against the possible loss of Oboe for precision bombing Headquarters Bomber Command raised an urgent requirement for the installation of Shoran in one squadron of Mosquito aircraft of the Pathfinder Force. Consequently a further reallocation of equipment was planned but owing to the slow rate of provision the war had ended before Shoran could be brought into operational use by Bomber Command.[1]

[1] Two AN/APN3 equipments arrived early in April, of which one was sent to the T.R.E. Two ground stations were received at the same time. One was installed at the Oboe Mark I station at Winterton and the other installed in a vehicle as a prototype mobile installation. (A.M. *File* C.25903/45.)

CHAPTER 11

RESPONDER BEACONS

Responder beacons were small ground radar installations which, although switched on, were silent until interrogated or challenged by an airborne radar equipment. The beacon then responded to such stimulus by transmitting a coded signal by means of which the aircraft could measure its exact range from the beacon and could home to it. The use of radar responder beacons originated in a suggestion by Dr. F. C. Williams of the Air Ministry Research Establishment towards the end of 1939 that modified aircraft I.F.F. equipment should be used as ground installations which, when used in conjunction with an airborne interrogator, would provide homing facilities.[1] At that early stage in the war such facilities were required by Coastal Command aircraft equipped with A.S.V. Experiments with an I.F.F. set modified to serve as an A.S.V. beacon by the A.M.R.E. proved so successful that Headquarters Coastal Command asked for similar installations to be made at several stations. This early small requirement was met by modifying I.F.F. sets. In the autumn of 1940 the T.R.E. designed a successful beacon to work with A.I. in Fighter Command. These early beacons proved useful but were not suitable for protracted use or large-scale installation. When in April 1941 Headquarters Fighter and Headquarters Coastal Commands asked for a greatly increased number of beacons for installation at airfields, the T.R.E. put forward suggestions for improved final-type A.S.V. and A.I. beacons. Development and production of the final-type beacons was a slow process and to meet the urgent needs of Fighter and Coastal Commands interim beacons, modified I.F.F. sets, were installed at a number of airfields in 1941. These gave good service but in April 1942 their replacement by final-type beacons began. The chief disadvantage of this beacon system was its lack of standardisation; Fighter and Coastal Commands had individual beacons built to respond to the particular radar equipment installed in their aircraft. This meant that homing and navigation facilities available to aircraft of one command were denied to aircraft of another. The T.R.E. therefore recommended the adoption of a standard beacon operating on a centimetric wavelength. This was agreed and development of the Separate Band Beacon was begun in May 1942. It was combined with research on I.F.F. Mark V and the equipment was known as I.F.F. Mark V/U.N.B. (United Nations Beaconry). Development work on the scheme was transferred to the U.S.A. and continued until it was abandoned in September 1945. Even when development was still in progress it was realised that considerable time would elapse before operational use could be made of the system, and in November 1944 it was decided to adopt Eureka Mark II as the standard homing beacon for all commands. Variants of the beacon were developed to operate on different frequencies and by the end of the war Eureka was gradually replacing A.I.

[1] T.R.E. Monograph, ' Radar Interrogator Beacon Systems '. For details of I.F.F. *see* Royal Air Force Signals History, Volume V : ' Fighter Control and Interception'.

and A.S.V. beacons. The abandonment of the U.N.B. project in 1945 was responsible for a post-war policy decision that Eureka should be the final standard homing beacon used in conjunction with the airborne interrogator Rebecca Mark IV. The use of centimetric aircraft radar stimulated development of centimetric beacons and by August 1943 some stations in Fighter Command were equipped with these beacons for use by aircraft fitted with centimetric A.I. Centimetric A.S.V. beacons were not produced on a large scale in the United Kingdom. The policy in Coastal Command was to fit metric interrogators in all aircraft. Where it was necessary to install centimetric beacons for use by American aircraft, supplies were obtained from the U.S.A. The beacon programme overseas was similar to that in the United Kingdom. Interim A.I. and A.S.V. beacons were installed first and were then replaced by final-type beacons which were eventually superseded by Eureka Mark II.

Early Development

When the possibility of using modified I.F.F. in conjunction with airborne radar for navigation and homing was first suggested, the I.F.F. system then existing involved the use of a small airborne apparatus which was a combined receiver and transmitter. The receiver portion picked up the pulses radiated by a ground transmitter and caused them to actuate the transmitter portion which then radiated, on the same wavelength, a pulse similar in shape to that received. The radiated pulse was received at the ground station superimposed on the normal radar response from the aircraft, which was several times weaker than the I.F.F. response.[1] The proposed use of I.F.F. equipment as homing beacons consequently meant a reversal of the procedure used for identification ; the I.F.F. set would be used on the ground and the aircraft search or interception equipment, A.S.V. or A.I., would enact the role of the transmitter and receiver.

A beacon was built at the A.M.R.E., Dundee, from an I.F.F. receiver driving a Metropolitan Vickers A.I. transmitter. The receiver received pulses emitted by an A.I. or A.S.V. transmitter fitted in an aircraft and used the received signals for triggering the ground transmitter working on the same wavelength. The pulses radiated by the transmitter were then received by the aircraft installation and gave an indication on the cathode ray tube similar in shape to that received as an echo from an aircraft or ship. As the time-lag in the receiving/transmitting process at the ground apparatus was negligible, a direct measure of the distance of the aircraft from the ground station or beacon was readily obtained from the range-scales.[2] By means of the D/F facilities provided in the A.I. or A.S.V. installation the aircraft could home to the beacon. The success of tests at Dundee stimulated interest at Headquarters Fighter Command, Headquarters Coastal Command, and at the Admiralty, in the possibility of using such I.F.F. ground beacons, modified to work on A.I. or A.S.V. frequencies, for navigation and homing purposes.[3] On 29 December 1939 the A.M.R.E. requested the Air Ministry to sanction development and manufacture of responder beacons, since aircraft equipped with A.I. operated from Manston, Martlesham, and Debden, while aircraft

[1] M.A.P. File SB.2456.

[2] M.A.P. File SB.2456.

[3] Until the introduction of H2S in 1943 aircraft of Bomber Command were not fitted with a radar system for interrogating beacons.

equipped with A.S.V. were expected to be operating from Leuchars and Pembroke Dock by the end of the year. Beacons giving homing and navigation facilities would be useful at those places.[1] Between January and April 1940 the development of A.S.V. beacons continued at sections of the A.M.R.E. at Dundee and St. Athan and a homing beacon was evolved at each establishment. That developed at Dundee was simpler but of lower power and was ideal for production in quantity for use with A.S.V. During those months several flight trials were carried out with the Dundee beacon, used both as a ground and as a ship installation, and ranges of about 30 miles with aircraft flying at 2,000 feet were obtained.[2] The experimental beacon was moved to Leuchars in April 1940 and the results of trials held there impressed Headquarters Coastal Command so much that on 27 April 1940, in spite of the fact that the beacon was still only in the experimental stage, the Air Ministry was requested to provide similar beacons at Leuchars, Thornaby, Bircham Newton and Wick. Beacon installations were also required at Pembroke Dock, Mount Batten, and Sullom Voe because, although at that date one Sunderland flying-boat only was fitted with A.S.V., others were being fitted and would require the homing facilities provided.[3] On 5 May 1940 the Ministry of Aircraft Production instructed the A.M.R.E. to design and build beacons for installation at the stations selected in Coastal Command. The A.M.R.E. agreed to supervise the design of the beacons but, because production and installation would seriously delay its research programme, suggested that a suitable contract be placed with the firm of Ferranti. The Air Ministry therefore placed a small development contract, for eight sets, with Ferranti on 10 June 1940. This was later increased to 16 sets, the first eight to operate on a frequency of 214 megacycles per second, the A.S.V. Mark I frequency, and the final eight on a frequency of 176 megacycles per second, the A.S.V. Mark II frequency.[4] Although the Air Ministry in May 1940 expected that the installation of beacons at the stations named by Headquarters Coastal Command would be rapidly completed, in October 1940 there was still only one beacon operating, and that was the experimental one at Leuchars. On 7 October 1940 Headquarters Coastal Command stressed the urgent need for immediate provision of beacons because the facilities they afforded were even more essential with the approach of winter weather conditions. The delay in beacon installation was due to the poor quality of beacons produced during the summer of 1940. Eight sets were manufactured by Ferranti but when tested at the R.A.E. in October 1940 were found to be unsatisfactory and in need of considerable modification.[5] Slowness in producing an aerial system was an additional factor in the delayed installation programme. The first prototype beacon was delivered in December 1940 and was installed at Bircham Newton for flight trials; performance was satisfactory. Another beacon was installed that month at Limavady. By the end of April 1941 A.S.V. beacons were installed at Limavady, Lough Erne, Carew Cheriton, Bircham Newton, Dyce, Wick, Oban, Thornaby, and at a site in Iceland. Some operated on 214 megacycles per second and others on 176 megacycles per second. The former type were regarded as of temporary value only while A.S.V. Mark I was still in use.[6]

[1] A.M. File CS.16810. [2] M.A.P. File SB.2456. [3] A.M. File S.4540.

[4] *See* Royal Air Force Signals History, Volume VI: 'Radio in Maritime Warfare', for details of A.S.V.

[5] A.M. File S.4540. [6] M.A.P. File SB.2456.

Meanwhile, experiments were made to supply similar beacon facilities for Fighter Command aircraft using A.I. The success of the A.S.V. beacon stimulated attempts by the T.R.E. and the Fighter Interception Unit, Ford, to construct an A.I. beacon in the autumn of 1940. One set was made consisting of a transmitter on the A.I. frequency with a clockwork switching attachment which allowed the transmitter to be on for 3 seconds in every 25 seconds. Air tests were held but the beacon was found to be unsatisfactory because no estimation of range could be obtained. Later that autumn the T.R.E. produced a special I.F.F. beacon, known as ' Cockerel ', and after trials at the F.I.U., it was installed at Middle Wallop for use by No. 604 Squadron equipped with Beaufighter aircraft fitted with A.I. Mark IV. The beacon was unsatisfactory in operation because the frequency swept from approximately 190 to 200 megacycles per second, the signal being received momentarily every six seconds. The sweeping mechanism was therefore removed and the beacon set on a frequency of 193 megacycles per second. Considerable improvement resulted and ranges obtained were about 80 miles with aircraft at 10,000 feet.[1] By the end of April 1941, A.I. beacons were installed at Middle Wallop, Tangmere, Digby, Church Fenton, Wittering and Acklington.[2] They were improved versions of the original T.R.E. ' Cockerel,' being converted I.F.F. Mark IIG sets. An indication appeared to the operator for 1½ seconds in every 6 seconds.[3]

Development of Metric A.S.V. and A.I. Beacons

Both A.S.V. and A.I. beacons proved so valuable as homing aids in Coastal and Fighter Commands that requests were made for an increased number of installations. In April 1941 Headquarters Coastal Command stated an urgent requirement for 30 additional beacon installations, and Headquarters Fighter Command asked for homing beacons at approximately 25 stations. At a conference at the Ministry of Aircraft Production on 23 April 1941 it was reported that the performance of the original A.S.V. beacon was satisfactory but the type was not suitable for full-scale production and presented many servicing difficulties. Headquarters Coastal Command was not satisfied with its coding and detailed construction. The T.R.E. therefore recommended, as a result of progress made with experimental A.I. and A.S.V. beacons during the preceding three months, that the A.S.V. beacon requirement be met by an equipment constructed in two units to contain respectively a transmitter/receiver using the I.F.F. Mark III circuit with the frequency sweep removed, and a mains power pack, and advised that accessory emergency equipment should also be provided. One problem encountered in early beacon development was the provision of some form of identification. The establishment of a chain of beacons all over the country necessitated some means of differentiation between neighbouring beacons. The identification was provided by means of coding. Headquarters Coastal Command considered that a continuous signal beacon should be provided, but the T.R.E. recommended that coding should consist of about 20 seconds of continuous signal followed by 10 seconds during which a Morse signal was flashed, the Morse dot lasting ⅓ second and the dash 1⅓ seconds, a system known as ' gap ' coding. The T.R.E. also submitted proposals for a final A.I. beacon. It was not possible to use the I.F.F. type of

[1] A.H.B. II/54/85. R.D.F. Beacon Panel Minutes of Meetings.

[2] M.A.P. File SB.2456.

[3] A.H.B. II/54/85.

circuit for an A.I. beacon because of the more stringent requirements of the strobe circuits proposed for A.I. Mark VIA. The T.R.E. suggested that it should consist of four units, transmitter, superheterodyne receiver, modulator and power supply. 'Gap' coding had been used in the early A.I. beacons but was considered no longer suitable as a means of identification because, with the introduction of the Pilot's Indicator in A.I., it was necessary for pilots of single-seater aircraft to be able to home to the beacon. The method of coding evolved by the T.R.E. was achieved by variation of the pulse width, the coding cycle being 20 seconds of continuous narrow pulses followed by 10 seconds of Morse indicated by a wider pulse. This was known as 'width' coding.[1] At the date of the conference functional prototypes at the T.R.E. had given satisfactory performance but neither beacon was in production.[2]

It was obvious that development of suitable A.I. and A.S.V. beacons would take time and interim beacons were needed to fulfil immediate requirements of the operational commands. It was therefore suggested that I.F.F. Mark IIG sets, modified to the design of the T.R.E., be used until final beacons were in production. The interim A.I. beacon, known as TR.3110, was arranged to receive and transmit on different frequencies. It was battery-operated and a coding device was included. A simple aerial system of vertical dipoles was needed as an addition to the I.F.F. set. The interim A.S.V. battery-operated beacon, known as TR.3111, consisted of I.F.F. Mark IIG equipment modified to receive and transmit on the same frequency and to include a coding device. Production contracts for 50 A.I. and 60 A.S.V. interim beacons were placed with the firm of Cossor in May 1941 and delivery was expected to begin the following month.[3] By May 1941 work on the final type beacons had proceeded so well that development contracts for the manufacture of three prototypes of each beacon were placed with the firm of Murphy. Production contracts for 100 A.I. and 120 A.S.V. beacons were placed, provisioning being on the scale of one main and one standby equipment for each site, plus 100 per cent spares.[4] On 21 May 1941 technical supervision of the manufacture and installation of the beacons, both interim and final, was undertaken by the R.A.E. on the instructions of the Ministry of Aircraft Production.[5]

The provision of monitor units for both A.I. and A.S.V. beacons was important because the success of the beacon chain depended upon full efficiency. The T.R.E. developed a common form of interrogator type monitor. The monitors for the two beacons were identical except for the setting of the HF circuits which were tuned either to A.S.V. or A.I. frequencies. The apparatus consisted of a small variable frequency pulse transmitter, a simple receiver covering the same frequency band, and a cathode ray tube of about three inches diameter with a high speed time-base. The apparatus had its own aerial system and power supply.[6] In May 1941 a contract for 110 monitor units was placed with the firm of Marconi Ekco Instruments, the estimated cost of production being £11,000.[7]

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[1] M.A.P. File SB.2456. [2] A.M. File CS.16810.

[3] 120 I.F.F. Mark IIG equipments were diverted from the firm of Ferranti to that of Cossor for modification.

[4] The estimated cost of the A.S.V. beacons was £42,000 and that of the A.I. beacons £40,000.

[5] M.A.P. File SB.2456. [6] M.A.P. File SB.12116. [7] M.A.P. File SB.2456.

Production and Installation

During the early summer of 1941 progress was made with the beacon scheme. Increasing use was made of the temporary beacons and by the beginning of July 1941 the 16 original experimental A.S.V. beacons built by Ferranti were all installed and operating at Coastal Command units. Six temporary A.I. beacons were operating in Fighter Command and, in addition, the command had built some models from its own resources. Work on the interim beacon programme was not as speedy as had been anticipated, difficulties with the coding mechanism in both types being the chief cause of delay. By the end of June 1941 seventeen interim A.S.V. beacons had been delivered to the R.A.E. for preliminary testing before redistribution to beacon sites, and one prototype installation had been started at St. Eval. Sixteen interim A.I. beacons had been delivered to the R.A.E. for testing.[1]

In August 1941 Headquarters Coastal Command drew up a comprehensive scheme for the provision of A.S.V. beacons covering the west, north, and east coasts of the United Kingdom. In several places, to complete the screen, the chosen sites had to be located away from Coastal Command stations, at other RDF sites. During the winter of 1941/1942 Headquarters Coastal Command submitted to the Air Ministry priority lists of sites for final A.S.V. beacons. They were also required overseas, at Malta, Alexandria, Suez, Aden, Basra, Karachi, Trincomalee, and Singapore. These sites all required beacons operating on 176 megacycles per second but in December 1942 arrangements were made to provide a chain from Chivenor to Thorney Island via the Scillies of six responder beacons operating on 214 megacycles per second for the use of aircraft equipped with L.R.A.S.V. Headquarters Fighter Command also expressed its beacon requirements in August 1941. Homing beacons were required at all night fighter airfields at home and overseas, and patrol marker beacons at certain points to fill gaps left in the airfield chain.[2]

Installation of interim-type beacons proceeded during the summer and autumn of 1941. Although the first prototype interim A.S.V. beacon was installed at St. Eval at the beginning of June 1941, full flight tests were not held until September because of bad weather and operational activity. When flight tests were eventually held performance was found to be satisfactory. The first installation was carried out by members of the R.A.E. staff and thereafter by trained personnel from Coastal Command. The production of interim beacons continued to be steady and by the end of October 1941, 24 stations in Coastal Command had been supplied with A.S.V. beacons, either the original Ferranti experimental models or interim Cossor modified I.F.F. Mark IIG sets, whilst A.I. beacons had been installed at several Fighter Command airfields.[3]

The first prototype final-type A.S.V. beacon was delivered in November 1941 to the T.R.E., where laboratory tests were carried out. It was then installed at the Telecommunications Flying Unit, Hurn, where flight tests with Beaufort and Hudson aircraft were held. The beacon operated satisfactorily and full type approval was recommended, subject to certain minor modifications.[4] In February 1942 full type approval was given to the A.S.V. and A.I. beacons.[5] In April 1942 delivery commenced of the final-type A.I. beacons and by the following month the replacement of interim versions had begun. The final A.I.

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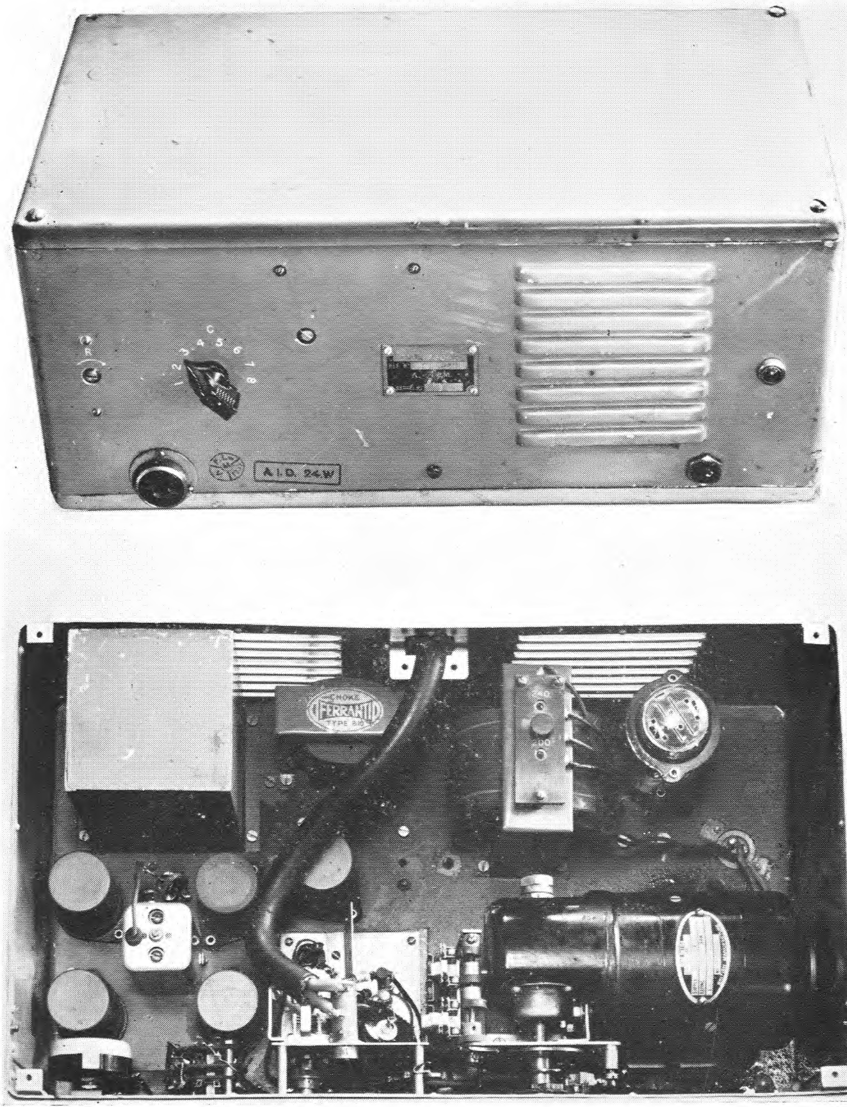
[1] M.A.P. File SB.2456.
[2] A.M. File S.4540.
[3] M.A.P. File SB.12117.
[4] M.A.P. File SB.2456.
[5] A.M. File CS.16810.



A.S.V. Beacon—July 1941

beacon was known as TR. 3107. It comprised a single-channel wide-band superheterodyne receiver covering 188 to 193 megacycles per second and two transmitters, one mains-operated and the second, provided as a standby, battery-operated. The transmitters used two valves Type VR. 135 giving 35-watt pulses on 195 megacycles per second; the duplicate transmitter also responded on 197 megacycles per second. The beacon was mounted on a six-foot rack and was mains operated from a 50-cycle AC supply. Up to 10,000 separate interrogating pulses per second could be accepted. With A.I. equipment operating at a pulse recurrence frequency of 800 cycles per second, up to 12 aircraft could interrogate the beacon at the same time. Coding of pulse width between 2 and 75 micro-seconds or gap coding by a neon-timed relay unit was available. Vertical polarisation was used, to conform with existing A.I. practice. The aerials were three separate vertical dipoles stacked above each other in order to obtain all-round reception. One aerial was connected to the receiver and one to each transmitter. Delivery of the final-type A.S.V. beacon also began in April 1942. This consisted of a super-regenerative receiver with automatic gain stabilisation. The receiver output triggered two oscillators, one of which gave a pulse about 25 micro-seconds long on 176 megacycles per second and the other a pulse about 10 micro-seconds long on 173·5 megacycles per second. The purpose of the 'off' frequency response on 173·5 megacycles per second was to provide aircraft with a beacon signal free from ground returns at short ranges up to about 20 miles. Up to 5,000 separate interrogating pulses per second could be accepted without over-interrogation being experienced. With A.S.V. transmitters operating on a pulse recurrence frequency of about 400 cycles per second, up to 12 aircraft could interrogate the beacon at the same time. The beacon was erected in a cabinet 3 feet 6 inches high containing the beacon itself, a neon-timed relay-operated coder which provided 'gap' coding, and a power pack of 50-cycle AC with a separate switch panel; its pulse power output was 8 watts. The aerial system was divided into two stacked arrays; one for reception and transmission on 176 megacycles per second and the other for transmission on 173·5 megacycles per second. Each array consisted of four horizontal driven elements and four reflectors.[1]

In June 1942 contracts for a further 180 A.S.V. and 70 A.I. beacons were placed. In that same month the Admiralty placed a contract for 20 A.S.V. beacons, modified to operate on 214 megacycles per second, in order to establish beacons for naval use at home and abroad.[2] A few months of operation of the final-type A.I. beacon showed that its performance was very satisfactory. In October 1942 it was reported that orders for it were being extended; 103 sets had been delivered and a contract was placed for a further 95 sets.[3] By June 1943, 180 final A.I. beacons had been produced and 76 installed at Fighter Command sites.[4] Operation of the final A.S.V. beacon was not so successful; its performance was poor and it required careful setting up. On 13 October 1942 the R.A.E. was instructed to investigate the reason for the failure and the firm of Murphy Radio was instructed to stop work on the beacon until the new TR unit Type 5 was available for incorporation. Again in November 1942 complaints were received of instability in operation. The R.A.E. recommended several modifications and advised that a superheterodyne, instead of a super-regenerative, receiver should be used. Investigation into the performance of

[1] A.H.B./II/54/85. [2] M.A.P. File SB.2456. [3] A.H.B./II/54/85.
[4] A.M. File CS.19143.

the beacon was also undertaken at the T.R.E. Further modifications were advised.[1] In December 1942 it was decided that the 'off' frequency response on 173·5 megacycles per second was not necessary or desirable. Therefore the 'off' frequency aerials and feeders were deleted from the installation. The 'on' frequency pulse width of 20–30 micro-seconds was considered excessive and it rendered accurate short-range homing impossible. It was agreed that the 'on' frequency pulse width should be reduced to 7–10 micro-seconds.[2] By January 1943 120 A.S.V. beacons had been delivered but only five had been installed because of their poor performance; others awaited modification before installation.[3] Trials of the beacon modified in accordance with the recommendations of the T.R.E. and the R.A.E. were held at the T.F.U., Defford, and at a meeting at the Air Ministry on 6 February 1943 it was reported that the R.A.E. modifications had resulted in the better range performance. It was therefore decided that these be incorporated. However, performance of the beacons continued to be the subject of complaints and in May 1943 R.A.F. Wick reverted to the use of the interim type in preference to the final type. On 16 June 1943 R.A.E. representatives visited Wick to try to discover the cause of poor performance. Flight tests using Anson aircraft from the B.A.T. Flight, Leuchars, were made. The main trouble was found to be due to poor setting up of the aerial systems and the R.A.E. recommended that whenever a final-type beacon was unsatisfactory in operation the aerial systems should be completely overhauled. A mismatched aerial system spoiled receiver sensitivity.[4] During the spring and summer of 1943 work at the R.A.E. was directed at producing an improved A.S.V. beacon. The improved version of TR. 3112, incorporating the R.A.E. improved TR unit, was known as TR. 3213. It was mains-operated and employed a superheterodyne receiver. It operated with A.S.V. Mark II but was not sensitive enough for SCR. 729 and Lucero. A contract for 263 sets was placed in the autumn of 1943.[5]

Installation of the experimental and interim beacons was carried out by personnel of the commands concerned under the supervision of the R.A.E. In March 1942, however, No. 26 Group was made responsible for beacon siting and installation although general direction was still exercised by the R.A.E. The final-type beacon installation consisted of a hut containing a mains-operated beacon, a standby (duplicate) beacon, a monitor unit and a standby power supply (battery). Three poles carried the aerial system for an A.I. beacon and four for an A.S.V. beacon.[6] In July 1942 it became obvious that the installation of responder beacons in Fighter and Coastal Commands was not proceeding satisfactorily. Considerable confusion existed as to the responsibilities of the various departments concerned. The final-type beacon programme was urgent because the interim beacons had been operating 24 hours a day for much longer than was originally intended and were beginning to wear out. A meeting was therefore held at the Air Ministry on 16 July 1942 to discuss the problem. It was agreed that the existing system whereby the Air Ministry gave approval and issued erection orders for each separate beacon site was too cumbersome. It was agreed that general instructions be issued by the Air Ministry; the stations concerned should choose the sites. These should be approved by command headquarters and notified to the Air Ministry. Works services were

[1] M.A.P. File SB.12117 Part II.
[2] M.A.P. File SB.12116 Part II.
[3] A.M. File CS.16810.
[4] M.A.P. File SB.12117 Part II.
[5] A.M. File CS.19143.
[6] A.M. File C.30400/46.

to be the responsibility of command headquarters. Technical installation was to be carried out by No. 26 Group. Servicing was to be the responsibility of local RDF personnel aided by visits by R.A.E. liaison staff officers at intervals of about six months. This scheme was adopted.[1] On 30 September 1942 arrangements for servicing were changed. Routine servicing remained the responsibility of station personnel; they were to carry out minor repairs including component replacement. Major servicing and repairs beyond unit capacity were entrusted to No. 26 Group.[2]

Separate Band Beaconry

The early development and use of responder beacons tended to be unco-ordinated; beacons were designed and manufactured on an *ad hoc* basis according to the type of aircraft installation with which they were to work. The original conception was that beacons were devices working in direct association with the main airborne search or interception radar installations in the 1½-metre band; their use was thus restricted to one type of interrogator. The early beacon scheme had many disadvantages. In the first place, it lacked flexibility in that aircraft of one command were unable to use the facilities provided by another. Secondly, the rapid development of many different forms of aircraft radar on frequencies varying from 47 to 10,000 megacycles per second rendered impracticable the existing plan of devising a different beacon to work with every type of aircraft installation. Thirdly, the introduction of I.F.F. Mark III covering the frequencies from 157 to 187 megacycles per second affected the existing beacon scheme because of the danger of overloading the wave-band. By the spring of 1942 radar beacons had outgrown their purely local application and some policy decision was required. On 11 March 1942 the RDF Board invited the Air Ministry to set up a panel to consider the problem of responder beacons and to make recommendations to the Board on the possibility of arriving at a comprehensive beacon policy. A Responder Beacon Panel was therefore set up and the first meeting was held on 8 April 1942 at which representatives of the Air Ministry, Admiralty, War Office, U.S. Navy, the T.R.E., R.C.A.F., Headquarters Coastal Command, and Headquarters Fighter Command were present.[3] It was stated that beacon facilities were required for aircraft fitted with A.S.V. and A.I. and surface vessels fitted with RDF. The T.R.E. opposed the existing scheme for developing a new type of beacon for each type of RDF apparatus and in a paper submitted to the panel in May 1942 recommended a final comprehensive beacon scheme in which the beacons operated on a frequency band set apart for that purpose. This scheme advocated by the T.R.E. was known as Separate Band Beaconry (S.B.B.). The wave-band suggested at that date was from 700 to 800 megacycles per second. The adoption of Separate Band Beaconry would confer two main advantages; first, a system of universal beacons and interrogators would enable aircraft of one command to use the homing and navigation facilities of the others; secondly the choice of a wave-band separate from that used by I.F.F. Mark III would avoid congestion of the interrogation services.[4] The T.R.E. considered that at that date RDF technique was sufficiently far advanced for a beacon of adequate power to be developed and that such a beacon could provide many facilities. These included homing to airfield beacons and transportable ground marker beacons, beam approach, navigation and blind bombing using two

[1] A.M. File C.16195/44. [2] M.A.P. File SB.12117 Part II. [3] A.H.B./II/54/85.
[4] A.H.B./II/54/85.

transportable ground beacons, homing to shipborne beacons, and homing to Rooster beacons installed in an aircraft.[1] As a result of discussions held at the second meeting of the Responder Beacon Panel on 13 May 1942 the panel recommended for consideration by the RDF Board the ideas submitted by the T.R.E., namely that a final universal beacon scheme operating on a separate band should ultimately be adopted for all craft requiring beacon facilities. As a suitable beacon required considerable technical development the panel proposed that the existing policy of individual beacons for each type of airborne apparatus should meanwhile be retained, and application be made to the Wireless Telegraphy Board for the frequency band 900 to 1,100 megacycles per second to be allocated for the exclusive use of responder beacons.[2] The RDF Board recommended adoption of the proposals to the Combined Co-ordinating Committee, who directed that the Aids to Navigation Committee should formulate a policy on the subject. In November 1942 the A.N.C. recommended that a universal beacon system be incorporated in I.F.F. Mark V. There was some difficulty in persuading the U.S.A. to combine Separate Band Beaconry with I.F.F. Mark V ; the U.S. Navy was particularly opposed to the scheme. The Ministry of Aircraft Production believed that I.F.F. Mark V was inseparable from S.B.B. and proposed that the name United Nations Beaconry be given to the project. Part of the difficulty experienced in obtaining agreement on the U.N.B. scheme lay in the opposing views held on I.F.F. The possibility that the enemy might obtain an I.F.F. Mark III equipment, manufacture exact copies, and install them in his aircraft and ships, thus confusing the whole identification system, was causing grave concern in the U.S.A., where proposals were made to abandon the I.F.F. Mark III programme in favour of the American system I.F.F. Mark IV. The British view was that the security of I.F.F. Mark IV was equally vulnerable operationally, and the British Chiefs of Staff were convinced that the highest priority should be given to the development and production of I.F.F. Mark V combined with U.N.B., and they thought that work on I.F.F. Mark IV should, if necessary, be abandoned.[3] The whole question was discussed by the RDF Board in January 1943 when it was considered that an integrated scheme was very important and suggested that scientists in the United Kingdom engaged on development of I.F.F. and research on S.B.B. should go to the U.S.A. to work under American direction on I.F.F. Mark V/U.N.B.[4]

The proposal was accepted and a team from the T.R.E. went over to the United States in 1943 and worked in conjunction with American scientists on the I.F.F. Mark V/U.N.B. research and development programme. In spite of expressed doubts of the wisdom of the scheme development continued throughout 1943, but by the middle of 1944 it became clear that, even with

[1] M.A.P. File SB.37282. *See* Royal Air Force Signals History, Volume VI : ' Radio in Maritime Warfare ', for details of Rooster.

[2] A.H.B./II/54/85.

[3] *See* Royal Air Force Signals History, Volume V : ' Fighter Control and Interception ', Appendix No. 11 for details of the I.F.F. Mark V scheme.

[4] Throughout 1942 the T.R.E. had continued experimental work on miniature responder beacons operating on frequencies of about 1,000 megacycles per second for the S.B.B. scheme. By November 1942 one had been developed which consisted of a super-regenerative receiver with automatic gain stabilisation and pulse amplifier stages driving a self-oscillator transmitter. An RF amplifier stage was used to isolate the transmitter from the receiver when a common aerial was used. It was intended that the beacon should rely on a miniature concentric triode valve then being developed at the G.E.C. laboratories.

increased priority, I.F.F. Mark V would not be available for use during the war. In September 1944 the Combined Communications Board recommended that I.F.F. Mark III should remain the universal identification system whilst research, development, and production of I.F.F. Mark V/U.N.B. were hastened. This policy was accepted by the Combined Chiefs of Staff but hostilities in Europe ended before I.F.F. Mark V/U.N.B. was ready for introduction. In September 1945 research work on the scheme ended.[1]

Standardisation and Installation of Metric Beacons

In the meantime, after a decision had been made in favour of a beacon system operating on an entirely separate band and while research on S.B.B. was progressing, an interim separate band beacon system had to be found. The Air Ministry continued to favour the provision of A.S.V. and A.I. beacons as homing and navigation aids for aircraft of Coastal and Fighter Commands, but the primary disadvantage of this scheme whereby aircraft of one command were denied the facilities of another was still effective. In May 1943 the wisdom of providing a universal homing beacon was again stressed and the Ministry of Aircraft Production recommended the general use of Eureka Mark II as an interim separate band beacon system. Eureka Mark II was a responder beacon normally used in conjunction with an airborne radar interrogator called Rebecca to guide aircraft to a selected spot where supplies for partisan organisations or parachute troops were to be dropped. Eureka Mark II appeared to have many advantages over A.S.V. and A.I. beacons. It was designed specifically for use as a beacon as opposed to equipment designed primarily for identification purposes. It had a high standard of frequency stability, and its efficient power unit gave longer duration of operation than was obtained with modifications of I.F.F. It had greater transmitter power and receiver sensitivity than the existing beacons, and it embodied five preset channels for transmitting and receiving which could be selected manually, whilst it was equally adaptable with suitable frequencies for use with A.I. Marks IV and V (193 megacycles per second), A.S.V. Mark II (176 megacycles per second), Mark VIII interrogator (183 megacycles per second), Rebecca Marks I, II and III (214 to 234 megacycles per second), and Lucero Marks I and II (173·5, 176, 214, and 219 megacycles per second), and it was readily adaptable for B.A.B.S. The introduction of Lucero as a metric interrogator with centimetric airborne radar increased the need for an improved beacon because the ranges obtained with Lucero against the early beacons were quite inadequate. A beacon with greater power and sensitivity was required, and Eureka was sensitive enough to fulfil operational requirements.[2] The development of B.A.B.S. was closely allied with that of beacons, and when in 1943 the T.R.E. began development of a universal wide-band B.A.B.S. suitable for all commands, complementary development of a beacon system was comparatively easy to fit in. There were, however, disadvantages in using Eureka Mark II in its existing form. It lacked any means of giving automatic coding responses for station identification. Existing coding

[1] A.M. File S.22841. In September 1945 the Inspector General's Air Traffic Control Practices Committee recommended that Eureka beacons of a suitable variety should be installed for standard use, in conjunction with Rebecca Marks II and IV modified to provide pilots' distance, homing and orbiting information, at all airfields provided with B.A.B.S. Mark II (A.H.B./IIK/85/94, Radar and W/T Ground Policy).

[2] A.M. File CS.19143.

facilities were for manual operation only so the addition of an automatic coding unit was essential. Also considerable development was required to provide one beacon unit operating on several frequencies, and for permanent installations a power unit was required to work from an AC mains supply.

A meeting was held at the Air Ministry on 21 May 1943 to discuss the standardisation of future 1½-metre beacon systems. A requirement for complete frequency coverage from 173 to 234 megacycles per second was stated. On 1 July 1943 the Ministry of Aircraft Production instructed the T.R.E. to proceed on top priority with the development of modifications and additions to Eureka Mark II for use as a homing beacon. As an interim measure, three versions were recommended, one for Fighter Command, one for Coastal Command and one for the Tactical Air Force. The T.R.E. considered it impracticable to use Eureka Mark II as a basis for development of one beacon to cover all requirements; such development would be lengthy as it involved the incorporation of several separate tuned circuits. Interim development of different versions of Eureka Mark II for use as homing beacons began at the T.R.E. in the summer of 1943; each equipment was modified to produce a single-frequency beacon. In August 1943 this work was sufficiently far advanced to enable a development contract to be placed with Murphy Radio. Type approval was given in October 1943 and in that month Masteradio were instructed to convert 200 Eureka Mark II on their production contract into transportable single-frequency homing beacons, using development models from Murphy Radio as prototypes.[1] One hundred of these were converted to operate on 176 megacycles per second (Eureka Mark IIC) for Coastal Command and 100 on 193 megacycles per second for Fighter Command (Eureka Mark IIF). Also, a further 205 Eureka Mark II were to remain on the frequency band 214 to 234 megacycles per second for installation as homing beacons for use with Rebecca and Lucero. These were installed at Bomber Command, Transport Command and Tactical Air Force locations. Another problem in the development of a standard homing beacon was the provision of an aerial system suitable for vertical and horizontal polarisation. The R.A.E. undertook experimental work on an aerial system in the summer of 1943. Finally a system was evolved whereby vertical polarisation for A.I. interrogation was obtained by dismantling the reflectors used on the A.S.V. array, rotating the dipoles through 90 degrees in a vertical plane, and moving the feeder connection which was common for either service.

By the autumn of 1944 the increasing operational use of homing beacons made the inherent disadvantages of the individual beacon systems even more apparent. Coastal Command and Fleet Air Arm beacons operated in the wave-band from 173 to 177 megacycles per second and used horizontal polarisation; Fighter Command beacons operated in the 190 to 197 megacycles per second band with vertical polarisation; Bomber Command, Transport Command and Tactical Air Force beacons operated on frequencies of 214 to 234 megacycles per second with vertical polarisation. By that time, too, considerable use was being made of I.F.F. Mark III and it was considered unwise to allow any transmissions to be made in that frequency band (157 to 187 megacycles per second) which were not directly essential for the identification system. The widespread use of 176 megacycles per second beacons and corresponding aircraft interrogator transmissions added to the clutter in the

[1] A.M. File CS.19143.

I.F.F. band. As a result of experience gained during development work on the use of Eureka Mark II as a universal homing beacon the T.R.E. suggested in October 1944 that all beacon systems be transferred to the 214 to 234 megacycles per second frequency band. This meant that beacons being used in Fighter and Coastal Commands and in the Fleet Air Arm would need to be replaced and aircraft equipment would have to be made capable of interrogating the new beacons. The T.R.E. considered that if one band was used for all beacon purposes, the development of a single installation for beam approach would be much easier. At a meeting at the Air Ministry on 25 October 1944 the requirements of the various commands for beacons in the 1½-metre band were discussed. The general opinion was that a standard beacon system in the 214 to 234 megacycles per second band should be adopted. In that band 20 channels were available if the various combinations of the five transmitting and receiving frequencies were used. Six ground installations, B.A.B.S. and beacons, could be operated in a circle of 10 miles radius and repeated in an adjacent circle. This did not fully meet the requirements of U.K. airfields but was possible for the Pacific area, where airfields were not closely clustered. In November 1944 the Air Ministry decided that Eureka Mark II was to be regarded as the standard radar beacon in the 1½-metre band and was to be widely fitted, replacing where possible the Coastal Command beacon operating on 176 megacycles per second. Where it was essential to retain the A.S.V. beacon Eureka Mark II was to be installed additionally. A standard interrogator was also required and Rebecca Mark VI was to be regarded as the standard 1½-metre interrogator for Coastal and Bomber Command aircraft.[1] This policy was slowly implemented from that date and by January 1945 A.S.V. and A.I. homing beacons were being superseded by variants of the Eureka beacon. In Coastal Command Eureka Mark IIC, operating on a spot frequency of 176 megacycles per second with horizontal polarisation, was used. In Fighter Command Eureka Mark IIF, operating in the band 190 to 193 megacycles per second with vertical polarisation, was installed.[2]

Operational Use of Beacons Overseas

The policy for the installation of A.S.V. responder beacons overseas was similar to that followed in the United Kingdom. They were set up at bases where homing facilities were required for aircraft equipped with A.S.V. The first A.S.V. beacon set up outside the United Kingdom was an early Ferranti model installed in Iceland in the spring of 1941. When interim-type beacons became available they were set up at bases where required and were eventually replaced by final-type beacons. In April 1942 interim A.S.V. beacons were despatched to Takoradi for use on the ferry route, A.H.Q. Malta, A.H.Q. Middle East, A.H.Q. India and A.H.Q. Gibraltar. Beacons were set up in the Azores during 1943. In January 1943 the Air Ministry decided to establish a chain of eight A.S.V. beacons in North-West Africa; this requirement was met by I.F.F. Mark IIG sets modified at the R.A.E. By March 1944 the replacement of interim by final beacons was in progress. In the Middle East four were held, two of which were operating at Shallufa and Gianaclis. Air Command, South-East Asia had six beacons, one of which was operating at Santa Cruz. There were nine in West Africa, of which one was operating at Aberdeen, one at Takoradi, two at Apapa and two at Pointe Noire. There were no A.S.V.

[1] A.H.B./IIK/85/94.

[2] A.M. File C.30400/46.

beacons in East Africa or in the central and western Mediterranean area. At the beginning of 1945 there were A.S.V. responder beacons at Bahrein, Karachi, Jiwani, Habbaniya, Calcutta and Sharjah.[1] A.S.V. and A.I. beacons were used as navigation aids in 2nd T.A.F. In March 1945 an A.S.V. beacon was installed on the tower of Blankenberghe Casino. It was specially beamed to serve Coastal Command Swordfish aircraft of No. 119 Squadron operating from Knocke, and also marked the entrance to the safe corridor through the Scheldt. A.I. beacons were operated in the assault area during the Allied landings in Normandy. Centimetric A.I. beacons were also used in the Mediterranean Allied Air Force by Beaufighter aircraft equipped with A.I. Mark VIII.[2]

Centimetric Beacons

Responder beacons were originally developed to work in conjunction with 1½-metre aircraft radar installations, and when the wavelength of these equipments was changed to the centimetric band, the addition of an attachment, Lucero, to the main radar equipment was necessary to ensure that beacon facilities remained available. Even before centimetric aircraft radar was introduced into Service use experimental work on the design of a responder beacon to operate with it began. The T.R.E. was engaged on this project in the autumn of 1941 and by the beginning of December a model was ready for development. It transmitted on a frequency of 3,300 megacycles per second and amplitude modulation at a frequency of four megacycles per second was provided. Although this experimental version was designed for centimetric A.I. the T.R.E. believed it could be adapted for use with A.S.V. A development contract for six beacons was placed with the firm of Murphy Radio on 31 January 1942. At the end of March the development contract was increased to twelve models. No production contract was placed at this stage. The Ministry of Aircraft Production was reluctant to take such a step because it was not then certain that a system of centimetric beacons would be set up on a large scale comparable with the existing chain, and stated in April 1942 that no contract would be placed until it was known that no alternative scheme would be adopted. The T.R.E., on the other hand, urged that a production contract be placed because A.I. Mark VIII was designed for use with centimetric A.I. beacons, and as the A.I. Mark VIII production and installation programmes were planned to re-equip almost the whole of the night-fighter force with centimetric A.I. the need for widespread centimetric beacon coverage was obvious. At the Air Ministry it was feared that no beacons would be available to give navigation and homing facilities when A.I. Mark VIII was introduced in Fighter Command, and in May 1942 financial sanction was requested for the provision of 100 centimetric A.I. beacons.[3] In June Treasury approval was given and on 4 September 1942 the contract was placed with Murphy Radio. During the summer of 1942 slow progress had been made on the development contract and, in spite of attempts by the T.R.E. to speed progress, the firm considered that the first prototype could not be made available before September. The delay was attributed to the Air Ministry failure to place a production contract earlier, resulting in an inability to obtain supplies of the requisite materials. On 3 September 1942 the first prototype was delivered to the T.R.E., who suggested several modifications

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[1] A.M. File C.16193/44.

[2] A.M. File C.30400/46.

[3] The estimated cost of each beacon was £850, including provision for spares and test gear.

for incorporation in the production models. Chief of these was the substitution in the transmitter of a klystron for the magnetron valve because of difficulties in the supply of the latter. Also the receiver unit had to be redesigned. The modifications retarded completion of both the development and production contracts but a second prototype was delivered in December 1942.[1]

Although in May the Air Staff had been prepared, in view of the urgency of the requirement, to accept the beacons without full operational trials, the development model was installed at the F.I.U., Ford, on 24 December 1942, and on 25 January 1943 trials were begun with a Beaufighter equipped with A.I. Mark VIII. By 6 March 1943 six major breakdowns and eleven other faults had occurred, and performance was unsatisfactory until after the sixth flight. From then until the thirtieth flight results were good with maximum ranges of up to 80 miles. After that, performance deteriorated, maximum ranges of about 30 miles only being obtained. It remained unsatisfactory until the fifty-fourth flight, when a maximum range of 71 miles was obtained, and after that maximum ranges were very satisfactory. It was found that when flights were made towards the beacon at a constant height from a considerable distance certain well-defined fading points existed. These were caused by the existence of gaps in the vertical field of radiation of the beacon. The fading periods were quite large at certain ranges but in practice they did not detract from the usefulness of the beacon as the signal always reappeared if the aircraft was kept on the same heading. It was also found that good results were obtained by four aircraft equipped with A.I. Mark VIII and several equipped with A.I. Mark VII when flying at the same time.[2] The T.R.E. considered that the faults and breakdowns which occurred were not excessive in view of the fact that the beacon was the first development model and was operated 24 hours a day. Most of the early troubles were due to faults in the valves and performance of these was improved by the addition of a specially designed switching unit. By the middle of May 1943 all the faults which could be attributed to bad design had been cleared. During the summer of 1943 production on both development and main contracts made progress and by August 1943 installations were completed at West Malling, Bradwell Bay, Coltishall, Ford, Scorton, Exeter, Middle Wallop and Acklington.[3] On 8 August 1943 a production version of the centimetric A.I. beacon, employing a klystron instead of a magnetron transmitter, was installed at the F.I.U.[4] This beacon gave good service in operational conditions and provided adequate homing facilities. Maximum range was about 60 miles at all heights from 3,000 feet upwards.[5]

Scientists were also engaged on the development of centimetric beacons in the U.S.A. In 1942 two centimetric beacons for use with centimetric A.S.V. were built at the Radiation Laboratory, Massachusetts Institute of Technology. In September 1942 Mr. J. E. Clegg, of the T.R.E., visited the M.I.T. for five months to study the centimetre beacon situation in the U.S.A. He made several recommendations for the standardisation of British and American

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[1] M.A.P. File SB.34160.

[2] A.H.B./II/54/93(A). F.I.U. Report No. 188.

[3] M.A.P. File SB.34160.

[4] The aerial system consisted of a rectangular structure 4 feet 6 inches square, 3 feet 6 inches high weighing 280 pounds. It had to be mounted 15 feet above ground. A.M. File CS.14654.

[5] A.H.B./II/54/93(A). F.I.U. Report No. 219.

centimetric beacons, most of which were adopted. In January 1943 one of the experimental beacons was sent to the United Kingdom for operational trials at Beaulieu. Its crystal video receiver operated over the range 3,300 megacycles per second plus or minus 33 megacycles per second and incorporated a discriminator which could be set so that only pulse widths in excess of two micro-seconds would trigger it. The beacon transmitter valve, a magnetron, was selected for frequency and then pulled by a stub tuner to 3,256 megacycles per second plus or minus three megacycles per second. The beacon transmitter was powerful but the receiver was insensitive, and, as a result of recommendations made after operational trials at Beaulieu, the production beacons, 250 of which were manufactured in the U.S.A. by the firm of Philco, were built with superheterodyne receivers, with which performance was improved. In March 1943 the experimental beacon was sent from Beaulieu to Port Lyautey, Morocco, for operational use by aircraft of the U.S.A.A.F. engaged on anti-U-boat duties.[1] In the autumn of 1943 six American centimetric beacons were sent to the United Kingdom. Two were installed in the Scilly Islands, one at Dunkeswell, one at the T.R.E. for experimental purposes, and two at Alconbury for the use of bomber aircraft of the United States Eighth Air Force.[2] The authorities in the U.S.A. embarked on a relatively large production programme, the intention being that aircraft equipped with centimetric radar would use centimetric beacons, thereby permitting the removal of the special beacon interrogators from aircraft. There was no large-scale production in the United Kingdom.[3] No further contracts were placed but during 1943 and the first half of 1944 installation of British A.I. centimetric beacons was continued where required at Fighter Command airfields. In June 1944 it was officially stated that the Air Ministry policy was to make use of American beacons where available, provided that too much modification was not involved.[4] The R.A.F. made a reciprocal agreement with the U.S.A.A.F. to install the beacons in theatres under R.A.F. control in which U.S.A.A.F. aircraft operated. In the summer of 1944 there was a renewed interest in the R.A.F. in centimetric beaconry, principally in Coastal Command, where there was a requirement for centimetric beacons at bases used by American aircraft with no $1\frac{1}{2}$-metre interrogators. This requirement was limited to six dual installations, and was met by American production of centimetric A.S.V. beacons.[5] At that date the intention was that all types of responder beacons then in use in the R.A.F. and U.S.A.A.F. should be replaced eventually by I.F.F. Mark V/U.N.B. when that had been developed. In March 1945 the Air Ministry again reviewed the beacon programme. It was believed that the use of centimetric responder beacons could be developed to include airborne use for identification, as an airborne beacon, and as a ' power responder ' for increasing the range of ground radar. For the rest of the war requirements for A.I. centimetric beacons were met from U.K. production. At Coastal Command bases in the United Kingdom centimetric beacons were provided from American sources for use by American aircraft in Coastal Command and by U.S. Navy aircraft operating from those bases.

[1] M.A.P. File SB.34160.
[2] A.M. File C.30601/46.
[3] A.M. File C.30400/46.
[4] M.A.P. File SB.34160.
[5] A.M. File C.30400/46.

CHAPTER 12

REBECCA/EUREKA

The Rebecca/Eureka system was a combination of an airborne radar interrogator, Rebecca, and a ground responder beacon, Eureka, whereby an aircraft could pinpoint a target.[1] From the information given by responses shown on the Rebecca indicator an aircraft could home from approximately 50 miles to the portable Eureka beacon with an accuracy of about 200 yards. The Eureka beacon had no controls and could be left unattended. The operation of the airborne apparatus was simple and required only one man in addition to the pilot. Timing of the aircraft's arrival over the target could be gauged fairly accurately because Rebecca indicated both the range and direction of Eureka.

The system was developed from the early wartime use of radar ground responder beacons interrogated by airborne apparatus for identification, and homing purposes. Experimental work began in the early days of the war but lapsed until 1941, when the Telecommunications Research Establishment was asked to provide radar target-finding equipment for aircraft employed by an organisation set up to drop supplies and agents to partisan groups in occupied Europe. The T.R.E. developed Rebecca from A.S.V. Mark II and Eureka from an I.F.F. beacon.[2] At first Rebecca/Eureka was used to mark dropping points for supplies and agents for the resistance movements, but its use was later extended to marking dropping zones for airborne forces. It was also used as a means of re-supplying army units in isolated spots, cut off from normal supply routes. Rebecca had uses other than target identification. It provided homing and beam approach facilities. The fact that it was an airborne radar interrogator, independent of any other radar system, meant that it could be used by aircraft not already equipped with a main radar installation. A navigation system, known as Rebecca-H, was developed from Rebecca aircraft equipment to assist photographic reconnaissance aircraft in the location of targets in enemy-occupied territory.

The various Marks of Rebecca were developed as appropriate to the uses to which they were put. Rebecca Mark I was designed solely for experimental work and preliminary trials, as was Eureka Mark I. Later Marks of Rebecca provided a choice of five frequencies. Rebecca Mark II was the standard installation in powered aircraft and Rebecca Mark III in gliders. Rebecca Mark IV was a light-weight version of Rebecca Mark II but provided facilities for interrogation of I.F.F., as well as of Eureka, other radar beacons, and B.A.B.S. Rebecca Mark VI was a complete interrogator set, embodying Lucero Mark II, and was originally intended to replace Rebecca Mark II. Rebecca Mark IV

[1] It is believed that the code name Eureka was given to the ground beacon after the Greek word meaning 'I have found it' and that Rebecca was derived from R.B.C.A. (Radio Beacon Control Approach) although it is possible that its choice was also influenced by the name of the woman in the Old Testament who 'followed Abraham's servant into another country'.

[2] T.R.E. Report No. 33/R.102/J.W.S.P.—Rebecca Homing System—and A.M. File CS.16328.

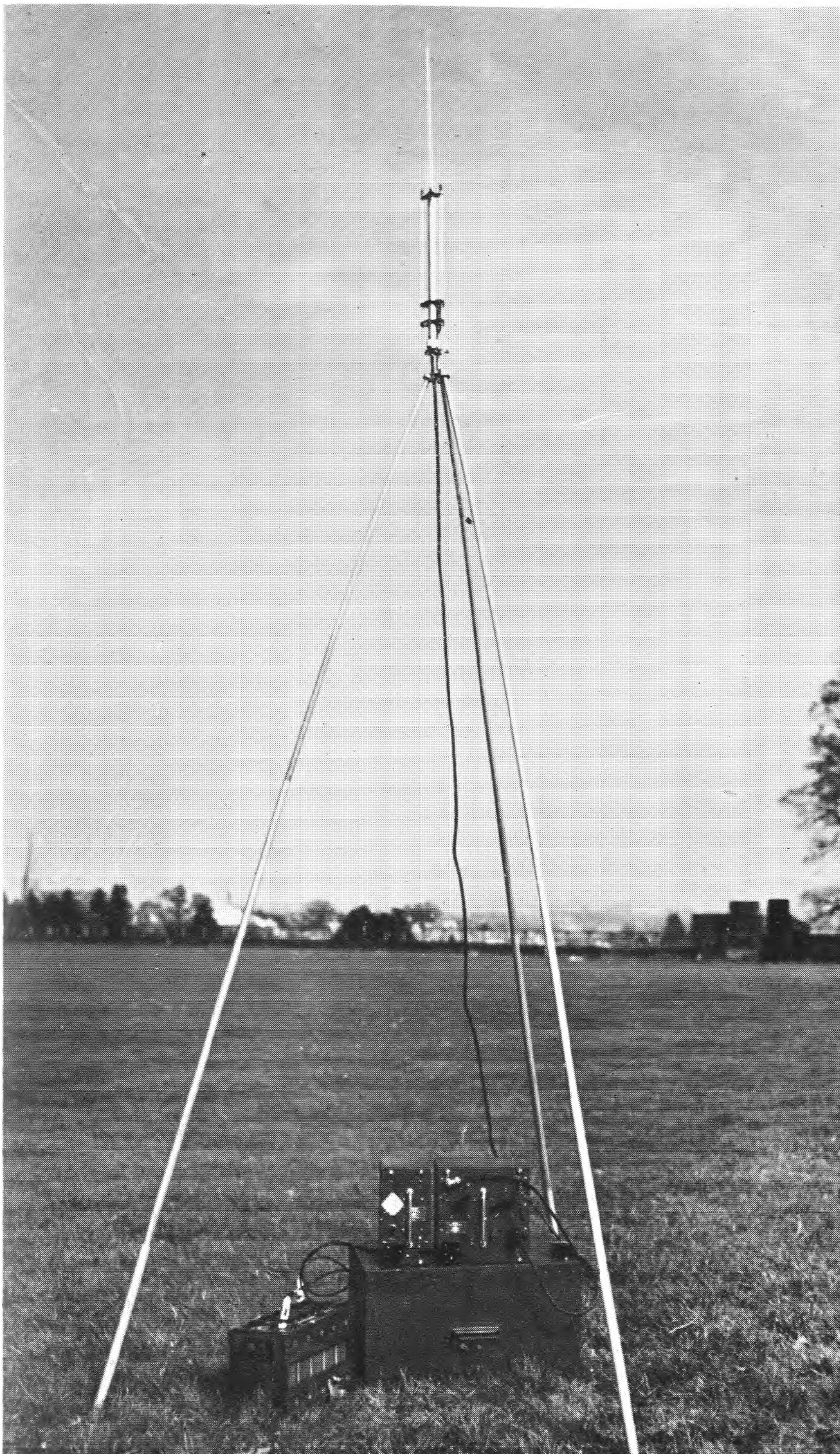
was eventually chosen because it afforded the same facilities as Rebecca Mark VI and in addition had the great advantage of light weight. Development was begun of Rebecca Mark V but the project was abandoned. Eureka Mark II was the standard ground beacon; it was transportable and could be dropped in a special container in the zone of operations or could be taken in by glider. Eureka Mark III was a miniature version, using American Type 9000 valves, and was designed to be completely contained in a harness worn by a paratrooper. In February 1943 work on the system was begun in the U.S.A. and American equivalents of Rebecca and Eureka were produced later that year. The American version was known in the United Kingdom as Rebecca Mark IIA, its American type number being AN/APN-2. The American versions of Eureka were known as AN/PPN-1 and AN/PPN-2.

The first development of the aircraft equipment eventually known as Rebecca was for use as an interrogator for identification purposes in single-seater aircraft. Ground radar responder beacons were widely used from the early days of the war in Fighter and Coastal Commands for identification, homing, and beam approach purposes. They were used in conjunction with airborne interrogators forming part of the main radar search equipment, such as A.S.V. or A.I. In the first year of the war the Air Ministry Research Establishment began experimental work on an airborne radar equipment, for installation in night fighters, which could interrogate I.F.F. sets carried in friendly aircraft and could also interrogate I.F.F. ground beacons. In May 1940 an experimental airborne transponder was fitted in a Battle aircraft and was tested in conjunction with I.F.F. Mark III in an Anson. This enabled the Anson to be identified up to a range of 25 miles. Trials were then conducted with two types of ground radar beacon. The first was the simple I.F.F. homing beacon type made by Ferranti and used in Coastal Command; this gave a maximum range of 25 miles. The second consisted of an A.S.V. receiver triggering a 100-watt transmitter and gave good results up to 32 miles. Experiments were continued at the A.M.R.E. until the end of 1940 when simple arrangements had been worked out to enable A.I. to interrogate I.F.F.[1]

Development for Target Identification

The idea of using responder beacons for target location by bomber aircraft was first suggested at the first meeting of the Committee for the Scientific Survey of Air Warfare. On 27 September 1939 the committee recommended that trials of I.F.F. apparatus as a ground beacon for the guidance of bomber aircraft be held. A separate interrogator was needed because at that time bomber aircraft carried no radar. In May 1940 the committee again discussed the possibility of radar beacons for target marking. It was thought that I.F.F. beacons might be placed by agents in enemy-occupied countries to afford navigational assistance to bomber aircraft, provided that those aircraft were equipped with some means of interrogation, possibly A.S.V. The C.S.S.A.W. therefore recommended that the Air Staff should give immediate consideration to the possibilities of using I.F.F. beacons as an aid to navigation of aircraft to targets in Norway. The problem of target location was one which was also faced by Army Co-operation Command, particularly the accurate location of dropping zones by aircraft carrying paratroopers or towing gliders. It was in

[1] A.H.B./IVA/1. A.M.R.E. Progress Reports.



Eureka Mark III Beacon

June 1941 that the T.R.E. first considered the application of radio aids to the problems of Army Co-operation Command when it was suggested that dropping zones might be marked by radar beacons to which aircraft could home by means of an airborne installation with directional aerials. The T.R.E. proposed that a light-weight beacon be parachuted into the zone or placed there by agents. Army Co-operation Command aircraft were not fitted with radar so the idea of using the experimental airborne transponder to interrogate the target markers was revived. In June 1941 two T.R.E. scientists took a modified I.F.F. set to the Air Officer Commanding-in-Chief, Army Co-operation Command, at his headquarters near Bracknell. The beacon was placed on the lawn outside the Officers' Mess while another T.R.E. scientist flew in a Blenheim equipped with suitably modified A.S.V. equipment to search for it. After cruising about for some time the pilot turned and homed to the beacon, which was then driven about in a car to prove its mobility, and was finally located in a wood. During the summer and autumn of 1941 much useful work was done in improving the transponder equipment, which was given a further trial in an Anson at the Central Landing Establishment at Ringway. This demonstration was the beginning of a close co-operation between the T.R.E. and the airborne forces, co-operation which eventually was to prove valuable in the D-Day landings in Normandy. However, in November 1941 it was decided that the problems of Army Co-operation Command were to be solved with non-radar methods and responsibility for further work for the command was transferred to the Royal Aircraft Establishment.

Development for Special Operations

The period of experimental work for Army Co-operation Command was not wasted. With the withdrawal of the British forces from Europe in the summer of 1940 and the consequent German occupation of the whole of north-western Europe, the problem of target identification became more acute because reinforcements had to be dropped secretly to partisan forces in the occupied countries. An organisation, known as the Special Operations Executive, was set up for the purpose of organising resistance movements in those countries, training agents in the United Kingdom, and dropping those agents, together with supplies, mostly armaments, newspapers and medical supplies, in occupied Europe.[1] This organisation was designed to enable the resistance movements to undertake such action against the enemy as might be judged best calculated to assist any future Allied military undertaking.[2] The organisation was a combined services' responsibility. The task of conveying supplies to the resistance cells was particularly difficult because most of them were, of necessity, situated in isolated spots. The use of sea transport was seriously limited because of the strict watch kept by the Germans on coastal areas. Air transport therefore became the chief supply line. It was essential that men and material should be dropped at the precise point planned so that immediate measures could be taken to dispose of them without arousing enemy suspicion. The normal methods of aircraft navigation by night were not sufficiently accurate to pinpoint a very small target, usually at some distance from towns, and often far from landmarks easily identifiable from aircraft at night. The number of skilled

[1] For details of S.O.E. *see* A.H.B. Narrative ' Special Duty Operations in Europe '.

[2] In August 1940 No. 419 Flight (Lysander aircraft) was set aside for use by the S.O.E. In August 1941 No. 419 Flight became No. 138 Squadron and in February 1942 a second Special Duty squadron, No. 161, was formed. In March 1942 the two squadrons were based at Tempsford in Bedfordshire.

navigators expert at map reading was insufficient for the needs of the organisation and in any event map reading was feasible only on moonlight nights. This meant that operations could be planned only for twelve or fourteen nights a month and even these small numbers had to be cancelled when weather conditions prevented flying.[1] At first, light signals were used to mark the dropping zones for supplies in conjunction with a very low-power equipment, the S-phone, but these lights easily attracted the attention of the Germans. Some other means had to be found.[2] The T.R.E. was approached by a Guards' officer from S.O.E. Headquarters. Discussions and meetings followed, as a result of which a highly secret development programme was initiated at the T.R.E. Under the direction of Mr. J. W. S. Pringle and Mr. R. Hanbury Brown an experimental Rebecca/Eureka system was designed in 1941, known as Rebecca/Eureka Mark I. Six airborne receivers and ten beacons were hand-made. The latter were made to look like biscuit tins. The beacons and dependent batteries were wrapped in four inches of sponge rubber and placed in suitcases which had been made to look as much like continental ones as possible.

Rebecca Mark I consisted of a transmitter/receiver unit weighing 36 pounds contained in a box 12 by 8 by 18 inches, with a power consumption of 150 watts, supplied by the aircraft engine-driven alternator. An interrogator was built into the side of the receiver. The indicator used was the standard A.S.V. indicator, 9 by 8 by 18 inches, weighing 20 pounds, and the aerial system consisted of two receiving and one transmitting aerials. The installation transmitted on a frequency of 213·5 megacycles per second and received on 213·5 and 217·5 megacycles per second. Eureka Mark I consisted of a fixed frequency I.F.F. beacon incorporating automatic gain stabilisation but without controls. The beacon weighed 16 pounds, the mains unit for A.C. mains 9 pounds, and the vibrator for a 12-volt battery 11 pounds. The battery was nickel-iron giving seven hours' duration. The aerial mast was nine feet high, and its total weight, including aerials, was 7½ pounds. The beacon transmitted on a frequency of 217·5 megacycles per second and received on 213·5 megacycles per second.[3] The method of operation was fairly simple. The operator switched Rebecca on as soon as the aircraft reached the neighbourhood of the beacon site, and observed the indication on the cathode ray tube. The ground beacon could be removed from its container and assembled with its aerial and power supply in one minute by one man. It was necessary for it to be sited at least 50 yards from any large obstruction and if possible, on high ground. The correct operation of the beacon was checked by means of a pair of headphones and a test button on the front panel. There were no adjustments to be made on the apparatus. When the aircraft came within range a characteristic note was heard by the ground operator in his headphones and a morse letter might be signalled by means of a tapping key or a push button on the beacon. This enabled the identity of the beacon to be checked.[4] On identifying the beacon the observer directed the pilot to turn until the aircraft was heading towards it, if homing was being carried out upwind or downwind, and then told him its range. The pilot could then reduce height progressively so as to pass over the

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[1] A.M. File C.30641/46.

[2] T.R.E. Monograph, ' Radar Interrogator Beacon Systems '.

[3] A.M. File C.30641/46.

[4] T.R.E. Report No. 33/R.102/JWSP and A.M. File CS.16328. The note was the aircraft equipment pulse recurrence frequency and varied according to the number of aircraft interrogating.

beacon at the optimum height for dropping. The final moment for release of the supplies or for parachutists to jump was determined by the operator from the indications on his set. Crosswind homing was more difficult and accounted for many errors.

The advantages of Rebecca/Eureka for highly secret operations were many in that the equipment afforded a high degree of security. In the first place Eureka did not transmit until interrogated by Rebecca. The high frequencies gave a ground-to-ground range of only four miles. A safeguard against use of the beacon by the enemy was ensured by the manually-operated identification system. The use of pulse transmissions made difficult discovery by the enemy for technical reasons and if necessary Eureka could easily be disguised as a telephone transmitter/receiver. Even if the Germans captured and examined Eureka little advantage would accrue to them because no component embodying a technique new to them was used. Early flight tests carried out by the T.R.E. revealed that range performance with the beacon placed on a clear site was 20 miles at 1,000 feet, 50 miles at 5,000 feet and 75 miles at 10,000 feet. Dropping accuracy was about 200 yards but the T.R.E. thought that could be bettered as operators became more expert in the use of the equipment and the design of the equipment itself was improved.[1] On 11 February 1942 trials were carried out by the S.O.E. to determine the accuracy with which a parachute could be dropped on a pinpoint without the use of other means of navigation. A beacon, contained in a suitcase, was placed in the grounds of Brickendonbury House, near Hertford. It was concealed under sacking on a piece of agricultural machinery in the middle of a field with only a small aerial projecting. An Anson aircraft fitted by the T.R.E. with Rebecca flew from Hurn and parachuted a small sandbag 400 yards from the beacon. If this had been a normal parachute container the distance would have been reduced to about 200 yards. The only information given to the pilot was that the beacon was located in the area Aylesbury-Hertford-Cambridge-Northampton, an area of over 100 square miles. The Officer Commanding, No. 138 Squadron, flew in the aircraft to give an impartial report. He was much impressed with the simplicity of navigation and the extreme accuracy of both direction and range. Air Ministry representatives from the Directorate of Bombing Operations and Directorate of R.D.F. were present at the trials, as were representatives of Coastal Command and the Ministry of Aircraft Production. All were impressed by the excellent results and the simplicity of the equipment.[2]

As a result of the successful trials with Rebecca/Eureka the Air Staff was requested to release the equipment for S.O.E. operations over enemy-occupied territory. In the early days of 1942 there was considerable doubt at the Air Ministry about the wisdom of using Rebecca over enemy territory for Special Intelligence operations. The Radio Policy Sub-Committee recommended that it should not be used in case its capture compromised A.S.V. Sir Henry Tizard considered that this was not a serious danger but held that the use of Rebecca should be reserved for use in major operations. The Director General of Signals at the Air Ministry recommended that Rebecca be used because it fulfilled the requirements of the S.O.E. for a navigation aid better than anything else. On 20 March 1942 the Chief of the Air Staff ruled that Rebecca could be used operationally by Nos. 138 and 161 Squadrons.[3] Aircraft sets were available

[1] A.M. File C.30641/46. [2] A.M. File C.39546/49. [3] A.M. File CS.13367.

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and the T.R.E. estimated that three weeks would be required to fit six aircraft with Rebecca. At a meeting on 21 March 1943 arrangements were made for the introduction of Rebecca into Service use, the initial provisioning being for 12 Rebecca sets for three Halifax and three Whitley aircraft, and eight Eureka beacons. The T.R.E. had already made six Rebecca sets so arrangements were made to divert six more A.S.V. Mark II receivers and indicator units from the manufacturer, E. K. Cole, to the T.R.E. for modification, and for the incorporation of detonators in all 12 sets as a security measure. The T.R.E. had already made five beacons and the Ministry of Aircraft Production agreed that the establishment should manufacture three more, the total of eight to be despatched to Tempsford, where the S.O.E. squadrons, Nos. 138 and 161, were stationed, for employment on operations, and the station and squadron establishments were suitably increased. One Whitley aircraft had already been fitted and this was allocated to No. 161 Squadron. The initial fitting of one Halifax and Whitley was undertaken at Hurn by a special Rebecca fitting party attached there, and arrangements were made for aircraft wiring and Rebecca aerials to be incorporated eventually on the Halifax and Whitley aircraft production lines.[1]

In February 1942, when Eureka beacons had first been taken to the headquarters of the S.O.E., two T.R.E. scientists instructed two agents, one Polish and one Belgian, in the use of the equipment. They were flown from Tempsford and dropped in Europe. A few hand-made Eureka beacons were dropped in Europe by the S.O.E. squadrons in the early months of 1942 and were used successfully to mark target zones for later drops of agents and material. The general use of Rebecca/Eureka was expected to increase the scope of supply-dropping operations to the most distant areas and in all conditions of weather and visibility. For this reason a programme was launched to step up production and installation and to train all potential operators. A special Signals section was formed at Tempsford to deal with all matters connected with the training, operation and servicing of Rebecca/Eureka. A radar officer was posted to Tempsford to train navigators in the operation of Rebecca and to give very simple training in the use of Eureka to S.O.E. personnel. A Whitley and a Halifax aircraft were used for training. Air crews of Nos. 138 and 161 Squadrons were trained at a rate of about three air crews per week and training of ground operators also progressed favourably. The Ministry of Aircraft Production arranged for 12 more Whitley and 12 Halifax aircraft to be fitted with Rebecca. A maintenance section, consisting of 15 mechanics, was set up. Thus, during the early summer of 1942, the scheme for using Rebecca/Eureka in S.O.E. operations appeared likely to achieve great success ; both air and ground staff were interested in the work, enthusiastic about the new equipment, and eager to use it on operations. In spite of this promising start conditions gradually deteriorated because of the lack of definite policy and direction on the part of higher authorities. Although Headquarters Bomber Command was impressed with the possibilities and promised to ensure that supplies to the S.O.E. of Rebecca and Eureka would be increased so that the scope of operations could be extended, production of equipment ceased, and the aircraft installation programmes were postponed indefinitely. The two training aircraft were transferred to No. 138 Squadron where, because of operational requirements, they could not be made available for training purposes. On 24 June 1942 the first Rebecca sortie was made to central France but was unsuccessful because the

[1] A.M. File CS.13367.

accumulators of the ground beacon were discharged. A later trip in October revealed a fault in production of the early sets. Difficulties were increased by poor organisation in sending operators to Tempsford for training. On two occasions trainees arrived with but one hour or less to spare; this was much too short a period, the normal time being two to two and a half hours, depending on the intelligence of the trainees. Several successful demonstrations were given, particularly two in September to Czech and Polish personnel, but in the six months from April to October 1942, Rebecca/Eureka was used on two operational missions only. All concerned in the operation and upkeep of the equipment began to lose their enthusiasm.[1]

Development for Airborne Forces

The effective use by the Germans of parachute and glider troops on the Albert Canal in 1940 and in Crete in 1941 had stimulated attempts in Britain to develop an airborne force as a military weapon. The airborne force started as a small group of people experimenting at Worth Matravers, drawn from all parts of the R.A.F. mainly because they had been actively interested in gliding before the war. This team then moved to Ringway airfield where it was formed into the Airborne Forces Development Unit. In January 1942 No. 38 Wing was formed at the Airborne Division Headquarters at Figheldean, near Netheravon, under the command of Group Captain Sir Nigel Norman, as an operational base for the new force. At the same time the R.A.E., Farnborough, took over much of the more technical work on gliders and parachute methods. In the spring interest in the employment of airborne forces was revived and the Airborne Forces Equipment Committee was set up in the Ministry of Aircraft Production under the chairmanship of Sir Robert Renwick. At this stage a vast airborne army was envisaged, with No. 38 Wing as merely the spearhead. Plans were made for all heavy-bomber aircraft in Bomber Command to be fitted with towing hooks so that they could tug troop-carrying gliders. In addition to a programme for the installation of Rebecca Mark II in the powered aircraft of No. 38 Wing and Rebecca Mark III in gliders it was hoped to have Lucero Mark II installed in aircraft of Bomber Command to enable them to home to Eureka beacons sited by the Independent Parachute Company advance parties of the Airborne Division. However, it was considered that Germany had to be weakened by bombing before a land attack could be launched and No. 38 Wing was kept as a token force throughout 1942 and early 1943, priority for radio development and production being allocated to the requirements for the night-bombing offensive. With the exception of a brief spurt of activity in order to equip the one and half squadrons which helped in Operation Husky in Sicily in June 1943, radar equipment for No. 38 Wing remained at the stage of experiment and trial. However, even though priorities for the airborne forces were very low, the commander and the signals staff of Headquarters No. 38 Wing, and later No. 38 Group, maintained an active interest in the possibilities of Rebecca/Eureka and, ably assisted by Mr. J. W. S. Pringle, evolved operating techniques and methods of operational use, and trained personnel to service and operate the equipment.

[1] On 6 November 1942 a meeting was held at the Air Ministry to discuss the unsatisfactory position at Tempsford. As a measure to improve the organisation of operations it was decided that all responsibility for the assembly and packing into special parachute equipment of Eureka beacons was to be made that of the station commander, through the radio officer, instead of being divided as it was previously. (A.M. File CS.13367.)

The S.O.E. trials of Rebecca/Eureka had revealed that the equipment was valuable for use in military airborne operations, both in the initial landing of parachute troops and gliders and for resupply operations to isolated formations. However, the essential security in force at that time was such that Headquarters No. 38 Wing was not aware of the use made by S.O.E. of the equipment. The first operation planned by Group Captain Sir Nigel Norman and his staff of two officers, one of whom was a signals officer, was the Bruneval raid. The operation was executed by No. 51 Squadron under the command of Wing Commander Pickard. Although it was highly successful the need for marking at the dropping zone and for approach aids was made apparent. As the result of a demonstration given at Hurn to Sir Nigel Norman and his signals officer by Mr. J. W. S. Pringle and Mr. R. Hanbury Brown, a request was made to Headquarters Army Co-operation Command for supplies of Rebecca/Eureka. In June 1942 Headquarters Army Co-operation Command asked for Rebecca/Eureka equipment in order that further trials might be undertaken. Two Eureka beacons were required for No. 38 Wing and Rebecca installations were required in two Whitley aircraft of No. 297 Squadron, one Horsa and one Hamilcar glider, or two Horsa gliders. The T.R.E. recommended that Rebecca Mark I be used for the trials because development of the improved versions was not then complete. At a meeting of the Airborne Forces Committee Signals Sub-Committee on 16 July 1942 it was agreed that two Whitley aircraft be fitted at Netheravon in August 1942 with Rebecca Mark I for training and operational research. More aircraft were to be fitted at Netheravon according to the requirements of No. 38 Wing and the supply of equipment. But because the production programme had been abandoned there was a shortage of equipment and installation programmes were delayed.[1] From 17 December 1942 to 17 January 1943 the crews of 'A' Flight, No. 295 Squadron, carried out trials of Rebecca/Eureka with six Whitley aircraft. 98 separate night drops, involving 32 aircraft sorties, were made. All the drops were measured by the 21st Independent Parachute Company and their accuracy recorded. Analysis revealed that the average error was 238 yards with a maximum error of 800 yards and minimum error of zero. In only 16 instances was the error above 400 yards and in 25 above 300 yards. It was concluded from the trials that, with average squadron crews who had special Rebecca training, the Eureka beacon could be used for night drops in any condition of darkness in dropping zones little larger than 700 yards by 600 yards when surface winds did not exceed 10 miles per hour. When winds were stronger a dropping zone of over 900 yards by 800 yards would be required. The performance and serviceability of the equipment were generally of a high standard and there were no indications of erratic behaviour or unreliability. Aircraft crews could be briefed to operate on a fixed time basis with every prospect of success.[2] The success of the trials resulted in Headquarters Army Co-operation Command confirming a requirement for Rebecca and Eureka for the airborne forces to mark target zones for landing parachute troops and troop-carrying gliders.

When the equipment was first developed it had been thought that it could be used for air operations in close support of ground forces and, in September 1942, Headquarters Army Co-operation Command requested that Rebecca be fitted in single-seater aircraft because of its many uses, including the location and identification of forward troops, so giving an approximate plot of their

[1] A.M. File CS.14847. [2] A.M. File C.30605/46.

disposition, and the location and identification of formation headquarters for message dropping. The Air Staff considered that the use of Rebecca should be restricted to airborne forces; the operational requirement for aircraft employed on tactical reconnaissance or Army air support could be met by VHF homing and the beacon approach system. Space was so limited in fighter aircraft that it had been decided to retain only those radar systems which were essential for the primary operational role of the aircraft. Rebecca Mark I and Mark II installations were not made in single-seater aircraft because of the limitations of the aircraft power supply, the weight of the equipment, the lack of space in the cockpit for the indicator unit, and the unsuitability of the indicator unit for pilots' use. The last two reasons also precluded use of Rebecca Mark III. It was agreed in January 1943, after discussion with the War Office, that there was no operational requirement for Rebecca in aircraft used in close-support roles.[1]

The proposed use of Rebecca and Eureka for airborne force operations emphasised the great weakness of the Mark I version of both air and ground equipments; the fact that they operated on one frequency only. Rebecca/Eureka was a cross-band system, interrogating on one frequency and replying on another, which eliminated ground returns as seen on A.S.V. and enabled greater ranges and more accuracy to be obtained. Effective use of the equipment for marking dropping zones was complicated because a beacon became saturated when between 30 and 40 aircraft interrogated it at the same time, and beacons had to be placed at least 600 yards apart when the transmitter frequency of one was within 5 megacycles per second of the receiver frequency of the other. This disadvantage had not been felt while Rebecca had been used by single aircraft only on special operations in which those aircraft merely had to find one particular target and were not required to distinguish between a number of dropping zones marked by beacons.[2] Rebecca Mark I was an experimental model intended originally only for preliminary trials and development work. Greater flexibility and a higher standard of performance were required. In March 1942 the T.R.E. was instructed by the Air Ministry to design an improved beacon incorporating a manual selection of a minimum of 10 frequencies over as wide a band as possible, and automatic coding. The frequencies were to be separated as far as possible from the $1\frac{1}{2}$-metre A.I. and A.S.V. bands and it was proposed that they should be near or above 250 megacycles per second. The development of a multi-frequency beacon necessitated a corresponding development of Rebecca to operate over the same frequencies and the Ministry of Aircraft Production was instructed to arrange for the development of a new type of aircraft installation. One stipulation was that Rebecca Mark II was to be completely interchangeable with Mark I.[3] By July 1942 a new development model had been produced by the T.R.E.[4] The early models of Rebecca and Eureka Mark II operated on a choice of four frequencies, 214, 219, 224 and 229 megacycles per second.[5] With later models of Rebecca Mark II five frequencies were available, 214, 219, 224, 229 and 234 megacycles per second. The transmitter and superheterodyne receiver were operated by push button control and could be used with all Marks of Eureka beacons, both British and American, and also with B.A.B.S. Mark II. Its weight when installed in an aircraft was approximately 160 pounds. Three time-base ranges were

[1] A.M. File CS.14847.
[2] A.M. File C.39546/49.
[3] A.M. File CS.13367.
[4] A.M. File C.30641/46.
[5] A.M. File CS.15553.

available, 9 miles, 36 miles and 90 miles. An additional advantage of Rebecca Mark II compared with Mark I was its increased power output, 350 watts. The lower power of Rebecca Mark I had been a disadvantage. Rebecca Mark IIB was similar to Rebecca Mark II but included additional facilities for I.F.F. interrogation and homing to A.S.V. beacons and Rooster on frequencies used in Coastal Command. The transmitter frequencies were 177 megacycles per second with horizontal polarisation, and three between 214 and 234 megacycles per second with vertical polarisation. The receiver frequencies were 173 and 176 megacycles per second with horizontal polarisation and two between 214 and 234 megacycles per second with vertical polarisation. The same time-base scales were available as in Rebecca Mark II. Its weight was greater than that of Mark II, approximately 200 pounds, and its power output less, 300 watts.[1]

At the same time as Rebecca Mark II was being developed, a multi-frequency beacon, Eureka Mark II, was designed as a transportable beacon to be used to mark paratroop dropping zones and supply points. It consisted of a transmitter, receiver, a simple aerial system Type 304, a vibrator power supply, earphones and a nickel-iron accumulator, the whole packed in a transit case. It was designed for fast-moving operations where installation time and low power consumption were of the utmost importance. There were variants of Eureka Mark II to make its use possible in all commands. In the Tactical Air Force, Transport Command, Bomber Command and the Fleet Air Arm the beacon operated on the frequencies 214, 219, 224, 229 and 234 megacycles per second. The transportable version for Allied Expeditionary Air Force and Air Defence of Great Britain was designed to operate on the Fighter Command frequencies 193 and 196 megacycles per second.[2]

Development for Installation in Gliders

Rebecca was made a requirement for gliders to enable them to rendezvous at a given spot and time for the important purpose of concentration and to enable distant release to be effected by tug aircraft. The projected use of Rebecca in gliders necessitated development of a special light-weight interrogator, since both Marks I and II were too heavy. At a meeting of the Airborne Forces Committee on 20 May 1942 the operational requirements of a Rebecca installation in a glider were stated. Range indication was essential. A maximum range of 50 miles at 10,000 feet was desirable but reduced range was acceptable if it enabled the apparatus to be simplified; a minimum range of 10 miles at 350 feet was required; an accuracy of plus or minus 400 yards for dropping parachute troops was desirable.[3] Another essential was that the installation should be battery-operated. During the summer of 1942 the T.R.E. was engaged on developing light-weight equipment, first known as Rebeccula and later as Rebecca Mark III. On 24 July 1942 at a meeting at the Air Ministry it was reported that the T.R.E. hoped to supply the R.A.E. with an experimental model fully flight-tested in powered aircraft by 7 August 1942, and it was considered that it would be adequate for a contractor to use as a prototype. Thereafter the R.A.E. was to be responsible for the development and contract supervision.[4] Rebecca Mark III was a battery-operated model

[1] A.M. File C.30703/46.

[2] T.R.E. Report No. 1739, G.43/R.5/KAW—Eureka Mark II Homing Beacons.

[3] A.M. File CS.14847.

[4] A.M. File C.30641/46.

with a power output of about 25 watts. It had a super-regenerative receiver and five frequencies were available by push button control in the band 214 to 234 megacycles per second. The installation consisted of a transmitter/receiver, a control unit, indicator, accumulator, and a transmitting aerial in the nose and two receiving aerials on the mainplanes of an aircraft.[1] Its weight, including the aerials and connectors, was 100 pounds. Two time-base scales were available, at first 10 miles and 50 miles, later changed to 6 miles and 36 miles. In August 1942 a trial installation in a Hamilcar glider was tested at the T.R.E., and the ranges obtained at 5,000 feet were, with Eureka Mark I, 35 miles, with Eureka Mark II, 35 miles, and with Eureka Mark III, 25 miles.[2] A development contract was placed with the firm of Cossor, and in October 1942 flight trials with a Cossor prototype in a Horsa glider were held at the R.A.E. Some alterations had to be made to the T.R.E. model. The indicator unit was not suitable for pilot operation; it had to be used with a standard A.S.V. rubber visor and an operator was necessary. The R.A.E. reported that the performance of Rebecca Mark III in a Horsa was satisfactory, a maximum range of 45 miles at 5,000 feet being obtained. At a meeting on 14 December 1942 the War Office was informed by the R.A.E. that it would have to accept limitations in the performance of Rebecca Mark III, because of the restrictions imposed by weight, power and size. It was agreed at this meeting that the time-base scales were to be altered to 6 miles and 36 miles in order to guarantee an accuracy of ¼-mile radius at 1½ miles and a minimum range of ¼ mile. An improvement in performance could be obtained with the addition of a small number of extra components, but it would entail experimental work which would delay production by about three months. Later in 1942 a production contract was placed with the firm of Cossor and by 27 January 1943 the first model was delivered to the R.A.E. for type approval.[3] At the end of January 1943 Headquarters Army Co-operation Command stated that it was prepared to accept a delay of three months until 31 July 1943 in order that the new range-scales giving the required degree of accuracy were incorporated, provided that 18 sets for training could be made available by the first week in February 1943.[4]

In February 1943 the R.A.E. carried out tests of the first production model of Rebecca Mark III. The transmitted pulse blotted out the first 1¼ miles of the time-base. As the suppression of the pulse would have involved a major modification Headquarters Army Co-operation Command was forced to accept a minimum range of 1¼ miles as an operational limitation of Rebecca Mark III. Production of the equipment was held up because of technical difficulties but in June 1943 the R.A.E. conducted trials of a prototype in a Hamilcar glider. Using Eureka Mark II a maximum range of 35 miles at 5,000 feet was obtained. In August 1943 trials of Rebecca Mark III in a Horsa glider were held at Netheravon. Eight glider pilots took part in them when 20 towed and 15 free approaches were made. The accuracy of pinpointing was adequate, the average error in reading being range 100 yards and azimuth 30 yards at altitudes of 1,000 feet. Range indications on the 6-mile scale were read to an accuracy of one-fifth of a mile and on the 36-mile scale to an accuracy of 1 mile. During the trials the ranges obtained were 8 miles at 500 feet, 12 miles at 1,000 feet and 18 miles at 2,000 feet. At altitudes below 1,000 feet the beacon pulse became partially obscured by an indicated range of 1 mile.[5]

[1] A.M. File C.30703/46. [2] A.M. File CS.23779. [3] A.M. File C.30641/46.
[4] A.M. File CS.23779. [5] A.M. File CS.23779.

Production Contracts

A contract for 100 sets of Rebecca Mark I and 100 Eureka Mark I beacons was placed with the firm of Masteradio in June 1942. It was decided on 24 July 1942 that Rebecca Mark I should be used for training only and Rebecca Mark II used for operational flying.[1] The S.O.E., however, found the first Mark preferable for their operations because it allowed the operator to tune over a band of a few megacycles per second and obtain good results from a beacon off frequency. It was often found that the sketchily trained agents set up a Eureka beacon inaccurately tuned.[2] By October 1942 five sets of Rebecca Mark I had been delivered.[3] On 24 July 1942 it was reported that the firm was experiencing difficulties in obtaining some of the necessary components. A contract for the aerial systems was placed with Cossor and installation parts were supplied by No. 43 Group.[4] On 27 January 1943 the Ministry of Aircraft Production reported that 30 sets of Rebecca Mark I and 35 Eureka Mark I beacons had been delivered and it was anticipated that the programme would be completed by April of that year.

Heavy demands were being expressed by various potential users of Rebecca and Eureka and this, combined with slowness of development and production, caused a shortage of the equipment. As early as June 1942 Headquarters Army Co-operation Command had stated a general requirement for the fitting of all airborne forces operational aircraft with Rebecca, and of all operational gliders with the light-weight Rebecca Mark III. Rebecca was required for 25 per cent of powered aircraft at Glider and Parachute O.T.Us. and Rebecca Mark III for 25 per cent of all training gliders. The Air Ministry confirmed that the final requirements for Army Co-operation Command were estimated as 144 sets of Rebecca Mark II for Whitley aircraft in No. 38 Wing, 430 sets of Rebecca Mark III for operational gliders and the training pool in No. 38 Wing, and 42 Eureka beacons for operations and training.[5] A meeting was held at the Air Ministry on 13 August 1942 to co-ordinate the requirements for Rebecca and Eureka of Army Co-operation Command, the Directorate of Intelligence at the Air Ministry, and Headquarters R.A.F. Middle East, to see how these could be met by existing and future production capacity. As a result of discussion the Air Ministry estimated the requirements of Rebecca and Eureka to the end of 1943.[6] The estimate was revised in January 1943 because during that month the re-organisation of the airborne forces was discussed by the Air Ministry and the War Office. As a result it was decided to reduce the number of gliders and powered aircraft. The requirement was altered to 1,560 sets of Rebecca Mark II, 2,170 sets of Rebecca Mark III, 30 Eureka Mark II beacons

[1] A.M. File C.30641/46. [2] A.M. File CS.24135. [3] A.M. File C.39546/49.
[4] A.M. File C.30641/46. [5] A.M. File CS.14847.
[6] Estimated requirements to the end of 1943 were :—

	Quantity	*Estimated Cost*
		£
Rebecca Mark II	2,450	269,500
Rebecca Mark III	3,675	275,625
Eureka Mark II	108	5,400
Eureka Mark III	810	12,150
Aerial systems and installation fittings.. ..	6,125	306,250
Test gear sets	709	389,812
Spare components	—	188,810
Total		£1,447,547

(A.M. File CS.16429.)

and 720 Eureka Mark III beacons.[1] The following August the requirement for Eureka Mark II beacons was again revised. 300 beacons were required for Rebecca test purposes and 205 for use as a homing aid with Rebecca, the estimated cost being £53,025.[2]

Development contracts for Rebecca Mark II and Eureka Mark II were placed with the firm of Murphy Radio in the spring of 1942 and by 27 January 1943 provisional type approval of Rebecca Mark II had been given. The firm produced a model which was used as the prototype for an additional production contract for 200 sets placed with the firm of Dynatron.[3] Development of Eureka Mark II was slower and a prototype was not received until March 1943. A contract for Eureka Mark II was increased to 505 in August 1943. The first deliveries of both Rebecca and Eureka Mark II were allocated for use in the operations connected with the landings in Sicily. Manufacture by the firm of Cossor of Rebecca Mark III began at the end of November 1942 and by 30 April 1943, 25 sets had been produced.[4] Production was at the rate of 15/20 per week. By 27 January 1943 six Eureka Mark III beacons had been delivered and the Ministry of Aircraft Production estimated that, up to the first 40, there would be no delay in delivery but after that delay would be occasioned by a shortage of I.F. transformers.[5]

Operational Use in Sicily Landings

Rebecca/Eureka was used in a major operation by airborne forces for the first time in Operation Husky, the Allied landing in Sicily in June 1943.[6] The operation was carried out by the 51st and 52nd Wings of the United States Ninth Troop Carrier Command, largely composed of American groups using C.47 (Dakota) aircraft. No. 38 Wing, composed of British aircraft and crews, was attached to the 51st Wing. It included all No. 296 Squadron (Albemarle aircraft) and one flight of No. 295 Squadron (10 Halifax aircraft).

The problem of training servicing crews for Rebecca had been discussed at the first meeting in July 1942 of the Airborne Forces Committee Signals Sub-Committee. It was estimated that six radio officers and 50 radio mechanics

[1]

	Rebecca		*Eureka*	
	Mark II	*Mark III*	*Mark II*	*Mark III*
Army Co-operation Command in U.K.	225	850	24	48
Airborne Force M.E.	500	875	—	80
Airborne Forces India and Far East..	500	10	—	50
Air Ministry (Intelligence)	24	—	—	400
Approximately 15 per cent for spares and 10 per cent war wastage ..	311	435	6	142
	1,560	2,170	30	720

(A.M. File CS.14847.)

[2] A.M. File CS.16429. [3] A.M. File C.30641/46. [4] A.M. File C.39546/49.

[5] A.M. File C.30641/46.

[6] In November 1942 two Halifax aircraft, equipped with Rebecca and operating from Skitten near Wick, towed two gliders carrying Royal Engineer personnel to demolish the 'heavy water' plant in Norway. One of the original Eureka beacons made in the T.R.E. laboratory and dropped by parachute with a specially trained Norwegian officer in the Telemark district, southern Norway, in October 1942, had been set up in the dropping zone. The ill-fated operation resulted in the loss of one Halifax and all the Royal Engineer personnel. The Eureka beacon was buried and was used again for supply-dropping operations in November 1943 and March 1944. In May 1944 it was replaced by a Eureka Mark IIIB beacon.

would be required. At that time two radio officers were being trained for Bomber Command at a three weeks' course at the T.R.E. They were posted to Army Co-operation Command after the course, two weeks of which were spent with Nos. 138 and 161 Squadrons at Tempsford in order to obtain first-hand knowledge of the working and maintenance of the equipment under Service conditions. On 8 August 1942 six radio mechanics were sent to the T.R.E. for one week's course. Thereafter radio officers and mechanics were trained at Netheravon with the help of the T.R.E. The C.S.O. No. 38 Wing, Wing Commander G. C. Godfrey, Flying Officer F. W. Campbell and Dr. Lines of the T.R.E. drew up a training syllabus for Rebecca operators which was in use in No. 38 Wing before Operation Husky.

During April and May 1943 a small crash programme was begun for producing quickly Rebecca/Eureka equipment for the combined operation and by the beginning of June all the Halifax and all but one of the Albemarle aircraft were modified to take Rebecca Mark II. The aircrews were trained in the use of the equipment by means of two Anson aircraft fitted with Rebecca Mark I and most of them had at least one instruction flight with Mark II in their own aircraft before leaving the United Kingdom. Training in the use of Eureka was given to about 40 personnel of the Independent Parachute Company, Airborne Division, and included such items as the choice of dropping zones and allowances for wind conditions. They also perfected their method of dropping with Eureka in a kit-bag strapped to their legs and let out on a length of rope before landing.[1] The first 60 sets of Rebecca Mark II and the first 28 Eureka Mark II beacons were allocated to No. 38 Wing but, owing to a last-minute decision to save weight on the Halifax aircraft, no sets were installed in them and the total available were the 30 sets in the Albemarles. Ten Eureka Mark II sets were flown out to Africa and another four were collected from Malta. American aircraft were fitted with the American version of Rebecca. Twenty-four new C.47 aircraft of 52nd Wing were fitted in the U.S.A. with an improvised version ; the receiver was a modified A.S.V. Mark II receiver with a tuning control enabling it to be operated on several channels by manual adjustment in the air. Eureka beacons were also sent from the U.S.A.

The results obtained with Rebecca/Eureka in Operation Husky were disappointing but this was attributed to poor servicing and the late and ineffective planning, rather than to inherent faults in the equipment itself. The deficiencies in planning were caused largely by the crash at St. Eval of the aircraft carrying the No. 38 Wing planning team to North Africa. Group Captain Sir Nigel Norman, whose knowledge of airborne forces' requirements was probably more comprehensive than that of any other R.A.F. officer, was killed. The servicing section in No. 38 Wing consisted of one officer, three N.C.Os. and nine airmen. Their task was difficult. In the first place, the test equipment and spares sent out by sea failed to arrive and servicing had to be carried out with what equipment had been flown out. The shortage of transport on the unit also added to the difficulties because it was impossible to carry out daily inspections and was probably the cause of unserviceability on operational sorties. The lack of planning was a serious fault. Plans to use Rebecca in the

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[1] Major J. Lander, O.C. 21st Independent Parachute Company, was mainly responsible for evolving most of the marking, and the kit-bag, techniques.

operation were made at the last minute, approval being given only after it was found that No. 296 Squadron was equipped and trained. Even then arrangements were unofficial, both in the 51st and 52nd Wing, where plans were made by No. 38 Wing in collaboration with the Independent Parachute Company. The system was regarded only as an auxiliary aid for a small fraction of the total force. In the landing at Syracuse on 9/10 July 1943 the use of Rebecca/Eureka was limited to homing to beacons at the base airfield and at Malta and Gozo because no Eureka beacons were taken to the dropping zones. In a landing made south of Catania on 12/13 July to capture and destroy bridges over the rivers Sureta and Gonalunga the party carrying one Eureka failed to reach the dropping zone and returned. A second Eureka was dropped but the aircraft did not receive the transmissions. Eureka beacons were again taken in on a supply-dropping operation for No. 2 Special Air Service Regiment but when the aircraft searched for them they could not be located. The use of Rebecca/Eureka in a landing behind Augusta was carefully planned but the operation was cancelled. Six Eureka beacons were dropped on one operation carried out by the 52nd Wing. One was located 30 miles from the agreed dropping zone and was therefore not followed. It was believed that the enemy captured and moved it to act as a decoy.

In spite of the disappointing results achieved with Rebecca in July 1943 some valuable experience was gained in the use of the equipment with airborne forces, experience which was to prove worth while in the Normandy landings. One lesson learned was that a more reliable method of getting Eureka to the dropping zone was required. It was also obvious that a less heavy beacon than Eureka Mark II and more than two beacons per dropping zone were needed. Another recommendation was that a member of the crew, other than the navigator, who at the dropping zone was busy searching for visual landmarks, should operate Rebecca, and it was proposed that the wireless operator should be given the responsibility. It was further recommended that guide beacons should be used for large-scale airborne force operations, that a pathfinder force should be specially trained and equipped to locate the dropping zones and ensure that the beacons reached them, that the whole of the follow-up force should be equipped with Rebecca, and that the light-weight Eureka Mark IIIA should be obtained as soon as possible. Certain recommendations for the technical improvement of Rebecca/Eureka were also made. These included a revision of the unreliable method of connecting the matching unit and aerial rod in aerial system Type 184, the simplification of the unnecessarily complicated switching system, and the installation of the Rebecca indicator unit so that it could be used by the wireless operator, not the navigator.[1] Above all, Operation Husky revealed the need for careful and accurate planning well in advance, and it was felt that a conclusive operational trial of the equipment had not been provided because of its disorganised use, but the heavy losses sustained in the operation clearly proved that a navigation system of the Rebecca/Eureka type was required to guide aircraft to the dropping zones. It was contended that effort spent on installing Rebecca, training crews and planning its use would be justified.[2]

[1] These recommendations were made by Mr. J. W. S. Pringle of the T.R.E., who visited the Mediterranean theatre from June to August 1943. He was sent out in order to obtain first-hand information on the operational use of Rebecca/Eureka.

[2] A.H.B./IIE/193/1. Rebecca in Operation Husky.

Operational Use in Special Operations

Complaints expressed at the end of 1942 about the poor operational results obtained with Rebecca/Eureka on S.O.E. flights caused the Air Ministry to ask the T.R.E. to investigate. T.R.E. experts visited Tempsford from 29 to 30 April and 19 to 22 June 1943. They reported that by the end of April half the Halifax aircraft of Nos. 138 and 161 Squadrons had been fitted with Rebecca Mark I and two Oxford aircraft had been fitted for training purposes. By the end of June all the Halifax aircraft for the two squadrons had been fitted retrospectively by a fitting party from No. 43 Group. The T.R.E. held that there were two main reasons for the poor results achieved with Rebecca/Eureka in the early part of 1943. First, the standard of servicing was very low because of lack of organisation, bad workshop accommodation and an insufficiency of test gear. Secondly, there was a general lack of direction and organisation at high levels, which resulted in inadequate training and insufficient air tests. The T.R.E. recommended that the establishment of R.D.F. officers at Tempsford should be reduced to two, the senior to be responsible for all operational aspects and training, and the junior for organisation and maintenance. More intensive training was urged on the basis of the syllabus used by No. 38 Wing. The T.R.E. considered that operations should be planned only in consultation with the senior R.D.F. officer at Tempsford, and should be carried out only with operators fully competent in the use of the equipment. Servicing inspections should be more frequent and more comprehensive. Finally, it was considered that the T.R.E. ought to be more concerned in the operational use of Rebecca/Eureka and recommended that Dr. Lines should be present at Tempsford during the next operational period to give his advice and that at all times the assistance of the T.R.E. should be sought until the system was considered to be satisfactory.

Poor servicing was the subject of a complaint from Headquarters Bomber Command in which it was stated that neither it nor Headquarters No. 3 Group had been able to give much assistance to Nos. 138 and 161 Squadrons because, the equipment being highly secret, they had not been given technical information. Also, the supply and installation arrangements had been made directly by the Air Ministry so that the two headquarters were unaware of them. In June 1943 the Air Ministry issued instructions that Headquarters Bomber Command was to be responsible for efficient maintenance of Rebecca/Eureka at Tempsford, and arrangements were made for the necessary technical information to be made available. This measure resulted in closer supervision of servicing procedure and a consequent improved standard of efficiency.[1]

As a result of the adoption of the recommendations put forward by the T.R.E., the operational results achieved with Rebecca/Eureka improved, but the value of the system was still doubted in some quarters. In September 1943 the commanding officer of Tempsford stated his belief that concentrated effort in the moon period obtained the best results and that use of Rebecca was unnecessary. He felt that extension of S.O.E. operations outside the moon period meant a general slackening off in that period and small achievement in the end. Official Air Ministry opinion disagreed, holding the view that if aircraft were not fitted with the equipment, bad weather during the moon period would preclude special operations altogether. The aim was that special operations could be attempted on all nights, regardless of the state of the moon

[1] A.M. File CS.13367.

and the weather. The S.O.E. itself reported that successes already obtained proved the value of the equipment and considered that if more Eureka beacons had been available more operations would have been completed. Rebecca/Eureka had been used on only a few operations but this was due not to distrust of the equipment but to a shortage of beacons in the field. Those that were available were of inferior quality and unreliable. In October 1943 the Air Ministry announced that squadrons at Tempsford were to be fully equipped with Rebecca because it had been proved by operations already carried out that it was a valuable means of pinpointing a small target. Rebecca/Eureka had thus proved its value for S.O.E. operations but the difficulty then to be faced was the shortage of equipment. Production was slow and S.O.E. requirements had to be fitted in with those of other organisations, particularly the heavy demands of the airborne forces.

Preparations for use in Normandy Landings

In the autumn of 1943 Army Co-operation Command was abolished. The R.A.F. elements of the airborne forces were regrouped in the 2nd Tactical Air Force, at first under the control of Headquarters Fighter Command, and later Headquarters Allied Expeditionary Air Forces, a combined British and American formation. The R.A.F. light-bomber force, No. 2 Group, was transferred from Bomber Command and earmarked for a future tactical role. No. 38 Wing was raised to the status of a group and began a programme of expansion. In October 1943 the establishment of the group was increased to four Albemarle, four Stirling and one Halifax squadrons, each consisting of 20 aircraft. The Whitley aircraft were relegated to O.T.Us. for training and the Stirling and Halifax aircraft were converted to be capable of carrying or towing a heavy load. The expansion meant an increased demand both for Rebecca and Eureka. The R.A.F. element was further augmented in the spring of 1944 by the transfer of No. 46 Group from Transport Command. This group used Dakota aircraft which by then were arriving from the U.S.A. already fitted with the American version of Rebecca. The Troop Carrier Command of the United States Ninth Air Force also assembled in the United Kingdom during the winter and spring of 1943 and 1944. Of this command the 52nd Wing had already taken part in the Sicily and Italy operations and was fitted with an early American version of Rebecca. The remainder of the force, all Dakota aircraft, had been fitted with the final American version of Rebecca and some crews had been given training in its use in the U.S.A. On 23 January 1944 it was arranged that the T.R.E. should assume responsibility, including design and post-design services, for American Rebecca equipment installed in aircraft of the Ninth Troop Carrier Command.

Preparation for the landings in Normandy included the training of aircrew of No. 38 Group in the use of Rebecca, which was carried out in Whitley Mark V aircraft of Nos. 295, 296 and 297 Squadrons. One difficulty experienced was the shortage of ground trainers which were urgently needed because they saved considerable time in air training. At that time the firm of Pye Radio had been given a development contract for two models but no production contract had been placed. Sir Robert Renwick therefore ruled that the development contract should be increased to ten and a production contract for 50 sets placed. Training arrangements included provision for glider pilots. At a meeting at Headquarters

Army Co-operation Command on 9 March 1943 it had been estimated that two battalions (800) of glider pilots required training in the operation of Rebecca. It was decided that the best method of ensuring this was by the establishment of training centres at Netheravon and at the headquarters of each of the two battalions of glider pilots. Ten instructors were to be provided by the Airborne Division. For the training of the instructors two officers were established in No. 38 Wing. They were sent to the R.A.E. for refresher radio training and certain special training required for working with Rebecca, and were then given an intensive training course at Netheravon, both on the ground and in the air, by Dr. Lines of the T.R.E. and the R.D.F. officer at Netheravon. The ten instructors of the Airborne Division then were given training by the two instructors from No. 38 Wing. After this had been done the two instructors reverted to the role of organising the training of glider pilots.

In February 1943 the Rebecca/Eureka requirement for No. 38 Wing had been estimated as 144 sets of Rebecca Mark II for Whitley aircraft, 430 sets of Rebecca Mark III for operational gliders and the training pool, and 42 Eureka beacons for operations and training. The requirement became quite inadequate when the airborne forces were reorganised and increased in strength. On 5 September 1943 Headquarters Fighter Command supplied the Air Ministry with details of the estimated requirements of the Tactical Air Force. No. 296 Squadron of No. 38 Wing, then in North Africa, was already fitted with Rebecca Mark II and required only spares and replacements. Nos. 295 and 297 Squadrons required 120 sets of Rebecca Mark II to allow for 100 per cent reserves; Rebecca Mark II was also required for tug aircraft to enable them to home to the landing zones selected by the advance party. Rebecca Mark III was required for a limited proportion only of the gliders to be towed by No. 38 Wing aircraft. The fitting requirement was limited to 12 Horsa and 40 Hamilcar gliders. A total of 18 Eureka beacons was required. At the end of April 1943 the Chief of the Air Staff ruled that provisioning of No. 38 Wing was to be afforded highest priority and, if necessary, all other programmes on high priority were to be overruled. On 5 October 1943 the Air Ministry informed Headquarters Fighter Command that a small quantity of Rebecca Mark II was already available and that main production was expected to begin in December 1943 at the rate of 150 sets per month. It was expected that all requirements of No. 38 Group would be met in full early in 1944. When the establishment of No. 38 Group was increased the requirement for Rebecca Mark II rose to 360 sets, and at the same time, with the increase in the scope of potential operations, which now envisaged 20 separate landing zones, the total requirement for Eureka beacons was increased to 80, preferably Mark IIIA, but Mark II if none other was available.[1] The equipment was required well in advance of the projected operations so that time was allowed for training and experience.

In November 1943 the shortage of Rebecca/Eureka equipment was causing acute concern. On 2 November 1943 the Director of Radar reported to the Controller of Communications that he had received many demands for the equipment from the Tactical Air Force, the Mediterranean Air Command, and from Air Headquarters India, and had found that available stocks were low and the various production programmes were in arrears.[2] One of the difficulties

[1] The requirements included sufficient equipment to enable a 100 per cent reserve to be held.

[2] R.D.F. was renamed Radar in September 1943 to conform with the terminology of the U.S.A.

was that potential users had not stated definite policies; this meant that it was difficult to estimate requirements and maintain pressure on development and production. In the meantime other programmes of specific nature and a higher priority had an adverse effect on Rebecca/Eureka production and fitting. A series of meetings, under the chairmanship of the Controller of Communications, was inaugurated in order to discuss the special requirements for Rebecca/Eureka and to devise measures to hasten the production and installation programmes to meet the operational requirements, bearing in mind other radar needs. On 18 November 1943 it was stated that the total requirement for Rebecca Mark II was 2,258 sets, and various measures were authorised to improve the situation. The production contract for Rebecca Mark II was increased to 3,200 and the Ministry of Aircraft Production was instructed to accelerate production by using additional contractor firms and by hastening type approval. Rebecca Mark III was required for all Hamilcar gliders and for 30 per cent of Horsa gliders, a total of 960; the existing contract was for 600 sets.[1] In January 1944 the Allied Expeditionary Air Forces' requirement was 250 Rebecca Mark II for powered aircraft, and 150 Rebecca Mark III for Horsa and Hamilcar gliders. By that date No. 38 Group had received 90 sets of Rebecca Mark II, production of which was expected to start in February 1944. Delivery of 200 sets by the end of March was anticipated. The forecast production of Rebecca Mark III was 150 by the end of January and 100 per month thereafter. In March 1944 the short-term provision to cover both training and operational requirements for the impending liberation of Europe was stated to be the installation of Rebecca Mark III in 50 of the 850 Horsa gliders available. The long-term policy was for the fitting of one-third of all gliders engaged in airborne forces' operations. Rebecca Mark I was more suitable for S.O.E. operations, and it was therefore possible to allocate all Rebecca Mark II deliveries to the A.E.A.F. By March 1944 the remaining stocks of Rebecca Mark I were exhausted and the Ministry of Aircraft Production initiated a contract for a further 200 sets for use on S.O.E. operations. By 25 April 1944 home requirements for Rebecca Mark I had been met and thereafter this version was installed in reinforcement aircraft sent to the M.A.A.F. By the beginning of May 224 sets of Rebecca Mark II had been delivered of which 200 had reached No. 38 Group.[2]

In spite of the fact that the Rebecca/Eureka system was considered to be inherently secure, the part it was expected to play in the initial landings was thought to be of such vital importance that certain measures were taken to prevent effective jamming by the enemy. The risk from ground stations located more than 30 to 40 miles from the dropping zones was slight, and plans to neutralise the German ground jamming systems had been made for other reasons, principally because of their effect on Gee. A more serious danger was employment by the enemy of airborne jammers. A detailed appreciation of the possibilities was made in February 1944 but it was not until the middle of May, after airborne jammers had been used by the *Luftwaffe* during a raid against Portsmouth, that an emergency programme was initiated to provide aircraft of No. 85 Group, Tactical Air Force, with the means of homing to airborne jammers. Several Lucero equipments were modified by the T.R.E. to give the widest possible frequency coverage in that role; the whole programme, involving extensive work on the equipment and its installation in six aircraft, was

[1] A.M. File C.39546/49.
[2] A.M. File CS.13367.

completed within ten days, whilst special jammers were also built for use in training. The anti-jamming aircraft were employed during the landings in accordance with plans made with Headquarters No. 11 Group and Headquarters No. 85 Group, but, in the event, the enemy did not employ airborne jammers against the system.[1]

The shortage of Eureka was more acute than that of Rebecca, partly because the beacons were required as an item of test gear as well as for operations, and partly because they were highly expendable, many being damaged or destroyed in the field. The same problem of conflicting requirements existed as for Rebecca. On 18 November 1943 it was stated that the requirement for Eureka Mark II was 225 for the airborne forces in the United Kingdom, 100 for the Mediterranean Air Command, 100 for the airborne forces in India and 30 for the Tactical Air Force; existing contracts covered the provision of 505 beacons. Eureka Marks IIIA and IIIB were required in large numbers and the Controller of Communications ordered contracts to be increased to 500 Eureka Mark IIIA and 1,600 Eureka Mark IIIB.[2] The latter were required by the S.O.E. for use in the United Kingdom, Mediterranean and India up to December 1944.[3] In January 1944 Headquarters Allied Expeditionary Air Force stated a requirement for 30 Eureka beacons for A.E.A.F. and 175 for No. 38 Group. The stock of Eureka Mark II was very low; the production forecast was 50 in January, 75 in February, 100 in March and thereafter 100 per month. Eureka Mark IIIA beacons were of the greatest use for S.O.E. operations and a crash programme of 100 Eureka Mark IIIA was started in December 1943, 50 of which were allocated to the S.O.E.[4] By February 1944, 40 Eureka Mark IIIA beacons were available and priority had to be decided between the requirements of S.I.S.[5] and S.O.E. The S.I.S., to meet its projects for Operations Crossbow[6] and Overlord,[7] required 30 for dropping during the March moon period and 20 during the April moon period. Thereafter 15 per month were required for May, June and July. The S.O.E. maintained that three or four times the number of special operations could be carried out if more Eureka beacons were available, and held that meeting the S.O.E. requirement for Rebecca/Eureka would be fully justified by the consequent reduction in the number of abortive sorties and the increase in scope of special operations in dark periods and bad weather. 500 Eureka Mark IIIB were required by 1 March and 810 by 1 June. This, added to the needs of the S.I.S., made a total requirement of 1,405. Attempts were made to resolve the conflicting priorities and on 13 April 1944 it was agreed that allocation should be made in proportion to stated requirements, that is, three to one, on each consignment of beacons delivered from the manufacturers. There was no conflict between Headquarters Allied Expeditionary Air Forces and the S.O.E. over Eureka requirements because Eureka Mark IIIB was unsuitable for operations carried out by the former.[8] By April 1944 the number of S.O.E. sorties carried out averaged 1,000 per month from

[1] T.R.E. Report, 'Work of T.R.E. in the Invasion of Europe'.

[2] A.M. File C.39546/49.

[3] A.M. File C.16332/44. The total extra cost involved by the increase of the Eureka Mark III programme was £138,000.

[4] A.M. File CS.13367.

[5] This organisation was controlled by A.I.2(c) at the Air Ministry.

[6] The code-name given to all operations against rockets and flying bombs.

[7] The code-name given to operations in north-west Europe.

[8] A.M. File CS.13367.

the United Kingdom, 1,000 per month from bases in the Mediterranean area and 500 per month in the Far East, and the existing supplies of Eureka beacons were sufficient only to cover 10 per cent of the operations.[1] By the middle of the month Eureka Mark IIIB equipment had been delivered by the firm of Cossor, 10 to the S.I.S. and 17 to the S.O.E. The first contract with the firm was due for completion in August 1944 and a second was to be placed in November, the gap between the two being filled by another firm scheduled to produce 25 sets per week from July. Considerable difficulties were being encountered with the production programme. One was a hold-up at the contractors caused by the high number of sets that were faulty. R.E.M.E. personnel from the S.O.E. organisation had been allocated for fault-finding duties and had proved invaluable but only two of the six men originally promised were sent and they could not cope with the entire output. The S.O.E. was urged to reinforce them and two more were sent in July. Another difficulty was caused by the shortage of test gear.[2] In June 1944 the Air Ministry reported that Eureka Mark II had been given wide operational use and the revised requirements were estimated at 1,323. This, it was believed, would cover the requirements of the Tactical Air Force, the airborne forces in the United Kingdom, M.A.A.F., and Air Command, South-East Asia, the S.O.E., training, spares and wastage. The wastage rate of Eureka Mark II beacons was very high because they were dropped with the pathfinding force of paratroops, and after the main force had been dropped, were usually destroyed to avoid the possible risk of capture by the enemy; the paratroops could not guard the beacons because they were engaged in active fighting. The Ministry of Aircraft Production therefore obtained financial sanction for the provision of an additional 818 Eureka Mark II beacons at a further cost of £81,800 on 24 July 1944.[3]

Another reason for the difficulty in obtaining supplies of Eureka beacons lay in the fact that not only the Air Ministry but also the Admiralty required them. In September 1944 the latter stated a requirement for 20 Eureka Mark IIIB to meet a training commitment between September and December 1944, and 600 Eureka Mark IIIA. At a meeting held at the Air Ministry on 26 September 1944 the Admiralty was asked to consider using the American version, AN/PPN-1, instead of Eureka Mark IIIA. Two sets of the American equipment were supplied for flight trials. Promising results were obtained, and in consequence the Admiralty cancelled its contract for 600 Eureka Mark IIIA. It was decided that the components released by this cancellation were to be used for an additional quantity of 600 Eureka Mark IIIB, thus increasing the total contract to 2,700.[4]

Production in the U.S.A.

One method of relieving the shortage of Rebecca/Eureka equipment was by obtaining supplies from the U.S.A. American interest in Rebecca/Eureka was first stimulated in the summer of 1942 when the U.S.A.A.F. was beginning to increase its strength in the United Kingdom. The troop carrier operations planned for Operation Torch, the landings in French North Africa, provided an opportunity for trying out the system. Four of the latest-type Dakota aircraft (C.47) of the Troop Carrier Command were fitted with British Rebecca Mark I and two officers were trained at the T.R.E. in the operation of Eureka, with the

[1] A.M. File CS.22066. [2] A.M. File CS.13367. [3] A.M. File CS.23062.
[4] A.M. File C.16332/44.

intention that they should be sent out in advance to set up a beacon as a guide for the aircraft flying from England. Unfortunately the system was not used because the risk of discovery was deemed to be too great and the beacon was destroyed. This experimental installation had, however, interested the U.S.A.A.F. authorities in the use of Rebecca/Eureka for transport and paratroop aircraft. At a meeting held by Sir Robert Renwick on 10 November 1942 it was agreed that the U.S.A.A.F. should allot one C.47 aircraft for fitting with a prototype Rebecca Mark II installation. The T.R.E. co-operated fully with the American authorities, giving them all available technical information. The aircraft was fitted at Burtonwood in January 1943 and left for the U.S.A. on 10 February; a Eureka Mark I beacon and an experimental model of the miniature Eureka Mark III were also supplied. In the meantime four U.S.A.A.F. mechanics were given a short course at the T.R.E. and thereafter went to Netheravon to gain experience in the ground servicing of Rebecca.[1]

Shortly afterwards, since it was clear that U.S.A.A.F. troop carrier aircraft would form the bulk of any Allied force in airborne army operations, Mr. R. Hanbury Brown of the T.R.E. was sent to the U.S.A. to give technical advice. He was largely responsible for the initiation of an extensive programme of fitting C.47 aircraft with the American equivalent of the British equipment. Development of the American version proceeded quickly and by April 1943 an interim Rebecca/Eureka system had been developed. Interim Rebecca was known as AN/APN-5 and consisted of a transmitter/receiver unit, two convertors and three aerials. The transmitter could be preset by screwdriver adjustment anywhere between 214 and 234 megacycles per second; the receiver consisted of an American version of A.S.V. Mark II with a local oscillator modified to cover 214 to 234 megacycles per second; the indicator was an unmodified A.S.V. Mark II indicator. The aircraft aerials were vertically polarised and consisted of two azimuth aerials on each side of the aircraft nose with a transmitting aerial under the nose. Each azimuth aerial consisted of a single dipole and director transmitter aerial complete with a wave radiator and one director. The interim Eureka was designated AN/TPN-1 and consisted of a modified version of I.F.F. Mark IIIG.[2] By July 1943 production had started in the U.S.A. of the final-type Rebecca/Eureka equipments. The final type of Rebecca was known as AN/APN-2 and its installed weight was approximately 75 pounds. It had a superheterodyne receiver, and a transmitter with five preset frequency positions and two manual frequency changes. The frequency coverage was 212 to 236 megacycles per second. The power output was approximately 500 watts. Three time-base ranges were available, 10 miles, 50 miles and 100 miles. The production version of Eureka was known as AN/PPN-1 and an improved version was designated AN/PPN-2.[3]

When in 1943 the shortage of Eureka beacons was acute in the United Kingdom attempts were made to obtain supplies from the U.S.A. In August 1943 the Ministry of Aircraft Production signalled to the British Air Commission an urgent requirement for 100 AN/PPN-1 for the S.O.E. because the supply of Eureka Mark III was almost exhausted. Fifty beacons were despatched in October and 50 in November. Of the first consignment two were allocated to the T.R.E. for examination. Two poor features which reduced the performance of the beacon were reported. First, the received band width was 2·0 megacycles

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[1] A.M. File C.39546/49. [2] A.M. File C.39546/49. [3] A.M. File C.30703/46.

per second instead of 3·5 megacycles per second, which had been considered desirable in the British equipment. Secondly, the aerial system was badly matched on 214 megacycles per second, which apparently caused poor ranges on that channel. However, no improvements could be incorporated in AN/PPN-1 because of the speed of production, but recommendations made by the T.R.E. were considered for a later improved version. Again in November 1943 the Ministry of Aircraft Production stated a minimum requirement of 50 Eureka beacons because all the demands of the British forces could not be met from home production. One difficulty in obtaining supplies from the U.S.A. was the large numbers needed by the American forces, not only in the European theatre but also in south-east Asia and the Pacific. While this need persisted the U.S.A. authorities were reluctant to issue equipment to the British forces and the British Air Commission hesitated to pass on requests from the Ministry of Aircraft Production for Eureka unless there was some assurance that its operational use would benefit American troops. In April 1944, Eureka beacons manufactured in the U.S.A. were being used in special operations by and for the Americans. By that date two squadrons of the U.S.A.A.F. were engaged on special duty operations and, fitted with Rebecca, were guided by Eureka beacons which were available for either British or American aircraft. The vital need for Rebecca/Eureka in S.O.E. operations in order to increase their scope and to reduce the number of abortive sorties was constantly stressed. In fact the Air Ministry estimated on 25 April 1944 that if sufficient equipment were available the effect would be equivalent to increasing the strength of the aircraft operating by some 20 to 30 per cent. British production of Eureka Mark III beacons was totally inadequate for S.O.E. needs although all of it had been allocated for this purpose. On 21 May 1944 the Ministry of Aircraft Production informed the British Air Commission that the minimum needs until the end of the year were 625 for the airborne forces and 930 for the S.O.E. In the U.S.A. General McClelland proved himself very helpful and applied all possible pressure to the Signals Corps in order to increase production.[1]

Operational Use in the Normandy Landings

The plans for the airborne army landings in Normandy were based to a large extent on the experience gained from Operation Husky. The final plans for the main operations were ready a fortnight before D-Day. The 6th Airborne Division was to be landed near the bridges crossing the Caen canal, while the two American divisions were to attempt to cut off the base of the Cherbourg peninsula. At the last moment the American plan was changed because of recent German troop movements and both divisions were to be landed near each other on the east side of the peninsula.

Rebecca/Eureka had three functions in A.E.A.F. operations; first, at base airfields, secondly, at rendezvous points and, thirdly, at dropping and landing zones. The British force, consisting of Nos. 38 and 46 Groups from airfields in the Salisbury and Swindon areas, crossed the coast in three streams at Worthing, Littlehampton, and at Bognor, and proceeded to a point off the French coast, near Le Havre, but just outside the range of the powerful coast defences. They then turned right, the Window-dropping diversion going straight on to the east of Le Havre area; the main force, arriving off the coast about the end of the Caen canal, flew inland to its various objectives. Three dropping zones were

[1] A.M. File CS.22066.

used ; general navigation to the dropping areas and timing of the aircraft to arrive at intervals of exactly 15 seconds at their release point was based on Gee. Coded Eureka beacons were put in operation at the three points on the south coast where the streams of aircraft had to cross. Each was on a different frequency channel, the same channel as that of the dropping zone to which the aircraft were proceeding, thus providing a final check before leaving England. The pathfinder forces had to drop their troops with the aid only of map-reading and Gee but the main force had Eureka beacons set up at each of the dropping zones working on different channels with no coding. The bulk of the British force in the first night's operation consisted of paratroopers, but two small glider-borne forces made attacks ; one against the Canal bridges and the other against a coastal battery. The three Horsa gliders used by the second force were fitted with Rebecca Mark III and it was hoped that the Independent Parachute Company would be able to move the Eureka beacon from dropping zone ' V ' to the neighbourhood of the battery in time for the glider landing. The Rebecca Mark III installations were working well as the aircraft crossed the rendezvous beacons on the way out but the Eureka beacons did not reach the landing area in time to be of assistance.

In addition to setting up Eureka beacons, the advance troops of the Independent Parachute Company had to put out an elaborate lighting system in the form of a ' T ' to provide visual aid. Preliminary reports seemed to show that the extent to which Eureka was used depended on the amount of visual aid available at the particular dropping zone ; aircrews preferred to rely on visual aids where possible, and on D-Day visibility at dawn was good. At dropping zone ' N ', where the lights were good, about 20 per cent of aircraft used Eureka to help them locate the target or to determine their range from it on the approach. At dropping zone ' K ', where the lights were not so good, 50 per cent of the aircraft used Eureka and at least one pilot dropped his troop with its aid. At dropping zone ' V ' no visual or radio aids were observed and this part of the follow-up force went astray to some extent and its troops were dispersed. The following evening the same zones were used again for a mass landing of gliders as reinforcements, and for resupply. By that time the beacons had been resited on more favourable ground and very good ranges were reported from a large proportion of the aircraft.[1]

Between 6 June and 10 July 1944 Headquarters No. 38 Group kept a complete record of the operational results of the use of beacons at base airfields. On 346 flights the average range obtained in homing was 25·2 miles at an average altitude of 2,170 feet. The amount of interference reported was negligible and serviceability figures averaged 90 per cent. Similar results were obtained from Eureka beacons installed at rendezvous points in the United Kingdom for aircraft participating in the operation, but the use of Rebecca/Eureka at dropping and landing zones was not so successful. An average of 10·5 per cent only of the total number of aircraft involved made successful use of the system to home to their targets, possibly because the majority of navigators preferred to find the targets by an alternative radar system (Gee) or by visual means. The general conclusion reached as a result of the study of the use of Rebecca/Eureka in No. 38 Group operations during June and July 1944 was that it was very satisfactory as a homing system to base airfields or to any specific point in

[1] T.R.E. Report, ' Work of T.R.E. in the Invasion of Europe '.

friendly territory. It was not so reliable as a homing system to targets in enemy territory but the percentage of success was sufficiently great to warrant its continued use. When it was possible for aircraft to receive the Eureka signal it proved a reliable homing aid. The handicaps to fully successful use of Rebecca/Eureka in enemy-held territory were the difficulties of siting Eureka beacons in the best possible position for transmission, the difficulties of adequately servicing the beacons, and the danger of Eureka being damaged or destroyed by rough handling or by enemy action.[1]

The Ninth Troop Carrier Command of three wings was based near Grantham, Reading, and Exeter. Aircraft had to cross the coast at Selsey Bill and fly to the west of the Cherbourg peninsula, turning off their southerly course when level with the base of the peninsula and flying across it from west to east. Again a Window diversionary force continued southward. Since only the leading aircraft in the American formations were fitted with Gee and SCR. 717C search radar, more use had to be made of track-marking beacons and four were provided either in England or in ships along the route. There were six dropping zones for the American troops. The pathfinder force flew in three aircraft per zone, the leader in each case navigating by Gee and the other two being ready to take over the lead immediately with sets fitted with other R.F. units if both the top Gee channels should be jammed. The advance troops marked the dropping zones with Eureka beacons. In some cases lights were also used but where enemy opposition was too great for visual aids to be provided the troops sheltered in ditches with only the aerial of the beacon projecting above ground. Of the follow-up force about 75 per cent used Rebecca to find the target and over 25 per cent dropped blind with its assistance owing to the absence of any visual signals from the ground. The American plan provided for manual coding of Eureka signals in addition to correct frequency selection as a safeguard against enemy decoys and this was successfully used.

The successful use of Rebecca/Eureka in the airborne army landings in Normandy justified the effort expended in development, production and training in the months before the operation. The reputation of the equipment, which had been shaken by its disappointing results in the Sicily landings the previous year, was restored and it was proved, as many had maintained, that the earlier failure was due not to an inherent weakness in the system but to lack of organisation. For successful operations troops had to be dropped, or gliders landed, in a compact force on a predetermined zone. The results of the Normandy operations proved that Rebecca/Eureka was helpful in locating dropping points where visual markers were ineffective through weather or other conditions.

Provisioning for Use in North-West Europe

As the Allied armies advanced across France the problem of supplying isolated units cut off from normal supply lines emerged, and the use of Rebecca/Eureka in resupply operations appeared essential. At a meeting at the T.R.E. on 20 June 1944 it was stated that no major developments of the equipment for the normal troop-carrying function seemed likely but future work depended on the use to which the system was put for the close-support and resupply roles. Special provisioning methods were devised for supplying Eureka beacons to

[1] A.E.A.F. Report AEAF/TS15512/Nav dated 7 August 1944. A.M. File CS.22822.

airborne forces. The Air Ministry was responsible for initial provisioning based upon recommendations from the War Office, and until they were required the beacons were stored and serviced at Headquarters No. 38 Group, where instructions for army personnel on siting and installation were prepared. Co-ordination of the times of operation of beacons during resupply operations was obtained by briefing in the United Kingdom of personnel taking part. Army personnel did not service beacons in the field, failure to operate being covered by the provision of a liberal number of spares. If possible, beacons were returned after completion of an operation to Headquarters No. 38 Group, where repairs or major overhauls were carried out; if not, they were destroyed in the field. The co-ordination of storage, preparation, issue, and maintenance at one central depot was found to be essential to ensure standardisation in setting up the required frequency channels and to save time and effort in getting beacons received from the contractors tested, set up and issued for use.[1] In September 1944 Headquarters A.E.A.F. requested the modification of Eureka Mark II to give higher power output because a more reliable equipment was required for operation on a 24-hour basis on airfields. The Ministry of Aircraft Production opposed this suggestion because modifications to improve the performance of the equipment would result in delays in production. Therefore the Air Ministry decided that production should proceed on the existing design, which was considered satisfactory for paratroop and supply-dropping operations.

The landing of Allied armies in north-west Europe was the signal for greatly increased activity among the resistance movements in the occupied countries. They needed supplies, and beacons to guide the supplying aircraft. On 24 June 1944 General Eisenhower signalled General Marshall in the U.S.A. asking for an allocation of Eureka for S.H.A.E.F. over and above those already allocated to the American forces in the United Kingdom. The U.S.A. authorities suggested that, as the entire June and July production had been allocated, S.H.A.E.F. should redistribute its own allocation as seemed fit. In July the Air Ministry informed S.H.A.E.F. that all Eureka beacons received from the U.S.A. were sent to Tempsford for issue to the S.O.E. and were used in western Europe, but British equipment was allocated between the various theatres and users, the war against Germany being given priority. Conflicting demands were referred to the Deputy Chief of the Air Staff for a decision. In spite of these urgent requests Eureka equipment was not available in the quantities required in north-west Europe in the early stages of the liberating operations. However, by the winter of 1944 the type of activity requiring Rebecca/Eureka equipment was very much reduced. In November 1944 the requirement was estimated at 2,430 AN/PPN-1 and 2,535 AN/PPN-2 for 1944 and 1945; this covered the known requirement supplemented by British production of Eureka Mark IIIB.[2]

The airborne forces found that the light-weight beacons, Eureka Mark III and the American AN/PPN-1, did not meet their requirements as well as did Eureka Mark II, and production of Eureka Mark II was given overriding priority at a meeting on 6 September 1944. This was also accorded to the delivery of controlled components but, even so, the Ministry of Aircraft Production could not promise delivery at a rate greater than 50 in February 1945, 100 in March and 150 per month thereafter. By the spring of 1945 a serious set-back to the production of the miniature Eureka Mark III beacons occurred because of the cessation of production of the American Type 9000 valves, the number of

[1] A.M. File C.30633/46.

[2] A.M. File CS.22066.

miniature beacons which could be made being limited by the stock of valves. The Air Ministry, however, stated on 25 March 1945 that the estimated production of the equipment in addition to the AN/PPN-1 sets available from the U.S.A. would suffice for all needs in the European war and for interim supplies to A.C.S.E.A.[1]

Operational Use in Overseas Commands

The use of Rebecca/Eureka was extended to overseas theatres of war when successful operations at home had proved how valuable it was for target location. Its application in areas outside the United Kingdom was limited because of the shortage of supplies; most of the equipment available was required for home operations.

In September 1942 the possible employment of Rebecca/Eureka was considered in the Middle East. The Operational Research Section at Headquarters R.A.F. Middle East recommended that the system be used in a comprehensive way as an integral part of all close-support operations. Its use in the United Kingdom was limited to specialised operations but its employment on a large scale was considered better for the Middle East because of the peculiar geographical features of the theatre. The possible uses to which Rebecca and Eureka could be put included position plotting, bombline direction, air-to-ground co-operation, target-marking, supply-dropping, and landing-point location. In October 1942 the Operational Research Section, Middle East, estimated that for operations in the Western Desert and the Delta 1,700 Rebecca, 450 Eureka Mark II, and 100 Eureka Mark III equipments were required. Additional quantities of equipment would be needed if hostilities spread to the Levant and Iraq; in addition to Rebecca installations in the aircraft engaged, 250 Eureka Mark II and 50 Eureka Mark III beacons would also be needed. In November 1942 Headquarters R.A.F. Middle East stated that Rebecca was not to be fitted in single-seater fighter, tactical reconnaissance or close-support aircraft. In January 1943 twelve sets each of Rebecca Mark I and Eureka Mark I and nine modification kits for Wellington Mark III aircraft were despatched from the United Kingdom to the Middle East. At the same time an R.D.F. officer and two mechanics trained in the servicing and fitting of the equipment were posted there. By April 1943 one Wellington, one Hudson and two C.47 (Dakota) aircraft had been fitted with Rebecca. Up to that time Rebecca was used in conjunction with parachute dropping only, because it involved merely simple homing with a Eureka beacon. The extended use of the system for direct air support, target indication and bombline definition involved fixing at a distance from the beacon and consequently a much higher standard of operation and much practice.[2]

The first operational use of Rebecca/Eureka on a large scale in the Mediterranean theatre was in Operation Husky. From 11 June to 26 August 1943, Mr. J. W. S. Pringle, of the T.R.E., visited the area to assist No. 38 Wing, to obtain first-hand information on the operation of air support in a land campaign, and to advise on the applications of Rebecca and related projects in the Middle East. Several recommendations were made to improve the R.D.F. organisation in the Mediterranean theatre. One feature noted was the lack of up-to-date information. Most of the R.D.F. staff officers had been overseas

[1] A.M. File C.16332/44.

[2] A.H.B./IIE/188/19. Rebecca.

for several years and were out of touch with the latest radio development at home. They were not able to appreciate the uses to which the newer radio systems might be put. The lack of information also resulted in requirements not being stated clearly. Overseas commands did not know what to ask for and departments at the Air Ministry could not always visualise completely overseas needs.[1]

The use of Rebecca/Eureka in the Far East theatre of war was accepted as early as December 1942. The Air Ministry stated that Rebecca Marks II and III and Eureka Marks II or III would be required.[2] Different types of Rebecca and Eureka were needed according to the operation planned. Eureka Mark II beacons were needed to cover resupply operations. Mobile beacons were urgently needed in that area because forward ground troops were completely dependent upon air supply for the whole period of operations, not merely during the assault phase, as in Europe. It was anticipated that Eureka would be deployed in forward areas with the minimum of servicing for weeks at a time, perhaps even months. Rebecca/Eureka homing was essential during the monsoon because in this period air supply had to be maintained even if operations were curtailed.[3] Eureka Mark III beacons were intended for use to mark paratroop dropping zones and on advanced landing strips. Rebecca Mark II was required for powered aircraft and Rebecca Mark III for gliders.[4] In spite of early requirements being stated equipment was not available for the Far East because commitments in the United Kingdom had priority. Demands for variations of the equipment continued to be received by the Air Ministry. From June 1944 urgent requests for Rebecca Mark IIB for retrospective installation in Liberator GR aircraft of Air Command South-East Asia were made. Rebecca was needed to replace SCR. 729, an American interrogator, which was difficult to read and unsuitable for homing and beam approach purposes. Every effort was made by the Air Ministry to fulfil this requirement but it was not until the end of March 1945 that 25 equipments were ready for despatch. These were used for fitting the Special Duty aircraft of No. 358 Squadron.[5] On 31 July 1944 Headquarters Air Command South-East Asia asked for 128 Eureka Mark IIIA and a meeting was called at the Air Ministry on 8 August to consider the request. It was stated that there was a general shortage of Eureka Mark IIIA and operations in Europe had priority over those in the Far East. At the end of that month the Air Ministry arranged for the despatch from Tempsford of 25 Eureka Mark IIIB to A.C.S.E.A. because supplies of that Mark at Tempsford were reasonable. By November 1944 131 Eureka Mark IIIB had been sent, 73 of which had been specially released from Tempsford. In December 1944 the S.O.E. stated a requirement for 50 Rebecca installations and 50 Eureka Mark IIIB beacons for supply operations in the Pacific area. As urgent demands for equipment continued to be received whatever could be spared was sent but the amount was small.[6] In April 1945 it was reported that only a very small fraction of the requirements of A.C.S.E.A. for Eureka had been met because of slow production in the United Kingdom. In order to bridge the gap I.F.F. sets were modified locally to operate on A.I. and A.S.V. frequencies, 193 and 176 megacycles per second respectively. Also a small quantity of AN/TPN-1 and AN/TPN-3 I.F.F. sets modified in the U.S.A. were sent to the Far East. From March 1945, Horsa gliders were

[1] A.H.B./IIE/193/1. T.R.E. Report No. 1573. [2] A.M. File CS.14847.
[3] A.M. File C.16332/44. [4] A.M. File C.30703/46. [5] A.M. File C.16215/44.
[6] A.M. File C.16332/44.

despatched at the rate of 20 per month all fitted on the production lines with the parts necessary for the installation of Rebecca Mark III. Kits, drawings and leaflets to enable 10 per cent of the gliders to be fitted with Rebecca Mark III retrospectively overseas were also provided.[1] Because of the shortage of beacons allocations were decided by Headquarters Air Command South-East Asia at monthly meetings, according to the importance of the task for which they were required. The end of the war with Germany made the supply position easier but even then complaints were received about the shortage of equipment. At the end of May 1945 Army and R.A.F. authorities were seriously alarmed at the shortage of beacons because the monsoon was breaking in Burma. The Air Ministry therefore arranged for 25 Eureka Mark II beacons to be despatched on top priority.[2] On 12 July A.C.S.E.A. reported that there were no stocks of British Rebecca and even supplies of the American version had been exhausted. About 100 Dakota aircraft, some Liberator aircraft of No. 357 Squadron, and Halifax aircraft of No. 293 Squadron, required installations. As an interim measure the Air Ministry arranged for the release from Tempsford of 50 Rebecca Mark I plus the necessary spares. Twenty-five Rebecca Mark II were also sent.[3] In July 1945 A.C.S.E.A. stated a requirement for 200 Eureka Mark II beacons per month. The heavy demand was occasioned by Special Duty operations in which the proportion of abortive sorties was high, because the Rebecca/Eureka system was not efficient. Low efficiency was due partly to an acute shortage of Rebecca but mainly to beacon failure. Many of the beacons never functioned at all and A.C.S.E.A. considered that the best plan was to drop beacons in pairs until the cause of failure could be ascertained and removed.[4] The shortage of Rebecca and Eureka equipment was made more acute by its failure to withstand climatic conditions. The early Marks were not tropicalised and suitable modifications had to be incorporated to enable them to be used for more than very short periods.

Rebecca/Eureka was adopted in the Bengal-Assam-Burma theatre in February 1944 but full implementation of the policy was not possible for several months because of the shortage of equipment and the scarcity of radar mechanics in the command. From February 1944 to January 1945 the transport squadrons, Nos. 31, 62, 117, 194, 435 and 436, were gradually fitted with AN/APN–2, and No. 357 Squadron was fitted with Rebecca Mark II. The establishment of each squadron was increased to allow for a Rebecca servicing party consisting of one sergeant, one corporal and nine aircraftmen. By February 1945 the installation programme for the squadrons was almost completed. Eureka beacons were employed in three ways in this theatre ; at base airfields, at forward airfields, and to mark supply-dropping points. The scheme was inaugurated in February 1944 and by March Eureka beacons were installed at Comilla and Agartala for aircrew training. Eureka beacons (AN/TPN–1) were set up at base airfields in such a way that there was an adequate chain at each stage of the advance of the ground forces from the Irrawaddy bend to Rangoon. Throughout the months until the end of the war with Japan a shortage of radar mechanics existed. This made it impossible to have a trained man on each site solely for the purpose of keeping the beacon in operation. Instead the beacon was switched on and supplied with power by air traffic control personnel. This was not very satisfactory, as accumulators were over-charged and then

[1] A.M. File CS.23799. [2] A.M. File C.30633/46. [3] A.M. File C.39546/49.
[4] A.M. File C.16332/44.

allowed to run down very low before recharging. This resulted in all components receiving a highly fluctuating power supply giving rise to varying ranges of pick-up which made navigators lose confidence in the equipment. Another fault was delay in reporting unserviceability. Signals wings were responsible for servicing but they too were so short of radar mechanics that routine inspection visits to sites were very uncertain. Eureka beacons used at forward airfields were the same type as those used at base airfields, AN/TPN–1. In April 1945, A.C.S.E.A. allocated 12 beacons for use on forward airstrips being temporarily used by transport aircraft. There was not such a shortage of radar mechanics as at base airfields for, whenever possible, a radar mechanic was kept at each beacon site. There was however a general shortage of radar mechanics, Eureka beacons, spares and test gear until the middle of 1945, and this proved the greatest handicap to the Rebecca/Eureka system. Nevertheless, serviceability of Eureka beacons at base and forward airfields was maintained at a fairly high standard, mainly because of the great efforts made by the few servicing personnel that were available, and successful improvisation.

Eureka beacons were also set up by forward Army units to mark points where supplies were to be dropped, the beacons used being the American AN/TPN–1 and British Eureka Marks II and IIIB. The use of Eureka to mark supply-dropping points was not successful; analysis of a sample of 9,321 dropping sorties showed that Rebecca was used to locate zones on 330 occasions only. There were several reasons for this. The beacons used were light-weight and therefore not robust; there was a lack of co-operation between the Army and R.A.F. at all points; the operators were initially untrained and consequently beacons were badly sited and power supplies were poor; Eureka operators were engaged on brigade signals work as well as beacon operation and when the pressure of work was high the beacon was apt to be neglected; it was very difficult to find good sites for beacons because the supply-dropping points had to be located at spots free from enemy attack and these were usually poor for Eureka transmission; both aircrew and ground operators easily lost faith in the system, ground operators if they had several beacons which quickly went unserviceable, and aircrew if they experienced several failures to locate Eurekas. Fortunately night drops were not necessitated in the area, since there was little enemy air opposition. Otherwise the shortage of success of Eureka beacons might have had even more serious results if night drops had been the only means of getting supplies to the troops. A definite policy for the supply and use of Eureka for supply-dropping operations was not formulated until February 1945 and was not fully operative even at the end of hostilities.[1]

Requirement for Talking Rebecca/Eureka

In the early part of 1944 the S.O.E. expressed a requirement for a portable communications system. By the middle of July 1944 the Telecommunications Research Establishment had completed development of a Rebecca/Eureka system to which duplex speech communication facilities had been added. In the aircraft installation a communication unit, measuring 9 by 8 by 18 inches, was incorporated in Rebecca Mark II. The normal interrogator system consisted of a transmitting aerial having fair all-round looking properties and two receiver aerials, one on each side of the nose of the aircraft. There were considerable

[1] A.C.S.E.A. O.R.S. Report No. S.71 dated 19 November 1945.

variations in signal strength as the aerials were switched from port to starboard except when the beacon was either dead ahead or astern. As the variations were likely to distort the received speech, a second aerial system, consisting of an omni-directional quarterwave element, was connected to the receiver by means of a remotely controlled aerial switch. The homing system was disconnected at the same time so that only range indication was given when the second aerial was used. A strobe unit was introduced to reduce the background noise. On the ground a Eureka Mark III beacon was used with the normal Eureka collapsible aerial and the addition of a speech unit which was approximately the same size and weight as the beacon. Communication was effected by means of the S-phone and the equipment was designed to give roughly the same communication ranges as the S-phone while, at the same time, retaining its normal homing and range measuring facilities.

Aircraft homed to the Eureka beacon by means of Rebecca until within 10 miles of the ground station. Speech transmission was then obtained by switching the interrogation pulse recurrence frequency from 300 cycles per second to 5 kilocycles per second and by modulating it over the band 3·8 kilocycles per second to 6·2 kilocycles per second. The ground station then detected the incoming pulses and, by suitable integrating circuits, the recurrence frequency was filtered out and the speech presented at the headphones of the beacon. The reverse channel was different. It was impossible to vary the pulse recurrence frequency of the beacon response because range indication to the interrogating aircraft had to be maintained. This difficulty was overcome by locking the beacon to the 5 kilocycles per second incoming pulses, the width of beacon responses being varied from 5 to 15 micro-seconds at a rate corresponding to the speech frequencies. Speech transmission could not commence until the aircraft switched its interrogation pulse recurrence frequency from 300 cycles per second to 5 kilocycles per second.

Trials of the equipment, carried out at the T.R.E., showed that the system provided homing up to 22 miles and speech facilities up to 10 miles with aircraft flying at a height of 1,000 feet.[1] Trials were held in No. 38 Group at the end of 1944 in which a maximum range of 12 miles was obtained with aircraft heights of 2,000 to 8,000 feet. After trials had proved the value of the equipment the T.R.E. made by hand, in the autumn of 1944, five sets of aircraft equipment and five talking units for Eureka Mark III for the S.O.E.[2] Two complete sets of equipment were also despatched to No. 38 Group for experimental use with the Special Air Service. On 26 September 1944 the Air Ministry stated that, even if it were given overriding priority, production of the equipment could not be undertaken for nine months and this would not be in time for the S.O.E. to make use of it. As a result the S.O.E. requirements were reviewed and subsequently cancelled. By the end of 1944 the T.R.E. had made 10 aircraft and 20 ground sets for No. 38 Group in order to provide for all possible future requirements for airborne operations in Europe, whilst 30 Eureka and 20 Rebecca equipments were requisitioned for holding against contingencies.

Because insufficient operational experience was obtained to justify large-scale provisioning no further production was arranged until, in January 1945, interest in the project was revived when the Air Ministry stated that experience of supply-dropping operations at Arnhem revealed the need for direct, reliable,

[1] A.M. File CS.22822.

[2] A.M. File C.30643/46.

rapid, and secure communications between the ground forces and aircraft in the event of the latter having to be diverted. Since the lightest possible ground equipment was required, talking Rebecca/Eureka seemed to be the most effective method. On 10 January 1945 a meeting was held to consider all possible future requirements for the equipment. Headquarters No. 38 Group stated that 20 Eureka and 10 Rebecca equipments would cover the requirements for all planned major operations in Europe. It was recommended that talking Eureka should be regarded as an expendable item and that provisioning should be on the basis of five times the number of talking Rebecca. It was tentatively agreed that 200 beacons and 50 aircraft installations should be provisioned to meet a possible requirement for supply-dropping in A.C.S.E.A., and in view of the stated needs for S.O.E. and S.I.S. operations in the Far East, the total requirement for all purposes was estimated as 500 Eureka and 300 Rebecca installations.[1]

Production and Operational Use

It was considered that sufficient quantities of Eureka Mark III had already been ordered from contractors to cover the requirement for talking Eureka and that sufficient reserves of Rebecca Mark II or IIB were already available. Only the equipment to enable the necessary modifications to be completed was required. Contracts for various items were placed with the firms of Murphy, Cossor and Monitor Radio. In July 1945 a technical officer from the T.R.E. was appointed co-ordinating officer responsible for the overall engineering of the complete system.[2] On 22 December 1945 the Air Ministry reported that, although the talking Rebecca/Eureka programme was almost completed, its abandonment was recommended. The design of talking Eureka was fundamentally not very satisfactory and it employed American valves, which, on the cessation of Lease-Lend, became very expensive to purchase. As Rebecca Mark II was to be superseded by Rebecca Mark IV it seemed unwise to continue with a talking version of the older Mark.[3] It was therefore agreed that a talking version of Rebecca Mark IV should be developed on a low priority. The operational use of talking Rebecca/Eureka during the war was limited because of the delay in stating a definite requirement in time for large-scale development and production, although by March 1945 No. 38 Group was using the T.R.E. hand-made sets on resupply operations. In an attempt to overcome errors experienced in medium-altitude container-dropping operations a path-finder technique was adopted, in which one aircraft equipped with talking Rebecca was briefed to act as a ' master aimer '.[4]

Use of Rebecca with Airfield Homing and Beam Approach Beacons

One of the important uses to which Rebecca was put was as an interrogator with the Beam Approach Beacon System (B.A.B.S.) and radar homing beacons. As an independent radar interrogator having its own display it could be installed in aircraft which were not fitted with main radar equipment for some other purpose. In the early days of its development the primary function of Rebecca was held to be the assistance of offensive operations, and airfield homing and beam approach facilities were regarded as incidental. There were some dissidents from this view. The Ministry of Aircraft Production realised the

[1] A.M. File C.30643/46. [2] A.M. File C.30643/46. [3] A.M. File C.39546/46.
[4] A.M. File C.30623/46.

value of Rebecca as an interrogator and recommended in September 1942 that aircraft not fitted with location or interception radar should be equipped with Rebecca. However, in an Air Ministry memorandum on Rebecca/Eureka published in March 1943, it was stated that although the installation of Rebecca enabled aircraft to use airfield homing and B.A.B.S. it was not worth while fitting it for that purpose alone.[1] This was because at that time operational aircraft used other approach systems or alternative interrogators. Bomber Command was still using S.B.A., and for B.A.B.S. Mark II the use of Lucero was envisaged. Fighter Command used V.H.F.B.A., and for B.A.B.S. Mark IF used the A.I. installation; Coastal Command used A.S.V. for interrogating B.A.B.S. Mark IC. Rebecca was regarded as an alternative to be used for airfield homing and approach only when it had been installed for a primary operational purpose.

The existing interrogator systems contained inherent disadvantages which necessitated the development of an independent installation. Their reliance on main radar installations was potentially dangerous if the main radar failed when the weather was poor and the aircraft required beam approach facilities to enable it to land. Consequently development of a version of Lucero not dependent on the main installation, known as Lucero Mark III, was begun. This consisted of Lucero Mark II, an I.F. strip and a Rebecca type of indicator. At a meeting on 8 May 1944 it was agreed that Lucero Mark III should be developed for use with Marks of H2S later than Mark III and for aircraft not equipped with H2S. As a long-term measure consideration was to be given to the replacement of Lucero Mark II by Lucero Mark III in all aircraft. In June 1944 it was decided that Lucero Mark III should in future be called Rebecca Mark VI.[2] The aim was to install eventually Rebecca Mark VI in all bomber aircraft other than those equipped with Gee-H, in which Rebecca Mark IIU was to be fitted but, as Rebecca Mark VI was not expected to be available before May 1945 and Rebecca Mark IIU before the end of 1945, the installation of Rebecca Mark II was decided on as an interim measure. It was recommended that interrogator facilities for Rebecca Mark II should be installed in such a way that a changeover to Rebecca Mark VI was simple.[3]

In August 1944 Headquarters Transport Command asked for the installation of A.S.V. Mark II to provide radar homing facilities in long-range aircraft but the Air Ministry recommended the installation of Rebecca IIB as it was 30 to 40 pounds lighter, and in December 1944 this was agreed. At the end of April 1945 Headquarters Transport Command made Rebecca a requirement for all home-based medium and long-range transport aircraft not already fitted. By 18 July 1945, 175 Rebecca Mark II modification kits had been manufactured. Sixty were sent to A.C.S.E.A. for retrospective installation, and sufficient equipments were available for equipping transport aircraft in the United Kingdom and M.A.A.F., whilst the Ministry of Aircraft Production estimated that Rebecca would be introduced as a production-line installation after the first 160 York aircraft had been delivered. Retrospective fitting of Dakota Marks III and IV was carried out at Kemble and of York Mark I aircraft at No. 32 Maintenance Unit. No. 45 Group in Canada installed Rebecca in Liberators Mark IX in July 1945.[4] At the same time Eureka beacons were required at Transport Command airfields. In the summer of 1945 the Air

[1] A.M. File C.39546/49. [2] A.M. File S.97074. [3] A.M. File C.30641/45.
[4] A M. File C.30622/46.

Ministry agreed that Eureka Mark II beacons should be installed at 25 Transport Command stations in the United Kingdom but warned the command that Eureka beacons were in short supply and installation was unlikely before August 1945. In August 1945 arrangements were made for the installation of Eureka beacons at Transport Command staging posts at Reykjavik, Bluie West, Goose Bay, Gander, and Dorval.[1]

The requirement for Rebecca equipment in Coastal Command was not expressed until 1944 because before that it was intended to use the American interrogator SCR. 729 with American A.S.V. in all aircraft made in the U.S.A. Trials of SCR. 729 revealed that an inherent lack of sensitivity resulted in severe interference between homing beacon and B.A.B.S. responses. Another disadvantage was that it had a very small cathode ray tube which necessitated the use of a magnifying lens to allow accurate ranges to be read. It was recommended therefore, in May 1944, that Rebecca Mark IIB should be used as the equipment was then in a state of development at which production could be expected to follow quickly. In that same month a Wellington aircraft fitted with Rebecca Mark IIB was released from Defford for trials at the Coastal Command Development Unit. On 14 June 1944 Headquarters Coastal Command reported that Rebecca Mark IIB was acceptable as the standard interrogator for Coastal Command aircraft equipped with American A.S.V. but in the following month elected to retain SCR. 729 in Catalina Mark IV aircraft because the additional weight of the Rebecca equipment was not acceptable.[2] On 9 February 1945 Headquarters Coastal Command stated an urgent requirement for the replacement of SCR. 729 by Rebecca Mark IIB in Liberators Mark II based in the Azores. This was necessary because it was essential for those aircraft to use both homing beacons and B.A.B.S. and this was not possible with SCR. 729. In that area no diversion to other bases was possible. The Air Ministry arranged to despatch 20 sets by mid-March 1945. By March 1945 the replacement of SCR. 729 by Rebecca Mark IIB in Liberator G.R. aircraft Marks V, VI and VIII was well under way.[3] Replacement Liberator Mark VIII were being fitted with the equipment at Prestwick. In March 1945 the Air Ministry stated the current policy for the use of Rebecca in Coastal Command. The aim was to fit all Coastal Command aircraft with the most flexible interrogator system possible. Because of its superiority over SCR. 729 Rebecca Mark IIB was to be fitted in all Coastal Command aircraft except those equipped with Marks of A.S.V. with which Lucero Mark II could be used. Ultimately Rebecca Mark VI was to replace all Coastal Command interrogators.[4]

The homing and beam approach facilities provided by Rebecca were of value to aircraft of the Tactical Air Force. On 17 November 1944 Headquarters 2nd T.A.F. stated a requirement for Rebecca Mark II for Anson aircraft of the communication squadrons. Communication aircraft were usually flown on definite point-to-point routes and their navigation was much simplified if they were provided with a means of homing to airfield beacons. For cross-channel flights they were required to use prescribed lanes and when flying over continental territory they needed to avoid gun-defended areas and balloon barrages. The beacon method of navigation was particularly suitable. Rebecca was also required for use with B.A.B.S. in order to maintain a regular communications service. It was essential that a pilot should be able to take off in

[1] A.M. File C.30620/46. [2] A.M. File CS.24130. [3] A.M. File C.16215/44.
[4] A.M. File CS.24130.

conditions of bad visibility confident that he would be able to land at his destination. The Air Ministry was unable to comply with the request, partly because supplies of B.A.B.S. Mark II were not likely to be available until May or June 1945, and partly because Rebecca Mark II was in very limited supply; it had been provisioned on a limited scale only for the airborne forces. The Air Ministry recommended that, if the requirement was likely to persist, the aircraft should be equipped with Rebecca Mark VI, which, in any case, was much more suitable for beam approach purposes than Rebecca Mark II.[1]

In August 1944 the Air Ministry stated that a requirement had arisen for beacons working on the same frequency as Eureka Mark II to be installed at permanent airfields to provide homing facilities, on the basis of two complete beacon installations per site in order to maintain a 24-hour service. The estimated total was 369 to cover needs in the United Kingdom and in A.C.S.E.A., where much larger areas needed to be covered. It was intended that the Eureka beacons should be used with Lucero as well as with Rebecca.[2] After the end of the war with Germany the operational requirements of Tiger Force assumed primary importance. It was agreed in May 1945 that both the first and second components, each consisting of four squadrons of Lancaster Mark VII aircraft, should be fitted with Rebecca Mark II so that they could interrogate B.A.B.S. Mark II.[3] Forty sets were supplied to No. 5 Group by the end of the month and Bomber Command was given the assistance of No. 43 Group fitting parties. The first squadrons fitted were at Coningsby and Metheringham. Bomber Command arranged for 16 Lancaster aircraft from No. 1660 H.C.U. Swinderby, No. 1654 H.C.U. Wigsley, and No. 1661 H.C.U. Winthorpe, to be fitted with Rebecca Mark II for training reinforcement crews for Tiger Force. In June 1945 two Eureka Mark II beacons were made available for training radar mechanics at the Bomber Command Radar School at Feltwell. Experience of the use of Rebecca with B.A.B.S. during 1945 showed that performance was greatly improved by the provision of a separate beam approach aerial located to avoid propeller modulation. The Air Ministry decided to introduce the aerial on the production line and retrospectively as a standard part of all Rebecca Marks II, IIB and VI installations, as well as of Mark IIA, which was the American version, AN/APN–2.

In 1944 it was decided to equip certain aircraft in Bomber Command, 2nd T.A.F., No. 38 Group and No. 140 Squadron with Gee-H.[4] Beacon and beam approach facilities were required, but no provision for the installation of Lucero or Rebecca had been made. During the latter part of the summer of 1944 development was proceeding at the T.R.E. of a version of Rebecca known as Rebecca Mark IIU, incorporating the indicator unit Type 166 which was employed in Gee-H so that, when installed with Gee or Gee-H, Rebecca signals were displayed on the common indicator. Rebecca Mark IIU also provided I.F.F. interrogation, normal Rebecca homing and B.A.B.S. facilities, and increased the range accuracy of Rebecca-H. A development contract was placed with the firm of Murphy Radio, and on 30 September 1944 financial sanction was requested for the installation of Rebecca Mark IIU in aircraft in

[1] A.M. File CS.24133. [2] A.M. File CS.23062. The estimated cost was £50,745.

[3] A.M. File CS.23614.

[4] Gee-H was required in No. 38 Group aircraft in order that resupply operations could be carried out at medium altitude, about 7,000 feet, as a result of the heavy losses of aircraft incurred when low-level operations were carried out at Arnhem.

which Gee-H Mark II was to be fitted. The aircraft were eight squadrons of Lancaster Mark II in No. 3 Group, all Mosquito Mark VI and Mitchell Mark III in No. 2 Group, all Stirling, Halifax and Dakota aircraft in No. 38 Group, and all Mosquito photographic reconnaissance aircraft in No. 140 Squadron. An installation involving two indicator units could not be accepted in the aircraft; in Mosquito, Mitchell and Dakota aircraft space considerations precluded the use of two separate indicator units, and in the other types crew duties necessitated the use of a common indicator.[1]

Development of Rebecca Mark IV

On 15 September 1942 a requirement was stated, at a Ministry of Aircraft Production meeting, for a small, light, mains-operated interrogator installation, with meter presentation, for single-seater aircraft. The Royal Aircraft Establishment suggested that the transmitter should be similar to that of Rebecca Mark II but with interchangeable units so that the frequency of 176 megacycles per second could be made available in the Fleet Air Arm, and the frequency bands of 188 to 198, and 214 to 234 megacycles per second, for Fighter and Army Co-operation Commands. The R.A.E. began development of equipment which was given the nomenclature of Rebecca Mark IV. More difficulties than had been anticipated were encountered and development was still in progress in the summer of 1943.

Originally it had been suggested that the equipment might be of value in close-support operations, when it would be used in conjunction with Eureka beacons sited by forward elements of the ground forces. Although the requirement had not been officially confirmed by the Air Ministry, there was an operational requirement for a cathode ray tube display which could be interpreted without difficulty in daylight.[2] The T.R.E. therefore modified a Rebecca Mark III equipment for installation in a Hurricane aircraft in the summer of 1943 so that flight trials of different tubes might be undertaken and because the Admiralty had drawn up specifications for an installation in single-seater aircraft of the Fleet Air Arm.[3] After several high-voltage tubes had been tried, the G.E.C. double electrostatic tube was selected as that which was most satisfactory for both night and day viewing. Its substitution for a normal tube involved increasing the length of the indicator unit from 10 to 12½ inches and the addition of another power unit to supply the higher voltages which became necessary. A small number of components in the control unit were increased in rating to deal with the higher voltages but this involved no increase in size and weight. The aerial system was designed to cover the band 214 to 234 megacycles per second using vertical polarisation. Separate transmitting and receiving aerials were used. The transmitting aerial was a quarter-wave rod with one director mounted below the engine. The receiving aerials were quarter-wave rods with one director and one reflector and were mounted under the mainplanes. The experimental installation weighed about 90 pounds.[4] Comparative trials of the R.A.E. Rebecca Mark IV and the T.R.E. modified Rebecca Mark III were held in September 1943.[5] It was found that the R.A.E. equipment did not solve the problem presented by the Admiralty so the T.R.E. variant of Rebecca Mark III was chosen for future development. It did not quite meet the specifications of the Admiralty but the T.R.E. considered that

[1] A.M. File C.39546/49. [2] T.R.E. Report No. T.1572. [3] A.M. File C.30641/46.
[4] T.R.E. Report No. T.1572. [5] A.M. File C.30641/46.

the necessary improvement was feasible with further development.[1] Headquarters 2nd T.A.F. had continued to show interest in the project throughout the period of development but in October 1943 definitely confirmed that there was no requirement for it. The efforts of the T.R.E. were consequently concentrated on meeting the naval specification. In December 1943 the Naval Staff stated a definite operational requirement for a miniature Rebecca with daylight viewing and remote control to operate on the frequencies 176 megacycles per second, 177 megacycles per second and on one frequency in the band 214 to 234 megacycles per second. The T.R.E. therefore aimed at producing an improved version of the modified Rebecca Mark III to meet Naval Staff requirements. The transmitter/receiver unit had to be altered to cover the frequencies required but five-frequency tuning was not needed. The aerial system was altered to provide homing on 176 megacycles per second with horizontal polarisation, and the transmitter/receiver was modified to allow common T and R working, made necessary because of the difficulty of fitting a horizontally polarised transmitting aerial to small, fast aircraft. The timebase scales were changed from 6 and 36 land miles to 6 and 60 nautical miles. For newer types of aircraft, such as the Firebrand, Hellcat and Martlet, the power unit had to be 24 volts. The equipment weighed about 75 pounds. Development was given high priority at the T.R.E.[2] During this period the modified Rebecca Mark III was known as Rebecca Mark IIIB but in April 1944 the T.R.E requested that the Fleet Air Arm equipment be known as Rebecca Mark IIIN. A Hurricane aircraft fitted with Rebecca Mark IIIN and a daylight viewing cathode ray tube was sent to Yeovilton for trials with the Fleet Air Arm. The trials were successful and the Admiralty requested a supply of 100 Rebecca Mark IIIN for eventual installation in Hellcat, Corsair and Martlet Mark V aircraft. The Ministry of Aircraft Production raised a separate contract for the naval requirements instead of allocating equipment destined for the R.A.F.[3] Rebecca Mark IIIN was regarded as an interim version to meet an urgent requirement for the Fleet Air Arm and while it was being developed the T.R.E. also conducted experiments with the view of developing, as a long-term project, a truly miniaturised version of Rebecca Mark IIIN weighing about 40 pounds which was to take over the name of Rebecca Mark IV from the R.A.E. project on which work had been discontinued.

During 1944 development of Rebecca Mark IV was continued under the direction of Mr. K. A. Wood and by January 1945 had reached the point at which it was possible to place a development contract with the Gramophone Company. The equipment consisted of a transmitter/receiver unit, control unit and indicating unit. The transmitter/receiver was enclosed in a pressurised cylinder 10½ inches in diameter and 17 inches long, to provide a factor of safety for operation at high altitudes and in tropical zones. The control unit contained all the manual and preset controls necessary for satisfactory operation of the equipment in the air and for daily inspection servicing on the ground. Six frequency channels in both the transmitter and receiver were available for preselection with facilities for fine tuning to secure maximum performance. The indicating unit consisted of a cathode ray tube enclosed in a duralumin cylinder suitable for direct mounting on the pilot's instrument panel. The picture area was 2 inches by 1½ inches but the display could be increased to three times that size by the use of a special plastic lens. The equipment was

[1] T.R.E. Report No. T.1572.

[2] T.R.E. Report No. T.1572.

[3] A.M. File C.30641/46.

designed to operate from the standard 80-volt 1,200–2,000 cycle AC supply. Facilities were also provided to give B.A.B.S. presentation on a meter instead of a cathode ray tube, involving the use of an external box weighing about 50 pounds. As the equipment was intended to be as small and as light as possible miniature components and light alloys were used throughout. The performance, however, was much superior to that of earlier small light-weight interrogators. The total installation weight was 48 to 55 pounds, as against 160 pounds for Rebecca Mark II.[1] One obvious difficulty encountered in development was in mounting the aerials on aircraft. The equipment could be operated on the 176 megacycles per second band and on the 214 to 234 megacycles per second band; the beacons to be interrogated were horizontally polarised on 176 megacycles per second and vertically polarised on the higher band. Therefore two sets of aerials had to be installed on aircraft, one set vertical and the other horizontal. This was easily done on a large aircraft where both sets of aerials could be mounted on the fuselage sufficiently far apart to ensure freedom from mutual electrical interference, but the only available space on small aircraft was on the mainplanes and this limitation presented difficulties. All excrescences reduced airspeed, and armament and fittings for projectiles affected the radiation patterns of the aerial systems. The T.R.E. therefore had to find some means of using one set of aerials only to cover both bands. After considerable experiment it was decided in January 1945 that the solution was to use vertical aerials only to cover the whole band from 176 to 234 megacycles per second. To avoid denying the use of beacon facilities to Coastal Command aircraft it was therefore necessary to provide 176 megacycles per second beacons with both vertical and horizontal aerial systems.[2] Rebecca Mark IV could be used with all types of British and American Eureka beacons operating on Coastal, Fighter and Bomber Command frequencies. It interrogated I.F.F. Mark III, Mark IIIGR and American equivalents, and had a limited operation with Walter and similar rescue beacons. Provision was made for operation with a meter presentation unit providing distance orbit and heading information. A contract was placed with the Gramophone Company on behalf of the Admiralty for 8,000 sets.[3]

Development of Rebecca Mark VI

In April 1944 development began at the T.R.E. of a Lucero equipment which was to be independent of centimetric radar installations except that it required a locking pulse. The requirement arose when the disadvantages of an interrogator for B.A.B.S. and homing beacons being dependent for its serviceability upon that of the main radar installation became obvious. There was also an urgent requirement for an interrogator for H2S Marks IV and VI, for which Lucero Mark II was unsuitable. This new equipment had its own I.F. amplifier, video output and display unit but incorporated the Lucero Mark II TR box. The I.F. and video stages would be connected to all types of Lucero and were contained in a box, together with a multi-vibrator, providing an independent locking source. It was called Lucero Mark III. At the beginning of May 1944 the T.R.E. reported that most of the necessary initial development work had been completed, although no air tests had been carried out, and recommended that a development contract should be placed with the firm of Pye Radio

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[1] T.R.E. Report No. 1930, Rebecca Mark IV.

[2] A.M. File C.26059/45.

[3] A.M. File C.26059/45.

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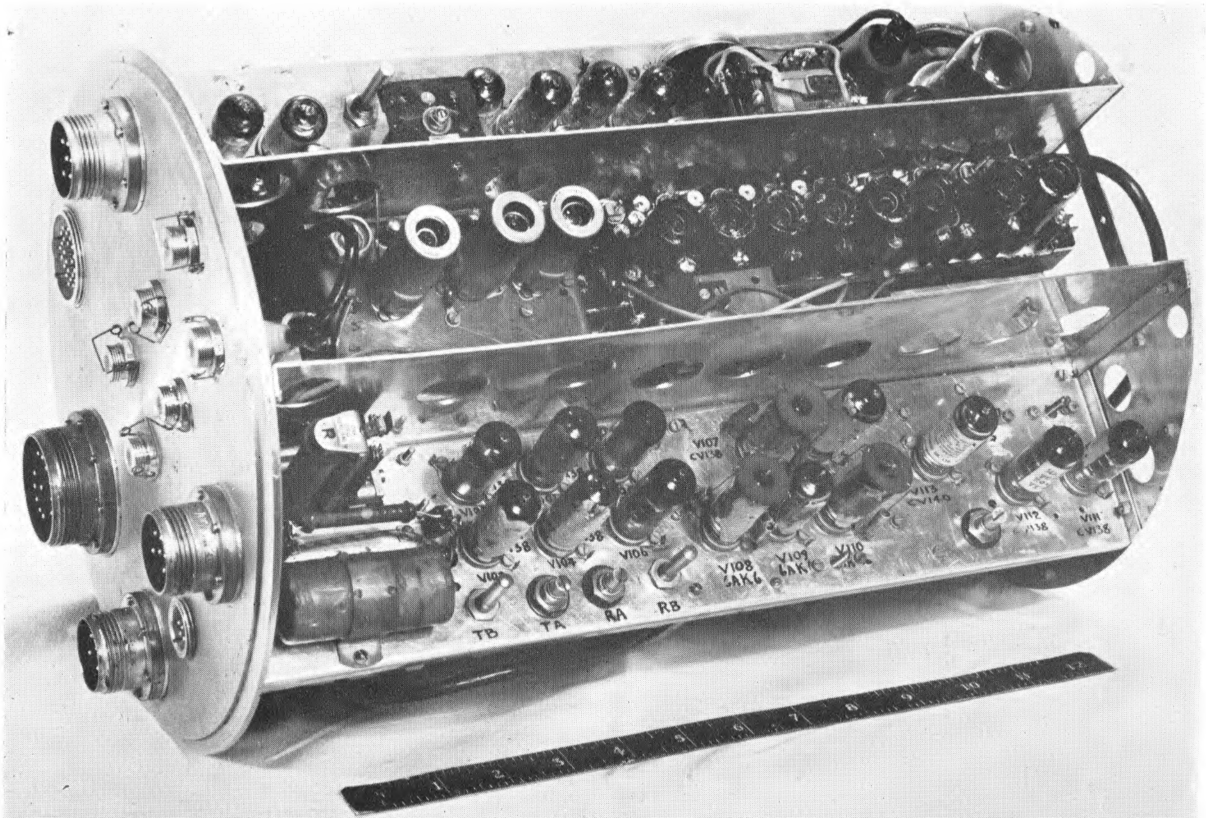

Rebecca Mark IV Transmitter/Receiver

because it had already developed the I.F. strip.[1] The performance of Lucero Mark III was very similar to that of Rebecca Mark IIB, which had the advantage of already being in limited production. Lucero Mark III, however, had a better display for use with B.A.B.S. and the T.R.E. considered that extra facilities, such as an indication of runway length and automatic amplitude control, could easily be provided. It could be made to lock to a main centimetric equipment, thus making possible a display of I.F.F. on a P.P.I. The lack of I.F.F. interrogation facilities had been a disadvantage when Rebecca Mark II was used with B.A.B.S. It afforded greater flexibility as it could easily be modified from Lucero Mark II by the addition of an indicator unit and an extra box containing the I.F. strip and video stages. A common transmitter and receiver box could be used thus avoiding the installation of a transmitting aerial required by Rebecca Mark IIB. The chief disadvantage of Lucero Mark III was its weight. The T.R.E. recommended in June 1944 that a crash programme for 200 sets should be arranged to meet Bomber Command's urgent requirement for an equipment giving an independent display in some aircraft, particularly the Halifax, where the H2S display was in the nose. This recommendation was supported by the Air Ministry. In July 1944 a development contract was placed with the firm of Pye.[2] In that month the name of the equipment was changed to Rebecca Mark VI because it was Air Staff policy to place all independent interrogators in the Rebecca series. On 8 August 1944 financial sanction was requested for the provision of Rebecca Mark VI for bomber aircraft not fitted with H2S Marks II or III, all training, all Halifax, and all Coastal Command aircraft.[3] For the last an independent interrogator was particularly important because the aircraft made long patrols at the end of which approaches and landings had often to be made in bad weather and the A.S.V. installation was sometimes unserviceable.

Adoption of Rebecca Mark IV

During 1945 there was considerable discussion at the Air Ministry and Ministry of Aircraft Production on the version of Rebecca to be chosen for ultimate universal adoption in the Royal Air Force. In the summer of 1944 Rebecca Mark VI had appeared to be the best available version and a production contract for 6,000 equipments had been placed. It was a heavy and bulky equipment but at that time there was no operational requirement for Rebecca in single-seater aircraft. The merits of Rebecca Mark IV when compared with Mark VI appeared to be many, the only disadvantage of Mark IV being that it was still in the development stage while Mark VI was in production by April 1945. Thus Rebecca Mark IV would not be available to the Service until considerably later than the larger equipment. It was suitable for use in tropical areas because it was fully tropicalised and its installation in an air-tight container permitted it to be pressurised for use at high altitudes. Therefore, when in January 1945 the Air Ministry expressed an operational requirement for a tropicalised version of Rebecca, the Ministry of Aircraft Production suggested that it could be met with Rebecca Mark IV. Its value was particularly high for installation in aircraft for which Rebecca Marks II and VI were too large or too heavy, a factor which became of increased importance in the spring when a requirement was stated for the equipping of Coastal Command strike aircraft with an interrogator. The use of Rebecca Mark IV was also considered to be important

[1] A.M. File C.26059/45. [2] A.M. File C.30641/46. [3] A.M. File C.39546/49.

in a proposed scheme for automatic blind landing. This required the provision of convertor boxes which added further to the weight and volume of the radar equipment in an aircraft but Rebecca Mark IV could be associated, without modification, with similarly miniaturised convertor boxes.[1] Non-miniaturised equipment was too cumbersome particularly if radar glide path equipment was incorporated. Rebecca Mark IV also offered certain technical advantages, particularly in the control of frequency selection. On 18 April 1945 the Director of Radar requested, in view of the obvious advantages of Rebecca Mark IV, financial authority for the provision of at least 1,000 equipments. He suggested that the contract for 6,000 Rebecca Mark VI should be reduced by 1,000 so that the new requirement would not be too great a strain on the radar production programme. The small size and light weight of Rebecca Mark IV was specially valuable in the Far East, where sacrifices of fuel for radar equipment were usually impossible because of the long distances to be flown.[2] In July 1945 a review was made of the Rebecca/Eureka programme because the end of the war in Europe changed requirements to some extent. Commitments in the Far East involved provision on a more liberal scale of spares because of tropical conditions and the need for equipment at staging posts. It was clear that existing stocks and the current rate of production of Rebecca Mark II were inadequate. Again the advantages of Mark IV, both for general and tropical use, were emphasised. The facility of selection of frequency channels at any point between 176 to 234 megacycles per second was particularly useful for air/sea rescue work as the tuning control was provided with a search device enabling operators to search for ' off-frequency ' signals. The Director of Radar requested sanction for doubling the monthly rate of Rebecca Mark IV production, for reducing Rebecca Mark IIB production if necessary, for cancelling the Rebecca Mark VI amplifier contract and for increasing both Rebecca Marks II and IV contracts. He also asked that, as an interim measure until Rebecca Mark IV was available, indicator unit Type 233 should replace indicator unit Type 6E in Rebecca Mark II to improve the performance.[3] It was then decided that Rebecca Mark IV should be adopted as the standard interrogator for the R.A.F. although no practical trials had been held, and in August 1945 all outstanding contracts for Rebecca Mark VI were cancelled. In October 1945 the Air Staff suggested that 20 pre-production models of Rebecca Mark IV should be provided for Service trials so that any modification found necessary could be incorporated in the production models, but the proposal was turned down for financial reasons. It was agreed, therefore, in April 1946, that Service trials should be held at Defford with two development models. There were considerable delays in the production of the equipment and it was not until November of that year that these trials were held.[4]

[1] A.M. File C.26059/45. [2] A.M. File C.39546/49. [3] A.M. File C.39546/49.
[4] A.M. File C.26059/45.

CHAPTER 13

LUCERO AND DINGHY RADIO

Before the advent of centimetric airborne radar, when A.S.V. and A.I. operated on the 1½-metre wavelength, aircrews of aircraft in which those equipments were installed were able to use I.F.F. facilities and radar homing and beam approach systems which had been built up on the metric wavelength. When the wavelength of the main installations was changed to 10 centimetres as the result of the development of the magnetron valve, aircrews were at first denied the use of those systems. The T.R.E. therefore, whilst developing centimetric beacons, also developed an interrogator which was part of and dependent on the main centimetric radar installation but permitted use to be made of the existing metric wavelength facilities. The interrogator was known as Lucero Marks I and II.[1] An interrogator which was independent of the main installations was also developed and was originally known as Lucero Mark III, but the name was changed to Rebecca Mark VI during the research stage.

Lucero consisted of a transmitter, working on a wavelength of 1½ metres, which was capable of interrogating beacon and identification systems, and the local oscillator and first two I.F. stages of a receiver. The transmitter was triggered by a pulse from the main installation so that returned signals from Lucero were in phase with responses obtained by that installation. The returned signals, after passing through the two stages of I.F. amplification in the Lucero unit, were mixed with the I.F. signals of the main equipment and then passed through a common amplifier and detector channel; they appeared on the main P.P.I. whenever a responder was within interrogation range. Beacon responses appeared on the display as two-sided signals divided by the central range-trace and the direction of a beacon was indicated by the larger side of a signal. Beam approach indications were given by fluctuations in the size of the signals, and the range of the aircraft from the approach beacon was continuously visible.[2] Lucero worked with a common T and R aerial system, independent of the main installation, mounted so that all-round cover and azimuth direction-finding were possible.

Lucero Mark I transmitted and received on the A.S.V. beacon frequencies, 176 and 173·5 megacycles per second. It had an additional switch control which permitted the use of A.S.V. B.A. There was no tuning control. Power output was 500 watts. The aerials were quarter-wave type, swept back at 45 degrees, and were mounted on either side of the nose of the aircraft. In Lucero Mark II there was a remote control unit to select any of four transmitter and four receiver frequencies in the bands 170 to 180 megacycles per second and 212 to 238 megacycles per second for either transmitting and receiving. Lucero Mark II had pre-set tuning and the whole equipment weighed about 25 pounds. At first the B.A.B.S. display was two-sided. Later a new display

[1] At a meeting held at the T.R.E. on 24 June 1942 it was suggested that the airborne interrogators should be known as Inquisitors and the names of prominent inquisitors given to different models of equipment. The interim model was to be known as Lucero Mark I and the final model as Lucero Mark II. (M.A.P. File SB.40365.)

[2] A.H.B./IIH/241/10/58(A). Bomber Command File BC/S.31076.

was developed because, owing to propellor modulation, it was necessary to employ a single aerial underneath the aircraft. This entailed using a single-sided display showing a broad blip for the ' dash ' zone with a narrow blip superimposed for the ' dot ' zone. In the equisignal zone both amplitudes were identical. When the aircraft was in the dot sectors the narrow blip protruded from the broad blip and the ratio of amplitude denoted the various dot sectors. When the aircraft was in the dash sector the broad blip predominated.[1]

Lucero Mark I

By the beginning of November 1942 development of Lucero Mark I, begun in March 1942 at the T.R.E., had reached the stage of flight trials, and a development contract for three different models was placed with the firm of Ericssons Telephones Limited. Lucero Mark I was at first regarded purely as an interim measure introduced to provide the bare essentials of interrogation at the earliest possible moment. It operated on one frequency only but was likely to be available some months before Lucero Mark II. Consequently the Ministry of Aircraft Production recommended that it should be installed only in a limited number of aircraft in which interrogation facilities were urgently required before Lucero Mark II became available.[2] A production contract for 400 Mark I equipments was placed with Ericssons, who received provisional type approval in March 1943 when, however, it was decided to enlarge the Mark I installation programme ; an additional contract for 500 equipments was placed with the Research Prototype Unit in April.[3] Meanwhile the firm of Murphy Radio had accepted a development contract for six models of Mark II in the autumn of 1942, and production contracts for 1,300 equipments had been placed with the same firm and that of Ultra. In the spring of 1943 it was proposed to install Lucero Mark I in aircraft of Coastal Command and the Fleet Air Arm and Mark II in aircraft of Bomber Command, which by then were being equipped with H2S.

The progress made by Ericssons was comparatively slow, mainly because the priority accorded Lucero was far lower than that given to the development and production of the main installations with which it was required to work, and in March 1943 it was not expected that the 400 equipments would be delivered before the end of May 1943.[4] Consequently, on 21 April 1943 the Air Ministry decided that Lucero was to be regarded as an integral part of A.S.V. Mark III, H2S, A.S.V.X., and A.I.X., and was to be accorded equal priority from every aspect. By the middle of May 1943 trial installations of Lucero Mark I had been completed in Lancaster, Halifax, Wellington, Swordfish and Sunderland aircraft.[5] In the same month trials of one prototype and one production model installation, operating on A.S.V. beacon frequencies, were conducted at Chivenor by the B.A.B.S. Familiarisation Party, against beacons at Chivenor, Angle Head, St. Eval, and in the Scilly Islands, and with B.A.B.S. Mark IC at Chivenor. The results obtained were inconsistent, but enabled some recommendations to be made. They included an increase in power, selective tuning, and the fitting of a tuning control near the indicator unit. Tuning in the air was an important and critical operation because it could not be guaranteed

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[1] Bomber Command File BC/S.52732/1.
[2] A.M. File C.30500/46.

[3] M.A.P. File SB.40365.

[4] Production was also retarded in April 1943 because the manufacturers received condensers which were faulty.

[5] A.M. File CS.18539.

that any B.A.B.S. installation or responder beacon was exactly on frequency. A recommendation that range scale should be presented on the tube was also made. On the existing model the operator had to look at another scale to read the range and this meant he might miss a slight B.A.B.S. indication. In June 1943 further trials of Lucero Mark I were held at Beaulieu by the Coastal Command Development Unit to ascertain the operational performance of the equipment with fixed A.S.V.B.A. After about 15 trial runs had been carried out the conclusion reached was that it was a practical addition to A.S.V. Mark III but its operational efficiency was impaired by the poor general layout of presentation and controls. The C.C.D.U. considered that a general improvement in the mounting of the equipment was necessary, and that the range scales should be placed in a position where reading of ranges and operation of controls was facilitated.

One result of the Coastal Command trials of Lucero Mark I was a request from Headquarters Bomber Command for the equipment to be made available at the Bombing Development Unit so that its value in bomber aircraft might be ascertained. The Air Ministry refused this request on the grounds that there was no point in trying out Lucero Mark I in Bomber Command because Mark II was being produced for bomber aircraft. In any event no Lucero Mark I or beacon equipment operating on 173 megacycles per second could be provided for trials in Bomber Command because all available installations were required for urgent operational needs in Coastal Command. The Air Ministry promised however that as soon as Lucero Mark II and B.A.B.S. Mark II equipment became available it would be sent to the B.D.U. for trials. So that development work might proceed in accordance with the operational requirements of Bomber Command, the Air Ministry advised that representatives from the command should visit the T.R.E.[1]

Production of Lucero Mark I by the firm of Ericsson was further delayed by difficulty experienced with faulty transformers and delivery of 400 equipments was not completed until the end of October 1943, by which time good progress was being made at the R.P.U.[2] An installation programme for aircraft of Coastal Command was continued throughout the winter of 1943/1944, and considerable use of Lucero was made during operational flights. Certain technical difficulties had already been encountered. One was mutual interference between B.A.B.S. and homing beacon responses on the P.P.I. display. Attempts were made to clear the trouble by filters but although several models were made none was satisfactory. Eventually a solution to the problem was reached by increasing the frequency separation between the two types of beacon.[3] Operational use revealed other weaknesses. On 16 October 1943 Headquarters Coastal Command reported that interference was being experienced from I.F.F. Mark III, attributable to the small amplitude oscillations which occurred even when I.F.F. was not being triggered. After investigations by the T.R.E. suitable modifications were incorporated. Another criticism made by Headquarters Coastal Command was that while Lucero was reasonably effective when used with homing beacons it was unsatisfactory for beam approach purposes. Because the indicator was small accurate interpretation of B.A.B.S. indications was possible only by skilled operators in exceptionally good conditions. The indicator used was, however, an integral part of A.S.V. Mark III, and to

[1] A.H.B. IIH/241/10/58(B). Bomber Command File BC/S.31076/Radar Part II.

[2] A.M. File CS.18539.

[3] A.M. File C.30500/46.

provide a larger cathode ray tube display involved not only the provision of a new indicator but also of separate I.F. and video amplifier units. Such equipment was already being developed for Lucero Mark III but was unlikely to reach the production stage for some time and, in addition, a great deal of modification and fitting work would be necessary on aircraft installations. Since the use of B.A.B.S. was important in Coastal Command, the installation and use of metric A.S.V., A.S.V. Mark II, for beam approach was seriously considered.[1] However, the definition of signals on the A.S.V. Mark III display was as good as, if not better, than those obtained on a larger tube ; an increase in size of the signals, mainly on psychological grounds, was all that was required. A simple remedy therefore was the employment of a lens to magnify the display. During March and April 1944 two models of a viewing lens, designed by the T.R.E., were tested by the C.C.D.U. with satisfactory results and a production order for 200 was placed.[2]

Lucero Mark II

During the early months of 1943 Lucero Mark II was being developed at the firm of Murphy. Type approval was delayed because the first prototype submitted had been found unsatisfactory as it caused interference with H2S. Main production was not expected to begin before November 1943, so in March of that year a crash programme, to begin in August, was arranged with the firm of Ultra to meet the most urgent of Bomber Command's needs. Progress made on the Murphy development contract was very slow because the firm was overloaded with work and it was not until December 1943 that the T.R.E. gave type approval to the prototype which was sent to the firm of Ultra for use in the crash programme. Another handicap to speedy development and production was the delay in stating a firm requirement. In August 1943 the T.R.E. complained that the only expressed requirement for Lucero Mark II in Bomber Command was for interrogation of I.F.F. for Fishpond, although development of the equipment was proceeding on the basis that it would be needed to work in conjunction with B.A.B.S. Mark II. At a meeting at the Air Ministry on 21 January 1944 it was stated that sufficient Lucero Mark II to equip all aircraft fitted with A.S.V. Marks III and VI was needed. Main production contracts for variants of Mark II were placed with the firms of Murphy, Dynatron and E. K. Cole.[3] In spite of the urgency of the requirement for Mark II, delivery from the crash programme was slow, no deliveries being made in February 1944.

Lucero Mark II was also required to operate on Fighter Command frequencies to act as an interrogator with centimetric A.I. (A.I. Mark VIII). Development work was carried out both at the T.R.E. and at Murphy Radio. In February 1944 trials of an A.I. Lucero against $1\frac{1}{2}$-metre A.I. homing and beam approach beacons, and as an interrogator for I.F.F. Mark IIIG, were held at the Fighter Interception Unit, Ford. The installation consisted of a Lucero box fitted in the position previously occupied by the A.I. Mark VIII interrogator and a control unit mounted behind the pilot's armour plate. Lucero made use of the wing-tip aerials fitted to the Mosquito Mark XIII, and its I.F. output was fed to the A.I. Mark VIII receiver I.F. strip. The results of the trials showed that the performance of Lucero with A.I. homing beacons was inferior to that of the

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[1] A.M. File C.30500/46. [2] Coastal Command File CC/S.14403/14.

[3] A.M. File C.30500/46.

metric A.I. equipment, A.I. Marks IV and V, and that the performance dead ahead was not so good as that on the beam. The F.I.U. believed that the provision of a separate transmitting aerial would improve the general performance but it was considered that an attempt to introduce a separate transmitting aerial at that stage would retard the fitting programme in squadrons. The performance obtained in the trials with the original aerial system was considered adequate for operational purposes. The performance of Lucero with A.I.B.A. was good in respect of signal strength and ranges obtainable but there was a flutter on the 'steady' signal when in the beam, which constituted a handicap to its operational use in very bad visibility. It was considered that in its existing state the equipment was a useful aid but its accuracy was substantially less than that of A.I. Mark IV. The results obtained in the interrogation of I.F.F. Mark IIIG were quite satisfactory, good range and definition of signals being obtained. Results with Eureka were poor. As a result of the trials it was recommended that frequency tolerances on the 1½-metre beacons should be decreased in order that the optimum performance of Lucero might be obtained, and that attempts should be made to eliminate the flutter appearing on the A.I.B.A. display. Certain improvements were incorporated by the T.R.E. In July 1944 further trials were held against A.I.B.A. at the F.I.U., which had moved to Wittering by then. During these trials no flutter was experienced on the A.I.B.A. display.[1] In May 1944 an improved aerial system was agreed; this was to include two forward aerials for homing purposes and a single aerial towards the rear of the aircraft on the underside of the fuselage, with a switch to transfer from one to the other. It had been proved that forward aerials were essential for homing purposes but, because of propeller modulation, a good beam approach display could only be provided by using rear aerials.

Development of Lucero Mark II proceeded concurrently with that of B.A.B.S. Mark II, the two equipments being complementary. In February 1944 an aircraft fitted with Lucero Mark II was sent to the Bombing Development Unit, Newmarket, for trials with B.A.B.S. Mark II. These were successful and resulted in a requirement for the equipment being stated on 22 April 1944. Lucero Mark II was required in all operational aircraft equipped with H2S Marks II and III, Lucero Mark III in all non-H2S operational aircraft fitted with H2S Marks IV or VI, and Lucero Mark III in all H.C.U. and O.T.U. aircraft except when such aircraft were equipped with H2S Marks II and III when Lucero Mark II was to be fitted.[2] This requirement was tentative and before confirming it Headquarters Bomber Command asked for extended operational trials at two bomber airfields. Wickenby and Driffield were chosen as the locations for the ground B.A.B.S. equipment and No. 12 Squadron (Lancaster aircraft) at Wickenby and No. 466 Squadron (Halifax) at Driffield were selected for equipping with Lucero which was to come from the crash programme. The target date for the trials was mid-July 1944 and it was expected that 100 sets would be available for fitting by May 1944.[3] Main production contracts were scheduled to begin in August 1944. Provisioning of Lucero was sufficient to equip all Bomber Command aircraft according to the type of H2S used but general fitting in the command depended on its

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[1] A.H.B./II/54/93(A) F.I.U. Reports.

[2] A.H.B./IIH/241/10/B(A) and Bomber Command File BC/S.31436.

[3] Bomber Command File BC/52732/1.

performance in operational trials. The rate of production, even on the crash programme, which had high priority, was disappointingly slow. A trial installation was made in a Lancaster aircraft in June 1944 and was inspected by Headquarters Bomber Command at Defford on 6 July 1944. By the beginning of October 1944 trial installations in aircraft of Nos. 12 and 466 Squadrons were completed, and during that month a fitting programme for all the aircraft of the two squadrons was begun by parties from No. 43 Group. At the same time crew training in the use of B.A.B.S. and Lucero was started.

In November and December 1944 Lucero was used on a few operational flights in conjunction with B.A.B.S. at Wickenby but Headquarters No. 1 Group was unable to reach any conclusions on the value of the equipment because insufficient information was available. The T.R.E. kept closely in touch with the progress of the installation programme and trials so that faults could be rectified immediately, and from October 1944 onwards monthly defect and progress reports were submitted to Headquarters Bomber Command. During training flights one difficulty experienced was that R/T traffic often prevented the pilot from hearing instructions passed on by the navigator from Lucero readings. The condensers in the transmitter units were a source of trouble but in February 1945 the T.R.E. altered the operating procedure so that the 80-volt A.C. current was not switched on until the navigator wished to use Lucero; this reduced the number of failures. In operational use the highest number of faults was caused by the failure of H2S, a fact which made more obvious the need for an independent interrogator.[1]

Throughout the early months of 1945 trials continued at Wickenby and Driffield and by the spring of 1945 sufficient information had been obtained to justify large-scale provisioning of B.A.B.S. and Lucero. The success of the trials confirmed the Bomber Command requirement and retrospective fitting of Lucero was extended to other squadrons in the command.[2] Main production was slow and a priority list had of necessity to be compiled.[3] By the middle of April 1945 fitting parties were engaged on fitting ten squadrons of Lancaster aircraft. By May 1945 fitting at Lindholme, Ludford Magna and Binbrook was complete. In that month the end of the war with Germany brought into prominence the requirements of Tiger Force and interrupted the Lucero installation programme. In June 1945 No. 45 Group fitting parties were diverted from the task of fitting Lucero in Bomber Command aircraft to that of fitting Rebecca in aircraft destined for Tiger Force. Installation of Lucero was continued, but at a slower rate, by station radar mechanics, who were provided with the necessary equipment by No. 43 Group.[4]

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[1] Bomber Command File BC/52732/29. [2] Bomber Command File BC/52732/29.

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Priority	*Station*	*Squadron*
1	Lindholme	1656 H.C.U.
2	Ludford Magna	101 Squadron.
3	Elsham Wolds	103 Squadron.
		100 Squadron.
4	Binbrook	460 Squadron.
5	Kirmington	166 Squadron.
6	North Killingholme..	550 Squadron.
7	Scampton	153 Squadron.
		625 Squadron.
8	North Luffenham	1653 H.C.U.

(Bomber Command File BC/52732/1).

[4] Bomber Command File BC/52732/1.

Replacement of Lucero by Rebecca

Lucero had many inherent operational disadvantages because it worked as an attachment to a main radar equipment. Even when Lucero itself was functioning perfectly it ceased to be of value immediately the main radar installation failed. The reliance on the efficiency of other equipment meant that use of homing and beam approach beacons was often denied to aircraft. Another disadvantage was that in the Halifax aircraft the H2S display was in the nose and although the navigator was able to remain in that part of the aircraft for most of the flight, for reasons of safety he had to retire to another position during approach and landing. He was thus unable to watch Lucero indications and pass information to the pilot at a time when most needed. Lucero could not be used in aircraft not fitted with main radar, nor with H2S Mark IV (3-centimetre) and H2S Mark VI (1¼-centimetre). These disadvantages stimulated development of a different version of Lucero and by May 1944 the T.R.E. had developed Lucero Mark III. In this equipment an extra unit consisting of an I.F. power pack and a wave-form generator was used in conjunction with Lucero Mark II and enabled it to function independently of the main radar equipment. It had a separate indicator unit.[1] Lucero Mark III was renamed Rebecca Mark VI in the summer of 1944 because the Air Ministry found it easier to have all independent interrogators given the same code name. Rebecca had obvious operational advantages over Lucero and it was intended that it should gradually replace the latter in all aircraft needing interrogation facilities. In November 1944 it was decided that Rebecca was to be the future standard interrogator for Coastal and Bomber Command aircraft. Installation of Lucero Mark II in aircraft fitted with H2S Marks II and III was to continue but the aircraft were to be fitted with a new aerial system giving cover in the 214 to 234 megacycles per second band with D/F facilities, and providing adequate efficiency in the 157 to 187 megacycles per second band to effect interrogation.[2] Originally it was planned to replace Lucero with Rebecca Mark VI but in 1945 the final choice of Rebecca Mark IV was made. The use of Lucero was continued until after the war, but as supplies of Rebecca Mark IV became available replacement retrospectively and on production lines began.

Dinghy Wireless Equipment

Early in the war, the need for an effective air/sea rescue organisation was emphasised, and the provision of radio aids to dinghy location became very necessary.[3] Even if S.O.S. signals transmitted by an aircraft wireless operator or by a fighter pilot before a ditching were received and enabled a fix to be obtained, some time usually elapsed before searching aircraft or surface craft could arrive in the vicinity of the location, and the dinghy meanwhile drifted from the original position. The problem of rescue was not therefore solved when a crew succeeded in getting into a dinghy, especially as sometimes there had been no time in which to send S.O.S. signals. At any time a dinghy was a small target for search, and it was necessary to give air/sea rescue craft something more than visual signals to look for.

In 1941 development of a dinghy wireless transmitter was begun, and a prototype was ready for trials in September 1941. By then, however, a much more efficient transmitter used by the *Luftwaffe* had been captured and examined.

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[1] A.M. File C.30641/46. [2] A.M. File C.30642/46.

[3] *See* A.H.B. Monograph 'Air/Sea Rescue' (A.P.3232) for full details.

As a result further work on the prototype was stopped and the Ministry of Aircraft Production made arrangements for manufacture by the Standard Telephones Company of 2,000 modified versions of the German equipment. Trials held in December 1941 were assessed as successful and the Air Staff raised a requirement for provision on the basis of one transmitter, known as T.1333, for every operational multi-seater aircraft; the production contract was consequently increased by 8,000. T.1333 was designed to transmit, automatically by the turning of a handle, or by manual keying, S.O.S. signals on the international distress frequency of 500 kilocycles per second. It weighed 18 pounds and was crystal-controlled. Although stowage in the dinghy itself was desirable, the shape of T.1333 made this impracticable, and in order that production in quantity should not be delayed it was agreed that the transmitter should be stowed loose in aircraft and brought out by hand at the time of ditching. The Standard Telephones Company estimated that the original order of 2,000 sets would be completed by June 1942, but in the early models the aerial was raised by means of a gas-filled balloon, a method which proved to be unsatisfactory. Experiments to evolve an effective method were therefore started and the balloon project was abandoned in April 1942 when trials of telescopic mast and rocket-launched kite aerial systems were begun.[1] The use of a mast entailed provision of a loading coil, and production in quantity of T.1333 was in consequence delayed. Delay was aggravated by faults in generator design, and only 16 transmitters were delivered to the Service in July 1942, when delivery of an additional 100 was promised for the following month.

The deficiency of dinghy radio equipment caused great concern and was discussed in the House of Commons; in the U.S.A. transmitters developed along similar lines to those used by the *Luftwaffe* were being produced and in view of the urgency of the requirement the U.S.A. authorities were requested to supply 1,000 sets to the United Kingdom. The first of the American equipments, known as SCR. 578, arrived in February 1943, by which time 1,600 sets of T.1333 had been delivered. SCR. 578 was in many ways similar to T.1333 but the aerial was brought into use by means of either a gas-filled balloon or hand-launched kite. To standardise the American and British equipments the SCR. 578 aerial system was replaced by the T.1333 rocket-launched kite system, and Coastal Command units began receiving the composite equipment in March 1943. In order that marine craft could home to dinghy radio transmissions high-speed launches and rescue motor launches were equipped with R.1155 and D/F loop. By the end of July over 8,000 sets of T.1333 had been delivered to units of all operational commands, and large numbers of SCR. 578 had been received by Coastal Command.[2]

T.1333 was found to be less satisfactory in use than SCR. 578, and considerable difficulty was being experienced in obtaining sufficient suitable ball-bearings and generators for its production. Although SCR. 578 entailed manual operation, a drawback when survivors were injured or exhausted, it was able to float, was shaped to fit between the knees of an operator and was provided with a strap for fastening it to the legs to alleviate strain, distinct advantages in the operating conditions usually met with in a dinghy, and was fitted with a

[1] The theoretical ranges with the systems were 180 miles with the kite and 14 to 20 miles with the mast.

[2] Some T.1333 equipments were modified to operate on 4575 kilocycles per second for use in the Middle East.

signalling lamp for use at night. Proposals for the substitution of T.1333 by SCR. 578 had been put forward in July and again in September 1943, and it was finally agreed that 12,000 SCR. 578 transmitters should be supplied to the R.A.F.; production of T.1333 was adjusted accordingly. Development of a replacement transmitter was begun when T.1333 was withdrawn from service, but at the end of the war the priority allotted to the project was reduced. Subsequently further development was postponed so that a joint R.A.F./Civil Aviation/Merchant Navy specification could be evolved.

Some progress was made with development of an auto alarm receiver for installation in aircraft. It was known as R.1530 and was designed to provide, automatically, audible warning when actuated by signals transmitted on the distress frequency. Work on the project was cancelled, however, because of the lack of uniformity of signals received from dinghy emergency transmitters.

All the air/sea rescue apparatus in use or being developed during the early years of the war was usually only effective if a ditching was quickly followed by the arrival of rescue aircraft. As the distances at which operational flying could be carried out increased it became apparent that it would be necessary to provide surviving crews with means to make their way, under their own power, to friendly territory or to waters where they could be more easily rescued. In September 1942 preliminary tests of an airborne lifeboat were successfully completed, and early versions were in operational use early in 1943. To enable the crews using airborne lifeboats to receive instructions by wireless, on the 500 kilocycles per second frequency, from escorting aircraft or ground stations, provision of a battery-operated watertight light-weight W/T receiver was required. Airborne lifeboat receiver R.1545 was adapted, as a wartime measure, from a receiver installed in all Merchant Navy lifeboats.[1]

One of the main disadvantages of the dinghy transmitter was that it was not a fixed installation in the dinghy. It could not be carried in a number of smaller types of aircraft because stowage space was lacking, and until suitable stowage in the dinghy pack could be found it had to be carried loose in those aircraft which could accommodate it. In consequence it was frequently left behind in aircraft when ditching occurred, especially since most Bomber Command ditchings took place at night, when it was more difficult to remove loose objects from aircraft. The need for Walter was therefore apparent, not only for fighter, but also for multi-seater aircraft.

Walter and Corner Reflectors

During 1941 and 1942 the possibility of using radar as an alternative to the dinghy wireless transmitter was being investigated, and experiments were conducted by the T.R.E. at Hurn with reflectors attached to the mast of a 'K' type dinghy to provide echoes on A.S.V. However, trials revealed a very limited range, and the project was considered to be impracticable. Development of a beacon, known as Walter, to meet an operational requirement for dinghy homing over the last five miles of a search, was begun at the R.A.E. in 1943. When development was completed Walter consisted of a cylindrical battery container and a telescopic mast extending to 7 feet 4 inches carrying at its top an oscillator unit and a horizontal dipole aerial. The transmitter was a

[1] A.H.B./IIE/44. Air Ministry Signals Bulletins.

self-squegging oscillator built round a valve Type CV.93. The frequency of oscillation was fixed at 176 megacycles per second and the squeg frequency lay between 35 and 60 kilocycles per second. The output from the oscillator was fed directly into the aerial. When the battery supplies were switched on the oscillator started transmitting the squeg pulses irrespective of the presence of an A.S.V. transmission. If operated continuously the battery lasted for only about eight hours but it could be made to last longer by intermittent operation. The signals were displayed on the indicator unit of the A.S.V. equipment. They covered the full length of the trace and appeared on both sides of it. The relative amplitudes of the two sets of signals were used to indicate the bearing in the usual way. The received signals were not locked to the A.S.V. time-base. No range information was available but aircraft equipped with A.S.V. Mark II, Lucero or SCR. 729 could locate and home to the beacon. By the end of 1943 development was sufficiently far advanced for tests to be held at the R.A.E. These showed that the pick-up ranges varied from 4 nautical miles at 50 feet to 25 nautical miles at 5,000 feet.[1]

The first twelve trial equipments were issued to Nos. 172 and 547 Squadrons for operational trials in February 1944. Although performance was fairly satisfactory, stowage was, as with the wireless transmitter, a main difficulty. It was not possible to include Walter in the dinghy pack without omitting other ancillary equipment. The Admiralty decided to do without sailing gear in Fleet Air Arm ' K ' dinghy packs and to attempt stowage in ' Mae West ' life-belts, but the Air Ministry was not completely convinced that Walter in its existing form was acceptable. However, when some equipments became available in March 1944 they were issued to Mosquito squadrons and flights of Nos. 8 and 100 Groups. About 4,000 sets had been delivered by September 1944 but they were not waterproof, and many of the 600 issued to the R.A.F. were used at Bomber Command stations for instructional purposes only. Development by the Gramophone Company had not been satisfactory ; the equipment had been redeveloped by the firm of Ultra, which, in conjunction with that of Cossor, had begun production of more satisfactory sets. Use of valves Type CV.93 in Walter was causing production difficulties because their low output caused many equipments to be rejected, and this combined with the comparatively low priority accorded the programme meant that the rate of production was slow. Meanwhile development of Walter Mark II, an improved design, had been started. It did not incorporate any new technique but provided a hand-driven generator as an alternative power supply to batteries, the generator and the battery container being interchangeable, and included improvements in the mechanical units and aerial design. It was being developed as two distinct types, one with the oscillator on the mast, and one with the oscillator contained in the set itself. It was planned that comparative trials should decide which type was to be accepted as Walter Mark II.[2]

By November the operational requirement for Walter Mark I had been confirmed as provision in all ' K ' dinghy packs for single and twin-engine fighters and fighter-bombers, and in all multi-seater dinghies carried in heavy bomber aircraft. Priority of issue was to be given to fighter and fighter-bomber aircraft, and it was to be a personal issue to all Fleet Air Arm crews. The equipment then being manufactured was watertight, and the necessary action was being taken to ensure that the specification for water-proofing was vigorously

[1] R.A.E. Tech. Note Rad. 175.
[2] A.H.B./IIE/111. Walter—Meetings.

enforced during production. Recent trials of Ultra equipments had produced satisfactory results, but some made by the firm of Cossor had not been so good, one fault being continuous oscillation. It was at first thought that faults in aerial matching were responsible for the trouble but investigation by the R.A.E. revealed that a more likely cause was the state of batteries after being left in a set for some time. A major drawback of Walter Mark I was its reliance on batteries ; even when in the best of condition their useful life was limited, and that was curtailed when the batteries were subjected to extremes of temperature. The firm of Cossor produced and delivered nearly 2,000 Walter equipments during November, and estimated that the monthly rate of production would rise from 3,000 in December to 5,000 in April 1945. Equipments produced by the firm of Ultra during November did not pass A.I.D. tests, and a forecast of delivery rates was not possible. However, by March 1945 a total of nearly 2,000 equipments had been delivered, and a combined monthly production rate of 6,000 was expected if sufficient suitable valves could be made available. The supply requirement was extended to include the provision of Walter Mark I in all R.A.F. aircraft equipped with ' K ' dinghy packs Types A, B and C, in all multi-seater dinghies and airborne lifeboats, in all Type F supply droppers, and in all ' K ' dinghy packs and multi-seater dinghies of the Fleet Air Arm. When, during the summer of 1944, the radio development programme was drastically reduced, work on Walter Mark II was stopped, but in November Sir Robert Renwick arranged that its development should be re-started. By March 1945 trials had been started but production in quantity had not begun when the war ended.

Whilst Walter Marks I and II were being developed in the United Kingdom development of a comparable equipment was begun in the U.S.A., but production was not expected to start until the end of 1945. Meanwhile, use was made of a corner reflector which consisted of a light-weight collapsible structure, with reflecting planes of wire mesh made of monel metal, that opened out like an umbrella. Three reflecting planes facing at right angles were capable of directing back to source a large proportion of radar energy intercepted, which in its turn could be detected by aircraft equipped with centimetric A.S.V. The corner reflector did not suffer the disadvantages attendant on the use of batteries as did Walter, but it offered no method of identification and its range when used in rough seas was restricted. However, the Air Staff considered that it would be valuable when used in conjunction with Walter, and when the U.S.A. authorities began planning quantity production in September 1944 orders were placed for the supply of corner reflectors on the basis of one for each set of Walter issued. The corner reflector was required as a complementary device to Walter, and was to be used in the R.A.F. when it was possible to include a reflector in stowages ; it was also intended to issue a corner reflector to all Fleet Air Arm aircrew in addition to Walter. By November 1944 requisitions had been placed for 32,000 Type MX. 137A for single-seater dinghies and 62,000 Type MX.138A for multi-seater dinghies. At that time production output was very small and no forecast could be obtained of the date or rate of delivery. MX.138A entailed provision of an aerial mast, and was designed to be screwed in the end of a paddle carried in American dinghies, so that a substitute for the paddle was also required. Early in 1945 it was anticipated that delivery in quantity of corner reflectors would begin in March 1945 but appreciable supplies were not received until just before the end of the war with Japan.

CHAPTER 14

COMBAT WARNING

When Bomber Command began its offensive against Germany, the ideal of air supremacy had not been attained, and the offensive had to be mounted and maintained against determined and well-organised fighter and ground defences; the bomber force required protection if prohibitive losses were to be avoided. The extent of vulnerability of bomber aircraft was bound up with many factors, of which the most important were their operational performance, the degree of fighter protection afforded them, the type of defensive armament mounted in them and the degree of accuracy achieved in its use, the depth of their penetration into enemy territory, and air and ground radar systems and countermeasures. Early experience of losses in daylight bombing raids showed conclusively that such raids could not be maintained. Even large fighter escorts failed to afford full protection, and they could not in any event be provided when penetration was deep. Bombing at night, although it brought many new problems and aggravated others, did, however, afford bomber aircraft the cover of darkness. An extensive and well co-ordinated system of anti-aircraft guns and searchlights was at first the greatest threat, and evasion was the main method of defence; as far as possible bomber aircraft were routed to avoid gun and searchlight concentrations. But with the rapid development of radar installations for night fighters and effective ground control techniques, it became increasingly important for bomber crews to be prepared for combat.

Prior to the use of Window, the basis of the German air defences was ground radar. The use of Window, beginning in July 1943, dislocated the enemy's flak and fighter control organisations and produced a marked drop in bomber losses. The enemy fell back on his only alternative—the employment of free-lance night fighters, both catseye and equipped with A.I. This change in German tactics had serious implications for our bomber force and made the further development of combat warning devices all-important.

By 1944, 70 per cent of bomber casualties at night were due to enemy night fighter successes. Of a total of 2,717 sorties carried out by Halifax Mark II and Mark V aircraft of No. 4 Group between November 1943 and February 1944, the percentage of aircraft missing was 8·5; with such a loss rate less than 8 crews in every 100 could survive a tour of 30 operations.[1] In such conditions no force could survive for long, and the permanent suspension of bombing operations against Germany of Halifax Marks II and V aircraft in February 1944 was a result. It was clear that any device which promised even the smallest protection to bomber aircraft was worth persevering with.[2] Although Bomber Command losses over the whole of 1944 were only 1·68 per cent, the estimate for the first three months of the year was very much higher, some 3·5 per cent. At that rate only one crew in five could survive an operational tour. So serious was the threat of the enemy night fighter organisation that for some time the primary objective of the combined R.A.F. and

[1] A.H.B./ID/12/96. A.C.A.S. (Ops.) folder Bomber Command Organisation.

[2] A.H.B./II/69/162. The apparent reduction in losses of 1·3 per cent for aircraft equipped with Visual Monica in early 1944 meant the saving of 40 aircraft and 280 aircrew in 3,000 sorties.

U.S.A.A.F. strategic bomber offensive was the German aircraft industry.[1] However, from March until late in the summer of 1944 Bomber Command operations were mainly confined to attacks against targets in France and the Low Countries in support of the campaign to liberate Europe. Thereafter the disorganisation of the enemy early warning and night fighter control systems during the advance of the Allied armies, coupled with the further development of Allied radio countermeasures, reduced the German night fighter force to a state of comparative impotence.

For many months, however, the application of radar in the enemy night defence system had constituted a serious threat to the continuance of the night bomber offensive. It was countered in a number of ways; by tactics, by jamming, by improvement of aircraft performance and armament, and by the installation in bomber aircraft of equipment designed to warn crews of the approach of enemy fighters.

Early Development of Equipment

In view of the success being achieved in the United Kingdom by Beaufighter night-fighter aircraft equipped with A.I. Mark IV and G.C.I. control in 1941, Headquarters Bomber Command requested that night-bomber crews should be provided with a warning installation. The matter had first been raised with the Air Ministry and considered by the Interception Committee in November 1940, when countermeasures to defeat radar methods of interception were proposed.[2] They were :—

(*a*) Complete neutralisation of bomber aircraft so that they gave no indication on enemy radar of their presence. This was not technically possible.

(*b*) Jamming of ground control radar and fighter A.I. from ground or air. Ground jamming equipment would have to be very powerful, and jamming apparatus carried in aircraft would give away the bomber's position.

(*c*) Installation of detectors in bomber aircraft to indicate whether enemy fighters were using A.I. in the vicinity. This seemed comparatively simple, and it did not necessitate transmission by the bomber.

(*d*) Installation of a form of A.I. in bombers so as to enable them to engage or evade enemy fighters at will. (The possible use of airborne radar for formation keeping and fighter detection had been first suggested by Dr. E. G. Bowen in October 1939.) Objections were that transmissions from a bomber's A.I. could be used for interception purposes, that the weight of such equipment would be excessive, and that A.I. was secret equipment and could not be used over enemy territory.

Pressed for a more precise statement of the operational requirement, Headquarters Bomber Command formulated specifications on 20 July 1941.[3] The T.R.E. was already developing equipment which met some of the specifications, and it was demonstrated at Hurn on 31 December 1941. Although it did not fulfil all requirements, Bomber Command representatives present at the trials were enthusiastic about the equipment, known as Monica Mark I.

[1] A.H.B./ID/12/96.

[2] A.H.B./IIH/241/3/185/(A). Bomber Command File BC/S.24573.

[3] A.M. File CS.9853..

Monica Mark I was not, however, ready for operational use until June 1943, nearly two years after the statement by Headquarters Bomber Command of the operational requirement. By this time, operating conditions had greatly changed, and Monica Mark I and the slightly modified Monica Mark IA were never successful. The operational weaknesses—quite apart from the fundamental weaknesses of vulnerability to jamming and homing—were the audio presentation and the absence of any indication of the direction of approach of fighters. Monica was later modified for visual presentation and to give information of direction, and as such it enjoyed a period of outstanding success in early 1944. But by June 1944, the use of Monica transmissions for homing purposes by enemy fighters was suspected, and in September 1944 Monica was withdrawn from all main force aircraft.[1]

The other main combat warning devices developed were Fishpond and Boozer. Fishpond was an attachment to H2S, echoes of aircraft picked up on the H2S scanner being presented on the Fishpond tube in a form easy to interpret. The area of search covered the lower hemisphere only, but this coverage was particularly desirable as enemy fighters generally attacked from below, aided sometimes by upward-firing guns.[2] Radar warning was essential as it was impossible for gunners to see enemy fighters against the earth background at night. In the first place it was expected that Fishpond would be an interim measure pending design and production of later marks of Monica and of A.G.L.T., and this influenced its design in that modification to the H2S system was not tolerated, and Fishpond itself had to be of simple construction and subordinate to the operation of H2S.[3] Although Fishpond was used with a varying measure of success up to the end of the war, it never realised its full potential because of its subordination to H2S.

Boozer was intended to be complementary to Monica, Fishpond or A.G.L.T., but due to the general shortage of combat warning equipment, Boozer had to be used by itself, and as such it suffered from the serious deficiency that it gave no indication of range or direction. Boozer was fundamentally sound in that it did not radiate, responding only to enemy transmissions, and apart from A.G.L.T. it was the only equipment that even approached the identification problem. Unfortunately, for the bulk of its period of operation it suffered from inadequate range. Jamming of the enemy's ground radar defence system forced on him the course of employing more and more A.I. fighters, and it was to counter the A.I. fighter that the comprehensive fitting of Boozer was urged. The equipment was, however, never satisfactory, and it was finally withdrawn in September 1944.[4]

A.G.L.T., although its function was not confined to combat warning, came under this general heading because its ultimate purpose—protection of the bomber from the enemy night fighter—was the same. Early experience with A.G.L.T. exposed the general unsuitability of a negative system of identification, and when it was later shown that this system was in fact particularly reliable, opportunities for blind firing had almost entirely ceased due to the collapse of the enemy.

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[1] A.H.B./IIH/241/3/262. Bomber Command File BC/S.30343/1.

[2] A.H.B./IIH/241/10/55(A). Bomber Command File BC/S.30146.

[3] T.R.E. Journal, July 1945.

[4] A.H.B./IIH/241/3/211. Bomber Command File BC/S.30594.

Relegation of Combat Warning to Secondary Role

The original specification stressed that an apparatus which would demand the employment of one member of the crew in continual observation should be avoided.[1] This precept tended to relegate combat warning to a secondary role ; the member of the crew detailed to carry out the observations would retain his former duties and these would take precedence. The addition of a special crew member to operate the equipment would have increased space, weight, and centre of gravity difficulties in aircraft, besides increasing training and manpower problems. In any event the necessity for avoiding the addition of a special crew member was never questioned. Speed of introduction was placed before perfection of equipment. Thus the absence of directional indication in Monica Marks I and IA was accepted. The failure of Monica Marks I and IA was the factor which left two-thirds of Bomber Command aircraft unequipped with a suitable combat warning device in the winter of 1943/1944.

Throughout the months of operational use of Monica and Boozer, and until a late stage with Fishpond, ample evidence was available to indicate that aircrews had not received sufficient training to enable them to obtain full value from the various combat warning devices. There was a tendency to regard combat warning measures as being purely defensive, and consequently to relegate their importance in comparison with that of installations and techniques regarded as being offensive. The tendency militated particularly against effective development and operational use of Fishpond, which was always regarded as secondary to H2S.

Delays in the production and fitting of combat warning equipment meant that in some instances apparatus designed to meet one set of conditions was introduced when those conditions were changing or had already changed. Planners were faced with two fundamental difficulties ; one, that the whole subject of combat warning presented a constantly changing picture on account of enemy reaction, so that it was never possible to state a clearly defined long-term policy for any particular piece of equipment ; and two, the vexed question of priorities.[2] Combat warning equipment was only one of a number of urgent requirements in the many facets of the radio war, but its importance was such that in January 1944 the A.O.C. No. 5 Group stated '. . . The biggest contribution to our bomber offensive at this time would be to equip the bombers at once with a very efficient tail warning device. . . .'

Methods of Assessing Results

Most assessments of the value of combat warning devices were made by a scientific study of the reports made by operators and crews and by a comparison of the loss and attacked rates of fitted and non-fitted aircraft. In making these assessments, scientists were hampered by the knowledge that reports were often carelessly rendered, that in any case they represented only the operator's interpretation of what he saw, and that even then reports were incomplete and inaccurate due to operators rarely being able to maintain continuous watch. Again, when an aircraft was lost, the precise circumstances of its destruction were rarely known. However, in default of sounder methods policy decisions had to be taken on the strength of statistics and deductions compiled from the evidence available.

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[1] A.M. File CS.9853.

[2] A.M. File CS.23032.

Statistics were of the highest value provided the conditions under which they were obtained were remembered, and provided the warnings of the scientists that they were not to be taken as conclusive where there were uncertain or unknown factors were not forgotten. In some of the monthly reports on Fishpond, for instance, it was possible to show that it was safer to be without Fishpond, but that if one had to have it, it was better to be untrained in its use.[1]

A more reliable method of assessing the value of radar devices was continuous photography of displays during flight. This was first projected in August 1944, the equipment chosen being Fishpond, but it was not until March 1945 that cameras suitable for the task became available. The investigation, although not carried far enough to produce results of decisive value, demonstrated that earlier introduction of photography of Fishpond would have produced results of value in the technical improvement of this device, its manipulation and its tactical employment. The information gained was far superior in quality to that obtained from interrogation of operators. The investigation confirmed that some form of automatic recording was essential for scientific research into the operation of aircraft radio devices.

Development and Production of Monica Mark I Series

When, at the beginning of the war, Fighter Command aircraft were being equipped with A.I., it was realised that, if the equipment proved to be successful in operational use, the enemy would eventually use a similar installation to assist in the interception of bomber aircraft. At the instigation of Headquarters Bomber Command countermeasures were discussed at a meeting of the Interception Committee on 28 November 1940, shortly after Headquarters Fighter Command put forward the first claim for an enemy aircraft destroyed by a night fighter equipped with A.I. Mark IV.[2] That success was the only one recorded for A.I. Mark IV during the remainder of 1940, and it was not until after effective ground control radar equipment had been brought into use early in 1941 that reliable night interceptions were achieved.[3] Then, on 20 June 1941, Headquarters Bomber Command reminded the Air Ministry that early warning of the approach of enemy fighters was of the utmost importance to bomber aircraft. Meanwhile, in view of the success achieved with A.I. by Fighter Command, investigation had been begun at the T.R.E. of the possibilities of the application of A.I. to the defence of bombers.

Headquarters Bomber Command on 24 June 1941 stated an urgent requirement for some form of aircraft installation which would give warning of the approach of enemy aircraft. It was obviously undesirable and impracticable to employ in bomber aircraft apparatus as complicated as the existing fighter A.I. equipment, and when Headquarters Bomber Command was asked for a more precise evaluation of the requirement, it was stated, on 20 July 1941, that the essential features were:—

(*a*) The device should give warning of the approach of other aircraft at ranges of 700 to 1,000 yards.

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[1] T.R.E. Journal, July 1945.

[2] A.M. File CS.14135.

[3] *See* Royal Air Force Signals History, Volume V: 'Fighter Control and Interception'.

(*b*) A weight of up to 250 pounds could be accepted provided the bulk did not unduly hamper the movements of the crew.

(*c*) If possible the apparatus should give an indication of the direction from which aircraft were approaching.

It was realised that details of the type of warning given would depend on the type of apparatus selected to fulfil the requirements. The first and most essential need was that the tail gunner should receive immediate warning. Next in importance were the gunners manning the dorsal and front turrets, and the captain of the aircraft. Finally the remaining members of the crew should be warned so that they could take advantage of whatever shelter was provided by armour-plating and the more solid items of aircraft equipment. Whatever the method of warning, Headquarters Bomber Command wanted to avoid the employment of one member of the crew in continual observation of the apparatus. The ringing of a bell, the sounding of a buzzer on the intercommunication system, or the flashing of lights visible only to the crew, was visualised.

The equipment being developed by the T.R.E. on the same principles as those used for A.I., although meeting the Bomber Command requirements for size and weight, gave no indication of the direction of approaching aircraft, and the T.R.E. was asked to investigate the possibility of modifications to meet this requirement. However, when in November 1941 a requisition for a development contract for 24 sets was raised, the equipment had not been modified to include this facility. The work of manufacturing the 24 development models was delegated to the firm of Cossor. The experimental sets had a weight of 40 to 50 pounds and a range of 3,000 feet, and gave aural indication on the intercommunication system of the approach of aircraft by means of warning pips whose periodicity varied with range. Spot frequencies of 223·5 and 227·5 megacycles per second were allocated by the W.T. Board. The equipment measured the range of the nearest echo, and when the echo came within the predetermined range of 3,000 feet, a 1,000-cycle note was switched on and off electronically, the rate of switching increasing as the range closed.

A demonstration flight of the T.R.E. prototype equipment took place at the Telecommunications Flying Unit at Hurn on 31 December 1941, at which representatives of the Air Ministry, Bomber Command and the T.R.E. were present. The device had been installed in a Wellington, and a Spitfire was used to play the part of intercepting fighter. The installation was switched on shortly after take-off, and ground returns were received in the form of a chopped note or pip until a height of about 3,000 feet was reached. The ground returns were irregular, varying with the ground contour. A series of attacks from astern was then made by the Spitfire, and at ranges of approximately 1,000 yards a slow, recurring and unmistakable pip was heard, the frequency of the pips increasing as the Spitfire closed range. Warning of approach was received within an elliptical cone covering approximately plus or minus 45 degrees in azimuth and plus or minus 30 degrees in the vertical plane. When the Wellington descended, the irregular pips which registered ground returns reappeared, and when it flew out to sea the ground returns suddenly became regular in the periodicity of the pips, giving a clear indication that the coast had been crossed. In spite of the lack of directional indication, the Bomber Command representatives were enthusiastic.

It now remained to await production of the development models and to plan flight trials. It was decided in March 1942 to fit five Wellingtons of Nos. 1483 and 1485 Flights, the respective training flights of Nos. 3 and 5 Groups, for Service trials. With 100 per cent spares allowed to the training flights, this left four sets for further development work and for the prototyping of fittings for heavy bombers should the trials indicate a reasonable prospect of success. It had been agreed that heavy aircraft should have priority over other types. The first priority in the actual fitting of the equipment was to be given to whichever type of heavy aircraft was in the greatest numbers in Bomber Command when the new equipment, now styled Monica, was introduced into the Service. When all the heavy bombers had been equipped, Monica could be fitted in Wellingtons. The first development model was expected before the end of April 1942, a further two by the end of May, and the remainder at the rate of five per month. The aircraft were to be flown to the Vickers aircraft firm at Weybridge, where installation in five aircraft of the first flight was to be carried out in June.

Provisioning action for quantity production of Monica could not be taken until the installation of the development models in heavy aircraft had been approved. This followed normal practice on the introduction of any new equipment. However, Bomber Command's experience on operations during the winter of 1941/42 suggested an urgency which would not be met by following established practice in this instance. This experience underlined the need for the immediate fitting of equipment capable of warning crews of the approach of enemy fighters. Many fighter attacks were developing completely unseen, the first warning the crew received being the fighter's opening burst, which very often completely disabled the aircraft.[1] The night fighter's technique was to approach slowly from behind and below under G.C.I. control until well within shooting range. In this position he was in that sector of the rear gunner's search area where he was least visible, and in which the rear gunner had to stand up in the turret to get a clear view.

The A.O.C.-in-C., Bomber Command urged that provision be made at once for the manufacture and fitting of Monica, without waiting for the results of the Service trials due to take place in the summer of 1942. Acceptance of this policy, it was argued, would enable the equipment to be introduced many months earlier than would be possible if the results of the trials were awaited, but on the other hand the risk would have to be accepted of the first production models developing technical troubles which might otherwise have been cleared during the trials.[2] The A.O.C.-in-C. insisted that the apparatus as tested at Hurn the previous December met the requirements put forward, and stressed that the time spent in producing equipment for further trials could not be afforded, however desirable such trials might be under less pressing circumstances. The fact that the apparatus did not in fact meet the original requirement in the vital matter of a directional indication was accepted or ignored. On 2 April 1942 the Air Staff authorised the immediate placing of an order for 2,000 Monica installations.

Considerable delay was experienced in developing the Monica receiver and the whole programme for the fitting of the 24 development models was retarded six weeks. As a result, deliveries from the main contract of 2,000 sets were not

[1] A.H.B./IIH/241/3/185(A).

[2] A.M. File CS.9853.

expected to start until September or October. Meanwhile, action was taken to obtain details and to place contracts for the airframe modification parts, and to organise travelling fitting parties, so that aircraft could be fitted retrospectively as soon as Monica equipment was available.

A meeting to consider production and installation of Monica was held at the Air Ministry on 10 June 1942. The full Monica equipment consisted of a transmitter, receiver, panel control, external aerial, and two test sets for setting up and testing the equipment on the ground, one of which was a cathode ray tube monitor and the other an artificial signal generator. In addition there were junction and switch boxes for the power supply, which were being designed by the R.A.E.[1] Only one complete set of equipment had been delivered and it was decided not to use it. The second set to be produced would therefore rank as the prototype.[2] The third set was required at the firm of Cossor for standardising, and it was expected that the balance of 21 sets would be delivered in August. Of the main contract of 2,000 sets, 150 were expected in November, 400 in December, 500 in January, 500 in February and 450 in March. On 27 August 1942 it was decided to plan installation on the basis of the provision of 100 per cent spares, and a new contract for a further 10,500 sets was placed, the intention being that when deliveries from the new contract began the spares provision would be reduced by two-thirds.[3] The R.A.E. was to fit aircraft for trial installations in the order Halifax, Lancaster, Stirling, Wellington, later changed by Headquarters Bomber Command to Halifax, Wellington, Stirling, Lancaster. Aircraft already in squadrons were to be fitted retrospectively within Bomber Command, with some assistance in airframe modification from outside. A revised estimate of deliveries of equipment reduced the original numbers slightly. The first 80 aircraft to be fitted were to be Halifaxes, followed by the Wellingtons of No. 3 Group. It was expected that fitting would begin in November, and arrangements for the provision of sufficient test equipment were made.

Trials

In view of the decision to initiate quantity production before trials, these were now confined to one flight only and were regarded not as Service trials but as tests for training purposes and operational experience. A radar officer was attached to No. 1483 Flight to advise as to the use of Monica, together with an N.C.O. radio mechanic and four airmen. The radar officer first visited the Cossor laboratories and the R.A.E. to gather technical information. Five Monica equipments were delivered to No. 1483 Flight in the first week in August, but difficulties due to the absence of certain parts essential to the completion of the installation prevented any flight tests being carried out before 10 August. By this date, however, one aircraft installation was complete and by 19 August twelve flights had been carried out with it.[4] The early flights were unsatisfactory but better results were soon obtained. The chief troubles were poor maximum range, intermittent warning (observed even on ground returns), and a tendency for the equipment not to start functioning until it had been switched on and off several times. The first two faults were not observed in later flights.

[1] A.H.B./IIE/13/1. Monica (Airborne R.D.F.) Minutes of Meetings.
[2] A.H.B./IIE/13/1. [3] A.H.B./IIE/13/1. [4] A.M. File CS.15389.

The purpose of the tests up to this point was mainly to check the range and angular coverage of the equipment, and the indication was that angular coverage was considerably wider than had been expected, especially below the horizontal, and that it extended round forward to the beam, though at those extreme angles range was reduced and minimum range seemed somewhat increased. To the rear of the aircraft and up to about 45 degrees off the centre line of the aerial the maximum range was 1,000 yards and the minimum about 200 yards. The limitations were governed by the range settings and were not due to the ultimate sensitivity of the apparatus. Given those settings, ground returns were observed up to a height of about 3,500 feet, the discrepancy between aircraft echoes and the higher maximum range of ground returns being due to the great difference in amplitude between the two signals.

The trials were completely disorganised from 27 August to 8 September for a number of reasons. Some aircraft were required for operations during this period and other aircraft were required to stand by, and there was also a bad patch of unserviceability among the remaining aircraft of the flight. Following this interruption, covering a period of 13 days, seven trial flights were undertaken between 9 and 12 September, and no less than five of these proved abortive owing to receiver failure.[1] Efforts to accelerate the trials were made, and aircraft of No. 1483 Flight were temporarily relieved of operational tasks. Although there were further slight delays through bad weather and unserviceability, the trials then went ahead in a more satisfactory manner. It was confirmed that the area over which effective warnings were obtainable extended from dead astern almost round to each beam in the horizontal plane, and in the vertical plane from about 45 degrees above and to the rear of the aircraft round through dead astern to slightly forward of a line drawn vertically downwards beneath the aircraft. Outside those areas intermittent warnings were obtainable in almost any direction except dead ahead.[2]

On 18 September 1942 the first five sets delivered to No. 1483 Flight were returned to the R.A.E. for servicing, in exchange for five new sets. The new receivers developed suppression troubles, but a representative of the R.A.E. who witnessed the trials reported on 7 October 1942 that they appeared to be proceeding in a very satisfactory manner. He saw some 14 flights made and on no occasion did Monica fail. He reported that most of the initial teething troubles had been overcome, and he did not anticipate that the receiver suppression trouble would cause any serious difficulty, especially as the first receivers had been satisfactory.

No. 1483 Flight made the first detailed report on the trials on 9 October 1942.[3] The main points enumerated were that the area of sensitivity was far in excess of that expected ; that changes in the range of aircraft could be detected readily ; that all faults originally encountered had been largely overcome ; that serviceability in the squadrons should be good ; and that Monica was considered sufficiently useful to justify its installation in all night bomber aircraft.

Policy for Introduction

On 21 November 1942 Headquarters Bomber Command asked for a policy ruling on the operational introduction of Monica. The danger was that if Monica were to be introduced piecemeal (the fitting of the majority of the bomber

[1] A.H.B./IIH/241/3/185(A). [2] A.M. File CS.15389. [3] A.M. File CS.15389.

force would take about three months), details of Monica would certainly become known to the enemy when only a small number of aircraft were equipped. If it was likely that the enemy could devise means of countering Monica during this period of introduction, the effectiveness of the device would be nullified by the time the whole force was equipped. On the other hand, if expert opinion held that Monica could not readily be countered by the enemy, nothing would be lost by its early and piecemeal introduction.

The possible action that the enemy might take should he capture Monica equipment had been considered early in 1942. It was then thought that he might initiate a jamming programme which would involve installation of jamming equipment in all his fighter aircraft, or install in his fighter aircraft apparatus enabling them to home to Monica transmissions, or install Monica in his own bombers. In the last instance, it was felt that the latest versions of A.I. would still enable fighters to make effective interceptions.[1] Thus the possibility that the enemy might develop equipment to enable his fighters to give a boomerang effect to Monica by homing to its transmissions was considered in the earliest stages of development, but no action was taken to incorporate modifications to render such homing impossible. However, on 31 October 1942, the Air Ministry asked Headquarters Bomber Command to analyse early Monica operations with a view to determining whether the use of Monica provided the enemy with any added facility for homing, and made suggestions for possible evasive action. On the third possibility, jamming, the early appreciation suggested that the enemy might be faced with severe practical difficulties. However, it was never contended that Monica was other than vulnerable to jamming.

A meeting of scientists was held at the Air Ministry on 28 November 1942 to discuss possible enemy counter-action against Monica. At this meeting the view was stated that, judging by the experience already gained of the enemy's ability to introduce effective countermeasures against new radio equipment, it would be at least three months and probably six months before any widespread counter was likely to be introduced. The period would depend to some extent on the amount of effort the enemy was prepared to put into it, and this in turn depended on his assessment of the operational value of the equipment. The recommendation of the Air Ministry was that Bomber Command's use of Monica should not be unduly delayed. A point that influenced this recommendation was that it was known that the enemy was already experimenting with various methods of jamming radio installations, and the longer the introduction of Monica was delayed the better might be his ability to deny its effective use.

Early in December it was the intention that Monica should be introduced as soon as aircraft were fitted and crews had received instruction in its use. Recent operational experience showed that bomber aircraft, and particularly Halifaxes and Wellingtons, were vulnerable against the strong enemy defences then established. The introduction of Monica gave promise of saving a number of these aircraft and thus contributing materially towards strengthening and expanding the bomber force. However, the decision on introduction had to be taken after consideration of four vital factors : the rate of fitting, the anticipated scale of operations, the time for which Monica might be effective, and the availability of a replacement.

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[1] A.M. File CS.9853.

On 14 December 1942 the R.A.E. emphasised the ease with which Monica might be jammed, and made a number of suggestions for the incorporation of anti-jamming facilities in a later Mark of the same equipment.[1] At the Air Ministry, there was a strong feeling that modification of the existing Monica to provide an anti-jamming facility was required in addition to the production of an improved Monica Mark II. A modification incorporating a simple change of frequency, to be known as Monica Mark IA, was suggested. If such a modification proved successful it was to be introduced into the bulk production of Mark I as soon as possible. For the proposed Monica Mark II, an investigation was made into possible frequency bands. The R.A.E. suggested 350 to 460 megacycles per second, but it was believed that enemy radar operated between 360 and 390 megacycles per second, and it seemed that a band above 400 megacycles per second might have to be used. It was emphasised at this early stage that the design of Monica Mark II would have to incorporate as far as possible the components then being used for Monica Mark I.

On 21 December 1942, Headquarters Bomber Command expressed fears that, in view of the official Air Ministry view that Monica could be rendered ineffective by enemy countermeasures within three to six months, and in view also of the expected delay of 12 to 18 months in the introduction of A.G.L.T. and the inherent limitations of Boozer, bomber aircraft would be left, some time during the summer of 1943, without an effective combat warning device. It was therefore recommended that there should be incorporated in Monica changes in design calculated to overcome the expected effect of enemy countermeasures.[2] The possibility of this object being achieved by means of a simple change of frequency was suggested. The R.A.E., however, considered that any modifications practicable to Monica Mark I after jamming had taken place were unlikely to be effective for more than a week or so.[3] This opinion was confirmed by the T.R.E., who agreed that the suggested Monica Mark IA was not worth the effort which would be required for its introduction, since it could be as easily jammed by the enemy as Mark I.[4] The R.A.E. thought that a prototype Mark II, embodying several anti-jamming features and interchangeable with Mark I as far as trays and connections were concerned, could be produced in about three months if given the highest priority, although such equipment was not likely to be available in quantity inside nine months. The difficulty was the production of valves to work on the higher frequency.

In January 1943 Headquarters Bomber Command formulated specifications for Monica Mark II. Maximum range was to be 1,200 yards and minimum 200 yards ; coverage in azimuth, plus or minus 60 degrees ; coverage in elevation, 45 degrees above the line of flight and 90 degrees below.[5] The increase on the original requirement for Monica Mark I was needed to counter enemy progress in night fighter tactics and employment of cannon-firing aircraft. On 22 February 1943 the R.A.E. gave details of the design of Monica Mark II, which was then in the laboratory stage.[6] It met the requirements of Bomber Command, and introduced more power into the transmitter, with a view, as an anti-jamming measure, to decreasing the sensitivity of the receiver. A means of detecting when jamming was in progress was incorporated. The question

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[1] A.M. File CS.9853.

[2] A.H.B./IIH/241/10/37(B), Bomber Command File BC/S.26203.

[3] A.H.B./IIH/241/10/37(B). [4] A.H.B./IIE/13/1. [5] A.M. File CS.9853.

[6] A.H.B./IIH/241/10/37(B).

of the frequency band to be used had been studied most closely in view of the recovery of German radar equipment from crashed enemy aircraft; this equipment was thought to be operating between about 340 and 365 megacycles per second. German coast-watching radar stations were known to operate in the 355 to 375 megacycles per second band, and the German radio-altimeter, which had also fallen into Allied hands, worked on about 370 megacycles per second. These were all the frequency bands known to be in use by the Germans within the proposed Monica II limits of 350-450 megacycles per second. The Monica II waveband was governed by limitations of equipment, which precluded the use of frequencies above 600 megacycles per second, which appeared to be clear. This left two possible bands free of interference from which to choose, 250 to 330 and 390 to 450 megacycles per second. The lower band was the wider but against this the higher frequencies were the more difficult to jam. The higher frequency range was chosen.[1] Unfortunately, Monica Mark II could not be constructed with stock valves owing to the frequency change, and it was certain that the production of new valves would delay its introduction until about April 1944. It was decided that this delay made it desirable to go ahead with the modifications to Monica Mark I known as Mark IA, and it was intended to begin their incorporation in July 1943.[2]

The situation in February 1943 was that production of a total of 12,500 Monica Mark I was under way. Monica Mark IA would be substantially identical with Monica Mark I except for a change in frequency of about 20 megacycles per second. Monica Mark II would be a new design, mechanically interchangeable with Mark I, and incorporating as many anti-jamming devices as possible. Its purpose would be to cover the gap between the application by the enemy of jamming measures to nullify Marks I and IA and the introduction of A.G.L.T. It was at first thought that Monica Mark II could be made available by October 1943, but later appreciations extended this to February and then April 1944. As Headquarters Bomber Command planned to introduce Monica Mark I as soon as a reasonable number of aircraft were equipped, and as a useful life of only four to six months could be allowed for Mark I and a further three months for Mark IA, it was evident that every effort would have to be made to get Monica Mark II into early production if continuity was to be achieved.[3] The aim was to introduce the Mark IA modifications into the main production line for Mark I by 31 July, and to begin the production of Mark II as soon afterwards as possible. Development of Marks IA and II proceeded at the R.A.E. on the highest possible priority.

Operational Trials and Training

A fitting party from No. 43 Group started retrospective installation of Monica Mark I in two Halifax squadrons on 20 November 1942, and retrospective fitting was to be continued until the necessary connector parts were introduced on the aircraft production lines. Halifaxes were expected to come off the production line modified to take Monica from the beginning of February 1943, Wellingtons from the beginning of January 1943. The Stirling and Lancaster programmes had not been decided but it was hoped that the modifications would be introduced on the production line by March 1943. Production

[1] A.M. File CS.9853.

[2] A.H.B./IIH/241/10/38(B), Bomber Command File, V.H.F. fighter-escorted bombers. Signals policy.

[3] A.M. File CS.9853.

of equipment was expected to be at the rate of 20 in November, 150 in December, 350 in January, and 400 in February. 40 sets of aircraft modification kits were to be fitted in November and a further 100 per month in December and January.

In the event, however, the firm of Cossor was forced to put back its delivery programme by five weeks through various changes of design and the shortage of an essential component. Meanwhile, the No. 43 Group fitting party was unable to start work because complete kits of modification items were not available, and aircraft required for operations could not be made available for piecemeal fitting. In mid-December, working parties of No. 35 Squadron were still deficient of 67 types of parts to complete the squadron fitting, and five types of parts to complete even one aircraft. The situation was much the same at the second squadron, No. 408. By 17 December modifications to one or two aircraft had been completed, but no Monica equipment had been delivered to No. 35 Squadron, and only four to No. 408, and those four lacked test gear.[1]

By 4 January 1943 only 20 equipments had been delivered and only 34 modification kits fitted, all in Halifax aircraft. A total of 50 modification kits had been made and future production was estimated at 30 per week. It was expected that 80 aircraft would be fitted by the end of January. Headquarters Bomber Command agreed to ground one flight at a time so that retrospective fitting could take place, but further delay was caused because the airframe modification kits produced by the Handley Page factory were deficient of certain parts.[2] Up to 6 March 1943, 100 Halifaxes had been retrospectively fitted with modification kits and it was expected that 200 would be completed by the end of the month. 60 modified Halifaxes had been delivered off the production line, and the rate of delivery was expected to rise to about 100 per month in April and 150 per month in June. 300 Monica equipments had been produced, a further 200 were expected by the end of the month, and the production figure was expected to rise to 500 per month in May and June. Fitting in Stirlings could not begin before May, but Lancasters equipped with H2S were already being modified on the production line. Wellington production was delayed and modified aircraft were not expected to come off the production line before the end of the month.

On 26 February 1943 the A.O.C.-in-C., Bomber Command drew attention to the serious delays in the introduction of Monica. He pointed out that the need for a warning device of this kind had first been the subject of correspondence in November 1940 and that an urgent requirement had been confirmed in June 1941. Again, at the Secretary of State's meeting for the co-ordination of the bomber offensive on 15 July 1942, the importance of Monica had been reiterated, and at that time introduction had been promised by October 1942. This was later put back to November and subsequently postponed from month to month, and Bomber Command was still not in a position to use the device operationally owing to the small number of aircraft modified. It was stressed that a high percentage of losses were due to crews being surprised by night fighters, losses which might have been avoided if a warning device had been available. Meanwhile, the effort expended by the enemy on his night fighter organisation and the efficiency of his defence operations had increased considerably.

[1] A.M. File CS.15386.

[2] A.H.B./IIE/13/1.

In addition to being concerned at the delay in the introduction of Monica, Headquarters Bomber Command was always conscious of the need for providing against an early operational failure of Mark I due to enemy countermeasures.[1] On 11 March 1943 it was again emphasised that, assuming that Monica Mark I were introduced within a few weeks and that Mark IA were ready for introduction in July, the short expectation of useful life of the two equipments together would mean that the bomber force would be without any form of Monica during the critical autumn and winter periods of 1943/44, unless the expected introduction of Mark II could be brought forward from April 1944. The introduction of Monica Mark II in October 1943 was therefore urged : if this target could not be achieved there was grave danger of the bomber force being exposed to avoidable hazard in the intensive operations planned for the winter period.

While the development of Monica Mark II was being continued at the R.A.E. it was felt that valuable experience would be gained if trials with Monica Mark I were made by Bomber Command in co-operation with Fighter Command.[2] There were two major advantages to be gained from such trials ; bomber crews would be given an opportunity of familiarising themselves with the equipment and of developing the best tactical methods in the realistic conditions provided by night fighters equipped with A.I., and, since it was known that the enemy bomber aircraft were being equipped with a device similar to Monica, the trials would give fighter crews experience of the type of evasive tactics to be expected.

The main object of the trials was to determine the most effective evasion tactics to be used when pursued by an A.I. fighter.[3] The elusion of a ' catseye ' fighter called for manoeuvres to put the fighter pilot off his aim and to exploit the possibilities of the bomber's defensive armament ; to elude an A.I. fighter by escaping from his A.I. coverage was more complex, and success depended on the type of A.I. used by the fighter and the relative flying characteristics of the opposing aircraft. There was little prospect of a heavy bomber eluding the A.I. fighter, once contact had been made, by speed alone. The most likely course of escape lay in exploiting the inherent limitations of A.I. equipment, particularly coverage and time-lag, and in a study of the flying characteristics of the fighter. The lag of indications could be exploited by a feint in one direction followed by a hard turn in the other, or by an increase in speed followed by a sudden decrease ; the second method also exploited the inability of the average fighter to slow down quickly. The bomber's objective was essentially to reach a position behind the beam or astern of the fighter where it would be outside A.I. coverage , the fighter would then have to be vectored again by ground control. The bomber crew's first problem was to decide whether the received A.I. signal emanated from friend or foe. In deciding this they had no positive assistance from Monica, but it was thought that the correct conclusion could be drawn from the reactions of the aircraft, as shown by the equipment, to the bomber's first manoeuvre. Secondly, when the probable identity of the contact had been guessed, it had to be shown what was the best action to take to evade combat or prepare to meet it.[4]

Three methods of evasion were tested, of which the most promising was that in which the bomber, on first receiving warning, dived 600 to 700 feet

[1] A.M. File CS.9853. [2] A.M. File CS.15389. [3] A.H.B./II/54/93(A).
[4] A.M. File CS.15385.

and turned 45 degrees off course, opening engine throttles with the object of encouraging the following aircraft to increase speed. If the indication died out and did not recur, the original course was resumed. If the warning persisted, or recurred, the bomber turned back towards its original course and pulled up steeply, losing speed as quickly as possible to a safe minimum, with the object of making the fighter overshoot below and lose contact. This was regarded as likely to precipitate the fighter into the field of vision of the rear gunner or downward searcher. Pilots of Beaufighters against whom this deception was employed by day doubted whether it would be possible to cope with it by night unless a visual contact had already been made. At the Bombing Development Unit this manoeuvre was regarded as promising a high degree of success, since even if contact was not definitely avoided the fighter was placed in an awkward position, the duration of contact was shortened, and the bomber was given a a chance of shooting back at short range. The chances of complete evasion were considered to be fairly high.[1] A suggested alternative was that on receipt of Monica warning the aircraft should simply corkscrew so that the fighter could not get in an easy shot. One special B.D.U. recommendation was a modification to introduce a cut-out for the navigator's intercommunication, as the pipping indication given by Monica was a distraction. The B.D.U. reported that the standard of serviceability of Monica was very low during the trials, but nevertheless considered that the equipment was well constructed with sound components, and if properly serviced would prove to be reliable. The value of Monica against fighters taking advantage of the difference between upward and downward visual ranges at night was especially noted during the trials. Fighters were known to prefer to attack from astern and below. During night trials with a fighter using this method of attack against a Halifax not equipped with Monica, the fighter followed the Halifax visually for twenty minutes at a range of only 500 yards without being seen. However, when Monica was used the bomber was warned at once of the presence of the fighter. So although Monica could not prevent the bomber from being seen, it gave under almost all conditions an earlier warning of impending attack than could be obtained visually.[2]

On 11 April 1943 the Air Ministry requested Headquarters Bomber Command to delay introduction of Monica on operations until the technical faults disclosed by the trials had been cleared.[3] Good progress was made at the R.A.E. and on 30 April Headquarters Bomber Command decided to make use of Monica operationally from about the middle of May. Meanwhile, additional arrangements were made for speeding the introduction of Monica.[4] R.A.E. civilian technical officers were attached to each of Nos. 4, 6 and 8 Groups to train group 'trouble-shooting' parties, a publication giving a technical description of Monica was distributed to the units concerned, and special training was given to airmen assigned to servicing duties.[5]

Trials had been carried out in March 1943 to determine whether the use of Window would impair the effectiveness of Monica. It was concluded that Window gave a strong response on Monica, but would interfere with its operation only if the range of Monica were set above 1,500 yards and if the density of Window exceeded five packets per cubic mile. It was not in fact intended to

[1] A.M. File CS.15385. [2] A.H.B./II/54/93(A). [3] A.M. File CS.15386.
[4] A.M. File CS.15389. [5] A.H.B./IIE/13/1.

exceed either of these limits.[1] During April, trials were carried out to discover to what degree Monica interfered with Oboe. The trials showed that the use of Oboe Mark I and Monica Mark I on the same operation was very likely to make Oboe ineffective even if the Monica and Oboe aircraft were several miles apart, but that Monica and K-Oboe could be effectively used together on the same operation and over the same target provided both equipments were not in one aircraft. The operational introduction of Monica was therefore bound up with the introduction of K-Oboe, which was first used early in June 1943.[2]

Following the loss of 23 of a force of 230 aircraft towards the end of April 1943, the A.O.C.-in-C., Bomber Command became doubly anxious to introduce Monica on operations as soon as possible. By 19 May, just over 1,000 Monica equipments had been delivered, aircraft were coming off the production line already suitably modified, and 312 aircraft had been modified retrospectively. They were spread over 17 Halifax squadrons, one Stirling, one Lancaster and one Wellington squadron.[3] On 31 May 1943 Headquarters Bomber Command notified all bomber group headquarters that it had been decided to start the operational use of Monica sometime between 1 and 16 June. Monica training flights were authorised, but until the exact date of operational introduction was confirmed Monica was to be removed from aircraft immediately after completion of training flights. On 2 June headquarters of groups were informed that Monica was to be used operationally with effect from the first night's operations after the night of 16/17 June ; from 15 June, Monica training flights were to be allowed at any time and equipment could remain in the aircraft.[4] An instruction on the use of Monica was issued for the guidance of crews on 1 June 1943, based on experience gained from the trials which had already taken place. The instruction gave only general procedure for the use of Monica, leaving much to the discretion of groups and squadrons. The manoeuvre recommended when the warning pips sounded was for the pilot to make a turn of about 45 degrees and lose about 500 feet in a shallow dive, returning to his original course after about thirty seconds. If the pips persisted, some manoeuvre such as an orbit was suggested.

Operational Use

Monica was first used operationally on the night of 19/20 June in a raid against Le Creusot, and again on 21/22 June for an attack against Krefeld.[5] Analysis of the use of Monica in the two raids showed that its introduction had been fairly successful, 80 per cent serviceability being achieved at the second attempt. The general opinion of air crews was that Monica would give them a useful warning on dark nights when they were out of the main bomber stream. By 30 June, six or seven operations had been flown on which Monica was used, but it was still much too early to assess its value.[6]

By 25 June 1943, Headquarters Bomber Command had decided that the existing maximum range setting of Monica Mark I, 1,000 yards, was too great, resulting in too many indications per sortie. Individual aircraft were reporting up to 50 indications, and instructions were issued to all groups to modify Monica to work at a maximum range of 800 yards. Within a few days of the issue of this

[1] A.M. File CS.15389. *See* Royal Air Force Signals History, Volume VII : ' Radio Counter-Measures ', for further details of Window trials.

[2] A.H.B./IIH/241/10/37(B). [3] A.M. File CS.15386. [4] A.M. File CS.15389.

[5] A.M. File CS.15389. [6] A.M. File CS.9853.

instruction it became apparent that the idea of a range reduction was not universally accepted as salutary. Some squadrons, enthusiastic about the value of Monica, had not been unduly worried by friendly indications and were not in favour of a reduction below 1,000 yards. Others had found the number of indications excessive and a nuisance and were in favour of reducing the range. At a discussion between representatives of Headquarters Bomber Command and the R.A.E., it emerged that it was possible by a simple adjustment on the ground to vary the maximum range of Monica from 1,000 yards down to about 200 or 300 yards, and that it would be a simple matter to fit the test set by means of which Monica was calibrated with a switch to select any number of alternative ranges. On 1 July 1943 it was decided to have four ranges, 1,000, 800, 600, and 400 yards, as standard automatic settings. A revised tactical instruction was issued informing groups that the number of friendly responses, admittedly excessive, could be reduced by reducing the range of Monica, and that the shortest possible range should be used consistent with reasonable warning.[1] The actual range for each sortie was left to the discretion of squadron commanders.[2]

At a conference held at Headquarters No. 4 Group on 22 July 1943 it was reported that so far Monica had had little effect, losses of aircraft with or without Monica being about equal. Crews were still receiving too many warnings to make evasive action feasible, but the modification to allow the range of Monica to be decreased had not been well received ; crews felt that 1,000 yards was the ideal warning range provided continuous warnings over the initial stages of a flight could be eliminated. A solution to the problem of continuous warning during the early stages of a flight, before the bomber-stream spread, was achieved in some squadrons by leaving Monica switched off until a position 40 miles from the English coast had been reached. By this time the warnings received from friendly aircraft were greatly reduced.[3] On 3 August 1943, Headquarters Bomber Command reported that recent operational experience had proved that with the existing coverage of Monica a large proportion of the responses received were echoes from friendly aircraft, whatever the range setting. The extent of concentration then being achieved on bomber operations had not been foreseen when the specifications for Monica coverage were first outlined, and the wide coverage was detrimental to effective use of Monica. Its reduction to prevent responses being received from more than 10 degrees above the horizontal was required. Since the zone above the horizontal could be scanned by gunners, and attack at night seldom developed from that direction, a coverage more than 10 degrees above the horizontal was unnecessary.

The R.A.E. considered that no simple modification could be introduced to cut down the coverage as required, and tests being carried out by the B.D.U. were unsuccessful.[4] As progress was being made with development of two other warning devices, Fishpond and Boozer, and as it had been agreed that Monica would not be a requirement in aircraft equipped with H2S and Fishpond, the existing coverage was accepted. However, Headquarters Bomber Command was dissatisfied with the general performance of Monica and doubted whether satisfactory results would ever be obtained. Its serviceability rate was low, averaging less than 85 per cent, whereas A.I. Boozer achieved a rate of over 96 per cent almost at once. The bulk of unserviceability was blamed on faulty

[1] A.H.B./IIH/241/10/37(B).
[2] A.H.B./IIH/241/3/262.
[3] A.H.B./IIH/241/3/262.
[4] A.H.B./IIH/241/10/37(B).

design. Again, apart from actual technical failures, there was considerable difficulty in adjusting the equipment to give satisfactory results. These were not simply teething troubles. After two months use the unserviceability of Monica persisted to such an extent that its operational value was small.[1] The view was not shared by the R.A.E., who thought that Monica could be made to work, and that certain simple modifications which could be carried out on squadrons would improve performance. The system employed for warning, which, in the event of component failure, resulted in continuous pips being heard by the crew, had been the subject of particular complaint. Incorporation of a visual indicator, to give indications of range only, had been suggested. The R.A.E. considered that its introduction would produce a very much more useful equipment, less sensitive to interference and giving more chance of identification between friend and foe, and that direction-finding facilities might also be incorporated without difficulty. Immediate steps were taken by the R.A.E. to improve the existing installation, and it was planned to institute trials of a visual indicator in two squadrons, the A.S.V. Mark II receiver being used for this purpose.[2]

Before deciding on further modifications to Monica, however, it was necessary to view the progress of other combat warning equipment to see to what extent and for what period Monica was likely to be required. Although it had been agreed that Monica and Fishpond should be alternative installations, and that all bomber aircraft would eventually be fitted with H2S and therefore with Fishpond, the planned H2S production of 600 per month would never be sufficient to enable all heavy bombers to be equipped, since wastage would account for more than half of the production as more and more squadrons were fitted. If the production of H2S and Fishpond were increased, all squadrons might be fitted by about mid-1945, but that was two years ahead and meanwhile Monica or some other alternative was needed. Any plan to dispense with Monica had to take these figures into account. There was also the question whether Boozer might be capable of replacing Monica, and over all there was promise of successful development and production of A.G.L.T., which was regarded as the final requirement in combat warning equipment. Production of A.G.L.T. was not scheduled to start before February 1944.

All heavy bombers and Wellington X aircraft were, in August 1943, in the process of being fitted with Monica Mark I. It was in operational use, and 1,500 aircraft had already been fitted.[3] Existing contracts covered a total of over 12,000 equipments. Fittings and plugs were being incorporated on the aircraft production lines in Wellington X, Halifax and Lancaster aircraft and would be introduced in Stirling aircraft about mid-September. One squadron of intruder Mosquitos was also equipped.[4] Production of Monica Mark IA had not yet begun and it was not likely to replace Mark I on the production line until December. The target date for the production of Monica Mark II was May 1944. The questions to be decided were the point of changeover of the manufacture of Mark I to Mark IA, and whether Mark II would be needed at all if Boozer did, in fact, supersede Monica.[5] A.I. Boozer had been introduced in June 1943, and some 2,000 sorties had been flown with it by early August.

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[1] A.H.B./IIH/241/10/37(A) and (B). [2] A.M. File CS.9853. [3] A.M. File CS.9853.

[4] *See* Royal Air Force Signals History, Volume VII: 'Radio Counter-Measures', for details.

[5] A.H.B./II/69/68.

Existing contracts covered a total of 2,200 sets. It was possible, indeed, that Boozer might be made available in numbers as quickly as Monica Mark IA, and it was regarded as being more likely to satisfy Bomber Command requirements, so whether Monica were jammed or not there seemed to be good reasons for its immediate and general adoption.[1] Its advantages over Monica were that there was no transmission from the aircraft and therefore no possibility of homing by enemy aircraft, and operation of the equipment was independent of the height of the aircraft; Monica was flooded by ground returns at heights up to 3,000 feet above ground. On the other hand it gave no warning of the 'catseye' fighter and was no help in avoiding collision with friendly bombers. However, in due course all bombers would be fitted with A.G.L.T. and the majority of bombers with H2S and Fishpond; it therefore seemed uneconomic to continue to develop two interim warning systems.[2]

A meeting was held at the Air Ministry on 27 August 1943 to discuss the provision of combat warning equipment for Bomber Command. The Monica Mark II programme was cancelled, since the start of production was so far ahead that H2S aircraft would by that time be fitted with Fishpond. Non-H2S aircraft would continue to carry Monica Marks I or IA. Of the total production of Monica, some 9,000 sets were being made by the firm of Cossor and 3,000 by that of Pye. It was decided to switch Cossor production from Mark I to Mark IA at the 7,000th set, thus providing some 2,000 Cossor-made sets of Mark IA as an insurance against possible enemy jamming of Mark I, and to cancel the Pye contract to make way for increased production of Boozer. All plans for the development and production of the various types of Boozer were accelerated.

On 14 October 1943 the T.R.E. produced a memorandum on proposed modifications to Monica. During the months of introduction of Monica Mark I it had become generally accepted that equipment designed to the original specifications of Bomber Command did not provide a satisfactory answer to the current operational requirements of a combat warning device. The overall effect of Monica on the loss rate had not been fully assessed, but, though serviceability was improving, the fundamental design continued to restrict performance. In the conditions of high bomber density existing in the latter half of 1943, successful evasion required more than a warning of the nearest approaching aircraft, and that was all that Monica Mark I could provide. All adjacent aircraft had to be kept under continuous observation in order to discriminate between an approaching hostile and surrounding friendlies. This could only be achieved by some form of visual presentation, allowing discrimination through the typically deliberate and sustained approach of the hostile and possibly by its smaller echo. In addition, knowledge of the bearing of the approaching hostile was necessary to enable successful corkscrew tactics to be employed, and also to improve the chances of engagement by the rear gunner. This again could only be achieved by a P.P.I. display. The weaknesses of Monica were the audio presentation, which could record only one approaching aircraft at a time—the nearest— and the absence of direction information.[3]

There was no point in going to the trouble of modifying Monica throughout the Service to provide visual presentation if H2S with the Fishpond attachment could be produced as quickly. The intention was that Fishpond should be added as a unit modification to H2S-equipped aircraft, and the rate at which

[1] A.M. File CS.9853. [2] A.M. File CS.9853. [3] A.M. File CS.15386.

this attachment could become available for operational use was therefore governed by the rate of delivery of aircraft equipped with H2S. It was expected that approximately 400 such aircraft would be delivered by the end of 1943, the anticipated rate of fitting thereafter being perhaps 100 per month. It was therefore unlikely that a large force of about 1,000 aircraft could have Fishpond before the summer of 1944, though in view of the rate of H2S production, 300 per month rising to 600 per month early in 1944, it was conceivable that the fitting programme might be accelerated. The modification of Monica for visual presentation, by the addition of the obsolescent A.S.V. Mark II receiver, could, on the other hand, be introduced with the help of fitting parties so as to equip 1,000 bombers by January 1944, provided the necessary plugs and sockets were made available. By the further addition of two receiving aerials on either side of the existing Monica transmitter aerial, and of somewhat more complicated cabling, indication of the direction of approach could also be given. The additional items were already available in A.S.V. Mark II equipment.[1]

Visual Monica—Monica Mark III Series

Trials of Visual Monica were carried out in No. 5 Group, who had requested its installation in two squadrons, at Syerston. General introduction of a visual indicator was not at first intended as it was felt that this would interfere with the production of Fishpond and A.G.L.T. The two squadrons were in the process of being equipped during October 1943 ; the modification included the visual indicator only and not the aerial modifications to provide indications of the direction of approach. Sufficient materials and equipment were supplied to fit 50 aircraft. It was thought, however, that results would be inferior to those obtained with the P.P.I. display provided by Fishpond, and it was clear that in that case a policy to modify Monica Mark I could only be correct if early availability in large numbers could be achieved.[2] The decision to modify Monica Mark I had to be made immediately or not at all, and before making it careful assessment was necessary of the extent to which installation of modified Monica Mark I would delay the introduction of Fishpond.[3]

The early results obtained by the two No. 5 Group squadrons were therefore watched critically. They were so encouraging that on 25 October 1943 Headquarters Bomber Command asked for the modification of all non-H2S Lancaster and Halifax squadrons which had been equipped with Monica Mark I, and confirmed on 10 November that Fishpond and Visual Monica were to be alternative installations, with a proviso that this decision would be reviewed later.[4] A special meeting was held at the Air Ministry on 12 November 1943 to discuss the use of Monica with a visual indicator. There were two visual adaptations of Monica Mark I to be considered: System A, retaining the Monica receiver, and System B, eliminating the Monica receiver.[5] Both systems were preferable to the aural system, but System B was the simpler installation. System A was styled Monica Mark III and System B Monica Mark IIIA. It was Mark III which had already been installed in some 40 aircraft of No. 5 Group. Only three aircraft fitted with Mark IIIA had been used on operations, but it was decided to adopt this system owing to its simpler installation. The immediate requirement was installation of Monica Mark IIIA in all non-H2S

[1] A.M. File CS.15386.
[2] A.H.B./IIH/241/10/37(A) and (B).
[3] A.M. File CS.15386.
[4] A.H.B./IIH/241/10/37(A).
[5] A.H.B./IIE/13/3. Monica (Airborne R.D.F.) Minutes of Meetings.

aircraft and, as an interim measure, in H2S aircraft not yet fitted with the Fishpond attachment ; this meant retrospective installation in approximately 400 aircraft. Priority was decided as 100 Lancasters, 100 Halifaxes, 150 Lancasters, 50 Halifaxes. Arrangements were made for the provision of 400 modification kits on a crash programme basis ; the modification of A.S.V. Mark II and the manufacture of fitting equipment was begun by No. 32 M.U. in the same month. It was also decided to provide for the modification within the Service of Monica Mark IA, production of which was not now expected to start until March 1944, since it was too late to arrange for it to be undertaken on aircraft production lines. The coupling of A.S.V. Mark II with Monica IA was known as Monica Mark IIIB.[1]

On 4 December 1943 Headquarters Bomber Command pointed out that the fitting of 400 non-H2S Lancaster and Halifax aircraft with Monica Mark IIIA would leave about 200 aircraft without Fishpond or Visual Monica. The future requirement of Monica Mark IIIA depended on a number of factors, notably the rate of supply and fitting of H2S, the number of Lancasters which could not be equipped with H2S and Fishpond because of their big bomb doors, the eventual production of the Lancaster IV, which could be equipped with H2S and Fishpond, and the availability of A.S.V. Mark II equipment.[2] Coastal Command requirements for A.S.V. prevented more than about 600 sets in all being diverted to Bomber Command, but this met the immediate requirement.[3] Meanwhile, arrangements were made for the conversion of the whole of the remaining stock of Monica Marks I and IA, but it was thought that production of the necessary visual equipment could not begin before September 1944. Development of a further type of Monica, Mark IV, to incorporate visual indication and anti-jamming facilities, was requested by Headquarters Bomber Command, and although the requirement was cancelled in December, the Air Ministry decided to go ahead with development and to consider the question of production later.[4]

By September 1943 the retrospective fitting of Monica Mark I in squadrons was largely completed and nearly 2,000 aircraft, about 1,000 of which were Halifaxes, 500 Wellingtons, and 400 Lancasters, had been fitted on the production lines ; fitting at the Stirling aircraft factories did not begin until towards the end of January 1944. The fitting programme was continued at the rate of between 400 and 500 per month until March 1944, after which it lapsed as there was no longer a requirement for Mark I ; by then about 8,000 sets had been made.

When the policy to install Fishpond or Monica Mark IIIA in all bomber aircraft was declared, groups were given the choice of continuing to use Monica Mark I or not until the new equipment was available.[5] Every effort was made to bring Monica Mark I up to the standards demanded for operational use. A post-design service party completely revised the setting-up procedures in October 1943 ; they made tests of frequency drift and spread, and considered stability to be reasonable. Serviceability was rated at about 80 per cent, and it was found that results with Monica were much improved at units where servicing crews were adequate, and where stocks were sufficient to enable

[1] A.H.B./IIE/13/3. [2] A.H.B./IIH/241/10/37(A). [3] A.M. File CS.9853.

[4] A.M. File CS.23032.

[5] A.H.B./IIH/241/10/46(A). Bomber Command File BC/S.26829/12.

unreliable sets to be withdrawn from service. The post-design party tested serviceability by using Monica in conjunction with Window; this method was in general use in No. 5 Group, where it had been found that the way Monica reacted to Window provided a sure means of checking its serviceability. Aircrews of No. 5 Group tested Monica by dropping one bundle of Window every fifteen minutes in areas where normal Window dropping had not been ordered. If pipping lasting approximately five seconds had not been received after two or three bundles of Window had been dropped, Monica was regarded as being unserviceable and was switched off. Subsequently the method was found to be too exacting. By January 1944, the knowledge that improved warning devices were on the way had contributed to making crews largely indifferent to the performance of Monica Mark I. Keenness was, however, still retained on some squadrons.

The crash programme of 400 Monica Mark IIIA equipments was completed by the end of February 1944, and some 250 Lancasters and over 100 Halifaxes were using Mark IIIA on operations by the first week in March.[1] A further 200 sets were produced in March 1944 making a total of 650 sets in all with the addition of the first 50 made by hand in No. 5 Group; this met immediate Bomber Command requirements and at the same time exhausted the supply of A.S.V. Mark II equipments.[2]

In addition to the 50 hand-made sets, No. 5 Group received most of the early deliveries from the crash programme, and after several weeks of operations with Visual Monica considered that it was an extremely simple and effective warning device and far more reliable than previous Marks.[3] Serviceability during the first six weeks of operations was 90 per cent, whereas the serviceability of Monica Mark I had never been much above 80 per cent. No. 61 Squadron developed and used a procedure for the operational use of Monica Mark IIIA in which the wireless operator reported only those blips which approached within 2,000 yards, unless the captain wished to check his position in the bomber stream, when the wireless operator reported all blips on the tube.[4] When a blip closed to within 2,000 yards range he reported 'Contact' followed by 'Port' or 'Starboard', the angle in degrees, and the range in hundreds of yards. If the blip remained stationary he said 'Steady'; if the blip moved away he said 'Going away'; if it continued to approach he said 'Closing slowly' or 'Closing fast' as the case might be. As the range closed he continued to report angle, range, and rate of closing. If at 1,000 yards the aircraft approaching could not be seen by the gunner, the pilot started a gentle turn towards the side from which it was approaching, or towards either side if it was approaching from dead astern. Thus if the approaching aircraft maintained its course it flew across the tail of the bomber at a reduced range, generally within visual range of the rear gunner. The pilot was then in a good position to take evasive action, or to turn back on course if the approaching aircraft was recognised as friendly. If, however, the approaching aircraft followed the bomber round in the turn and continued to close, it could be designated hostile and evasive action could be taken even if a sighting had not been obtained. This manoeuvre allowed the wireless operator to continue reporting on aircraft within 1,000 yards range, giving the gunners great assistance in obtaining a sighting, and eliminating corkscrewing and violent evasive action when the

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[1] A.M. File CS.15386. [2] A.H.B./II/69/251. B. Ops. Folder, Warning Devices.
[3] A.H.B./IIH/241/10/37(B). [4] A.H.B./IIH/241/3/262.

approaching aircraft was friendly. It also allowed the wireless operator to keep watch for aircraft on the beam and thus reduce the risk of collision. During the actual bombing run, blips were reported within a range of 1,000 yards only.

Although between October 1943 and February 1944 relatively few sorties were flown by aircraft carrying either Monica Mark IIIA or Fishpond, it was possible for an assessment of their effectiveness to be made.[1] The proportion of main force aircraft missing was 15 to 20 per cent lower for aircraft with than for aircraft without one or the other of the devices; there was a somewhat greater reduction in the proportion of equipped aircraft actually fired on by enemy fighters. Strong evidence was thus provided that aircraft were being saved by the warning given; not only were aircraft operating with a lower loss rate, but also they were being warned to take action in time to prevent an approaching fighter reaching a position where it could open fire. The need for some means of identification was still, however, strongly felt. Another urgent need was for ground trainer layouts to familiarise wireless operators with the essentials of the equipment, since they had to be given a good deal of training to get the best out of the equipment.[2] Another fact that emerged from the early use of the two warning equipments was that Visual Monica had a number of advantages over Fishpond. Monica was an independent equipment and could be operated to the best advantage throughout a sortie, whereas Fishpond was subordinate to H2S, and the use of H2S by the navigator often militated against good Fishpond detection. Monica was more reliable, its serviceability on operations being higher than that of Fishpond, and, owing to its greater coverage, Monica gave warning of the approach of fighters in a far greater proportion of combats than did Fishpond. Nevertheless, difficulties of supply dictated that use of both devices be continued.

Monica Mark IV

In spite of the continued fitting of Monica Mark IIIA and Fishpond, a serious deficiency still existed in Bomber Command because of the failure of Monica Mark I, and this was aggravated by the continued expansion of the German night fighter force. The Monica Mark IIIA crash programme catered for only a small fraction of the total force, and in mid-February 1944 there were still 830 operational aircraft without either Monica Mark IIIA or Fishpond.[3] The H2S/Fishpond programme would not enable the gap to be closed and full production of A.G.L.T. was still not in sight. A review of policy was therefore made.[4]

Fishpond was the requirement for use with A.G.L.T., mainly because of the possibility of Monica being jammed and the uncertainty of supply of Visual Monica equipment. However, Monica had been in use for more than six months without any jamming activity being recorded, and it seemed probable that the jamming of Monica was a more complex problem than had been anticipated. There was therefore no apparent reason why further production of Mark IIIA should not be arranged. It was regarded as a better proposition than any other existing warning device, and its installation in all bomber aircraft was recommended. In January 1944 a supply of 3,000 sets was ordered, sufficient to equip the entire bomber force. The production-line conversions of Marks I

[1] A.H.B./IIH/241/3/262. [2] A.H.B./IIH/241/10/37(A). [3] A.H.B./II/69/251.
[4] A.H.B./IIH/241/10/37(A).

and IA into Visual Monica were named Monica Mark IIIC and Monica Mark IIID, and elevation indication was included. On 23 March 1944 the order was increased to 6,500 ; deliveries, however, were not expected until late in the year. This production was to be followed by a contract for Monica Mark IV, for which Headquarters Bomber Command was asked to submit new specifications.

By April 1944, when the Monica Mark IIIA crash programme was completed, there still remained the prospect of many months during which a large number of bomber aircraft would be without a combat warning device. A small number of A.I. Mark IV installations, known as Monica V, were made available for use in bombers, but shortage of test equipment severely limited the number of squadrons which could use them for combat warning purposes. The crash programme for A.G.L.T. Mark I was only just beginning. In an effort to cover the deficiency, the target date for deliveries of the first production models of Visual Monica was brought forward to August 1944, a monthly rate of 100 rising to 300 by the end of the year being aimed at. The final requirement was for all operational aircraft of Bomber Command to be fitted with Monica Mark IV.

Headquarters Bomber Command submitted specifications for Monica Mark IV on 26 April 1944. These were studied by the T.R.E., and a meeting was subsequently held at the Air Ministry on 22 June 1944. The main feature of Mark IV as confirmed at this meeting was its resistance to potential jamming. This was achieved by the ability to tune the equipment in the air to any frequency in the 390 to 450 megacycles per second band, coupled with the incorporation of high transmitter power and low receiver sensitivity. These features covered Bomber Command requirements except in the matter of presentation. A two-tube azimuth and elevation system was specified, but a single-tube system was recommended by the T.R.E. and was favoured by the Air Ministry. Development of Mark IV proceeded and flight tests with a prototype were planned for November 1944. The target date for production was later fixed at August 1945.[1]

The future operational requirements of Bomber Command for combat warning devices were discussed at the Air Ministry on 26 June 1944. The production programme for Monica Marks IIIC and D was confirmed, the programme being designed to cover the fitting of all heavy bombers in Bomber Command up to the end of 1945. The main danger to Monica was still considered to be enemy jamming, and the possibility that such jamming might occur before the introduction of Monica Mark IV was regarded as covered by the Fishpond programme. Although Monica was preferred to Fishpond, improvements to the Fishpond equipment and its general production were being proceeded with, since it would be many months before the Visual Monica programme was completed. It was recommended at this meeting, and later confirmed, that Monica should be installed in aircraft equipped with 3-centimetre H2S and Fishpond in aircraft equipped with 10-centimetre H2S.

Withdrawal of Monica

Some six months before the introduction of Monica Mark I, the Air Ministry had asked Headquarters Bomber Command to report on any apparent tendency for Monica to be used by enemy fighters for homing purposes. No such tendency had been detected, and even in Mark IV no modification had been incorporated

[1] A.M. File C.16038/44.

to make the equipment impervious to homing. However, it was discovered in July 1944 that the enemy was able to home to Monica from a range of about 20 miles. A report was submitted at this time describing the organisation which had been set up in Germany and France to listen to radio signals emitted from bomber aircraft, and reference to the relative loss rates for various groups of aircraft suggested that homing to Monica was indeed taking place.[1]

The proportions of main force aircraft attacked and lost had continued to be lower for Monica-equipped aircraft up to and including April 1944. In May, however, Monica-equipped aircraft had the same loss and attacked rates as unequipped aircraft, and in June the proportion of casualties was greater for Monica-equipped aircraft than for unequipped aircraft. It was therefore a distinct possibility that Monica transmissions were being used to such an extent by enemy fighters for homing purposes that they were leading to a higher rate of losses.

An appreciation of the effect of the use made by the enemy of transmissions from bombers was therefore made by the Operational Research Section at Headquarters Bomber Command in July 1944 and circulated in August.[2] It was already known that the enemy ground plotting organisation was using the radar transmissions of bomber aircraft to assist fighters to home into the bomber stream, and the use of two new radar equipments, '*Flensburg*' for homing to Monica and '*Naxos*' for homing to H2S/Fishpond, was also known. What was not known was the extent to which this homing was successful and the extent to which the use of Monica or H2S/Fishpond by a small part of the bomber force was endangering the whole force. The first question was answered through the fortuitous capture of a *Ju.88* carrying the latest German radar equipment; trials were begun to decide how serious was the threat of homing to Monica by *Flensburg* and whether the new '*S.N.2*' could be effectively jammed by the latest type of Window. The extent to which the use of radar by a small part of the force endangered the whole force had been acceptable while losses as a whole were shown to be reduced, but in view of the loss and attacked figures for June there seemed to be no justification for retaining Monica. It was recommended by the O.R.S. that if the trend was confirmed by the July figures, the use of Monica should be discontinued, at any rate until such time as the enemy's use of its radiation properties could be prevented or minimised.

Meanwhile, tests carried out with the captured *Ju.88* showed conclusively that, whereas interception by means of the *S.N.2* could be completely frustrated by use of the latest type of Window, homing to the bomber stream and even to single aircraft by means of *Flensburg* used against Monica transmissions presented no difficulty. Again, the loss and attacked rates for July showed a steady upward curve for Monica-equipped aircraft.[3] It was clear that the presence of a small number of Monica-equipped aircraft was indeed endangering the whole bomber stream by enabling a greater number of fighters to find it. The enemy's interception problems had thus been simplified and the effectiveness of Allied jamming largely nullified.[4]

It was arguable that this state of affairs could be tolerated if the whole bomber force was fitted with Monica and if the early warning provided by it enabled the bomber to meet the fighter in combat on equal terms: but a study of loss

[1] A.H.B./ID/12/96. [2] A.H.B./IIH/241/3/262. [3] A.H.B./IIH/241/3/262.

[4] *See* Royal Air Force Signals History, Volume VII: 'Radio Counter-Measures', for further details.

rates suggested that this was not so. Again, if the enemy was able to home easily to the bomber stream by means of his latest A.I. equipment and without the aid of Monica, there could be little objection to Monica on the homing score; but the trials carried out by the R.A.E. showed that the new German A.I. was useless against Window. Investigations were continued to determine whether the homing menace inherent in Monica could be overcome tactically or technically, but, in the meantime, Monica was withdrawn from operational use on 12 September 1944, and the equipment was removed from all main force aircraft.[1]

Trials were continued at the B.D.U. to determine whether the advantage gained by receiving an indication of the approach of an enemy fighter outweighed the homing risk. Exhaustive tests were made in conjunction with fighter aircraft equipped with *Flensburg* and *S.N.2*, but the conclusions arrived at tended to support the decision already taken to suspend the use of Monica.

The overall requirement for Monica, however, did not lapse at once. Production proceeded, connectors were fitted in all production-line aircraft, and Monica equipment was stored so that reintroduction would be possible at short notice. Possible situations which might result in a decision to reintroduce Monica were the ability to fit 100 per cent of the main force, discontinuance by the enemy of the use of *Flensburg*, or the equipping of all bomber aircraft proceeding to the Far East after the cessation of hostilities in Europe. It was thought that Monica would enjoy a period of immunity from interference and homing in the Far East.[2]

Production of Monica Marks IIIC and D was expected to reach 400 per month from November 1944, and equipment to fit all heavy bomber aircraft was scheduled to be ready by April 1945. It would, however, take a considerable time to fit the whole force. Production of Monica Mark IV was not expected before Autumn 1945. An automatic frequency sweep to prevent jamming was made a requirement. A similar device was developed by No. 5 Group in conjunction with the T.R.E. for use with Monica Mark III. Its purpose was to change the Monica frequency while airborne so as to counter the enemy homing equipment. Headquarters Bomber Command requested in December 1944 that the device be incorporated in all Monica Marks IIIC and D. Production of the device was arranged within the command through local purchase orders.[3]

Meanwhile the requirement for Monica Marks IIIC and D was reduced to a total of 1,900 to cover installation in Lancasters of No. 5 Group, in all heavy bombers of No. 100 Group, and in a number of training aircraft in heavy conversion units supplying these groups.[4] Manufacture of 1,900 equipments would be completed by April 1945, and so far as the home bomber force was concerned Monica production would be cancelled after that date. It was no longer considered that any set of circumstances was likely to eventuate which could justify the general reintroduction of Monica. When, on 27 December 1944, the combat warning policy for the Far East crystallised, the provision of Monica was not included and instructions were given for the cancellation of all Monica production after 1 April 1945.[5]

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[1] A.H.B./IIH/241/3/262 and A.H.B./IIH/241/10/37(C).

[2] A.H.B./IIH/241/10/37(C).

[3] A.M. File CS.23032.

[4] A M. File C.16065/44. The aircraft did not operate in the main bomber stream.

[5] A.M. File CS.23032.

Development of Fishpond

Fishpond was a visual warning device which showed the relative position, range and movement of other aircraft in the vicinity of the bomber in which it was installed. The information was supplied to Fishpond by the H2S equipment. The device consisted of a simple cathode ray tube indicator unit which was plugged into the H2S system in parallel with the H2S indicator. Echoes of aircraft picked up by the H2S scanner were presented on the tube in a form easy to interpret. The indicator was fitted with a rotatable bearing scale and a perspex screen with track lines. Range circles and a line-of-flight marker were presented electrically on the tube, the line-of-flight marker indicating continuously the heading of the aircraft. The position of the bomber itself always remained in the centre of the tube. Echoes from other aircraft appeared as bright green blobs. Their movement could be watched continuously and their relative position, range and movement readily determined. The height of the bomber above ground corresponded to the maximum range, and the minimum range was about 300 yards. The area of search was all-round and covered the entire lower hemisphere up to ten degrees above the horizon.[1]

The possibility of employing an attachment to H2S to give continuous indication of all aircraft within range of the H2S scanner was first thought of in the spring of 1943, impulses from aircraft having been consistently received on the H2S equipment.[2] A P.P.I. display attachment known as Fishpond because of its likeness to a pond in which fish swam in and out of ken was first tried out at the B.D.U. in May 1943. It was found to give good all-round cover under the aircraft up to a range of about three miles at operational height. Cover in the lower hemisphere was the major requirement at the time because of the gunner's difficulties in spotting fighters approaching from below; enemy fighter tactics took full advantage of the difficulties and attacks were generally made from that direction. As a result of the trial, production was arranged on a high priority on the basis of the fitting of all H2S aircraft, and a crash programme for the first 200 sets was instituted. Fifty sets were to be delivered by August and the balance by the end of September. Main production, at a rate commensurate with H2S production, was planned to follow without a gap. Six development models were made and delivered in June and July, and trial installations for Lancaster, Halifax and Stirling aircraft were cleared. Plans for the introduction of connector parts on the aircraft production lines went forward, and an order for modification parts for retrospective fitting was placed. One of the first development models was delivered to the B.D.U. and trials began early in July 1943.

An early appreciation of the trials, made on 14 July 1943, disclosed the opinion that Fishpond was a far better warning device than Monica Mark I or Boozer, since it gave in simple form detailed information of the relative manoeuvres and ranges of other aircraft. When evasive action was taken, the effect on an approaching aircraft could be watched continuously and it could be seen immediately whether it had been shaken off or had overshot. A full report on the Fishpond trials was made on 16 August 1943. The B.D.U. found that the useful presentation on the P.P.I. covered a maximum radius of about 3½ miles. Suppression of signals occurred when the target closed to within 400–500 yards; below this range no signals were observed. Within these limits signals from below the aircraft were clearly defined, but aircraft on the same

[1] A H.B./IIH/241/10/55(A). [2] A.H.B./IIH/241/10/37(A).

level or above gave somewhat intermittent returns. The equipment was not reliable above the horizontal. Fishpond was considered to be simple to operate but needed an operator whose normal duties in the crew would not be affected by the impairing of night vision consequent on the brightness of the tube. Trial installations were therefore made at the wireless operator's table. As with Monica, there was no serious consideration given to the provision of an additional crew member to operate the equipment.

No instance of unserviceability was reported throughout the trials, and the B.D.U. concluded that Fishpond was a reliable and effective early warning device that would have more tactical value than either Monica or Boozer. It was stressed, however, that there were three basic limitations :—

(*a*) Fishpond was available to H2S-equipped aircraft only.

(*b*) It covered only that area of the sky below the horizontal.

(*c*) Although hostile intentions should be apparent from the behaviour of the impulse received, Fishpond provided no positive identification of friend or foe.[1]

Production and Installation

The first sets of parts for retrospective fitting in Bomber Command began to arrive in September 1943, and the first 100 sets off the crash programme were delivered by the middle of the month. Thirty sets were fitted and in use in the P.F.F. by the end of October and over 100 by mid-November. The main reason for the apparent delay in the retrospective fitting programme was the difficulty of installation in aircraft actively engaged on operations. A secondary reason was a shortage of connector sets, but production of these had caught up with demand by the end of October. By mid-December all P.F.F. heavy aircraft had been fitted, about 125 Lancasters and 40 Halifaxes, and fitting in main force aircraft had begun. The main production programme, originally totalling 4,000 sets and later increased to 12,000, followed the crash programme without a gap, and by the end of 1943 over 1,000 sets had been delivered, some 400 of which had been retrospectively fitted.[2]

Production-line fitting in Lancasters and Halifaxes began in February 1944 and small deliveries were made by early March. Nearly 1,000 aircraft had been fitted, mostly retrospectively, by the end of March, and over 2,500 sets made.[3] Production was then 600 sets per month rising to 900 per month in August 1944. In addition to the Lancasters and Halifaxes, a small number of Stirlings were fitted. By the end of May 1944 the totals of fitted aircraft were 1,074 Lancasters, 403 Halifaxes and 63 Stirlings.[4] All operational H2S aircraft had been equipped with the Fishpond modification by the end of January 1944, and retrospective fitting of Fishpond generally kept pace with the output of H2S-fitted aircraft up to the time of general production-line fitting. There was no shortage of Fishpond equipment. The limiting factor was the production of H2S.[5]

The introduction of Fishpond meant that A.G.L.T. Mark I, previously discounted as giving insufficient cover, became acceptable. A.G.L.T. had a cone of search of only 30 degrees, and it had previously been decided to concentrate

[1] A.H.B./II/69/206. B. Ops. Folder, Fishpond.
[2] A.H.B./IIH/241/10/55(A).
[3] A.M. File CS.21346.
[4] A.M. File CS.15536.
[5] A.H.B./IIH/241/10/46(A).

production on A.G.L.T. Mark II, which would have a cone of 120 degrees. However, A.G.L.T. Mark I could be made ready some nine months before A.G.L.T. Mark II, and, used in conjunction with Fishpond, it gave the required cover. A decision was therefore taken to proceed with the introduction of A.G.L.T. Mark I. Arising from this decision, it was suggested in August 1943 that Fishpond should be withheld until A.G.L.T. Mark I was ready, since when the enemy discovered the characteristics of Fishpond his fighters would attack from above, where no warning could be given by Fishpond. But if the enemy responded in this way, his fighters would be attacking from a position in which they would be easily visible to the gunners. Again, the interference of Window with enemy A.I. was forcing him to employ more and more 'catseye' fighters, against which the value of Boozer was nil, whereas Fishpond operated independently of enemy A.I. The introduction of Fishpond was therefore allowed to continue.[1]

Group H2S instructors and signals leaders began to receive training in the use of Fishpond at the B.D.U. in late 1943.[2] A trained Fishpond or Monica operator was regarded as one who had completed four trips with serviceable equipment.[3] This arbitrary arrangement was never satisfactory, and lack of proper training devices hampered the advance of Fishpond for many months. The T.R.E. was working on the development of a Fishpond trainer, but little progress was made at first, and a scheme proposed by Headquarters Bomber Command on 20 April 1944 in which radar workshops were modified to provide training facilities pending the production of the T.R.E. trainer was adopted.[4]

In order to establish the identity of aircraft seen on the Fishpond indicator, an alteration of course was necessary. If the suspected aircraft followed the Fishpond aircraft it was regarded as likely to be a hostile aircraft in pursuit. The captain of the bomber then decided what further alteration of course to make. The alteration recommended was 20 to 30 degrees. The gunner most suitably placed searched in the direction estimated by the Fishpond operator. Range and direction could be estimated, but not height, except that by the natural limitations of the equipment it was not necessary to search more than about 10 degrees above the horizontal.[5]

Operational Use and Modifications

Fishpond was first used by three P.F.F. squadrons during October 1943. In the following month further aircraft were fitted and two more squadrons used the equipment on operations. The training of wireless operators proceeded meanwhile and crew co-operation, poor at first, showed some improvement. In many instances visual confirmation was obtained by the gunners, and as a result confidence in the equipment increased. The serviceability of Fishpond itself was generally good, but there were many difficulties associated with the dependence of the equipment on the serviceability and manipulation of H2S; if the H2S equipment was badly tuned the Fishpond screen became mushy and the responses faint, while on some H2S settings Fishpond was practically unusable. The fundamental weakness of Fishpond, its subordination to H2S, was thus spotlighted at an early stage. Operational experience generally

[1] A.H.B./IIH/241/10/55.
[2] A.H.B./IIH/241/10/55(A).
[3] A.H.B./IIH/241/10/93. Fishpond—training of aircrew.
[4] A.M. File CS.21346.
[5] Bomber Command File BC./52715/46.

confirmed the scope and limitations of the equipment as revealed by the B.D.U. trials. The five squadrons operating with Fishpond in November 1943 made 553 reports on its use, showing a percentage loss of 2·2 per cent, lower by 0·7 per cent than that for H2S aircraft not equipped with Fishpond and 0·9 per cent than that for non-H2S aircraft.[1] However, since most of the aircraft fitted at this time were of the P.F.F., where losses in any event were lower than those of the main force, the results so far were inconclusive.[2]

By the end of February 1944, 19 squadrons were operating with Fishpond, and it was possible to make some assessment of its worth. The main factors affecting performance were :—

(*a*) The high rate of unserviceability of H2S.

(*b*) Shortage of equipment, lack of competent instructors, and paucity of flying training complicating training in Fishpond so that the best use was not made of the equipment available.

(*c*) Lack of crew co-operation, especially between the H2S and Fishpond operators.

Losses during February 1944 were the same for Fishpond-fitted aircraft as for those not fitted. The potential value of Fishpond was still thought to be high, however, and the fact that its use was not accompanied by any marked reduction in the loss rate was believed to be due to the low standard of training. This was borne out by comparative figures over the next few months, during which the loss rates for Fishpond-fitted aircraft, although slightly higher overall than those for aircraft not fitted, were much lower than for main force aircraft if fully trained crews only were taken into consideration.[3]

The serviceability of Fishpond improved over this period, but operational reports continued to confirm previous trends, However, in July 1944 Fishpond had its most successful month up to that time. More than two-thirds of the sorties made against German targets by heavy bombers using Fishpond carried fully-trained operators, and the total number of warnings of enemy aircraft received, and confirmed visually, with serviceable Fishpond was 151. Of these, Fishpond warning before attack was given in 84 cases, and of the remaining 67, only three were confirmed as having attacked from below and only two from the same level.[4] Although there could be no analysis for aircraft shot down, it was evident that Fishpond was now pulling its weight. H2S continued to have a bad effect on serviceability, but the increased confidence of crews was reflected in the more detailed reports that were made.

The first few months of operation of Monica Mark III and Fishpond indicated that Monica was without doubt the more efficient. It was easier to use, gave a more clearly defined P.P.I. indication, and had a higher serviceability rate. Best of all, it was independent of other equipment. On 2 June 1944 Headquarters Bomber Command made Monica the requirement for all bomber aircraft to the exclusion of Fishpond.[5] It was intended that the introduction of Monica in H2S aircraft should coincide with the cessation of the Fishpond requirement. However, the production of Monica Marks IIIC and D would not be sufficient for the wholesale replacement of Fishpond until April/May 1945, so the production of Fishpond, and the incorporation of modifications and improvements, had to be continued. As a result of operational experience, filter unit Type 173 was designed by the T.R.E. to effect a reduction in the minimum

[1] A.H.B./II/69/206. [2] A.H.B./II/69/206. [3] A.H.B./II/69/206.
[4] A.H.B./II/69/206. [5] A.M. File CS.15536.

range of Fishpond. Prototype models were sent to the Pathfinder Force and the B.D.U. early in January 1944 for Service trials. The filter unit was designed to reduce the minimum range to about 200 yards, but the B.D.U. trials suggested that the minimum range would be about 450 yards.[1] Since there had been numerous reports of enemy aircraft being lost on the Fishpond indicator when still over 1,000 yards distant, the filter unit appeared to represent a worthwhile improvement.[2] Provisioning action for 500 units was taken, on a crash programme basis, on 31 January 1944, in anticipation of the confirmation by Headquarters Bomber Command of an operational requirement. Provisioning action for main production was taken on receipt of confirmation on 9 March 1944. Deliveries of the first units began towards the end of April. Early deliveries did not reach the required standard, and a modification to the unit, which was then styled Type 189, was made a requirement. B.D.U. trials which followed showed that the modified unit reduced minimum range by a further 150 to 200 yards, greatly improving the tactical value of Fishpond. In September 1944 Headquarters Bomber Command requested the early provision of the modification, and also of a second modification, already tested at the B.D.U., known as independent brightness control. Meanwhile the decision to abandon the use of Monica in all main force aircraft, leaving Fishpond as the main warning device in Bomber Command pending the introduction of A.G.L.T., made it of the utmost importance that Fishpond modifications needed to bring the equipment up to the standard required by Bomber Command be pressed forward urgently.[3]

Fishpond gain and contrast settings had always been subordinate to the settings necessary for the satisfactory operation of H2S, and when the H2S operator switched to the 10-mile scan in the target area, Fishpond could not normally be used at all.[4] The function of the independent brightness control, as suggested by its name, was to make the operation of Fishpond independent of the H2S operator's control settings.[5] It was decided on 26 June 1944 that the modification should be incorporated as soon as possible, and on 18 July it was decided to go ahead with production without awaiting the results of Service trials. Later, B.D.U. trials showed the addition of this control to be entirely satisfactory. The total number of aircraft to be modified was expected to be about 1,000, starting in February 1945.

A forecast of the future production rate of Fishpond and its two modifications was made on 9 October 1944. Production of Fishpond was forecast as 200 per month in October and 300 per month thereafter, and of the filter unit Type 189 as 300 per month in October and 500 per month thereafter, but no contract had yet been placed for the independent brightness control, and the earliest date for production of this item was forecast as May 1945.[6] In view of the importance now attached to Fishpond as the main combat warning device, Headquarters Bomber Command asked for production of the brightness control to be accelerated, and by mid-January 1945 it was confirmed that production would be 100 in March, 200 in April, and 400 per month thereafter. Meanwhile by mid-November 1944 a total of 100 filter units Type 189 had been delivered and issued to various squadrons in Nos. 5 and 8 Groups. Unfortunately the early results with this modification were disappointing.

[1] A.M. File CS.21346. [2] A.H.B./II/69/296. [3] A.M. File C.16065/44.
[4] Bomber Command File BC./52715/46. [5] A.M. File C.16065/44.
[6] A.M. File C.16065/44.

In October 1944, losses and contacts fell to such an extent that it became evident that far fewer German fighters were being employed against the bomber force. Fishpond was by then the only combat warning device employed in heavy bomber aircraft, of which about one-sixth were fitted, and a direct comparison between fitted and non-fitted aircraft engaged on the same raids showed that Fishpond aircraft had an average loss rate of about one half of that of the whole force.[1] There was a marked improvement in performance and serviceability, which was maintained until the end of the war. Fishpond eventually proved to be far more effective than early experience had indicated, and it was clear that the increased effectiveness was due largely to increased enthusiasm for the device ; some squadrons still gave much higher priority to Fishpond training than others, and they were the squadrons that achieved the best results.[2] There were also many reports of the avoidance of collisions due to the use of Fishpond.

Early Development of Boozer

A receiver capable of accepting the emissions made by enemy ground radar used for controlling fighters and gunfire was devised by the T.R.E. in 1942, and given the code-name Boozer. Six experimental sets were supplied to Bomber Command. The device was arranged so that a red light was observed by the wireless operator when the Boozer receiver was activated ; thus visual indication was given when an aircraft was being followed by a ground radar beam. Boozer was carried in a small number of Stirlings of No. 7 Squadron on four raids in November 1942, and again on 2/3 December 1942, its first use against a target in Germany.[3] Aircrews showed a great interest in Boozer, and those who first used it were enthusiastic about it, principally because it indicated when the enemy was taking a direct interest in them. Early results were encouraging, but it was too soon for an accurate assessment to be made of its real value.

Research continued at the T.R.E. on improved forms of Boozer, firstly a double-channel type that would distinguish G.C.I. beams from G.L., and secondly, after the wavelength of enemy A.I. had been confirmed, a triple-channel type that would give different indications for G.C.I., G.L., and A.I. In order that further operational trials could be conducted, 18 of the double-channel and six of the triple-channel receivers were made.[4] With the double-channel type the same lamp was used to give both indications, a dim red light showing for G.C.I. and a bright red light for G.L. In the triple-channel set an additional yellow light gave A.I. indication. The pilot and wireless operator stations were both provided with indicator units, wired in parallel.

Up to 18 March 1943, 119 sorties had been made with double-channel and 28 with triple-channel Boozer.[5] Pilots found the bright indications on double-channel Boozer of value in indicating lightly-defended target areas, where warning was given of unseen *flak*. In all heavily-defended target areas the bright indications were too numerous to be of value ; what was needed was some means of eliminating the shorter bright indications of a few seconds' duration. Dim indications also were too numerous and needed some restriction. On triple-channel Boozer, the A.I. indicator was considered to have great

[1] A.H.B./IIH/241/10/55(A).

[2] A.H.B./II/69/206.

[3] A.H.B./II/69/168. B. Ops. Folder Boozer.

[4] A.H.B./II/69/168.

[5] A.H.B./II/69/168.

possibilities. The value of the A.I. channel naturally depended on the proportion of enemy aircraft equipped with A.I. It was to be expected that the number and proportion of such aircraft would increase.

The requirements for Boozer, conditioned by the need for simplicity to help speed production, were stated by Headquarters Bomber Command in March 1943 to be :—

(*a*) The same indication, e.g. a red light, for both G.L. and G.C.I., with a time delay, preferably variable, of five seconds in the G.L. circuit and three minutes in the G.C.I. circuit. The times might have to be modified as the result of further consideration and experience.

(*b*) The indication of G.L. and G.C.I. to be given only when the aircraft was at the centre of the beam.

(*c*) A separate indication, e.g. a yellow light, for A.I.

It was requested that, if a version of Boozer with these characteristics could be developed, it should be put into production immediately, without waiting for Service trials.[1] At that time the possibility that there might be a gap in the Monica programme after the anticipated jamming of Marks I and IA was causing concern, and Bomber Command was particularly anxious to have some warning equipment to counteract the A.I. night fighter, which was regarded as the greatest potential danger to bomber aircraft. A requirement was therefore raised for A.I. Boozer to be provided on the basis of one per operational heavy and medium bomber, and it was emphasised that if the production of Boozer equipment covering A.I., G.C.I., and G.L. was likely to be difficult and to delay its introduction, a separate A.I. warning receiver was wanted first.[2] The G.C.I./G.L. equipment could then be provided later, either as a separate receiver or as a three-channel set in substitution for the simple A.I. set.

Headquarters Bomber Command asked at the same time for a number of technical factors to be taken into account :—

(*a*) Owing to the existing lack of knowledge of the power and performance of German A.I., it was not yet possible to design a receiver to operate at a definite maximum range. The sensitivity of Boozer was therefore to be variable, the aim being to give a crew five to six minutes warning before an A.I. fighter reached lethal range.

(*b*) Indication was to be by yellow light to the pilot only.

(*c*) H2S suppression was to be included to enable Boozer to be used simultaneously in the same aircraft.

(*d*) Monica suppression was also to be included if necessary.

(*e*) The aerial was to be positioned so that evasive action by the bomber did not screen it from enemy A.I. transmissions.

(*f*) If Carpet, an airborne radar jammer, were installed in bomber aircraft, consideration should be given to the feasibility of A.I. Boozer and Carpet operating simultaneously.[3]

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[1] A.H.B./II/69/168.
[2] A.H.B./II/69/168.
[3] *See* Royal Air Force Signals History, Volume VII : 'Radio Counter-Measures', for details of Carpet.

A.I. Boozer

On 7 April 1943 the Air Ministry informed Headquarters Bomber Command that 200 A.I. Boozer receivers were to be produced on the highest priority ; the target date was 1 June.[1] The equipment was designed so that a G.C.I./G.L. unit could be incorporated when it became available ; the production of 200 G.C.I./G.L. units was being undertaken in parallel with that of A.I. Boozer but in such a manner that it would not interfere with it. Twelve test sets were also to be made, and in view of this small number the Air Ministry recommended that the first 200 A.I. Boozer receivers should be installed in squadrons of a single group.[2] The production of a further 1,000 A.I. and G.C.I./G.L. sets was planned.

Trial installations of A.I. Boozer in Lancaster, Stirling and Halifax aircraft were completed, and P.F.F. aircraft were the first to be fitted. The policy of fitting all P.F.F. aircraft had been decided on 16 April, but on 22 May it was changed and a new priority of fitting was agreed.[3] As a result A.I. Boozer was to be installed only in aircraft not equipped with Monica, as delivery from production began while the Monica fitting programme was still in progress. P.F.F. aircraft were fitted first, and then aircraft of Nos. 3, 1 and 5 Groups in that order. By the end of June, 127 aircraft had been equipped, chiefly in the P.F.F., and 232 operations completed.[4] Results were most encouraging, and very little unserviceability was reported.

By 22 August 1943, 248 Lancasters and 123 Stirlings had been fitted. So far no G.C.I./G.L. sets had been installed. An analysis was made of some 2,000 sorties carried out by aircraft equipped with A.I. Boozer between 11 June and 11 August 1943, the period in which Window was first used.[5] For the pre-Window period, the loss rate showed little evidence of any reduction traceable to the use of Boozer, although the percentage of attacked aircraft was slightly less than that for the force as a whole, and there were a few individual instances in which it seemed that Boozer warning had been of considerable aid to the bomber in escaping. The loss figures for the post-Window period were more promising. However, considering the whole period over which A.I. Boozer had been used, the effect on losses was disappointing.

It was decided to modify Boozer to increase the range, and in view of this, and of the evidence that the use of Window was causing the enemy to rely more and more on A.I., it was decided that the equipping of bombers with A.I. Boozer should be continued as rapidly as possible.[6] About 1,500 aircraft had been fitted with Monica Mark I, and an installation programme was still in progress, but Monica Mark IA was not yet in production, and it was thought that Boozer might be made available in quantity just as quickly. At the time Boozer was regarded as being more likely to fulfil Bomber Command requirements than Monica. Although Boozer gave no warning of the approach of night fighters not using A.I., and was of no help in avoiding collision, it fitted in with plans for the further provision of combat warning equipment in that it could be retained as an identification device after the introduction of A.G.L.T. On 27 August 1943 it was decided to increase the production of Boozer to 600 per month to enable all bombers on aircraft production lines to be fitted. This decision necessitated further trials by the T.R.E. to enable the final design to be completed.

[1] A.H.B./IIH/241/22/1(a). Bomber Command File BC/S.28806.
[2] A.H.B./II/69/168. [3] A.H.B./IIH/241/10/43(A). [4] A.H.B./II/69/168.
[5] A.H.B./II/69/168. [6] A.H.B./II/69/168.

Meanwhile operational use of the existing A.I. Boozer was continued but generally it was unsatisfactory because its effective range was too short. The original specification had been for a maximum range of approximately 3,000 yards, but design was based on an estimate of the radiated power of the enemy A.I., and experience showed that this estimate had been too high.[1] The effective range of Boozer was reduced to not more than 1,500 yards, and in fact the range for any direction of approach other than dead astern was considerably less. This was one of the most disturbing features, and a very much greater all-round range was wanted.[2] It was clear that Boozer in its existing state should never be depended upon to the exclusion of visual warning, and that the disappearance of an indication was no guarantee that a fighter had given up or had been shaken off ; the fighter might be making a different approach. It was recommended that immediate action in the form of a defensive manoeuvre should be taken on receipt of any Boozer warnings.

G.C.I./G.L. Boozer

The main fault of the original G.C.I./G.L. Boozer had been the large number of indications received, and two modifications were introduced to reduce them. They consisted of split discrimination, which caused an indication to be received only when the aircraft was at or near the centre of the *Wurzburg* beam, and separate and variable time delays in the G.C.I. and G.L. circuits.[3] These were first set at 5 seconds in the G.L. circuit and about 30 seconds in the G.C.I. At the beginning of June 1943, five sets modified by the T.R.E. were ready for operational use.[4] They incorporated split discrimination, but the time delays were not variable. They were fixed at 5 to 10 seconds in the G.L. circuit and 25 to 35 seconds in the G.C.I. Up to September 1943, 76 sorties had been flown with the modified experimental sets. The number of indications received was very much smaller, and averaged about one per sortie of each type. The evidence suggested that the value of G.C.I./G.L. Boozer was thus much increased. A G.C.I. time delay of one minute was recommended for future operations.

During the summer of 1943, following the introduction of Window, it was for consideration whether G.C.I./G.L. Boozer was still necessary. The use of Window afforded the main bomber stream a considerable degree of protection against *Wurzburg*. However, the evidence collected suggested that the enemy was still using his ground-controlled fighters whenever he had the opportunity, and stragglers from the main concentration of bombers were still in danger from this source.[5] The requirement for the provision of G.C.I./G.L. units in all aircraft therefore remained.

Triple-Channel Boozer

Three hand-made models of the complete triple-channel Boozer were made at the T.R.E., and were tested operationally from 24 July 1943.[6] They included variable time-delays and used a new form of aerial, and the A.I. range was believed to be about 2,500 yards. Production was expected to start in December 1943. Arrangements were made to modify existing A.I. Boozer receivers, by

[1] A.H.B./II/69/168. [2] A.H.B./IIH/241/3/262.

[3] *Wurzburg* was the German G.C.I., Searchlight and A/A control. *See* Royal Air Force Signals History, Volume VII : ' Radio Counter-Measures ', for further details.

[4] A.H.B./IIH/241/3/263. Bomber Command File BC/S.30343/2.

[5] A.H.B./IIH/241/3 263. [6] A.H.B./IIH/241/3 263.

the addition of a pulse transformer, to provide the same range. Full production of triple-channel Boozer did not in fact begin until February 1944.[1] A priority of allocation was decided, and 250 sets were allocated to four different groups in March 1944; a further 200 were allocated during April. Production was expected to be 400 sets per month from May onwards, up to a total of 2,000, and they were all to be fitted retrospectively in aircraft of Bomber Command. On operations, the G.L. delay was set at 7 seconds to ensure that unnecessary evasive action was not taken, and the G.C.I. delay at 60 seconds as it was considered that any Giant *Wurzburg* beam following for less than 60 seconds could not be engaged in arranging an interception. There was no delay on the A.I. beam, the range of which was found in practice to be about 1,700 yards.

The operation and recommended action for triple-channel Boozer was as follows:—[2]

G.L.—The appearance of a bright red light indicated that a *flak* battery might be about to open fire. The action recommended was an alteration of course of 20 to 30 degrees to port or starboard about every 25 seconds when below 15,000 feet and about every 30 seconds when above. Irregular alterations were then made until the bright red light went out, indicating that the *Wurzburg* was no longer following the aircraft.

G.C.I.—The area covered by the Giant *Wurzburg* beam at any height above 10,000 feet was so large that no manoeuvre by an aircraft could shake it off. The only action possible on receipt of this warning was intensification of search for enemy aircraft and preparation for combat, since an indication meant that the aircraft was being plotted by a G.C.I. station with a view to arranging an interception.

A.I.—The recommended action was corkscrew evasive action until the warning indication disappeared.

Operational Use of Boozer

Early reports on operational use of the various production types of Boozer were conflicting. The first reports, analysed in November 1943, suggested that the G.C.I. and G.L. channels had proved most useful in enabling pilots to avoid accurate predicted *flak*. They indicated that, in spite of Window, the enemy was still using *Wurzburg* for *flak* and searchlight control with some success. Further reports made up to March 1944 suggested that the usefulness of G.C.I./G.L. Boozer was much diminished by the change in enemy control methods since Window was first employed. On the A.I. channel there was a similar divergence of opinion.[3] Some reports stated that Boozer was popular and effective but in No. 1 Group, from December 1943 to April 1944, the loss and attacked rates for 1,031 sorties made with Boozer-equipped Lancasters were rather higher than those for non-equipped aircraft on the same raids. A general assessment of combat warning devices showed that whereas Monica and Fishpond appeared to have had a definite effect in reducing the loss and attacked rates, Boozer did not.

From the time when A.I. Boozer was first brought into operational use in June 1943, up to September 1944, during the period of introduction first of G.C.I./G.L. Boozer and then of triple-channel Boozer, at no stage could it be

[1] A.H.B./II/69/168. [2] A.H.B./IIH/241/3/263. [3] A.H.B./ID/12/96.

said that there was direct evidence that Boozer was saving aircraft. During a great part of this time the A.I. range of the device was, without doubt, inadequate.[1] An increase in sensitivity was provided by the addition of a pulse transformer, and the triple-channel receivers were operated with a new aerial system which brought a further improvement; but the equipment was still unsatisfactory after many months of operation.[2]

Boozer was intended to be complementary to either Monica or Fishpond. It had been expected that the association of Boozer with Monica or Fishpond would enhance the value of both members of the combination, since the identification given by Boozer would sometimes be added to the information on position given by the other devices. However, due to the general shortage of warning equipment, for a long time many aircraft were fitted with Boozer only, and by itself Boozer suffered from the serious deficiency that it gave no indication of range or direction.

Because Boozer was fundamentally sound in that it did not radiate and responded only to enemy transmissions, it was persevered with for longer than might otherwise have been the case. Had the attempts to improve the usefulness of Boozer been successful, it would have been extremely difficult for the enemy to counter it without changing his own system. Boozer was still regarded as a standard requirement for all bomber aircraft, in addition to any other warning equipment, in the early months of 1944, but by the end of March enthusiasm was waning, and in June it was confirmed that no further sets would be required beyond the 3,000 then on order.[3]

Withdrawal of Boozer

Boozer was removed from all bomber aircraft except Mosquitoes in September 1944, as a direct result of the adoption by the enemy of a new form of A.I. known as *S.N.2*, working on a frequency outside the range of Boozer; it was known that *S.N.2* was fast becoming a universal installation in night fighter squadrons.[4] A secondary reason was the final acceptance of the fact that Boozer was a failure. The G.C.I./G.L. channels were not affected by the new German equipment, but they too were abandoned; and there was no move to produce an A.I. Boozer to cover the new *S.N.2* frequency. There remained, however, the possibility that jamming of *S.N.2* might force the enemy to revert to the use of *Lichtenstein*, and against this eventuality stocks of Boozer were conserved.[5]

Development of A.G.L.T.

The use of automatic gun-laying in aircraft was first suggested by Squadron Leader F. V. Heakes, then R.C.A.F. liaison officer at the Air Ministry, in July 1939. Squadron Leader Heakes believed that the basic weakness of radar for fighter interception was that although it might bring the fighter within striking distance of an enemy aircraft, it did not thereby ensure that the fighter pilot made contact, or that he would be able to hit his target if

[1] A.H.B./II/69/68. [2] A.H.B./IIH/241/10/37/(C). [3] A.M. File C.16038/44.

[4] A.H.B./IIH/241/10/37(C).

[5] A.H.B./IIH/241/3/263. *Lichtenstein* was German A.I. which operated on frequency of 490 megacycles per second; *S.N.2* on the band of 75 to 100 megacycles per second. *See* Royal Air Force Signals History, Volume VII: 'Radio Counter-Measures', for further details, and Volume VI: 'Radio in Maritime Warfare', for details of use of Boozer in Coastal Command.

he did. A further step was needed: the provision of an R.D.F. gunsight of such qualities that the pilot could open fire without actually seeing his opponent.[1]

By 1942 three versions of a radar automatic gun-laying system were under development at the T.R.E. The turret equipment included a scanner, a simple radar control box, a complete Mark II gyro gunsight installation and a small cathode ray tube. The scanner, with a rotating dipole, was mounted externally underneath the turret and moved in azimuth with it; it was linked to the guns for movement in the vertical plane. The cathode ray tube was housed in a collimator and fixed to the gyro gunsight. It projected an image in the form of a green spot in the line of sight of the gunner when he looked through the gunsight. When the scanner picked up a target aircraft, the green spot moved off in the direction of the target and sprouted wings; when it was pointed within 4 degrees of the target aircraft the green spot was superimposed upon the target and the gunner was thus presented with a visible target at which to aim with the aid of the moving graticule of the gunsight. Radar equipment located in the fuselage provided an automatic ranging device for the gyro gunsight, a visual indicator, showing range in yards, which was watched by the wireless operator, and a warning which was audible on the intercommunication system.

The first of the T.R.E. systems, known as A.G.L.T. Mark I or Village Inn, had a manually-operated scanner; a 30 degrees cone was scanned automatically and could be projected in any direction by manual operation of the guns or the turret. A wider beam could be attained by de-focusing the scanner; it was estimated that de-focusing would increase the coverage of the cone to 50 degrees. In the second system, known as Mark II, the scanner was automatically operated; a 90 degrees cone was scanned automatically, and this again could be increased by manipulation of the turret. The third system was similar to Mark II except for location of the scanner. The Air Staff decided that the coverage offered by Mark I was too limited and that it would be better to concentrate on the development of Mark II, although this meant accepting an additional nine months delay, since it was unlikely to be available for trials before the end of 1944. The drawback of Mark I was that with a cone of only 30 degrees centred around the longitudinal axis of the guns, continuous manipulation of the turret would be necessary to give reasonable cover. It was considered that such manipulation, besides quickly exhausting the gunner, would also tire the pilot, since it would not be easy to maintain a steady course while the turret was being continually swung.[2] Mark II was therefore accorded the higher priority, although development of Mark I was continued.

The success of the flight trials of Fishpond in May 1943 inspired the idea that A.G.L.T. Mark I, if used in conjunction with Fishpond, would be acceptable.[3] A.G.L.T. Mark I could be made available some nine months before A.G.L.T. Mark II, and used in conjunction with Fishpond it gave the required cover. The Air Staff therefore decided to develop Mark I as quickly as possible, relegating Mark II to the role of a possible successor to Mark I, which it was hoped would be ready by June 1944. It was not known at first what the

[1] A.M. R.E. File D.2153. [2] A.M. File CS.9853. [3] A.H.B./IIH/241/10/55(a).

A.G.L.T. Scanner and Dipole

performance of A.G.L.T. alongside H2S/Fishpond would be, as the prototype A.G.L.T. Mark I was fitted in a Wellington without H2S, but trials at the T.R.E. soon confirmed that the directional accuracy was satisfactory. Development contracts were placed, the target date for production being 1 April 1944. The T.R.E. expected to have two complete prototypes by September 1943 and four more by November. The early introduction of A.G.L.T. Mark I was given the highest priority, additional staff, labour and other facilities being accorded to this end.[1] The Air Staff requirement was that it should be fitted in all H2S aircraft, and early in July the target dates were advanced; it was planned that 200 sets of equipment, for 100 Lancaster aircraft installations with 100 per cent spares, should be produced on a crash programme starting on 1 February 1944.

An air-to-air identification system was a fundamental requirement of automatic gun-laying, and that developed for use with A.G.L.T. Mark I was known as Type Z, a trial installation of which was made in a Lancaster on 11 February 1944. Infra-red ray transmitters with automatic coding box and two downward identification lamps were mounted in the nose of bomber aircraft; the emissions were made visible to the tail gunner of preceding aircraft through a simple infra-red telescope aligned with his gunsight. When he observed a contact on his A.G.L.T. display, he checked to see if infra-red transmissions were being made. If no emissions were visible he was entitled to assume that the contact was hostile and to open fire. Thus the system suffered from the same failing as did the I.F.F. system; it was purely negative. It did not meet the Air Staff requirement for positive identification, but nor did any other method when in February 1944 all other possible systems were surveyed. The best solution to the problem seemed to be offered by a system known as Liquid Lunch, in which it was intended that warning would be received when A.G.L.T. was pointed within 4 degrees of the target aircraft. Green, amber and red lamps would indicate respectively when Liquid Lunch was in operation, when the aircraft was illuminated by A.G.L.T., and when it was being aimed at by A.G.L.T. It was decided to develop the system as a replacement for Type Z and to investigate by experiments the possibility of a reverse signal triggered by Liquid Lunch being received by the A.G.L.T. beam in such a way that the aircraft contact blip was neutralised.

A.G.L.T. was suitable for installation in the more modern turrets only. The only turret in operational use which could accommodate A.G.L.T. was the Frazer Nash 120, two of which were modified and delivered to the T.R.E. for trials.[2] A Lancaster fitted with an F.N. 120 turret and A.G.L.T. Mark I was tested for aircraft stability and gunnery at Boscombe Down, and the report was satisfactory. Modification of the F.N. 120 to enable it to accommodate A.G.L.T., and also of the two new types of turret which were expected to come into production in 1944, the F.N.82 and the Boulton and Paul Type D, was initiated. On 28 July 1943 the Air Staff stated the requirement afresh as installation of A.G.L.T. Mark I in all Bomber Command aircraft equipped with F.N.82, and also in Type D and F.N.120 turrets, but only until and without prejudicing the introduction of the F.N.82. It was decided at the same time not to proceed with A.G.L.T. Mark II, but to develop a new and

[1] A.H.B./IIE/6/63. A.G.L.T. Agenda and Minutes of Meetings.
[2] A.H.B./IIE/6/63. A.G.L.T. Agenda and Minutes of Meetings.

improved equipment designated A.G.L.T. Mark III, which included such refinements as automatic search, lock-follow permitting blind firing, and improved presentation. In the event, development of Mark III was delayed because all available effort and resources were required for Mark I. By July 1944 it was, however, being undertaken at the T.R.E. with the object of overcoming the major weaknesses of Mark I revealed by operational experience, although it was realised that, despite any pressure that might be brought to bear, the equipment was unlikely to be available before the end of the war.[1] By September 1944 it was possible to estimate that production could be started about one year later. At the same time the R.A.E. had been engaged on development of Mark IV, a completely miniaturised equipment suitable for tropicalisation. It was estimated that production could begin about six months after that of Mark III.

Production and Installation

Service trials of A.G.L.T. Mark I installed in a Lancaster were conducted at the B.D.U. from October 1943 to January 1944, and the results were encouraging. A number of limitations were revealed, however, which necessitated specialised technique and operational restrictions. Since a very high standard of serviceability could not be expected until experience had been gained it was essential to provide the gunner with means of knowing whether or not the equipment was working correctly, and the installation in the turret of simple test gear to give reliable and quick indication of serviceability at any time was required. With the turret and guns stationary the scanner searched a cone 30 degrees in width and was effective to a range of 1,330 yards. The area searched could, however, be greatly increased artificially by movement of the turret and guns, which changed the direction in which the scanner was pointing. The F.N.121 turret, a modification of F.N.120, could be rotated to 85 degrees on either beam and the guns depressed 45 degrees and elevated 60 degrees, although the scanner was limited in elevation to 45 degrees. Those movements, combined with the field of radiation of the scanner, enabled A.G.L.T. to be used as an early warning device over an effective area of search extending to 100 degrees on either beam and to 60 degrees in elevation and in depression. Blind firing was of course restricted to the degree of movement of the centre line of the scanner, 85 degrees on either beam and 45 degrees in elevation and depression. The speed with which the turret could be conveniently manipulated for continuous search was limited. It took between 30 and 40 seconds to cover the maximum possible area of search, during which time an enemy fighter might have closed in by 600 yards. It was, however, unlikely that effective attacks would be made from wider on the beam than 60 degrees or at a greater elevation than 30 degrees. The gunner, could, therefore, safely limit his gun elevation to about 15 degrees, but difficulty was experienced in restricting movement in azimuth because the gunner had little idea of the direction in which his turret was pointing. Incorporation of a device by which the gunner could be informed when he reached 45 degrees in rotation was consequently required. Rotation of the turret during search caused a certain ruddering effect on the aircraft but did not prove to be unduly tiring to the pilot or detrimental to navigation.[2]

[1] A.M. File CS.22851.

[2] A.H.B./ID/12/315(A). A.I. Equipment.

Meanwhile, hopes were entertained that the crash-programme production of 200 A.G.L.T. Mark I would be delivered by the end of March 1944, and the first 100 possibly by the end of February. Quantity production of 3,000 equipments was due to begin in March, deliveries from which were not expected before July. Two A.G.L.T. trainers were made by the R.A.E., and four instructional courses for radar mechanics were arranged at the T.R.E., the first of which was nearly completed by the end of January. Two squadrons, one in No. 1 Group and one in No. 5 Group, were to be equipped with equipment from the crash programme.[1]

A number of turret wiring faults were found in early deliveries of aircraft equipped with A.G.L.T. Mark I. Most of them were due to cables not being laid in accordance with drawings, but some were more fundamental. On 18 March 1944, by which time eight aircraft had been delivered, the installation programme was suspended whilst trials were continued at the B.D.U. By 26 April an improvement in reliability enabled fitting to be resumed. There were still many difficulties, due mostly to a shortage of aircraft connector sets, the varying dimensions of individual turrets, and poor minimum range.[2] However, by 5 August 1944, one squadron had been completely equipped and fitting in the second squadron had begun.

It was the intention to manufacture one A.G.L.T. set for each turret produced up to the end of 1944, and sufficient sets thereafter to cover the aircraft production programme in addition to the necessary maintenance and stock-building requirements. However, in July 1944 it became evident that the aim would not be achieved, and, to make matters worse, even the existing limited A.G.L.T. programme was retarded by difficulties which arose in production. The possibility of increasing the rate of production had been under discussion for over a year, but, with the many other urgent commitments that industry had to meet, any increase was found to be impossible. It was apparent that, for the next twelve months at least, more than half the heavy-bomber force would be without A.G.L.T.[3] Production of Type Z equipment had reached 150 by mid-August. The first sets delivered were rejected by the R.A.E. because the telescope misted at a temperature of 40 degrees centigrade and production was delayed while the fault was cleared. Instructions for the use of A.G.L.T. and Type Z were issued by Headquarters Bomber Command on 25 June 1944.[4] The main points were :—

(*a*) Blind firing was forbidden in certain areas, mainly over friendly territory, but there was no restriction in the use of A.G.L.T. as a warning device in those areas.

(*b*) In unrestricted areas the gunner, before opening fire, had to identify either visually or by Type Z. It was emphasised that the onus of correct identification rested entirely on the gunner, who was under no circumstances to open fire if there was any doubt.

(*c*) The navigator was responsible for the correct functioning of the Type Z transmitter during flight.

(*d*) As soon as a gunner was completely satisfied that a contact was hostile, he was to open fire at 700 yards range. When the range closed to 400 yards the pilot was to start immediate corkscrew evasive action.

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[1] A.M. File CS.19968. [2] A.M. File CS.19968. [3] A.M. File CS.19968.
[4] A.M. File CS.22851.

A.G.L.T. Mark I with Type Z identification was used operationally in one squadron of No. 1 Group from the last week of July 1944. It was recognised at once that the biggest handicap to the successful operation of A.G.L.T. was the poor performance of the infra-red identification system; gunners were forced to rely on visual identification, thereby nullifying to a large extent the advantages of A.G.L.T.[1] In spite of this severe handicap, and the difficulties arising from the need for continuous manipulation of the turret for searching purposes, A.G.L.T. appeared to be a most efficient warning device and a formidable weapon against the enemy night fighter. Headquarters Bomber Command confirmed that A.G.L.T. Mark I was an urgent requirement for all heavy-bomber aircraft and asked for full-scale introduction to be hastened on the highest priority.

The A.G.L.T. programme provided for the fitting of F.N. 121 turrets in Lincoln and Lancaster aircraft, F.N. 82 turrets to supersede F.N. 121 turrets in first Lincoln and then Lancaster aircraft, and Boulton and Paul Type D turrets in Halifax aircraft. By mid-September 1944, contracts had been placed for 9,030 A.G.L.T. Mark I equipments, the requirement being:—

(*a*) 3,130 at the rate of 170 per month for F.N. 121 turrets in Lincolns and Lancasters.

(*b*) 4,120 at the rate of 230 per month for F.N. 82 turrets in Lincolns and Lancasters.

(*c*) 1,780 at the rate of 100 per month for B. and P. Type D turrets in Halifaxes.

Delivery of Lancasters modified for A.G.L.T. Mark I installations began in January 1945 at the rate of 30 per month. This rate rose to over 100 in April and then fell steadily as Lancaster production fell and was supplanted by that of Lincoln aircraft. All Lincoln I aircraft were fitted with A.G.L.T. Mark I from the start of production.

It was decided on 28 January 1945 not to fit Halifax aircraft with A.G.L.T. The trial installation had not been cleared and it was doubtful whether A.G.L.T. could be introduced on the production line before June/July 1945. By that time it was unlikely that Bomber Command would have much interest in the Halifax, as its production was rapidly declining. The policy was that all Lincoln and Lancaster aircraft in which H2S Mark IIC or later Marks was installed on the production line were to be equipped subsequently with A.G.L.T.[2] Aircraft of the P.F.F. were to be equipped throughout with A.G.L.T. before a start was made with main force squadrons.[3] Some of the crash programme equipments withdrawn from No. 1 Group when that group began to re-equip with the Rose turret were transferred to the P.F.F. to provide initial training facilities.

In March 1945, No. 32 M.U. was installing A.G.L.T. Mark I and H2S Mark IIIA in P.F.F. aircraft at the rate of 30 per month. The installation programme absorbed the whole of the manufacturer's output of modified Lancasters, but in April the flow of aircraft increased substantially, and the unit was able to equip from 60 to 70 Lancasters per month. Headquarters Bomber Command

[1] A.M. File CS.22851. [2] A.M. File CS.23266. [3] A.M. File CS.19968.

therefore agreed that A.G.L.T. should be installed in aircraft of No. 5 Group when the Pathfinder Force commitment had been met, and in aircraft of other main force groups, in an order of priority to be nominated at a later date, when the No. 5 Group programme had been completed.[1] It was expected that the rate of fitting at No. 32 M.U. could be maintained and improved up to the end of May, when other commitments would reduce it. Headquarters Bomber Command had previously agreed to accept the task of equipping main force aircraft in due course, provided that aircraft modifications had been completed. The installation of A.G.L.T. equipment itself was not a heavy burden, and in any event the flow of aircraft would not be great until the end of 1945. Up to 23 March 1945 the total number of Lancasters delivered to No. 32 M.U. was only 78, and no progress had yet been made with Lincolns.[2] However, in Bomber Command, manning in the trade of radar mechanic was some 25 per cent below establishment, and although it had been decided that the introduction of A.G.L.T. should not be held up because of likely servicing difficulties, it was no longer possible to undertake an installation programme. It was therefore requested that the capacity of No. 32 M.U. should be increased to enable installation to be made in 100 aircraft per month, and that consideration should be given to the possibility of installing A.G.L.T. on the aircraft production line or at other maintenance units.[3] However, the rate of fitting at No. 32 M.U. could not be raised above 100 per month, and that figure even would be reduced in June; from a number of alternative programmes Headquarters Bomber Command chose the following in order of priority :—[4]

(*a*) 30 Lancasters per month for the Pathfinder Force, with F.N. 121 turrets and A.G.L.T.

(*b*) 15 Lancasters per month for allotment to Nos. 3 and 5 Groups, with F.N. 121 turrets but without A.G.L.T.

(*c*) 45 Lancasters for No. 5 Group, with F.N. 82 turrets and A.G.L.T.

Operational Use

An Operational Research Section report on the operational use of A.G.L.T. Mark I crash programme equipment attributed the lack of success to several factors. The shortage of test gear, the fact that radar mechanics were unfamiliar with the equipment, and numerous weaknesses in design and construction combined to make the standard of serviceability a very low one ; not unusual when new equipment was introduced on the basis of a crash programme. The standard of serviceability of A.G.L.T. was limited in any event by that of H2S, Fishpond and other related equipment, and the expected maximum possible was rated as 80 per cent ; faults in A.G.L.T. equipment itself reduced the rating to 65 per cent. Such a standard was obviously unsatisfactory, and a requirement was raised for modifications which would make the effective operation of A.G.L.T. independent of other equipment. Adequate aircrew training facilities had been provided at heavy conversion units, but there had not yet been time to overcome the lack of adequately trained personnel. In addition it had become apparent that the introduction of the new types of A.G.L.T.-equipped turrets made it not only essential that air gunners should

[1] A.M. File CS.22851. [2] A.M. File CS.19968. [3] A.M. File CS.19968.
[4] A.M. File CS.19968. Lincolns were to be substituted as they became available.

be more highly trained but also that a higher standard of personnel selection was required. The principal factor affecting the successful application of A.G.L.T. was, however, that of identification. The Type Z, being a negative system of identification, never inspired confidence in air gunners, whose responsibility it was to identify a contact before opening fire; they hesitated to fire even when they received no response.[1] 25 Liquid Lunch equipments were manufactured in 1944, but Service trials indicated that the system offered no substantial improvement on Type Z.

However, since automatic gun-laying was a very great advance in air gunnery, possibly the greatest yet made, and was the best solution in sight of the problem of the defence of the night bomber, it was felt that it would be a tragedy if it were not given a fair trial before the war ended.[2] It was considered that considerable effort should be expended to obtain a wider experience of A.G.L.T. if this could be done without prejudice to operations. Records showed that the Type Z transmitter was very nearly 100 per cent reliable, and it was thought that knowledge of this fact would develop in gunners a readiness to fire blind. The receivers were 91 per cent reliable, and, since nearly all the 9 per cent of failures were made obvious to the gunner by means of his test gear, he was able to switch off A.G.L.T. and revert to visual methods of identification. In February 1945 Headquarters Bomber Command instituted a drive to ensure that Type Z transmitters were always switched on, and the Air Ministry recommended that the Type Z circuit should be connected to the main aircraft electrical switch to ensure that Type Z was always switched on so long as the aircraft was airborne. It was made clear to all crews that A.G.L.T. gunners were expected to fire on all contacts not showing Type Z. A factor militating against implementation of this policy, however, was the shortage of radar mechanics, a shortage that would be even more acutely felt when installation of A.G.L.T. by squadrons began. If the A.G.L.T. and Type Z equipment could not be properly serviced a policy calling upon gunners to fire on all contacts not showing Type Z would be untenable, It remained to assess to what extent the potential value of A.G.L.T. was being unrealised through users not accepting responsibility for opening fire without positive identification, and the lack in Bomber Command of sufficient personnel qualified to install and service the equipment. It seemed that the second factor was the more fundamental, since A.G.L.T. could never be brought into effective use unless it was properly serviced and understood.[3]

There was, however, another vital factor which prevented full realisation of the potential value of A.G.L.T. After the introduction of the A.G.L.T. crash programme equipment on operations in July 1944, enemy night fighter opposition became negligible. It was estimated that in the last few months of the war the average sightings of enemy night fighters were one in every thirty sorties. In other words, during a complete operational tour a gunner could expect to see only one enemy fighter. It was not surprising therefore that gunners were reluctant to believe the evidence of Type Z when it suggested that a contact was an enemy fighter. Their opportunities for firing of any kind were almost nil.

[1] A.M. File CS.19968. The fact that navigators sometimes omitted to switch on the Type Z transmitter, in spite of clear instructions, was another factor in undermining confidence.

[2] A.M. File CS.22851.

[3] A.M. File CS.22851.

The squadrons equipped from the crash programme were unable to build up either the confidence or the experience necessary with such a revolutionary equipment as A.G.L.T. Then and later, due to the high rate of effort, crews were finishing their tours in record time, with the result that, although A.G.L.T. was occasionally used for blind firing when it was first introduced, the initial experience became progressively diluted. By the end of April 1945 it was apparent not only that there was insufficient operational experience of A.G.L.T. for its value to be accurately assessed, but also that it was most unlikely that conditions favourable to its use would recur. In June 1945 it was decided that A.G.L.T. would not be a requirement in overseas theatres during Stage II, and the total number of equipments to be produced was reduced to 2,000.

CHAPTER 15

RADIO ALTIMETERS

Aneroid altimeters used in aircraft in their most sensitive form gave very accurate readings of altitude when corrected for local atmospheric pressure, but suffered from the grave limitation that readings could be grossly inaccurate if the local atmospheric pressure was not known precisely. Many attempts had been made to obtain a direct measurement of the height of an aircraft above the ground. Development from 1920 to 1930 was chiefly centred on sonic altimeters, but the high noise-level in aircraft, and their increasing speed, made sonic methods impossible. Attention was turned to the use of radio, and as early as 1927 a frequency-modulating system was proposed. Research was mainly carried out in the United States of America and a radio altimeter based on that principle was demonstrated there by the manufacturers, the Western Electric Company, in 1938. Continuous electric waves were emitted, with rhythmic variations in frequency, from the underside of the aircraft. The reflected wave from the ground or water underneath was received in the aircraft and its frequency was compared electrically with the wave then being sent out. The longer the time-interval between the emission of the original wave and its reflection back to the aircraft, the more its frequency differed from that of the wave being emitted when it returned. The frequency difference was made to show the true terrain clearance directly on an instrument dial, and for small and medium distances, up to about 5,000 feet, the system worked fairly satisfactorily. The Standard Telephones and Cables Company became agents in the United Kingdom for the equipment, and in November 1939 supplied the Royal Aircraft Establishment with a model given the Service nomenclature of Radio Altimeter Type 1.

Development of Radio Altimeters Types 1 to 5

The altimeter was installed in a Bristol 142 aircraft, prototype of the Blenheim, and flight trials were begun in January 1940. It consisted essentially of a transmitter, receiver, power unit and aerial system, operating on a wavelength of 70 centimetres, and covered a single range of heights from 50 to 1,500 feet.[1] The aerial system consisted of two wide-band tuned dipoles mounted on a fairly flat section underneath the fuselage about 12 to 18 feet apart, end-on to each other, and connected through coaxial transmission lines ;

[1] A.H.B./IIE/247. R.A.E. Paper, Radio/S.5204/BAS/14.

	Transmitter Unit	*Receiver Unit*	*Power Unit*
Dimensions in Inches.	9 × 6 × 21	9 × 6 × 21	9 × 6 × 21
Weight in Pounds.	15½	11	17
Detail.	Valve transmitter and modulator using Western Electric Company type of valve.	Diode mixer unit, L.F. amplifier, frequency counter, and meter operating circuit.	Total power consumption at 12 volts was 320 watts. H.T. provided by rotary converter.

one to the receiver and the other to the transmitter. During the trials accuracy was checked against a Kollsman aneroid altimeter and readings agreed within 10 per cent. On completion of the trials the equipment was rebuilt as an experimental frequency-modulated A.I. system and it was not further developed as an altimeter until October 1940 when a model was installed in a Bristol Botha aircraft. Mainly because of the necessity to use long aerial feeders the installation did not operate satisfactorily as an altimeter, and, with the co-operation of the Standard Telephones and Cables Company, the Royal Aircraft Establishment carried out extensive modifications which included the provision of two ranges, 0 to 500 feet and 0 to 5,000 feet. In January 1941 Headquarters Army Co-operation Command raised a requirement for the installation of a radio altimeter reading up to 10,000 feet in a Lysander aircraft which was to be used for calibration of the London anti-aircraft artillery barrage rangefinders. A suitably modified Type 1 was installed but proved to be no more satisfactory than the standard Kollsman aneroid and its use was abandoned. However, flight trials of the Botha installation were conducted in March 1941 when at heights between 150 and 8,000 feet accuracy within 10 per cent was obtained.[1]

Meanwhile, the advantages gained by Coastal Command with the installation in maritime aircraft of A.S.V. were to a great extent being nullified, especially during operations carried out at night, by the limitations of aneroid altimeters.[2] The degree of success achieved, particularly against U-boats, depended very much on the ability to conduct operations at optimum height of A.S.V. However, the atmospheric pressure at the operational area was often less than the pressure obtaining at base at the time of take-off, and if the drop in pressure had not been accurately forecast, the altimeter would indicate a height several hundred feet more than the actual true height of the aircraft above sea level, especially since reasonable calibration errors were bound to exist. Consequently, pilots were naturally apt to fly beneath cloud when the sky was overcast, disregarding the most effective height for A.S.V. performance, because they were unable to trust the altimeter readings sufficiently to descend through cloud to investigate an A.S.V. contact. Even if it were possible to preset altimeters to the correct local barometric pressure and to assume that calibration was accurate, the time-lag on readings during descent, coupled with changes of pressure within and around the cockpit at different speeds, made barometric altimeters unsuitable for such operations.[3] The provision of a direct-reading altimeter, accurate at low altitudes, was important for general A.S.V. reconnaissance purposes and essential for effective anti-U-boat operations carried out in darkness or in poor visibility, especially since the type of weapon in use limited successful attacks to heights between 120 and 500 feet.[4] In February 1941 a detailed specification for an altimeter which was independent of barometric pressure was formulated. It was to indicate, on a meter, heights from 20 to 2,000 feet, and no ambiguity was to occur below 500 feet. Weight

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[1] A.H.B./IIE/247.

[2] *See* Royal Air Force Signals History, Volume VI : 'Radio in Maritime Warfare'.

[3] In January 1943 the Royal Aircraft Establishment successfully completed a series of experiments with various types of maritime aircraft, in which static vent-holes were cut in hulls and fuselages at carefully selected points where pressure inside and outside was enabled to equalise at all speeds. (C.C. File S.7012/13.)

[4] Successful illumination of the target was not achieved until the introduction of the Leigh Light in June 1942.

of the equipment was to be reduced as much as possible, a target figure being 30 pounds exclusive of power supply but including the rotary transformer, which was to be capable of working with a 24-volt battery liable to vary from 21 to 29 volts during use. Power consumption was to be reduced to a minimum, a target figure being 100 watts.[1]

By April 1941 a Radio Altimeter Type 1, modified to indicate heights from 0 to 1,200 feet, had been installed in a Sunderland aircraft. Ground tests were considered to be satisfactory, but flight trials were a failure because the load placed on the aircraft power supply was too heavy. During May 1941 various methods of overcoming the defect were discussed by the Royal Aircraft Establishment, the Standard Telephones and Cables Company, and the aircraft manufacturers. It was eventually decided to provide a separate power supply for the altimeter. In the following month, by which time the operational requirement had become urgent, five altimeters were sent to the aircraft factory for installation on the production lines and ten to No. 10 R.A.A.F. Squadron at Pembroke Dock for installation under squadron arrangements. The aircraft fitted by the firm of Short Brothers were allocated to No. 201 Squadron at Lough Erne, and five aircraft were equipped by No. 10 Squadron. At the end of 1941 nine Radio Altimeters Type 1 were in operational use ; one fitted aircraft of No. 10 Squadron had been lost. The majority worked satisfactorily for short periods only. Their unreliability was mainly due to faulty components and the short working life of the transmitting valves was a permanent source of trouble, whilst a shortage of test equipment increased the difficulties of servicing. Altogether 24 were delivered to the United Kingdom by the Western Electric Company, all manufactured in 1938 and 1939, and four were still in operational use in October 1943.[2]

At about the same time that Headquarters Coastal Command officially stated an operational requirement and produced a detailed specification, the Standard Telephones and Cables Company had begun, as a private venture, investigating the possibility of manufacturing a light-weight radio altimeter of smaller range than the Type 1. A development contract for seven equipments was placed with the firm in February 1941, and the first two experimental models were sent to R.A.F. Pembroke Dock in April 1941. The equipment, eventually known as Radio Altimeter Type 2, comprised two units, one containing the transmitter, receiver, LF amplifier and counter circuits, and the other the power unit. The aerial system was similar to that designed by the Western Electric Company. The altimeter was designed to give readings between 0 and 1,200 feet, and it was estimated that an RF output of 0·25 watts would be adequate, enabling a triode valve type RL.18 to be used as an oscillator. The modulating motor was a modified 24-volt DC camera motor, and a direct feed was used from the transmitter to the mixer stage, which was a balanced diode circuit designed to eliminate amplitude modulation as much as possible. The beat frequency between transmitted and received signals was, after rectification, fed to the frequency counting circuit, which actuated the indicating meter. The LF amplifier and frequency counting circuits were the same as those of Radio Altimeter Type 1, and the Western Electric Company indicating meter, calibrated from 0 to 1,200 feet, was also used.[3]

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[1] M.A.P. File SB.8740.   [2] A.H.B./IIE/247.   [3] A.H.B./IIE/247.

All seven development models differed in detail, and considerable trouble was experienced in keeping them serviceable, mainly because of their many mechanical defects. Set No. 1 could not be made to work satisfactorily in spite of experimental improvements and was returned from Pembroke Dock to the manufacturers for further modification. In August 1941 it was again sent to R.A.F. Pembroke Dock for extended flight trials. Set No. 2, after the incorporation of similar modifications, was given flight trials at the Coastal Command Development Unit in June and July 1941. Set No. 3 was delivered to Gosport late in August 1941 only to be returned to the makers for modification because it could not be made to function. During September it was sent back to Gosport where, at the end of November 1941, it was considered that, although the altimeter contained inaccuracies, if known errors could be eliminated it would be satisfactory for torpedo-dropping operations. Set No. 4 was received by the Royal Aircraft Establishment in September 1941 and, after one month had been spent in making it serviceable, was installed in a Whitley aircraft, the aerials being mounted at a distance of four feet six inches from each other below the starboard mainplane outboard of the engine nacelle. During flight trials the indicated heights were compared with those obtained by means of photographing a ground pattern. Measurement of the pattern, the focal length of the lens, and the photograph, enabled heights to be quite accurately calculated. In November 1941 the establishment reported the radio altimeter to be reasonably accurate. Set No. 5 was sent to R.A.F. Wyton in September 1941 but never operated satisfactorily because of a faulty transmitter and set No. 6, sent to R.A.F. Bircham Newton in November, was never fully tested because height indications were unsteady ; it was however put into use in December but the aircraft was lost on operations. Set No. 7 was sent to Heston in December 1941.

Naturally, in view of the way in which the development models had been distributed and because they were all different in varying degrees, it was not possible to locate and eliminate all their faults, and type approval could not be given to any one model in particular. All that was learnt was that whenever the altimeters did work they went near to fulfilling the specifications laid down, and no production order could be given although Headquarters Coastal Command, in urgent need, recommended production in quantity.[1] However, the manufacturers were sufficiently encouraged to begin making, during the summer of 1941, at their own risk, an additional 40 sets.[2]

Meanwhile the firm of E.M.I. had evolved an altimeter, weighing 75 pounds and consuming about 40 watts, in which interference by ground or sea surfaces with the electrostatic field of a condenser located on the underside of an aircraft gave an indication of height from zero up to a height equivalent to double the wing span of an aircraft. Although such a range was inadequate for maritime reconnaissance aircraft, the altimeter, ultimately known as Radio Altimeter Type 5, showed promise as a direct aid for blind landing, and the possibility that it might make development of a glide path system unnecessary was suggested. Prototypes were given Service trials in May 1941, when accurate height readings were obtained in a Whitley between 0 and 60 feet and in a Wellington between 0 and 120 feet. Type approval was given and by August 1941 an additional 25 development models were being manufactured. At

[1] Coastal Command File CC/S.18401.

[2] T.R.E. File 4/7/23 Part II.

the same time the Telecommunications Research Establishment had begun development of Radio Altimeter Type 4, based on the same principle used in Types 1 and 2 but working on a wavelength of 12·5 centimetres. It weighed about 50 pounds complete with generator and its power consumption was about 100 watts. The altimeter itself was designed to be contained in one standard box measuring 9 by 18 inches, whilst the power supply unit, which could, if required, be the same as that used for Type 2, was housed in a second container. The establishment considered it was essential that power should be supplied from a battery because, when the altimeter was used for blind landing, the engine speed was likely to be too low for satisfactory operation of an engine-driven generator. Since no other valve which could act as a replacement had yet been made, the use of the Standard Telephones and Cables Company valve Type S22A was planned, but modification would be necessary if large-scale production were required. The aerial system envisaged was two six-inch diameter paraboloid mirrors located side by side flush with the aircraft skin, or small Yagis. Two ranges of height were available on the indicator, 0 to 200 feet and 0 to 2,000 feet.

On 26 September 1941 a conference was held at the Air Ministry to discuss the performance of various types of radio altimeter and the possibilities of introduction into Service use. No definite policy had been stated and the Air Staff could not make a decision until the technical aspects and results of trials had been fully considered.[1] There were two main operational requirements; altimeters for specific tactical purposes and altimeters for blind landing. Obviously it would be desirable to produce one instrument to meet both needs and the implications were studied. Blind-landing trials had been carried out with both Type 2 and Type 5. The latter began giving indications of height at approximately 160 feet, and was reliable from 120 feet downwards, whilst with the Type 2 it was reasonable to expect indications down to 25 feet. The conclusions drawn from experience obtained during the trials were that it was necessary for an altimeter to give reliable indications from 100 feet down to a minimum of 5 feet, and that the ideal form of indication was a combination of a sensitive aneroid and a radio altimeter in which the latter indicated 90 feet at the same point as the aneroid indicated 9, with similar comparative indications at lower altitudes. Headquarters Coastal Command enumerated four different requirements for radio altimeters for operations at night against U-boats:—

(*a*) 60 to 1,000 feet for dropping bombs.

(*b*) 50 to 150 feet for dropping depth charges.

(*c*) 50 to 150 feet for dropping torpedoes.

(*d*) 500 to 1,200 feet, and if possible somewhat higher, for Toraplane attack.[2]

The need of Bomber Command was primarily an altimeter suitable for blind landing, but secondary requirements were one suitable for use during mine-laying operations and one which indicated heights from 10,000 feet up to the operational ceiling of bomber aircraft. Fleet Air Arm requirements were similar

[1] A.H.B./IIH/241/3/209. Radio Altimeters, Operational Aspect.

[2] A.H.B./IIH/241/3/209. The Toraplane was a naval 18-inch torpedo, fitted with stub wings and tail fins, which on release glided towards the target in the air, and on entry into water behaved like a normal torpedo. For further details *see* A.H.B. Narrative, 'The R.A.F. in Maritime War'. .

to those of Coastal Command but also included specifications for minelaying, minesweeping, and blind landing. Height indications were required from 20 to 1,200 feet with two scales, one from 20 to 200 feet and one from 1,000 to 1,200 feet with 'hold-off' at 2,200 feet.[1] It was of paramount importance that size and weight should be reduced to a minimum. At the time there was no demand for radio altimeters in Fighter Command, and it was not until May 1943 that an official requirement was raised for an installation to be made in Beaufighter night-fighter aircraft in order to exploit to the greatest possible extent the advantages conferred by centimetric A.I. for interceptions at low altitudes over the sea.[2] Then American altimeters AYD and AYF were being introduced into the Service.

The meeting agreed that Radio Altimeter Type 5 was suitable for blind-landing purposes when fitted in aircraft of the same size as, or larger than, the Wellington, but would not be satisfactory for smaller aircraft because the maximum height indications would be inadequate. However, no other altimeter with the required performance was in a sufficiently advanced stage of development, and the need was urgent, especially since it was very important that pilots of operational bomber aircraft should be able to make blind landings during the winter months. With the expansion of the bomber force the problem of landing large numbers of aircraft was likely to become acute. In addition to the inherent difficulties of controlling large concentrations of aircraft, the emergencies likely to be created by bad weather and enemy intruder aircraft had to be borne in mind, and it was possible that completely blind landings might become the general rule. Consequently, recommendations for the accelerated production of Type 5 were made, although work on the development of an effective glide path indicator was to be continued in order that comparative trials might be held.[3]

Headquarters Coastal Command stated that Radio Altimeter Type 2 met the requirement of maritime aircraft, but expressed a preference for the indicator scales specified for the Fleet Air Arm. A contract was placed with the Standard Telephones and Cables Company for the 40 models which the firm had already started making by hand in its model-shop, which had only a limited output capacity. The drawings which had been completed made it possible, however, for the firm to pass manufacturing information to other contractors if and when required. At the best of times model-shop production was not very effective but difficulties were increased by an inability to obtain an adequate supply of the special small Pullins camera motors and Mortley Sprague rotary converters, and it was essential that there should be complete agreement on the design of such components before quantity production could be established. The Mullard RL18 valve was difficult to manufacture, and the other two types of valve used could be obtained only from the United States of America.

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[1] When an aircraft climbed above the height which was the maximum indicated on the meter of a radio altimeter, the indicating needle stayed hard over against the stop at the top of the scale until, as the aircraft continued to climb, it reached an altitude where the needle began to fall back on the scale. The point at which it occurred was known as the 'hold-off' height, and was the point at which the wave reflected from the ground became so weak that it failed to operate the receiver. Hence 'hold-off' was an indication of the 'strength' of the transmitter and receiver and gave a margin of readings which measured the ability of a given installation to cope with varying sets.

[2] A.M. File CS.19991. *See* Royal Air Force Signals History, Volume V: 'Fighter Control and Interception', for details of A.I.

[3] A.H.B./IIH/241/3/209.

Although the altimeter circuits appeared to be satisfactory, mechanical defects, faults in the aerial feeder system, and the question of the provision of test equipment had to be cleared. The first model was delivered on 17 February 1942 to the Royal Aircraft Establishment, where it was closely examined and tested. As a result, a number of modifications were agreed with the manufacturers. It was apparent that if the required accuracy was to be obtained in spite of the variations of supply voltage a carbon pile voltage regulator would be required. The voltage variation on all types of aircraft had presented a problem, to which no satisfactory solution had been found, for some years. Undoubtedly the introduction of carbon pile regulators with each piece of radio equipment in an aircraft eased the situation and overcame many of the difficulties but it was rapidly becoming essential to tackle the problem at its source, a project which had been on only very low priority at the Royal Aircraft Establishment for a long time. The Air Staff decided to give the task very high priority.[1] Arrangements were made for a representative of the Royal Aircraft Establishment to inspect every altimeter Type 2 before it left the contractor's factory, and provisional type approval was given on 28 February 1942.

Although further development was officially encouraged, production orders were limited because the intention was to use Type 2 only until Type 4 was ready for introduction in adequate quantity. The Air Staff requirement had been clarified to some extent. For Bomber Command the primary need was an effective blind-landing system ; a requirement existed for both a glide path indicator and a radio altimeter. The glide path indicator was given the higher priority because preliminary trials had shown it to be the preferable method, but an altimeter reading down to 5 feet was acceptable as an interim measure. It was apparent, however, that radio altimeters would not be available for general use during the winter of 1941/1942, and Headquarters Bomber Command therefore officially requested that all heavy-bomber aircraft be provided with Type 5 during the winter 1942/1943, and stated that the lack of a suitable radio altimeter for Wellington aircraft would be accepted until Type 4 became available some time late in 1943. Radio Altimeter Type 5 was also made a requirement for torpedo-dropping aircraft based in the Middle East. For Coastal Command the primary and immediate requirement was for an altimeter reading from 50 to 1,500 feet, and a glide path system was a secondary need. Although Type 4 was considered to be preferable, Type 2 was acceptable in its existing form in view of the urgency of the requirement.[2]

A contract to develop Type 4 for production had been placed with the Standard Telephones and Cables Company in November 1941, and the firm thought that development would take at least one year, to which a period for tooling-up had to be added. It was considered that the best the same firm could do in delivery of Type 2 was 10 sets in June 1942, 15 in July and 20 in August and each month thereafter. If the altimeter was required in larger quantities for operational use until Type 4 was generally introduced it would be necessary to place orders quickly with additional contractors, since the development of a production prototype of Type 4 would be retarded if the firm was required to increase output of Type 2. In February 1942 the Air Ministry was advised by the Chief Technical Executive of the Ministry of

[1] A.M. File CS.15245.

[2] T.R.E. File 4/7/23.

Aircraft Production, Sir Frank Smith, to raise a requisition for 1,500 Type 2 altimeters, of which 200 were to be manufactured, by semi-tooled methods, at the Standard Telephones and Cables Company, 500 were to be obtained from the United States of America, and 800 from other contractors in the United Kingdom.[1] The British Air Commission was informed of the requirement for Radio Altimeters Type 2 and Type 4, and was given all the necessary technical data. Investigations were made of the possibility of manufacturing Type 5 in the United Kingdom at the rate of 300 per month.

The first delivery of Radio Altimeter Type 2 was made in June 1942 when eight were sent to the Coastal Command Development Unit for installation and flight trials in Wellington aircraft, and the production situation was then reviewed. 100 sets were being made by the Standard Telephones and Cables Company under model-shop production arrangements, and the output was expected to be 10 in October, 20 in November, and thereafter 20 per month until completion of the contract. An additional 100 sets were also to be made in the model-shops of Radio Transmission Equipment Limited, who expected to deliver 10 in November and 60 in December, a partially-tooled basis of production being employed. No contract had been placed in the United States of America ; the remaining 1,300 were to be made up by 500 from the Standard Telephones and Cables Company, and 800 from Radio Transmission Equipment Limited, at the rate of 60 per month from January 1943 onwards. No further modifications were to be incorporated unless they were essential and did not delay production ; since the total requirement was only 1,500, mass production methods were not practicable. Although the development contract for altimeters Type 4 had been placed over six months previously, no sets had been received from the makers, who were unable to promise that deliveries would begin before August 1942. The importance of ensuring rapid and adequate production in quantity of Type 4 before even considering the possibility of terminating contracts for either Type 2 or Type 5 was strongly emphasised. Because there were but few firms with the necessary laboratory and workshop facilities the development contract could not reasonably be transferred from the Standard Telephones and Cables Company, but plans were made for placing quantity production contracts elsewhere. Although originally the Air Staff was given to understand that output of altimeters Type 5 was expected to begin in or about March 1942, a production contract was not placed until June 1942, when an order for 8,000 sets was given to the Gramophone Company, who promised to begin delivery at the rate of 25 per week in November, rising to 250 per week by about April 1943. The delay made it necessary to hasten the proposed installation programmes by the provision of an additional supply of electrodes and transformers, so that aircraft could be modified whilst on the assembly lines, thus very much simplifying the task of installation when eventually the altimeters became available.[2]

Although the degree of efficiency of altimeters Type 2 was still an unknown quantity, as many as possible were required urgently for aircraft of Coastal Command, and in view of the importance of radio altimeters for anti-U-boat operations, priority of installation was decided as Leigh Light Wellingtons, Leigh Light Catalinas, other types of aircraft fitted with the Leigh Light, Sunderlands, Whitleys, and Catalinas. Of the first eight models received by

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[1] T.R.E. File 4/7/23 Part II.

[2] A.M. File CS.15245.

the Coastal Command Development Unit only four could be made serviceable because of faulty and incorrect wiring. All four were inaccurate below 200 feet and were sent to the Royal Aircraft Establishment for modifications, mainly to the LF amplifier circuit. They were then returned to the development unit, and flight, as distinct from Service, trials, were concluded in mid-August 1942. Although on some particular flights performance of the altimeters was within acceptable tolerances, they were generally unreliable, largely owing to inferior mechanical design and workmanship. It was doubtful if any of the first 40 models would be satisfactory, and, at the suggestion of the Standard Telephones and Cables Company it was decided that, as work on them had progressed too far for further modifications, although known to be desirable, to be incorporated, the contract should be abandoned, and all modifications included in the remainder of the sets on order. The original design had continually been revised, and in order to achieve some degree of stabilisation it was agreed that the Royal Aircraft Establishment would try to give final type approval to 20 models which the firm intended to complete at the end of the year.

Five modified models were received by the Royal Aircraft Establishment in January 1943, and they were all unserviceable, a total of 35 different faults being discovered.[1] Four were eventually made serviceable and sent to the Coastal Command Development Unit for installation in Wellingtons. Three installations were completed, and flight trials were started, whilst main production was suspended at both manufacturers until tests of the first 20 models made by each had been fully and satisfactorily tested. Trials of the Standard Telephones and Cables Company models indicated that there was but little promise of an efficient altimeter Type 2 being produced within a reasonable time. It was clear that even more development was required before main production could be restarted. Although trials of the apparently superior Radio Transmission Equipment Limited version had not been completed, it was extremely doubtful whether the Royal Aircraft Establishment would be able to recommend the design for further production, and, with the advent of Type AYF, in July 1943 contracts for the manufacture of Radio Altimeters Type 2 were cancelled.[2]

The failure of the Type 2 altimeter project emphasised the vital need for an early stabilisation of design if rapid production in quantity was to be achieved. Many difficulties had been encountered by the manufacturers, and they had an adverse effect on the development of Radio Altimeter Type 4. There was a general shortage of skilled labour, and suitable training of unskilled labour took at least six months. Valve production presented a big problem. Many of the valves required for radio altimeters were difficult to make, and the capacity for valve production was, at the time, badly strained. The capacity of the valve industry in January 1941 for receiver type valves was about 11,800,000, and for other types of valve, about 280,000, per year.[3] By the end of 1941 it had been increased to 19,300,000 and 1,000,000. The extent of the expansion of the valve industry was indicated by the fact that new projects in connection with it approved in 1941 totalled in value about £2,450,000. Of that amount £45,000 had been allocated for receiver valve capacity, and the remainder for transmitter and special valves ; no less than £1,500,000 for special valves alone. Only about £100,000 was spent on

[1] A.H.B./IIE/247. [2] A.M. File CS.15245. [3] T.R.E. File 4/7/23 Part II.

buildings, the rest being required for the provision and erection of plant. In the United Kingdom the valve companies designed and made the plant themselves, with the assistance of a few small firms. Difficulty was experienced in getting the companies to undertake such large expansion projects as they were mostly of the opinion that such undertakings were too much for them to handle. Plans had been made to obtain half the required plant from the United States of America, but that country's entry into the war deferred realisation of the plans for some time, and made it impracticable for either the required valves or the complete equipments to be manufactured there.

By June 1942 over one thousand production drawings had been completed for the Type 4 altimeter, and the design of the main production prototype was nearing completion. In view of the many difficulties, including that of finding a manufacturing firm able to accept a production contract, a decision on the production of Type 4 in quantity was deferred until completion of the trials of Type 2 in July and August 1942. By then, of the 24 development models being made, one was ready for flight trials, but no power unit was available. Workmanship had been improved and the results of ground tests were promising, and at the end of August 1942 two models were sent to the Royal Aircraft Establishment. Arrangements had been made that trials should be conducted with the first 12 models whilst changes, resulting in simplification and standardisation, should be incorporated in the second 12 models, which were to be prototypes for mass production.[1] Results of the flight tests undertaken at the Royal Aircraft Establishment quickly showed that the altimeters were unsatisfactory. There was considerable needle fluctuation, especially above 1,000 feet, and the models were unreliable below 150 feet when the 0 to 1,500 feet scale was used, although they were accurate down to 5 feet when the 0 to 150 feet scale was in use. Obviously immediate production was out of the question although further research and development were thought to be justified. The Standard Telephones and Cables Company was instructed to suspend temporarily further work on the Type 4 altimeter project in order that more effort might be concentrated on the production of a satisfactory Radio Altimeter Type 2. The firm delivered three assembled but unwired models to the Telecommunications Research Establishment where they were completed for installation by the Coastal Command Development Unit in Wellingtons for Service trials. Two installations rapidly became unserviceable, but with the third accurate readings were obtained on the low range, as had been found at the Royal Aircraft Establishment. On the high range readings were accurate up to 500 feet after which performance deteriorated, and the set was returned to the Telecommunications Research Establishment for further development. By March 1943 reasonably good results were being obtained, and arrangements were made for trials to be carried out by the Telecommunications Flying Unit who, in April 1943, reported very favourably on the results. However, delivery of altimeters from the United States of America had begun and the Air Ministry decided that production in quantity of Type 4 altimeters was no longer a requirement ; development was to be completed, but on low priority, as an insurance against failure of the American instruments.

Meanwhile unexpected difficulties had been encountered with the introduction into the Service of Radio Altimeter Type 5. In July 1942 the Royal Aircraft

[1] A.M. File CS.15245.

Establishment began experiments to determine whether Monica and radio altimeters could be installed together in an aircraft. It was found that the close proximity of the Type 5 altimeter electrode caused the Monica radiation pattern to be distorted, and in order to eliminate the interference it would be necessary to modify considerably the electrodes and connectors of the altimeters, thereby delaying production by some months. In view of the successful development and use of glide path indicators, and the weight and drag factors imposed by the installation of radio altimeters, the operational requirement for heavy bombers was cancelled in May 1943. 350 sets, enough to meet the immediate needs in the Middle East, had been delivered from the contractors by March, and it had been agreed that production should be maintained at a reduced rate of 100 per month to continue the installation programme for Wellingtons allotted to the Middle East Command. However, production at such a rate proved to be an impracticable proposition, so in May 1943 it was decided that a higher rate should be maintained until 1,750 sets had been delivered, and the requirement for the outstanding balance of the order for 8,000 was cancelled.[1]

To meet the requirements of the Fleet Air Arm, the Standard Telephones and Cables Company was asked in November 1941 to develop a light-weight version of Radio Altimeter Type 2. Two designs were completed and a prototype of each was delivered to the Royal Aircraft Establishment in March 1942 for type approval tests. Because they were mechanically unsound they were rejected. The contractors submitted modified models in September 1942, when flight tests were satisfactory. As a result the Royal Aircraft Establishment and the manufacturers together evolved a design which became known as Radio Altimeter Type 3, and in which it was hoped to overcome the defects of Type 2. In October 1942 a development contract for 12 models was placed with the firm, and delivery to the Royal Aircraft Establishment began in June 1943. Two were installed in Albacore aircraft for trials at the Telecommunications Flying Unit and one in a Wellington for trials at the Coastal Command Development Unit. Reports from the Royal Aircraft Establishment indicated that the altimeters were superior in reliability and workmanship to the Type 2, and they appeared to be accurate. However, before any decision to arrange production was made, considerably more detailed information was required. Experience had shown that not only were thorough Service trials a necessity, but also a thorough assessment of the suitability of the instruments for quantity production methods. Reports of the Service trials, which were continued by the Fleet Air Arm as well as the Royal Air Force until October 1943, were encouraging, but as the Type 3 altimeter was not outstandingly superior to the altimeters being received from the United States of America, production in quantity was not ordered.

Research and development of radio altimeters based on pulse and frequency change principles had continuously been pursued in the United States of America, especially in the laboratories of the Radio Corporation of America, and the progress achieved was carefully studied by the British Air Commission, which was kept fully informed of the operational requirements of the Royal Air Force and the Fleet Air Arm. Orders were placed for development models of the R.C.A. altimeters in November 1941, and in the summer of 1942 the British Air Commission approached the Munitions Assignment Board for an allocation

[1] A.M. File CS.15245.

of AYD and AYF altimeters. The knowledge and experience gained during the processes of development and trials in the United Kingdom were utilised when the British Air Commission, through the Joint Radio Board, formulated a common requirement and specification acceptable to all the Services of both countries.

Procurement and Trials of AYB, AYD and AYF Altimeters

An experimental model of the R.C.A. altimeter, known as Type AYB, was flight-tested successfully in the U.S.A. on 17 November 1941. The first engineered version of the AYB altimeter was lent to the British Air Commission by the United States Navy, who were convinced of the paramount importance of the operational requirement for a radio altimeter to be used in conjunction with A.S.V. and the Leigh Light, and was taken to the United Kingdom in September 1942 by Dr. A. G. Touch. Within one week the altimeter had successfully passed all the tests imposed by the R.A.E. It provided satisfactory readings between about 15 and 400 feet, its power consumption was low, and its weight, including cabling, was only 26 pounds. The B.A.C. was instructed to arrange for an allocation from production, and by April 1943 nearly 350 had been delivered to Fort Worth for installation in Liberators, and 12 to the United Kingdom. Meanwhile, an important engineering aspect of altimeter installation had been settled. It was the practice in the U.S.A. to earth the negative side of the battery in the aircraft, whilst in the United Kingdom a system of twin wires, both insulated from the airframe, was employed. When, initially, AYB and AYD altimeters were accepted for installation in American aircraft the difference did not matter, but when installation in British aircraft was projected, an agreement became necessary, and eventually the Ministry of Aircraft Production accepted the American principle, which was still standard British practice at the end of the war.[1] Production of AYD was estimated as 300 in April, 400 in May, and 500 in June 1943, when delivery to the United Kingdom was expected to begin. In March 1943 a hand-made model of AYF was sent to the United Kingdom. It provided readings between 0 and 400 feet and 0 and 4,000 feet, operated on a frequency of 420 megacycles per second, contained a limit height indicator, was suitable for controlling an automatic pilot, and weighed about 25 pounds. A production model was tested at the R.A.E. in November 1943, and several recommendations for modification were made, including reduction of the maximum height indication to 2,000 feet, a change of modulation frequency from 120 to 80 cycles on switching from low range to high range, and reduction of the transmitter coupling so that half of the available transmitter power was fed into the aerial. It was considered that incorporation of the modifications would considerably reduce errors.

By November 1943 the R.A.E. had completed flight tests of trial installations of AYD in 16 types of aircraft; Wellington Marks XI and XII, Beaufighter, Fulmar, Barracuda, Swordfish, Albacore, Firefly, Lancaster, Halifax, Catalina, Sunderland, Mosquito, Hampden, Liberator and Hudson. At first the R.A.E. attempted to follow the installation methods recommended by the R.C.A. and the United States Navy, particularly for positioning of aerials, but results were unsatisfactory until aerials were mounted on the tailplane, when performance was very satisfactory, error amounting to no more than 5 per cent over the

[1] AYD was a production version of AYB modified so that it was suitable for controlling an automatic pilot.

whole range.[1] The great advantage of the tail installation lay in the fact that there was no possible source of spurious coupling between aerials caused by reflection from the airframe.

By January 1944 400 AYD altimeters had been received in the United Kingdom, but by the end of April 1944 the manufacture and supply of AYD had ceased, and in the following month it was decided that, as stocks of AYD were inadequate to meet existing R.A.F. requirements, AYF altimeters were to be installed, for use on low range only, in all types of aircraft other than the Wellington, for which the stocks of AYD were reserved.[2] AYD and AYF both consisted of transmitter/receiver, aerial, limit switch, and connector units, and altitude indicator unit. The aerial, limit switch, and connector units were interchangeable both physically and electrically, and the transmitter/receiver units were interchangeable physically. The altitude indicator units were not physically interchangeable because the methods of mounting were different, but an AYD meter could be used with an AYF transmitter/receiver, and an AYF meter with an AYD transmitter/receiver, to give satisfactory results over the 0 to 400 feet range. An Air Staff requirement was stated for installation of radio altimeters in all general reconnaissance, fighter reconnaissance, torpedo-bomber, air/sea rescue and meteorological aircraft of Coastal Command; in Mosquito night-fighter aircraft of A.D.G.B. and A.E.A.F. ; in night-fighter aircraft equipped with centimetric radar, and torpedo-bomber, rocket projectile and Leigh Light-equipped aircraft of the Mediterranean Allied Air Force ; aircraft of Flying Training Command ; and five squadrons of Transport Command.[3] Future requirements were anticipated to be installations in intruder aircraft of A.E.A.F. and Bomber Command, and in all maritime aircraft based in A.C.S.E.A. and West Africa.

Because of technical difficulties an AYF installation programme was not begun until July 1944 and was further delayed by the absence of test gear, production of which fell seriously behind schedule. The lack of test gear not only caused delay, but prevented the use of completed installations. In September 1944 the R.A.E. completed trials of 74 installations. Results indicated that, given correct operating conditions, normal maximum errors would fall within limits of plus or minus 60 feet plus or minus 10 per cent above 1,000 feet, and plus or minus 60 feet plus 37 per cent and minus 10 feet below 1,000 feet, on the high range, and plus or minus 6 feet plus or minus 10 per cent above 50 feet on the low range.[4] It was therefore decided that when AYF replaced an AYD installation only the low range was to be used and slight modifications were introduced to prevent use of the high range and to bring its performance into line with that of AYD. Both AYD and AYF provided inaccurate readings below 50 feet and consequently their use for landings was dangerous, and the high range of AYF was considered to be unsafe. Main force aircraft of Bomber Command were not therefore included in the installation programme, which was restricted to special duty and maritime reconnaissance aircraft, and to night fighters to facilitate interceptions over the sea at low altitude. In December 1944 the R.A.E. experimented with AYF to ascertain whether it could be safely used from 1,000 to 4,000 feet, and subsequently considered that, with aerials spaced 10 feet apart it could be safely used by maritime reconnaissance and night-fighter aircraft, but only when over the sea.

[1] A.M. File CS.19648. [2] A.M. File CS.21402.

[3] The remainder of aircraft used by Transport Command were equipped with altimeters in the U.S.A. [4] A.M. File CS.22905.

Consequently, when permission was requested to install AYF in pathfinder aircraft of M.A.A.F., it was granted only with the limiting conditions that the altimeter readings were to be used solely when aircraft broke through cloud over areas of sea, and never over land.

Installation of AYD and AYF in R.A.F. Aircraft

An AYD installation programme for Wellingtons of Coastal Command was begun in July 1943 by five fitting parties of No. 26 Group, a start being made with Nos. 172, 407 and 612 Squadrons.[1] By the end of March 1944 retrospective fitting in those squadrons and Wellingtons of Nos. 179 and 304 Squadrons, Beaufighters of Nos. 144 and 254 Squadrons, and Halifaxes of Nos. 518 and 520 Squadrons, had been completed, whilst the Liberators of Nos. 53, 59, 120, 224, 311 and 547 Squadrons had been equipped in the U.S.A. Progress was being made with installations, on high priority, in Catalinas of No. 210 Squadron, Halifaxes of Nos. 58, 502 and 517 Squadrons, and Sunderlands of Nos. 10, 228 and 461 Squadrons, and a programme on low priority for 19 other squadrons, and for operational training units, was planned.[2] However, the operations to be undertaken for the projected liberation of Europe necessitated the provision of radio altimeters in all aircraft of Coastal Command, and every endeavour was made to introduce aircraft production-line installation as rapidly as possible, and the number of fitting parties was increased.[3]

Until April 1943 there was no requirement for the provision of radio altimeters in fighter aircraft, but then a requirement for a trial installation of Radio Altimeter Type 4 in a Beaufighter night-fighter aircraft was stated in order that the possibility of extending even further the advantages conferred by centimetric A.I. for low-altitude interceptions over the sea might be investigated. Great difficulty was being experienced in intercepting enemy aircraft engaged on minelaying and maritime reconnaissance duties at night because they were operating at very low heights, and the standard barometric altimeters were unsuitable for safe use below 100 feet. As it had been decided not to proceed with the production of Type 4 altimeters, and in view of the fact that Coastal Command Beaufighters were able to operate safely down to within 50 feet of the sea when equipped with AYD, trial installations of AYD in night-fighter aircraft were arranged. Headquarters Fighter Command stressed that an assessment of the merits of the radio altimeter as such was not required; the object of the trials was the determination of its value as an aid to successful interception. Preliminary trials of an AYD installation in a Mosquito XII were carried out by crews of the Fighter Interception Unit, who used it for operational patrols. They considered that the radio altimeter was a valuable addition to the equipment of night-fighter aircraft; it gave pilots the necessary confidence to dive to and fly at low altitudes over the sea at night for the interception of minelaying aircraft and for intruder sorties.[4] In August 1943, therefore, Headquarters Fighter Command requested that thorough Service

[1] A.M. File CS.19648. Headquarters No. 43 Group assumed responsibility for retrospective installation in aircraft of Coastal Command in June 1944. (A.M. File C.16146/44.)

[2] A.M. File CS.21403.

[3] In addition to the comprehensive fitting of Coastal Command aircraft, in April 1945 AYF and AYD altimeters were in use in many aircraft of other commands, including over 100 Mosquitos of the Tactical Air Force, over 200 Mosquitos of Fighter Command, over 350 Dakotas and 350 Liberators of A.C.S.E.A., about 50 Mosquitos, 150 Liberators and 15 Wellingtons of M.A.A.F., about 180 Mosquitos and 20 Lancasters of Bomber Command, and about 50 Wellingtons and 40 Liberators of R.A.F. Middle East.

[4] F.I.U. Report No. 213.

trials of AYD and AYF should be arranged ; it was not then possible to express a precise operational requirement, but installation of AYD or AYF in six night-fighter and six intruder Mosquito aircraft was suggested. A prototype trial installation was made by the R.A.E., during the process of which several technical problems were encountered, chief among them being the need to remove some other equipment in order that adequate space might be provided. Eventually it was decided that the rate-of-climb indicator should be removed, and successful flight tests of the installation were made in December 1943. Operational trials were continued during the first few months of 1944, and as a result Headquarters Air Defence of Great Britain stated an operational requirement for the installation of AYD, in its existing form, in all night-fighter aircraft likely to be engaged on low flying over the sea at night. Its provision in intruders was not a requirement since it did not fulfil the need for accurate readings between 0 and 4,000 feet ; intruder aircraft did not always approach enemy coastline at low altitude but were often forced by bad weather to fly at above 10,000 feet until the target area was reached, when height had to be lost rapidly.[1]

When the role of night-fighter aircraft in the Normandy operations was planned it was decided that one of the major problems likely to be met in the defence at night of shipping in the operational area would be the interception of torpedo-bombers at very low altitudes. It was known that anti-shipping aircraft of the *Luftwaffe* were equipped with an efficient radio altimeter which enabled pilots to fly with confidence as low as 50 feet above the sea even in complete darkness. Dependence on aneroid altimeters in similar conditions was believed to have been the cause of many casualties in the R.A.F., and of many failures to destroy enemy aircraft. In view of the shortage of supplies and the installation priority accorded aircraft of Coastal Command and the Fleet Air Arm, it was decided that one squadron, No. 604, of Mosquito XIII aircraft should be equipped as an urgent requirement and should be given special training in low-level interceptions. Arrangements were made for a special fitting programme, and by 7 May 1944 the first installation had been completed ; the operational requirement was increased to installations in nine night-fighter squadrons.

In July 1943 it was agreed that a radio altimeter providing accurate readings between 0 and 600 feet was a requirement for aircraft used for dropping paratroopers, and the possibility of modifying AYF so that the 0 to 400 feet range was extended to provide accurate readings at 600 feet was considered. The Air Ministry was disinclined to authorise such a modification unless it was operationally essential and proposed that trials should be conducted with AYD. However, in the following month it was reported that the modification entailed to make AYF provide readings from 0 to 800 feet was negligible, consisting mainly of a readjustment of the frequency sweep during the process of lining-up ; similar modification of AYD was not feasible because, although the range was increased, the hold-off height was comparable with the maximum reading. The possibility of effectively modifying AYF was investigated by the R.A.E., the only model in the United Kingdom, the R.C.A. experimental version, being used for the tests. Flight trials revealed that the altimeter could be made to function satisfactorily from 0 to 800 feet ; a reasonable maximum error to be expected was plus or minus 5 per cent with additional errors of plus or minus

[1] A.M. File CS.19991.

12 feet. Considerable controversy regarding the practicability of modification ensued. The manufacturers could not be expected to upset the planned production programme in order to incorporate the change, and retrospective modification in the United Kingdom involved dismantling the equipment in order that the indicator dial might be repainted ; a process which entailed recalibration. However, experiments revealed that retrospective modification was feasible, although if large numbers were involved the work would have to be carried out by a firm of instrument makers rather than by unit personnel. In January 1944 flight trials of a modified AYF installation in an Albemarle aircraft were considered to be satisfactory, and Headquarters Transport Command stated a requirement for the installation of suitably modified altimeters in 150 Dakota aircraft. In April 1945 270 Dakotas in service with Transport Command were equipped with modified AYF and 50 Stirlings with modified AYD.

Specifications for British Altimeters, 1944

Specifications for British altimeters to be developed in the United Kingdom, based on the experience gained with AYD and AYF, were discussed at the Air Ministry on 23 August 1944.[1] AYD and AYF altimeters provided facilities otherwise unobtainable but would not meet future requirements, and complete dependence on development and production in the U.S.A. was undesirable. Specifications were formulated for two types of altimeter, one, employing frequency modulation, for use up to 5,000 feet, and another, employing pulse modulation, for use from 800 to 50,000 feet. The first was required for installation in aircraft engaged on low-level bombing, torpedo and rocket projectile attacks, parachute dropping, mine-laying, night fighting, and routine flights in poor visibility. Two ranges were required, 0 to 1,000 and 0 to 5,000 feet, with a maximum fixed error of plus or minus 3 feet and maximum additional general error of plus or minus 2 per cent on the low scale, and a maximum fixed error of plus or minus 15 feet and maximum additional general error of plus or minus 15 per cent on the high scale. Indication was to be provided on a single meter inscribed with graduations increasing in separation towards the lower end of the scale. The installation was to include an optical warning system by means of which a pilot would be able to preselect a critical height and be informed, by a simple light code, when he was just above, just below, or precisely at that height. Weight was not to exceed 20 pounds. The second altimeter was required for installation in aircraft engaged on high-level and high dive-bombing, meteorological flights, photography, and night fighting, and for navigation generally. The range required was from 80 to 50,000 feet, with a maximum error of plus or minus 30 per cent, and stability within plus or minus 30 feet over a period of 10 minutes. Indication was to be provided on a cathode ray tube. A critical height indicator, auxiliary to the main equipment and detachable if not wanted, was to be provided for use in high dive-bombing operations. Weight was not to exceed 35 pounds. Both altimeters were to be interchangeable to the maximum extent possible.[2]

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[1] A.M. File CS.22904.

[2] Flight trials were carried out at the R.A.E. in November 1943 of another radio altimeter developed in the U.S.A., SCR.718. It was designed to provide readings between 300 and 40,000 feet with a maximum error of plus or minus 50 feet plus or minus ¼ per cent. The transmitter and superheterodyne receiver were housed in one container, operated on 440 megacycles per second, and weighed about 9½ pounds. Indications were presented on a cathode ray oscilloscope with a circular time-base, the unit weighing about 10 pounds ; total weight of the installation was about 35 pounds. (A.M. File CS.21403.)

CHAPTER 16

STANDARD BEAM APPROACH, RADIO TRACK GUIDES AND V.H.F. BEAM APPROACH

The earliest experiments in blind landing were carried out in the U.S.A. in 1929 when a demonstration of a completely hooded flight, from take-off to landing, was given. A beam system was used and further development was undertaken in the U.S.A. by the Bureau of Standards. The radio equipment operated on frequencies of 200 to 400 kilocycles per second, which were reserved in the U.S.A. for air navigation radio. In Europe, however, those frequencies were utilised for broadcast stations, and when experimental work was begun in Germany frequencies of 30 megacycles per second and above were employed. The German system was installed at Tempelhof airport and was demonstrated to British representatives of the Royal Aircraft Establishment and civil aviation. The *Lorenz* Company invested a considerable amount of money in development and the system was eventually produced by them for commercial use. By 1936 it was being widely used by European civil airlines as an aid to blind landing. Meanwhile the Hegenberger system, in which a radio compass was used, was being developed in the U.S.A. During this period no research or development was being undertaken in the United Kingdom although a Fog Landing Panel at the R.A.E. received and studied reports of systems being developed abroad. In 1935 the Air Ministry made arrangements for experiments to be conducted at the R.A.E. with the Hegenberger system and purchased two sets of equipment. Before their installation was completed the Air Ministry accepted an offer made by the firm of Standard Telephones and Cables to provide, free of charge, a portable military version of the German equipment for trials.[1]

The *Lorenz* beacon blind-landing system consisted of both ground and aircraft radio equipment. The ground equipment comprised a main beacon transmitter and two smaller beacon transmitters. The main transmitter operated on about 33 megacycles per second to energise a special aerial system which laid down the necessary track. It was sited on the extreme edge of an airfield and projected an equi-signal zone of 4 degrees width across it to a range of approximately 20 miles at 1,500 feet. The aerial system of the main beacon could be lined up on any desired bearing, the one chosen being that which gave the minimum of obstructions along the centre of the beam. It was necessary to inform the pilot of the bearing before a landing was attempted. The two small auxiliary marker beacon transmitters and aerial systems were installed along the line of approach, the inner one usually being sited at the opposite end of the airfield from the main beacon and the outer one about 3,000 yards further out; they operated on 35 megacycles per second. The aircraft installation consisted of a receiver, weighing about 80 pounds, a fixed vertical aerial, and a marker beacon aerial.

[1] The firm was the agent in the United Kingdom for the *Lorenz* Company. Both were controlled by the International Telephone and Telegraph Company of New York. (A.M. File 445921/35.)

There were three phases in *Lorenz* approach procedure. In the first the aircraft was navigated, either by dead-reckoning or with the assistance of wireless direction-finding, to the vicinity of the beam, usually to a point about 15 miles from the airfield. Then the approach was begun. The pilot was given aural and visual indications of his position in relation to the centre of the beam no matter what his heading. Indication of his distance from the airfield was furnished by the marker beacons, the transmissions of which were radiated vertically and were received aurally or visually. Two neon lights, mounted on the instrument panel, glowed when the aircraft passed directly above the appropriate marker. When he was flying along the centre of the beam the pilot received a steady signal ; when he was to port dots were received, and the reception of dashes indicated deviation to starboard. Also, visual indications were displayed on a meter, the pointer of which ' kicked ' to port or starboard as the aircraft deviated from the beam, and remained stationary when the pilot was flying along the correct path. A glide path indicator was provided to give information of height, but proved to be inadequate unless approaches were being made over completely flat terrain.[1] The third phase was the actual touch-down.

Pre-war Development of *Lorenz* in the United Kingdom

Preliminary work was undertaken by the R.A.E. in the early months of 1936 for trials of the *Lorenz* equipment to be held in May. The airfield at Abingdon was chosen for them because that at Farnborough was considered to be unsuitable for the practice of blind approaches, and they were carried out simultaneously with trials of the Hegenberger system.[2] The aircraft used were twin-engined Monospar S.T.25, two of which were specially obtained for the trials. They were equipped with Sperry blind-flying instruments, sensitive Kollsman altimeters, and rate of ascent meters ; all ignition and electrical services were fully bonded and screened. The trials were prolonged because delays had been caused through a series of technical troubles and faults in the tuning up and maintenance of the equipment ; some difficulties were caused by lack of previous experience but others were attributable to faults in design. At one stage of the trials the aircraft equipped with *Lorenz* was flown to the civil airport at Heston so that approaches could be made there, and the pilot was accompanied by a representative of the firm of Standard Telephones and Cables. Approximately 30 approaches were made with *Lorenz*, of which eight in the early stages were failures, mainly due to lack of experience on the part of the pilot. On the whole the approaches were very successful and in about 70 per cent of flights the approach procedure ended in a successful landing, the pilot still being hooded.[3] At the end of July 1936 senior officers from the Air Ministry, Bomber, Fighter, Training and Coastal Commands inspected the Hegenberger and *Lorenz* systems and were given demonstrations of blind approach flying.

The *Lorenz* system contained certain disadvantages. It had not the homing property of the Hegenberger system, for pilots had to locate the beam in the first instance by other navigational means. Also, in the early development stages, no information was available of the direction in which an aircraft was heading other than that it was on the beam. The glide path indicator was

[1] A.H.B./IIE/228. Blind landing. [2] A.M. File 445921/35. [3] A.H.B./IIE/228.

definitely unreliable and further research and development were needed. The advantages of the system appeared to outweigh the disadvantages, a main one being that it could be introduced into the Royal Air Force quickly because it required very few alterations, and the chief one being its manufacture with British components. The Hegenberger system required considerable development to fit it for Service use and as it was an M.F. system the radio compass suffered from interference. A further advantage lay in the confidence likely to be produced by the *Lorenz* track system; pilots would know that, once they were on the beam, their approach path was free from obstructions. It was possible for them to land at the first approach, of great value when returning from operations, but, on the other hand, if they made bad approaches, they could, without undue strain, return for a second attempt. The fact that *Lorenz* operated on frequencies of 30 to 35 megacycles per second was of great importance because interference was experienced to a far less degree than on the frequencies used in the Hegenberger system. Thus, from both the technical and flying points of view, the *Lorenz* system was considered preferable. The technical officers from the R.A.E. and the pilot who flew the aircraft during trials of both systems were agreed on this. Considerable research and development was necessary, but it was practicable to use the equipment in its existing form. An important point was that the pilot regarded the equipment as an approach system only; completely blind landing was not feasible as a general rule though possible in certain cases.[1]

A recommendation that the Royal Air Force should be equipped with the *Lorenz* system was made at the third annual Direction Finding Conference on 27 November 1936, when it was proposed that 12 sets of ground apparatus and 80 aircraft installations should be purchased for Service trials in the various commands; the former were to be mobile so that trials could be held at different airfields.[2] *Lorenz* had been adopted by various European countries and as a result of trials held at Heston and Croydon in 1936 it was likely to be standard equipment for civil airlines in the United Kingdom, but Service trials were needed to find out whether it was suitable for use in the Royal Air Force.[3] In February 1937 the recommendation was approved by the Chief of the Air Staff.[4]

The need for blind approach and blind-landing systems in the Royal Air Force was urgent. To avoid delay it was decided that versions of the German equipment, similar to that used at Abingdon, should be produced by Standard Telephones and Cables, rather than that the firm should attempt to develop a new design based on the German one. *Lorenz* was an approach system only

[1] A.M. File 445921/35. The pilot was Flt. Lt. R. S. Blucke, R.A.F.

[2] £50,000 was provisionally included in the 1937/1938 Air Estimates to cover the cost of the proposal; £3,000 for each ground, and between £150 and £200 for each aircraft, installation. The allocation of equipment was :—

	Ground	*Aircraft*
Bomber Command	3	36
Fighter Command	1	3
Training Command	2	6
Coastal Command	2	Enough to equip one flight of Ansons and one squadron of flying-boats.
Spare	4 (for future allocation)	

[3] By December 1937 three ground installations had been completed at Croydon, Heston and Gatwick. (A.H.B./IIE/228).

[4] A.M. File S.39487.

and could not be used for blind landing by the average pilot, but there was no time to await the development and production of a blind-landing system, and *Lorenz* was already in the production stage.[1] The R.A.E. was instructed to preparê specifications, embodying such improvements as had been devised during the experimental work done on the original *Lorenz* set lent to the Air Ministry the previous year.[2] Specifications of operational requirements for the *Lorenz* installation were also prepared. On 10 June 1937 a meeting was held between representatives of the Air Ministry, the R.A.E. and Standard Telephones and Cables to discuss production of *Lorenz* for Service trials. It was decided that the specification prepared by the R.A.E. should be widened to permit modification of the ground equipment to make it portable. British valves and mainly British components were to be used in construction, but in reply to a request from the radio firm, the Air Ministry gave permission for the use of German castings. During the late summer of 1937 the wisdom of the choice of *Lorenz* for Service use, which had already been doubted, was again questioned, and it was proposed that all radio firms already working on the research and development of a blind-landing system should be invited to submit designs. As the primary consideration was the need for speedy provision the decision to proceed with *Lorenz* was reaffirmed, rather than to risk further delay by waiting for a new and experimental system, and in August 1937 a development contract was placed with Standard Telephones and Cables.[3] *Lorenz* was to be used for Service trials; from information acquired at the trials, specifications were to be produced so that commercial firms might compete to evolve the best design.

In December 1937, after the commands had decided where the ground beacons were to be situated, the Air Ministry agreed to the R.A.E. allocation of frequencies, which were to be contained in the band 35·5 megacycles per second to 40·5 megacycles per second. Beacons operating on the same frequency were to be at least 60 miles apart; if they were any closer there was to be a frequency spacing of at least one megacycle per second. It was decided that there should be three different operating frequencies for the 12 transmitters; 36·25 megacycles per second, 39·25 megacycles per second and 40·25 megacycles per second.[4] In August 1938 the first two were changed to 36·4 megacycles per second and 39·4 megacycles per second. In October 1938 the frequency allocation was again changed because a six-channel receiver was substituted for the original three-channel receiver.[5]

In August 1937 Headquarters Bomber, Fighter, Coastal and Training Commands informed the Air Ministry at which stations the installation of *Lorenz* beacons, allocated under the initial contract, was required. In September and October of that year representatives from the R.A.E. visited the selected stations to find out whether the sites were suitable, and carried out tests, using the ground equipment and specially fitted aircraft employed for the Abingdon trials. By the beginning of 1938 the R.A.E. tests were completed and representatives from Standard Telephones and Cables then visited the sites to examine them. To assist them the representatives were provided with the R.A.E. siting reports and plans for the proposed beacon positions at each

[1] A.M. File S.39509.
[2] A.M. File 625411/37.
[3] In June 1938 the contract for 12 ground installations was increased by one, and that for aircraft installations was increased from 80 to 82. (A.M. File S.39509.)
[4] A.M. File 625411/37.
[5] A.M. File S.39509.

airfield. The firm submitted proposals for any alterations considered necessary and after that works services, such as power supply to the beacons, control lines from the Watch Office to the main and inner beacons, and the clearance of trees, shrubs, and other obstructions, became the responsibility of the Air Ministry Works Department. The General Post Office provided control lines from the Watch Office to the outer marker beacons. Progress was made with the initial works services throughout 1938 although the actual installation of ground transmitters did not begin until May 1939. It was arranged that an engineer from Standard Telephones and Cables should be present for about three weeks at R.A.F. stations where ground transmitters were to be set up in order to assist the local personnel in the operation and maintenance of the system.[1] As *Lorenz* was a new and rather complicated equipment the Air Ministry arranged that prototype installations in each type of aircraft in which it was to be fitted were made by the R.A.E. When they had been completed the installation programme was the responsibility of the aircraft contractors. Signals personnel of squadrons were instructed to glean as much information as possible on the operation and servicing of the sets while expert tuition was available. Until sufficient test oscillators were provided for use with the equipment, periodic inspection tests, similar to those devised for W/T sets, were to be held.[2]

The anticipated date of delivery of 12 ground and 80 aircraft equipments' May 1938, proved to be over-optimistic, and difficulties were encountered when attempts were made to install the equipment in bomber aircraft because of lack of space.[3] In April 1938 it was decided that all beacons, except one allocated to Coastal Command, were to be installed on a permanent instead of a transportable basis because it was difficult to monitor mobile beacons. The difficulty could be overcome for trials of comparatively short duration but was insurmountable in operational conditions and the contract was therefore amended. Throughout the second half of 1938 and the first of 1939 the R.A.F. policy on the subject of blind approach was gradually changing. The original plan for the design to be kept static until Service trials had been completed, in order to hasten introduction, was abandoned because of the slowness of production. In view of the slow progress made it was considered preferable to accept *Lorenz* as a standard beam approach system, without waiting until trials had been held and tenders accepted from radio firms for experimental equipment, and to incorporate suitable modifications.

In November 1938, attention was drawn to certain defects in the equipment, notably the unreliability of the glide path indicator used with it, and it was suggested that the use of horizontally-polarised waves might obviate them. Without satisfactory glide path indication it was not possible to convert a blind approach into a blind landing, and in February 1939 development of a suitable indicator was included in the Standard Telephones and Cables contract. The design and installation of *Lorenz*, the best means of developing it to meet future needs, and the relative merits of various blind-landing systems developed by radio firms in Europe and the U.S.A. were the subject of discussions at the Air Ministry. It was noted that a blind-approach system developed by the firm of Phillips was very efficient in that a good equi-signal zone was provided,

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[1] A.M. File S.39509. [2] Bomber Command File BC/20755 Pt. II.
[3] A.M. File S.39509.

but it was estimated that it would take at least one year to bring it to the same stage of production as *Lorenz* had reached. The immediate requirement of the R.A.F. was still to be met with *Lorenz*, and future development of blind-approach systems was to be entrusted to commercial radio engineering firms, with the R.A.E. acting in a supervisory capacity.[1] In May 1939, although Service trials of the *Lorenz* equipment ordered under the initial contract had not been held, a second contract, for 25 ground and 2,500 aircraft installations, was placed with Standard Telephones and Cables. Similar arrangements as with the first contract were made for a representative of the firm to visit sites selected by the Air Ministry to ascertain their suitability. Delivery of the first sets of ground equipment was expected at the end of that year.[2]

The position at the outbreak of war was that, of the 13 ground sets ordered for Service trials, nine had been installed and four more were in process of installation.[3] 73 aircraft equipments had been delivered and had been installed in Whitley, Wellington, Blenheim, Hampden, Battle, and Harrow aircraft of Bomber Command, as well as in four Gladiator aircraft of the Meteorological Flight at Mildenhall. Amongst the aircraft awaiting fitting at the contractors were Manchesters, Stirlings, Halifaxes, and Ansons.[4]

Training in the servicing and operation of *Lorenz* was given to signals personnel at airfields and at manufacturers by Standard Telephones and Cables representatives in 1938 and 1939. By the outbreak of war the subject had been introduced into the syllabus of wireless electrical mechanic apprentices of No. 1 Electrical and Wireless School.[5] In the autumn of 1939 the Blind Approach Training and Development Unit (B.A.T. and D.U.) was formed at Boscombe Down, where operational pilots not only received instruction in blind-approach technique but also gained valuable experience in the use and behaviour of the ground and aircraft equipment.[6] From October 1939 until the late spring of 1940 experimental work on the system was continued at Boscombe Down and it was notable that flying was never cancelled that winter on account of weather, except during a 'glazing ice' period in late 1939, even though fog was experienced many times.[7]

Early Use of Standard Blind Approach

Soon after war began the German name *Lorenz* gradually fell into disuse and that of Standard Blind Landing was adopted instead. The original German design had been considerably developed, both by scientists from the R.A.E. and radio engineers from Standard Telephones and Cables, but on 27 April 1940, at a meeting held to discuss the progress report of the R.A.E., the limitations of the equipment were finally officially recognised and it was decided that the description of the *Lorenz* system should be altered from blind-landing to blind-approach equipment; the name Standard Blind Approach was gradually

[1] A.M. File 625411/37. Meanwhile, two types of blind landing equipment, Air Track and Bendix, were purchased from the U.S.A.

[2] A.M. File S.39509.

[3] Installation was complete at Mildenhall, Abingdon, Boscombe Down, Waddington, Wyton, Leuchars, Linton-on-Ouse, Manston, and Upavon and incomplete at Northolt, Hornchurch, Tangmere and Calshot.

[4] Bomber Command File BC/S.20755 Pt. II.

[5] A.M. File S.39509.

[6] A.M. File S.49915.

[7] A.M. File S.67167, and personal account of Air Vice-Marshal Blucke (retd).

adopted throughout the Royal Air Force and abbreviated into S.B.A.[1] It was not until August 1941 that the name of Standard Blind Approach was formally changed to Standard Beam Approach.

Early in the war the Air Staff raised the question of whether S.B.A. was taking up too much of the limited technical and production resources available and all works services on S.B.A. installation were suspended temporarily until the matter had been investigated. The Air Ministry decided that the capacity of radio engineering firms was sufficient to meet all anticipated demands and as far as S.B.A. was concerned all development had practically been completed and the factory was ready for quantity production. Although it was doubted if sufficient time could be made available to train pilots to the high standard required if efficient use was to be made of the system it was decided that the S.B.A. programme should be continued as originally planned.

Headquarters Bomber Command reported in September 1940 that 36 Wellington, 13 Whitley and 9 Hampden aircraft were equipped with serviceable S.B.A. Approximately 30 more aircraft had been fitted but had since been lost. During the first year of the war little progress had therefore been made towards the fulfilment of the aim of large-scale use of S.B.A. by all operational aircraft. An effort had been made to foster a blind-approach training programme and a number of instructors had been trained in the operational use of the equipment at the B.A.T. and D.U., but when they returned to their squadrons they found themselves unable to put their knowledge into use because so few ground installations had been completed and so small a proportion of aircraft were fitted with receivers.[2] The rather disappointing history of S.B.A. during the first year of the war culminated in the disbanding of the Blind Approach Training and Development Unit in June 1940 because events in France made it necessary for all available pilots to be diverted to operational flying.[3]

Operational Requirements for S.B.A., 1940

In the autumn of 1940 Air Ministry interest in S.B.A. was revived as a result of the abnormally large number of flying accidents which occurred at that time. Expert opinion attributed the accidents to the lack of a landing approach system, and an attempt to introduce full-scale S.B.A. installation and training programmes throughout the Royal Air Force was launched. Its value to bomber aircraft was particularly emphasised. The first measures to be taken were those to improve the rate of equipping the Service. Most new aircraft leaving the production lines were already fitted but of the aircraft already in use most were not fitted with the S.B.A. receiver, and in October 1940 the Air Ministry asked the Ministry of Aircraft Production to begin a retrospective installation programme.[4] Aircraft were being delivered at operational units without the equipment and, as there were still some pilots trained in the use of S.B.A., it was essential there should be equipment on which they could practise. Standard Telephones and Cables had produced 1,000 aircraft sets; only 100 Service aircraft, however, were equipped. The remainder of the equipments were being kept at storage and maintenance units until items

[1] A.M. File S.49915.

[2] It was proposed that similar training should begin at Watchfield in January 1940 but delays in building and provision of equipment prevented the opening of the school.

[3] A.M. File S.67167. The unit was reformed shortly afterwards as an R.C.M. Squadron.

[4] A.M. File S.67167.

such as power units became available for installation in aircraft. The rate of production was 300 per month, and whilst aircraft contractors were supplied with sufficient sets to enable them to equip aircraft on the production lines retrospective fitting was to be carried out at Service units by a fitting party to be formed in No. 26 Group and at storage units by No. 41 Group.[1]

The Chief of the Air Staff considered the use of blind-approach equipment so important a factor in aircraft safety, particularly that of aircraft returning from bombing operations, that he called for monthly progress reports from commands on the equipment, training and operational aspects.[2] The reports, first rendered at the end of October 1940, were continued throughout that winter and the following year. Details given were the number of pilots trained, the number of ground and aircraft installations completed, the number of training flights flown and the number of blind approaches made under operational conditions. Information about ZZ approaches was also given.[3]

The drive for the comprehensive installation of S.B.A. and its operational use could only be made effective by an extensive training programme because the system could be used successfully only if pilots were well trained initially and had constant practice subsequently. Between October 1939 and June 1940, when the B.A.T. & D.U. was operating, 137 pilots were trained in the use of S.B.A., but by October 1940 many of these had become casualties and only about 50 pilots were available to act as instructors in bomber units.[4] The first step taken to meet an urgent requirement was the formation, in October 1940, of No. 1 Blind Approach School at Watchfield, where instructors' courses were held with a weekly output of six pilots, later rising to eight, who, on completion of training, were posted back to their squadrons for instructional duties. Output from the one school was insufficient to ensure that the supply of trained pilots kept pace with the installation programmes and it was therefore recommended in November 1940 that blind-approach training flights should be established at the 15 stations where S.B.A. was in operation. However, owing to the shortage of aircraft, flights could be established at ten operational stations only, eight in Bomber Command and two in Coastal Command.[5] Instructors for the flights were given refresher courses at Watchfield. The aircraft allocated to the flights were Whitley Marks I and II, Wellington Mark I and Blenheim Mark IV, all obsolescent types for which overhaul before use was necessary. The S.B.A. aircraft equipment was sent direct to No. 30 Maintenance Unit, Sealand, for installation.[6]

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[1] The No. 26 Group fitting party was eventually located at No. 1 Signals Depot, West Drayton. (Bomber Command File BC/S.20755 Pt. III.)

[2] A.M. File S.67167.

[3] ZZ approaches were made with the assistance of a D/F station suitably positioned near the airfield and in line with a runway clear of all obstruction, and of control officers experienced and suitably trained to undertake the responsibility of landing aircraft under ZZ conditions. It was not considered such a good method as S.B.A. because the responsibility for the approach was divided between the pilot in the aircraft and the controller on the ground. The progress report for January 1942 omitted any record of ZZ approach progress as the method was dying out.

[4] A.M. File S.44162A.

[5] Abingdon, Linton-upon-Ouse, Mildenhall, Wyton, Honington, Waddington, Finningley, and Wattisham. Thornaby and Leuchars. (A.M. File S.44162A).

[6] A.M. File S.67167.

By the end of January 1941, 20 instructors had been trained and were posted to organise the formation of the ten flights. Aircraft fitting was delayed because of late delivery of the aircraft, small supplies of equipment, and snow on the airfield at Sealand. Full-scale training was not therefore possible until March 1941. By the end of that month the eight Bomber Command flights were equipped with two aircraft each, either Wellington or Blenheim, and the two Coastal Command flights with Whitley aircraft. Limited training only was begun at the Coastal Command flights in the early part of 1941.[1] After the establishment of the ten B.A.T. flights all vacancies on courses at the B.A. School at Watchfield were reserved for fighter pilots. Training was given at the Receiver School, Boscombe Down to wireless personnel for the servicing of equipment, and one wireless electrical mechanic was established for each ground installation.[2]

The drive for ensuring that the Royal Air Force was adequately equipped with S.B.A. received renewed impetus once the decision had the full backing of the Air Council. Suitable airfields throughout Bomber, Coastal and Fighter Commands were equipped with the ground equipment from the autumn of 1940 onwards. In November 1940, 17 ground installations had been completed and 14 more were in progress.[3] At that stage the supply of aircraft equipment was not sufficient to enable installations to be made in all aircraft coming off the production lines because of the rapid increase made in aircraft production consequent on the expansion programme. There were many other difficulties to face before S.B.A. could be put into general operational use. The choice of airfields was important in that long runways were as essential as was freedom from obstructions, such as buildings and trees, on the approach path. Another limiting factor in the choice of airfields was that beams operating on the same frequency could not be placed too near each other because of the danger of mutual interference.[4] In March 1941 Headquarters Bomber Command was requested to compile a priority list of S.B.A. requirements at airfields in the command where installation was feasible. In the following month a technical survey of all airfields was arranged, priority being given to Bomber and Coastal Commands and special Regional Control airfields. Satellites and relief landing grounds were included but installations were to be limited to parent airfields if possible. The amount of works services involved in laying the power supply and cables to each of the three beacon positions was considerable but once this had been completed the actual erection of the beacon structure and the installation and setting up of the apparatus took only five weeks. In April 1941 the supplies of beacon cabling were plentiful but labour was not, and considerable difficulty was being experienced in conveying power to the outer marker beacon. A temporary expedient to overcome this was the use of self-powered transportable beacons. In that month it was confirmed that S.B.A. was to be installed at every operational station, Service flying training school, and operational training unit at home and abroad. It was emphasised that when the S.B.A. programme was fully implemented other problems would have to be faced, such as the shortage of servicing personnel and of petrol-electric sets and trailers, and it was decided that solutions to these problems were to be sought immediately.[5]

[1] A.M. File S.67167.
[2] Bomber Command File BC/S.20755 Part III.
[3] A.M. File S.67167.
[4] A.H.B./II/69/154. Blind Approach Reports.
[5] A.H.B./II/69/189. Blind Approach and Airfield Lighting.

In spite of all efforts made by the various government departments to hasten manufacture of the necessary items of equipment, production did not keep pace with demand as the Royal Air Force, particularly Bomber Command, expanded. In May 1941 the situation became serious and the Secretary of State for Air and the Minister of Aircraft Production personally investigated the possibility of increasing the rate of production. It appeared that everything was being done to produce the equipment quickly but the drawback was that it was necessary to produce in quantity a new design simultaneously with its development, and no firm other than Standard Telephones and Cables could be brought in.[1]

Throughout the first half of 1941 it was clear from the monthly reports submitted by each command that, although slow, some progress was being made in the installation of S.B.A. At the same time the large number of pilots trained at the B.A.T. flights were making increased use of S.B.A. on return from operations. By the end of July 1941, 943 pilots had been trained and increased knowledge of the system seemed to be accompanied by increased enthusiasm. It was reported from Mildenhall and Honington, where B.A.T. flights had been established, that operational pilots were eager for instruction and realised the value of S.B.A. to them on return from operational flights. Fixed ground installations had been completed at 34 airfields, and four groups in Bomber Command were completely fitted with the aircraft equipment, whilst two groups had very few aircraft fitted and one group had about half. Of these Headquarters No. 2 Group had decided not to fit any more aircraft as its daylight operations were not likely to be undertaken in bad weather, and the very extensive modifications to Blenheims necessitated aircraft being unserviceable for several days. In Coastal Command about half the aircraft were being fitted but the position was rather unsatisfactory because Hudson Marks I and II could not be equipped for reasons of weight. So much modification was required for Hudson Mark III aircraft that the delay on the production line in the U.S.A., and in consequence the delay in availability for operations in the United Kingdom, could not be tolerated. In Fighter Command experiments were being conducted with V.H.F. Beam Approach, a method which utilised the existing V.H.F. apparatus in fighter aircraft.[2]

One of the problems encountered with the general introduction of S.B.A. was that of maintaining the aircraft and ground equipment in a fully serviceable state, fit for instant operational use. In March 1941 a travelling flight was formed of personnel capable of clearing faults, in both aircraft and ground installations, which were too difficult for unit personnel, but in the following month Headquarters No. 26 Group assumed responsibility for the maintenance and upkeep of ground installations.[3] Periodic visits by technical officers to carry out general checks of the installation were arranged, and if essential repairs were beyond the scope of the unit, technical assistance was provided.[4] In November 1941 Headquarters Bomber Command issued instructions that S.B.A. ground installations were to be switched off for definite periods during daylight hours for regular daily and weekly inspections because it had been difficult to fit in routine servicing on account of the almost continuous

[1] A.H.B./ID/2/258. Lorenz Blind Approach Landings—Provision of Equipment.

[2] A.M. File S.67167.

[3] A.H.B./II/69/154.

[4] Bomber Command File BC/S.20755 Part IV.

operation of the system at night for operational use and during the day for training or practice flights. One hour for the daily and four hours for the weekly inspection were allotted.[1] The Air Ministry repeatedly stressed the importance of keeping the equipment fully serviceable at all times so that pilots would gain confidence in it.

Beam Approach Training, 1941

Until the middle of 1941 the intensive training effort was confined to the retrospective training of operational pilots. The policy of using small training flights at operational stations was a temporary expedient necessitated by the shortage of equipment ; all available equipment was sent to operational units and there was little left over for training units. It was, however, considered that every pilot should be trained in the use of S.B.A. at the very outset of his flying career.[2] In July 1941 the Air Council decided that B.A. training should be incorporated in courses at all Service flying training schools at home and abroad, and instructor training was to be given at the Central Flying School, Upavon. Installation of S.B.A. at flying schools in the United Kingdom was to be on the basis of two ground installations for each school, one at the airfield and one in its vicinity for use when the airfield was congested. Approximately 30 ground transmitters were allocated for use at the Empire Air Training Scheme flying schools abroad.[3]

The retrospective training of pilots was unsatisfactory because it did not keep pace with the intake of pilots ; the commands did not make full use of the B.A.T. flights. On 26 August 1941 a meeting was held at the Air Ministry to discuss the B.A. training of bomber pilots. The main difficulty, in the opinion of Headquarters Bomber Command, was the struggle between operational effort and B.A. training, for often pilots were sent on B.A. courses when they were urgently needed for bombing operations. Another argument put forward against too great a concentration of B.A. training was that the use of S.B.A. was often not necessary in practice. Bombing operations could seldom be undertaken if the weather was so bad that it necessitated the use of beam approach on return to the United Kingdom. The existing system meant that a number of operational pilots were trained or partially trained in the use of S.B.A. at about the time when they completed their normal tour of duty. For this reason Headquarters Bomber Command supported the decision to incorporate S.B.A. training at the S.F.T.S. stage so that pilots were qualified by the time they were posted to operational squadrons.[4] In addition to the decision to incorporate S.B.A. training at S.F.T. schools, a further widening of the training programme was envisaged by a recommendation to form 15 new B.A.T. flights. This new total of 23 B.A.T. flights would be able to train 912 pilots per month.[5] Priority was to be given to bomber pilots before they went to an O.T.U. Surplus vacancies were to be given to the retrospective training of operational pilots who had still to complete the greater part of their tour of duty. This would mean that pilots would be trained in the technique early and would go to O.T.Us. with a higher standard in instrument flying and with confidence in the equipment. The proposals were agreed at the end of August, and in September 1941 Air Ministry instructions were issued as to

[1] Bomber Command File BC/S.20755 Part IV.
[2] A.M. File S.39509.
[3] A.M. File S.39509, Part II.
[4] A.M. File S.67167.
[5] The number of pupils requiring training was 200 per week, rising to 240. (A.M. File S.67167.)

where B.A.T. flights were to be formed and the order of formation. A request from Headquarters Bomber Command that O.T.Us. should be omitted was acceded to as far as possible. Each flight of eight Oxford aircraft was an independent unit, similar to the existing B.A.T. flights, and servicing personnel and instructors were established on a double-shift basis. The flights were lodged on operational stations but all training matters were dealt with by Headquarters Nos. 21 and 23 Groups of Flying Training Command.[1] The flights were disbanded and absorbed into S.F.T. schools when beam approach equipment became available, so that the aim of completing S.B.A. training at an early stage was fulfilled.[2]

Beam Identification

As the number of S.B.A. installations increased, confusion was caused by the number of beams transmitting on the same frequency and being aligned on the same, or approximately the same, bearing. It was difficult to differentiate between them and in some cases pilots returning from operations used the wrong approach beam.[3] In October 1941 Headquarters Bomber Command recommended that an identification letter superimposed on the beam signal should be introduced as a matter of urgency, even if it entailed a short period of unserviceability. This method was followed in the case of the S.B.A. installation used as a radio track guide on the east coast, where it had proved very successful.[4] In December the Air Ministry agreed, as a trial measure, to install equipment to enable the main beacon on six ground installations to transmit an identification letter, although it was not considered to be a satisfactory method in that an interruption of the beam might endanger the safe approach of an aircraft as it neared the inner marker. Another method whereby the beam was unaffected but the dot and dash sectors were broken by the transmission of identification signals was advocated.[5] On 9 March 1942 it was agreed that identification signals should interrupt the beam and should be employed on full-power beams only. Further experiment was necessary before a firm decision was reached on the questions of the speed of keying and the interval between identifications. It was therefore decided that Headquarters No. 80 Wing should monitor German beams which were keyed with recognition signals. A report from No. 80 Wing later in the month stated that the Germans employed the system of interruption of the beam, not superimposition upon it ; there was an interval of approximately half a second before and after the identification signal.[6] By September 1944 80 per cent of all airfield beams and all radio track guides in the United Kingdom had been equipped.[7]

Security Measures

When war began certain restrictions had to be placed on the use of S.B.A. to prevent enemy bombers being guided to R.A.F. airfields along the beams. As S.B.A. was of German origin it would be a simple matter for their aircraft

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[1] A.M. File S.67167. [2] A.H.B./II/69/154.

[3] On the night of 26/27 November 1941 the pilots of eleven different aircraft from four stations in No. 3 Group returning from operations went down the Driffield beam thinking they were homing to Marham. This resulted in seven of the aircraft being dispersed on airfields in No. 4 Group. In the same way aircraft of No. 4 Group homed to Marham instead of Driffield. (BC/S.20755, Part IV.)

[4] Bomber Command File BC/S.20755, Part IV.

[5] Bomber Command File BC/S.20755, Part IV.

[6] A.M. File CS.12820. [7] A.M. File CS.19063.

to be fitted with receivers which could make use of the British beacons as navigational aids. In November 1939 power of the main beacons was reduced so that effective range to an aircraft at 2,000 feet was limited to 20 miles. The system was completely shut down when a 'Yellow' air raid warning was received. In February 1941 instructions were issued that transmitters were to be put into operation only when requested by aircraft captains in bad weather or when they were required for practice or test purposes. If for the latter they were to be closed when a 'Red' air raid warning was received. Headquarters Bomber Command deprecated the security measures as it was felt that they hampered training in beam approach, the most important factor in the successful use of the system. It was pointed out that in bad weather W/T frequently could not be used and thus the aircraft captain had no means of calling for the assistance of S.B.A. In any event, the equipment was designed to be used in conditions of low visibility, when enemy aircraft were unlikely to be operating. It was preferable by far to assist British aircraft and crews in distress than merely to hinder enemy aircraft. The following month the Air Ministry cancelled the instructions and ruled that the equipment was to be operated at the discretion of station commanders; if they considered that visibility conditions were such that R.A.F. aircraft would require approach assistance transmissions from the beacon were to be started. Full power was to be employed at all times so that the utmost help was given to aircraft.[1]

In March 1942 the danger of the enemy making use of S.B.A. transmissions was again considered. By that time there were 33 S.B.A. installations and three radio track guides in almost continuous operation in the United Kingdom, and it was most important to adjudge their value to the R.A.F. compared with their value to the enemy. One solution to the problem was presented in the fact that as the number of installations increased they would have to be operated on low power to avoid mutual interference because of the limited number of frequencies available. The range of low-power installations was about 25 miles only and security would be further increased by the proposal to use the same frequency for parent and satellite airfields and then to ring the changes on the installations. Radio track guides would of necessity have to be used on full power and when it became obvious that the enemy were using them they were to be subject to radio control by Headquarters Fighter Command. Under these arrangements, if information obtained by Headquarters No. 80 Wing made it clear that enemy aircraft were using an S.B.A. installation the Radio Control officer at Headquarters Fighter Command was to be informed and he was to order that station to cease S.B.A. transmissions. In the same way Headquarters Fighter Command was to be informed when it was certain that the enemy was no longer using the beam. No S.B.A. installation was to be closed down unless the denial of its navigational aid to the enemy outweighed its value as a homing or approach aid to Allied aircraft. These instructions were issued but were to be held in abeyance until it was believed that enemy aircraft could tune in to British S.B.A. frequencies. Security control of the identification signals was also required. The safety measures were planned to meet this danger; identification signals were so constructed that they were capable of being turned off at any given moment. If it were ascertained that enemy aircraft were using S.B.A., identification letters would be changed daily.[2]

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[1] A.M. File S.39509.

[2] Bomber Command File BC/S.20755.

Operational Use of S.B.A., 1941/1942

In the autumn of 1941 attention was once again focused on the extent to which S.B.A. was being used operationally. On the night of 20/21 September 1941 unusually heavy losses were incurred by bomber aircraft on returning to bases from operations. The Air Ministry asked Headquarters Bomber Command whether the universal use of S.B.A. would have reduced the losses to any appreciable extent. It was emphasised that for one year much money and effort had been expended on providing S.B.A. ground and aircraft equipment and in training pilots to use it. The need for training was stressed because constant practice and familiarity with the equipment gave the pilot confidence in using it. The formation of the B.A.T. School at Watchfield and the B.A.T. flights on operational stations had been the result of this policy. It was clear from the replies given by Headquarters Bomber Command that the measures taken to ensure the safety of aircraft on return from bombing operations relied far less on general use of S.B.A. than on a policy of diversion throughout the command. If an airfield was shrouded in fog pilots were ordered to land on clear airfields rather than risk aircraft and crew by attempting a fog landing with the aid of S.B.A. The landing of an aircraft on a strange airfield, even though free from fog, often led to accidents. In September and October 1941 bombing operations were considerably hampered by bad weather and little effort was made to alleviate its effect by the use of S.B.A., which by that date was readily available. On many nights it had been found impossible to operate at all even though the weather over enemy country was good, because the weather over the home bases was expected to deteriorate by the time the bombing force returned.[1]

By October 1941 S.B.A. was available at 35 stations and the supply of aircraft equipment was satisfactory.[2] Training at the original 10 B.A.T. flights was at the rate of 200 per month but the formation of the 15 new flights was very slow. Many difficulties were being encountered, chief among them being the delay in completing ground installations. This was caused by large-scale extensions and alterations to airfields, and the slow provision of control and power cabling to the beacon sites by the Air Ministry Works Department because of the labour shortage.[3] However, training at some had begun by October 1941. At the same time the Air Ministry continued to urge the importance of post-graduate practice by pilots who had already completed an S.B.A. course and had returned to operational flying. Headquarters Bomber Command agreed that continued practice was important but considered that congestion was caused by the allocation of non-operational B.A.T. flights to operational and O.T.U. stations. In bad weather the number of aircraft using a beam was strictly limited and as the B.A.T. flights had to be given priority, opportunities of giving pilots post-graduate training were very small. Therefore the removal of non-operational B.A.T. flights from Bomber Command airfields was requested. The Air Ministry found that this was not possible because of the leeway in training which had to be made up, and considered that congestion would be relieved by the proposed extension in January 1942 of each S.B.A. course from seven to fourteen days. Both types of training could be carried out if the training were properly organised, and each station was to ensure that the best possible use of the beam was made while operational flying was in progress.[4]

[1] A.M. File S.67167.
[2] A.M. File S.74991.
[3] A.M. File S.39509, Part II.
[4] A.M. File S.74991.

As the number of beams in use increased, the problem of the frequencies on which new beams were to operate became more urgent. S.B.A. aircraft equipment could be set to select six spot frequencies from about 40 frequencies available in the band. All ground installations were working at full power and had a range of about 100 miles, so it was necessary for two stations working on the same frequency to be separated by at least 200 miles. To fulfil the intention of installing S.B.A. at 250 airfields it would be necessary to restrict ranges. The alternative was to reduce the number of installations. On 9 March 1942 a meeting was held at the Air Ministry to discuss the question and it was agreed that beams would have to operate on low power as the number of installations increased. This was not an ideal solution as low-power beams could be used only in the approach role and were of no use as navigational aids, at that time a more important function, but it was unavoidable until more frequencies could be made available. It was intended that S.B.A. should be used more extensively in the future as a landing approach system in bad weather, and with the increased use of Gee the need to use S.B.A. beams as homing aids would lessen. It was agreed that the operation of radio track guides on full power was to be continued as they were designed solely as navigational aids. The question was again considered by Headquarters Bomber Command in May 1942. It was decided that the range of most beams should be limited to 25 miles so that two beams on the same frequency could be located as near as 50 miles to each other.[1]

Operational Use of S.B.A., 1942/1943

By the beginning of May 1942, 40 S.B.A. ground installations were in operation; 25 at operational airfields, nine at O.T.Us., three at training airfields and three as radio track guides.[2] By the end of June, 49 S.B.A. installations were in service, 15 were in course of installation, and the necessary cabling was being laid at another 100 airfields.[3] The installation programme continued to make progress at home and abroad, where some mobile installations had been shipped for use at flying training schools; 35 of the first 66 transportable sets ordered were allocated to the Empire Air Training Scheme.[4] The greater proportion of S.B.A. ground equipment which became available in 1942 was allocated to training units at home and abroad with the intention that great emphasis should be laid on the system in the early stages of pilot training. It was hoped that pilots would be full of enthusiasm for the system by the time they joined operational units. Equipment was allocated strictly according to the degree of priority accorded to each airfield and so that beams operating on the same frequency were sited far enough apart to avoid mutual interference. The priority list was changed only when exceptional requirements arose. The production of aircraft receivers also proceeded steadily, and by the end of November all bomber and appropriate training aircraft were being delivered from the production line equipped with S.B.A. and there was an ample reserve of replacement equipment. 75 ground installations were available for use and a further 126 were in process of installation or reinstallation. 50 transportable sets had been sent overseas for use in training units.[5]

Repeatedly throughout 1942 the Air Ministry emphasised the value of S.B.A. and the importance of all pilots using it for landing approaches in bad weather. Increased use of the system would result only when all concerned were convinced

[1] A.M. File CS.12820. [2] A.H.B./II/69/154. [3] A.M. File S.74991.
[4] A.M. File S.39509, Part II. [5] A.H.B./II/69/154.

of its value to aircraft safety. It was considered necessary for every pilot to have adequate basic training in the use of the system and constant practice thereafter so that its use in emergency became automatic and he was fully confident of his ability to land in perfect safety in poor visibility.[1] This confidence had to be further strengthened by ensuring that the equipment was always in perfect working order and all technical faults had been eradicated. After this confidence had been ensured it was the responsibility of Headquarters Bomber Command to order diversions only for pilots whose flying was not of a sufficiently high standard to permit them to land on the beam when bad weather prevailed at the home airfield.[2]

Ground installations were completed at nine Coastal Command and two Fighter Command airfields but these were primarily for the assistance of bomber aircraft diverted from their home bases. In Coastal Command the use of S.B.A. was being superseded by that of A.S.V.B.A. and in Fighter Command V.H.F.B.A. was used.[3] On 2 April 1942 Headquarters Coastal Command informed the Air Ministry that there was no requirement for S.B.A. in Coastal Command aircraft other than long-range fighters. It was therefore arranged that no installations were made but the provision of fixed fittings and wiring was continued so that S.B.A. could be installed if the aircraft were diverted to other commands. A.S.V. was being installed in all Coastal Command aircraft except long-range fighters and its use in conjunction with B.A.B.S. provided an adequate approach system.

S.B.A. was used mainly by Bomber Command. During the first half of 1942 the number of adequately trained operational pilots and the number of bomber aircraft fitted with serviceable equipment were approximately doubled and the number of available ground stations was increased by 50 per cent. The training programme was satisfactory because by June 1942 the effect of the formation of the 15 new B.A.T. flights had been felt. The number of pilots trained increased each month and in June alone it was 1,145. It was estimated in the summer of 1942 that by the following winter most of the operational pilots in Bomber Command would be fully trained. In an effort to ensure that post-graduate training was not neglected Headquarters Bomber Command issued instructions that each pilot was to make two practice approaches a week ; experts believed this to be the minimum for pilots to remain competent in beam approach technique. These practice approaches were not scheduled as special training flights but were carried out on normal training or operational flights, even when blind flying conditions did not exist.

In spite of this there had been little increase in the operational use of S.B.A. and by this very fact it appeared that all the expenditure of money, manpower and productive effort had been wasted. The main reason was that, instead of making use of S.B.A., aircraft were diverted to airfields where the weather was suitable for visual approach and landing. Many bomber pilots lacked confidence in S.B.A. because there was no reliable means of ascertaining the height and position of the aircraft in the final stage of the approach to the runway and they were afraid of flying into the ground. The S.B.A. approach procedure in itself was complicated and was another reason why pilots were disinclined to

[1] 100 yards horizontal and 100 feet vertical. [2] A.H.B./II/69/154.

[3] 185 aircraft only in Coastal Command were fitted with S.B.A. receivers. (A.H.B./II/69/154.)

make use of the system.[1] Constant practice was essential but at most units operational pilots found they were unable to make training flights because, during the periods of intensive operations, the intervals between operations were used for S.B.A. servicing; also, so much work was involved in moving heavy bomber aircraft from a dispersal point for flying that pilots were reluctant to fly except on operations. The S.B.A. method of approach required a high standard of instrument flying from the pilot and this additional strain, imposed after an exhausting bombing raid, was often too much for him, particularly if he was flying a damaged aircraft. Bomber pilots, did, however use S.B.A. beams a good deal for homing.[2]

The problems that hindered the full use of S.B.A. in bombing operations were so numerous that, in October 1942, the Beam Approach Development Unit was formed at Watchfield. The object was to develop all types of beam approach technique and to incorporate improvements in the equipment. The unit was adminstered by the Flying Training Command unit at Watchfield but was operationally controlled by the Air Ministry.[3] Naval aircraft and personnel were included and in all experiments and research the closest co-operation was maintained with the Admiralty. One of the main problems to be solved was that of speeding up the rate of landing, which at that time was four heavy bombers per hour, too slow for Bomber Command operational requirements. A new system had already been tried out at Watchfield in July 1942. In this aircraft were brought in, without using the existing complicated procedure, from a 'stand-off' marker beacon which was placed eight miles in front of the main transmitter. It was considered that if this method was satisfactory 15 medium or 10 heavy bomber aircraft could be landed in an hour. After the formation of the B.A.D.U., trials of the procedure continued simultaneously with trials of a method in which two adjacent beams were used, one as a stand-off beam while aircraft were brought in on the other. Other schemes which were tried out included the effect of narrowing the beam to a width of 1½ degrees. Tests of the Standard Telephones and Cables glide path indicator, which had been started at Polebrook in the previous August but had been abandoned because they caused interference with operational flying, were continued so that the necessary landing technique could be evolved, and trials of a multi-channel S.B.A. receiver were begun.[4] In November 1942 the experiments to discover a feasible means of landing heavy bombers quickly were transferred to Downham Market, where, with the aid of No. 218 Squadron (Stirlings), trials were undertaken of radio altimeters, the glide path indicator, and automatic control of the aircraft in azimuth.[5]

During the winter of 1942/1943 the question of abandoning the use of S.B.A. was broached. Headquarters Bomber Command stated that the system was seldom used for the purpose for which it was provided. Landings were certainly made with its help after operations but only in a few instances was the weather so bad that landing would have been impossible without S.B.A. The Bomber Command view was that there was no real need for S.B.A. because

[1] An aircraft approaching on the beam had to carry out an elaborate figure-of-eight course before landing. The procedure involved the pilot getting himself to the correct height at the inner marker beacon for making a normal landing, to achieve which might require several attempts. (A.H.B./IIE/76A—War in the Ether.)

[2] A.M. File S.74991.

[3] Directorate General of Aircraft Safety.

[4] A.M. File S.74991.

[5] A.M. File S.87187.

the operational policy was to launch full-scale bombing raids only on nights when the weather was favourable. It was recommended that only one airfield in three should be equipped with S.B.A. This was considered to be necessary in any event because of the limited number of frequencies available and the geographical spacing required to avoid mutual interference. It was considered that the economies would in no way detract from the operational efficiency of the command.[1] However, the S.B.A. programme had involved considerable expenditure in money, labour and material, and it was not until the winter of 1942/1943 that the full effect of the intensified S.B.A. training, introduced about one year earlier, began to make itself evident. The Air Ministry hoped that increasing use of S.B.A. as a landing approach system would be made as crews became more experienced and more confident. Some aircraft from Holme on return from operations had used S.B.A. for landing in visibility of 300 yards, one of them with a full load of bombs and only three serviceable engines. This was held to be an encouraging sign of increased enthusiasm for S.B.A. among bomber pilots and it was urged that a decision on the future of the system should be deferred until the summer of 1943 when its value during winter operations could be more fully assessed. In deciding the future of S.B.A. various factors had to be considered, chief among them being the good supply position and the absence of a suitable alternative. It was believed by the Air Staff that the policy of diverting aircraft would not meet the problem raised if and when unexpected bad weather caused bomber bases to become unfit for normal landings whilst aircraft were on bombing raids. There would almost certainly be congestion over the clear airfields, and then the emergency runways and S.B.A. equipment would be called into use. Another factor to be considered was the growing activity of enemy night-fighters over Germany, which was so endangering the safety of Allied bomber aircraft that the only possible solution appeared to be that of sending bombers over in weather too bad for fighter operation.[2] Also, between July and December 1942, 197 bomber aircraft crashed when attempting to land or descend through bad weather on return from operations. Some of those accidents might have been avoided if pilots had been skilled in the use of S.B.A. and if it had been regarded as the normal method of approach through cloud or in bad visibility.[3] The Air Ministry considered that nothing would be gained by drastic curtailment of the S.B.A. programme but recommended that economies should be effected by limiting ground installations to 50 in Bomber Command, provided that a constant review of requirements was maintained. The installation of S.B.A. receivers in all bomber aircraft was to be continued and intensive training was to be aimed at with the object of achieving satisfactory landings in visibility as low as 100 yards. Research and trials were to go on in an attempt to improve the system; it was believed at both the Air Ministry and Headquarters Bomber Command that the value of S.B.A. would be enhanced with the incorporation of improvements then undergoing trial.[4]

Investigation by the Inspector-General of the R.A.F.

The feeling that some modification of the S.B.A. programme was necessary was so widespread that, at the third meeting of the Committee for Co-ordination of the Bomber Offensive, the Secretary of State for Air directed that a committee

[1] A.M. File S.87187. [2] A.H.B./II/69/154. [3] A.M. File CS.18395.
[4] A.H.B./II/69/154.

be convened to review the existing S.B.A. policy in the hope of effecting economies. The committee met at the Air Ministry on 18 December 1942 and consisted of representatives of the Air Ministry, Headquarters Bomber Command, Headquarters Flying Training Command and the U.S.A.A.F. It was agreed that the S.B.A. programme should be reduced in Bomber Command to one installation per clutch of three operational airfields except that all O.T.U. airfields, and those at which pathfinder squadrons were based, were to have one installation each. S.B.A. was also to be installed at all Flying Training Command airfields, and a total of 33 equipments was required to meet planned commitments up to the end of 1945. Bomber Command requirements were to be reviewed once more when the trials of various systems had been completed. When the decisions were made known to the Chief of the Air Staff he was assured that the effort expended on S.B.A. was justified by the immense assistance the system would render to the bombing offensive, but he was doubtful of the efficacy of S.B.A. He did not consider valid the argument that use of S.B.A. would increase the number of bombing raids by making it possible for them to be carried out in worse weather than was otherwise practicable. He believed that the average pilot would not achieve a high standard in S.B.A. technique because an average operational tour was not long enough to permit it. However, he did not want to obstruct the development of any system that could in any way benefit the bombing offensive and suggested that the Inspector-General of the R.A.F. should be asked to report on the operational use of S.B.A. and to advise whether he considered that it would increase the effectiveness and lower the casualty rate of Bomber Command. The Secretary of State of Air agreed on 23 December 1942 that investigation should be carried out as a matter of urgency.[1]

As a result the Inspector-General of the R.A.F. undertook a detailed and thorough investigation of the operational use of S.B.A. In his report, which was issued on 21 January 1943, he stated that Bomber Command was fully committed to the use of S.B.A. and a great deal of effort had been put into implementing the original scheme, which was 70 per cent complete. S.B.A. was being used for many purposes including approaching and lining up on the runway in bad visibility, homing, as a navigational aid or check, as a means of keeping on the circuit of an airfield in bad visibility or above cloud, and for providing the starting point of an outward course when over cloud. It was used very rarely for blind landings and then only by experts, and was very little used for breaking cloud. The use of S.B.A. had been increasing before the introduction of Gee, especially for homing, but since then most pilots had not used the beam, particularly as they had little operational practice. Pilots did not like S.B.A. because the approach procedure was complicated and they felt its use was dangerous. The Inspector-General considered that the operational results obtained from the use of S.B.A. did not justify the effort expended on it but thought that its value to the Service could be enhanced. The first essential was to inspire pilots with confidence. He urged that it should be emphasised that S.B.A. was designed to help an aircraft approach within sight of the runway ; if it was regarded as a blind-landing system pilots would think that they might be required to land in difficult and dangerous conditions. As things were, they preferred to be diverted rather than to attempt landings by S.B.A. It should be available for pilots who were able to

[1] A.M. File S.87187.

use it, and they should be allowed to use it if they so wished instead of being compulsorily diverted to another airfield.[1] The Inspector-General insisted that, above all, constant practice was essential before S.B.A. could be successful. Such practice was normally very difficult to fit in on operational units so he recommended that S.B.A. should be used as the standard mode of return to base from operational sorties, and that for this a satisfactory and simple control system to speed up the rate of landing was necessary and very important. If a faster rate could be achieved further development of S.B.A. was considered to be justifiable.[2]

The Inspector-General recommended that a straight approach technique, using a distant marker or distant homing beacon on the front beam, should be adopted. Such a method would be much simpler than the figure-of-eight approach and trials should be arranged right away. If straight approach on the front beam was possible then elimination of the back beam to reduce congestion should be considered. If the back beam could be eliminated attempts should be made to make S.B.A. mobile instead of being anchored to one runway. He understood permanent aerials could be erected for each runway and the transmitters made mobile. The provision of short straight lines of four contact lights between the outer and the inner marker were recommended so that the pilot could line up on them. A further suggestion was the provision of more by-tracks from the main runway so that aircraft could be got away quickly. The Inspector-General recommended that a variable tuning device, used by the Fleet Air Arm, should be incorporated in the S.B.A. receiver because that would eliminate the existing tuning troubles and increase the number of frequencies available for use. He considered that the introduction of the new radio glide path indicators would be helpful in giving confidence to the pilot, an essential prerequisite, when he was descending through cloud. The use of an electrical low-reading altimeter might similarly instil confidence when S.B.A. was used in very bad weather.[3]

The recommendations were studied by the Air Ministry, and those considered feasible were incorporated in S.B.A. development. It was possible to erect permanent aerials so that mobile equipment could be used but it was not considered worth while in view of the extra expenditure and time involved, because it would take about one day to realign a beacon to its aerial array every time it was moved. There were disadvantages as well as advantages in the incorporation of a variable tuning device in the aircraft receiver. Among the advantages was the fact that the pilot would be able to choose any channel on the band instead of being restricted to six frequencies, and the amount of servicing required would be considerably reduced. No test oscillator would be required except for tuning the marker receiver and for a periodic check on the main receiver, whilst the trimmer condenser and the wave-change switch, both weak features, would be eliminated. On the other hand the identification problem would be intensified as the pilot would be able to choose any frequency. This meant that each beam would have to transmit identification signals and each aircraft would have to carry a list of the code. In order to send identification signals the beam approach signals would have to be

[1] A.M. File CS.18395.

[2] On 18 January 1943 one of the Lancasters returning from Berlin had to wait one hour and twenty minutes over its base before being allowed to land. (A.M. File CS.18395.)

[3] A.M. File CS.18395.

interrupted and this might have an adverse effect on an approach made by pilots unskilled in S.B.A. flying. If so, identification signals would have to be stopped during approaches and the result would be to slow down the rate of landing. The installation of a remote control tuning head was essential in order to facilitate tuning and this complicated the aircraft installation. It had to be placed so that it could be easily seen by the pilot and had to be illuminated for night use. Another point requiring consideration was the threat to security as all airfields would be made identifiable to the enemy.

At the Air Ministry it was considered that the disadvantages could be overcome. Interruption of the beam was standard procedure on the radio range system in the United States of America. The provision of remote control would be the greatest difficulty. It was preferable that the tuning head should be near the pilot, but if this was not possible it could effectively be located near the navigator or wireless operator. The threat to security was not then very real because, as far as was known, the enemy had not adjusted his aircraft receivers to the Allied frequencies.[1] The Chief of the Air Staff approved the incorporation of a tunable receiver and at the end of March 1943 several sets were suitably modified by Standard Telephones and Cables and were tested by No. 101 Squadron at Holme. During 1943 no large order was placed because of indecision regarding the future of S.B.A. and because full-scale production would hamper the production of other equipment; Headquarters Bomber Command preferred that supplies of S.B.A. should be slowed up rather than that the production of such systems as H2S, Monica, and Gee should be hindered.

There were two designs of tunable receiver, the R.1466, mechanically-tuned equipment, and the S.B.A.–X, later known as the R.1544, electrically-tuned equipment. The first was the best tunable equipment that could be produced as a relatively minor modification of the fixed-tune receiver but the S.B.A.–X was a completely new design and had many advantages over the former. Mechanically-tuned receivers were fitted in Mosquito aircraft of No. 1409 Meteorological Flight at Oakington for Service trials in the summer of 1943. The range of the installation was approximately 7 to 10 miles in normal conditions at a height of 2,000 to 3,000 feet. Sensitivity varied according to the direction of the aircraft in that signal strength was much greater when flying towards the main beacon than in the opposite direction. The tuning indicator was comfortably positioned for the pilot and was easily read in all conditions. Calibration was fairly accurate throughout the range of 30 to 40 megacycles per second but the identification of beams by keyed letters was necessary in order to ensure accuracy in homing. Servicing was very much easier because the components which gave the most trouble in the fixed receiver were eliminated.[2] The trials were so successful that Headquarters No. 8 Group (P.F.F.) requested that all its operational aircraft should be fitted with the tunable S.B.A. receiver in the existing form; improvements were to be incorporated later as modifications. The Air Ministry agreed at the end of September to provide 60 receivers for extended trials. In November Headquarters No. 8 Group stated a requirement for 150, but provision on such a scale was difficult because of the decision taken on 5 November 1943 not to renew the existing S.B.A. contract but to concentrate on the installation of

[1] A.M. File CS.18395.

[2] Bomber Command File BC/S.20755/2.

G.C.A. and B.A.B.S. Although large-scale production of the tunable receiver was impossible it was agreed that a requirement for a small number of tuning controls could be met by a continuation of an existing small contract for transport aircraft installations. Headquarters Bomber Command required the installation of tunable receivers in aircraft of Nos. 139 and 627 Squadrons and Nos. 1409 and 1507 Flights because they frequently operated when the weather was so bad that operations by the main force were impracticable. 60 receivers were required initially and thereafter 10 per month. In December the Air Ministry allocated 100 to Bomber Command because the Transport Command requirement had been cancelled. In January 1944 Headquarters Bomber Command reported that the use of tunable receivers by Mosquito aircraft of No. 8 Group was giving very satisfactory results and asked for the provision of an additional 150. This was agreed by the Air Ministry but production was not guaranteed before July 1944.[1]

In August 1944 it was estimated that electrically-tuned receivers could not be produced for at least eighteen months, but a supply of mechanically-tuned receivers, sufficient to meet the requirements of Flying Training Command for the next two years, could be adapted immediately from existing stocks of fixed-tune receivers. This was considered to be sufficient because it was believed that in two years' time Flying Training Command would have been equipped with V.H.F. R/T equipment and would be able to use V.H.F. B.A.[2] In October 1944 electrically-tunable receivers were installed in one Lancaster Mark X and two Halifax Mark III aircraft at Ludford Magna and Service trials were held throughout that month and the following one. The pilots who carried out the trials were experienced S.B.A. pilots and they considered the equipment to be superior to the fixed-tune receiver, both in sensitivity and in selectivity. As a result Headquarters No. 6 Group stated a requirement for its installation as the prospect of obtaining B.A.B.S. seemed very remote. The requirement could not be met because of the production delay and Headquarters Bomber Command preferred to make immediate use of mechanically-tuned receivers and to rely on G.C.A. and B.A.B.S. as long-term approach systems.[3]

On 16 November 1944 the Air Ministry decided that further development of electrically-tuned receivers was to stop, and that mechanically-tuned receivers were to be installed, on the production lines, in all aircraft which were to be fitted with S.B.A. Production of the new receiver would be achieved by modification of the fixed receiver R.1124, of which there was a stock of 16,500. Delivery of the tunable receivers was not as speedy as had been anticipated, however, and in June 1945 the Air Ministry was forced to issue instructions that certain aircraft were to be equipped with the fixed-tune receivers. These were to be replaced when tunable receivers became available. It was estimated that main production would begin in January 1946 when priority of installation would be allotted to training aircraft because S.B.A. would be the only approach system available to them.[4]

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[1] Bomber Command File BC/S.20755/2. [2] A.M. File A.85487.

[3] Bomber Command File BC/S.20755/2.

[4] A.M. File S.87187, Part II. Mosquito aircraft of Bomber Command which were equipped during the summer of 1945 retained the equipment.

Experiments were conducted in No. 26 Group on the possibilities of distinguishing between the front and back beam. There were two possible methods. The simplest was one in which a screen provided with an earthing switch was placed behind the beam aerial. When the screen was earthed signals were received normally. When the screen was isolated the pilot could home towards the main beacon by turning the aircraft through 360 degrees and flying the heading on which maximum signal strength was received. The second method was less clumsy; the two letters of the identification characteristic were so transmitted that when the pilot received the signals in the front beam the first letter was picked up at a greater strength than the second; in the back beam the reverse was the case. If a pilot approached the main beacon at right-angles to it the two letters were heard with equal intensity. It was considered that the second system was the more successful but its introduction entailed the use of an entirely new equipment designed by Marconi; the existing ground equipment manufactured by Standard Telephones and Cables could not be modified. It was the method eventually chosen but by the time all technical difficulties had been overcome the decision to abandon operational use of S.B.A. had been taken. Installation was therefore restricted to radio track guides and the installations retained for use by training aircraft.[1]

In March 1943 the R.A.E. was instructed to investigate the problem of back-radiation. The object was to reduce its strength but at the same time to keep the beam-width within reasonable limits. The early research was done on the V.H.F. approach beacon because of its smaller size and it was believed that if a satisfactory solution to the problem was found for aerials operating on 120 megacycles per second, a similar scheme could be easily adapted for aerials operating on 30 to 40 megacycles per second. After experiments with reflectors behind the aerial array had been conducted work was transferred to the S.B.A. transmitters. The solution of the problem was achieved after about three months' work by clamping two reflectors to a tube frame which was attached to the centre S.B.A. mast. A further mast was erected behind to increase stability. The result was an increase in range of the front beam to about 45 miles and a decrease in that of the back beam to about 10 miles.[2]

Certain economies were effected in the S.B.A. equipment programme as a result of the Inspector-General's report, but supplies could not be drastically reduced because there was nothing to replace the system. Before the report was issued the aircraft equipment programme was planned to cover all aircraft for which S.B.A. was approved, plus maintenance requirements and a stock to meet contingencies. The normal stock holding was for six months, covering both aircraft equipment and maintenance. It was decided to reduce the stock to that required for three months' aircraft supply and six months' maintenance. As a result of this economy the number of sets ordered on the existing contract was reduced. It was agreed that installation of ground equipment should proceed at the rate of one beam for each clutch. Cabling of all new stations was continued and installations were to be completed if they were so far advanced that there would be no material saving if work was stopped.[3]

Another result of the Inspector-General's investigation was that the trials in which S.B.A. was being used as a method of controlled approach to the airfield were intensified. The Inspector-General considered it to be a promising

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[1] A.M. File S.87187. [2] R.A.E. Technical Note No. 135. [3] A.M. File A.85487.

line of development but thought that Downham Market was unsuitable because the surrounding flat country made approach very easy. He recommended Holme as a more suitable location for the experiments because it was in difficult country and because the station was commanded by an S.B.A. expert and enthusiast.[1] The Air Ministry agreed and the trials were continued by No. 101 Squadron. They lasted from 10 April to 4 May 1943 and were designed to find out whether a method of approach known as the 'Gate' procedure was workable. This entailed the placing of an additional marker, the gate, in the beam at a distance of 5¼ miles from the outer marker. When aircraft were 40 miles from the gate their estimated time of arrival at the marker was passed by R/T to flying control at the airfield. If more than one aircraft estimated similar times, flying control regulated them by instructing others to delay their arrival by an appropriate number of minutes. When a pilot reached the gate and heard the marker signal he announced his identity and was instructed by the controller either to go ahead or to wait for a certain period. This filtering was necessary so that aircraft might fly along the beam safely. Once the pilot was authorised to go ahead he flew down the beam and again announced his identity after passing the outer marker, and landed on the appropriate runway after being given appropriate instructions. The procedure involved certain modifications to the aircraft receiver and the addition of the extra marker on the ground, whilst it was necessary to replace the TR. 9 with the TR. 1196 because the former provided insufficient R/T range. The objects of the trials were to find out whether the procedure could be used by an average bomber pilot on return from operations, whether it would speed up the rate of landing, and whether it could be used in low visibility. The results were rather disappointing. It did not appear to be a working proposition when used by the average pilot trained to wartime standards.[2] The trials were successful for seven operational nights when the weather was clear but on the eighth, with a fog bank between the outer and inner markers, three crashes occurred. Later investigation revealed that on the clear night pilots were flying by visual contact though no doubt using the beacon as well. On the eighth night the inexperienced pilots were unable to fly accurately by the beam alone.[3] It placed too great a reliance for accurate timing on navigators and pilots fatigued on return from operations and imposed heavy strain on flying control staff. It was considered that the standard of instrument flying of most wartime-trained pilots was not high enough for a safe final approach in poor weather conditions. The failure did not rest entirely with the pilot as the existing blind-flying instruments were not sufficiently accurate and further research was needed. It was clear that the first essential for increasing the rate of landing was experienced crews and ground staff.[4]

Decision to Substitute B.A.B.S. and G.C.A. for S.B.A.

One of the most important factors which had governed the policy of S.B.A. provision was the absence of an effective substitute; even if S.B.A. was not used extensively for the purpose for which it was intended it was the best approach system then available.[5] However, whilst the wisdom of expending still more effort and resources on its further development was still being

[1] Group Captain R. S. Blucke, the pilot who carried out the first trials in England of the *Lorenz* equipment in 1936. From 8 November 1940 to early 1942 he had been at the Air Ministry (T.F.3) in charge of the arrangements for S.B.A. training.

[2] A.M. File S.94886. [3] A.M. File S.94886. [4] A.M. File S.87187.

[5] A.M. File S.87187.

questioned a new approach system came to the notice of the Air Staff. This was Ground Controlled Approach, invented by an American, Dr. L. W. Alvarez. The system was given trials in the United Kingdom in July and August 1943; these proved that G.C.A. was the safest and most efficient radar approach system then invented. The discovery of this new method had a great effect on the future of S.B.A. By September 1943 a declaration of Air Staff policy on its continued use within the Service was urgently required because since publication of the Inspector-General's report that its operational use in Bomber Command did not justify the effort expended on it anxious queries had been received from overseas flying training schools as to whether S.B.A. was still being used operationally. Reports that little use was made of it had reached them and the authorities considered that, if this was so, the extensive training and the installation of the equipment was unnecessary. The Air Ministry was unable to give a definite decision on the future operational use of S.B.A. but the overseas flying training schools were assured that, although the value of the extensive S.B.A. programme had been questioned, the only alternative approach system was G.C.A., the widespread adoption of which seemed unlikely for at least eighteen months.[1] Therefore, S.B.A. training was to be continued, especially as it provided invaluable instrument training. In September 1943 a committee was formed to investigate the requirements of radio aids for flying control and to recommend what the future Air Staff policy should be. Special attention was paid to the needs of Bomber Command. The report of the committee, published at the end of September, stated that S.B.A. was an efficient navigational aid and could be used as an approach aid but it was very little used by operational aircraft as an aid to landing in bad weather. It referred to the opinion of the Inspector-General that the effort put into S.B.A. was not justified by the operational results but that it could be a valuable method if pilots had confidence in their ability to use it and a control method was evolved to speed up the rate of landing. Some of the technical improvements which the Inspector-General had recommended had been incorporated but the main one, the introduction of a variable tuning receiver, had been delayed until the future of the system had been decided because it entailed a major production programme which could not be completed for two years. The committee considered that the failure to employ S.B.A. on a large scale was attributable to several causes; training difficulties, technical faults, and the strain endured by the pilot because he had to interpret aural signals in addition to carrying out normal instrument flying. By April 1943 40,000 aircraft sets had been manufactured and a further 22,000 were on order. This involved great expenditure of productive effort, manpower and material which hampered the manufacture of radar systems. The final recommendation of the committee was that if there were available an effective alternative equipment which relieved the operational strain on the pilot and could be produced and operated economically, it should be substituted for S.B.A. The existing S.B.A. equipment could be used for training because it was an excellent aid to instrument training. The relative merits of two other approach systems were assessed, Radar Beam Approach Beacons and Ground Controlled Approach. It was stated that both S.B.A. and Radar B.A.B.S. required a radio glide path indicator for perfect presentation because neither of them indicated the position of the aircraft on the correct glide path. The committee considered that G.C.A.

[1] A.H.B./ID/12/308. Standard Beam Approach.

should be adopted as far as possible and that where its use was limited because of the communications problem Radar B.A.B.S. should be employed. Contracts for S.B.A. equipment could be adjusted so that the supply to Bomber Command could continue until the alternative systems were available.[1]

On 5 November 1943 the Air Staff agreed that G.C.A. should replace S.B.A. where it could be made available and that the radar beam approach equipment should be fitted where it was impossible to site G.C.A. installations. The use of S.B.A. was to be gradually discontinued and the existing contract for it was not to be renewed. This contract would provide sufficient S.B.A. equipment to fulfil 100 per cent of aircraft requirements until September 1944 and 50 per cent for the first six months of 1945. If the production and use of G.C.A. and B.A.B.S. were unsatisfactory the contracts could be renewed in the middle of 1944, and 1 July 1944 was chosen as the date for review of the position. Although the operational use of S.B.A. was to be discontinued it was to be retained at advanced flying training schools because S.B.A. training ensured a satisfactory standard of instrument flying.[2] The use of S.B.A. overseas had been confined to the Empire Air Training Scheme flying schools and it was never installed for operational use in the Mediterranean, India or South-East Asia theatres of operations. The decision was straightforward but its implementation was made difficult because the introduction of G.C.A. and B.A.B.S. took longer than had been anticipated. It was obvious that the changeover would take some time and the Air Staff wished the use of S.B.A. to be continued until it was completed. But in the early months of 1944 it appeared that use of S.B.A. was becoming increasingly neglected, not only operationally in Bomber Command but also in training at the advanced flying training schools. On the night of 16/17 December 1943 exceptionally heavy losses were incurred by Bomber Command aircraft on return from operations. The Inspector-General conducted an enquiry and attributed the losses to two causes; one, the lack of any pre-planning and practice of a scheme for homing in bad weather and, secondly, the almost complete neglect of S.B.A. It was noticeable that losses were light in No. 5 Group, where bad-weather homing plans were carefully worked out and the majority of crews were kept in S.B.A. practice. The Inspector-General stated that an impression that S.B.A. was obsolete had been created. Consequently S.B.A. was tending to be devalued within Bomber Command and it was feared that heavy losses in men and aircraft would result. The Air Ministry considered, however, that there had been no appreciable reduction in the use of S.B.A., and it was concluded that neglect of S.B.A. was not the primary cause of the heavy losses in December.[3] Headquarters Bomber Command believed that

[1] A.M. File S.87187. [2] A.M. File S.87187.

[3] Number of occasions on which S.B.A. was used during poor weather conditions by aircraft on operational flights :—

	No. 1 Group	*No. 4 Group*
*December 1942	49	118
October 1943	37	64
November 1943	65	52
December 1943	106	74

Number of occasions on which S.B.A. was used by aircraft on training flights :—

*December 1942	240	172
October 1943	109	215
November 1943	65	254
December 1943	100	218

* At the time of the Inspector-General's investigation into the use of S.B.A. (A.M. File S.87187, Part II.)

the chief reason for the high accident rate then was the sudden deterioration of the weather at home bases, but was, however, requested by the Air Ministry to encourage further training and operational use of S.B.A., even though it was to be replaced eventually.[1]

A review of the S.B.A. programme had been planned for 1 July 1944, when the question of renewal of contracts was to be decided. At the end of February 1944 it was clear that, owing to delays in production of G.C.A. and the slow development of Eureka B.A. for use with Lucero, it would not be possible to supply Bomber Command with a substitute before the existing supply of S.B.A. equipment had been exhausted.[2] The Air Ministry informed Headquarters Bomber Command that the introduction of G.C.A. and B.A.B.S. would not be completed for eighteen months and that installation of S.B.A. equipment in all bomber aircraft would not be possible after about six months. Therefore, unless the S.B.A. contract were renewed there would be an interim period during which the command would have neither S.B.A. nor more than a limited number of G.C.A. sets. The renewal of large-scale S.B.A. production would seriously affect the production of other radar equipment and it was necessary to decide whether S.B.A. was an essential operational requirement for all bomber aircraft during the interim period.[3] At the beginning of May Headquarters Bomber Command decided that S.B.A. was to be removed immediately from aircraft of Nos. 1, 4 and 5 Groups. No. 3 Group would remove it during the interim period if necessary and Nos. 6 and 8 Groups would retain it until more modern aids were available. Headquarters Nos. 1, 4 and 5 Groups had decided that until B.A.B.S. was available, Gee would be used as a means of locating and approaching airfields. The interim use of Gee was considered a safe expedient, but it was an expedient and nothing more.[4] Such an arrangement would eke out the supply of S.B.A. and would not affect the production of radar equipment. Of the bomber training groups No. 91 Group wished to retain S.B.A. Installation on production lines of Lancaster, Halifax and Wellington aircraft was to be continued for as long as the equipment was available.[5]

In September 1944 an appreciation was made of S.B.A. ground installations. Commands were still reluctant to do without them before replacements were provided although less use was being made of them. In Bomber Command 50 installations were in operation and 11 were projected but it was estimated that these would be redundant in March 1945 when it was hoped 60 to 70 airfields would be equipped with B.A.B.S. Mark II. In Coastal Command 10 installations were in operation but these could be dispensed with when B.A.B.S. Mark IC (A.S.V. B.A.) became available, at, it was hoped, the end of 1944, although even then some S.B.A. installations would still be required for the use of diverted bomber aircraft. 11 installations were in operation and one was projected at airfields of the Allied Expeditionary Air Forces mainly for the use of diverted bomber aircraft, troop carrier aircraft, and glider tugs of No. 38 Group. It was estimated that the requirements would lapse by February 1945. In Transport Command six installations were in operation and four were projected; they

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[1] A.M. File S.87187, Part II. No. 8 Group made extensive and successful use of S.B.A. operationally, mainly because the pilots were more experienced and it was the only group in which S.B.A. was installed at every airfield.

[2] A.M. File S.99682. [3] A.M. File S.87187, Part II. [4] A.M. File S.97074.

[5] A.M. File S.87817, Part II.

would not be needed when SCS. 51 became available.[1] It was concluded that the total number of installations required was 103; at that time 105 S.B.A. ground installations were in service and 21 were under construction.[2]

Withdrawal of S.B.A. in 1945

Throughout the early months of 1945 the operational commands listed the airfields at which they no longer required S.B.A. If the installations were not required by another command which was willing to provide the necessary servicing personnel they were closed and the equipment recovered. Although not using it extensively Bomber Command was unwilling to discard S.B.A. until alternative systems were in operation. In February 1945 Headquarters Bomber Command requested the amendment of the original policy by which, in order to avoid duplication of approach systems, S.B.A. was to be removed immediately the installation of B.A.B.S. Mark II had been completed. It was considered necessary to retain S.B.A. at 48 airfields until all operational bomber aircraft were fitted with Lucero or Rebecca Mark VI.[3] This was agreed by the Air Ministry because the works services involved were not unduly extensive. At stations where simultaneous siting of S.B.A. and B.A.B.S. was impossible the removal of S.B.A. had to be accepted but normally it was reinstalled at an adjacent airfield, so that simultaneous operation of both equipments was possible and there was not a large gap in the S.B.A. cover. By March 1945 S.B.A. had been replaced in Coastal Command by B.A.B.S. Mark IC, except at five airfields, and was in operation at 13 Fighter Command airfields.

Plans were formulated for the almost complete withdrawal of the system. Flying Training Command was to continue the use of S.B.A. and radio track guides for instrument-flying training until they could be replaced, possibly in 1947, and Transport Command until SCS. 51 could be obtained from the U.S.A. In Bomber Command the number of ground installations was to be progressively reduced in phase with its decreasing use by aircraft until bombing operations against Germany were no longer required. The supply of aircraft equipment was to be constantly revised as other systems became available. By 1946 the changeover to B.A.B.S. had almost been completed. In April, 26 S.B.A. installations remained in the operational commands, 35 in Flying Training Command, and six at airfields used in emergency and by experimental aircraft and it was decided in the following month that S.B.A. equipments no longer required by the R.A.F. were to be transferred to the Ministry of Civil Aviation.

Radio Track Guides

S.B.A. beacon transmitters were used mainly as homing beams by pilots of bomber aircraft, and in March 1941 an extension of the system was suggested when Headquarters Bomber Command proposed that high-power beam beacons should be sited on the east coast of England for the use of aircraft returning from operations over Germany.[4] It was anticipated that the planned increase in the number of aircraft engaged on the bombing offensive would place

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[1] A.M. File S.87817, Part II. [2] A.M. File CS.19063. [3] A.M. File S.87187, Part II.

[4] A plan to use them for target-location had been abandoned because range was too limited.

a severe and impracticable strain on the wireless direction-finding organisation, successful use of which, in any event, depended entirely on the continued serviceability after a bombing raid of aircraft W/T equipment.[1] In addition, it was hoped that use of a radio beam homing system might confuse the enemy radio intelligence to such an extent that unrestricted use of Gee, to be introduced into operational use the following year, might be prolonged before the inevitable jamming measures were started.[2] A trial installation of a high-power beam transmitter, similar to the main beacon used in S.B.A., was made at Cransford, near Southwold, in July 1941. The installation was static and its beam, 10 degrees in width, was directed towards Cologne. No. 3 Group was detailed to carry out trials, but all aircraft equipped with an S.B.A. receiver were encouraged to make use of the beam. The transmitter was within V.H.F. radio range of enemy-occupied territory so, in order to minimise the risk of jamming and the possibility of providing the enemy with an indication of the direction of attack, it was not switched on until the first aircraft were due to leave the target, and then only when the return route was via western Germany and the Low Countries. The beam could not therefore be used for navigation on the outward track and, because the alignment of the beam was fixed, its usefulness was strictly limited. Ranges of 100 to 150 miles were obtained, and although many pilots still preferred to use airfield S.B.A. installations, which in many instances happened to be on or near the homeward track, and which could be used for homing to base, its value and potentialities were clearly recognised. Three high-power beam transmitters were consequently installed at Cransford, Fulstow and Haine. The aerial systems were rotatable so that the beam could readily be aligned on any bearing to within an accuracy of less than 10 seconds of arc. The Cransford and Fulstow transmitters operated on a frequency of 36 megacycles per second and that at Haine on 36·4 megacycles per second, and the width of the beams was reduced to 1½ degrees. At each site an outer marker beacon was installed at a distance of approximately 50 yards from the main beacon. It transmitted continuously a beam identification letter, provided navigators with a pinpoint location of the beam, and enabled the risk of following the back beam to be avoided. The restriction preventing operation of the beams before aircraft left the target was removed, and crews were encouraged to make maximum possible use of the system for navigation both to and from the target. The beams were known as radio track guides or 'Jay' beams.[3] The Cransford beam (Jay beam 'B') was aligned on the main target whenever it lay eastward of England. The Fulstow beam (Jay beam 'C') was, as far as possible, aligned along the normal route to the main target followed by the aircraft of Nos. 1, 4 and 5 Groups if this was not through East Anglia. Care was taken to ensure that the two beams did not converge closer than 50 miles at a distance of 100 miles from Cransford. The Haine beam (Jay beam 'D') was aligned on Den Helder to intersect with the Cransford beam so providing a definite fix over the North Sea on the route to the target area. The alignment of beams 'C' and 'D' was given to navigators at briefing before an operation. The Jay beams provided good ranges, averaging about 350 miles to aircraft at 10,000 feet. The use of the beams to assist in target location did not in any way affect their value as homers, as they were kept in operation continuously

[1] Bomber Command File BC/S.25857. [2] A.H.B./IIE/76A. 'War in the Ether.'

[3] Bomber Command File BC/S.25857.

whenever bombing raids were in progress. Crews were briefed to keep just inside the beam, checking direction occasionally by flying to the edge, which was sharply defined, or to wander from one side of the beam to the other in an attempt to counteract the assistance given to the enemy for interceptions. Navigators found the beams of value because they could always obtain a position line which, combined with a D/F loop bearing, gave them a reasonably accurate fix. Crews soon began to make extensive use of radio track guides, and it was estimated that, by the end of March 1942, over 50 per cent of aircraft on bombing operations used the system. One disadvantage of the use of radio track guides for long-range homing was the additional strain it placed on a tired pilot in that he had to listen continuously to a monotonous signal.[1]

Throughout 1942 more beams were installed along the east coast of England, and in May Headquarters Bomber Command reported that although these beams were of value their usefulness was restricted by the limited arc through which the rotatable aerial system was effective and the unreliability of the back beam.[2] S.B.A. transmitters were also set up to act as track guides at Prestwick, Squires Gate, Silloth, and Valley for the benefit of aircraft flying across the Atlantic Ocean. The first three were directed at an M.F. leader beacon sited at Lough Erne. Aircraft homed to the leader beacon by using D/F loops and were then directed to an airfield, which they located by flying along the track guide. At the actual site of the S.B.A. transmitter a marker beacon was installed to indicate arrival at that point.[3]

In April 1944 a scheme was devised by Headquarters No. 26 Group and the Empire Central Flying School for the provision of a chain of radio track guides extending over the British Isles. It was aimed to provide navigational assistance for all aircraft equipped with S.B.A., particularly in areas where airfield concentration was greatest. Navigation to individual airfields from the tracks provided was to be made by dead-reckoning and with the assistance of local navigational aids such as beacons. The scheme was designed to fulfil three functions. First, to enable Flying Training Command aircraft to fly with safety in and above cloud and to provide a safe means of breaking cloud at any time during flight. This would permit training to be carried out in worse weather conditions than was then possible. At that time training was confined, with certain exceptions, to flights below cloud, because of the danger involved in breaking cloud without adequate radio navigational assistance. Secondly, to enable Flying Training Command to give more effectively the intensive training in cloud flying which was an urgent requirement and thus to raise the standard of instrument flying. Thirdly, to enable communication flights by aircraft not equipped with radar to be undertaken in safety when bad weather would normally make such flights impossible. The existing radio track guides, except the one between Hendon and Prestwick, formed no definite system of air routes, but when used in conjunction with the 130 approach beams installed at airfields they provided an almost continuous navigation system. The decision taken in November 1943 to discontinue gradually the use of S.B.A. in Bomber Command would reduce the number of S.B.A. installations and continuous guidance would not be available.

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[1] A.H.B./IIE/76A. [2] Bomber Command File BC/S.25857.

[3] A.H.B./IIK/54/1/7. Coastal Command Atlas of Aids to Navigation.

The scheme involved the establishment of eleven new radio track guides, the reorientation of three existing ones and the equipping of all Flying Training Command aircraft with S.B.A. At that date a maximum of six frequency channels was available on the S.B.A. receiver. This meant that five frequency channels could be used for the track guides, the remaining one being left for the local S.B.A. installation at the destination. Consequently track guides operating on the same frequency would need to be located 80 miles apart because of the danger of mutual interference, and the number that could be sited in any specific area was limited. A number of existing S.B.A. installations would have to be closed down because it was essential that radio track guides operated on high power. It was therefore proposed that the disposition of airfield S.B.A. installations should be replanned on a regional and geographical basis rather than on the existing basis of one per clutch of three airfields. It was assumed that a range of 120 miles at 2,000 feet would be available, 60 miles each for the front and back beams. Operation of the scheme required an adequate measure of control, and four methods were proposed. First, markers operating on track guide frequencies were to be placed at track intersections and at frequent intervals along the track. Secondly, markers were to be placed at all track guide transmitters for positive 'cone of silence' identification. Thirdly, speech beam facilities were to be provided on all track guides for broadcasting instructions to all aircraft simultaneously. Finally, a number of control points were to be instituted at regular intervals along all the track guides. They were normally to be at track intersections but common control was to be used where several intersections occurred near the same point. All the equipment required to implement the scheme was available. Only minor items needed to be manufactured and then only in small quantities. The number of personnel required to operate the scheme from sunrise to sunset was 40 exclusive of those required for controlling.

The Inspector-General of the R.A.F. was in favour of the scheme for he considered that S.B.A. could be of great value if used properly, and deprecated the increasing neglect of S.B.A. as an approach system by operational pilots of Bomber Command. In November 1944 the Director of Signals recommended its adoption but pointed out that frequencies could not be made available until the number of S.B.A. installations in the United Kingdom had been substantially reduced. In the meantime, however, it was possible for the installation of equipment to be started. The scheme met with some opposition, as it was considered that the use of M.F. radio ranges would meet the need. After investigation, however, it was decided that the use of M.F. radio ranges would not meet the cloud-flying training requirements of Flying Training Command and that the only short-term method of meeting them was the use of S.B.A., for three reasons. First, 50 per cent of Oxford aircraft had already been fitted with S.B.A. and enough equipment had been supplied to enable a complete installation programme to be made. Secondly, only 20 per cent of Oxford aircraft were equipped to use M.F. radio ranges and very few operators were trained in the use of the equipment. Thirdly, Transport Command needed M.F. radio ranges and the supply of equipment was inadequate to meet the requirement. The use of radio ranges by both Flying Training and Transport Commands would invite flying accidents. The Air Ministry, however, considered that the original scheme involved excessive expenditure in time and money and suggested that a smaller scheme incorporating the addition of one or two track guides to those already existing should be devised.

By January 1945 about 30 airfields in Flying Training Command had been equipped with S.B.A. and it had been decided to equip all Oxford, Anson, and Harvard aircraft with tunable S.B.A. receivers. A new radio track guide scheme was approved by the Air Ministry in June 1945. It involved the use of eleven radio track guides. The three major ones which formed the Hendon to Prestwick air route were to be made available to Flying Training Command when a new route on a different alignment had been provided, by means of M.F. radio ranges, for transport aircraft. Additional routes which intersected as many Flying Training Command beams as possible were to be provided by increasing the power of S.B.A. installations at Sealand, Church Broughton, Chipping Warden, Spitalgate, and Mona. The network was to be completed by the addition of three new radio track guides providing routes from Anglesey to Devon and from Devon to Hertfordshire. It was realised at the time of acceptance that the scheme was a short-term measure because even in Flying Training Command the use of S.B.A. was to be discontinued in 1947.[1]

V.H.F. Beam Approach

Fighter Command, in common with the other commands, required a beam approach system. S.B.A. ground equipment was installed at Fighter Command airfields, but only for the benefit of bomber aircraft in emergency; space limitation prevented the installation of S.B.A. receivers in single-engined fighter aircraft. Experiments in which use was made of the V.H.F. radio telephony equipment installed in fighter aircraft as a means of meeting the beam approach requirement were therefore initiated. Development along similar lines to provide a method by which enemy aircraft, equipped with jammers operating on a frequency band of 100 to 122 megacycles per second, could be intercepted, had already been started, and the system was suitably adapted.[2] The ground equipment consisted of one main beacon operating on frequencies from 100 to 124 megacycles per second, and two marker beacons operating on 360 megacycles per second. The aircraft R/T installation was modified so that the main beacon dot and dash signals could be received, and its output was used in conjunction with a diode detector, an audio-frequency amplifier and a separate aerial system for reception of the two marker beacon signals. No provision was made for visual presentation.[3]

In July 1941 arrangements were made for V.H.F. B.A. equipment to be installed in intruder, night-fighter, and day-fighter aircraft, in that order of priority. Ground installations were to be set up at each night-flying airfield and each sector airfield, with the intention that every sector should have at least one installation for day or night-fighter use.[4] By November 1941 one set of ground equipment had been produced and it was installed at West Malling for trials.[5] 13 operational and two training aircraft had been equipped, and eight operational pilots had been trained in the approach system.[6] The trials were successful and by the end of the year 69 ground installations had been ordered. The same difficulties were experienced as with S.B.A., and the rate of installation was very slow. The West Malling installation was moved to

[1] A.H.B./II/97/1/1. Radio Track Guides. Scheme for British Isles.

[2] Loop aerials were first used for homing, until their inherent disadvantages caused them to be discarded.

[3] Radio Aids to Air Navigation Committee Paper No. 2.

[4] A.M. File S.96994. [5] A.M. File S.67167. [6] A.M. File S.74991.

Bovingdon in January 1942 for special tests, and by the beginning of February 1942 two main beacon transmitters and two marker beacons had been delivered and were awaiting prototype approval by the R.A.E. An installation at Wittering was completed in March 1942 and by the end of that month No. 264 Squadron at West Malling, and the B.A.T. flight and one squadron at Wittering, had been fitted with the aircraft equipment. At the end of 1942 ten transportable V.H.F. B.A. ground equipments were in service and eight were in process of installation.[1]

In May 1944 Headquarters A.D.G.B. was asked to review requirements for V.H.F. B.A. in view of the fact that A.I. B.A. equipment was being made available. At the end of the month it was agreed that although there was no requirement for V.H.F. B.A. in single-engined day-fighter aircraft, it was still required in night fighters and in intruder aircraft; if, after trials, A.I. B.A. was found to be superior to or as good as V.H.F. B.A., the possibility of dispensing with the latter altogether was to be considered.[2]

[1] A.M. File CS.12820.

[2] A.M. File S.96994.

CHAPTER 17

BEAM APPROACH BEACON SYSTEM

The Beam Approach Beacon System was a combination of the principles of two existing radio systems, radar responder beacons and the *Lorenz* beam. An airborne interrogator transmitted pulse signals, on receipt of which the responder beacon retransmitted dot and dash signals by means of two aerials to the right and left of the runway, the power being switched alternately between the two aerials. The signals overlapped to form the beam, an equi-signal zone in the centre, which was aligned along the centre of the runway to form the approach path. The signals were received by the airborne apparatus and displayed on a cathode ray tube. The operator obtained information from the CRT display of the position of the aircraft in relation to the beam because the beam transmission was so arranged that the strength or amplitude of the pulses increased as the beam was approached. Continuous range information was derived from a measurement of the time taken by the pulses to make the double journey at the known and constant speed of radio waves. The first B.A.B.S. equipment was devised early in 1941 at a Coastal Command station in Northern Ireland. An I.F.F.-type beacon based on the A.S.V. homing beacon was used with A.S.V. Mark II as an airborne interrogator. An improved version was built by the Telecommunications Research Establishment, which also designed a version for Fighter Command for use with A.I. A.S.V. B.A. was adopted for Coastal Command and A.I. B.A. for Fighter Command, and installation proceeded slowly throughout 1943 and 1944. There were some serious faults in this early system, B.A.B.S. Mark I as it was later designated, but it proved a useful approach aid in both Fighter and Coastal Commands.[1] In 1943 a Bomber Command requirement arose for B.A.B.S. to be used in conjunction with Lucero; insufficient range was obtained with B.A.B.S. Mark I. Development began at the Telecommunications Research Establishment in 1943 of B.A.B.S. equipment operating on a wide frequency band, using Eureka as the ground beacon and Lucero or Rebecca as the aircraft interrogator. Many of the faults of the older version were eliminated; in particular the aerial system was much improved. It transmitted on the Bomber Command frequencies of 214 to 234 megacycles per second. Successful trials were held at the beginning of 1944 and in the autumn of that year it was decided that the new system should be adopted as the main approach aid for Bomber Command. A large-scale programme was initiated. During experimental work the equipment was known as Eureka B.A., later as Lucero B.A., and in June 1944 the name was changed to B.A.B.S. Mark II. A mobile version, known as B.A.B.S. Mark IIM, and an air transportable version, B.A.B.S. Mark IIA, were also developed. B.A.B.S. Mark II was easily modified to operate on Fighter Command frequencies, 190 to 196 megacycles per second, and this version was called B.A.B.S. Mark IIF, while the Fighter Command mobile version was referred to as B.A.B.S. Mark IIFM. Installation of this equipment had not proceeded far by the end of the war because of the slow rate of production.

[1] A.S.V. B.A. became B.A.B.S. Mark IC, and A.I. B.A. became B.A.B.S. Mark IF, in 1944.

Early Development of A.S.V. B.A.

The first use of A.S.V. beacons as a beam approach system was made in February 1941 at Limavady in Northern Ireland where No. 502 Squadron was stationed. A method of using A.S.V. homing beacons for beam approach, employing the *Lorenz* principle of interlocking dot-dash signals to form an equi-signal zone, was devised by Mr. Hinkley of the T.R.E., signals officers at the station, and certain pilots of No. 502 Squadron who showed exceptional interest in the homing beacon.[1] Its obvious advantage over S.B.A. lay in the fact that the pulse system gave continuous range information. At Limavady a one-degree beam was produced by the use of two five-element Yagi aerials taken from a Wellington aircraft and the output of an I.F.F. set was switched on to each aerial in turn but for different time periods.[2] Reports of the use of an A.S.V. beacon as a beam approach aid were given to the Air Ministry, Ministry of Aircraft Production and the T.R.E. by a member of the staff of the Radio Department, R.A.E., after a visit to Limavady in February and March 1941.[3]

On 18 March 1941 Mr. A. P. Rowe, Superintendent of the T.R.E., obtained authority from the Ministry of Aircraft Production to begin a programme of research into the use of A.I. and A.S.V. beacons for blind approach. By May of that year sufficient progress had been made, and sufficiently promising results achieved, to warrant operational trials at the Coastal Command Development Unit at Carew Cheriton, which were held in June 1941.[4] The experimental model was then given trials at Abingdon so that its performance might be compared with that of S.B.A. At a meeting at the Ministry of Aircraft Production on 25 July 1941 the official opinion expressed on the system was that, as it stood, it was no better than S.B.A., but it was cheap and mobile and was a potential requirement for Coastal Command airfields, most of which were not equipped with S.B.A.[5] At this meeting it was recommended that the new system should be tested at a Coastal Command station in Service conditions. Limavady was chosen and later trials were also held at Wick and St. Eval. Headquarters Coastal Command had to rely on the resources of the T.R.E. for the provision of the necessary equipment for the trials because no contract could be placed with a radio firm until specific requirements could be formulated. It was therefore agreed that the T.R.E. should manufacture three sets of aerials operating on 176 megacycles per second and two more sets operating on 214 megacycles per second. The first T.R.E. experimental model had operated on the latter frequency.[6]

The interim A.S.V. B.A. system developed by the T.R.E. was a modified version of I.F.F. Mark IIG used in conjunction with A.S.V. Mark II.[7] The ground equipment consisted of two A.S.V. beacons, the first of which was the homing beacon and the second the approach beacon. The homing beacon was similar to those already in use in Coastal Command and was used in conjunction with an aerial system giving a horizontally polarised radiation pattern. The homing beacon worked on a fixed radio frequency, that of A.S.V., and its output was coded for recognition purposes. An I.F.F. Mark IIG set was installed in a 10 cwt. van and two Yagi aerial arrays with a switch box were mounted above

[1] M.A.P. File SB.2456. [2] T.R.E. Report No. T.1740. [3] M.A.P. File SB.2456.

[4] M.A.P. File SB.18641. [5] A.M. File CS.18619. [6] M.A.P. File SB.18641.

[7] *See* Royal Air Force Signals History, Volume V : ' Fighter Control and Interception ', for details of I.F.F., and Volume VI : ' Radio in Maritime Warfare ', for details of A.S.V.

the roof of the van.[1] The I.F.F. set was modified to work on a single fixed radio frequency and the coding mechanism was put out of action. The approach beacon operated on a radio frequency 2½ megacycles per second higher than that on which the A.S.V. transmitter and the homing beacon worked. This had the effect of reducing possible confusion due to the two beacons operating in close proximity and also reduced interference from ground echoes, enabling the approach beacon signal to be received and observed free of interference. The Yagi aerials were four director arrays mounted on a light wooden framework above the roof of the van so that they could be folded for travelling and extended for use. When extended the longitudinal axes of the aerial arrays were inclined 25 degrees to the fore-and-aft axis of the van, one being inclined to the left and the other to the right. The switch box contained the feeder network, and a motor-driven cam enabled the output of the I.F.F. aerial system to be switched to each aerial alternately. The aerials were symmetrically arranged so that they radiated one to one side of the approach heading and the other to the other side. The aerial that covered the left-hand side of the approach, looking downwind, was energised for approximately two seconds with about half-second intervals, and the aerial that covered the right-hand side was energised for approximately half a second with two-second intervals, so that they interleaved. This gave a two-second dash sector to the left, a half-second dot sector to the right, and a steady continuous equi-signal path in the middle. The equi-signal path was arranged to lie along the approach course. The aerials were so mounted on the motor vehicle that the equi-signal path was along the fore-and-aft axis of the vehicle, shooting forward. The vehicle containing the approach beacon was placed at the upwind end of the runway, with the fore-and-aft axis pointing straight down it. The beacon was switched on only when aircraft were landing.[2]

The homing beacon, the effective range of which was about 75 miles, was used to home aircraft from a distance to within about one mile of the beacon. Pilots were provided with continuous information on the A.S.V. display of the direction and range of the beacon. When within one mile R/T communication was established with airfield control so that landing instructions and barometric pressure information could be obtained. Aircraft were then flown away from the airfield on the reciprocal of the approach heading for a distance of five or six miles. The distance flown from the airfield was indicated on the A.S.V. display by means of the backward radiation from the A.S.V. aerials ; this was not great but was enough for a range of a few miles. When at a distance of approximately six miles from the airfield aircraft turned on to the approach heading and the A.S.V. receiver was tuned from the frequency of the homing beacon to that of the approach beacon.

When the A.S.V. operator received signals from the approach beacon he informed the pilot of the range of the aircraft from the beacon ; this range was given continuously by the position of the approach beacon signal on the time-base scale of the A.S.V. indicator. The A.S.V. operator continued to give the pilot range readings every half-mile until a range of two miles was indicated, after which a reading was given every quarter-mile. The A.S.V. operator also observed whether dots or dashes were reproduced on the display, and this information was also passed to the pilot. If dots only, or dashes and dots with

[1] The Yagi aerial array was a directional aerial system.

[2] M.A.P. File SB.18641.

dots predominating, were received, the aircraft was to the left of the approach path, and if dashes only, or dashes and dots with dashes predominating, were received, then the aircraft was to the right of the approach path. The A.S.V. operator informed the pilot of any deviation from the equi-signal zone and the pilot then made the necessary corrections to regain it. By the dot-dash indications and the range and altimeter indications the pilot was able to fly his aircraft over the boundary of the airfield at the correct height and heading straight towards the runway. The final hold-off and touchdown was done visually and it was emphasised by the T.R.E. from the beginning that A.S.V. B.A. was a blind approach, not a blind landing, aid.[1]

The advantages of this method of approach were many. It required very little additional equipment in aircraft already fitted with A.S.V. There was a great measure of secrecy because the A.S.V. beacon did not radiate continuously but only when interrogated by A.S.V.; security was also ensured by the fact that the signals from the ground could not be received by continuous-wave wireless equipment. The method of approach was much easier than that used with S.B.A.; range indication was continuous whereas with S.B.A. it was only available when the aircraft passed over the marker beacons.

In November 1941 Headquarters Coastal Command stated that trials of A.S.V. B.A. indicated that it fulfilled operational requirements, and they requested provision of 168 fixed and 28 mobile beacons with aerials for installation at landplane stations.[2] The Air Ministry approved the provision of A.S.V. B.A. equipment for Coastal Command airfields but considered it to be an impracticable system for any command in which aircraft were not already fitted with A.S.V. because of the weight and complication of the aircraft equipment.[3] In December 1941 a development contract was placed with the firm of Murphy Radio for six final-type A.S.V. B.A. sets. Various modifications found necessary as a result of experimental work at the T.R.E. and of the Coastal Command trials were incorporated. The R.A.E. was appointed the supervisory design authority in conjunction with the T.R.E. In the meantime, the T.R.E., in response to a request from Headquarters Coastal Command, agreed to construct further interim-type A.S.V. B.A. installations from I.F.F. Mark IIG because of the urgent need within the command for adequate beam approach coverage. By March 1942 five such sets had been made, all of which were in operational use.[4]

In January 1942 Headquarters Coastal Command reported that trials had been carried out with two methods of beam approach for flying-boats. The first consisted of homing over a beacon installed in a launch, sited at the downwind end of the safe landing area, and the second of landing along a beam, the beacons being sited on the windward shore. Both methods were considered superior to S.B.A. and an operational requirement for A.S.V. B.A. for flying-boat bases was raised.[5] At a meeting of the Radio Aids to Air Navigation Committee held at the end of January 1942 Headquarters Coastal Command repeated its belief that A.S.V. B.A. was preferable to S.B.A. and agreement was therefore reached that the necessary modifications to aircraft radar equipment to enable beam approach procedure to be followed should be permitted in all Coastal Command aircraft.[6] In March 1942 the Air Ministry obtained

[1] M.A.P. File SB.18641. [2] A.M. File CS.18618. [3] A.M. File CS.18619.
[4] M.A.P. File SB.18641. [5] A.M. File CS.18619. [6] A.M. File CS.18618.

authority from the Treasury Inter-Service Committee for the provision of beam approach facilities at 43 landplane and 17 flying-boat stations in Coastal Command, and a production contract for 163 final-type A.S.V. B.A. installations was placed with the firm of Murphy Radio.[1]

Development of Final-Type A.S.V. B.A.

Development of the final-type A.S.V. B.A. was undertaken by the firm of Murphy Radio under the supervision of the T.R.E. and the R.A.E. In place of the I.F.F. Mark IIG set, which had been used in the experimental stages, the A.S.V. homing beacon was adapted for beam approach purposes. This homing beacon employed the I.F.F. principle and was found readily adaptable for the approach role because it required only the addition of an aerial switch unit to provide the interlocking dot and dash signal path. The transmitter/receiver unit and the AC power unit of the homing beacon were retained but the coding unit was replaced by a battery-driven power unit embodying a rotary convertor and an aerial switching unit.[2] The receiver received pulses from the aircraft interrogator, amplified them and caused them to trigger the transmitter. This radiated energy in two broad diverging beams. Power was fed into the aerials alternately so that one aerial radiated for a period of 0·2 seconds and the other for the succeeding period of 1·2 seconds, the cycle being repeated indefinitely as long as interrogator pulses were received from the aircraft. The aerial which radiated for the shorter period was called the dot aerial. Viewed from the aircraft during an approach the dot zone was on the left and the dash zone on the right. The aerials were so arranged that the runway lay in the zone in which the signals from both aerials were, so far as the approaching aircraft was concerned, of equal strength. If the aircraft was on the right path to the airfield signals of equal amplitude were received from each aerial. The aerial switching was effected by means of a Post Office Type 3000 relay with two changeover contacts. Stub-line switching was chosen rather than straight changeover switching in order to reduce to a minimum power going into the wrong aerial. The transmitting aerials consisted of two identical six-element Yagis (reflector, folded dipole and four directors) mounted on a framework on top of the beacon.[3] A super-regenerative receiver was used. The beacon operated on a frequency of 176 megacycles per second. In the early days of its development and use the apparatus was referred to as A.S.V. B.A. or A.S.V. B.A.B.S., the code name B.A.B.S. Mark IC, which was given to it later, not being generally used until 1944.[4] When the first model underwent experimental tests at the firm it was found to be unsatisfactory in that it was very susceptible to load variations. It was decided in November 1942 that the superheterodyne principle, as used in A.I. B.A., then undergoing development at the same firm, should be incorporated in the transmitter/receiver unit of A.S.V. B.A.[5]

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[1] M.A.P. File SB.18641. The estimated cost was £100,562.

[2] M.A.P. File SB.18641.

[3] SD.0245(2). Beam Approach Beacon Systems.

[4] When referring to the radar beacon system of beam approach in general, as opposed to a particular version for any one command, the terms B.A.B.S. or radar B.A.B.S. were used, especially when Fighter Command adopted the Coastal Command system and needed a description for it.

[5] M.A.P. File SB.18641.

Early Development of A.I. B.A.

The use of I.F.F. beacons for beam approach with A.I. was begun in the early summer of 1941 by No. 604 Squadron at Middle Wallop, with beacons made locally from I.F.F. Mark IIG.[1] This was known as the two-beacon system and was installed at various Fighter Command airfields during 1941.[2] During that year three schemes based on this principle were developed in Fighter Command but the system was merely an interim measure because it was primarily designed for use with A.I. Mark IV. Meanwhile the T.R.E. developed a beam approach system for Fighter Command which was based on the B.A.B.S. method adopted by Coastal Command. In October 1941 the Telecommunications Flying Unit at Hurn began arrangements for testing the various A.I. B.A. systems developed by the T.R.E. and Fighter Command to find out which was most suited to operational use within that command. The main systems developed were five in number, three using the two-beacon system and two being based on the Coastal Command system. The three versions of the two-beacon system differed among themselves chiefly in the positioning of the beacons on the airfield.[3] Two different versions of the radar beam system were built by the T.R.E. for Fighter Command and were installed at the T.F.U. Hurn for comparative trials with the other methods in January 1942. One of the models used a battery-driven I.F.F. beacon which fed two independent wire-netting corner aerials through a stub switching arrangement driven by a multi-vibrator. This did not give a satisfactory performance. The other used a beacon constructed from modified I.F.F. Mark IIG and an aerial system comprising two Yagi arrays set at an angle of 25 degrees and separated by a wire-netting sheet. The whole structure was mounted on a wooden framework measuring approximately 10 feet by 6 feet at the base and 10 feet high. A mechanical switching arrangement was incorporated giving dots of $\frac{1}{3}$ second and dashes of $1\frac{1}{3}$ seconds' duration. It radiated on 190·5 megacycles per second. This system worked well with A.I. Mark IV, could be made to work with A.I. Mark V if certain modifications were incorporated, but did not work with Mark VI.[4]

In January 1942 the T.F.U. Hurn made flight tests of the five approach systems, using A.I. Marks IV and V in Anson, Blenheim, Havoc and Beaufighter aircraft.[5] In February 1942 aircrew from the Fighter Interception Unit at Ford and from Nos. 29 and 219 Squadrons visited Hurn and participated in trials.[6] At a meeting at Hurn on 25 February 1942 Headquarters Fighter Command representatives, together with pilots who had participated in the trials, discussed the different approach systems and agreed that the B.A.B.S. system was preferable to the two-beacon system. It was a satisfactory method with an average pilot and operator in conditions of 300 feet cloud-base and 300 yards horizontal visibility.[7] It was recommended that the method should be adopted for Fighter Command but, before stating a definite requirement, Headquarters Fighter Command wanted to hold Service trials at West Malling and requested the provision of equipment for that purpose. The T.R.E. agreed to manufacture the equipment although it was unable to supply more than two

[1] For details of A.I. *see* Royal Air Force Signals History, Volume V : 'Fighter Control and Interception'.

[2] M.A.P. File SB.18641.

[3] M.A.P. File SB.30209.

[4] M.A.P. File SB.18641, Part II.

[5] M.A.P. File SB.30209.

[6] M.A.P. File SB.18641, Part II.

[7] M.A.P. File SB.30209.

aerial systems and one beacon. The trial installation was set up in June 1942 at West Malling where aircrew of No. 29 Squadron carried out trials.[1] At first operation of the experimental beacon was not satisfactory, the chief complaints being that the edge of the pulse was ragged and that the signal faded too rapidly beyond six miles at 1,000 feet. An expert from the T.R.E. was sent to investigate the faults and as a result of modifications effected by him performance was improved.[2] In the late summer of 1942 Headquarters Fighter Command complained of beam shift but by October 1942 T.R.E. modifications, consisting of the incorporation of a new type of aerial and strengthening of the concrete bases, appeared to have eliminated the fault.[3] Twenty hours' flying, mainly in daylight, was carried out with the improved experimental A.I. B.A. equipment, and pilots considered its performance to be satisfactory. There was one suggestion that marker beacons should be introduced to improve the range accuracy but the T.R.E. considered this provision would be unnecessary when the unstable time-base of A.I. Mark IV had been eliminated. The installation was moved to Church Fenton in December 1942 for continuation trials and experimental work. Complaints were again received of beam shift, particularly noticeable during wet weather. In December the entire responsibility for research and development of B.A.B.S. was entrusted to the R.A.E. and experts from that establishment were sent to investigate. The problem was solved by the placing of celluloid cones over the aerial arrays for protection against rain and by the middle of February 1943 the performance of the system was considered satisfactory by Headquarters Fighter Command.[4]

A development contract for six A.I. B.A. installations had been placed with the firm of Murphy Radio in December 1941 at the same time as that for A.S.V. B.A. It was then impossible to draw up any production contract because no operational requirement had been stated.[5] However, at a meeting of the Radio Aids to Air Navigation Committee on 13 January 1942 Headquarters Fighter Command raised an operational requirement for the provision of A.I. B.A. at all night-fighter airfields, subject to the outcome of Service trials being satisfactory.[6] At the end of March 1942 the Ministry of Aircraft Production urged that Headquarters Fighter Command should state a definite and formal requirement, particularly as the Service trials at West Malling in the preceding months had shown that B.A.B.S. was operationally suitable for the command. This requirement was needed so that financial authority might be sought and a production contract placed in time to prevent a serious gap between the completion of development work and the commencement of main production. In April 1942 Headquarters Fighter Command stated that A.I. B.A. was required at 50 airfields, possible overseas demands being included in the estimate. The initial supply of equipment per site was the same as for Coastal Command, namely six aerial arrays, three beacons, two huts and one van. Treasury approval was given in June 1942 and a production contract for 150 equipments was placed.[7]

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[1] A.M. File CS.18619.
[2] M.A.P. File SB.30209.
[3] M.A.P. File SB.18641, Part II.
[4] A.M. File CS.18618.
[5] M.A.P. File SB.18641, Part II.
[6] A.M. File CS.18618.
[7] A.M. File CS.18618. Total estimated cost was £135,000.

Development of Final-Type A.I. B.A.

The A.I. homing beacon was not adaptable for beam approach work so the final type of A.I. B.A. beacon, TR. 3137, was specially developed from the A.S.V. B.A. beacon. It consisted of a transmitter/receiver unit incorporating a superheterodyne receiver, the same AC power and battery-driven units as used in A.S.V. B.A., and an aerial switching unit similar in design and purpose to the A.S.V. B.A. unit but differing in that it incorporated a co-axial cable. The system was housed in a cabinet type of rack. In the development models provision was made to include variable delayed pulse facilities so that the delay on each beacon could be adjusted to suit the runway on which it was operating and so give the homing aircraft a distinct indication of the beginning of the runway. With this feature, the beginning of all runways fitted with the equipment gave a consistent time-base indication to an accuracy of approximately 200 yards.[1] The final type A.I. B.A. was later given the code-name B.A.B.S. Mark IF.

The differences in the construction of the radar beam approach systems developed for Fighter and Coastal Commands resulted from the fact that they were interrogated by different aircraft installations. A.S.V. B.A. was tuned to a fixed frequency of 176 megacycles per second to respond to A.S.V. Mark II while A.I. B.A. operated on a frequency of 193 megacycles per second to work in conjunction with A.I. In the final-type A.I. B.A., aerial system Type 150, consisting of three corner aerials, was used. It was omni-directional, providing 360 degrees of coverage, and vertical polarisation was found to be the most suitable. In A.S.V. B.A., the Type 151 aerial system, using three Yagi aerial arrays, was employed. The aerials were partially directional, with coverage in the horizontal plane of approximately 120 degrees, and horizontal polarisation was used because it resulted in less interference being experienced from sea returns. Both types of approach beacon had an effective range of 10 to 15 miles.[2]

Production of B.A.B.S. Mark I

Work on the development contract for A.S.V. B.A. beacons began in December 1941 and on that for A.I. B.A. beacons in March 1942.[3] A contract for the production of aerial systems for both approach beacons was placed with the firm of Dynatron.[4] As no technical development was required and as there was no shortage of components, production of the aerial systems was fairly rapid and was soon in advance of that of the beacons. Work on the beacons was still largely experimental and even after the contracts were placed and financial authority given, progress was considerably slowed down, both by the shortage of component parts and by various technical problems that required solution. In March 1942 the Ministry of Aircraft Production estimated that the first A.I. B.A. development model would be completed by the end of April and the other five would be ready by mid-July if no major modifications were required as the result of prototype tests. The first setbacks to production occurred through the shortage of components. In May 1942 it was reported that a hold-up in the supply of condensers was causing delay and in June the shortage of rack cabinets had the same effect.[5] To overcome these troubles

[1] M.A.P. File SB.18641, Part II.
[2] M.A.P. File SB.18641, Part II.
[3] M.A.P. File SB.18641, Part II.
[4] A.M. File C.16192/44.
[5] M.A.P. File SB.18641, Part II.

the Ministry of Aircraft Production increased the priority of both items. In August 1942 unexpected technical difficulties were encountered by Murphy Radio in the production of aerial switching units. As the accuracy and safety of the system depended so much on the correct functioning of this part of the equipment the Ministry of Aircraft Production ruled that no attempt was to be made to relax the design requirements in order to keep to the production dates originally forecast. As a result of the difficulties the Ministry of Aircraft Production forecast that the main production of A.S.V. B.A. was not likely to start until the end of October 1942 and that of A.I. B.A. before the end of February 1943.

A further delay in the production of A.S.V. B.A. occurred in September 1942 when it was found, on testing the development model, that the super-regenerative receiver worked unsatisfactorily. On 6 October 1942 it was decided to use a superheterodyne receiver as in A.I. B.A.[1] This setback meant that development and production of A.S.V. B.A., which had previously been ahead because of the earlier trials and stated operational requirement, fell behind that of A.I. B.A. Earlier it had been hoped that A.S.V. B.A. would be available fairly soon after the contract had been placed because it required very little development from the A.S.V. homing beacon whereas A.I. B.A. was an entirely new design. This unexpected delay caused much concern in Coastal Command, where a radar approach aid was required for training and operational use in the winter of 1942/43. In order to meet the urgent need the Ministry of Aircraft Production suggested to the Air Ministry that, as an interim measure until type approval was given and production of the final system begun, beacons based on I.F.F. Mark IIG should be used. The proposal was agreed and the firm of Dynatron was asked to supply 20 interim-type beacons. Coastal Command personnel were to be responsible for installation, and for making the aerial systems with the assistance of drawings from the R.A.E.

Research and development continued, both at the contractors and at the research establishments. A satisfactory design for the aerial switch unit was produced by the R.A.E. in February 1943. In order to speed the production of B.A.B.S. the R.A.E. agreed to release a technical officer to work at Murphy Radio in close co-operation with the contractor's technicians in order to make sure that, as the design progressed, development could immediately be approved by the R.A.E. At that date one A.I. B.A. development model had been given provisional type approval and it was hoped that the remaining five A.I. B.A. and six A.S.V. B.A. equipments would be completed and type-approved by the beginning of March 1943. In April 1943 the Ministry of Aircraft Production estimated that production models of B.A.B.S. would be manufactured at the rate of five per week from the end of August 1943. On 15 April 1943 the programme was given a higher priority in order to avoid further delay. Additional measures to speed production were taken in June, after type approval had been given to A.S.V. B.A. They included raising the priority of outstanding components needed for B.A.B.S., raising the priority of and increasing the effort expended on the erection of suitable buildings, hard standings and supply cables to the runway sites, and applying the highest priority to the supply of vehicles.[2]

[1] M.A.P. File SB.18641, Part II.

[2] M.A.P. File SB.18641, Part II.

In spite of these efforts to increase production the Air Ministry had again to ask, in June 1943, for a further supply of modified I.F.F. Mark IIG, this time 25, in order to ensure that the use of B.A.B.S. facilities in Coastal Command could be continued until the main B.A.B.S. production models were available. The slow production of B.A.B.S. was causing acute concern, both at Headquarters Fighter Command and at Headquarters Coastal Command. The decision to adopt A.S.V. B.A. in place of S.B.A. had been taken on the understanding that it would be provided by the winter of 1942/43. The existing A.S.V. B.A. ground equipment was a temporary measure and provided only training facilities. It did not meet operational requirements for bad weather landing. In June 1943 the Commander-in-Chief, Coastal Command complained forcibly to the Air Ministry about the apparent lack of progress made with the production programme. '. . . I find it difficult to persuade myself that it has been handled with the energy and determination that its importance warrants. I need not remind you of the repeated attempts to increase the numerical strength of Coastal Command at the expense, usually, of the bombing offensive. At the same time we are complacently accepting a state of affairs in which the lack of a relatively simple article of equipment, asked for 19 months ago, is reducing the operational capacity of the command by the equivalent of several squadrons by making it impossible to operate in weather which, with adequate A.S.V. B.A. facilities, should be no bar to flying. . . .'[1] The Air Ministry stated that strenuous efforts were being made and a Beaconry Working Sub-Committee had been formed which was responsible for reviewing in detail the Coastal Command requirement for A.S.V. homing and beam approach beacons and for implementing the policy to provide the facilities by the autumn of 1943. At the same time questions were raised about the delay in the A.I. B.A. installation programme. At the 2nd meeting of the Night Air Defence Committee on 24 June 1943 the Air Ministry was asked to investigate the delay in the provision of A.I. B.A. at airfields used by night fighters. In the following month the Air Member for Supply and Organisation submitted a report on the B.A.B.S. programme. He stated that, in the first place, the design and development of a satisfactory beacon had been slow, partly because of the large number of defects experienced with the experimental models, partly because of the division of responsibility for research and development between the T.R.E. and the R.A.E. and partly because of the lack of enthusiasm for that type of navigational aid in the squadrons which conducted the early tests.[2] Secondly, A.S.V. B.A. was given a higher priority of production than A.I. B.A. because V.H.F. B.A. was being developed and produced for Fighter Command. Finally, installation plans had been made which involved building effort outside the scale available and lack of the necessary labour and materials made a change in plans necessary at a later date.[3]

When the development models of both versions of B.A.B.S. Mark I had been approved in April 1943 one of each was allocated to the contractors to serve as prototypes for main production, one of each to the R.A.E. for development purposes, and the other four of each type to airfields chosen by Headquarters Coastal and Fighter Commands. The former permitted one of their instal-

[1] A.M. File CS.18618.

[2] R.A.E. experts attributed many of the fundamental faults in the early B.A.B.S. equipment to the unsatisfactory early division of design authority whereby the T.R.E. was responsible for research and the R.A.E. for engineering. (M.A.P. File SB.18641, Part II.)

[3] A.M. File CS.18618.

lations to be transferred to the R.C.A.F. and one to the Royal Navy for experimental work. Colerne, Middle Wallop, Chivenor, and St. Eval were the first operational airfields selected as locations for B.A.B.S., and the other two A.I. B.A. equipments were installed at Ford and Hunsdon.[1]

With the installation and operational use of the B.A.B.S. development models certain technical faults quickly became apparent particularly in the A.I. B.A. version. Chief among them were frequency-pulling, rapid pulse amplitude modulation, and frequency modulation over the pulse width. Frequency-pulling, a change of frequency with aerial switching, was caused by the difference in reactance of the aerials, and was especially noticeable when B.A.B.S. was interrogated by A.I. Mark VIII. Then, because the interrogator was not very sensitive, it was necessary to get as much power as possible from the beacon transmitter by tight coupling, but this was difficult to achieve without frequency-pulling and pulse-distortion. The use of trimming condensers to balance the reactance was not sufficient. The fault caused incorrect indications to be received in the aircraft. It was considered by the R.A.E. that the only remedy possible was to employ looser coupling for the transmitter thus reducing the range of B.A.B.S. with A.I. Mark VIII to five miles. The T.R.E. also thought it might be necessary to accept a shorter range, or to abandon altogether the use of A.I. Mark VIII for radar beam approaches. In November 1943 the problem was partially solved when Headquarters Fighter Command stated that there was no operational requirement for B.A.B.S. with A.I. Mark VIII.[2] Amplitude modulation caused a fluttering of the top of the pulse which masked the observation of small keying changes and resulted in degradation of the beam width. The R.A.E. evolved a means to secure freedom from amplitude modulation by modifications of a comparatively minor nature. The amount of frequency modulation experienced was dependent on the extent of freedom from frequency-pulling so that the solution of the former problem rested with that of the latter.[3] By the middle of December 1943, as a result of the various modifications incorporated in an installation located at the Fighter Interception Unit, Ford, performance was much improved. A mechanical change enabled both transmitter aerials to be swung as one unit above a common pivot; the production-type radiators were used for the first time and these were joined to their lead feeder by a polythene moulding; an adjustable tap in the switch unit enabled the selection of one of three speeds of keying; modifications to the TR unit had eliminated variation in the size of the outgoing RF pulses; the coupling between the output coil and the tank circuit of the oscillator was decreased in order to reduce the magnitude of frequency-pulling between aerials. Arrangements were made in December 1943 for the modifications to be incorporated in the production models being built by Murphy Radio. Main production had been stopped pending the result of R.A.E. investigations, but was recommenced as the technical troubles were cleared.[4] At a meeting of the Beaconry Working Sub-Committee on 15 December 1943 it was stated that adequate supplies of components were available for modifications to be made, both on the production line and retrospectively.

An A.I. B.A. development equipment was installed at Hunsdon in September 1943, and was regarded as being the prototype B.A.B.S. Mark IF installation for

[1] A.M. File CS.18618.
[2] M.A.P. File SB.18641, Part II.
[3] M.A.P. File SB.18641, Part II.
[4] A.M. File CS.18619.

Fighter Command. The F.I.U. carried out check flights with various marks of A.I. Results were not satisfactory and it was transferred to Ford for intensive trials. Performance continued to be unsatisfactory but as work to eliminate technical faults was still in progress on the other equipment at Ford, it was decided that an installation programme of the equipment as it stood should be started in Fighter Command, and necessary modifications incorporated retrospectively, in order to hasten the provision of B.A.B.S. However, in October 1943 it was decided that the Hunsdon model should be sent to Defford for incorporation of such modifications as had already been devised by the R.A.E. It was reinstalled at Ford on 17 December 1943 where further trials took place. Apart from the first three runs after installation, when the beam was well off the runway, all approaches were satisfactory. Aircrews commented favourably on the definition and width of the beam. The conclusion reached was that the A.I. B.A. beacon was operationally acceptable for beam approach when A.I. Marks IV and V were used.[1]

Meanwhile quantity production of A.S.V. B.A. had also been stopped whilst investigation into technical faults proceeded. The difficulties experienced with this equipment were not so serious as those encountered in its Fighter Command counterpart although some of the development models of A.S.V. B.A. were prone to frequency-pulling and pulse jitter. In August 1943 the development installed at St. Eval was temporarily transferred to the B.A.T. Flight at Leuchars.[2] The R.A.E. incorporated the modifications necessary to remedy shortcomings which had been disclosed and arranged for a supply of components to enable the other development models to be modified. In October 1943 it was reported that preliminary trials of the installation showed very good results. This model was designated as the prototype for No. 26 Group installation in Coastal Command. Arrangements were made for the B.A.B.S. Familiarisation Party from the Signals Development Unit at Hinton-in-the-Hedges to conduct flight acceptance trials, from which a standard of acceptance was evolved for future installations in Coastal Command. By the middle of December 1943 the R.A.E. investigation into technical faults was completed and new designs were cleared. Production was recommenced and final type approval was given on 3 March 1944.[3]

Installation Procedure

Preparatory plans for the installation of B.A.B.S. Mark I at airfields in Coastal and Fighter Commands had been made and Headquarters No. 26 Group was made responsible for siting and installation with help from the R.A.E. in the early stages. Selection of sites was made in the first place by No. 26 Group. Each site was then visited by representatives of the user command and tested with an interim B.A.B.S. equipment. By the end of March 1943, sites had been selected and approved at five airfields in each command.[4]

It was agreed in June 1942 that each airfield selected should be provided with a permanent installation on the runway most frequently used and with aerial systems for use only with mobile B.A.B.S. on other runways, and instructions to that effect were issued by the Air Ministry to the Air Ministry

[1] A.H.B./II/54/93(A). F.I.U. Report No. 228.

[2] M.A.P. File SB.18641, Part II.

[3] M.A.P. File SB.18641, Part II. Installation of 18 B.A.B.S. Mark IF equipments had been completed by April 1945. In July 1945 B.A.B.S. Mark IF was declared obsolete.

[4] A.M. File CS.18618.

Works Department in August 1943. Four aerial systems and concrete plinths were to be installed at each airfield but power supply was to be provided only to the permanent site, about 170 yards from one end of the preferred runway. Both the R.A.E. and Headquarters No. 26 Group opposed this policy on the grounds that it was unsatisfactory since an equipment which had been correctly aligned on a site was unlikely to work well after removal and replacement. Changes in electrical performance of the feeders were probable, especially during damp weather, with a possible deviation of the beam from the runway. The original scheme had been dictated by the need to economise on radar equipment but the Air Ministry considered the need for effective performance to be greater. Headquarters Coastal Command, when recommended to place all installations on a permanent basis, stated that it was appreciated that frequent movement of mobile equipment from one place to another damaged the feeders and upset the correct operation of the installation but denied that in practice moves were frequent. The spare set was seldom used and was held mainly against emergencies. Installation plans through the early part of 1944 consequently proceeded on the basis of one preferred site for each airfield and several subsidiary sites. In October 1944 Headquarters No. 26 Group again stressed the undesirability of the policy because of the danger of beam swing. It was recommended that two preferred sites should be chosen at each airfield and provided with mains power supply, a beacon in a standard hut, standby power supply and remote control facilities, and that the two sites should be complementary to each other. Headquarters No. 26 Group considered that the works services involved would not be excessive as at most airfields the subsidiary sites could easily be supplied with mains power. Headquarters Coastal Command finally agreed to the suggestions, subject to approval being obtained from the Director-General of Works.[1] The Air Ministry therefore requested Headquarters No. 26 Group to review all Coastal Command airfields equipped with B.A.B.S. Mark IC and to submit an estimate of the extra works services involved.[2]

In the meantime progress was made with works services at the airfields chosen for B.A.B.S. installation, although held up to some extent by the shortage of material and labour, and by 15 December 1943 works services had been completed at 21 airfields in Coastal Command.[3]

Monitoring and Servicing

Headquarters No. 26 Group was responsible for testing and calibrating each new B.A.B.S. installation before it was handed over to the user command. Acceptance standards had been compiled for each version from the initial tests carried out on development models. To meet the commitment the Signals Development Unit, which absorbed the former Beam Approach Development Unit, was formed in the spring of 1943 and was based at Hinton-in-the-Hedges.[4] The unit was incorporated in the Signals Flying Unit when the latter was established at Honiley in August 1944, and its responsibilities in regard to B.A.B.S. were taken over by the new unit.

After initial acceptance tests had been completed by No. 26 Group, monitoring was a unit responsibility. Accurate monitoring of the beam was essential

[1] A.M. File CS.18618. [2] A.M. File C.16261/44. [3] A.M. File C.16192/44.

[4] A.M. File CS.18619. The unit used four Anson aircraft, two equipped with A.S.V. and two with A.I.

to ensure perfect alignment, and Headquarters Fighter Command considered after experience had been gained with the experimental A.I. B.A. installation at Ford, that regular monitoring of the beam was a necessity if aircrew were to retain confidence in the system. The monitoring equipment used in Coastal Command consisted of a van containing A.S.V. Mark II, a petrol-electric set, and an aerial system, and was thought to be adequate, but in the autumn of 1943 Headquarters Fighter Command stated that the equipment did not meet requirements because it was unreliable. At Ford a simple monitoring system constructed by the T.R.E. was used. Headquarters Fighter Command considered it to be the more satisfactory method and requested its provision at 40 airfields. The equipment was criticised in December 1943 by the R.A.E. as having too small a range, the maximum being 50 yards. Technical experts felt that monitoring could only be carried out satisfactorily at a distance of 100 yards and recommended the adoption by Fighter Command of a monitoring system similar to that used in Coastal Command. In April 1944 the R.A.E. produced a new method with a range of 170 yards which was accepted by Headquarters A.D.G.B. It was installed at Wittering, where the F.I.U. had moved to from Ford, on 8 May 1944. In June 1944 the F.I.U. reported that it was satisfactory for establishing the position of the beam and provided an approximate indication of power output but it gave no indication of pulse shape or of receiver sensitivity.[1] Development was continued with the aim of evolving a comprehensive monitoring system acceptable to both commands.

In February 1943 an R.A.E. system of remote monitoring had been demonstrated to Fighter and Coastal Commands but, although it indicated whether or not the beam was radiating, it gave no information of beam alignment, and was only partially satisfactory. A similar system which included some means whereby beam alignment could be checked in the airfield control tower was required. In October 1943 an experimental remote control unit made at Ford by the R.A.E. was demonstrated to Headquarters No. 26 Group who considered it to be sufficiently promising to warrant further development. It made use of existing telephone lines from the operations room to the beacon, and provided remote switching of the beacon, two-way telephone facilities, audible monitoring, and a means whereby a separate interrogator could be remotely switched if desired. However, effective remote control was not achieved until B.A.B.S. Mark II had been developed.

The responsibility of Headquarters No. 26 Group for B.A.B.S. servicing was limited to the remedy of faults which were too complicated for units, who were responsible for routine servicing, to deal with. In order that B.A.B.S. might be operated with maximum efficiency, standard servicing schedules, based on those used for S.B.A., were compiled by the R.A.E.[2] Daily inspections were carried out by unit personnel, and the S.F.U., Honiley carried out six-weekly and quarterly ground and air checks. Alignment of the beam was checked two or three times daily with a mobile monitor.[3]

Allocation Overseas

In October 1942 an operational requirement was raised, by both Coastal and Fighter Commands, for a transportable B.A.B.S. which could be erected and set up in working order within six hours of its arrival at a site, for standby use

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[1] A.M. File C.16261/44. [2] A.M. File CS.18619. [3] A.M. File C.16261/44.

if the permanent installation should fail.[1] The provision of mobile A.I. B.A. presented a much greater problem than did that of the Coastal Command system because of the large corner reflectors in the aerial array of the former. In February 1943 the R.A.E. reported that the first prototype mobile A.S.V. B.A. equipment was nearing completion. The mounting of Yagi arrays on a signals van had been achieved comparatively easily, but no method had been found for providing an adequate mobile A.I. B.A. aerial system. Attempts were therefore made to mount the beacon and its feeders on a small covered trailer. Headquarters Coastal Command estimated the requirement for mobile B.A.B.S. equipment to be 65 ; Headquarters Fighter Command required only four at that date but anticipated that overseas commitments would increase the number.[2] When the R.A.E. completed the prototype a development contract was placed with the firm of Centrup. The Coastal Command requirement was cancelled at the end of the year but as development was far advanced by then it was decided to allow the development contract to be completed.[3]

Development, production, and installation of B.A.B.S. Mark I was so slow that very little equipment could be spared for use in overseas commands. However, at the end of 1943, when the Coastal Command requirement for mobile equipment was withdrawn, six mobile B.A.B.S. were allocated from the development contract when an overseas requirement was raised. They were ready by March 1944 and were despatched to No. 338 Wing in North Africa, and to Nos. 323 and 325 Wings in Italy.[4] In June 1944 Headquarters A.C.S.E.A. asked for 33 mobile A.S.V. B.A.B.S. and 32 mains-operated A.I. B.A.B.S. No more mobile A.S.V. B.A. equipments were immediately available and A.I. B.A. had not then been installed in the United Kingdom and could not be allocated overseas until satisfactory Service trials had been held. However, sufficient equipment had been ordered to enable the needs of A.C.S.E.A. to be met eventually. In August 1944 the Air Ministry signalled that ten A.S.V. B.A. installations were likely to be available by late September, but delays in the production of A.I. B.A. meant that allocations were unlikely before December 1944. The commitments in Europe were the more urgent, and in October 1944 three A.I. B.A. installations were despatched to No. 85 Group. One was installed at Amiens/Glisy and another at Lille/Vendeville. As the equipment underwent trials until the beginning of March 1945, only slight operational use had been made of it when it was withdrawn at the end of that month with the transfer to a forward area of the squadrons. Results were never very satisfactory, the chief technical fault being that of beam drift.[5] By the winter of 1945 an installation of B.A.B.S. Mark IC had been made in the Azores.[6]

Development of B.A.B.S. Mark II

Both versions of B.A.B.S. Mark I contained inherent technical faults which, in spite of continuous experimental work and the incorporation of numerous modifications, were never completely eradicated, and performance was never entirely satisfactory. The size of the side-lobes of the aerial radiation pattern, already large, was increased even more if the beacons were not set up carefully on the correct frequency, thus providing false equi-signal paths, some of

[1] A.M. File CS.18618. [2] A.M. File CS.18618. [3] A.M. File C.16192/44.

[4] A.M. File C.16192/44.

[5] A.H.B./IIS/88/2. Radar in 2nd Tactical Air Force.

[6] A.M. File CS.24130.

which were about 40 to 50 degrees off the line of the runway, which dangerously confused aircrews. The equi-signal zone could be swung out of alignment with the centre of the runway very easily because the two transmitter aerials were fed by two separate lengths of high-frequency cable which were apt to change their characteristics as they became affected by weather conditions. This meant that the signals arriving at the two aerials were not equal and the difference accounted for the beam swing. Beam swing was aggravated by the fact that any change of impedance at the aerial input caused the transmitter coupling to change and resulted in frequency-pulling as well as a change in the power delivered to the two feeders.[1] The B.A.B.S. display on the aircraft installation indicator was rather confusing, especially to less experienced aircrews. The method used, comparison of changes in signals amplitude, was undesirable in an aircraft equipment where the tendency was always towards unsteady amplitudes, caused by factors such as propeller modulation, changes in aerial field strength patterns due to changes in aircraft altitude, and ordinary aircraft vibration. The faults of B.A.B.S. Mark I, disclosed in practical operation, provided a basis upon which the improved B.A.B.S. Mark II was developed.

The inauguration of a development programme for an improved version of B.A.B.S. arose in the first place from an expressed requirement for a beam approach system to work with Rebecca. In December 1942 a modified form of B.A.B.S. Mark IF was installed at Tempsford to provide approach facilities for aircraft of the special duty squadrons. As a result Headquarters Army Co-operation Command asked for the provision of a fully mobile B.A.B.S. equipment because its relatively small bulk and small power requirements, compared with those of S.B.A., would make it readily adaptable for use at forward airfields. The installation was required to operate on the frequencies of Rebecca, the only interrogator available in aircraft of the command. In February 1943 the T.R.E. produced an experimental model for trials at Netheravon and on 19 March 1943 it was agreed that the T.R.E. should construct a further 12 sets for use in Army Co-operation Command. In June 1943, however, the plan was abandoned so that the resources of the T.R.E. might be concentrated on research work in connection with a wide-band Eureka B.A.B.S. system being developed for use with Lucero in Bomber Command. It was felt that if a successful fixed B.A.B.S. installation was evolved, mobile and portable versions could easily be developed.[2] In any event, a complete redesign was needed to overcome the inherent defects in B.A.B.S. Mark I, and the fact that Lucero was being installed in all aircraft equipped with centimetric A.S.V. and H2S necessitated the provision of an efficient beam approach system to work with it. In June 1943 trials were conducted at Beaulieu by the T.R.E. to investigate the performance of Lucero Mark I with all types of Coastal Command beacon. It was found that Lucero was unsatisfactory with B.A.B.S. Mark I because its low power output, compared with that of A.S.V. Mark II, resulted in a reduction by approximately two-thirds of the ranges normally obtained.[3] In addition the wide frequency band of the Lucero receiver resulted in signals from both B.A.B.S. and the homing beacon appearing on the indicator simultaneously.[4]

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[1] Early beacons were not provided with a power amplifier stage between the oscillator and the aerial.

[2] A.M. File CS.19185.

[3] A.M. File CS.19143.

[4] M.A.P. File SB.18642, Part II.

Development was required, therefore, of a wide-band system covering the frequencies 214 to 234 megacycles per second. Eureka Mark II was to be used as a basis, although it was unsuitable in its existing form. The frequency emitted by the beacon varied with the reactance of the load and while the variation was not sufficiently great to affect the beacon seriously when used for homing, it was not satisfactory in the approach function and might lead to beam instability. In addition, the power output was not independent of pulse width and it was proposed to use a 'wide-narrow' type of display. Necessary modifications included an increase in size, circuit changes, and the inclusion of a power amplifier.[1] A new display, less confusing than that used with B.A.B.S. Mark I, was also required, and to obtain the required coverage, the simple aerial system used with B.A.B.S. Mark I had to be replaced by one with wide-band characteristics.

During 1943 the problem of an approach system for Bomber Command became more pressing. S.B.A. had been adopted before the war but in January 1943 the Inspector-General of the R.A.F. after an investigation had come to the conclusion that the operational use of the system in Bomber Command did not justify the effort expended upon it. In the summer of 1943 a new radar approach system, Ground Controlled Approach, had been introduced into the United Kingdom from the U.S.A. and had proved its worth in operational trials. A committee was therefore formed in September 1943 to investigate the problem of radio aids to flying control, with particular reference to the needs of Bomber Command for an efficient approach aid. The committee considered that G.C.A. was the best alternative to S.B.A. but, as its use was limited by the small number of R/T channels available, it was recommended that existing B.A.B.S. systems should be retained in Coastal and Fighter Commands and that Eureka B.A.B.S. should be developed as a replacement for S.B.A. at Bomber Command airfields where G.C.A. was not available.[2]

On 5 November 1943 a conference was held at the Air Ministry to discuss the recommendations of the committee and to decide future policy for the use of radio aids for flying control in all commands. The relative merits of G.C.A., S.B.A. and B.A.B.S. were considered. Headquarters Bomber Command wanted to replace S.B.A. by a suitable version of B.A.B.S. for the use of aircraft which could be fitted with Lucero. It was therefore decided that G.C.A. would be installed where possible, that most aircraft would make use of B.A.B.S., and that the use of S.B.A. would be gradually discontinued. It was agreed that the provision of a radio glide path was an operational requirement if B.A.B.S. was employed but its development was to be on a low priority.[3] It was hoped that the use of Eureka B.A.B.S. would enable a universal homing system to be developed for all commands. The B.A.B.S. versions previously developed could be used only by aircraft of the command for which they were designed. The rigidity of this system was one of its disadvantages. It was intended that B.A.B.S. for Bomber Command should operate on frequencies of 214 to 234 megacycles per second with vertical polarisation, that for Fighter Command on frequencies of 193 to 196 megacycles per second with vertical polarisation and that for Coastal Command on 176 megacycles per second with horizontal polarisation.[4]

[1] A.M. File CS.19143. [2] A.M. File S.97074. [3] A.M. File S.97074.
[4] M.A.P. File SB.41807, Part I.

In September 1943 Headquarters Bomber Command requested installation of the B.A.B.S. equipment being developed for use with Lucero Mark II at the Bombing Development Unit, Newmarket, for trials to determine whether the new system was sufficiently superior to S.B.A. to justify its introduction in Bomber Command. The T.R.E. was therefore instructed to proceed with the preparation of equipment for Bomber Command trials.[1] By November 1943 development had reached a fairly advanced state. The beacon consisted of a low-power battery-operated receiver/transmitter, a switched cavity resonator aerial system and a short range monitor, the whole being housed in a small vehicle. The cavity resonator in the aerial system required further development because no satisfactory switching mechanism had been devised. A super-regenerative receiver was used but a superheterodyne receiver was also being developed and it was suggested that this should be used for fixed installations where power was available. By December 1943 the first experimental model of the new system was ready for trials at the Telecommunications Flying Unit at Defford, but these were held up until the end of January 1944 by bad weather. During early experimental work difficulty was experienced by the T.R.E. in finding a name for the new equipment. It was at first decided to refer to it as radar B.A., and later in its development the beam approach equipment for Bomber Command was known as Eureka B.A.B.S.[2] On 8 May 1944 the name Lucero B.A. was adopted, the homing beacons being referred to as Eureka beacons. On 5 June 1944 the name was again changed and thereafter permanently remained as B.A.B.S. Mark II.[3]

The improved aerial system of B.A.B.S. Mark II was a distinctive feature of the new equipment. It consisted of a metal cavity with two radiating slots mounted in a corner reflector, the slots being energised from a common source and switched alternately by mechanical shorts across them. It operated both as a receiver and transmitter system for vertically polarised radiation on spot frequencies between 214 and 234 megacycles per second; the receiving and transmitting frequencies were, in general, different. The radiation pattern took the form of one or the other of two mutually symmetrical off-centre beams which could be switched alternately at 10 cycles per second. The beam was switched simultaneously to code the beams so that short pulses of radiation of 5 micro-seconds duration (dots) were transmitted in one beam and long pulses of 12 micro-seconds duration (dashes) in the other. Bearings of range from the runway were indicated in aircraft installations by amplitude ratios of signals received from the two beams. The fact that the new system used a single feed cable and a single unipole or probe meant that one of the most serious faults of B.A.B.S. Mark I was eradicated; it was free from inequalities of beams arising out of variations in matching or attenuation in separate feed cables. Beam symmetry in B.A.B.S. Mark II was completely dependent on physical symmetry of the aerial system. The probe which energised the aerial was constructed of 3¾-inch brass tubing projecting through a central hole in the top of the aerial box. Different probe lengths had to be provided for different frequencies in the band. The aerial was switched by shorting the centre of the slot, which was not required to radiate. Switching was effected by a relay at each slot and the relays were controlled by a master relay which ensured that one slot was closed before the other opened. Coding of the transmitted pulses was done by means of two high-speed relays in the beacon transmitter which governed the pulse

[1] A.M. File C.30496/46. [2] M.A.P. File SB.41807. [3] A.M. File S.97074.

B.A.B.S. Mark II Aerial System

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length. When one relay was operated narrow pulses were transmitted and when the other was operated wide pulses were transmitted. A high-speed relay could only operate when the appropriate slot was open and the other closed, so that when both slots were closed no transmission took place.[1] The new method of display involved no change in the aircraft apparatus but the ground aerials were switched symmetrically and arranged so that the broad pulse from the beacon was switched in during the radiation period of the left-hand beam to give dash sectors and a narrow pulse during the radiation period of the right-hand beam giving dot sectors. Thus the display on the aircraft indicator was such that narrow and broad echoes were viewed simultaneously, one within the other. On the equi-signal path the amplitudes were identical. When the aircraft was in the dot sectors the narrow blip protruded out of the broad blip and the ratio of amplitudes denoted the various dot sectors. When the aircraft was in the dash sectors the broad blip predominated.

Flight Trials

Flight trials of an experimental model of B.A.B.S. Mark II were held at the Telecommunications Flying Unit, Defford, from 27 January to 1 March 1944, with an Oxford aircraft equipped with Rebecca Mark II. During 16 flights 42 approaches were made, 32 of them open and 10 hooded. The large number of open approaches were made so that the accuracy and reliability of the system could be tested and a check made of the standard of performance of the equipment in the hands of inexperienced radar operators. The trials were carried out mainly in very bad weather. The ground equipment was switched on for 43 hours altogether. The performance obtained was encouraging. Strong signals were received at 1,000 feet out to ranges of at least 10 miles. At first a very severe modulation of pulses, approximately 50 per cent of the signals, was apparent. It was ascertained that the fault was propeller modulation and an interim remedy was sought by the installation under the aircraft fuselage of an aerial in such a position that the propellers did not affect it.[2] At 5,000 feet signals from the beacon were received at 40 miles when the aircraft was facing it. Throughout the trials the beam remained aligned with the runway and was of a suitable width—approximately one degree. An attempt to use a small Eureka beacon at the touch-down end of the runway as a boundary marker failed because the Eureka signal disappeared into the direct pulse at approximately one mile. Presentation in the aircraft was more satisfactory than the earlier B.A.B.S. display. The time of approach was reduced because it was possible to identify the sector by the width of the pulse. The clearly marked linear scale gave accurate ranges. The system of transmitting on one frequency and receiving on another avoided confusion with ground returns. The navigators, most of whom were not used to the B.A.B.S. approach method, gave the pilots information of beam sector and range, and were able to make good approaches at the first attempt in spite of lack of experience. The mobility of the equipment was a further point in its

[1] M.A.P. File SB.41807. The original conception of B.A.B.S. Mark II, including the particular type of slot aerial and the broad and narrow pulse display, was that of Mr. K. A. Wood of the T.R.E.

[2] M.A.P. File SB.41807. Propeller modulation was a variation of signal due to variations in the phase, amplitude, and direction of radiation reflected from the rotating propeller blades. When it was present both the D.F. ratio and the amplitude of the signal were liable to fluctuate in an erratic manner and confuse the C.R.T. display.

favour since it took twenty minutes only to move the beacon from one end to the other of a 2,000-yard runway and to realign the beam.[1]

In February 1944 a second experimental installation built by the T.R.E. was despatched to the Bombing Development Unit for comparative trials with S.B.A. The general opinion after the trials was that the system was preferable to S.B.A. in many ways. The aircraft installation display was interpreted by the navigator so that the pilot did not have to concentrate so hard as with S.B.A. and could focus his attention on flying accurately. Far less training and practice was required than with S.B.A. because three or four hours in the air was enough to enable most operators to achieve a high standard of reliability. It was thought that control from the ground could be more easily effected with B.A.B.S. than with S.B.A. because it was not necessary for an aircraft to be in the beam before a pilot could ascertain his exact position. The information made available on the indicators of Lucero and Rebecca was more comprehensive than that supplied by S.B.A. B.A.B.S., within a given area, supplied an instant and accurate fix in terms of range and bearing so that a course could be set for any point within the beacon range. S.B.A. supplied a single position line, and specific fixes only at the outer and inner markers. Also, the degree of accuracy of a B.A.B.S. fix was higher than that obtained with S.B.A. The circle of error at the S.B.A. inner marker was about 80 yards in diameter while at an equivalent position when B.A.B.S. was being used the diameter of the circle of error was about 40 yards. During the trials the B.A.B.S. ground installation was operated for 103 hours without a fault and was serviced by R.A.F. radar mechanics with only occasional supervision by T.R.E. personnel.[2]

One of the problems encountered during the Defford trials was distortion of the beam caused by reflections from hangars or similar structures on the airfield. This distortion was not so pronounced in the new system as in B.A.B.S. Mark I because no large side lobes were radiated but there were some reflections on the approach line from the sides of the main forward lobes. At Defford no distortion occurred in the normal approach run but only on the runways themselves. The useful opportunity offered of carrying out tests to eliminate distortion on other airfields was accepted. In June 1944 the T.R.E. obtained authority to experiment with a sloping screen of fine wire mesh suspended from the roof of a hangar at Defford down to the ground, facing the landing area at an angle of 45 degrees with the horizontal, in order that incident radiation would be reflected upwards where it could not interfere with any part of the beam normally used by aircraft.[3]

Difficulties were experienced in May and June 1944 over the discrepancies in range measurements obtained with Lucero. Headquarters Bomber Command stated that circuit delays in the ground and aircraft equipment varied through a wide range and in consequence the equipment was operationally unacceptable. The method of calibration was unsatisfactory. A measurement, to within plus or minus 200 feet, of the range of aircraft from the downwind end of the runway was required. The T.R.E. investigated the problem and devised a new setting-up procedure and new test gear, but it was found impossible to guarantee a better accuracy than plus or minus 100 yards, which, however, was accepted by Headquarters Bomber Command.[4]

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[1] A.M. File S.97074. [2] A.M. File S.97074. [3] M.A.P. File SB.41807.
[4] A.M. File CS.22955.

Production

Although the B.D.U. trials were successful, it was not until 22 April 1944 that Headquarters Bomber Command stated a firm requirement for the installation of B.A.B.S. Mark II, to work in conjunction with Lucero, at all operational and O.T.U. airfields. Provision was planned on the basis of one mobile set per airfield at first, to be followed by fixed installations in addition to one mobile equipment for use as a standby in the event of failure of the main beacon.[1] A requirement for a glide path indicator for use with B.A.B.S. because of the lack of height information was also stated, but its development at the T.R.E. was given low priority.

Both the Ministry of Aircraft Production and the T.R.E. were concerned in the choice of a radio firm for the development and production of B.A.B.S. Mark II and B.A.B.S. Mark IIM, the mobile version. After the capacity of several had been investigated the firm of Pye of Cambridge was considered the most suitable, and was given a development contract for ground equipment in January 1944.[2] Pye estimated that development models could be delivered by May 1944 and a start made on quantity production by August. The development contract was originally for four prototypes but in May 1944 this was increased to ten with the highest priority.[3] Of these one was to operate on the A.E.A.F. frequency band. A requirement had been raised by Headquarters Allied Expeditionary Air Forces for a mobile B.A.B.S. system, to work in conjunction with A.I. Mark VIII and Lucero, for the use of night-fighter aircraft of No. 85 Group. Specifications included a compact aerial system, a simple and reliable siting device for rapid and accurate alignment, and a minimum range of 15 miles. The T.R.E. considered that B.A.B.S. Mark IIM could be modified effectively to operate on 193 megacycles per second. The placing of the production contract was held up because of delay in obtaining financial sanction.[4] This was finally obtained and in July 1944 the Ministry of Aircraft Production placed a production contract with the same firm for 130 fixed and 460 mobile installations and spares sufficient for 12 months' maintenance.[5] The first development model was ready in June 1944 but it was considered to be technically faulty by the T.R.E. and work was begun on a new model which was not ready for type approval until the end of August. The Ministry of Aircraft Production considered that the delay of six weeks was justified because it was essential for the successful introduction of B.A.B.S. Mark II into the Service that the equipment was entirely free from technical faults.[6] Meanwhile Headquarters Bomber Command had become increasingly interested in the B.A.B.S. programme because of the slow rate of production

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[1] A.M. File C.30496/46. Allocation was planned as :—

Bomber Command operational airfields ..	95
Bomber Command diversion airfields	170
Bomber Command training units	23
Allied Expeditionary Air Forces	20
United States Army Air Force	20
India (for bomber airfields)	6
Reserve for overseas requirements	50
Total ..	384

(A.M. File S.97074.)

[2] M.A.P. File SB.41807 and A.M. File C.30496/46. [3] M.A.P. File SB.41807.

[4] A.M. File S.97074. [5] M.A.P. File SB.41807. [6] M.A.P. File S.97074.

of G.C.A. in the U.S.A. and because stocks of S.B.A., the contract for which had not been renewed in the spring of 1944, were diminishing. On 4 May 1944 the Bomber Command groups agreed on a plan to ration out existing stocks of S.B.A. rather than renew the contract because that would delay the supply of modern equipment. At the same time the inauguration of an immediate crash programme, to provide Lucero for two squadrons equipped with H2S, and B.A.B.S. installations at two stations, so that squadrons might obtain operational experience of the new approach system, was recommended.[1] The urgent need for an efficient approach aid at Bomber Command airfields was realised at the Air Ministry and Ministry of Aircraft Production, and arrangements were made to meet the request for a crash programme to enable adequate knowledge of the system to be obtained before a full-scale installation programme was begun. On 5 June 1944 authority was given for the necessary works services to be undertaken at Wickenby and Driffield.[2]

At progress meetings held periodically arrangements were completed for both the crash and the main B.A.B.S. programmes including such matters as technical development, the rate of production of both ground and aircraft equipment, works services, and installation plans, but production on development and main contracts proceeded very slowly. Initially delays had occurred because priority was not high, but even after the Air Staff had increased priority because of the urgency of the need for Bomber Command to have an efficient approach system in operation by the following winter the rate of manufacture was still slow because of congestion in the Pye workshops, where Oboe and H2S were also being made.[3] On 27 September 1944 Headquarters Bomber Command complained about the delay on the grounds that earlier in the year it had been agreed to remove S.B.A. from some groups on the understanding that B.A.B.S. would be available before the approaching winter. As a result they were faced with the prospect of many aircraft being without an approach aid during winter bombing operations. Unless aircraft could fly in all weathers the highly developed systems of blind bombing would never be fully employed. The Air Ministry considered that Headquarters Bomber Command was partially responsible for the situation as the urgency of the need for B.A.B.S. had not been stressed until late in the summer of 1944 and even then it had not been made clear whether B.A.B.S. was required at the expense of other radar systems such as H2S, Gee, Gee-H, and A.G.L.T. In October the installations at Driffield and Wickenby were almost completed and installation at other airfields was not anticipated before the end of the year. The Air Ministry refused to sacrifice technical efficiency in favour of speedy production. Headquarters Bomber Command was assured that every effort was being made to implement the undertaking to provide B.A.B.S. facilities for the bombing operations of the winter 1944/45.[4] It was for this reason that the T.R.E. was asked in the autumn of 1944 to manufacture six emergency equipments in order to ensure that there was a skeleton B.A.B.S. organisation in Bomber Command before delivery from the main programme

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[1] A.M. File S.97074.

[2] Wickenby was to have the first B.A.B.S. mobile ground installation and No. 12 Squadron (Lancasters) at Wickenby was to be the first squadron to be fitted with Lucero. The first B.A.B.S. fixed ground equipment was also to be installed at Wickenby. Driffield was to have the second and third mobile B.A.B.S. installations. No. 466 Squadron (Halifax) was to be the second squadron to be fitted with Lucero. (A.M. File S.97074).

[3] A.M. Files C.30496/46 and S.97074.

[4] A.M. File S.97074.

was begun. They were similar to the development models produced for the Wickenby and Driffield trials, but contained only one beacon per installation, so that there was no standby set, whereas the Pye models had two beacons.[1] The T.R.E. sets were not as fully engineered as those built by the radio manufacturers and the absence of a standby set meant that the failure of a component part put the whole system out of action. The T.R.E. therefore suggested that four of the six sets might be used to provide spares for the four installations at Wickenby and Driffield and the remaining two to equip another Bomber Command airfield.[2] The Air Ministry ruled that the first four sets might be used for ensuring the provision of 100 per cent spares at Wickenby and Driffield but Headquarters Bomber Command preferred to await delivery from main production for installation at other airfields, rather than use the T.R.E. sets.

Service Trials

It had been originally intended that Pye production models should be used for the Wickenby and Driffield trials but the slow rate of production and the delay in obtaining type approval necessitated the use of equipment from the development contract. Trials at Wickenby began with two mobile installations and 19 aircraft of Nos. 12 and 626 Squadrons fitted with Lucero. Some faults were experienced with the aircraft and ground equipments but these were attributed to the fact that the apparatus was new and not to any serious fundamental defect. At the very outset of the Wickenby trials an effort was made to overcome one of the difficulties of the operation of beam approach equipment, that of ensuring an adequate standard of training. Therefore, the training in B.A.B.S. was designed to incorporate as much as possible of the normal landing procedure. Pilots, navigators, and flight engineers were given two hours' ground training. This was followed by air training which averaged about one hour dual and 1¼ hours solo. After that approaches using B.A.B.S. were practised on all non-operational flights. Three special exercises were held on 11, 12 and 13 December 1944 and on each of these ten aircraft used B.A.B.S. for landings. On the first day the aircraft were landed in 40 minutes in visibility of 1,500 yards and when the cloud-base was 2,500 feet. On the second they were landed in 54 minutes in bad visibility of 800 yards decreasing to 400 yards. One aircraft whose Lucero equipment was unserviceable was led in by another which itself made an overshoot. During these trials the approach run was reduced to 4 miles, which was found quite satisfactory. On 24 April 1945 a special B.A.B.S. exercise was held at Wickenby in which 15 aircraft took part. Pilots were briefed to arrive at a point 94 miles from the airfield, known as the gate, in four waves at three-minute intervals, and to report arrival by R/T, at a height of 15,000 feet, to the control tower, from where approach and landing instructions were issued. All 15 aircraft were landed in 33 minutes.[3]

In December 1944 Headquarters No. 1 Group forwarded recommendations to Headquarters Bomber Command. It was felt that the system was simple enough for an average crew to learn quickly, and that up to 20 aircraft per airfield could be landed at intervals of three minutes in visibility of 800 yards using an oval circuit approach. A serious disadvantage was the reliance upon the altimeter for recording height information, and a glide path indicator

[1] A.M. File C.30496/46. [2] M.A.P. File SB.41807, Part II.

[3] A.M. File CS.22955.

was a definite requirement. It was recommended that the interrogator/indicator should be entirely independent of H2S so that the serviceability of the former was not dependent on that of the latter. This recommendation was supported by Headquarters No. 4 Group when reports of trials being held at the same time at Driffield were submitted. At one time difficulty was experienced in aligning the beam of the fixed installation at Driffield but it was found to be due to the proximity of bulldozers and other metal equipment, and when these were removed no further trouble was experienced.[1] Another complaint was made about the misalignment of the mobile beacon which resulted in pilots making a 'dog-leg' involving a 10-degree alteration of course. It was feared that the danger of this manoeuvre would cause aircrew to lose confidence in B.A.B.S. and thus prejudice its successful introduction into the R.A.F. T.R.E. investigation of the problem revealed that the misalignment was caused by the moving of a monitor post in front of one of the beacons and when this was corrected the beacon operated satisfactorily. The trials provided an opportunity to compare the performances of fixed and mobile beacons. It was reported in January 1945 that both fixed and mobile beacons gave the same results from the air, but whereas the fixed beacon seldom wandered once it was aligned, the mobile beacon was difficult to set up accurately and could never be guaranteed. This meant that the monitoring of the fixed beam could be carried out by occasional checks during air tests and slight corrections made to align the beam accurately along the runway, but with the mobile type it was necessary to rely on correct visual alignment. In May 1945 the T.R.E. conducted tests with the B.A.B.S. installation at Driffield and reported that when the beam was aligned by means of the monitor system it was accurate, that the beam width was sufficiently narrow to ensure an approach to the centre of the runway within plus or minus 25 yards, and that no false beams occurred in the sector 90 degrees to either side of the beacon line-of-shoot.[2]

Installation at Home and Overseas

At the end of October 1944 the Air Ministry estimated that December 1944 would see the beginning of the main B.A.B.S. programme for Bomber Command. It was hoped that 14 airfields would be fitted by the end of December and 70 to 80 by the end of March 1945.[3] Unfortunately the estimates proved to be unduly optimistic and it was not until the end of February 1945 that the first production models of B.A.B.S. Mark II arrived at the T.R.E. from the contractors. By April 1945 11 sets had been delivered, and were first sent to No. 26 Group for testing and then to the chosen airfield for installation, the requirements of Bomber Command being given priority. By the end of the war in Europe 28 equipments had been produced and by the end of July 1945 44 had been delivered to No. 26 Group. Of this number 21 had been despatched to Chigwell for the Tiger Force commitment, including six for staging posts. By then installations had been completed at 11 airfields in the United Kingdom.[4]

[1] A.M. File CS.22955. [2] A.M. File CS.22955. [3] A.M. File S.97074.

[4] They were :—

(*a*) Defford, Newmarket, Netheravon, Bottisham, Shepherd's Grove and Mildenhall for development and trial purposes;

(*b*) Wickenby, Driffield, Ludford Magna, Coningsby and Metheringham for Bomber Command operational requirements.

Of these 12 runways had Class A beams, that is, beams passed by Headquarters No. 26 Group as perfect for CRT presentation purposes, and 14 runways had Class B beams, that is, beams in which the ' on beam ' path was perfect but which contained slight discrepancies of ratios in the outsectors.[1]

With the end of the war in Europe and the cessation of bombing operations against Germany Bomber Command requirements dropped sharply and those of Tiger Force took first place. It was decided that B.A.B.S. Mark II was to be provided for this force but, as it was not likely that all would be equipped with H2S, Rebecca Mark II was also required. At a meeting on 8 June 1945 first priority was given to the provision of training facilities within Technical Training Command and Bomber Command for Tiger Force. Production was still very slow and careful assessment of claims to equipment was essential.[2] In March 1945 Headquarters Transport Command had asked for an allocation of B.A.B.S. Mark II because no SCS. 51 equipments had been received. Six installations were required along the U.K./Karachi route for the use of reinforcement aircraft, and installation was also required at 14 terminal airfields in the United Kingdom. In June 1945 the requirement was increased to 54 equipments and Headquarters Transport Command predicted that the demand would eventually be for 60. In August 1945 the Air Ministry ruled that any B.A.B.S. equipment not required for Tiger Force could be used on the U.K./Karachi route.

With the cessation of hostilities the priority for B.A.B.S. Mark II was again altered, the primary task of the R.A.F. having become the transport of troops; in October 1945 the trooping commitment was given overriding priority.[3] With the cessation of Lease-Lend, Transport Command was faced with the danger of the failure of supplies of SCS. 51, and the Chief of the Air Staff ruled that work was to be accelerated on any buildings or ground installations necessary for Transport Command use and was to have priority over Bomber Command projects, other than at airfields used for Bomber Command trooping.[4] By the end of October 1945, 113 equipments had been received from the manufacturers and the task of siting and installation was going ahead both at home and overseas. Prestwick, Melbourne, Holmesley South, and Blackbushe had each been provided with one mobile set.[5]

In September 1945 Pye produced the first B.A.B.S. Mark IIM modified to operate on 193 megacycles per second. This was called B.A.B.S. Mark IIFM and was sent to the T.R.E. for type approval in November 1945. It did not operate satisfactorily but the T.R.E. attributed this not to its adaptation to the Fighter Command frequencies but to faults in manufacture. Once these were cleared the T.R.E. agreed to give type approval, and considered that the necessary modifications to produce B.A.B.S. Mark IIFM from Mark IIM could be incorporated by Service personnel. Fighter Command sent four radar mechanics to the T.R.E. for training and by January 1946 they had modified one model there. It was sent to West Raynham for trials. In the spring of 1945 the Air Ministry stated a requirement for an air transportable model of B.A.B.S. Mark IIM to be known as B.A.B.S. Mark IIA. A development contract was placed with the firm of Pye in June 1945 but work did not

[1] T.R.E. Memorandum 43/M.14/KAW. B.A.B.S. Mark II—Summary of Performance.
[2] A.M. File C.30496/46, Part II.
[3] A.M. File C.30496/46, Part II.
[4] A.M. File S.103233.
[5] A.M. File S.103233.

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start for some months because the original documents were lost in transit. By the winter of 1945 development work had started on this project.[1]

The rate of production of B.A.B.S. Mark II was so slow that, apart from initial provisioning for Tiger Force and trooping commitments, no equipments were available for installation overseas during the war. One requirement that could not be met was that of the Tactical Air Force, who requested the installation of 10 mobile equipments in north-west Europe at airfields used by communications squadrons. It was considered that B.A.B.S. Mark IIM would be most suitable for installation along the U.K./Karachi route, and the T.R.E. modified standard equipment for use in tropical climates.[2] A T.R.E. representative visited the Transport Command staging posts in July 1945 to advise on the problems of siting and general installation. By the end of September 1945 works services had begun at six airfields, and in the following month arrangements were made for the installation of mobile B.A.B.S. at 10 Transport Command staging posts in the Middle East.[3] In November 1945 the Air Ministry informed Headquarters B.A.F.O. that B.A.B.S. Mark II was to be fitted at six staging posts in Europe.[4]

Headquarters No. 26 Group was made responsible for the siting, installation, calibration, and servicing beyond unit capacity, of B.A.B.S. Mark II at United Kingdom airfields. The command concerned selected an airfield, subject to Air Ministry approval, and specialist siting officers from No. 26 Group surveyed it, chose sites, and forwarded siting plans and works requirement schedules to the Air Ministry. Wherever possible the existing S.B.A. main beacon and inner marker plinths were converted for use with B.A.B.S. Mark II as was the existing mains power supply to sites.[5] A number of aircraft were provided within No. 26 Group specifically for the purpose of undertaking flight trials during installation and for subsequently making periodic checks on the calibration of the ground equipment. Headquarters No. 26 Group found difficulty in keeping fitting parties fully manned in the autumn of 1945 because of full-scale demobilisation, and this slowed down the introduction of B.A.B.S.

At the end of 1944 Headquarters Bomber Command expressed dissatisfaction with the existing policy that S.B.A. was to be removed from airfields before B.A.B.S. was installed, because during the period of B.A.B.S. installation no approach facilities were available. A list was submitted to the Air Ministry of 46 airfields at which it was considered desirable to retain S.B.A. until all operational bomber aircraft had been fitted with the requisite B.A.B.S. equipment and adequate ground installations had been made available. The Air Ministry agreed that this should be done at stations where no increase in works services was involved, but where simultaneous siting was impossible S.B.A. would have to be removed.

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[1] M.A.P. File SB.41807, Part II.

[2] A.M. File S.97074. In July 1945 instructions were issued for spraying B.A.B.S. Mark IIM as a temporary method of tropicalisation until suitable arrangements could be made on production lines. (A.M. File C.30582/46).

[3] Elmas, Luqa, Castel Benito, Shaibah, Bahrein, El Adem, Almaza, Lydda, Habbaniya, Catania.

[4] Melsbroek, Evere, Copenhagen, Oslo, Fuhlsbuttel, Gatow.

[5] A.M. File S.103233.

Technical officers of the T.R.E. who had been concerned with the development work on B.A.B.S. were insistent that adequate measures should be taken to ensure its successful introduction. They feared that if care were not taken to achieve perfect operational efficiency the R.A.F. would lose confidence in the aid and thus be prejudiced against it from the start. Consequently in May 1945 the T.R.E. recommended to the Air Ministry that command parties should be organised to supervise the introduction of B.A.B.S. Mark II and to ensure that it was maintained at the very highest standard. Senior officers should be suitably briefed on the details of the system and its repercussions on the general flying organisation of the Service. Servicing efficiency was important and those responsible should be adequately trained ; the emergency servicing party provided by No. 26 Group should be adequately established, reliable and efficient. Adequate control was essential and to this end it was recommended that B.A.B.S. should be absorbed in the local flying control procedure for fair weather landings as frequently as possible. However, in order that confidence in the system was not impaired it was also recommended that B.A.B.S. should not be used if there was any doubt about the performance of an installation. The T.R.E. feared that, if the necessary precautions were not taken, B.A.B.S. Mark II would be no more efficient than S.B.A. had been.[1] The Air Ministry agreed with the T.R.E., established command servicing parties, and when B.A.B.S. was installed overseas, issued instructions based on the T.R.E. recommendations. In October 1945, when plans were made for the installation of B.A.B.S. in the Middle East, a nucleus installation and maintenance servicing party of one R.A.F. officer and 10 airmen was trained in the United Kingdom by No. 26 Group and posted to the Middle East to work under the supervision of a T.R.E. officer. Headquarters Middle East was recommended to build a specialist party from this nucleus to check periodically the efficiency with which the equipment was being serviced at units. Until radar personnel trained on B.A.B.S. equipment were posted from the United Kingdom, station personnel were to be trained by the installation party, which was to be afforded every facility for that purpose.[2] Similar instructions were given to Headquarters B.A.F.O. in November 1945, when it was also decided that a standard aircrew B.A.B.S. drill should be introduced for use at home and overseas. Headquarters No. 26 Group was instructed to prepare a syllabus which was to be incorporated in the Link Trainer Instructors' course. In order to ensure constant practice in the use of the system it was agreed that the drill should be introduced into routine squadron navigation training as soon as each squadron was equipped to use B.A.B.S. The importance of maintaining the equipment at the highest pitch of efficiency was stressed and it was agreed that technical advisers should be included in servicing parties. Instructions were issued that B.A.B.S. installations were to be kept permanently switched on at the end of the runway in use so there was no delay when they were required.[3]

The problem of training mechanics for B.A.B.S. Mark II was discussed at a meeting held at the T.R.E. on 19 July 1944. At that date the problem was two-fold ; there was, first, the immediate problem of providing the necessary training for squadrons at Wickenby and Driffield to ensure that the Service trials were not hampered by inefficient servicing, and, secondly, the need for

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[1] A.M. File S.97074. [2] A.M. File S.103233. [3] A.M. File C.30582/46.

more comprehensive training courses in readiness for the introduction of B.A.B.S. on a major scale. To meet the first need two radar mechanics from Driffield and two from Wickenby were sent to the T.R.E. for ten days' training. After that the T.R.E. provided two courses, each of four weeks' duration, one in July 1944 and one in the following month. These consisted of a three weeks' conversion course which dealt mainly with the particular radar circuits involved in the radar beam approach technique and a further week on the special problems encountered in B.A.B.S. Mark II. By October 1944, 24 radar mechanics from Bomber Command had been trained at the T.R.E. Thereafter the responsibility was transferred to Technical Training Command and it was agreed that training should commence at Yatesbury in the middle of January 1945. The Air Ministry arranged for B.A.B.S. equipment to be allocated for the purpose but it was not until February 1945 that it was made available and then it was one of the models built by the T.R.E.[1] At the end of October 1945 the Air Ministry confirmed that arrangements had been made for a total of 50 radar mechanics to be trained at Yatesbury before undergoing further training at the S.F.U. Honiley. The first twelve were already there, and twelve or thirteen mechanics were to pass through the radio school every fortnight.

The provision of a remote control and monitoring system was one of the hardest problems to solve. It was required so that beacon installations might be left unattended during operational use. The site of the beacon at the end of the runway was dangerous in the event of an overshoot, and in December 1944 it was reported from Driffield that, owing to overshoots, there had been several occasions on which the beacons had been almost destroyed and the attendant mechanics had had very narrow escapes.[2] Because of the danger the installations at Wickenby and Driffield were left unattended during the period of landing. Headquarters Bomber Command considered this to be very unsatisfactory because the failure of the equipment or the radiation of incorrect information was liable to cause a crash. Consequently it was ruled that installations were to be manned by a mechanic throughout the period of use and any risks run were held to be normal risks of war.

Meanwhile efforts were being made to provide remote control and monitoring facilities. As a result of consultations with Headquarters Bomber Command the Air Ministry raised a requirement in November 1944 for development to be undertaken at the T.R.E. on the highest priority. The requirement was fourfold ; remote switching, remote monitoring of the beam, an alarm device, and remote control of the beam.[3] In January 1945 the Air Ministry sanctioned, as an interim measure, a method proposed by the T.R.E. which could be applied to all fixed and mobile B.A.B.S. Mark II installations operated from sites where AC mains and a minimum of four pairs of telephone cables were available.[4] One extra unit was installed with the existing equipment. It included the circuits necessary to display information on any standard indicator of the beam transmission in the control tower. The display allowed a continuous check to be made of alignment of the beam along the runway, of correct radiation of the pulses, and of the aerial switches.

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[1] M.A.P. File SB.41807, Part II.
[2] A.M. File CS.22955.
[3] A.M. File C.30582/46.
[4] A.M. File S.97074.

CHAPTER 18

GROUND CONTROLLED APPROACH AND SCS. 51

Early in 1943 it was becoming increasingly obvious that, with the intensification of the bombing offensive, an urgent requirement existed for a system which would enable large numbers of aircraft to be landed speedily and safely in poor visibility. At that time the R.A.F. was using the Standard Beam Approach system. In January 1943 an investigation made by the Inspector-General of the R.A.F. of the use of S.B.A. at operational units revealed that Bomber Command was heavily committed to the system in that 126 airfields had been equipped with the ground equipment and 30,000 aircraft installations had been manufactured by the end of 1942. It was considered that operational results were not justifying the outlay mainly because pilots of operational units were not obtaining adequate practice in beam flying and therefore lacked the confidence which was essential, and because Bomber Command employed a policy of compulsory diversions and so denied pilots the opportunity of using S.B.A. operationally. However, the system was the only one available on a large scale in the United Kingdom.

Description of G.C.A. System

Meanwhile a mobile radar method of blind approach, known as the 'Talk-down' or Ground Controlled Approach system, had been developed at the Radiation Laboratory, Massachusetts Institute of Technology, to the specifications of Dr L. W. Alvarez. It consisted of two separate radar systems with a common high-voltage power supply. The first was designed for the control of aircraft in the airfield circuit and the second for guiding aircraft down an approach path to the runway. The control system operated on a wavelength of 10 centimetres with peak power of 80 kilowatts and was capable of 'seeing' aircraft at ranges of 15 to 20 miles within angles of elevation of 2 to 10 degrees. Signals were presented on two plan position indicators in parallel with switchable range scales of 7, 15, and 30 miles. The two P.P.I. operators were known as the traffic controller and the despatcher. The approach system operated on a wavelength of 3 centimetres with a peak power of 3 kilowatts. Two dipole aerial arrays giving a narrow fan beam were used; a horizontal array gave a beam approximately 0·8 degrees wide in azimuth and 1·5 degrees wide in elevation, mechanically scanned in azimuth through 14 degrees, and a vertical dipole array gave a beam approximately 0·45 degrees wide in elevation and 3 degrees wide in azimuth, scanned in azimuth through 10 degrees. The driving mechanism was synchronised and the supply of power to the two arrays was controlled by a mechanical chopper geared to the driving motor. Power was alternately switched from the horizontal to the vertical arrays. Since the beam was so narrow, simple servo mechanisms were needed to maintain both arrays on the target. The two systems could be trained around in azimuth through 20 degrees at the azimuth operator's will; the elevation of the azimuth array was maintained at its correct position by the elevation operator. The signals from each appeared on separate B-scope indicators, plotting in rectangular co-ordinates angle versus range.[1] The operator for each cathode ray tube controlled, by means of a hand wheel, the position of a short-line electronic angle marker on his scope. He followed the aircraft signal in his respective co-ordinate by maintaining the angle marker on the centre of the aircraft signal. A third operator, the range man, seated between the other two, followed the aircraft in range with another electronic marker. In doing this, he controlled a cam system, known as the director, which placed the angle marker on the tubes at the desired position of the aircraft in the approach path. In the director there were two cams; the shape of one represented the relationship between the azimuth angle and the range for a given desired approach path and that of the other showed the elevation versus range relationship. Cam followers fed electrically so as to place the electronic angle markers on the tube at the desired angular position corresponding to the aircraft range. When the angle operator moved his marker on to the aircraft signal he automatically cranked out the angular deviation of the aircraft from its desired position. This angular error was multiplied electrically by range and the results appeared on the controller's meter as a voltage proportional to the linear error of the aircraft in that co-ordinate. The controller had three meters, mounted in a panel, in front of him, two giving linear errors of the aircraft in elevation and azimuth, the third being the range meter. From the information thus presented, the controller was able to guide the aircraft down the approach path towards the runway; he also gave the pilot information as to his distance from the airfield boundary. Communication with the aircraft was by means of radio telephony.[2]

The equipment was contained in two vehicles, sited within 50 yards of each other, which were positioned about 50 yards to the port side of the runway in use and about one third of the distance along it from the upwind end. The first contained the radar transmitting and receiving equipment, and the dipole aerial array mounted on the roof, in addition to the diesel-electric power supply. The second, the control room, housed the indicators, the controller's error system, and six radio communication sets.[3]

The first stage of the procedure in assisting an aircraft to approach was that of sorting out and identifying the aircraft nearing the airfield. This was the task of the traffic controller, who gave the pilot flying instructions on one of the R/T channels until his turn came for landing. This operator then handed the aircraft over to the despatcher, who guided the pilot, over a second R/T channel, to a position where the aircraft could be seen on the approach radar system and from which the final approach was to be made.[4] This point was usually about ten miles from the runway and the normal height of the aircraft was 2,000 feet.[5] Instructions on the course to be flown and cockpit drill were given. When the aircraft reached the point at which the final approach was to start a reflected signal was shown on the two 'precision' cathode ray tubes. The operator of each of these followed the path being flown by keeping a spot of light on the signal. The movements of the controls which kept the two spots of light on the

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[1] B-scope was a radar display showing position of target in bearing, horizontally, and in range, vertically.

[2] A.M. File S.87187. [3] A.M. File S.95191. [4] A.M. File S.87187.

[5] A.M. File S.89814.

elevation and azimuth signals showed by how much the pilot deviated in azimuth and elevation from the correct approach path. These errors appeared on the controller's meters and he gave the pilot instructions on a third R/T channel, correcting his position in azimuth and elevation so that he flew in on the correct path. At the same time the pilot was told when to increase the angle of flaps and when to extend them fully. He was informed of his distance from the runway at various stages of the approach, and finally at a prearranged distance from the runway he was given the distance and instructed to take over and land the aircraft by visual means.[1]

In addition to the approach instructions given by R/T, an aural signal was given to assist pilots. This was automatically generated from the azimuth error voltage and could be used by pilots who were trained in flying on the beam approach method. This signal gave an aural indication of the position of the aircraft in relation to the azimuth track. It was superimposed on the R/T channel and was regulated so as not to interfere with speech. If the aircraft was to the left of the track the pilot heard a succession of dots which increased in pitch as deviation from the track was reduced. If the pilot was flying to the right of the track there was a continuous note which rose in pitch as the distance from the track increased. As the aircraft was flown along the correct approach path the signal died out and a ' pip ' sounded every three seconds to assure the pilot that his R/T was still serviceable.[2]

Service Trials of G.C.A. Mark I

In January 1943 an M.A.P. Technical Mission visited the U.S.A. to discuss development of a glide path landing system. The main objects of the visit were, to specify the technical requirements for a system for common use in the U.S.A. and the United Kingdom, to discuss possible future developments of instrument landing systems, and to see if the U.S.A. authorities had any valuable new ideas for landing systems.[3] The mission received very favourable reports from Navy and Army pilots of Ground Controlled Approach, and, after attending demonstrations, considered that, although it was not suitable for completely blind landings, it appeared to be the most efficient existing system. The opinion was confirmed by four R.A.F. pilots from the B.A.C. who, in February, practised G.C.A. approaches ; only two were beam approach specialists, the others were not in regular flying practice.[4] The favourable reports made by the M.A.P. Technical Mission and the B.A.C. pilots were studied with great interest at the Air Ministry because of the recent investigation into S.B.A. ; Air Staff policy towards existing approach systems would obviously be influenced if there was an effective alternative method available.[5] There were, however, some doubts and the R.A.F. Delegation was requested to supply more information and to assure the Air Ministry that the alleged superiority of G.C.A. over other systems was not exaggerated. To prove its worth and to allay doubts Service trials were necessary and the B.A.C. recommended to the U.S.A. authorities that the equipment should be sent to the U.K. with its operating crew so that trials might be carried out with the R.A.F. and the U.S. Eighth Air Force. In

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[1] A.M. File S.87187. [2] A.M. File S.87187.

[3] The Technical Mission consisted of Mr. R. E. Gray of the Radio Department, Royal Aircraft Establishment, Mr. J. E. Clegg of the Telecommunications Research Establishment and Squadron Leader R. J. Falk of the R.A.E.

[4] A.M. File S.89814. [5] A.M. File C.30491/46.

March 1943 General McLelland agreed to send the laboratory model, known as G.C.A. Mark I, on the understanding that it was to be used for operational trials and not for experimental work.[1] A military operating crew and some of the Radiation Laboratory personnel would accompany it. The equipment could not be made available for shipment to the U.K. before June 1943 as it was being used by the Radiation Laboratory to test new electronic scanning and display arrangements which were to be incorporated in G.C.A. Mark II, then being produced by the firm of Gilfillan.[2]

On 15 March 1943 a panel was formed to make arrangements for the trials.[3] Its terms of reference were '. . . to make all necessary arrangements so that the G.C.A. equipment on arrival in the U.K. can be used immediately for operational trials for aircraft and crews of R.A.F. Bomber Command, R.A.F. Coastal Command, R.A.F. Fighter Command and R.A.F. Army Co-operation Command . . .' The Royal Aircraft Establishment was asked to release Mr. R. E. Gray for attachment to the Directorate of Communications Development at the Ministry of Aircraft Production so that he might act as technical co-ordinator.[4]

Originally Holme on Spalding Moor was suggested as the most suitable location for the trials but in April 1943 Elsham Wolds was chosen and arrangements were made for G.C.A. to be despatched there on its arrival from the U.S.A.[5] The airfield at Elsham Wolds was suitable because it was equipped with Drem Mark II and contact lighting, and S.B.A., so that flying in bad weather was practicable.[6] Considerable care was taken over the allocation of R/T frequencies because the success of the new system depended to a very large extent on the efficiency of R/T communication between aircraft and the controller. The frequencies 5005 and 5280 kilocycles per second were allocated as special G.C.A. frequencies ; 5135 kilocycles per second was allocated for communication between the airfield controller and aircraft before they were handed over to G.C.A. control; 6440 kilocycles per second for Bomber Command 'Darky' and 2410 kilocycles per second for Coastal Command 'Darky'.[7] All aircraft taking part were fitted with I.F.F. Mark III, Mark IIIG or Mark IIIGR.

The trials were conducted from 26 July to 23 August under the direction of the Deputy Director of Aircraft Safety, and were attended by Dr. Alvarez and other scientists from the Massachusetts Institute of Technology to see how the equipment worked in operational conditions and to supervise its operation and servicing. Over 300 approaches were made with all types of

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[1] A.M. File S.89814.

[2] A.M. File S.89814.

[3] The chairman was the Deputy Director of Aircraft Safety. He was assisted by the Deputy Director of R.D.F. and a member of the Directorate of Communications Development. (A.M. File S.89814).

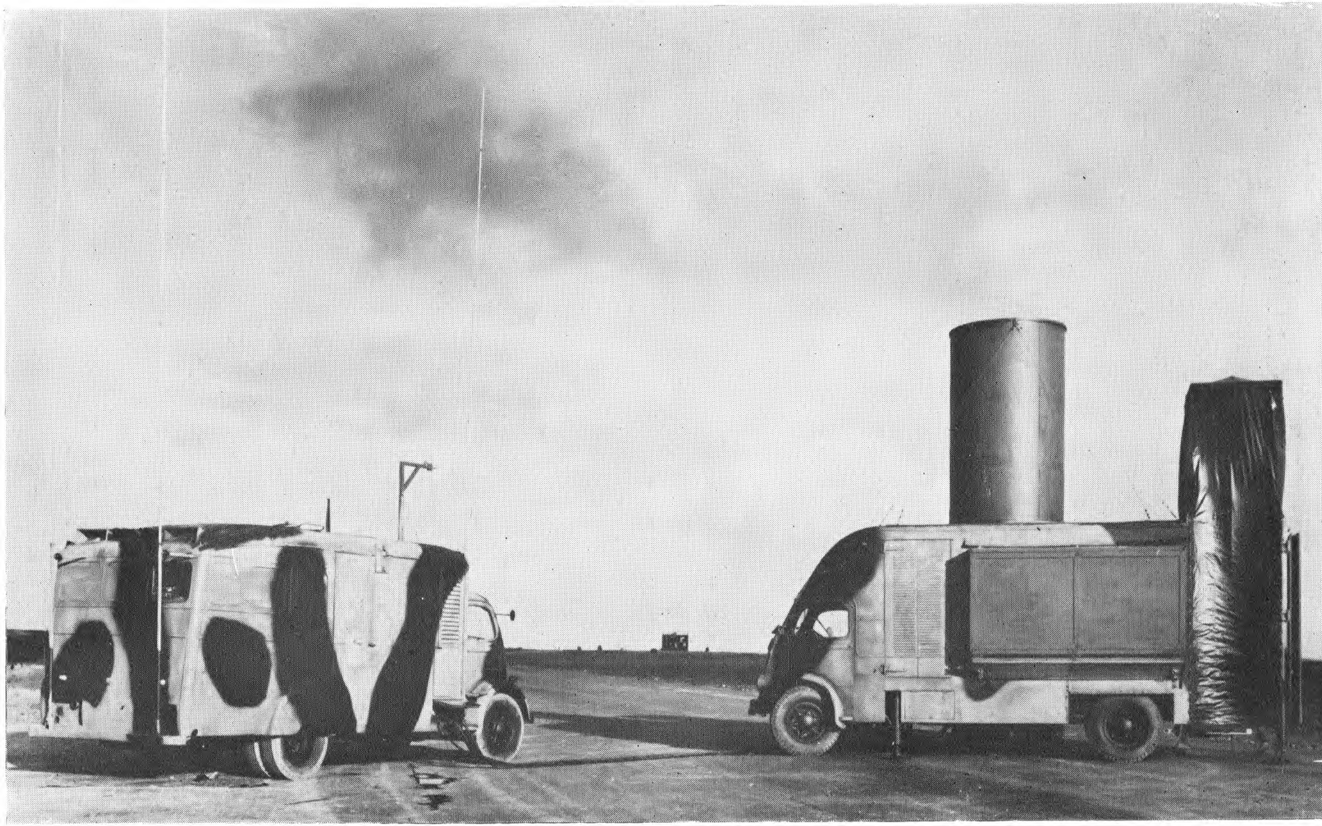
[4] A.M. File S.89814.

[5] A.M. File S.89814.

[6] *Drem Lighting*. Lights were spaced at intervals of 100 yards and were screened from above. They were visible only up to an angle of approximately 11 degrees from the horizontal. The system was installed as a normal flying aid in clear weather. It was simpler and a more economical installation than the contact system.

Contact Lighting. Consisted of sunken lights, spaced at intervals of 50 feet on each side of a beam runway. When visibility was 100 feet two lights could be seen ahead from any selected light point. The system was satisfactory in visibility conditions as low as 30 yards but required quick response from the pilot. The lights were not screened from above so the system could be used only in thick overcast conditions for reasons of security.

[7] A.M. File CS.19359.



G.C.A. Mark I

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aircraft and individual flights were made by pilots of all ranks, none of whom had used the system before.[1] American pilots also took part and representatives of the Admiralty Signals Department and the Admiralty Signals Establishment were present.[2]

The trials were conducted in three phases. The first part consisted of tests with various types of aircraft to ascertain their flying qualities under G.C.A. control;[3] the second part was composed of tests to determine the speed at which numbers of aircraft could be handled and the point at which they were to come under G.C.A. control; the third phase consisted of the approach control of Lancaster aircraft of No. 103 Squadron on return from operations. From the first stage of the trials, it was clear that the method of approach by G.C.A. would vary with each type of aircraft; this meant that it was essential for the controller to have considerable flying experience himself and to know what type of aircraft was coming in. The second stage of the trials was occupied with the particular problem of Bomber Command, that of landing a large number of aircraft safely in as short a time as possible. 44 approaches were made, 33 of which were successful; the average rate of landing was three every nine minutes. The lesson learnt from this stage was that a satisfactory procedure for feeding aircraft to the control point would have to be found to obviate delay in the landing approach. It was concluded that twice as many landings in bad weather were possible as with S.B.A. because G.C.A. could bring the aircraft to the boundary of the airfield, from where the pilot landed visually.[4] For the third stage of the trials pilots were given no training on the new system and no special briefing, other than a short explanation. 20 Lancaster aircraft returning from operations on the night of 22/23 August 1943 were landed under G.C.A. control, and 17 successful approaches were made. The result showed that even with G.C.A. it was not possible to land large numbers of aircraft quickly when they arrived at the airfield at the same time, but G.C.A. was no slower than other methods.[5] During the trials three communication channels were used; one by the G.C.A. controller and two by the P.P.I. operators. Five aircraft could be handled simultaneously; three by the first P.P.I. operator, one by the second, and one by the G.C.A. controller. If more than three aircraft were seen on the P.P.I. at the same time serious identification and control problems arose. A means would have to be found of controlling the aircraft round the airfield circuit, identifying the aircraft as they approached, and feeding them into the G.C.A. system.[6]

Appreciation of G.C.A. Mark I

The main advantages and disadvantages of G.C.A. when in operational use emerged from the trials. One great merit of the new system was its flexibility. It was mobile and contained its own power supply, and so could be moved from one runway to another when the wind direction changed. It could be used in all weathers in conjunction with the normal airfield flying control organisation; aircraft could approach from any direction. The fact that no aircraft equipment other than an R/T installation was required was of benefit in several ways; there was no heavy installation to increase weight, the system could be

[1] A.M. File CS.19359. [2] A.M. File S.89814.

[3] Tests were made with Spitfire, Typhoon, Mosquito, Master, Oxford, Anson, Liberator, Halifax, Stirling, and Lancaster aircraft.

[4] A.M. File S.87187. [5] A.M. File S.87187. [6] A.M. File CS.19359.

applied to all aircraft and so could become standard for all commands, pilots were accustomed to R/T and were practised in its use. Responsibility for the whole approach up to a short distance from the runway rested with ground personnel so that aircrew were relieved of the strain of concentrating on yet another set of instruments in order to land in bad weather. This was particularly helpful to crews returning from operational flights. The ground controller had an accurate picture of the position of the aircraft in range, elevation, and azimuth, and pilots merely followed his instructions, knowing that flying errors would be corrected from the ground. No special aircrew training was required. Since communication between aircraft and ground was by two-way R/T, the G.C.A. controller was made immediately aware that the system was in use. Servicing was simplified to some extent because all the vital radar components were readily accessible on the ground.[1]

A problem was raised by the necessity of multi-channel R/T; until V.H.F. R/T was introduced into the R.A.F. on a widespread scale, the existing H.F. R/T organisation limited the number of G.C.A. sets which could be installed in one particular area. The manning of the ground crews was also likely to be a problem. Although G.C.A. did not necessitate specialised aircrew training, the ground crews, both operating and servicing, required a very high standard of selection and training, since the control crew were entirely responsible for the safe approach of aircraft. Training would be long and intensive and controllers would have to be carefully selected, with great attention being paid to their personal qualities and previous experience. Expert servicing was also required to keep the equipment effective as G.C.A. was one of the most complex radar equipments then evolved.[2] As the only means of conveying instructions was by R/T, there was a language problem in dealing with foreign pilots. There was no device inherent in G.C.A. Mark I which enabled the ground crew to identify the aircraft under their control. An ancillary system was needed and during the Elsham Wolds trials I.F.F. was used. The identification requirement was two-fold; identification of an aircraft when it first approached the vicinity of the airfield, and its identification when it was handed over from the traffic controller to the approach controller.[3] Various methods were tried and G.C.A. Mark II included facilities for the separate installation of an I.F.F. system. In February 1944 the provision of a D/F loop was suggested.[4] A report received from the U.S.A. in May 1944 revealed that a fairly useful grid map system to facilitate identification had been developed.

The trials made it clear that a very efficient R/T communication system was essential for successful operation. A minimum of three channels was required. It was estimated that the minimum geographical separation between stations operating on the same frequency would have to be at least 60 miles to avoid mutual interference. To equip all airfields in Bomber Command 180 channels would be needed. As the number of additional channels available in the standard H.F. R/T equipment was not more than ten the number of airfields at which G.C.A. could be used was very limited. If the number of stations was not more than five in any one area of a radius of 30 miles, and if the local flying control frequency of each was used for G.C.A., 17 to 20 airfields could be equipped in Bomber Command and 35 to 40 in the rest of the United Kingdom. When

[1] A.H.B./ID4/257. Radio Aids to Flying Control.

[2] A.M. File S.95191. [3] A.M. File CS.19028. [4] A.M. File C.30491/46.

V.H.F. R/T was brought into general use in the R.A.F. the situation would be eased.[1] Stations would then have to be 120 miles apart but the number of channels available would be larger. If 90 kilocycles per second spacing on the V.H.F. band were accepted 90 stations in Bomber Command could be equipped, provided that density of stations was not more than 46 per area of radius 60 miles. In the rest of the country 200 airfields could be equipped. By careful selection a fairly continuous G.C.A. service could be set up. Eventually the problem of R/T communication did not become so pressing as was at first feared because the production of G.C.A. equipment in the U.S.A. was very slow and not more than 50 reached the United Kingdom before the end of the war with Germany.[2]

Air Staff Policy

On 23 September 1943 when a conference was held to discuss radio aids to flying control, it was stated that requirements varied within commands; the main need in Bomber Command was a system which would assist in speeding considerably the landing rate of large numbers of heavy aircraft arriving at an airfield within a short time of each other, while Fighter and Coastal Commands needed a system by which aircraft in much smaller numbers could be assisted to land safely in all weathers with less emphasis on the time-factor. The principles governing the choice of an approach system were the amalgamation of the bad weather system with the normal flying control procedure, the reduction of strain on the pilot and crew by assistance from the ground, a standard system for all commands, the provision of immediate assistance to aircraft in distress, and mobility of equipment. Three systems were discussed: Standard Beam Approach and the Beam Approach Beacon System, both of which required a radio glide path indicator for full presentation, and Ground Controlled Approach. The last was considered to be the best available, but could only be introduced in limited quantities because of the need for multi-channel R/T and because of the heavy manpower requirement. The committee recommended that it should be adopted on as wide a scale as possible and that B.A.B.S. should be employed where the use of G.C.A. was impossible.[3]

On 5 November 1943 a conference was held at the Air Ministry, to decide the future policy for the use of radio aids for flying control in all commands. The Deputy Chief of the Air Staff was chairman, the Inspector-General was present, and all the operational commands were represented. It was agreed that G.C.A. was practicable, provided that R/T communication was good. As a firm decision on its introduction into the R.A.F. was required before equipment could be obtained from the U.S.A., it was decided that G.C.A. should be employed as it became available, that most aircraft would have to use B.A.B.S. in the meantime, and that the use of S.B.A. would be gradually discontinued. No difficulty in providing and training ground crews for G.C.A. was anticipated.[4] Production of G.C.A. in the United Kingdom was at no time considered to be a practicable proposition; reliance was placed on production in the U.S.A. and the outcome of the operational trials was awaited before a large-scale production plan was formulated. Early in 1943, however, small orders were placed with American firms; 10 equipments were ordered from the firm of Gilfillan, and the U.S. Navy placed a contract with Bendix for 15.[5] On 2 November 1943 the R.A.F.

[1] It was thought to be unlikely before the end of 1945. (A.M. File CS.19028).
[2] A.M. File CS.19028. [3] A.H.B./ID4/257. [4] A.H.B./ID4/257.
[5] T.R.E. File D.1295.

Delegation informed the Air Ministry that the U.S. Army had ordered 10 G.C.A. Mark II and 47 Mark III from Gilfillan; three of the Mark II equipments were earmarked for the R.A.F. The U.S. Navy had ordered 20 G.C.A. Mark II from Bendix and might allow the R.A.F. to have 12 of these if it could be proved that G.C.A. was urgently required for operations in the U.K. The R.A.F. Delegation required a firm operational requirement so that bids could be made for the requisite number of equipments.[1] Later in November, when G.C.A. had been accepted as the primary approach aid for the R.A.F., the Air Ministry stated that full details of requirements had not been worked out but that 500 seemed to be a likely figure.[2] On 8 February 1944 the Ministry of Aircraft Production gave the British Air Commission full details of United Kingdom requirements. Production of S.B.A. was to be discontinued and the immediate requirement for G.C.A. was 175; the blind approach policy in the R.A.F. depended on whether sufficient equipment could be obtained from the U.S.A.[3] Although the urgency of the requirement was repeatedly emphasised production of G.C.A. was very slow because only limited manufacturing facilities were available. In May 1944 the Gilfillan contract was split with the firm of Federal in an effort to hasten delivery but supplies of G.C.A Mark II did not begin to arrive in the United Kingdom until 23 June 1944, and by the middle of August only five had arrived.[4] In June 1944 Headquarters Bomber Command after a careful study of the more recent reports on G.C.A., together with a comparison of its advantages and disadvantages, reduced the requirement for G.C.A. to 15 installations throughout the command as it was apparent that G.C.A. did not meet the most urgent need, that of a system for safely landing large numbers of aircraft quickly. This change in opinion of the chief user of G.C.A., in combination with the difficulties of production and frequency allocation, led to a modification of the original policy, officially expressed in September 1944, when it was decided that B.A.B.S. Mark II was to become the standard approach system throughout the operational commands of the Royal Air Force. G.C.A., in conjunction with FIDO, was to be installed at suitably geographically spaced airfields for use when B.A.B.S. Mark II aircraft equipment was unserviceable or when aircraft had to be landed in an emergency in worse weather conditions than visibility 1,000 yards and cloud ceiling 200 feet. The slow rate of production of G.C.A., the wide separation of airfields at which it could be used necessitated by the inadequate number of R/T channels available, and the limitation of manpower resources, all meant that the original number of equipments required had to be drastically reduced.[5] Thus the conception of G.C.A. as the primary approach system was altered; instead it was regarded as a supplementary aid, to be used in emergency only.[6]

Development of G.C.A. Mark II

As a result of the trials of the first laboratory model of G.C.A. certain improvements were incorporated in the production equipments made by the firm of Gilfillan. The method of housing the equipment in two vehicles had caused delays when G.C.A. Mark I had to be moved from one runway to another. The uncoupling of the power supply vehicle from the control vehicle meant that the valves and cathode ray tubes in the second vehicle cooled down and a long

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[1] A.M. File C.30491/46. [2] A.M. File C.42741. [3] A.M. File C.42741.
[4] A.M. File CS.19028. [5] A.M. File S.94422. [6] A.M. File S.97074.

wait was necessary in the new position after the power supply was switched on again before they were ready for use.[1] G.C.A. Mark II was housed in a four-ton six-wheel prime mover which contained air conditioning equipment and two 7½-kilowatt petrol-electric generators, and a trailer which contained all the radar and communications equipment.[2] This lessened considerably the delay caused by a move between runways as the valves and tubes remained at their working temperature while the vehicles were in motion. Modifications were also incorporated in the radar equipment. The precision aerials were no longer rotated with the entire array and reflector ; the beam was scanned electrically by phase-changing in the wave-guide itself. Higher scanning rates could be used and considerable elimination of ground returns was effected. Expanded sector plan position indicators replaced the angle-range scopes for the display of azimuth and elevation information ; two for azimuth, with ranges respectively of 10 and 2 miles, and two similar indicators for elevation. Both azimuth and elevation paths appeared as straight lines so that linear distances could be obtained directly from the cathode ray tube. The controller was located between the azimuth and elevation P.P.I. operators so that he could see their displays in addition to his own error meters. This gave him a more realistic picture of the approach.[3] The cathode ray tubes were placed at an angle of 45 degrees facing downwards and were viewed indirectly in a mirror. This method of viewing lessened eye strain because it prevented the operator from peering too closely at the screen. Maps or charts could be placed beneath the mirror. There were other alterations. No range operator was required. A mechanical marker set on the aircraft signal was used to compute deviations from the approach path. This allowed more rapid alignment than the electrical marker of G.C.A. Mark I. There was still no means of identifying aircraft but the specification for the trailer included the provision of a cable termination for power, telephones, and synchronising pulses in order that a separate I.F.F. system might be attached if required.[4]

G.C.A. Mark II made by Bendix followed the same general functional design as the original Mark I laboratory model and embodied the same main improvements as those incorporated in the Gilfillan Mark II equipment. There were, however, some differences. The Bendix design placed the air conditioning equipment entirely in the operating trailer, while the main power system, including the regulator for the auxiliary supply, was in the prime mover. There were differences in the materials of which the equipment was made, and some minor differences in the technical construction. A noise limiter was added to prevent interference with the V.H.F. communication equipment. In February 1944 Dr. A. G. Touch, of the British Air Commission, had visited the Gilfillan factory and reported that with G.C.A. Mark II there was considerable interaction between the radar and communication equipment because they were both housed in the trailer and no action had been taken to prevent interference. The radar was not screened, none of the leads carrying pulses were shielded, and no filters were incorporated. He considered that the Gilfillan factory and engineering staff were too small to cope with the problems of production of such a complex piece of radar equipment. The Bendix model appeared to be more satisfactory and the engineering staff of the firm were more able to cope with the problems. As a result of the operational trials of G.C.A. Mark I technical

[1] A.M. File S.87187. [2] A.M. File S.95191. [3] A.M. File S.87187.
[4] A.M. File S.95191.

officers from the R.A.E. had drawn up a list of requirements in November 1943 for later Marks. These were checked by the engineering staff of Bendix, who tried to incorporate the British suggestions. Where they were unable to do this they had devised satisfactory alternatives.[1]

G.C.A. Marks III and IV did not differ very much from Mark II. Mark III differed in that the precision radar equipment operated on a wavelength of 3·3 centimetres instead of 3·2, and Mark IV was merely an improved version of Mark III. Towards the end of the war development was begun of a system known as 'Split G.C.A.' in which the control equipment was installed in the airfield control tower whilst only the precision equipment was required to be mobile.[2]

G.C.A. Training

The original laboratory model of G.C.A. Mark I was retained in the U.K. for further operational trials and for the training of crews, so that when the first Mark II production equipments were received they could be put into immediate operational use. The equipment was moved from Elsham Wolds in August 1943 to Davidstow Moor and from there to St. Eval in September for Coastal Command trials.[3] The crew who had accompanied the equipment in the summer remained with it in order to train a crew consisting of one R.A.F. sergeant, one R.A.F. corporal and four A.C.W. W.A.A.F. radar operators so that they could take over operation of the equipment when the Americans left.[4] The trials were not as successful as those at Elsham Wolds, partly because at St. Eval all approaches were carried out under a hood whereas at the first trials this was not done, and partly because the equipment was badly affected by wear and tear. On 8 October 1943 the last of the original G.C.A. crew returned to the U.S.A. and the problem of servicing grew more and more acute. Although crew training was continued it was often interrupted because the equipment broke down.[5] In January 1944 Headquarters No. 26 Group were made responsible for the technical efficiency of the equipment, and on 14 March 1944 they advocated its removal to the Signals Development Unit at Hinton-in-the-Hedges. The necessity for thorough training had been emphasised by difficulties experienced with S.B.A., and it was agreed that this equipment should not be used operationally but should be used only for training and for the investigation of operational problems; a busy operational airfield was not therefore a suitable location.[6]

In addition to servicing personnel, highly skilled controllers were needed, both to inspire confidence in the pilots and to extract the utmost from the equipment. The effectiveness of the system was increased by good operators; at Elsham Wolds aircraft were brought down to within 440 yards of the runway but by the time the equipment was under the control of less experienced operators at St. Eval this distance was increased to half a mile.[7] In May 1944 it was agreed that a G.C.A. school should be set up and Hinton-in-the-Hedges was recommended as the location if suitable accommodation could be provided.[8]

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[1] A.M. File C.30491/46. [2] A.M. File C.30565/46. [3] A.M. File S.89814.

[4] A.M. File C.30491/46. A team consisting of one officer, one sergeant, and three aircraftmen was also sent on a course at the Gilfillan factory in Los Angeles in July 1943. It returned to the U.K. in June 1944 for duty at the G.C.A. school.

[5] A.M. File CS.20588. [6] A.M. File S.89814. [7] A.M. File CS.20588.

[8] A.M. File S.94422/43.

A large training school was required since it was estimated that 128 crews would need to be trained by the end of 1945 ; eight by the end of 1944 and 10 crews per month in 1945.[1] At the end of June 1944 Headquarters No. 26 Group suggested that another airfield be transferred to the group to accommodate the Signals Development Unit and the G.C.A. wing because the major works services required at Hinton-in-the-Hedges would take a long time to complete and the G.C.A. training school was an urgent commitment. In July 1944 Honiley was chosen as the location of the Signals Flying Unit, which was to incorporate the Signals Development Unit, previously at Hinton-in-the-Hedges, the new G.C.A. wing, and a servicing wing.[2] It had been proposed that a combined G.C.A. training school for the U.S.A.A.F., U.S.N., R.A.F., and R.C.A.F. should be established in the U.S.A. but this was rejected by the G.C.A. panel on the grounds that crews had to be trained quickly and training had to be linked with operational procedure in the United Kingdom. Liaison with other Services could be achieved by the exchange of instructors and information.

In June 1944 the composition of a G.C.A. crew was decided. The crew captain, who would also act as relief controller, was to be a squadron leader with considerable flying experience on many types of aircraft, and was whenever possible to be a pilot who had completed an operational tour of duty. The radio navigation officer, who would also act as relief director, was to be a flight lieutenant with operating experience of aircraft radar equipment. Two approach controllers of the rank of flight lieutenant were required to guide the aircraft down the approach path. Officers with pilot's qualifications were preferable for this task, but if these were not available men with experience of flying control and G.C.I. duties were recommended. Four flight sergeant directors were required for the initial approach stage ; selection from aircrew N.C.Os. with operating experience of aircraft radar was recommended. Finally five W.A.A.F. aircraftwomen radar operators were required for employment as trackers. The composition of a servicing crew was one flight sergeant, one sergeant, two corporals, and two aircraftmen radar mechanics and two M.T. drivers or fitters. A crew of this size would be sufficient to man one unit for 8 to 12 hours operational use each day.[3] A high standard was required from both operating and servicing crews for the successful introduction of G.C.A. into the Service. Headquarters No. 26 Group was made responsible for the selection of suitable personnel for G.C.A. training.[4] When, in November 1943, the decision to adopt G.C.A. had been made, no manpower difficulty was anticipated, but in the event it proved to be very difficult to find sufficient

[1] Estimated requirements were :—

Bomber Command	15
Coastal Command	17
Transport Command	16
A.E.A.F. (including A.D.G.B.)	25
Flying Training Command	10
Overseas	30
	113
Reserve	10
	123

[2] A.M. File S.101140. The establishment for the G.C.A. training unit was eight Oxford, eight Wellington and two Lancaster aircraft, and 38 officers and 250 other ranks.

[3] A.M. File S.94422/43.

[4] A.M. File S.101140.

personnel of the high standard and the experience required and amongst the suggestions put forward were the reduction of B.A.T. flights, the closing of the Flying Control and Airfield Controller School at Watchfield, the reduction of the home radar chain, and the disestablishment of all airfield controllers.

The five G.C.A. Mark II equipments received in the U.K. were used for training, which began at Honiley on 1 October 1944 with three crews under instruction. The equipment, as had been foreseen, was from Gilfillan production and was not very satisfactory, considerable modification being necessary. At the end of July 1944 a G.C.A. trainer, constructed from two trainers Type 29 and a C.H.L. receiver by R.A.F. and T.R.E. personnel, was despatched to Honiley ; a trainer had been ordered from the firm of Gilfillan but its development was very slow and it did not reproduce operational conditions sufficiently well for satisfactory training.[1] In November 1944 it became apparent that Honiley was not a suitable location for the G.C.A. training unit because extensive works services were required and labour was very difficult to obtain. Stratford was considered a suitable alternative and in March 1945 the G.C.A. training school was moved there. The S.F.U. remained at Honiley and was responsible for the administration and supervision of training. During the winter of 1944/45 the training programme outstripped the production programme, and by the time the school moved five trained crews were awaiting the arrival of equipment. In April 1945 three Bendix models were received and were allocated to the school at Stratford.

Operational Use of G.C.A. Mark II

G.C.A. was put into operational use by the R.A.F. for the first time when, in Februaıy 1945, a Mark II equipment and crew were taken from the school and transferred to Epinoy for use by aircraft of 2nd T.A.F. By the middle of April over 100 G.C.A. approaches had been made, and Headquarters 2nd T.A.F. reported very favourably on the system, stating that its accuracy had overcome the normal prejudice against control from the ground. A requirement was stated for more equipment and crews in north-west Europe. Such a favourable opinion in the first command to use G.C.A. operationally influenced a reallocation of available equipment and personnel. A further six Bendix production sets arrived in the U.K. in May 1945, and by October G.C.A. was in operation at six airfields ; Lyneham, Prestwick, Melsbroek, Wunsdorf, Fuhlsbuettel, and Schleswig. At Prestwick it was used continuously by the Transport Command All-Weather Flight, including occasions when visibility was between 50 and 500 yards and cloud-base down to between 50 and 150 feet. The highly-specialised aircrews showed great faith in the system, which was at its best when used with single aircraft only.[2]

In September 1945 the Air Traffic Control Practices Committee submitted to the Air Council a report on the use of radio navigational systems in bad weather. It was considered that G.C.A. was the best existing approach system because it was the simplest for aircrew to use although its operation and servicing required highly-skilled personnel on the ground. A recommendation

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[1] A.M. File C.43429/51.

[2] M.A.P. File SB.41807, Part II. G.C.A. was almost ready for operational use at Manston, St. Eval and Bassingbourn, and three more equipments had been allocated to Carnaby, Valley and a site to be chosen by Headquarters Transport Command.

was made that it should be used in conjunction with V.H.F. R/T to provide a common-user safety service for all types of aircraft. However, the actual use of G.C.A., and SCS. 51, was limited by the fact that only a small number of equipments could be purchased from the U.S.A. after the cessation of the Lease-Lend agreement, and by the wastage of trained crews caused by demobilisation.

Description of SCS. 51 System

SCS. 51 was the short title given to an approach aid known as the American Air Forces Instrument Approach System.[1] It was first used by the U.S.A.A.F. in the summer of 1943, and by August 1943 the system was installed or undergoing installation at all stations along the Army Airway from Mitchell Field, New York, to Gander Lake, Newfoundland. During September and October American O.T.Us. were also equipped.[2]

The installation consisted of a localiser for guidance to the runway, markers to fix position along the approach path, and a glide path to provide information as to the correct line of descent from 10 miles to the point of contact on the runway. The localiser was of the two-course visual type, furnishing a line of guidance down the centre line of the runway. The heading was produced by overlapping modulation patterns of 90 and 150 cycles per second which were selectively filtered and differentially rectified in the aircraft receiver to actuate the vertical needle of the cross-pointer indicator. Six frequencies were available in the band 108·3 to 110·3 megacycles per second, and radiation was horizontally polarised. It was installed in a 2½-ton vehicle and power was supplied by a self-contained three-kilowatt petrol-electric set. The localiser vehicle was normally placed 750 feet from the end of the runway opposite to the approach direction. The glide path was of the equi-signal straight type, provision being made for adjusting the descent path to any angle between two and five degrees. The glide path in space was produced by overlapping signal patterns modulated at 90 and 150 cycles which were filtered and rectified in the aircraft to indicate its position with respect to the path by movement of the cross-pointer indicator. The glide path employed a single-channel carrier frequency of 335 megacycles per second. The glide path transmitter was installed in a two-wheeled trailer which was normally sited 400 feet off the runway centre line approximately 700 feet in from the approach end of the runway. There were three marker beacons which operated on a carrier frequency of 75 megacycles per second. The boundary marker was placed at the edge of the usable area of the airfield; it was not keyed. The middle marker was situated 4,500 feet from the approach end of the runway; it was keyed at two dashes per second. The outer marker was placed three and a half miles from the middle marker; it was keyed at six dots per second. The equipment was towed and transported in a quarter-ton vehicle, three of which were supplied with the system. The aircraft equipment for use with the SCS. 51 system consisted of an aerial array, transmission line and fittings, a localiser receiver, a glide path receiver, a marker beacon receiver, a pilot's control box and a cross-pointer indicator. The aerial array included a U-shaped folded dipole mounted on a mast, nine inches in height, for localiser reception, and a straight dipole mounted just forward of the U on the same mast for reception

[1] A.M. File S.96994.

[2] A.M. File CS.21021.

of glide path signals. The localiser receiver was of the superheterodyne type and provided six crystal-controlled channels. The glide path receivers were of two types—super-regenerative and crystal-controlled superheterodyne. Early types were single-channel. The control box was approximately two and a half inches square and was located within reach of the pilot. The cross-pointer indicator was of standard instrument size and was mounted on the instrument panel. The vertical needle of the indicator was pivoted at the top of the face and moved right or left to indicate the position of the localiser course with respect to the aircraft. The horizontal needle of the indicator was pivoted at the left and swung up and down to indicate the position of the glide path with respect to the aircraft. The intersection of the needles represented the proper flight line in space and the entire instrument when inbound for a landing was flown by ' follow the needle ' sensing. If the intersection was to the left of and above the centre of the instrument then the desired flight path was above and to the left of the aircraft. The marker beacon receiver was a simple tuned RF and detector system feeding through a rectifier to a relay which operated an indicator light on the instrument panel.[1]

Trials in the United Kingdom of SCS. 51

In September 1943 the Britain Air Commission informed the Ministry of Aircraft Production that the U.S.A.A.F. authorities were very anxious to test SCS. 51 in the United States Eighth Air Force in operational conditions in the United Kingdom. It was therefore suggested that the equipment be sent to the U.K. for joint tests between the R.A.F. and the Eighth Air Force. The Air Ministry agreed to the proposal but stipulated that experimental trials, under Ministry of Aircraft Production arrangements, rather than Service operational trials, were to be held.[2] One ground and six aircraft installations despatched from the U.S.A. especially for the trials arrived in the U.K. in the middle of January 1944. Concurrent British and American trials were held at the Telecommunications Flying Unit, Defford, from 5 February to 4 March 1944. The aircraft equipment was installed in U.S.A.A.F. Fortress and Liberator aircraft and in R.A.F. Lancaster, Stirling, Wellington and Oxford aircraft. During the early stages of the trials visibility was about 1,000 yards or less and on one day tests were made by three pilots in a snowstorm, when flying by accepted standards, even with the assistance of S.B.A., would have been prohibited. The R.A.F. aircraft made 70 approaches, 26 hooded and 44 open, and the equipment in general proved to be very reliable. The localiser failed once during flight but for less than five minutes and neither the glide path nor the aircraft equipment failed. The airfield boundary marker was unreliable, but the general performance of the equipment was good. At 1,000 feet the localiser range was approximately 25 miles and the glide path range 15 miles, range being increased with height. The conclusion reached as a result of the trials was that SCS. 51 was a reliable system of instrument approach and one easy to learn. It was considered that a pilot of average ability would thoroughly grasp the system in two hours' flying instruction and that the amount of training required was considerably less than for any other pilot-operated system.[3]

[1] A.M. File CS.21021.

[2] Because of this the personnel engaged on the trials were confined to those of the R.A.E. and T.F.U. (A.M. File CS.21021.)

[3] A.M. File S.96994.

Introduction into Service Use

As a result of the joint British-American trials at Defford the U.S.A.A.F. in the United Kingdon decided to adopt SCS. 51 and in March 1944 installations were proposed at 21 airfields. At first there appeared to be no operational requirement for SCS. 51 in the R.A.F. In January 1944 it had been stated at a meeting held to discuss the trials that they were being undertaken for interest only, the Air Staff policy being to use G.C.A. as an approach system. As an interim measure S.B.A. and V.H.F. B.A. were to continue in use, as were the various Marks of B.A.B.S.[1] Further deterrents to the adoption of SCS. 51 lay in the difficulties of obtaining supplies from the U.S.A. and of installing new equipment in aircraft. The T.F.U. report on the trials, however, emphasised that R.A.F. aircraft, particularly in Transport Command, would be able to make good use of the equipment when landing at or operating from American bases.[2] Representatives from Transport Command participated in the trials and on 28 April 1944 Headquarters Transport Command expressed an operational requirement for the installation of SCS. 51 in all transport aircraft and at all terminal airfields, main alternative airfields, and major staging posts. This did not modify the Transport Command requirement for the provision of G.C.A. The view of the command was that SCS. 51 had several advantages over the existing S.B.A. equipment. A positive glide path was provided for the pilot, and presentation was visual and easier to follow accurately than the corresponding aural signals of S.B.A. The ground equipment was mobile and could be moved rapidly from runway to runway. It did not involve installation of extensive permanent ground stations linked up by long underground cables, which were liable to develop faults just when the equipment was most urgently required. The aircraft equipment was light and easy to install and represented an overall saving in weight of approximately 70 pounds compared with the S.B.A. aircraft equipment.[3] Air Ministry opinion was favourably inclined towards the limited use of SCS. 51 in the R.A.F. and in May 1944 official approval was given to the Transport Command proposal that aircraft sets be fitted in all heavy transport aircraft and ground sets installed at all terminals, main alternates and major staging posts. The aircraft involved were York, Dakota, Stirling Freighter, Warwick Freighter, Liberator C.87 and Liberator Marks I and II. The total number of airfields at which installation was planned was 14 in the United Kingdom and 20 overseas.[4]

Installation and Operational Use

The main handicap in the use of SCS. 51 in the R.A.F. was the fact that the supply of equipment was limited to the small amount which could be obtained from the U.S.A. Most of what was manufactured there was required for the U.S.A.A.F., which had adopted the system as its main approach aid in all theatres. The Ministry of Aircraft Production submitted a tentative request for 70 ground and 1,000 aircraft installations but in June 1944 the British Air Commission stated that there was little possibility of obtaining bulk supplies of SCS. 51 from the U.S.A. in 1944. As a result the Air Ministry assessed the immediate needs of Transport Command at 100 aircraft and six ground installations.[5] The shortage of supplies meant that installation of SCS. 51

[1] A.M. File CS.21021. [2] A.M. File S.96994. [3] A.M. File CS.22388.
[4] A.M. File CS.21021. [5] A.M. File C.29698/46.

in the United Kingdom was very slow. In April 1944 the experimental equipment was moved from Defford to Bovingdon for use by the United States Air Transport Command.[1] At the same time the Bovingdon installation was used to enable comprehensive tests to be carried out by the R.A.E. to investigate the degree to which mutual interference might be experienced between SCS. 51 and V.H.F. R/T. It had been feared earlier that the localiser signals would interfere with V.H.F. R/T because the localiser transmitted in the Fighter Command frequency band; frequencies were not identical but a serious problem of adjacent channel interference was anticipated. As a result of observations at the Defford trials, however, the T.F.U. and Headquarters A.E.A.F. had reported that the chances of interference between localiser and V.H.F. channels would be small providing sufficient care was taken in the allocation of localiser frequencies.[2] This danger of mutual interference meant that the frequency allocations for all proposed SCS. 51 installations in the United Kingdom, both R.A.F. and U.S.A.A.F., had to be submitted to the Air Ministry for approval before the equipment was installed.[3]

During the winter of 1944/45 three SCS. 51 installations were completed by the U.S.A.A.F. for Transport Command at Prestwick, Valley and St. Mawgan. These were the only R.A.F. ground installations in operational use during the war in Europe and were considered to be very satisfactory. During 1945 a few SCS. 51 aircraft sets were received and were fitted in Transport Command aircraft.[4] After the first three aircraft installations had been made by the U.S.A.A.F., Headquarters No. 26 Group was made responsible for all R.A.F. siting, installation and servicing, and the first SCS. 51 ground installation allocated to the United Kingdom was retained at the Signals Flying Unit, Honiley, for No. 26 Group experimental purposes. During the summer of 1945 larger supplies began to arrive in the United Kingdom and installation plans went ahead. On arrival sets were sent to the S.F.U. for checking and to enable 26 Group personnel to familiarise themselves with the equipment.[5] One problem the R.A.F. had to contend with in the operation of SCS. 51 was the manpower situation. When supplied from the U.S.A. all items of the ground equipment—localiser beacons, glide path beacon, and three marker beacons—were powered by separate petrol-electric generating sets and therefore each required an attendant while in operation. The U.S.A.A.F. was able to provide the necessary manpower but it was impossible for the R.A.F. to do so. The Air Ministry therefore decided that British installations were to be fitted with remote control and fault indication facilities. As this decision involved more extensive works services than with the American installation existing S.B.A. fittings were to be used as far as possible.[6]

The shortage of equipment affected the SCS. 51 training programme because the few sets which were needed for operational purposes could not be diverted for use in training schools. The U.S.A.A.F. provided the necessary training facilities. In July 1945 two R.A.F. N.C.Os. were given three weeks' instruction on the SCS. 51 installation at Bovingdon by U.S.A.A.F. personnel; they were then posted to the 1406th Army Air Force Base Unit at St. Mawgan to instruct R.A.F. mechanics on servicing the equipment.[7]

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[1] A.M. File A.97774/51. [2] A.M. File CS.21021. [3] A.M. File C.29698/46.
[4] A.M. File CS.22388. [5] A.M. File A.97774/51. [6] A.M. File C.29698/46.
[7] A.M. File A.97774/51.

The SCS. 51 system proved to be so satisfactory that in November 1945 items of ground equipment were issued to the firm of Pye Radio so that they might develop a British equivalent. In that same month a policy decision on the future installation of SCS. 51 was reached. Ground equipment, either American or the British civil version, was to be installed, in addition to B.A.B.S. Mark II, only at Transport Command airfields which were in common use with American military or civil aircraft, and British civil aircraft, and at a selected training airfield. Aircraft equipment, in addition to Rebecca Marks II or IV, was to be installed in aircraft which were required to land at American military or civil, and British civil, airfields.[1]

[1] A M. File C.29698/46.

CHAPTER 19

WIRELESS DIRECTION-FINDING, 1919–1934

Experience gained during the First World War had shown that several forms of wireless direction-finding were practical propositions as aids to air navigation.[1] They included the use of Bellini-Tosi ground stations, of aircraft D/F equipment for obtaining bearings from ground wireless beacons located at known positions, and of aircraft wing coils arranged so that signals of maximum strength were received when the aircraft was heading towards a ground wireless station. Basically they were the systems over which controversy raged during the ensuing fifteen years.[2]

Formulation of Early Direction-Finding Policy

During the war aircraft had made use of the many Admiralty D/F stations with very useful results. However, the siting of the stations, being entirely coastal, was not of great use to the R.A.F. in peacetime, and it is therefore not surprising that the Air Ministry showed little interest in the opening of nine of them to the Mercantile Marine on 1 June 1919, nor in the subsequent proposals for a permanent direction-finding service made by the Imperial Communications Committee of the Committee of Imperial Defence at a conference on 12 May 1921.[3] The proposal that the new peacetime service should be operated by the Post Office was accepted, but before it could be taken over reorganisation was needed, and permanent buildings had to be erected. Trials were begun at Niton, Isle of Wight, in 1921/22 to decide what form the new organisation should take. In view of subsequent experience, reports made as a result of the trials are of interest :—

(*a*) Under normal conditions bearings accurate to within two degrees could be ascertained by wireless direction-finding apparatus.

(*b*) Bearings taken at night were subject to a variable error which increased with distance.

(*c*) The reliable range was about 100 miles in daytime and 50 miles at night.

(*d*) A D/F station when first erected required the co-operation of a ship for calibration, and for maintaining a periodic check on the working of the station, particularly in the event of any modification being made in the apparatus.

(*e*) The personnel of a D/F station required extended experience in D/F work before undertaking the duty of giving bearings to ships. Special preliminary training was essential.

Research and development was continued at the new Wireless Experimental Establishment at Biggin Hill in the years immediately following the war.[4] A flight test of an aircraft fitted with D/F wing coils was arranged between the

[1] *See* Appendix No. 10 for details of the technical principles of wireless direction-finding.

[2] During this period the aircraft W/T most generally in use was a combination of T.21A and Tf.

[3] A.M. File S.14394.

[4] A.M. File 293488/21.

Director of Research and the Instrument Design Establishment at Biggin Hill in 1920, the co-operation of H.M. Signal School, Portsmouth, and H.M.S. *Antrim* being offered by the Admiralty. Two flights were made in November/December 1920, and successful homing to H.M.S. *Antrim*, situated some miles off the coast, was carried out on each occasion.[1] The R.A.F. was also keenly interested in the development of several other items of D/F apparatus ; indeed, the long and somewhat nebulous list on the W/T Research Programme for 1922/23 illustrated the doubt which existed at that time about future D/F policy, although training in wireless D/F had been included in the syllabus of the Navigation School since 1919, first at Andover and then at Calshot. At a meeting held to decide the 1923/24 programme the only system recommended was wing coils, which were still being used for homing purposes and for locating W/T stations generally.[2] But when, in July 1923, the wireless equipment for the navigation of airships from England to Bombay was discussed, it was freely admitted that D/F equipment in airships was still in the experimental stage, and that reliance would have to be placed on obtaining bearings from ground stations. As yet there were no R.A.F. D/F ground stations in England, although there were two at Croydon and Pulham operated on behalf of civil aviation ; R.A.F. D/F stations were in existence or being planned in Malta, Egypt, and Iraq.

It had to be decided what forms of radio communication were available for, and would be needed by, Home Defence bombing squadrons. Knowledge and experience available at the Air Ministry were not sufficient to enable a decision to be reached, and as a preliminary to the holding of a conference on 27 November 1923 the views of the Commandant of the Staff College, the A.O.C. Coastal Area, the A.O.C. Inland Area, and the O.C. Central Flying School, were sought.[3] As a result of the conference the Chief of the Air Staff formulated on 19 December 1923 the types of wireless equipment to be installed in existing day and night bomber aircraft and the lines of development to be followed for bomber aircraft of the foreseeable future. Two selected squadrons were to be equipped with two-way W/T and wing coils, and two W/T ground stations were to be established for position-finding ; one Vickers Vimy squadron was to be equipped with two-way W/T and with rotating coils for direction-finding if possible ; as each of the next three new night-bombing squadrons were formed they were to be equipped with two-way W/T. The shape of future direction-finding policy was outlined in the emphasis laid on the need for development of the revolving beacon method.[4]

Progress during the next three years was retarded by difficulties encountered in the supply and installation of equipment. Manpower and workshop facilities were limited ; radio telephony trials were coupled with those of W/T ; R/T and D/F in any form were barely out of the experimental stage ; most aircraft had never been fitted with wireless and no installation designs or plans were in existence ; bonding and screening involved up to 4,450 man-hours in some aircraft ; installation involved the design and manufacture of numbers of small parts which had not reached the stage of standardisation. Month by month the Air Staff requirement was increased, and as time went on many modifications became necessary ; some because of failures and others because of the advances made in wireless technique between the mock-up stage and delivery of new types of aircraft. Modifications created their own train of procedure delays,

[1] A.M. File 311127/20. [2] A.M. File S.22239. [3] A.M. File S.23185.
[4] *See* Appendix No. 11.

which included the time taken to estimate cost, to raise a contract, and to obtain financial sanction. The Chief of the Air Staff was particularly perturbed about them and caused arrangements to be made so that modifications were embodied, after they had been given due consideration, at stated intervals of about one year, instead of piecemeal.[1] Development of the four main direction-finding systems, rotating coils installed in the fuselage, fixed coils located on the main-planes, rotating beacons, and D/F ground stations, was uneven.

Aircraft Direction-Finding Loops

Although in 1923 opinion generally did not favour the rotating coil system, installation in one Vickers Vimy squadron was completed, but only with great difficulty because of the size of the coils. After some months of trials it was found that technical difficulties made the system impracticable, and it was eventually temporarily abandoned by the R.A.F. Over a period of two years satisfactory results were obtained with the wing coil system. Two squadrons were equipped ; No. 100 armed with Fawn and No. 207 with D.H.9A aircraft. Pressure of work prevented installation in replacement aircraft and the trials were discontinued ; it was recognised that the system was effective for homing only.

The R.A.E. was requested, in January 1934, to develop a rotating loop for aircraft installation so that trials might be made on the marine beacon waveband of 290 to 320 kilocycles per second.[2] Late in 1933 Headquarters Coastal Area had raised a requirement for aircraft D/F equipment which would enable attacking aircraft to home to the transmissions of shadowing or reconnaissance aircraft.[3] The loop, with a modified R.68 receiver, was installed in a Vildebeeste of the Coast Defence Training Squadron. Trials included homing to a ground station, maintaining a bearing from a ground station, and obtaining fixes from several ground stations. In September 1934 Headquarters Coastal Area considered that the results indicated that the rotating loop was of value. Meanwhile, however, the R.A.E. had installed loops in other aircraft, with which trials were conducted. Loop bearings taken at night on broadcasting stations in the medium-frequency band showed that the symptoms usually associated with night effect were observed and did not differ in any respect from those observed on similar equipment at ground level. The loop was not recommended as a reliable means of navigation at night except when the stations used were known to be within 50 miles of the aircraft.[4]

Rotating Beacons

The rotating beacon system entailed no transmissions from aircraft, and enabled an aircraft to determine its position without any wireless apparatus except the ordinary W/T receiver and trailing aerial. The observer in the aircraft timed the period between certain known wireless signals by means of a stop-watch, and this period enabled him to determine his bearing from the beacon station. The ground station consisted of a frame aerial rotated by mechanical means with a definite periodicity, usually one complete revolution per minute. The aerial threw a revolving beam of radio waves in exactly the same manner as a lighthouse throws a beam of light waves. A special signal was

[1] A.M. File S.23185. [2] A.M. File 295032/33. [3] A.M. File S.32774.
[4] A.M. File S.34611.

made when the beam was pointing due north, and it was by accurately measuring the time which elapsed from the moment of this signal until the signal strength received in the aircraft died to a minimum that the aircraft navigator was able to determine his bearing from the beacon station. The Germans had employed two stations using this principle on the Schleswig coast for their submarines during the war. Experiments had been begun in the United Kingdom in July 1918. The experimental apparatus was replaced in 1920 by a rotating loop operating on a wavelength of 1,550 metres, and very limited ranges were obtained. The R.A.E. then became responsible for development ; a station was erected at Farnborough and preliminary tests took place in September 1923 with a five-foot loop when ranges of 35 miles were obtained.[1] By September 1924, a higher-powered installation had been completed, and R.A.E. tests were successful up to 50 miles range.[2] Early in 1925 Vickers Virginia aircraft of No. 58 Squadron joined in the tests and in July 1925, when the beacon began to transmit on a regular schedule by day and by night, transmissions were observed by aircraft of four squadrons, Nos. 7, 9, 58 and 207.[3] Results were disappointing in the extreme, interference being very bad, ranges poor, and bearings erratic. The use of a wavelength of about 700 metres was decided upon, but ranges were still so disappointing that on 26 February 1926 all aircraft except No. 58 Squadron were taken off the trials and regular transmissions ceased. Carrying on the tests alone, No. 58 Squadron found the new beacon wave of 707 metres fairly free from interference. By July 1927, it was thought that the experimental period of the rotating beacon could be said to be over, and that the time had come to judge its probable utility. Headquarters A.D.G.B. considered that the system had proved sufficiently promising to warrant further trials and to justify alteration of wavelength to one free from interference, and there was general agreement that this was the most efficient and most easily-operated system of D/F for air navigation produced so far, and that it had great advantages over the Bellini-Tosi system in that no transmission by the aircraft was necessary, any number of aircraft could take bearings at the same time, and night error was apparently absent. The erratic results which had at times been obtained were thought to be due to inexperienced operating, and it was undoubtedly true that operators of experience were getting greatly improved results. Later in 1927 the Air Ministry was asked by the Board of Trade to contribute to the cost of erection of a new rotating beacon at Dungeness.[4] An experimental beacon for use with ships had been set up at Gosport in 1924, and in view of its efficiency the Board of Trade wanted to erect another. The Air Ministry had been planning the erection of a new beacon at Martlesham Heath, and the idea of combining with the Board of Trade to share costs seemed sensible. However, the cost of erecting the beacon at Dungeness proved to be prohibitive, and later Orfordness was chosen as the site, since it already had R.A.F. power supplies and communications. Trials were suspended while the new beacon was being built by the R.A.E.

On the basis of experience gained so far, the rotating beacon system was regarded as the panacea for all D/F ills. Wing coils were regarded as being at best a possible stop-gap pending the introduction of further rotating beacons, and it was decided not to fit any more, although aircraft were wired in

[1] A.M. File S.27499. [2] A.M. File 709343/26.

[3] Half-Yearly Report on Signals Work of the R.A.F., 31 December 1925.

[4] A.M. File S.27499.

readiness in case the decision should be reversed. Rotating beacons were also envisaged as the ultimate replacement of the Bellini-Tosi system and as the main source of D/F navigation by day and night.[1] '. . . The special value of the rotating beacon, if the Council's expectations are fulfilled, will be that it will afford a reliable means, at present lacking, of direction-finding during the hours of darkness, and that it will obviate the necessity of carrying complicated instruments in aircraft . . .' stated an Air Ministry letter to the Treasury in July 1928, the month in which trials of the new beacon began at Farnborough.[2] Treasury agreement for the estimated expenditure involved in the erection of this beacon at Orfordness followed on 7 August, costs being shared by the Air Ministry and the Board of Trade.

The main points disclosed by the early trials at Farnborough were that the new wavelength of 1,040 metres was more satisfactory, ranges up to at least 200 miles being obtained, and that with the increased signal strength it was much easier to train operators. The C.A.S. was satisfied with early progress but was not sure that all units were taking full advantage of the facilities offered. However, operation at Farnborough was only a temporary arrangement, and in February 1929, with trials completed satisfactorily, the beacon was dismantled for subsequent erection at Orfordness.[3] By May 1929, erection had been completed and calibration tests were in progress. An air publication for the guidance of operators using the beacon when it commenced routine transmissions was distributed throughout all bomber units of A.D.G.B., who were to carry out the trials.[4] Special note was to be made of any appearance or evidence of night effect. The beacon began routine transmissions on 20 June 1929.[5] Informed of the opening of the beacon, the C.A.S. stated '. . . This is very interesting and satisfactory . . . it looks to me as if these beacons will replace the Bellini-Tosi type . . .'[6]

In spite of the importance of the trials, reports at first revealed a seeming lack of interest but those made at the end of October showed that bomber squadrons generally had made much more use of the beacon, though there was still far too little information on night effect. An analysis of the returns showed that a high percentage of errors of more than two degrees were due to such factors as inexperience of operators, interference from broadcasting stations, and difficulty with the type of stop-watch in use. Errors by the operating crews were undoubtedly responsible for many inaccuracies, and better results were confidently expected with more practice and the introduction of an improved type of stop-watch. The reports showed that presence of night effect was characterised by flat and displaced minima, and that the limit of effective range appeared to be about 150 miles.[7] However, just as the value of the rotating beacon system seemed likely to be assured, the Air Ministry became concerned about its possible use by an enemy. Ways and means of restricting use by an enemy were suggested, but it was admitted that it would not be impossible for skilled enemy operators to use the beacons on occasions, although the R.A.E. was of the opinion that it would be quite possible to ensure comparative secrecy in time of war.[8]

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[1] A.M. File S.23185. [2] A.M. File 779442/27. [3] A.M. File 863874/28.

[4] A.P.38—'Position and Direction-Finding by means of Wireless Transmission'.

[5] A.M. File 863874/28. [6] A.M. File 779442/27. [7] A.M. File 863874/28.

[8] A.M. File S.27499.

By the end of 1929, the Air Staff was anxious to reach a decision on future D/F policy. H.F. D/F equipment was being developed at the R.A.E. but the question was whether the rotating beacon or the Bellini-Tosi method should be the future system of direction-finding, or whether it was still necessary to continue developing them both. Circumstances in the Royal Air Force from 1919 to 1929 were not comparable with later periods. The R.A.F. had suffered drastic cuts following the First World War, and money was not available for ambitious development schemes, either of aircraft or ancillary equipment. The same aircraft receiver, the Tf, was still in general use, and since it was mostly installed in the same aircraft types, or anyway in aircraft of similar performance and range, no doubt it was adequate for W/T communication, but all tests with new ground-to-air wireless apparatus had to be measured against the known limitations of the aircraft receiver. Also, there was not the stimulus of the threat of war, and officially there was no apparent enemy. Experiment and development therefore tended to follow their own course, and not a course dictated by war strategy, geography, or operational necessity. Consequently, it is not perhaps surprising that the same equipment was in use in 1929 as in 1919; that development of the rotating beacon had taken seven years to reach the stage of regular routine transmissions and a further four and a half years to undergo any kind of extended trial; and that the question of its being of more use to enemy than friendly aircraft had not apparently been raised in the Air Ministry until eleven years after the beacon's conception.

In December 1929, a memorandum on position-finding by wireless was prepared for the Air Staff by the Signals Staff. It showed that direction-finding by rotating beacon had many disadvantages, and the tenor of the memorandum strongly favoured adoption of an improved Bellini-Tosi method.[1] Although the right conclusion had been drawn, unfortunately some of the reasons for it were misconceived, and advocates of the rotating beacon seized on them to discredit the premises and prolong the period of indecision. The Signals Staff was certainly over-optimistic in predictions about cathode-ray direction finding, but its faith in the Adcock aerial was later justified. Briefly, it was contended that, so far from being free from night error as claimed, the rotating beacon was very definitely liable to it, if only to an extent; that night error could be almost completely eliminated in the Bellini-Tosi system by substitution of Adcock aerials for the existing aerials; that the risk of aircraft being located through transmitting requests for D/F assistance would be greatly reduced by the shorter transmission period required with the new cathode-ray oscillograph; that rotating beacons might be of more use to enemy aircraft than to our own; that it was easier for D/F ground stations to locate an aircraft position accurately than for aircrew personnel to do so by means of rotating beacons; that it was an easier matter for an enemy to jam beacon transmissions than a D/F ground system; and that it was essential for aircraft taking bearings on rotating beacons to break off listening-out watch on the traffic wavelength whilst doing so.[2] The A.O.C.-in-C., A.D.G.B. commented on the memorandum in detail but his main point was that it was highly dangerous to attempt to settle future policy on assumptions regarding equipment which had not been tried out in the Service and which had not, in fact, emerged from the laboratory stage of development. Although in April 1930 the Signals Staff reported that

[1] A.M. File S.27499.

[2] A.M. File S.27499.

the problem of night effect on medium wavelengths used by D/F ground stations had been solved, the Chief of the Air Staff ruled in May that development of both systems was to be continued, and Air Staff hopes were pinned on the eventual success of the rotating beacon. In order that the rotating beacon system might be fully tested a second beacon was required so that fixes could be obtained, and a suggestion that the experimental beacon at Farnborough should be operated, to save the expense of erecting another beacon pending the results of further trials, was accepted. The beacon began to operate in November 1930. Improvement in the accuracy of bearings obtained by crews during 1930 was noted with satisfaction by the Air Ministry. Night effect, while present, seemed to be negligible.[1]

The future of the Orfordness beacon was considered by the Wireless Direction-Finding Committee at the Board of Trade on 24 January 1930, where it was recommended that the beacon should continue to operate until 31 March 1931, when the position would be reviewed. In August of the same year, the C.A.S. ruled that the beacon would almost certainly be required by the R.A.F. for a further three to five years as a means of developing the rotating beacon method, and by April 1932 the Air Ministry was satisfied that the beacon would be required to remain in operation as an essential adjunct to the Home Defence force, at any rate for several years. However, the General Lighthouse Authorities, with whom the Board of Trade was sharing the expense of running the beacon, were not prepared to state that they could continue contributing after 31 March 1933. Shipping representatives had already expressed a preference for the fixed type of radio beacon.[2] Finally, the General Lighthouse Fund made a reduced contribution as from 1 April 1933. Previously, in May 1931, the Air Ministry had again posed the question of the security of rotating beacons and trials took place in August of that year, three aircraft representing our own bombers being in possession of full particulars of certain changes to be made in beacon characteristics, while three other aircraft represented the enemy and had no prior knowledge of the changes, being informed of them by an ' enemy ' ground W/T organisation. Technical opinion after the exercise was that changes could be made to rotating beacons which would render them of little value to enemy aircraft in time of war, but the Air Staff, as well as the commands concerned, thought the results were inconclusive. The unselective Tf receiver was still being used and undoubtedly hampered the trials, and the C.A.S. ruled that trials should recommence when the replacement receiver was available.[3] This decision was again in line with the policy that until new W/T apparatus had been produced, no definite decision about the tactical use and employment of wireless in aircraft could be made. The Air Staff view of the various forms of radio aids to navigation at that time was succinctly stated on 31 October 1931. ' . . . One of the principal uncertainties regarding wireless lies in the form of D/F to be adopted finally. There are three types :— Rotating Beacon, Adcock (improved Bellini-Tosi), and Wing Coils. The rotating beacon would be the most promising if (*a*) it had the range, and (*b*) the enemy could be prevented from using it ; because any number of aircraft can use it at the same time and any aircraft receiver can use it. . . . '[4]

Navigation by means of the two rotating beacons at Orfordness and Cove (Farnborough) was still attempted, but in the years that followed, even when

[1] A.M. File 863874/28. [2] A.M. File 957803/29. [3] A.M. File S.27499.
[4] A.M. File S.27499.

the new aircraft receiver was used, many limitations were disclosed. The main difficulties to be contended with were atmospherics, jamming, and general inaccuracy at medium and long ranges, and it was argued that, if jamming by other stations assumed serious proportions during peacetime, it would probably be easy for an enemy to effect even greater interference during war. It was also pointed out that in practice flights the W/T operator was not disturbed by any consideration such as listening out for operational signals or looking out for hostile aircraft.[1] The Farnborough beacon was moved to Tangmere in 1932/33 so as not to interfere with other experimental and development work at the R.A.E.

The final word on rotating beacons was not spoken until 16 October 1934, when, at the first annual D/F conference, it was agreed that, in spite of certain great advantages, the beacon had such grave operational disadvantages that its development would be discontinued and finance and training efforts concentrated on other methods.[2] Although by this time the R.A.E. was developing a rotating loop for use in aircraft, development of which had lain dormant with the failure of the Vickers Vimy installation, no new factor had come to light which could be said to turn the Air Staff against the rotating beacon method. D/F on high frequency and cathode-ray D/F were still unproved, and the introduction of new and reliable W/T apparatus had not been made on any scale. There was, then, no reason why the decision to abandon the rotating beacon method should not have been taken years earlier, and certainly it could well have been made on the strength of the Signals Staff memorandum of December 1929, with a saving of nearly five years' work.

Direction-Finding Ground Stations

A proposal to build two D/F ground stations, one at Eastchurch and one at Worthy Down, was agreed in March 1924; the Worthy Down station was transferred to Andover early in 1927.[3] At first the time taken by the stations to provide bearings caused concern. In April 1925 No. 58 Squadron was detailed to drop its rotating beacon trials whilst it concentrated for one month on working with the two Bellini-Tosi stations in an effort to speed up operating procedure.[4] All aircraft equipped with W/T made use of the ground stations but little was known at the Air Ministry of the results obtained until in the latter half of 1927 a comprehensive report was compiled by Headquarters A.D.G.B. which summarised the results of two months concentrated wireless duties undertaken by No. 100 Squadron in April and May. W/T communication had been good and the bearings obtained from Andover and Eastchurch had been satisfactory during daylight hours within the area in which a reasonable cut could be provided; at night they were unreliable. By that time both Headquarters A.D.G.B. and Headquarters Coastal Area were pressing for extended D/F coverage: the former wanted a temporary station to be erected for trials at Bircham Newton to replace eventually the station at Eastchurch, which was subject to site error; the latter wanted a station at Cattewater in view of the increased employment of flying-boats and seaplanes

[1] Report by Air Pilotage School on use of W/T D/F in a Home Defence War, August 1933. (A.M. File S.27499.)

[2] A.M. File S.34418.

[3] Half-Yearly Report on Signals Work of the R.A.F., 30 June 1927.

[4] A.M. File 709343/26.

in that area.[1] As a result the D.C.A.S. reviewed the experience gained in the two and a half years during which the stations had been working '. . . Up to the present all D/F training had been carried out on the Bellini-Tosi send-receive method and the results have been very satisfactory during daylight; night results cannot at present be relied upon. The rotating beacon at Farnborough has not so far produced very good results and it is doubtful whether a D/F service on this method will be established for the next two or three years. . . .'[2] Acting on this basis he supported the erection of a station for Coastal Area and agreed that tests should be made of the suitability of Bircham Newton. Two new D/F stations at Mount Batten (Cattewater) and Bircham Newton were completed and in operation in 1928 by which time the Eastchurch station had been dismantled; in the event of war the existing civil stations at Croydon, Pulham and Lympne were to be taken over.[3]

On 5 March 1929 Headquarters Coastal Area requested the provision of another D/F station in the west in view of the increasing use of the Irish Sea and its approaches on exercises and navigation flights. Four days later, Headquarters Wessex Bombing Area made a similar request, but in this instance the need for a fourth D/F station arose from the positioning of the other three, which were all on practically the same base-line. The Air Ministry at first proposed to open a new station at Sealand, and this met with the concurrence of both headquarters. The equipment formerly at Eastchurch was available and could be transferred to Sealand, but it was feared that if the erection of a Bellini-Tosi station at Sealand were authorised, the rotating beacon installed at Orfordness would have completed its trials by the time the new station was in operation, and it was thought probable that the rotating beacon system would render Bellini-Tosi obsolete. The C.A.S. agreed that the matter should be shelved until the end of the year, whilst a careful watch on the Orfordness trials was to be maintained.

A demonstration of direction-finding by means of a cathode-ray oscillograph was given by the Radio Research Board on 15 January 1930. As a demonstration of a scientific principle developed to a practical form the results obtained were satisfactory, but it was quite clear that further research was required before equipment could be produced which would attain the standard of robustness, simplicity and reliability sought by the Service.[4] However, the Radio Research Board was asked to prepare equipment for subsequent experimental use at the R.A.E. Features which the Air Ministry required to be incorporated included a frequency range of 200 to 400 kilocycles per second and an accuracy of plus or minus one degree, with sufficient sensitivity to enable signals to be received from aircraft transmitters, using 0·25 kilowatts, at ranges up to 300 miles. Selectivity and simplicity of operation were also needed. In 1933 equipment employing the cathode-ray method in conjunction with Bellini-Tosi reached the stage of preliminary pre-Service trials at the R.A.E. Research at that establishment into the possibilities of short-wave direction-finding was continually shelved because of shortage of facilities and staff but by 1932 determined efforts had been made and two short-wave direction-finders capable of operation in the 3,000 to 7,500 kilocycles per second band had been constructed. The

[1] A.M. File 745533/27.

[2] A.M. File S.23366.

[3] Half-Yearly Report on Signals Work of the R.A.F., 31 December 1928, and A.M. File S.23366.

[4] A.M. File 963920/29.

R.A.E. equipment was given Service trials at Hornchurch and Biggin Hill, and early results were satisfactory.[1]

The trials were continued in 1933 and 1934, although they were held up in 1934 while the development of special receivers was completed by the R.A.E.[2] Although results continued to be satisfactory, insufficient data was available to enable definite conclusions to be drawn. Belief in the efficacy of the Bellini-Tosi ground station system was fostered early in 1930 when the airship R.100, during the course of endurance trials, cruised for seventeen hours in cloud, effectively checking position by D/F. British civil aviation had always found the system to be adequate but the navigation problems of the R.A.F. were thought to be different, civil aircraft being mainly concerned with navigating on regular services between well-known points, whilst Service aircraft were required to operate across unfamiliar country and over large expanses of sea. However, the use of Bellini-Tosi stations was continued by all types of bomber aircraft, and in 1932 the station at Andover was converted to Marconi-Adcock. Development of Adcock D/F stations had been slow, mainly because of the very poor ranges obtained with aircraft. This failing was apparent in the Andover installation until the R.A.E. suggested a method of improving signal pick-up which subsequently became universal in all Adcock stations. It was at once found that Adcock D/F was considerably more accurate; the improvement was maintained and one year later pilots were showing increasing confidence in the system. The possibility of being able to control aircraft tracks by some method of radio direction-finding was first considered in 1933 at a time when the risk of collision between aircraft flying on converging courses in cloud was causing much concern. Models of a visual azimuth indicator were expected to be ready for Service trials in mid-1934, and it was hoped that the equipment would provide an effective warning system. In 1935 it was found that it did not meet the requirement, and an alternative suggestion that a ground W/T organisation should be devised to keep track of the position and height of aircraft so that they might be ground-controlled was put forward; the scheme was the precursor of subsequent ground control systems.[3]

[1] Half-Yearly Report on Signals Work of the R.A.F., 30 September 1932.

[2] Half-Yearly Report on Signals Work of the R.A.F., 31 March 1934.

[3] A.M. File 149335/31.

CHAPTER 20

WIRELESS DIRECTION-FINDING, 1934–1939

Although the period 1919–1934 was dominated by the attempt to meet an operational requirement by development of the rotating beacon, and was inevitably a period of frustration, it had been possible to investigate other systems, and the design of equipment, both ground and aircraft, was sufficiently well-founded to enable rapid progress to be made in the next five years. In June 1934 Air Marshal R. Brooke-Popham, Commander-in-Chief, Air Defence of Great Britain, stated that the time had come for a critical survey of existing radio navigational systems to be made in relation to the probable requirements of the next five years. '. . . Progress towards longer aircraft ranges and flying under much more unfavourable weather conditions than formerly has outstripped the existing organisation of wireless direction-finding services . . .'[1]

The R.A.E. had been instructed by the Air Ministry, in 1929, to investigate the possibility of using H.F. D/F for aircraft navigation, particularly in relation to fighter aircraft. R.A.E. work on H.F. D/F development was initiated by testing an experimental H.F. rotating Adcock equipment which had been developed by the Royal Navy. This, however, was found to be unsuitable because its effective range when used with fighter aircraft was about five miles only. The R.A.E. had therefore further developed the Adcock system to increase its range potential; this involved an entirely new design. The major advance made was the conception of using large capacity aerials so that the aerial current was larger and built up a larger voltage across the inevitably large capacity of the shielded leads. Circuit development was undertaken to fit in with this conception and, as a result, not only was a direction-finding system for fighter aircraft successfully evolved, but the Adcock system was also improved. The original method of using vertical aerials with screened horizontal leads for direction-finding, introduced by Adcock during the First World War, had not been used for working with aircraft because of the very short ranges obtained; for this reason the first Marconi-Adcock system installed at Andover had been of limited value. The experience gained by the R.A.E. during the development of H.F. D/F aerials resulted in action being taken to change the aerial system of the Andover M.F. D/F station so that aerial capacity, and consequently effective ranges when working with aircraft, was considerably increased. Thus accurate wireless direction-finding, by day and by night, had been made possible by 1931.[2]

A precise statement of Air Staff policy was made shortly before the first annual conference on direction-finding and radio beacons was held at the Air Ministry on 16 October 1934. It was considered essential that the wireless D/F system should reveal neither the position of outward-bound bomber aircraft nor the fact that they were outward-bound. The transmission of any form of wireless D/F signal by bombers on the outward journey was to be restricted to aircraft which were completely lost. Transmissions were permissible, both from

[1] A.M. File S.34418. [2] Narrator's interview with Group Captain C. K. Chandler.

aircraft and ground stations, during the return to base. The ground organisation was therefore to be capable of controlling numbers of aircraft, singly or in formation, and of directing them when thick cloud was prevalent to the vicinity of their airfields by night and by day. There was to be no restriction on transmissions by fighter aircraft and ground stations working with them, if the procedure adopted was proof against use by enemy bombers as an aid to navigation. A direction-finding system, organised on a mobile basis and complying with the general requirements for bomber and fighter aircraft, would be required at the outbreak of war to work with a force estimated at twenty bomber and five fighter squadrons. In a Home Defence war, the W/T requirements of Coastal Area would be subordinated to those of A.D.G.B., but in a war in which there was a serious threat to merchant shipping operations of Coastal Area would be given a high priority, and D/F was expected to be of great value to aircraft undertaking long patrols in poor visibility out of sight of land. D/F coverage would then be required for :—

(*a*) The approaches to the English Channel and the southern approaches to the Irish Sea.

(*b*) The southern part of the North Sea.

(*c*) The northern approaches to the Clyde and the Irish Sea.

The main conclusions reached at the conference were that the Royal Air Force should concentrate on the provision of Adcock D/F ground stations and rotating loop aircraft installations ; a bold decision in view of the cautious policy followed during the previous six years. In July 1933 preliminary trials to ascertain the possibilities of taking bearings on high-frequency aircraft transmissions had been started with ground equipment developed by the R.A.E.; all previous direction-finding had been carried out on medium frequencies. The conference decided that further trials were to be held, using an A.D.G.B. fighter aircraft working with the Radio Research Board high and intermediate-frequency Adcock station at Slough. The changeover of all R.A.F. Adcock D/F stations to high-frequency, and the linking up of groups of D/F stations by landline, was envisaged. The question of liaison with Civil Aviation was discussed, and it was agreed that Civil Aviation should continue to use existing methods, R.A.F. and Civil Aviation D/F developing independently according to requirements during peace, with sufficient co-ordination to ensure immediate co-operation when needed.

The existing home R.A.F. D/F organisation was one Adcock station at Andover and three Bellini-Tosi stations at Mount Batten, Bircham Newton and the Scilly Isles, all operating on a frequency of 340 kilocycles per second. The conference recommended the following additions and changes, to be in working order by 1938 and fully operative by 1941 :—

(*a*) *A.D.G.B.*

One Adcock station at Leuchars (part use of the R.R.B. Adcock Station at Leuchars had already been arranged) ; one Adcock station at Sealand ; the conversion of Bircham Newton from Bellini-Tosi to Adcock.

(*b*) *Coastal Area*

Conversion of the Bellini-Tosi station on the Scilly Isles to Adcock ; the existing Bellini-Tosi at Mount Batten to be abolished and replaced by an Adcock at Prawle Point ; the installation of a new Adcock station further east, probably on the Isle of Wight. It was also thought that Coastal Area might be able to share the use of Bircham Newton, Andover, Sealand, and Leuchars. In addition, certain Bellini-Tosi civil aviation stations, which might subsequently be converted to Adcock, could be used by either A.D.G.B. or Coastal Area on request to the Air Ministry.

(*c*) *Expeditionary Force and Air Striking Force*

The requirement was provisionally estimated as nine mobile stations, but further consideration was thought to be necessary. Other points agreed by the conference included the provision of six H.F. Adcock equipments for Service trials (three in A.D.G.B., two in Coastal Area, and one at Waddington) ; further research into and development of D/F aids, including particularly cathode-ray D/F ; the sending of a representative of the staff of the Director of Scientific Research to the U.S.A. to study development there ; the provision of three pilot-operated R/T installations in No. 24 (Communication) Squadron for working civil and R.A.F. stations on medium-frequency ; the provision of six rotating loops for trials in Coastal Area aircraft, and two loops each for Coastal and A.D.G.B. for trials on the ground. A direction-finding conference to review progress and development was in future to be held annually. The Chief of the Air Staff agreed to the proposals but brought forward the date by which the expansion of D/F services was to be completed to 1 April 1939.

High-Frequency Direction-Finding

H.F. D/F trials, undertaken by the Radio Research Board Adcock station at Slough, in conjunction with fighter aircraft of A.D.G.B., in late 1934 and early 1935, confirmed the results obtained with the R.A.E. H.F. D/F equipment at Biggin Hill and Hornchurch. Satisfactory bearings could be taken on fighter aircraft at R/T ranges up to the accepted limits of efficient R/T working, about 70 miles at 10,000 feet.[1] In addition, a pilot could, with very little practice, navigate on bearings given him by D/F, and maintain a position above a given point.[2] Provision of a D/F organisation was discussed at a conference held at Headquarters Fighting Area in October 1935. It was expected that fighters might often be called upon to operate out of sight of ground even though over their sectors, and also to operate over the sea when intercepting or when chasing an enemy. In either instance D/F would be necessary, to keep aircraft in the area in which they might be expected to meet the enemy, or to bring them back to their sectors or airfields after a chase. Headquarters Fighting Area therefore defined the requirement as :—

(*a*) Two or more groups of H.F. Adcock stations sited on the coast, to give bearings and fixes to aircraft over the sea.

(*b*) An H.F. Adcock station at each sector headquarters to deal with aircraft on patrol out of sight of ground, and to bring back lost aircraft to their sectors or home stations.

(*c*) A homing system to enable aircraft to reach their bases in bad visibility.

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[1] A.M. File S.34768.

[2] An automatic switching device to switch fighter aircraft R/T installations from ' receive ' to ' transmit ' periodically for H.F. D/F purposes was developed. This was the forerunner of Pipsqueak, details of which are given in Royal Air Force Signals History, Volume V : ' Fighter Control and Interception '.

The second annual direction-finding conference, held in November 1935, confirmed the general policy of concentration on rotatable coil installations for aircraft and Adcock ground stations.[1] Indeed, it was considered that the target date for completion of the new D/F system, 1 April 1939, precluded any major alteration in policy, though there was room for minor modification and experiment, mainly with approach and landing systems, and the radio compass. The six H.F. stations ordered as a result of the first conference had been delivered during the year. One had been erected at Waddington and was about to be brought into operation ; at Duxford and North Weald instructions had been given for installation to await site testing by a Marconi engineer ; and the three remaining equipments, for the Scillies, Prawle Point, and Northolt, had been sent to the R.A.E., where collapsible huts and aerials for them were under construction. Service trials with D/F loops had been satisfactory, and the trials carried out with I.F. and H.F. Adcock stations had shown that although satisfactory results could be obtained from up to 100 miles and from 200 miles upwards, bearings were liable to be inaccurate between about 100 to 200 miles. The main point at issue, however, was the provision of a network of H.F. D/F stations.[2] Under the new expansion announced by the Government in May 1935, the question arose how many stations would be required by bomber, fighter and coastal aircraft.

The requirements of fighter aircraft, and for what afterwards became Fighter Command, were assessed as one D/F station at each sector airfield (Biggin Hill, Catterick, Church Fenton, Digby, Duxford, Hornchurch, Kenley, North Weald, Tangmere and Wittering), one D/F station at Usworth, and one at each of five training stations ; sixteen stations in all. By November 1936, considerable use had been made of the H.F. D/F stations in the new Fighter Command and their possibilities had been carefully studied. It was found that ranges of 70 miles were possible with fighter aircraft fitted with the TR.9 installation if the aircraft flew at a suitable height.[3] The average accuracy obtained was two to three degrees, which was enough for homing, for ordinary navigation, and for keeping aircraft within their sectors. However, a much higher degree of accuracy was required to enable fighters to intercept, and further research work was put in hand. One cathode-ray direction finder had been in use in Fighter Command at Northolt for six months, and had given great satisfaction. Orders had been placed for eight sets of this type, four from each of two manufacturers, in order that manufacturing and supply problems might be investigated and to provide models for Service trials ; they were expected to be available in about March 1937.

Fighter Command policy was to establish a D/F organisation and to train personnel in the use of the Marconi-Adcock radio goniometer H.F. D/F equipment as a temporary measure until sufficient cathode-ray sets were available.

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[1] A.M. File S.34418.

[2] A.M. File S.34418. The problem of manning had also to be solved. The R.A.F. was already well under strength in signals personnel, and with the new H.F. D/F requirement an additional 70 N.C.Os. and 280 operators were needed. Training presented a further problem. The conclusion reached at the Electrical and Wireless School was that while direction-finding principles could be taught at the school, practice in D/F operating would extend the syllabus unduly, besides raising difficult questions of signals organisation, and would be costly in aircraft and apparatus. It was therefore decided to transfer trained operators at units to D/F work and replace them on point-to-point work by trainees from the school.

[3] A.M. File S.37600.

At that time it was thought that the cathode-ray method would replace the goniometer method within two or three years. The equipment would be installed at all stations not provided with cathode-ray equipment, and general installation was expected to begin early in 1937. The system would consist of Marconi-Adcock aerials and radio-goniometers coupled to the R.1084 receiver. A standard station consisted of a wooden D/F hut measuring ten feet by ten, and an additional hut containing a rest room and battery-charging room, in which was also housed the flasher for obstruction lights if they were fitted. The plan was that when cathode-ray apparatus was eventually fitted the second hut would contain a standby motor generator plant for use in the event of a power supply failure. The D/F station would be electrically heated, and would be connected by control cable to the station operations room. At first the D/F stations worked on the operational frequency, but when the TR.9 was modified a separate D/F frequency was established. Following the No. 11 (Fighter) Group exercises of 1936, it became apparent to the Director of Signals that at least two D/F stations per sector would be needed, and he continually pressed for their provision until the principle was finally agreed by the Chief of the Air Staff on 2 December 1937.[1]

Concurrently with other exercises and trials, the Biggin Hill experiments were conducted in 1936, and although they were primarily concerned with the interception problem, H.F. D/F as the latest method of assisting fighter navigation played an important part in them.[2] Three D/F stations, at Biggin Hill, North Weald, and Northolt, undertook the positioning and homing of the fighter aircraft, and M.F. D/F stations at Bircham Newton and Andover provided fixes for the 'hostile' bomber aircraft. However, the distances involved were too great for accurate fixing on either high or medium-frequencies, and, in view of the low power of the TR. 9 aircraft installation, it was clear that H.F. D/F stations should be sited close to the area where navigation assistance was required. Support for the contention that one station per sector was insufficient was provided on 31 March 1937 by the A.O.C.-in-C., Fighter Command, who outlined his probable future requirements as three per sector, one at sector headquarters, and the other two about half-way between sector headquarters and the coast in each instance. Two additional H.F. D/F stations were provided in the Biggin Hill sector two months later, and in August the A.O.C.-in-C. confirmed his estimate of the requirement. Then began the selection of sites, applications for the lease of land, requests for financial approval, and the purchase of additional D/F equipment, delivery of which was not expected before 1939.

By the end of 1937, five sectors, Biggin Hill, North Weald, Hornchurch, Northolt and Duxford, had been equipped with three H.F. D/F stations each. They were of the goniometer type, Marconi DFG. 12.[3] A second fighter group, No. 12, had been formed in April 1937, and to equip all sectors in both groups required a further 14 sets of D/F equipment. Further expansion subsequently

[1] In spite of the success achieved with H.F. D/F the R.A.E. had little faith in the system and advised against its adoption. No alternative scheme was offered, however, and the Director of Signals decided to disregard this advice and to urge forward completion of an H.F. D/F system, especially for Fighter Command.

[2] *See* Royal Air Force Signals History, Volume V: 'Fighter Control and Interception', for further details.

[3] Trials of cathode-ray equipment were still in progress.

increased this requirement to a total of 29 sets, but no contract was placed at once, as it was hoped that tests with cathode-ray equipment would be successful and enable that type to be ordered. This was the very kind of hiatus that planning at the annual D/F conference had been designed to avoid. The delay lasted until 30 March 1938, when it was pointed out that the cathode-ray trials were still inconclusive, and the purchase of goniometer equipment was urged.[1] Provision could be made for subsequent fitting of cathode-ray apparatus, if it finally proved satisfactory, without alteration to the existing aerial system or feeder lines. Purchase of the goniometer equipment was approved one week later, on 7 April 1938. There was also some delay in the provision of the forward R/T relay stations, only five of the projected 29 being connected by mid-1939. By that time, 9 only of the 18 fighter sectors had a D/F fixing service in operation. A spurt in the speed of installation of H.F. D/F stations and forward relay R/T stations was made in July 1939, but on 22 August there were still four sectors which could not hope to be completed before mid-September 1939.

At first, pilots tended not to take proper advantage of the new D/F facilities. In February 1939 all Fighter Command units were adjured to make full use of the new stations, and constant practice in obtaining homing bearings as a matter of routine, and routine testing of R/T equipment immediately after take-off, were ordered.[2] By the time of the Home Defence Exercise in August 1939 pilots had largely overcome their initial apathy, and it was clear that a great improvement had been made since the air exercises of the previous year.

Under the expansion schemes, the question arose how many H.F. D/F stations would be required to provide a service for Bomber Command aircraft. The Air Staff laid down that there was no necessity to direct an aircraft all the way in to its own airfield ; it would be sufficient to fix the position of aircraft within five miles of its airfield, and from there the pilot would have to find his own way in.[3] The use of D/F in blind flying conditions was not at that time visualised. The D/F system for bombers was also to be capable of providing fixes and bearings for aircraft returning from raids while they were in the skip area of local stations situated in eastern England, and of guiding them until they were within range of the local stations. This ruling postulated the erection of long-range D/F stations with radio transmitters of higher power in central or western districts.[4] Bomber airfields were organised in well-defined groups of from four to six stations each, with two or more squadrons at each station. Therefore although the Air Staff stated that the aim was continuity of attack rather than density, it was thought that any one group of stations might have to deal with ten returning aircraft in a 15-minute period. Such a rate demanded some system of traffic control by ground D/F stations.

The D/F conference of 1935 had provided for a total of 37 H.F. D/F stations for Bomber Command, on the basis of one per station. This was obviously the ideal, but it was subsequently considered that it would be too expensive in equipment and personnel, and Headquarters Bomber Command was informed

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[1] A.M. File S.39190. [2] A.M. File C.11533/42. [3] A.M. File S.38130.

[4] Due to the limitations imposed on H.F. D/F by the ' skip area ' phenomena, the same D/F station could not fulfil the two functions of (*a*) giving positions to aircraft returning from raids at 200 miles distance, and (*b*) homing. It was therefore necessary to install a number of long-range stations on the western side of England.

on 31 October 1936 that requirements would be met by a total of 27 stations, allocated to give the five bomber areas, Boscombe Down, Bicester, East Anglia, Lincolnshire and Yorkshire, short and long-range cover at the rate of two short and two long-range stations per area, except that East Anglia would have an extra pair of short-range stations owing to the greater concentration of airfields there.[1] The remaining five stations were allocated to isolated training units not situated within any particular area. The stations were located to give, as far as possible, a real homing service to the aircraft based at each airfield as well as a positioning service to aircraft seeking neighbouring airfields.[2] The short-range stations were equipped with Marconi DFG. 12 aerials, feeders and goniometers, and the R. 1084. D/F stations working together were connected by landline, and the short-range stations were provided with both R/T and W/T facilities.[3]

Headquarters Bomber Command continued to urge the provision of one D/F station per airfield. It was argued that, in practice, pilots and navigators had so little experience, especially of high-speed aircraft, that a fix was of little use to them since they must work forward in each case from the line of the fix to obtain their true position. In conditions of stress and difficulty, it was unlikely that they would have the confidence and calmness of judgment, engendered by experience, to do this. In fact, aircraft of Bomber Command could be regarded as being in the same position as those of Fighter Command, where it was accepted that the pilot could not navigate and that homing D/F stations must be provided at every airfield. A scheme for the provision of one D/F station per airfield was finally approved by the Chief of the Air Staff on 11 April 1938. Headquarters Bomber Command had also asked for a Regional Control service at a number of selected airfields, which would provide :—

(*a*) H.F. D/F.
(*b*) *Lorenz* blind landing.
(*c*) Short-range R/T control.
(*d*) Full night-flying lighting.
(*e*) Modern fog-lighting.
(*f*) Regional weather broadcasts.
(*g*) W/T guard on S.O.S. wavelength.
(*h*) A Duty Control staff with a Regional Control officer always on duty to assist aircraft in difficulties.

Nine Regional Control stations were provided, at Leuchars, Linton-on-Ouse, Waddington, Wyton, Abingdon, Boscombe Down, Mildenhall, Manston, and near Sealand, and in May 1939 approval was given to the provision of a second H.F. D/F station at each.[4]

[1] A.M. Files S.38120 and S.34418. The stations were to be situated at Benson, Boscombe Down, Abingdon, Cranfield, Watton, Wattisham, West Raynham, Honington, Grantham, Finningley, Leconfield, Driffield, Abbotsinch, Turnhouse, Aldergrove, Castle Bromwich, and Speke, plus ten long-range stations, three pairs of which were to cover the Belgium and Holland approach lanes and two pairs the approach from north Germany.

[2] A.M. File S.37600.

[3] In 1936 it was decided that all bomber aircraft should be fitted with W/T equipment, the only reservation being that light-bomber squadrons were limited to three per squadron until they were rearmed. The previous policy had provided for W/T installations for all night bombers but for only three aircraft per day squadron. The new policy meant one W/T operator per aircraft, and entry and training programmes for the signals trades were revised in order to cope with the new demand. (A.M. File S.23185, Part II).

[4] A.M. File S.38120.

By November 1938, progress in the erection of a total of 29 long and short-range stations for Bomber Command was as follows :—

(*a*) *Erected*—Mildenhall, Abingdon, Boscombe Down, Cranfield, Honington, Finningley, Leconfield and Grantham.

(*b*) *Erection anticipated complete in December*—Waddington, Linton-on-Ouse, Wyton.

(*c*) *Under erection*—Marham, Feltwell, Upwood, Watton and Wattisham.

(*d*) *To be erected*—Benson, West Raynham, Dishforth, Driffield, Hemswell, Scampton, Bassingbourn, Bicester, Stradishall, Harwell, Hucknall, Cottesmore and Upper Heyford.

Erection of the outstanding D/F stations did not proceed altogether smoothly, and arrangements were made for two Marconi engineers to tour the outstanding stations and to give advice to contractors and A.M.W.D. engineers.[1] The need for rigid discipline and constant expert supervision in this type of work was obvious.

When the original allocation of H.F. D/F stations was made in November 1935, Coastal Command was provided for on the basis of one station at each airfield or base.[2] Later, for reasons of economy, the allocation was reduced, but Headquarters Coastal Command joined with Headquarters Bomber Command in fighting the reduction.[3] The station erected in 1936 in the Scilly Isles gave useful service to Coastal Command aircraft pending the introduction of the full H.F. D/F service. Then, in 1936, it was hoped that cathode-ray apparatus would be ready in time for other installations.[4] Later, when it became obvious that development of the cathode-ray equipment was indefinitely delayed, installation of the goniometer type was proceeded with, and in April 1939 the Coastal Command H.F. D/F organisation comprised Pembroke Dock, Felixstowe, Dyce, Thorney Island, Thornaby, Leuchars, Catfoss, Manston, Bircham Newton, Wick and Detling.[5]

A programme for the erection of a total of 62 H.F. D/F stations for operational use, plus a further 20 for marginal and training purposes, was included in the Air Estimates for 1936/37, but as early as the first few months of 1936 it was apparent that constant pressure would have to be brought to bear if the target date of 1 April 1939, set by the Chief of the Air Staff, was to be achieved. Further, if the D/F organisation was to be fully operative by April 1939, it was desirable that the majority of stations should be working not later than April 1938 to give aircrew and ground operators the necessary experience. Contracts for equipment were placed at once, but in view of the many urgent commitments in the Service and in industry it was not to be expected that any appreciable delivery would be forthcoming within twelve months. Also, sites required careful selection, land had to be purchased or leased, and personnel and works services had to be provided. By 26 March 1938, a total of 33 sites for D/F stations had been found. The average time taken from first inspection to access was six months, most of this time being taken up in negotiations. Further planned expansion meant that another 45 sites were wanted, and at this stage the Air Ministry arranged for two technical officers to be permanently employed in selecting sites.

[1] A.M. File S.38120. [2] A.M. File S.34418. [3] A.M. File S.38120.
[4] A.M. File S.37600. [5] A.M. File S.38120.

It was regarded as essential for an officer of the Lands Branch to accompany each technical officer to open negotiations, but experience had shown that the Lands Branch was often hampered and prevented from closing a deal on a lease for a D/F site quickly because the price asked was a few pounds higher than seemed justified; the ensuing bargaining took months, and in the meantime the whole D/F organisation was held up. The Lands Branch was therefore asked to make available two officers armed with such freedom of action that they could close a reasonable bargain on the spot without subsequent criticism.[1] The Director of Works contended that the most fruitful causes of delay were the demands peculiar to D/F siting and the restrictions they imposed on the surrounding land, involving not only the lease of two or three acres for the site but also the restriction of cultivation of some fifty acres of adjoining land, coupled with continually changing Signals requirements. The Signals Staff agreed to modify the restrictive demands if one week's notice could be given of the proposed use of such machinery as tractors in the vicinity of sites. The Lands Branch was already fully occupied in acquiring land for operational airfields, training establishments, satellite airfields, and radar sites, as well as D/F and *Lorenz* sites, and the Director of Works was consequently unable to release two officers as requested. He tried without success to obtain extra staff, and the position on 16 September 1938 was that negotiations involving 18 sites passed to the directorate earlier in the year were still outstanding, while delivery of four sets of D/F equipment was expected by 23 September and a further ten sets one week later, making fourteen awaiting sites. Further sets were likely to accumulate in the weeks that followed because, as a result of pressure from the Chief of the Air Staff, the firm of Marconi was proposing to work 24 hours a day and at week-ends. A progress report made by the A.M.W.D. at the time gave some indication of the difficulties. Among their many obstructions were tenants' resistance, protracted negotiations with owners, acquirement of the sanction of county councils, and sometimes the abandonment of sites for technical reasons. In February 1939, authority was obtained to employ outside Lands agents, and the rate of acquisition then began to improve considerably.[2] Acceleration of the rate of erection after sites had been acquired was also necessary, and the Air Staff was in exactly the same position as the A.M.W.D. had been; technical officers could not be spared to supervise the work. Instead, arrangements were made for two Marconi engineers to tour sites individually, advising contractors, dealing with difficulties, making recommendations, and reporting briefly to the Air Ministry on progress.[3]

Use of H.F. D/F for Blind Approach

Two early systems for making a blind approach to an airfield in bad weather, the QGH and ZZ systems, made use of two-way ground-to-air communication. In each the ground and air operators followed a set procedure at the end of which pilots of aircraft were generally in visual contact. QGH was simply a descent-through-cloud procedure, and ZZ landings were not normally attempted unless visibility exceeded 1,000 yards. In the ZZ procedure, the aircraft called the airfield D/F station and was given courses to steer which brought it over the airfield at a stated height, generally 2,000 feet. The aircraft was then

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[1] A.M. File S.34418.

[2] A.M. File S.34418.

[3] Sites outstanding in mid-June 1939 were :—*Lorenz* Beacons 78, V.H.F. D/F 37, Cathode-Ray D/F 16 and H.F. D/F 9. (A.M. File S.34418).

instructed by the ground station to fly away from the airfield on a given course, letting down at a given rate per minute. The aircraft continued to transmit its call-sign at intervals, and eventually it was given a reciprocal course to steer. While it turned on to this course the operator transmitted the word ' turning '. The let-down then continued, given heights being reached at given distances from the start of the runway. The aircraft continued to make transmissions and the ground operator gave the course corrections. In the hands of experienced operators the system was good, and it was used up to the end of the war at airfields which had no beam approach system. However, the approximate safe limitations of such a system were a cloud base of about 600 feet and visibility of about 800 yards, and it was realised some years before the war that an improved system was needed. The probable R.A.F. requirements and the necessity for co-ordinating R.A.F. and civil aviation methods were discussed at the first annual D/F conference in 1934, and during 1936, trials were made of the *Lorenz* and Hegenberger systems, as a result of which Standard Beam Approach was eventually introduced into the R.A.F. Meanwhile, ZZ procedure remained the only blind approach system in use, and it was decided that new H.F. D/F stations were to be sited, in relation to the airfields they served, so that ZZ approaches were facilitated. In order to use them for this purpose, it was desirable to site a station in a direct line with the runway. Two H.F. D/F stations, at Aldergrove and Mildenhall, were erected on this basis and were used successfully for ZZ approaches, but subsequently, when other sites were being selected, the strongest opposition to their erection in the best approach lanes was forthcoming from station commanders, whose attitude was supported to some extent by Headquarters Bomber Command.[1] The policy was therefore changed and endeavours were made to site D/F stations so that they offered as little obstruction as possible while being close enough to the airfield to offer ZZ facilities.

Aircraft Direction-Finding Loops

Development of D/F loop installations in aircraft had been started during the First World War, and was one of the methods of D/F navigation considered at the time of the statement of policy on the use of radio communication by Home Defence bombing squadrons at the end of 1923. But at this time the loop was very much out of favour. It was too unwieldy for inclusion in any but the largest aircraft, and even in those its installation was impracticable. So for ten years from 1924 to 1934 little research or development was undertaken in this form of D/F in the United Kingdom. Undoubtedly the potential value of the rotating loop as an aircraft installation had been obscured in the fifteen years following the war by the obsession with the rotating beacon on the ground. The operational requirement was a direction-finding system which was independent of transmission by aircraft. There were three systems to choose from; the rotating beacon, the rotating loop, and the fixed wing coil. Early experience led the Air Staff to believe that the rotating beacon was in every way superior to the other two, and in fact the limitations of the fixed wing coil were obvious. So it was not until it was becoming obvious in 1933 that the rotating beacon did not adequately meet the requirement that an alternative system was sought. As a result of the trials made of the rotating loop system in 1934, the first annual D/F conference decided it was to be one of the two major forms of wireless direction-finding used in the R.A.F.

[1] A.M. File S.38120.

After the rotating loop trials had been in progress for about one year Headquarters Coastal Area was unable to provide much further data, but considered that the system was sound and constituted the best all-round method so far tried in aircraft, and its installation in all flying-boats was recommended.[1] The A.O.C. Wessex Bombing Area also thought that the degree of accuracy obtained with the rotating loop was most satisfactory when it was remembered that the wireless operators carrying out the trials had had no previous experience in direction-finding by wireless. At the second annual D/F conference in November 1935, Headquarters Coastal Area and Headquarters A.D.G.B. recommended that the rotatable loop be standardised for all appropriate types of aircraft, and provision for a total of 1,074 loops was made in the Air Estimates for 1936. However, with the advent of high speed aircraft, designers were concerned at the drag to be expected from external loop installations, and development of retractable loops was begun.[2] On 25 June 1936 the Aircraft Equipment Committee recommended the introduction of non-retractable loops for Vildebeeste, Singapore III, Scapa, Valentia, London, Stranraer and Hendon aircraft, and trials of retractable installations in Harrow, Whitley, Battle, Blenheim, Anson and Wellesley aircraft.[3] Six firms undertook the design of retractable loops, with the assistance of the R.A.E., but an inspection of the designs aroused some apprehension in 1937 because of the danger of the loop icing up.[4] Meanwhile, in November 1936 the policy of fitting loop aerials in aircraft was confirmed.[5] By that time, retractable rotating loops had already been included as part of the standard equipment on civil aircraft flying the Transatlantic and Empire routes, and they were also being employed to an increasing extent on the European routes.[6] External loops mounted on top of the fuselage were fitted in five Whitley and five Harrow squadrons in 1938, and the fitting of other squadrons followed.[7]

Towards the end of 1937, the Air Ministry began to show interest in the possibility of using the D/F loop on high as well as on medium-frequency, for homing at short range to ground stations using the T.1087, with suitable coupling between the loop and the R.1082 in aircraft.[8] Information was required of the ranges at which such homing might be possible, and of whether errors would be so large as to lead aircraft on to a wrong track on first receiving a bearing at say 45 degrees to the axis of the aircraft. Early in 1938 the R.A.E. was asked to carry out tests in the 70 to 100 metre wave-band, to discover at what range polarisation error was negligible and at what range homing was unreliable. It was recognised by the Air Ministry at that stage that even medium-range homing might be of assistance not only to Bomber Command but also to enemy bombers. Tests carried out in a Handley Page troop-carrier aircraft showed that, by day, polarisation error was plus or minus two degrees up to a range of 70 to 75 miles, but that beyond those limits polarisation and fading became appreciable; safe homing was possible up to 100 miles. Generally, results obtained beyond this range were characterised by fading, apparent swinging of bearing, and occasionally by absence of minima. By night, polarisation error was plus or minus two degrees up to 25 miles, and the safe homing range was 45 to 50 miles. Rapid and irregular fading and absence of definite minima were experienced at greater ranges. Signal strengths

[1] A.M. File S.34611. [2] A.M. File S.39974. [3] A.M. File S.34611.
[4] A.M. File S.39974. [5] A.M. File S.39487. [6] A.M. File S.37600.
[7] Bomber Command File BC/S.20758. [8] A.M. File S.43388.

were still good above 300 miles, but fading and absence of minima prevented bearings being taken. The R.A.E. drew attention to the well-known vagaries of H.F. propagation phenomena, and emphasised the danger of attempting to draw general conclusions regarding H.F. propagation from a limited number of observations.

In June 1938 further tests were proposed to ascertain to what extent ranges were affected when the ground transmitter was of high power, such as those at Ongar and Rugby, and what quadrantal error was obtained. However, the R.A.E. considered that the previous tests had shown conclusively that the limit of satisfactory homing range was not due to any limitation of power at the transmitter, and there was no reason to expect that an increase in transmitter power would result in an increase in satisfactory homing range; the limiting factor was the presence of a reflected ray producing fading, change of bearing, and flat minima. The quadrantal error had been measured on 3,500 kilocycles per second and was found to be 3 degrees. At the time the R.A.E. was planning to investigate the properties of an opposed-loop homing system for its freedom from night errors; it was intended that further tests on the single-loop homing system should be merged with experiments on the opposed-loop system, so that a direct comparison of the two methods could be made.[1] Experimental work was continued for a number of years, but was finally shelved in April 1941 in view of the impending trials of Gee, and, to a lesser extent, because of the projected introduction in operational aircraft of navigator-operated loop receivers.

Trials were carried out as early as 1935 to test the value of B.B.C. transmitters for direction-finding purposes; the results showed that bearings could be obtained although they might be unreliable over large areas.[2] Before the war began preparations were completed for denying to the enemy their assistance to navigation in the form of M.F. beacons.[3] Arrangements were made for the synchronisation of a number of transmissions of each B.B.C. programme, so dispersed as to make it impossible for the *Luftwaffe* to use them in conjunction with aircraft D/F loops. The Air Staff policy then was that no beacons would be made available in the United Kingdom, in view of their possible use by enemy aircraft. This was a defensive policy in keeping with the state of preparedness of the country, but it severely restricted the value to the R.A.F. of aircraft loops, both for training in peacetime and for operations in war. The loop might be useful as a check on D.R. navigation during long operational flights if suitable enemy or neutral beacons or broadcasting stations could be found for the purpose, but it could not be used for homing unless there were beacons in the United Kingdom. However, great difficulty in navigation on long operational flights was not anticipated; there was general confidence in the standards of D.R. navigation, and it was not until after the war began, when the many difficulties and hazards came to be fully appreciated, that provision of a system of home-based navigation beacons was decided upon. Indeed, the Air Ministry announced in March 1939 that even D/F ground stations would only be brought into use in extreme emergency, and it was considered that conditions would never be such that a D/F station would be busy with many aircraft at one time. The need for the operation of a continuous navigational

[1] A.M. File S.43388.

[2] A.M. File S.35602.

[3] *See* Royal Air Force Signals History, Volume VII: 'Radio Counter-Measures'.

service was not envisaged.[1] Anxiety was also felt about the threat of enemy use of the transmissions of H.F. D/F stations for loop D/F, and the problem of spoiling aerials at ground stations so that homing would not be possible except at very short ranges. Further tests were therefore carried out in November 1938 on two Daventry short-wave transmissions, which showed that if an aircraft flew in the approximate direction of the beam, the error of 90 degrees expected on horizontally-polarised beam transmitters was consistent and could be taken into account ; it was, therefore, not an error at all when the operator was aware that a station was emitting horizontal polarisation. Further research on this problem was continued after the outbreak of war.

In July 1939 it was suggested that, in time of war, a certain number of transmitting stations, both enemy and neutral, could be exploited for navigation purposes if aircraft navigators and wireless operators were trained to make the best use of any Intelligence that could be provided. Arrangements were made for the collection and dissemination of such Intelligence, but it was not until after the outbreak of war, on 17 January 1940, that a beacon for training purposes began transmissions from Andover.[2]

Medium-Frequency Direction-Finding

By the middle of 1937 the recommendations made in 1934 regarding the provision of M.F. D/F stations had been carried into effect with certain minor changes, and there was in force a medium-frequency D/F safety service. It comprised Adcock stations at Andover, Bircham Newton, Leuchars and Sealand, operating on 340 kilocycles per second ; Adcock stations at Mount Batten, Tangmere and on the Scillies, operating on 285 kilocycles per second ; and Bellini-Tosi stations at Bircham Newton and Manston operating on 370 kilocycles per second. The stations were connected by a landline system designed for the speedy passing of bearings from one to the other without the use of W/T.

In 1938, the policy for the wartime absorption into the Service of the civil aviation M.F. D/F organisation was formulated together with instructions for bringing it into force. The main objects were to give Coastal Command a D/F service for the use of G.R. squadrons working over the sea, to provide an alternative service for Bomber Command aircraft in difficulties, and to contribute towards the scheme for identification of friendly aircraft in conjunction with R.D.F. The civil network covered the whole of the British Isles, but since most of the stations were Bellini-Tosi, a separate reduced organisation using the Marconi-Adcock civil stations was necessary for operation at night. Meanwhile, under the threat of war, the changeover of civil stations which were to be re-equipped with Marconi-Adcock under the Maybury scheme was speeded up, the R.A.F. being particularly concerned since Bomber Command aircraft were expected to require D/F assistance mostly at night.[3] Nevertheless, the service was to be used in emergency only, since the position of civil stations was well known to the enemy, and it was thought that continuous transmission would enable enemy aircraft to make use of them as radio beacons. Arrangements were made for manning the stations on the outbreak of war, the plan being to retain civilian operators where possible, and sealed instructions were issued to them, to be opened on the declaration of an emergency. In each instance the nearest R.A.F. unit was detailed to act as ‘ parent ’ station.

[1] A.M. File S.49652. [2] A.M. File S.1520. [3] A.M. File S.45337.

Use of M.F. D/F for Identification

There were two major problems of identification to be solved. One was the separation of friendly from enemy aircraft on radar screens ; the other was the necessity to ensure that enemy aircraft could not make use of D/F ground stations simply by imitating call-signs. The first problem was much the more serious, and it began to give concern to Headquarters Bomber and Fighter Commands in 1936.[1] An exercise was held on 1 July 1937 with the object of ascertaining the capacity of a pair of D/F stations to fix the position of bomber aircraft approaching the coast, the fixes obtained being telephoned to the Fighter Command Operations Room immediately they were determined.[2] The stations employed were Andover and Bircham Newton, the line joining the two being assumed to be a coastline which was being approached by returning bombers. A total of 64 transmissions was made from the air at the rate of one per minute ; a fix was successfully obtained by the two stations during each transmission, and the degree of accuracy was acceptable. As a result of the trials, it was suggested that a number of medium-frequency D/F stations, including some of the civil stations, should be use as the basis of an identification organisation, Bomber Command homing needs being met by its H.F. D/F system and possibly by a beacon system. A proposed layout and bracketing of stations was put forward, having the capacity to deal with the expected number of returning aircraft.[3]

In October 1937 possible methods of providing warning or of routeing returning bombers through certain defined lanes were discussed. The possibility of using set routes and corridors was dismissed as it was thought that the required degree of accuracy in navigation could not be expected from aircraft returning from long operational flights, and a system of challenge and reply by W/T was decided upon, the reply to include aircraft position, height, course and speed, and an identification number. The system suffered from the same basic defect as the corridor system ; aircraft navigators could not be expected to give all the required information with any certainty of accuracy at all times. The method was tested in December and proved to be altogether too cumbersome. A revised method was introduced in which positions of returning bombers were fixed by a ground organisation which reported direct to Headquarters Fighter Command. The bomber was not challenged, but made a simple identification signal. In essence this was the same system as that tried out in the first exercise in July 1937. During the Home Defence exercises of August 1938 the new identification procedure was used, but the exercises showed that the only real solution was automatic identification on the screens of the radar reporting system.[4] A method of distinguishing friendly from enemy aircraft on radar screens during the process of detection and location was already being developed at Bawdsey, but no final solution was in sight.[5] Meanwhile, the exercises confirmed that the best interim course was to make use of the M.F. D/F system, and this method, known as the Voluntary Identification Method, in which the operator transmitted automatically when the navigator calculated the aircraft was 100 miles from the English coast, was in force at the outbreak of war.[6]

A requirement also existed for a system whereby D/F ground stations could identify aircraft calling for assistance, and thus prevent help being given to

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[1] A.M. File S.39973.

[2] *See also* Royal Air Force Signals History, Volume V: 'Fighter Control and Interception'.

[3] A.M. File S.40818.

[4] A.M. File S.40818.

[5] A.M. File S.39973.

[6] A.M. File S.40818.

enemy aircraft. A method had been used in Home Defence exercises in which a serial number transmitted after the aircraft call-sign acted as identification.[1] This system, involving the use of what was known as a Movement Serial Indicator, was introduced in 1939, in spite of objections from Headquarters Coastal Command, who thought it would complicate the task of the aircraft wireless operator, increase the time taken to obtain navigational aid, and reduce the number of aircraft which could obtain assistance. Headquarters Coastal Command also considered that the risk of the enemy making use of D/F stations located in the United Kingdom was small and could be accepted. However, the Air Ministry view was that confusion should not arise, as an aircraft worked only one pair of D/F stations, and then only in emergency ; once again it was clearly stated that transmission for D/F purposes between air and ground would take place only in conditions of absolute emergency.[2]

Cathode-Ray Direction-Finding

The visual cathode-ray direction-finding method held a number of advantages over the aural radio-goniometer method, and when it was decided to include the development of a cathode-ray oscillograph, with Adcock aerials, and with aural reception incorporated as part of the circuit, in the 1930/1931 development programme, high hopes were entertained that this type of equipment would eventually replace the aural method.[3] Development was continued at the R.A.E. until 1935, when an installation was made available for Service trials in Fighter Command. It was brought into operation at Northolt early in 1936, and was then probably the only one of its kind in existence, certainly in the United Kingdom. The equipment worked fairly well, and a review of the year's work put before the third annual D/F conference stated that it had given great satisfaction ; but in actual fact the tests revealed a number of faults. However, the A.O.C.-in-C., A.D.G.B., on 5 February 1936, stated that sufficient data had been collected to justify the adoption of the cathode-ray system for all direction-finding in the Service.[4] The Air Ministry, acting on recommendations made by the annual development programme conference on 24 February 1936, ruled in March 1936 that specifications should be produced by the R.A.E. in collaboration with the R.R.B. ; trials were to be completed as soon as possible, and if results were satisfactory, the cathode-ray system was to replace the goniometer system.[5] On 30 March, when the co-ordination of D/F and R.D.F. and allied problems was discussed, a change of policy in provision of the aural to the visual direction-finder was recommended.[6] The Air Ministry decided however, that specifications and drawings for the aural type should be completed, and that it was impracticable to adopt the visual type until the planned Service trials had been completed.

In May 1936, the R.A.E. produced specifications for both the Service trials' cathode-ray equipment and the production Marconi goniometer equipment, DFG. 12 with R.1084.[7] Development contracts for four sets of cathode-ray equipment were placed with the firms of Plessey in September 1936 and Marconi in October 1936.[8] Nearly three years after the specifications had been completed,

[1] A.M. File S.49652. [2] A.M. File S.49652.

[3] Cathode-ray D/F enabled bearings to be taken on transmissions of extremely short duration. When reception conditions were bad it was possible for comparatively inexperienced operators to obtain reasonably accurate bearings quickly. (A.M. File S.46122).

[4] A.M. File S.35037. [5] A.M. Files S.37600 and 471526/35.

[6] A.M. File S.38091. [7] A.M. File 471526/35. [8] A.M. File S.38091.

in 1939, the four Marconi DFG. 16 sets were installed at Leconfield, Honington, Pembroke Dock and Biggin Hill, and the four Plessey DF. 14 R sets at Kenley, Leuchars, Hornchurch and Aldergrove. Completed reports on Service trials of the equipment had been received from all eight stations by the outbreak of war, and with minor recommendations all the reports were favourable. Equipping of the new H.F. D/F stations had been held up for a time in the hope that the cathode-ray equipment would be ready to replace the aural goniometer equipment. Eventually it was decided to go ahead with the installation of the aural-type equipment, but installations were completed in such a way that the aural equipment could be replaced by visual cathode-ray equipment without difficulty. Even so, the H.F. D/F programme lagged behind schedule, and was still incomplete on the outbreak of war, when it was too late to introduce the cathode-ray equipment on any wide scale.

Direction-Finding in Overseas Commands

The first direction-finding station to be erected by the R.A.F. for the use of aircraft was installed at Ta Silch, Malta, and was in operation by January 1924. By then a station had been built at Abu Seuir and a location for a second station in Egypt was being sought, while in Iraq equipment for two stations had been supplied but had not been installed. Two Bellini-Tosi stations began working at Mosul and Ramadi in 1925, but their use was discontinued, and it was not until 1930 that a regular D/F service was supplied by the erection of two Bellini-Tosi stations at Shaibah and Hinaidi. The Iraqi Government provided a civil D/F station at Rutbah in 1932, a second at Baghdad in 1933, and a third at Basrah in 1935. The R.A.F. stations at Shaibah and Hinaidi were converted to Adcock in 1933, and in 1934 one of the Bellini-Tosi equipments thus released was erected at Mosul. Improvised forms of D/F were in use in Iraq well before 1930. In 1929 a locally made D/F set was used for training purposes, and practice in the use of portable frame aerials for direction-finding was carried out by all aircraft and armoured car units. Exercises took place in which aircraft equipped with frame aerials were required to locate a supposed force-landed aircraft. A system was developed which met with much success and was instrumental in locating an aircraft which actually had been obliged to land in the desert at night.

In 1929 there was a revival of interest in wing coils, several squadrons in Iraq using them in conjunction with the Tf receiver. Then, in response to a request from No. 205 Squadron, Singapore, two sets of wing coils were prepared at the R.A.E. for installation in Southampton flying-boats. These were fitted at Singapore early in 1932, and after a few months of trials the squadron reported on the layout and asked for modifications. However, the need for a full D/F service at Singapore remained, and in 1933 it was decided to open an Adcock station for the use of R.A.F. and civil aircraft. Delivery of the equipment took place in 1934.

In consequence of the expiration on 1 October 1932 of the agreement with Persia for the use of Persian territory by Imperial Airways aircraft *en route* to India, an alternative route along the Arabian coast with aerodromes at Bahrein and Sharjah was established.[1] D/F equipments were installed at Sharjah in 1933 and at Bahrein in 1934.[2] The Government of South Africa began to install

[1] Half-Yearly Report on Signals Work of the R.A.F., 31 March 1933.

[2] A.M. File 262955/33.

Bellini-Tosi D/F stations in 1932, and by 1933 a triangle of stations was in operation at Germiston, Victoria West and Capetown. In 1934 the provision of a further ten wireless stations, to include D/F facilities operating on the Adcock principle, was planned, so that at any point on the air routes two or three stations would be available for cross bearings.

In 1934, civil D/F stations were installed at Cairo (Almaza) and Alexandria, and in 1935 at Brindisi and Mersa Matruh on the India route. Generally speaking, the policy was to transfer the responsibility for handling air transport traffic to administrations over whose territory the air routes passed.[1] Arrangements of this kind had been made in Iraq, Egypt and the Sudan, the Sudan Government having installed a chain of D/F stations from north to south by 1937. Stations were also built on the route to West Africa from Khartoum, while the Nigerian government erected stations at Kano and Lagos ; communication with these stations was effected on H.F. and direction-finding on M.F. In India, too, a network of civil M.F. D/F stations was built along the trans-India route and also on the west coast at Bombay and on the east coast at various points and as far south as Madras. The trans-India network was continued through Burma to Rangoon and further south to Tavoy and Victoria Point ; not all the stations were regarded as reliable for direction-finding. In the Far East civil M.F. stations were built at Singapore, Penang and Hong Kong. The 1936 direction-finding conference recommended the installation of an M.F. station at Kuching and H.F. stations at Rangoon, Singapore, Kuching and Hong Kong.[2]

Although the overseas air routes were fairly well provided with M.F. D/F stations, the policy of allowing them to become the responsibility of the local government as civil stations meant that the R.A.F. had few D/F facilities under its own control for its own use. Obviously such a situation might be expected to right itself to some extent on the outbreak of war, when air traffic would mainly assume a military nature and the R.A.F. could expect to receive the priority accorded in peacetime to civil aviation. There was, however, clearly a requirement for an increase in D/F coverage and particularly for the introduction overseas of H.F. D/F, experiments with which had been begun abroad in 1934. Results indicated that installation of H.F. equipment would be of great advantage at nodal points on the air routes, especially in areas where atmospheric interference was high, such as the Persian Gulf and Malaya.[3] It was therefore decided in July 1938 to provide an additional six M.F. D/F and 10 H.F. D/F stations.[4] The M.F. stations were to be located at Singapore, Kuching (Sarawak), Kuantan (Malaya), Aqir (Palestine), Aden and Ceylon, and the H.F. stations at Singapore, Kuching, Jesselton (British North Borneo), Sungei Patani (Malaya), Egypt (two), Nairobi, Aden, Rangoon and Ceylon. However, it was not found possible to send H.F. equipment abroad before the war, and in the ensuing months many changes were made to the plan. But it formed the basis of provision of direction-finding equipment overseas during the early war years.

[1] In 1938 a great increase in the density of civil air traffic in Egypt made it necessary for the civil aviation authorities to restrict R.A.F. use of their direction-finding stations to the use of a Marconi DFG. 11 portable Bellini-Tosi installation at Heliopolis. DFG. 11 equipment was also installed at Amman, Transjordan, in December 1938.

[2] A.M. File S.37600. The plan to provide H.F. D/F at Hong Kong was not implemented as it was considered that the civil M.F. station fulfilled the direction-finding requirement.

[3] Half-Yearly Report on Signals Work of the R.A.F., 31 March 1934.

[4] A.M. File S.45161.

CHAPTER 21

WIRELESS DIRECTION-FINDING IN HOME COMMANDS 1939–1945

Because the M.F. D/F organisation, including that taken over from civil aviation, was largely required as an identification system, and was in any event of no use to Fighter Command, and since security considerations had prevented the establishment of a wireless beacon system, the only wireless navigation system available to all commands in 1939 was H.F. D/F. The planned H.F. D/F installation programme had suffered many delays, and had not been completed.

Research on and development of H.F. D/F had been continually shelved until 1930 because the rotating beacon had absorbed so much of the R.A.E. research potential. Then, following the decision made in November 1935 to equip all Fighter Command sector airfields and all Bomber Command and Coastal Command bases with H.F. D/F stations, several setbacks occurred. The principle that at least two stations were required at every Fighter Command sector was not finally approved until December 1937, over one year after the exercises of 1936 had shown such provision to be necessary. The original decision to provide every Bomber Command airfield with one H.F. D/F station was changed in October 1936, as the project was considered to be too expensive in equipment and personnel, and the policy was not reintroduced until April 1938. In addition, although the original intention had been to establish the D/F organisation and to train personnel with radio-goniometer equipment installed in such a way that it could readily be replaced by cathode-ray equipment if Service trials were satisfactory, a stage was reached in 1937 when contract action for the provision of radio-goniometer equipment to meet requirements was postponed in anticipation of the successful production of cathode-ray equipment. This resulted in a delay of one year before the purchase of the required equipment was approved. Then followed the series of delays in the siting and erection of the various stations, and by September 1939 four fighter sectors still awaited completion of their H.F. fixer organisation. In Bomber Command too, several stations awaited completion of H.F. D/F facilities, and continual expansion of the programme meant that there was always an installation back-log. One result was that pilots and crews were not sufficiently accustomed to the use of D/F facilities to have the confidence which they afterwards gained.

However, there had been no H.F. D/F service of any kind before 1936, yet by 1939 it had become the only sure radio aid to navigation, apart from the M.F. D/F identification and safety service, for all R.A.F. commands. It was providing the only means of blind-approach landings, and it had become a vital link in the Fighter Command system for the air defence of Britain. There had been some delay through an over-optimistic appreciation of the development state of the cathode-ray system, but it was natural that there should be resistance to the spending of much effort and money on a system believed to be outmoded. Altogether from 1934 to 1939 the right balance between vigorous planning and caution in introducing unproved equipment was preserved.

General Survey of D/F Systems

From the outbreak of war it was found that aircraft crews had the utmost difficulty in navigating successfully on long trips over enemy territory and over the sea.[1] The basis of all air navigation was dead-reckoning, but the difficulty of forecasting wind velocities accurately over long distances resulted in large errors in D.R. positions.[2] For aircraft of Bomber Command there were no radio aids to navigation deep in enemy territory except possibly enemy and neutral beacons. In emergency, radio silence could be broken and assistance of the allotted M.F. D/F section requested, but the chances of getting an accurate fix at long range were poor. When returning to base, bomber aircraft could use the station H.F. D/F frequency for homing when within 100 miles, but there were no M.F. beacons, all B.B.C. transmitters had been synchronised and spoiled, and the M.F. D/F service, although available in emergency, had another important function entirely unconnected with assistance to aircraft, that of identifying returning aircraft and fixing their position for the benefit of the Fighter Command defence system. Thus it was that bomber crews had the utmost difficulty in finding their targets and in returning to base.

D/F was never regarded as a method of navigation ; the only recognised method of navigating an aircraft was D.R.[3] There were three other means by which the position of aircraft could be determined, map-reading, radio position-finding, and astro-navigation, but all were subject to certain natural limitations. The three main limiting factors in radio position-finding were enemy interference, distance from the source of transmission, and technical failure, and the early aids dependent upon wireless transmission were particularly susceptible to these factors.

Complete confidence was placed in dead-reckoning navigation, and navigation was never carried out solely by radio. Radio operators were carried in case of emergency and because it was convenient to combine their rôle with that of air gunner ; their status in the early days of the war was not in any way comparable with that of other aircrew. The importance of radio was recognised by the Air Staff, who had laid down in 1936 that all bomber and similar aircraft should be equipped with it, but there were a number of factors which militated against full appreciation of radio as a navigational aid. The equipment in use in aircraft left much to be desired, both in performance and reliability.[4] The standard of operating was low.[5] Bearings from D/F ground stations varied in accuracy.[6] There were no M.F. beacons available in Britain or France.[7] The strict W/T silence that was imposed for security reasons tended to mask the value of radio. There was a general lack of confidence in radio in all its aspects, and while bearings given by ground stations and bearings taken in the air with

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[1] A.M. File S.40818. [2] Radio and Air Navigation Committee—Paper No. 5.

[3] Radio and Air Navigation Committee—Paper No. 3.

[4] A.H.B./IIE/75A. 'War in the Ether.' [5] Coastal Command File CC/S.9119/1.

[6] Bomber Command File BC/S.20489, Part II. [7] A.M. File S.2712.

the D/F loop were regarded as a useful check, a bearing which disagreed with the dead-reckoning position was likely to be discarded as useless.[1] This underlined the need for wireless operators to be in continual contact with the ground; a navigator was likely to place more reliance on a series of bearings from trusted stations than on an isolated fix from a remote one, and an operator who was in continual contact with the ground was far more likely to be able to anticipate a navigator's needs. However, in the early stages of the war, with W/T silence the rule, an operator could not always feel complete confidence in his ability to get the right kind of D/F assistance just when it was wanted; still less could he inspire such confidence. Again, in many of the early aircraft the operator had to man a gun during long periods, generally during just those periods when navigational assistance was most needed. An attempt was made to overcome the second difficulty by providing a D/F loop to be operated by the navigator, but no real answer was found until the increased size of aircraft allowed the carrying of a crew-member whose sole duty was to operate the wireless equipment.

A memorandum on the use of D/F as an aid to navigation was issued to bomber squadrons by Headquarters Bomber Command on 24 March 1940.[2] The highest importance was attached to crews reading and absorbing the information contained in it, the gist of which was that, while successful air navigation was based on dead-reckoning, accurate navigation over long distances could not be maintained by D.R. alone owing to the inability of meteorologists to forecast wind velocities accurately over wide areas. On the other hand, none of the methods used to assist dead-reckoning was sufficient in itself to conduct the navigation of aircraft in all circumstances; D.R. navigation therefore remained of paramount importance. The errors likely to be encountered when using D/F were particularly stressed, and indeed attempts by operators to obtain, for instance, H.F. D/F homing at distances far greater than 100 miles showed that the limitations of the particular forms of D/F were not as widely known as they should have been. The difficulty at that stage, that is, the stage at which pilots and crews had completed their training and probably several operational sorties, was to remind them of the limitations and inherent inaccuracies of D/F without undermining their confidence in it. This the memorandum endeavoured to do.

The most important period for D/F as an aid to navigation may be said to be from the winter of 1940/41, when aircraft began to operate in increasing numbers, to the middle of 1942, when the advent of radar aids greatly reduced the need for D/F. At the start of the war, the D/F organisation was well able to cope with the scale of operational flying possible at that time, but as the commands expanded, parallel expansion of the D/F services brought many problems, and the production of new equipment at times lagged behind the operational requirement.[3] Every Bomber Command base had its own H.F.

[1] Courts of enquiry investigating flying accidents not attributable to enemy action often found that pilots preferred to attempt to fly below cloud and rely on visual contact navigation than fly above cloud and make use of aids to navigation. The overall percentage of accidents involving errors in navigation and misuse of radio aids for the period 1940/1943 was slightly over 7. Within the period, percentages varied. From mid-1942 until the end of 1943 the figure was just under 4 per cent, the reduction being directly attributable to the introduction of Gee; it is evident therefore that from 1940 until mid-1942 the percentage was much higher than 7.

[2] Bomber Command File BC/S.20768/88/Sigs. *See* Appendix No. 13.

[3] A.H.B./IIE/75A.

D/F station, eventually most of them had two, and congestion on high frequencies became a serious problem until the introduction of radar aids made homing on H.F. the exception, and allowed the closing of fifty per cent of the stations. Up to April 1941, the M.F. organisation was hampered by its responsibility for the identification procedure, but it reached a peak as a fixing service early in 1942, and continued to be widely used right to the end of the war. The M.F. beacon policy was reversed in 1940, when a system of homing beacons was brought into force, albeit under the overriding control of Headquarters Fighter Command.

Radio ranges, which had been used in the U.S.A. for some years before the war, were subsequently installed in all areas from which U.S.A. aircraft operated, and a number were made available in the United Kingdom and abroad for the use of aircraft of Transport Command. The radio range was a refined form of radio beacon whereby signals were beamed into two or four beams. The beams were orientated so that they pointed in the most useful directions, such as along an approach route normally used or towards another main airfield, and, in some instances, along a main runway for use as an airfield approach aid. The sectors between the beams radiated the letter A or N in morse code, adjacent sectors radiating different letters ; the overlap between the two letters formed a steady beam. The pilot of an aircraft flying along one of the beams heard a steady note ; when he was flying off the beam to either side he heard either A or N. Signals could be received, on the two or four fixed tracks to which the system was limited, at distances up to 100 miles. Theoretical accuracy of plus or minus one degree was seldom achieved because of ground irregularities near range stations. Development of an omni-directional radio range was in progress by 1945 in both the U.S.A. and the United Kingdom, and an experimental model developed by the R.A.E. had reached flight test stage by the end of the war.

The ' Darky ' system, an emergency R/T organisation providing low-power communication, was introduced in March 1941 primarily for the use of Bomber Command aircraft at night, and was intended to supplement the facilities already provided by the D/F and regional control systems. Aircraft and ground stations used TR.9D on a frequency of 6440 kilocycles per second, and the already short range of the equipment was further reduced so that if an aircraft in distress or uncertain of its position over the United Kingdom received an answer to its call, it was able to determine its approximate position by obtaining the identity of the station answering the call. The aircraft could then ask for weather information, and the assistance of searchlights as directional beacons could also be obtained. The facilities provided by the Darky system were later made available to aircraft of Coastal Command.[1] With the development of the balloon barrage as a method of passive defence, and the establishment of such barrages around large towns and at many key points on the east coast, there arose a danger that Allied aircraft might inadvertently fly into them, although their siting was known to all flying units. Balloon sites were therefore equipped with automatic transmitters, known as ' Squeakers ', which radiated a characteristic signal on 6440 kilocycles per second when balloons were in position.[2] On reception of the signals aircraft not only received warning of the danger, but in many instances were provided with an approximate check of position.

It was a long time before the production of new aircraft radio equipment allowed the fitting of even a majority of operational aircraft, and the old

[1] Coastal Command File CC/S.7512/7/4. [2] A.H.B./IIE/76A.

equipment caused many difficulties. Fighter Command fought the Battle of Britain virtually without V.H.F. D/F, and the introduction of this equipment was never fully completed outside Fighter Command. Coastal Command aircraft had great difficulty in meeting convoys, and at a vital phase of the maritime war their ability to home to convoys was restricted by W/T silence. A requirement for homing aircraft to the transmissions of U-boats was never successfully met. The cathode-ray D/F service was a disappointment to Bomber Command, though it later gave good service to Transport and Coastal Commands. The rapid expansion of all commands brought many personnel difficulties, the standard of air operating at one point being dangerously low.

Aircraft Wireless Equipment

At the outbreak of war the standard wireless equipment installed in R.A.F. aircraft was W/T receiver Type R.1082 with transmitter Type T.1083, and the modified version of R/T transmitter/receiver Type TR.9, which was the only wireless equipment available for single-seater aircraft. The R.1082/T.1083 installation was difficult to tune and to operate, the most serious drawback being the necessity to change coils in both transmitter and receiver for most changes of frequency, and particularly when changing over from H.F. to M.F. or vice-versa. No spot-frequency tuning or click-stop device was provided, with the result that much time was usually required to set up the transmitter when frequency was changed. With the natural difficulties inseparable from working in a cramped space, particularly in flying clothing, frequency-setting whilst airborne was poor, and considerable tolerance had to be allowed by ground station operators. Many of the wireless failures and instances of non-compliance with procedure instructions could be traced to inexperience of operators, but their duties were carried out in conditions of great practical difficulty, and only a thoroughly well-trained operator could fulfil all his duties satisfactorily with the equipment at his disposal.

The Directorate of Signals had raised an operational requirement for a replacement for the R.1082/T.1083 installation in 1935/36. Development of a suitable aircraft installation, to enable full use to be easily made of the proposed radio navigational systems and to provide adequate communication channels, was required. However, by the outbreak of war no progress had been made at the R.A.E., so the assistance of the radio industry was sought by the Director of Signals. An installation, eventually known as T.1154/R.1155, was developed with the utmost urgency, in conjunction with the Marconi Company, from existing new Marconi equipment. Authority to introduce T.1154/R.1155 into general Service use was not obtained until a committee set up by the Chief of the Air Staff approved the proposals made by the Director of Signals.

The Marconi installation incorporated a system by which frequencies could be pre-selected, and a special D/F circuit, with visual indication for homing, was included in the receiver. Its operation was simple and straightforward and its performance was much superior to that of R.1082/T.1083. By the end of April 1940, design and layout of the Marconi installation had been completed for five types of aircraft which were to be retrospectively equipped, Wellington, Blenheim, Hampden, Whitley and Hudson.[1] However, the output from production was insufficient to permit more than a protracted retrospective

[1] A.M. File S.49915.

installation programme in addition to installation on aircraft production lines, and T.1154/R.1155 did not begin to reach squadrons until the end of 1940, and then only in limited quantities. It was not until 1943 that the last R.1082/T.1083 was replaced in Coastal Command.

Aircrew Wireless Operators

The expansion programme for 1938/39 included a requirement for 2,500 pilots, 2,069 observers, 3,867 wireless operator/air gunners, and 554 air gunners, to be provided by the recruiting programme. However, changes in the method of recruitment and in the terms of service of non-pilot aircrew had to be made in October 1938 in an attempt to improve the quality of recruits and to speed up recruiting. For some time there had been a growing belief that the existing system of providing observers, wireless operators and air gunners from the tradesman ranks could not be relied upon to produce efficient crew members fully competent to meet any emergency. Experience showed that the effective employment of non-pilot aircrews in their basic trade in addition to their crew duties was impracticable even in peacetime, and in any event it had always been accepted that wartime aircrew employment would be on a full-time basis. It was therefore decided in October 1938 that all wireless operator/air gunners should be drawn from the ranks of the boy-entrant wireless operator, and that they should be employed continuously on aircrew duties after completing crew training. Then, after about three years as wireless operator/air gunners, some 25 per cent of them would be selected for training as observers, and would spend the remainder of their service as such. This was in line with previous policy, as the trade of wireless operator had for long been one of three from which the supply of observers was mainly drawn. The remaining 75 per cent would complete their initial aircrew engagement. Observers were also to be obtained, as a temporary measure, by the direct entry of young men of a high educational standard, but the intention was that eventually all observers should be drawn from wireless operators.[1]

An essential condition of success for the new scheme was that the assumption that observers could be men of a lower standard than pilots should be finally abandoned, and that they should be placed on an equal footing with pilots as regards pay, status, prospects of promotion and commissioning. Had the scheme been fully implemented it would have greatly improved the prospects not only of the observer but also of the wireless operator/air gunner, who could have looked forward to the possibility of eventual commissioning as an observer. But the scheme had one inherent weakness; it was patently uneconomic, at any rate in wartime, to train a man for one task and subsequently transfer him to another. So, although some months after the outbreak of war Air Ministry pressure on the Treasury brought the granting of equal career prospects for pilots and observers, the career prospects of wireless operator/air gunners were not enhanced in any way until later in 1940, when aircrew were automatically given senior N.C.O. status on completion of training. Even then wireless operators were not eligible for time-promotion in the same way as pilots and observers, and their opportunities for commissioning were restricted to a small proportion of air gunner posts which were to be filled by officers in order to attract men of the right type into the category. The posts were fundamentally

[1] A.H.B. Monograph 'Manning Plans and Policy'.

created for gunnery leaders, and normally went to air gunners rather than wireless operator/air gunners, and, in the event, by June 1941 only 2 per cent of airman air gunners had been commissioned.

It was of course natural that there should be a sharp distinction between the rewards offered to the PNB (Pilot, Navigator, Bomb-Aimer) recruit on the one hand and the wireless operator/air gunner recruit on the other. The standard of education necessary for the latter was below that required for the study of navigation ; wireless operators received a grounding in the theory of electricity and wireless but they were not signals specialists, and the gunnery course was at first restricted to a few weeks. Qualities of leadership were not likely to be so widely needed in this category as amongst pilots, and a slightly lower physical standard could be accepted. The category of wireless operator/air gunner gave ample opportunity for young men of average fitness and intelligence with a sound but undistinguished educational background to play an active and important part in the air war, and it gave the same opportunity to those who failed as pilots or navigators or were unacceptable for some superficial physical reason. Nevertheless, the gap between the rewards and career prospects of the wireless operator/air gunner and those of his fellow crew members was very wide, and undoubtedly contributed to the low standard of operating which persisted until improvements were made.

Early in 1941, Headquarters Coastal Command drew attention to the increasing occurrence of W/T failures, almost invariably due to bad servicing or to faults which could have been rectified in flight, and ordered that in all instances where negligence or inefficiency was apparent, disciplinary action was to be taken.[1] An analysis of W/T failures, carried out by Headquarters No. 18 Group, revealed that nearly every failure was due to inefficient air operating, and Bomber Command squadron commanders were continually reporting on the low standard of efficiency of operators arriving from operational training units.[2] The general situation was a bad reflection on signals training and policy. The large number of operators who persisted in requesting D/F assistance on group operational frequencies showed that the signals organisation was not properly understood. Congested and unsuitable frequencies were used unnecessarily, and it was evident that signals briefing left much to be desired. Group training flights were eventually formed in Bomber Command, especially designed to improve operators who were below standard, and excellent results were achieved, and remedial measures were instituted generally, but even as late as 1942 the situation was still causing concern. However, during that year the percentage of signals failures dropped steadily, and the general standard of operating was generally improved.

Meanwhile, during 1941, the government of Canada had begun to urge the commissioning of wireless operator/air gunners on the same basis as that employed for pilots and observers, up to 33 per cent of output of training schools and a balance of 50 per cent after operational experience had been gained. The strict limitation of the number of commissions available to wireless operator/air gunners had doubtless assisted in attracting the majority of the best aircrew candidates to training as observers and pilots, and in Canada

[1] Coastal Command File CC/S.9119/1.

[2] Coastal Command File CC/S.9119/1 and No. 3 Group O.R.B., September–December 1941.

it was regarded as essential that greater inducement should be offered to candidates of high quality to enter the wireless operator category. A compromise was reached in July 1941 when it was agreed that commissions should be granted to 10 per cent of output on completion of training and an additional 10 per cent after operational experience. To provide for personnel already trained, retrospective commissioning action was taken with 20 per cent of the total output up to that time less the number already commissioned.[1]

Operating Procedure

In the early days of the war aircraft were deemed to be the responsibility of their parent station from take-off to landing, and operators kept watch on their station H.F. D/F frequency when they were not using M.F. for navigational assistance or for identification.[2] All reporting and control was done on the station H.F. frequency, and the D/F facility enabled aircraft to be homed to base at the end of their flight. When 100 miles from the English coast on the return flight operators changed to M.F., identified, and obtained a fix or bearing if required to do so by the navigator. In practice, due to errors in D.R. navigation, fixes were often requested when aircraft were as much as 400 miles out, and identification was frequently not given until aircraft were in sight of the coast.

By the middle of 1942, when all aircraft had been equipped with I.F.F., and nearly all with Marconi T.1154/R.1155, the whole of the M.F. D/F organisation was used almost exclusively for its intended purpose, a system of M.F. beacons was in operation, the emergency Darky organisation was in being, and group operational frequencies were in use in all groups, the operating procedure had undergone many changes.[3] In the interests of security, and because the increase in the number of operational aircraft meant that the amount of assistance which could be given to each was decreased, as far as possible only radio aids to navigation which did not involve transmissions by aircraft were used, such as beacons and radio track guides. Those systems which involved transmissions by aircraft were used only in emergency. In Bomber Command an M.F. D/F section was allotted to each group and normally received all distress calls, requests for D/F assistance, and identification signals. In an emergency, or when an aircraft was flying in an area for which its own M.F. section was unsuitable, any other appropriate section could be called. It was impressed on operators that bearings were not to be requested from H.F. D/F stations, of which there was one at nearly every Bomber Command airfield, when an aircraft was more than 100 miles distant, as beyond that range lay the skip area, in which the risk of large errors and reversed sense was very great. Wireless operators were to be ready to give the correct verification signal if challenged by a D/F ground station, and to challenge ground stations if their signals were thought to be of doubtful authenticity.[4] When aircraft were over the sea, transmitters were set up on the appropriate M.F. D/F frequency so that no time would be lost if it became necessary to transmit a distress call.

[1] A.M. File S.69366 and A.H.B. Monograph 'Manning Plans and Policy'.

[2] A.H.B./IIE/75A.

[3] *See* Appendix No. 15 for full details of signals procedure in a bomber group.

[4] As verification by use of the code S.D.1082 considerably slowed down the service, ground stations did not challenge an aircraft which used a correct call-sign unless there was good reason to suspect that the call was not genuine.

Whenever possible, aircraft on return flights were to approach the English coast at a height not exceeding 2,000 feet ; if I.F.F. was working properly identification procedure could then be dispensed with. If I.F.F. was unserviceable, or if aircraft were not equipped with it, identification signals were to be made when 60 miles from the coast. No signals could be transmitted without the authority of the captain, who was to be kept informed of the station with which the wireless operator was in contact or about to establish contact, and who was to be notified immediately in the event of wireless failure.

The signals organisation and procedure stood the test of the first 'thousand bomber' raid on 30/31 May 1942 remarkably well, but one or two revisions were made before the second similar raid on 25/26 June. Operators were particularly requested to keep traffic down to the minimum essential for safety because of the heavy loading of all D/F sections, and special attention was drawn to the amount of interference liable to be encountered on the M.F. beacon frequencies and to the tendency of the enemy to operate only some of his beacons on any one particular night. A change in the identification system was also made ; although all aircraft were expected to approach the English coast on return at a height below 2,000 feet, I.F.F. was to be used, and those returning according to the planned times were not to identify on M.F. because of the congestion that would otherwise result. Aircraft forced to turn back before the target had been reached were, however, to carry out identification procedure if flying below 2,000 feet in order that needless interception might be avoided.

A standard distress procedure was stipulated for aircraft of each individual command. Bomber Command aircraft made distress and other relevant calls on the frequency of the M.F. D/F section allotted to them for the sortie. Coastal Command aircraft made distress calls on the appropriate group operational frequency, and also by R/T on the convoy frequency of 2,410 kilocycles per second if within range of a convoy or shore station. Then, if time permitted, aircraft changed frequency to that of the appropriate M.F. D/F section and repeated the distress signal. Fighter Command aircraft made distress and other relevant calls on R/T. Air/sea rescue aircraft, and other aircraft detailed for air/sea rescue work, listened out on the distress frequency of 500 kilocycles per second, to which dinghy transmitters were set, and also used 385 kilocycles per second for homing purposes, including the homing of marine rescue craft to dinghies after sighting. Marine craft were equipped with R.1082/T.1083 and M.F. loop for homing to search aircraft and dinghies, in addition to R/T. Exercises in air/sea rescue organisation and D/F homing were carried out regularly. The whole organisation for the rescue of aircrew forced down in the sea was dependent upon bearings taken on the transmissions of the aircraft before ditching, or on transmissions from the dinghy radio after ditching. Dinghy radio, however, was not in general use until late in 1942, because of the delays in production experienced after its development early in 1941.[1]

The possibility of altering I.F.F. impulses to indicate on ground radar screens that an aircraft was in distress was considered at an early stage of design, and a system of switching I.F.F. to a different channel so as to widen the generated impulse was incorporated. The effectiveness of this method, which was never more than supplementary to the normal distress procedure, depended to some

[1] *See* A.H.B. Monograph, 'Air/Sea Rescue' (A.P. 3232).

extent on range, but in addition there was always the possibility that disaster would come upon an aircraft so suddenly that there would be no time to send a distress message or S.O.S., although there might be time to switch the I.F.F. from one stud to another. An extension of this method, the use of broad I.F.F. by an orbiting aircraft as a means of homing rescue vessels to dinghies, was given operational trials in 1943, and was introduced in No. 19 Group in August 1943. It had only a limited success, however, due to the fact that there was much spurious broad I.F.F. caused by faulty I.F.F. equipment and negligence in the correct setting of switches. Headquarters A.D.G.B. expressed particular concern that the use of broad I.F.F. for this purpose should not add to the confusion already existing from spurious impulses. By early 1944 marine rescue craft had been fitted with R.1155 and Marconi loop, and marine craft operators had become skilled in the use of D/F equipment and in homing procedure.[1]

H.F. D/F Organisation

When the principle of one H.F. D/F station per Bomber Command airfield was restored in April 1938, the first installation programme was for a total of 29 stations. There were, however, serious delays in the erection of the stations, and in July 1939 many of them were still outstanding. Eleven stations had been completed at Mildenhall, Abingdon, Boscombe Down, Cranfield, Honington, Finningley, Leconfield, Grantham, Waddington, Linton-on-Ouse and Wyton. The position with the outstanding stations improved considerably in the next few weeks, a further ten coming into operation by the outbreak of war.[2] Marham, Harwell, Bassingbourn and Watton opened watch, though on restricted hours only because of personnel difficulties. Upwood, Wattisham and Hemswell, which were in the process of being calibrated, had further calibration waived and came into operation. Feltwell opened a restricted watch, having only one trained D/F operator, and Cottesmore was also on a restricted watch pending the completion of training of Service operators. Benson was ready but was temporarily unserviceable.

At first, Bomber Command stations were ordered to keep continuous watch if the personnel situation allowed, whether aircraft were operating or not, but experience showed that this system was detrimental to efficient watch-keeping, particularly when no calls were received over long periods.[3] The system made heavy demands on the limited numbers of D/F operators available, and imposed an unnecessary strain. After five weeks of continuous operating, Headquarters Bomber Command suggested a system which restricted the hours of watch-keeping, and asked the groups to submit their views.[4] The groups agreed with the suggested revision, and on 20 December 1939 Headquarters Bomber Command proposed that all regional control D/F stations continue to keep a 24-hour watch, that each group maintain one non-regional station on a 24-hour

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[1] Coastal Command File CC/S.9110/3/Sigs.

[2] The H.F. D/F requirement for R.A.F. aircraft in France was stated as one station for every two bomber or reconnaissance squadrons, one for each fighter squadron, and one at Nantes. By the end of April 1940 five stations had been completed for the force of ten bomber squadrons, but only three stations were in operation for seven fighter squadrons, no special H.F. D/F service had been provided for the four reconnaissance squadrons, and there was no station at Nantes. However, three stations were in operation for regional control and identification purposes.

[3] A.M. File S.38120.

[4] A.M. File S.20489, Part II.

watch, and that all other stations not engaged with aircraft from their parent station should be prepared to open watch at one hour's notice on request. The system was operated within the command from late December 1939, formal Air Ministry approval being given in February 1940.

Meanwhile, the expansion of Bomber Command continued. In September 1939, notification was given that H.F. D/F would be required at seven more bases, North Luffenham, Syerston, Swinderby, Oakington, Waterbeach, Coningsby, and Middleton-St.-George. By January 1940, 23 Bomber Command H.F. D/F stations were in operation, five of which were regional control stations and a further five of which were keeping watch under the new system.[1] Several more outstanding stations were completed in the early part of 1940. About this time, congestion on H.F. frequencies became a serious problem, and to relieve it a second H.F. D/F station was installed at all the larger bases. In August 1940, provision of a second station at O.T.Us. was also agreed. With further expansion, another 15 bases were being planned and prepared, and sites for H.F. D/F stations were selected and preparatory work begun.[2]

With the approach of the winter of 1940/41, all H.F. D/F stations which were manned with sufficient D/F operators began to keep continuous watch during the hours of darkness, in view of expected aircraft diversions due to winter conditions.[3] If a group cancelled operations, the D/F stations in that group were not closed down without reference to Headquarters Bomber Command, who gave the necessary authority only if aircraft of other groups were not operating. Stations unable to keep continuous watch for personnel reasons were kept ready to open watch immediately on receipt of instructions. Instead of each operational base tending to regard its H.F. D/F station as its own exclusive property, any station could be switched quickly to the assistance of aircraft within its range.[4] Thus each station became part of a flexible organisation which could be used to the best advantage. The new organisation was of particular value in that production facilities for any large increase to meet the requirements of the 1940/41 winter did not exist, and there had been a delay in the production of new D/F equipment. However, it did not alter the primary function of an H.F. D/F station, which remained that of homing aircraft to their base.[5]

On 24 December 1940 Headquarters Bomber Command and Headquarters Coastal Command were informed that, consequent upon the universal adoption of V.H.F. equipment in Fighter Command, a number of D/F stations belonging to No. 11 Group would shortly be relinquished.[6] It was anticipated that the seven stations belonging to Biggin Hill, Hornchurch and Kenley could be given up almost at once, and five belonging to Debden and Tangmere in the near future. Further stations would be available from the Northolt and North Weald sectors but not for some time. Subsequently, stations from Nos. 12 and 13 Groups were added to the list. However, a change in V.H.F. policy delayed the date by which any of the stations could in fact be released.

Headquarters Bomber Command considered that the best use to which the stations could be put would be to link them to the regional control centres with the object of providing an H.F. fixer service for aircraft diverted to these centres.

[1] A.M. File S.20489, Part II.
[2] A.M. File S.38120.
[3] Bomber Command File BC/S.20489, Part II.
[4] No. 7 Group O.R.B., December 1940.
[5] No. 1 Group O.R.B., 1941.
[6] A.M. File CS.8571.

On 15 April 1941, the Air Ministry completed proposals for forming the stations into a regional control fixer service. Headquarters Bomber Command at first agreed, but later, on 22 July 1941, asked that suitable stations should be allocated in pairs to the operational group areas and tied by direct landline to group operations room switchboards. This was agreed and stations were allocated to:—[1]

No. 1 Group	West Lutton, Lutton.
No. 2 Group	Shropham, Steeple.
No. 3 Group	Coltishall, Wix.
No. 4 Group	Loftus, Swanland.
No. 5 Group	Gayton-le-Marsh, Hockwold.
No. 8 Group	Stow Upland, Great Wakering.

Provision was made for the laying of landlines, but owing to further delays in the Fighter Command V.H.F. R/T installation programme, and to a shortage of line plant in the Huntingdon and Brampton area, the approach of winter 1941/42 found Bomber Command still without the new fixer service.

The H.F. Fixer Service finally came into operation in January 1942. The stations were not equipped with transmitters, but were connected by telephone to the group operations switchboard. They were calibrated to all frequencies used by D/F stations in the group so that they could be set up on any one of them accurately and rapidly, and they were manned throughout the progress of operations. Requests for fixes were telephoned from H.F. D/F stations to group operations officers, who gave the necessary information to the fixer stations. The bearings obtained by the fixer stations were plotted, and the fix was passed to the aircraft.[2] Redundant operators from Fighter Command were transferred to man the fixer stations.[3] Although the system proved of value in helping to deal with the large number of calls for assistance during the early 'thousand bomber' raids and similar operations, it was never widely used, and was suspended because of a shortage of operators in No. 4 Group as early as October 1942.[4] The system was finally discontinued when Gee became firmly established.[5]

That D/F stations should be forced to close for want of operators was surprising in view of the number transferred from Fighter Command and of the output of the radio school, but, in fact, Bomber Command was expanding at such a rate that all these operators were absorbed in manning new stations. In October 1941, it was agreed that all operational airfields, including satellites, be provided with H.F. D/F. Seven of the first 31 satellite D/F stations had been sited by November 1941, leaving 24 outstanding and a balance of approximately 80 more to be dealt with subsequently. By November 1942, 123 H.F. D/F stations had already been installed in Bomber Command, and an additional 75 were scheduled for installation in 1943.[6]

In all commands, H.F. D/F stations, other than those equipped with cathode-ray sets, were equipped with Marconi DFG. 12, of which there was a permanent

[1] A.M. File CS.8571. In addition five were allocated to existing regional control centres, one to Tangmere for a new regional control centre, and one to Coastal Command.

[2] No. 1 Group O.R.B., January 1942.

[3] A.M. File CS.8571.

[4] No. 4 Group O.R.B., October 1942.

[5] A.H.B./IIE/75A.

[6] A.M. File CS.8571. The figures include D/F stations transferred or scheduled for transfer to the United States Eighth Air Force.

type and a transportable type. The set operated on both W/T and R/T, although R/T was not often used outside Fighter Command. However, in March 1941, two new D/F ground installations designed by the Marconi company to replace the DFG. 12 made their appearance.[1] They were the DFG. 24, which took the place of the permanent-type DFG. 12, and the DFG. 25, which superseded the transportable-type DFG. 12. The sets were designed as a result of the experience gained in the preceding years, and the company claimed that all weaknesses had been corrected. A feature was that it was not possible for reversed sense to be given except through extreme negligence on the part of the operator. Previously the firm of Marconi had designed a low-power set specially for satellite use, the P.3. It had been accepted on the assumption that aircraft would normally obtain main homing bearings from the parent station and change ovei to the satellite at short range, but it proved unreliable at night even at short range and was withdrawn in favour of the new equipment. However, due to slow production, delivery of the new receivers lagged behind the completion of new airfields.[2] Of 16 airfields due to be completed in the period March to May 1942, receivers were installed in time for the opening date at only four. The position improved in June, when 15 more receivers became available.

The policy of siting D/F stations so that they offered as little obstruction as possible while being close enough to the airfield to offer ZZ facilities was so successful that, in December 1939, of 30 Bomber Command bases in use or under construction, all but six had their H.F. D/F stations sited so as to be suitable for ZZ landing approaches and in each of the outstanding six it was possible to find an alternative at a nearby base, or to site the second D/F station to allow ZZ approaches to be made.[3] This meant that at that time virtually all Bomber Command bases were equipped for ZZ landings. A complication arose in 1941, however, when considerable difficulty was experienced in the siting of D/F stations because the main runways were being extended at certain airfields.[4] Since ZZ landings were not attempted unless visibility exceeded 1,000 yards, Headquarters Bomber Command considered that a site 800 yards from the 1,600 yard mark of the main runway, assuming it was projected to this distance, was close enough to allow good control of ZZ landings. The Air Ministry went even further and agreed that the requirement would be met if the ZZ hut was situated on the airfield perimeter. With the introduction of Standard Beam Approach at all operational airfields, the siting of the H.F. D/F station on the axis of the main runway became no longer necessary. By early 1942, ZZ was in use only at No. 2 Group stations and satellites and at certain O.T.Us. The replacement of ZZ by S.B.A. had a secondary advantage in that some of the congestion on high-frequency was relieved ; aircraft requiring homing had sometimes been unable to obtain sufficient attention because the D/F station was engaged in carrying out ZZ procedure with another aircraft.[5]

A reduction in the number and importance of H.F. D/F stations became inevitable as Gee became more widely used. Their use for homing, for instance, almost ceased, although the Service was maintained in an attenuated form until the end of the war, as a safety aid and communication channel.[6] In

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[1] A.M. File S.38120.
[2] A.M. File S.38120.
[3] Bomber Command File BC/S.20489, Part II.
[4] A.M. File S.38120.
[5] A.M. File S.2712.
[6] A.H.B./IIE/75A.

January 1943, Headquarters Bomber Command suggested that the abolition of the flying control H.F. D/F installation at bomber bases could be effected without detriment to the safety of aircraft and with considerable economy in personnel and equipment, the dual role being well within the scope of one D/F station ; 16 stations were closed as a result. By December 1944, when the Air Ministry carried out a review of H.F. D/F policy and requirements in the United Kingdom, the total number of installations still in use in Bomber Command had been reduced to 64. The scale of equipment included one installation at each operational base and one at each O.T.U., a reduction of fifty per cent. The importance of all wireless aids to navigation was steadily decreasing with the increasing use of radar aids, and future Bomber Command policy had been outlined at an Air Ministry meeting the previous month, when it was agreed that on the introduction of the complete V.H.F. R/T scheme all H.F. D/F stations remaining in Bomber Command could be given up.

From 1939 to the summer of 1942 H.F. D/F was of vital importance to Bomber Command, as a method of control, a means of homing, and for a short while as a fixer service. The stations gave good service, and although care had to be exercised in homing from over 100 miles, it was soon found that good homings were possible well outside this limit.[1] Although congestion on high frequency raised many problems as Bomber Command expanded and aircraft of Allied air forces joined in the offensive, H.F. D/F would undoubtedly have retained its usefulness to the end of the war but for the advent of Gee.

When the R.A.E. produced the specifications for the Marconi DFG. 12 receiver in 1936, it was expected that the equipment would be replaced by a cathode-ray set in due course. In point of fact nearly three years elapsed between the specification and Service trial stages of cathode-ray D/F equipment so that nearly all H.F. D/F stations in Fighter Command up to 1941 were of the radio-goniometer type. From 1941 onwards, following the general introduction of V.H.F. R/T in Fighter Command, all aircraft were fitted with the TR. 1133 in succession to the TR.9, and V.H.F. D/F ground equipment replaced the DFG.12. The limitations of H.F. D/F in Fighter Command arose mainly from the inadequate performance and range of the TR.9 and an insufficiency of channels.[2] Very few complaints were made about the operation of the ground stations, although there were reports of inconsistencies at first.[3]

In Coastal Command, H.F. D/F stations were established by the outbreak of war at all bases, and by November 1940 the organisation consisted of stations at Leuchars, Thornaby, Dyce, Pembroke Dock, St. Eval, Down Thomas, West Freugh, Felixstowe, Catfoss, North Coates, Bircham Newton, Thorney Island and Detling. Later all 'Type One' flying control stations in the command were equipped with two installations, and these, together with one installation at each of the 'Type Two' flying control stations and the O.T.Us., made a total of 67 stations in use in December 1944.[4] The intention then was to

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[1] A.H.B./IIE/75A.

[2] *See* Royal Air Force Signals History, Volume V : 'Fighter Control and Interception', for full details.

[3] A.M. File S.47712.

[4] 'Type One' stations had full control facilities including V.H.F. D/F, H.F. D/F on control and station frequency, Darky watch, and S.B.A. and/or B.A.B.S. 'Type Two' stations might have all or any of these facilities except H.F. D/F on control frequency.

retain all the installations pending the general introduction of V.H.F. R/T, which would not take place until the Bomber Command programme was completed, and could not therefore be expected before 1946. The requirement for H.F. D/F did not lapse in Coastal Command with the introduction of radar aids to the same extent as in Bomber Command owing to the many operations carried out beyond the range of Gee and Loran chains.

A very economical and flexible H.F. D/F organisation was maintained in Flying Training Command, stations changing from the normal W/T frequency to an R/T frequency as required. Much of the flying was solo flying in twin-engined aircraft which kept within R/T range of base. For training flights over the Irish Sea the command maintained a control centre at Ramsey, Isle of Man, but this had no fixer service, maintaining its position plots by monitoring H.F. D/F stations situated at airfields around the Irish Sea and by reports passed from aircraft. By 1944, approximately 50 H.F. D/F stations were in use in Flying Training Command.

Transport Command was formed in March 1943, at a time when all radar aids were being concentrated in Bomber Command, and it was therefore inevitable that the main system of navigational aid should be H.F. D/F. In view of the high standard of flying safety to be aimed at in a command the main duty of which was the carrying of passengers, it was natural that demands for H.F. D/F installations should be heavy. By December 1944, the total number of installations in operational use was 21, in addition to nine at O.T.Us. Transport Command also used three long-range cathode-ray networks totalling twelve stations, and three chains of Training Area flying control special fixing services comprising nine stations. However, the majority of Transport Command flights were made overseas on the reinforcement routes. The Transport Command H.F. D/F policy resulted in recurring demands for equipment, personnel, and frequencies with each expansion in operational responsibility, but the Air Ministry was unable to provide any alternative system until the supply position enabled emphasis to be transferred from wireless to radar aids. However, by the end of the war, radar was in general use in Transport Command, and investigation of the possibility of a reduction in the number of H.F. D/F stations was begun.

M.F. D/F and Identification

During the period 1939 to 1942 the M.F. D/F organisation using Marconi DFG. 10 ground equipment, as the only long-range radio navigation system available to Bomber Command other than the cathode-ray system, was the most important of all radio aids to navigation. A common-user service which operated in the 300 to 400 kilocycles per second band, it was designed to give bearings and fixes up to the limit of range. The general coverage provided a good service all round the coast and inland, and the accepted range at a normal operating height of 7 to 8,000 feet was 350 miles.[1]

[1] R.A.F. aircraft based in France were able to use an existing civil M.F. D/F organisation which was divided into two sections. One consisted of 23 stations, 15 of which were equipped with Adcock, and the other of six stations used mainly for identification. The first operated on 333 kilocycles per second, and the second on 330 kilocycles per second with an alternative frequency of 300 kilocycles per second for use if interference by the enemy was experienced. An R.A.F. system, to consist of three stations operating on 309 kilocycles per second, was not completed by the time of the evacuation.

At the beginning of the war the M.F. D/F service had an important function which had nothing to do with direction-finding assistance to aircraft ; identification of friendly aircraft crossing the English coast.[1] The whole organisation was split in two to cope with the requirement, leaving the number of stations available for their real purpose dangerously small.[2] An aircraft returning from an operation, and in the early days many operations were simply reconnaissance by a single aircraft, called the control station of its M.F. identification section and passed what was known as its movement serial indicator ; the position of the aircraft was fixed and its identity verified. Later, when the movement serial indicator was abolished, aircraft relied on call-signs only for identification. Call-signs were entered on the appropriate pre-flight papers and the information forwarded to the D/F stations concerned.[3] The fix was passed to the filter room at Headquarters Fighter Command, where it was related to information from R.D.F. sectors reporting the approach of aircraft. As yet there was no automatic identification device available. The system worked fairly well, but it had inherent weaknesses. A wireless operator for various reasons might be unable to pass the message ; also, when more than about six aircraft returned at the same time, congestion resulted. But in general, the M.F. D/F organisation proved itself well able to meet the operational requirements of the period. Comparatively few aircraft were available for bombing operations until early in 1941 ; the bomber effort was sustained mainly by the few Blenheim squadrons of No. 2 Group and the Wellingtons and Hampdens of Nos. 3 and 5 Groups, and aircraft could be certain of getting all the assistance they wanted.[4]

A third and vitally important function of the M.F. organisation was the distress procedure. Throughout the war, aircraft wireless operators were strongly advised to send S.O.S. messages on M.F. The chances of two or three snap bearings producing a fix were much higher on this service than on any other, and the majority of successful air/sea rescue operations were based on M.F. fixes taken before the aircraft ditched.

There was, however, one qualification in the use of M.F. — security. It was thought that frequent transmission might render the service capable of use by enemy aircraft, and on the outbreak of war Headquarters Fighter Command was given authority to instruct M.F. transmitter stations to close down or to restrict transmissions if enemy aircraft were known to be within 50 miles range. When ordered to close down or reduce transmissions to a minimum, stations arranged for their traffic to be carried on by another station or section which was not so restricted. This was all right when enemy raids were concentrated in one area and our bomber force was operating in small numbers, but when enemy raids were scattered over wide areas and Bomber Command was operating on a large scale it was difficult to find alternative M.F. stations. But the situation was not allowed to reach a stage at which the safety of our aircraft was jeopardised, the risk of bombing being regarded as more acceptable than the risk of losses in Bomber Command.[5]

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[1] A.H.B./IIE/75A.

[2] Sections F, G, H and J were reserved for identification and for D/F fixes in emergency only. Section D (Heston, Hull and Newcastle) was reserved for Bomber Command. Sections A, B, C and E, although primarily intended for Coastal Command, were also used by Bomber Command in emergency.

[3] Coastal Command Signals Review, Volume 1, No. 2, February 1944.

[4] A.H.B./IIE/75A.

[5] A.M. File S.45337.

Although as the war progressed the introduction of radar aids tended to reduce the number of M.F. fixes asked for, the older generation of navigators found it hard to regard this service as anything but the basic navigational aid, and indeed it was still giving tremendous service late in the war.[1] The service was extremely accurate, as an analysis made in September 1943 of some 200 'cocked hats' from two different M.F. D/F sections showed.[2] An allowance was made in each case for the varying angles of cut and distances from D/F stations, and the final figure arrived at as an average error for first-class bearings was plus or minus two degrees. The proportion of the three classes of bearings varied greatly with distance, but otherwise was the same from station to station and almost the same during day or night. For distances up to 100 miles, 90 to 95 per cent of bearings were first-class and only 0·5 per cent third-class; at greater distances the proportion of first-class bearings fell as that of third-class bearings rose, until at 400 miles 75 per cent were third-class and only 10 per cent first-class. One reason for the falling-off in class of bearing with distance was that as distance increased the received signal level more nearly approached the noise level, making an exact determination of bearing more difficult; thus the variations depended to some extent on the power of the aircraft transmitter. In addition, because of geographical limitations, and particularly the inadequacy of the length of the British Isles as a baseline, it was not possible to arrange each set of stations so as to ensure reasonable accuracy at extreme ranges; as range increased accuracy decreased, particularly over Germany.

During the early part of 1942 it was not unusual for that part of the M.F. D/F organisation which dealt only with Bomber Command operational aircraft to give as many as four fixes per aircraft operating. With 100 aircraft operating, this involved up to 400 fixes over a period of perhaps five hours, or 80 fixes per hour. Owing to the signalling procedure involved in getting a fix, any one section could not be expected to give more than about 20 fixes per hour, and because of the baseline factor not more than five sections could be made available to cover any one operation. So it was evident that the organisation was reaching the limit of its capacity when, in the absence of another system, more than about 100 aircraft were likely to need help. If an emergency arose due to bad weather or other causes the rate of requests for fixes might be so high over a short period that congestion and delay would result.[3]

Difficulties were soon encountered in the method used for identification of returning bombers. Aircraft W/T operators maintained watch on the operational frequency, which was in the H.F. band, throughout the flight until within 100 miles of the English coast on the return journey, except for any change of frequency necessitated by calls for D/F assistance. At 100 miles from the coast they were supposed to change to M.F. and to send the identification signal, but within a few days of the outbreak of war Headquarters Fighter Command was reporting that the identification signals were not being received.[4] The difficulties of aircraft W/T operators in the early days affected the efficient working of the identification procedure. The process of changing coils and retuning was a complicated one with the equipment in use at that time, and this of itself made operators reluctant to interfere with the setting of their equipment once they were satisfied that it was properly tuned. Wireless was

[1] A.H.B./IIE/75A.
[2] C.C. O.R.S. Report No. 251, 18 September 1943.
[3] A.H.B./IIE/75A.
[4] A.M. File S.40818.

being used to obtain fixes and homing bearings, to listen out for operational messages, and as a means of identification, but even so, W/T silence was observed for the major part of any sortie, and an operator's main concerns were to be sure not to miss any operational message, and to be able to break W/T silence in emergency and be sure that his signals would be received at once. Signals failures were frequent, and operators developed an antipathy to any procedure which disturbed their equipment when it was correctly set up and in apparent good order.

Under the principle that efficient intercommunication can only be achieved if both ends of the system used are under the same control, the M.F. D/F identification stations were taken over by Headquarters Bomber Command. This at least meant that responsibility for failure of the identification procedure could be quickly tracked down. But, in addition to signals failures, there was another factor which militated against successful operation of the procedure. The errors arising in navigation on long operational flights over territory where meteorological forecasts were unreliable were greater than had been expected, and any system of identification which depended on bomber aircraft being able to fix their position over the sea after a long operational flight could never be more than makeshift with the aids available at that time.[1] Nevertheless, great efforts were made, and following a conference at Headquarters Fighter Command on 7 September 1939, after which the importance of the correct observance of identification procedure by aircrews of Bomber Command was again stressed, the percentage of returning bombers identified rose to 75. This was a great improvement, but the basic need for a system by which friendly aircraft were automatically identified on the Home Chain radar screens remained. Changes in the disposition of the stations were made in the light of experience, and as by December 1939 aircraft were being equipped with I.F.F. at a steady rate, its early introduction on a widespread scale was anticipated.[2]

The identification procedure had originally been devised in the light of two assumptions: transmission from M.F. D/F stations would be limited to a minimum to deny their use to the enemy as beacons; and acknowledgments of identification messages by the D/F ground stations would overload the service. Experience in the first six months of the war suggested that the danger of enemy use had been exaggerated, and that since most aircraft called some section of the M.F. D/F service for a fix either before or after identification, that call could be used for identification purposes without causing congestion. All D/F sections could thus be thrown open for a combined security/identification service, removing the unnatural divisions which existed. A new system on these lines was brought into force, in Bomber Command only, on 15 June 1940.[3] It was intended to pave the way for comprehensive introduction of the I.F.F. system, with a great easing of the burdens of the air wireless-operator, who would no longer have to change frequency to identify, or to carry out protracted identification procedures. It was considered that the advantage gained by lightening his task, and thus improving chances of successful homing, greatly outweighed the possible disadvantage that the enemy might be able to make some use of the ground transmissions. But in

[1] A.M. File S.40818.
[2] A.M. File S.40818.
[3] A.M. File S.40828, Part II. *See also* Royal Air Force Signals History, Volume V: 'Fighter Control and Interception'.

spite of these hopes, ten days later, on 26 June 1940, the new arrangements were cancelled and separate M.F. sections for security and identification were again allotted to each group.[1]

By October 1940, 90 per cent of Bomber Command aircraft, not including Battles, were fitted with I.F.F., and the average nightly serviceability of I.F.F. equipment was believed to be about 90 per cent.[2] Nevertheless, the identification procedure was still being used in addition, and was in fact revised and re-promulgated in November 1940. Instructions for the use of I.F.F. were included, but its use did not yet raise the obligation to send the W/T identification signal. Trials were carried out by Bomber and Fighter Commands in collaboration to test the suitability of I.F.F. as the primary means of identification. As a result, from 1 April 1941, aircraft were obliged to identify themselves by W/T in the following circumstances only :—

(*a*) When Form 'J', the form giving details of the flight, had not been submitted in advance.

(*b*) When aircraft were not fitted with I.F.F.

(*c*) When I.F.F. was not functioning correctly.

(*d*) When aircraft were flying below 2,000 feet.

(*e*) When aircraft were seriously off course or off schedule.

M.F. Beacons and Aircraft Loops

The need for a radio aid to navigation which did not involve transmission by aircraft had long been recognised, and much of the research and development carried out during the inter-war years was directed to this end. A final decision was made at the first annual D/F conference in 1934 to concentrate on development of D/F loops in aircraft in conjunction with that of ground beacons. However, on the outbreak of war, security considerations had outweighed all others and no beacons were available to R.A.F. aircraft based in the United Kingdom or in France. Much of the development work carried out on the loop, and the production capacity taken up in building and fitting it, was therefore set at naught. Most twin-engined aircraft carried a D/F loop but there were no signals for it to receive. By October 1939 a number of continental broadcasting stations were being used in conjunction with the D/F loop by Bomber Command, notably Quotala, Kalundborg, Hilversum, Kootwyk, Brussels and Beromunster. By the end of that month it had also been established that certain enemy beacons were operating on a recurring system, so that it could be forecast which would prove of value to aircraft operating over enemy territory. Headquarters Bomber Command had not the facilities for compiling the data from which a forecast could be made, and asked the Air Ministry to issue a daily bulletin, combining this if possible with the neutral stations' bulletin already being issued. It was stressed that aircraft were without any assistance from beacons or broadcasting stations in Great Britain and Northern Ireland, while the neutral stations were few in number and in any event closed down at midnight, thus making their value extremely limited.[3]

A conference was held at the Air Ministry on 17 November 1939 to discuss means of utilising enemy and neutral transmitters for loop D/F, the policy to be adopted with regard to erecting beacons in the United Kingdom, and

[1] The allocation of M.F. D/F sections is shown at Appendix No. 14.

[2] A.M. File S.40818, Part II.

[3] A.M. File S.2712.

associated technical problems. The conference decided that efforts to utilise enemy and neutral transmitting stations should be made, and that while a system of fixed wireless beacons in the U.K. for general use was undesirable, an organisation should be established to provide suitably located emergency beacons which could be brought into use, under careful control, for short periods, and that the possibility of using mobile beacons for such an organisation should be investigated. As an interim measure, the Admiralty agreed to make transmissions available from the naval W/T station at Cleethorpes. Arrangements were also made for the de-spoiling of the B.B.C. transmitters at Manchester and Borough Hill so that they could be used as M.F. beacons in emergency pending the introduction of the new organisation.[1]

The need for training wireless operators in the use of D/F loops and M.F. beacons was recognised, and a beacon intended primarily for training purposes began transmission from Andover on 17 January 1940. The overriding responsibility for closing down the beacon at any time to deny its use to enemy aircraft lay with Headquarters Fighter Command. If it became necessary to use the beacon for operational purposes, Headquarters Bomber Command consulted the controllers at the Fighter Command Operations Room, and if the local situation warranted it, the beacon was switched on. For normal training purposes, precautions were taken to restrict the range to 120 miles, and to ensure that periods of transmission were irregular.[2] A summary of reports on the operation of the Andover beacon up to 13 February was prepared by Headquarters Bomber Command, and it showed that because of bad weather, flying had been greatly restricted and very little experience had been gained with the beacon. R.A.F. Andover reported on 26 February that the beacon had been closed down on seven occasions on orders from Headquarters Fighter Command, and a later report from Headquarters Bomber Command on 4 March gave an instance where homing had been successfully carried out; Headquarters No. 3 Group considered that the beacon services would prove invaluable.[3] Further reports showed that operators generally were gaining confidence although all groups complained of weak signals; two aircraft of No. 3 Group had been navigated back to base by use of the beacon after W/T transmitter failure.

At the end of April 1940 beacons operated on request at Andover, Borough Hill and at Odiham, installed as a second training beacon. The Admiralty station at Cleethorpes could be used by the R.A.F. on request, and other Admiralty stations at Rosyth and Scapa could be used as beacons when they were transmitting. A new chain of beacons built to Air Ministry specification was shortly to be completed, and was intended primarily for training purposes. The first two stations, at Pembroke Dock and St. Athan, opened on 24 April, a third at Evanton opened on 29 April, and a fourth at Kinloss on 5 May. The B.B.C. transmitters at Manchester and Borough Hill were brought into this synchronised scheme, but were reserved for emergency use by operational aircraft and were not used for training purposes. Arrangements were made for the use of two other B.B.C. transmitters when no alternatives were available. A system of mobile beacons for operational aircraft, which was recommended by the beacon conference of November 1940, was in preparation.

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[1] A.M. File S.2712. [2] A.M. File S.1520. [3] A.M. File S.2712.

The Air Ministry decided in December 1940 that four beacons were to be constructed on a mobile basis, two in the Yorkshire area and two in East Anglia ; the total was later increased to six. Sites were selected which were not too near vulnerable points although near enough to the area they were designed to cover. High masts with good aerials were erected, and the sites were connected by landline to Headquarters Bomber Command so that instructions for switching on and off could be given quickly. Arrangements were made so that the disposition of the transmitters and their frequency and call-sign could be interchanged to cause the maximum possible difficulty to an enemy endeavouring to make use of them. Three stations worked quasi-synchronously in the same way as the B.B.C. medium-wave stations. The separation between the three station zones was such as to leave the utility of a station as a beacon unimpaired within a radius of 50 miles, while the transmissions were so synchronised that the transmitter locations could not be fixed by D/F ground stations in Germany. As there were two groups of three stations they could periodically change partners, so that even if the three stations of a group were all identified on one day, the information would be useless to the enemy on succeeding days.

The mobile beacon system was completed in September 1940, and the two groups were :—

(a) *Beacon Group ' A '.*

(i) Wolsingham (approximately 10 miles north-west of Bishop Auckland).

(ii) Ravenscar.

(iii) Eavestone (approximately 6½ miles south-west of Ripon).

(b) *Beacon Group ' B '.*

(i) Frithville (approximately 4 miles north of Boston).

(ii) Salthouse (3 miles north of Holt, Norfolk).

(iii) Little Downham (approximately 2½ miles north-west of Ely).

In practice, one transmitter in each group worked at any given time, transmitting the call-sign of its group followed by a long dash. The beacons operated between 1900 and 0700 hours, subject to overriding control by Headquarters Fighter Command ; they were not operated by day except at the special request of Headquarters Bomber Command. Aircraft carried only such beacon information as was necessary to cover the duration of a flight.[1]

Fortunately it was not until the end of 1941 that the enemy began to use a beacon-spoiling system similar to that used in the United Kingdom, and full use could be made of enemy beacons during the period before the introduction of radar aids such as Gee. But even after 1941, Headquarters Bomber Command was generally able to keep crews informed of changes in the German system ; when a new enemy beacon system came into force on 15 June 1942, the rota in use was broadcast continuously on a special frequency by Headquarters Bomber Command, and the beacons were still used with success during operations.[2]

The standard reached with use of the D/F loop in Bomber Command during the years 1941/42 was fairly high, although errors such as not setting the loop to zero, and tuning in to the wrong beacon, still occurred.[3] Operations carried

[1] A.M. File S.2712, Part II.

[2] No. 4 Group O.R.B., June 1942.

[3] No. 3 Group O.R.B., 1942.

out at maximum range by Stirling aircraft of No. 3 Group were often greatly assisted by the use of enemy and neutral beacons, while on some trips the lack of suitable enemy beacons contributed to navigation failures. Great use was made of the loop by aircraft of No. 1 Group, and analysis of 239 sorties in January 1942 revealed that the average number of bearings taken per aircraft was eleven. A survey of the accuracy of loop bearings carried out by Headquarters No. 1 Group showed that for every reliable bearing received, it was estimated that there was also one unreliable bearing which could be used for approximation, and one useless bearing. The only satisfactory method was to use the mean of six bearings as a single position line, disregarding the obviously bad readings. A summary of general errors in the same group showed that there was still failure in some degree to use the navigational aids available, and fatal accidents still occurred which were attributable to navigators conducting sorties on dead reckoning, using forecast winds only. It was impressed upon crews that forecast winds were issued purely as a guide and that they should never be considered by navigators as more than an approximation, but as late as February 1942 navigators were still relying on them, with resultant navigational errors. However, navigation on No. 1 Group operations at about the same time was carried out largely by use of D/F loop bearings and fixes.[1] Another point which operational experience brought to light was that failure to obtain frequent loop bearings often resulted in an isolated loop bearing or fix being ignored by the navigator because the discrepancy between loop fix and D.R. position was so great, and the need for loop bearings to be taken and plotted at frequent intervals was made evident.

On 2 September 1944, Headquarters Coastal Command raised a requirement, approved a few days later, for the installation of two M.F. beacons, one in the Shetlands and the other on the west coast of France. A beacon in the Shetlands had long been a requirement, but objections had previously been raised by the naval authorities on security grounds. The objections were considered to be no longer valid, and although an early establishment of Loran in the area was expected, provision of a high-powered M.F. beacon was still thought to be desirable. The need for the second beacon had arisen paradoxically enough through the success of the Allied liberation armies. As a result of the fall of the Brest peninsula, the *Sonne* beacon at Quimper had been destroyed by the Germans. Great use had been made of the beacon by Coastal Command aircraft flying over the Bay of Biscay beyond Gee range.[2]

The installation of retractable D/F loops in Harrow, Whitley, Battle, Blenheim, Anson and Wellesley aircraft had been recommended by the Aircraft Equipment Committee as early as June 1936. However, the early designs were not ideal, and difficulty was encountered, particularly in Blenheim aircraft, because above certain speeds the slipstream was apt to cause the mechanism to jam. A modification to improve the loop movement was given a high priority, but this was later reduced owing to other urgent needs, and the Blenheim squadrons began operations without a satisfactory loop installation.

In addition to the technical difficulties, there were associated tactical problems. Headquarters Bomber Command had stated a requirement for a system of

[1] No. 1 Group O.R.B., January 1942.

[2] Coastal Command O.R.B., September 1944.

M.F. beacons for loop navigation, but early in the war the view prevailed that such beacons were too susceptible to use by the enemy. However, Bomber Command experience in the first weeks of the war emphasised the need for additional aids to navigation; the duties of the wireless operator/air gunner during that part of an operational flight when loop bearings were most needed kept him at his guns, and it was therefore for consideration whether a navigator-operated loop could be installed. An overriding factor was that Headquarters Bomber Command would not accept any installation, however efficient in other ways, which affected the speed or performance of the aircraft.

As a result of an unfavourable report on the early installations in Blenheim aircraft of No. 2 Group, representatives of the Royal Aircraft Establishment visited the Bristol Aeroplane Company on 21 November 1939 to inspect installations at the works, and reported favourably on them. However, the Chief Signals Officer of Bomber Command met representatives of both the R.A.E. and the Bristol Aeroplane Company at Wyton six days later, and as a result of the meeting and trials in the air he had no hesitation in recommending to the Air Ministry that no more aircraft be fitted with the existing layout. A few days later, on 6 December 1939, Headquarters Bomber Command asked for consideration to be given to the provision of a navigator-operated D/F loop installation in Blenheim aircraft. Meanwhile, work on installation of the loop in Blenheim aircraft was stopped. Trials and examinations of the old installation were carried out at the R.A.E. and the B.A.C., and a meeting was held at Bristol's on 8 January 1940 to find possible ways of meeting Bomber Command requirements. It was found that design and incorporation of a modification to move the loop to a position where it would be accessible to the navigator could not be completed before the Blenheim construction programme had reached an advanced stage; extensive retrospective fitting would then be necessary. In fact, a satisfactory control for the navigator within a reasonable time was out of the question. On the other hand, Bristol's promised that the existing installation could be brought to an acceptable standard quickly.[1] The Air Ministry had already agreed to the provision of a system of fixed and mobile M.F. beacons, so that an efficient D/F loop operated by the wireless operator would at least provide homing facilities, even though its use would still be restricted by the wireless operator's gunnery duties throughout most of a flight. It was therefore decided that an unsatisfactory installation at a unit should be selected by Headquarters Bomber Command and should be brought up to an acceptable standard by the Bristol Company. The installation would then be thoroughly tested, and, if accepted, would be used by the firm as a standard for all other installations.[2] In February 1940 trials of a modified loop were carried out for several days but the results were very little better than those previously obtained, and it seemed clear that the existing system of mounting and remote control was impracticable because of distortion produced by slipstream pressure. The need for a navigator-operated loop was again stressed and it was considered that if it could not be supplied the possibility of fitting loops in Blenheims should be abandoned. However the Bristol Company was confident that a modification could be made to the existing installation which would satisfactorily overcome the mechanical defects so far experienced; and the Air Ministry did not want existing arrangements for the installation of loops in

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[1] A.H.B./IIH/241/10/1. Bomber Command File BC/S.20758/3.

[2] A.H.B./IIH/241/10/1.

Blenheims cancelled until the modification had been tested. The A.O.C.-in-C., Bomber Command was not prepared to sacrifice speed for the navigational assistance offered by the loop, and thought that the Blenheim might become obsolete before the navigator-operated loop could be produced, so that its development would be absorbing productive capacity which could be more usefully employed elsewhere. It was shown that the loss of airspeed with the loop retracted was negligible, and with the loop extended was not more than 3 m.p.h. at maximum speed, and it was established that the Blenheim was likely to be in service for some time. It was 21 March 1940 before the A.O.C.-in-C. was able to recommend the continuance of action to make the wireless operator's loop satisfactory and efficient. At the same time development of the navigator-operated loop which would ultimately replace it was requested.[1]

An aircraft at West Raynham was allocated for loop modification, but when the installation was air-tested rotation of the loop became extremely difficult at 190 m.p.h. and it locked completely at 210 m.p.h. On the same day, 9 April 1940, the Air Ministry was informed by the Bristol Company that the loop was considered satisfactory and ready for any examination. In the next few days further modifications were incorporated and on 25 April representives of all interested parties tested the equipment. As a result it was decided to accept the loop in its final modified form if each loop passed an air test at 200 m.p.h. Arrangements were accordingly made for a B.A.C. working party to modify existing loops to the standard required and to install satisfactory loops in aircraft deficient of them. The No. 2 Group squadrons were given priority, and the working party arrived at Wyton on 6 May 1940. At the end of June, however, it was reported that no further fitting was being done, that the loops already installed were not being used, and that in most instances they suffered from all the defects of the original rejected installation.[2] In the following month Headquarters No. 2 Group asked if, with the employment of Blenheim squadrons on night operations, the aircraft could be provided with navigation aids similar to those installed in heavy-bomber squadrons, and especially an effective D/F loop, so that use could be made of United Kingdom and enemy beacon systems. Fitting of the new Marconi receiver, the R.1155, with a new Marconi D/F loop, had begun, but the set was not yet available in sufficient numbers to equip all Bomber Command aircraft. In addition, the requirement for a navigator-operated D/F loop still remained. The Air Ministry favoured the provision of a second Marconi R.1155 for this purpose, but it was not expected that the set would be available in sufficient quantities to enable installations to be made at the rate of two per aircraft until February 1941.[3] Five months later, in December 1940, following two serious navigation failures involving experienced crews, Headquarters No. 2 Group again raised the question of navigator-operated loops. The Blenheim was by then fitted with a twin-gun turret which made coil changing very difficult, so that full use of the M.F. D/F service could not be made, and the need for a navigator-operated loop was even more urgent. A trial installation of the Marconi loop was completed at Watton during the same month, but general fitting was still not possible. However, a trial installation of a Bendix D/F loop and receiver was completed at Wattisham,

[1] A.H.B./IIH/241/10/1. [2] A.H.B./IIH/241/10/1. [3] A.H.B./IIH/241/10/1.

and performance was so satisfactory that the immediate allocation of 160 sets believed to be in the country was made as a temporary measure until replacement aircraft fitted with the additional Marconi set for the navigator were available.[1] By June 1941 it was considered that the size and weight of the R.1155 precluded the installation of two of them in Beaufort and Blenheim aircraft.[2] Since the need for a navigator-operated loop was confined mainly to the smaller types of aircraft because of the gunnery duties of the wireless operator, the requirement was no longer of importance in Bomber Command.

By August 1940, Headquarters Coastal Command was expressing dissatisfaction with existing loop installations and asking for the fitting of later models.[3] The loop was then used in conjunction with the R.1082, and although a great improvement was expected with the introduction of Marconi equipment, the likely date of provision was still not known. In addition, the R.A.E. considered that it would not be practicable to fit the latest type of loop with the R.1082. A keen interest in the provision of navigator-operated loops, which had been installed in a number of Hudson aircraft fitted with the R.1082, and in all Sunderlands, in view of their long flights over the sea, had been evinced in Coastal Command, but the main interest in the operation of the loop lay in its use to home aircraft to convoys for patrol duty, to home strike forces to aircraft shadowing enemy shipping and submarines, and to home aircraft to transmissions made by U-boats.

The loop installation in Beaufort aircraft was never entirely satisfactory up to the time of the fitting of the Marconi R.1155 and ancillary equipment. In August 1941, No. 22 Squadron, based at Thorney Island, reported that owing to the large errors experienced with the Bristol loop and the short distances over which their aircraft operated, loop homing had not been employed; direction-finding by other methods had proved adequate. Up to that time, no instance had been recorded in the squadron of loop homing being of any assistance to aircraft whilst returning to base.[4] Complications arose when Beaufort Mark I aircraft, fitted with the R.1082 and Bristol loop, were required to home to a shadowing aircraft, and in March 1942 Headquarters Coastal Command reported that extreme difficulty was being experienced, and requested action which would be of immediate benefit, pending the general easing of the situation which was to be expected when more receivers R.1155 were in use. The R.A.E. considered that the problem of quadrantal error, which worried Headquarters Coastal Command, was really a small handicap, as although the first few bearings taken might be incorrect, when an aircraft settled down to follow a series of bearings, quadrantal error would be negligible. Homing with the R.1155 was thought to be possible up to 60 to 80 miles and more, but although good results might be obtained at times with the R.1082, the equipment could not be regarded as being generally satisfactory for homing to another aircraft, mainly because of lack of signal strength and the width of minima. No satisfactory solution was found to the Coastal Command problem, but with further deliveries of aircraft fitted with the R.1155 and Marconi loop the situation eased.[5]

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[1] Difficulties of fitting a D/F loop, prior to the production of the Marconi T.1154/R.1155 and ancillary equipment, were not confined to Blenheim aircraft. Precisely the same trouble was experienced with Hampdens.

[2] Coastal Command File CC/S.14126.

[3] Coastal Command File CC/S.14126.

[4] Coastal Command File CC/S.14126.

[5] Coastal Command File CC/S.14126.

In November 1942 Headquarters Coastal Command began considering the possibility of removing the D/F loop from all aircraft in the command, but Air Staff opinion was not unanimous. On 18 February 1943, at a conference known as the 'Christmas Tree' conference because its object was the removal of all but absolutely essential equipment from aircraft, it was decided that the Coastal Command D/F loop requirement should be the subject of further investigation so that definite recommendations might be made for continued installations or immediate withdrawal. On 8 March 1943, it was decided that the D/F loop could be removed from all Beaufighters and Wellington Mark XI and XII aircraft but was to be retained in reconnaissance aircraft because the majority of Allied shipping was not equipped with Rooster for A.S.V. homing.[1] The D/F loop was, in fact, given considerable use in Coastal Command as a radio aid to navigation until the end of the war.

In November 1944 the Coastal Command Development Unit completed an analysis of loop bearing errors.[2] It showed that good results were obtained at ranges up to 200 miles by day, but that fairly large and random errors could be expected at night. Over 200 bearings, obtained at varying ranges and heights, were examined. By day, at 100 miles range and 2,000 feet aircraft height, errors varied from plus 1½ degrees to minus 7 degrees, with an average of 2·1 degrees; at 170 miles and 3,000 feet, errors varied from plus 2½ to minus 5½ with an average of only 1 degree; at 300 miles the average error rose to 10 degrees. By night, the best results were obtained at a range of 200 miles and a height of 3,500 feet when errors varied from plus 6 to minus 13 with an average of 3·6 degrees. Because both height and range were changed together, the analysis gave no real indication of the effect of height on accuracy.

Homing Applications of Aircraft Loops

Shortly after the outbreak of war a requirement arose in Bomber Command for a method to enable aircraft of a strike force to home from a distance of about 20 miles to a reconnaissance aircraft engaged on shadowing an enemy naval unit, when ordinary navigation systems had been used to position the strike force at that distance from the target.[3] Exercises had been carried out at the request of the Admiralty early in 1939 with discouraging results but towards the end of the year the practicability of using an aircraft D/F loop in order to home to M.F. transmissions made by another aircraft was tried out. The active interest of the Admiralty was again stimulated by the report of an attack by enemy aircraft against H.M.S. *Juno* on 17 October 1939, in which it appeared that air-to-air D/F or homing was used for directing a strike force to shadowing aircraft. Air Ministry interrogation of a prisoner from a *Ju. 88*, with other information supplied from Intelligence sources, indicated that German bombers were being homed to reconnaissance aircraft by M.F. D/F. Results of the Bomber Command homing trials indicated that reliable air-to-air homing was possible from a range of 40 to 50 miles on M.F. when the Marconi receiver R.1155 was used. Homings could be completed to within one mile, although at very short distances indications of bearings became completely unreliable. The use of a visual indicator by pilots made homing a simple process, but it was necessary for aircraft to be flown at approximately the same height.

[1] Coastal Command File CC/S.14126. *See also* Royal Air Force Signals History, Volume VI: 'Radio in Maritime Warfare', for further details of Rooster.

[2] S.E.A.C. O.R.B. Navigation Appendices, November 1944.

[3] A.M. File S.2501.

For the time being, however, the majority of aircraft, especially those of Coastal Command, were fitted with the R.1082 receiver, and were not equipped with visual indicator equipment. In an attempt to find an interim method until the Marconi receiver became available in quantity, a proposal was made to use A.S.V. in conjunction with I.F.F. Experiments were carried out at Leuchars in April 1940, and the advantages of what became known as Rooster over the loop system became evident. The nature of the aerial systems was such that polarisation errors were much smaller than those obtained with loop aerial systems. The characteristics of A.S.V. provided range measurement and identification as well as homing. Jamming and interference were much less likely. These facts were summarised at the time by Mr. R. A. Watson Watt, who recommended, as an emergency measure, the fitting of 36 I.F.F. sets to work with A.S.V. for homing. He considered that, although homing by loop on M.F. was the only sound alternative method, both systems could be regarded only as stop-gaps until the operational requirement could be met with radar. However, there were many practical difficulties in the use of A.S.V. with I.F.F., and in any event neither type of equipment was available on any large scale, so it was decided to continue with the installation of Marconi receivers and D/F loops.[1]

On 9 January 1942 an exercise was held to test the signals organisation to be used in the event of a bomber strike force being despatched to intercept an enemy surface raider in the Western Approaches, the strike force homing to a shadowing aircraft of Coastal Command.[2] The exercise disclosed certain faults in the system but showed it to be practicable, and similar exercises were carried out over a period of eighteen months so that all strike leaders in Bomber Command should be conversant with the system and have recent experience of it. It was emphasised that the success of such operations would depend on the training and ability of air crews in homing to the reconnaissance aircraft, and operational training units as well as operational squadrons were instructed to pay special attention to practice in obtaining loop bearings on ground stations and in air-to-air homing. One point revealed by the exercises was that signal strength was greatly improved when the strike force approached well below the shadowing aircraft, so that the structure of neither aircraft interposed between the trailing aerial of the transmitting aircraft and the D/F loop of the receiving aircraft.[3] This was reversed when the strike force contained no aircraft equipped with D/F loops and were receiving loop bearings from the shadowing aircraft. In some conditions a system of automatic D/F homing was used, the circumstances generally being those in which an aircraft had located an enemy force or vessel and could transmit call-signs and dashes at regular intervals so that H.M. ships in the area could home to them without breaking W/T silence.[4] The system meant that a number of ships could get bearings simultaneously, and the same procedure was used for homing aircraft, the shadowing aircraft being known as the beacon aircraft. Beacon aircraft flew as high as possible to make homing easier. The D/F procedure for homing

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[1] A.M. File S.2501. In the Middle East, Wellingtons equipped with T.1154/R.1155 were able to take reliable loop bearings on shadowing aircraft at ranges up to 80 miles. Experience in the Mediterranean in 1944 also emphasised the value of W/T homing against U-boats.

[2] Coastal Command File CC/S.9105/5/1. [3] Coastal Command File CC/S.9105/5/1.

[4] Coastal Command Signals Review, Volume I, No. 2, February 1944.

strike forces to a shadowing aircraft was retained until the end of the war, although it was superseded by Gee and Loran when the aircraft were fitted with those systems and when the target was within the prescribed cover.

A good example of the smooth continuity which could be achieved when successive shadowing aircraft made homing transmissions was provided on 27 December 1943, when a Sunderland of No. 201 Squadron sent a sighting report of a blockade runner in the Bay of Biscay at 1015A, and an amplifying report a quarter of an hour later. An accurate description of the ship was included, and two Liberators of No. 224 Squadron were at once diverted to the position given. At 1122, the Sunderland was told to start making homing transmissions on 385 kilocycles per second, the homing frequency, and immediately afterwards the two Liberators were able to start homing. In the ensuing half-hour two more Sunderlands arrived at the scene of action, and at midday another Liberator and a Wellington were diverted to the scene and were instructed to home on the transmissions of the first Sunderland. By now this aircraft was approaching its prudent limit of endurance, so at 1305 one of the other Sunderlands which had made contact took over the homing transmissions, the first Sunderland returning to base after delivering its attack. Another Liberator, which had begun homing on the first Sunderland's transmissions at 1245, reached the target at 1428, and took over the homing transmissions at 1616 when the second Sunderland reached its P.L.E. The first really successful attack was carried out at 1646 by one of the diverted Liberators, the ship being set on fire. Further homing was completed by other aircraft, and at 1722 the shadowing Liberator reported that the ship had been abandoned and was on fire with 70 survivors in the boats. The final report at 1813 gave the position in which the ship was sinking.[1]

From the beginning of the war, Coastal Command aircraft found the greatest difficulty in meeting the convoys they were detailed to escort. The position of a convoy, particularly of an incoming convoy, could rarely be accurately predicted, and even when it could be, the fact that D.R. navigation was not an exact science meant that aircraft sometimes failed to make contact.[2] Long-range A.S.V. was not available in Sunderlands and Catalinas until the latter half of 1941, and the only aid to locating a convoy was W/T homing. But early in 1941, when the monthly sinkings by U-boats were at their worst, strict W/T silence was still in force, thus removing the only available aid to location.

It was recognised in May 1941 by the Director of Anti-U-boat Warfare that radio silence was defeating its own ends in that it resulted in many escorting aircraft failing to make contact, and this view was supported by the A.O.C.-in-C., Coastal Command.[3] At the same time, with the delivery of an increasing number of Catalinas from June 1941 onwards, escort further and further out into the Atlantic became possible, thus aggravating the navigation problem. Previous instructions on the meeting of convoys were therefore reviewed in August 1941, when it was agreed that all aircraft on contacting their convoy should send a signal to base giving the convoy position as a bearing and distance from a pre-arranged datum point. On the other hand, if after two hours' search a location had not been made, the signal 'Not Met' was to be

[1] Coastal Command Signals Review, Volume I, No. 2, February 1944.

[2] A.H.B. Narrative 'The R.A.F. in Maritime War'.

[3] A.M. File S.88156/1.

sent. On receipt of the 'Not Met' signal, the C.-in-C., Western Approaches decided whether or not the circumstances justified the convoy escort vessels' breaking W/T silence to home the aircraft to the convoy. If it was decided that W/T silence could be broken, the senior officer of the escorting vessels was ordered by W/T to transmit call-signs and dashes on 385 kilocycles per second at a specified time; the aircraft was similarly instructed to listen out at the specified time and to home to the convoy by means of its D/F loop.[1] This method of homing was known as Procedure 'A'. There were, of course, many other factors which affected the percentage of abortive sorties, but W/T homing was generally acknowledged to be the most reliable means of ultimately ensuring a meeting.

By early 1942, A.S.V. was becoming more generally fitted in long-range escort aircraft, but the average range from which a convoy could be recognised, about 25 miles, although of great assistance in the final location, was no help in the earlier stages of homing. The equipping of escort surface vessels with A.S.V. beacons gave promise of much greater A.S.V. range, but the rate of provision of beacons was slow, and W/T homing remained the only solution.[2] At the Admiralty Trade Protection Meeting on 6 January 1942, concern was still being expressed at the number of aircraft which failed to meet their convoys, and at the reluctance of convoy escorts to break W/T silence to home aircraft. An analysis covering the period July to December 1941 had been made of the proportion of failures of aircraft to meet convoys between 400 and 600 miles out, the range at which aircraft escort was most valuable, and it was found to be above 35 per cent.[3] Beyond 600 miles range this figure rose to 60 per cent. The navigation problem was complicated, especially in the case of incoming convoys, by the difference between the estimated position of convoys and their actual position. Further, convoys which were successfully located were only met after a long search, and it was estimated that not more than 20 per cent of effective flying time was spent with convoys. The proportion of 'Not Met' sorties continued to be depressingly high. Other factors such as weather greatly affected the figures, but it was still felt that the homing procedure left much to be desired, and during April 1942 an alternative procedure was introduced whereby the aircraft sent its call-sign and dashes on 385 kilocycles per second and the escort vessel or ship concerned took a bearing and transmitted it to the aircraft. This method was called Procedure 'B'.[4] In July 1942 its use was extended to H.F., and frequencies of 3,925 and 6,666 kilocycles per second, generally the former, were used. Much improved results were obtained with the use of Procedure 'B', which entailed less W/T signalling by the convoy; it was in fact a far more logical arrangement than its predecessor.

With the introduction of Procedure 'B', a new policy was agreed with the C.-in-C., Western Approaches:—

(a) When any convoy was being shadowed by *Focke-Wulf* aircraft or U-Boats the homing procedure was in general always to be employed.

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[1] No. 15 Group Operational Instructions.

[2] A.H.B. Narrative 'The R.A.F. in Maritime War'. By early 1943 responder beacons were being fitted more generally on H.M. ships, the aim being to ensure that at least one ship in each convoy was so equipped.

[3] Coastal Command File CC/S.7011/1, Part IV and A.H.B./II/39/7.

[4] No. 15 Group Operational Instructions, Amendment No. 6.

(b) For SL, OS, HG, OG, and other southbound convoys which were not being shadowed, the homing procedure was not to be employed in normal circumstances when the convoy was south of latitude 52 degrees north.

(c) For transatlantic convoys the homing procedure was to be used as a matter of routine.

Instances occurred where aircraft failed to meet a convoy and the naval authorities considered it undesirable for the convoy escort to break W/T silence to home the aircraft. In such instances the area combined headquarters could order the aircraft to change to an appropriate M.F. or long-range cathode-ray D/F section wavelength and transmit call-signs so that its position could be fixed; the D/F control station concerned was informed whether the fix was to be transmitted to the aircraft or reported to A.C.H.Q. The aircraft sent its call-sign and dashes for three minutes, waited for one minute to see if the D/F control would pass the fix, and then reverted to its operational frequency. If A.C.H.Q. considered it advisable, the fix or further directions were then communicated to the aircraft.[1]

From July 1942 to March 1943, Procedure 'B' was used almost exclusively with the North Atlantic merchant convoys. Up to March 1943 it was used on about two-thirds of all such sorties, and subsequently it was used almost invariably.[2] The procedure was more successful on H.F. than on M.F., solely because two-way contact was established more easily on the higher frequencies. In fact, the most frequent cause of failure was the simple inability of ship and aircraft to establish two-way W/T contact. The blame for this appeared to be equally divided. In theory Procedure 'B', like Procedure 'A', was to be used only when search by D.R. navigation failed. In practice, aircraft crews were generally instructed before take-off to carry out Procedure 'B', beginning at a certain time, usually when it was estimated they would be about 100 miles from the convoy. The convoy also knew in advance that W/T homing was to be used. The only disadvantage of this interpretation of Procedure 'B' was the continual breaking of W/T silence; this prevented its use on the North Africa convoys at the time of Operation Torch, but was no longer regarded as a serious consideration in the North Atlantic. From the point of view of efficiency in meeting convoys, the practice was an improvement on the theory, since no time was lost before homing began. If the homing was successful, no time at all was lost in searching.

Experience with Procedure 'B' up to March 1943 showed that its use decreased the number of 'Not Met' sorties by about 7 per cent. The figure seemed disappointingly low, but had to be related to a number of other factors. The overall percentage of 'Not Met' sorties was roughly proportional to the distance of the convoy from the aircraft base; the percentage of 'Not Met' sorties rose as distance increased, and over the shorter distances W/T homing was seldom used. Therefore most of the additional meetings resulting from W/T homing were at the greatest distances, where an increase in escort was most valuable. In March 1943, 28 sorties were made on convoy-escort duties at distances beyond 600 miles, and all used Procedure 'B'. The actual number of meetings was 20. Experience indicated that had W/T homing not been used the expected number of meetings would have been at least 25 per cent less.

[1] Coastal Command File CC/S.9118/8, Part II. [2] C.C. O.R.S. Report No. 220.

The increasing use of very-long-range aircraft underlined the advantages of W/T homing and emphasised the need for its perfection. The percentage of successful W/T homing was remarkably constant up to March 1943, but from April onwards the results were much more satisfactory, due almost entirely to an improvement in W/T communication. Already, between July 1942 and March 1943, aircraft which were successful in establishing W/T contact with their convoys had succeeded in meeting them nine times out of ten. But in April 1943, of 56 sorties on escort to the North Atlantic merchant convoys, of which 52 were ordered to use Procedure ' B ', no less than 49 met their convoy, and two of the three which failed to meet did so through being forced to return to base with engine trouble. Significantly, of the four sorties which did not use Procedure ' B ', three failed to meet their convoy. W/T homing by Procedure ' B ', begun as an emergency measure, came to be used almost invariably by No. 15 Group in the North Atlantic. It substantially increased the percentage of meetings, especially at long range, and enabled escort aircraft to fly straight to their convoy, thus spending the maximum possible time on the vital duties of escort.

In the summer of 1940 a merchant ship especially equipped with radio interception equipment was sent by the Admiralty to investigate U-boat radio emissions in the Atlantic, and as a result a determined drive to equip convoy-escort destroyers with H.F. D/F was begun. Results were not encouraging at first, but gradually, as more was learnt of the new technique, successes became more frequent, and by April 1942 H.F. D/F had become an essential part of the equipment of escort craft.[1] The possibility of loop homing by aircraft on U-boat transmissions was first suggested by the A.O.C.-in-C., Coastal Command in July 1941, when a requirement was stated for H.F. loop homing to take advantage of the transmissions of enemy surface vessels and submarines in the 4 to 14 megacycles per second frequency band.[2] At the Battle of the Atlantic Committee meeting of 21 October 1941 it was suggested that a sub-committee should be formed with representatives of the Admiralty, the Air Ministry, and Headquarters Coastal Command, whose terms of reference would be to keep under review enemy use of radio in the attack on trade, to consider suitable countermeasures, and to make recommendations. Air Ministry approval was given on 13 November, and the first meeting of the Battle of the Atlantic D/F Sub-Committee followed a fortnight later. The meeting considered the types and frequencies of W/T signals made by U-boats and *Focke-Wulf* aircraft, the sequence in which they were made, and their purpose.[3] It was considered that the first signal was likely to be one made on M.F. by a *Focke-Wulf* aircraft homing U-boats to a convoy, followed by its sighting report on H.F. U-boats able to reach the convoy would then report on H.F. the bearing of the *Focke-Wulf* M.F. transmission, and the direction of the signals could be established either by the escort or by the convoy. However, as such signals might emanate from U-boats up to 300 miles or more away, action on them might be wasteful, though a search by air escorts to a limited range would do no harm and might be fruitful. The next indication, a sure and necessary forerunner of a massed U-boat attack, was the U-boats first convoy-sighting report, followed by amplifying reports, all on H.F. The reports provided a fruitful source for direction-finding and subsequent search by surface and air escort, though the problem of reception

[1] Admiralty Files C.B.04050(42)4 and (44)9. [2] A.M. File CS.9931.

[3] Coastal Command File CC/S.9117/9.

was complicated by the number of frequencies on which the reports might be sent. There usually followed a most promising use of M.F. by the shadowing U-boat, half-hourly transmissions being made to which other U-boats homed. Clearly air and surface escorts could similarly get bearings of the shadowing U-boat, whose range from the convoy would be somewhere near the limit of visibility. A prompt search should therefore result in an attack on the shadower. If the convoy was not successful in shaking off the shadower at this stage, either by attack or by alteration of course at dusk, additional U-boats made contact, and even though their transmissions might be received and homed on, the prospects of a mass attack developing increased rapidly. A study of the whole sequence of the pack-attack control scheme built up by Admiral Doenitz showed that it was of the greatest importance that offensive and evasive action should be taken against the first U-boat in order to prevent a mass attack developing.[1] Employment by the first U-boat of H.F. transmissions to make its reports provided confirmation of the operational requirement raised by the A.O.C.-in-C., Coastal Command in the previous July.

Previous tests with the D/F loop on H.F., which had been carried out by the R.A.E. at the request of the Air Ministry in 1938, had shown that the safe homing range by day was up to 100 miles. Tests beyond this range had been characterised by fading, apparent swinging of bearing, and occasionally by absence of minima.[2] However, a possible range of 100 miles was not discouraging. A tactical instruction on the use of the M.F. transmissions of U-boats was issued by Headquaters Coastal Command on 15 December 1941, and meanwhile the R.A.E. investigated the possibility of modifying existing equipment so that it could be used for loop direction-finding on H.F.[3] The development of new equipment could only have been achieved after prolonged experiments which would possibly be wasted if the enemy made any considerable change in his use of frequencies, and it was in an endeavour to produce quick results that the R.A.E. attempted modifications aimed at making use of the existing facilities in loop design and receiver installation. As a temporary measure, the first tests were carried out with the R.1082 receiver.[4] Although the results were by no means satisfactory they indicated that skilful application would go some way towards solving the problem, and by 1 February 1942 the installation had been made to work reasonably well in a Catalina, the standard Bendix loop being plugged into a special R.1082 instead of into the Bendix radio compass.[5] Experimental work was in hand at the R.A.E. to replace the R.1082 with an adaptor on the Bendix radio compass, and preparations were made for adapting the Marconi R.1155 should it become a firm requirement in Catalina, Liberator and Fortress aircraft, using the Bendix loop and receiver, and in Sunderland, Whitley and Wellington aircraft, using the Marconi loop and receiver. In point of fact, the A.O.C.-in-C., Coastal Command had stated a clear requirement on 5 July 1941, but its complexity and implications were so great that it came to be regarded as a matter for full investigation rather than an immediate operational requirement. By April 1942, six modified R.1082 receivers were in use in Catalina aircraft of Nos. 209 and 210 Squadrons, and development of suitable modifications of Marconi and Bendix equipment was being undertaken by the

[1] Coastal Command File CC/S.9117/9.

[2] A.M. File S.43388.

[3] Coastal Command File CC/S.9117/9. There was never any evidence of success in using the D/F loop on transmissions.

[4] A.M. File CS.9931.

[5] Coastal Command File CC/S.9117/9.

firms of Marconi and Plessey.[1] It was recognised that the proposed extension of employment of radio equipment would demand the services of an additional crew member, and four wireless operator/air gunners were selected and trained in the new technique, one being attached to the R.A.E., two to No. 209 Squadron and one to No. 210 Squadron. They in their turn were to train other crew-members as aircraft were fitted.

At the ninth meeting of the Air/Sea Interception Committee on 9 July 1942, the A.O.C.-in-C., Coastal Command stated that a Catalina fitted with special H.F. D/F equipment had returned to Sullom Voe, and that although no U-boat transmissions had been heard during operations, transmissions had been heard when the aircraft was riding a buoy at Sullom Voe.[2] At that time, only the temporary R.1082 sets had been fitted, and the A.O.C.-in-C. felt that substantial progress must be made by the autumn. In view of the success of shipborne equipment it was decided to hasten development of the airborne sets, and the A.O.C.-in-C., Coastal Command formally confirmed an operational requirement on 18 July 1942. Fifty frequency-changers, styled Type R.1369, were ordered from the firm of Plessey for fitting in conjunction with the Bendix receiver, and the firm of Marconi had been given a development contract for similarly modifying three R.1155 receivers, but little progress had been made. Provisioning action for a further 200 Plessey converters for Catalina, Fortress and Liberator aircraft was taken, and the Marconi development contract was increased from three sets to 50 so that equipment would be available for Sunderlands, Whitleys and Wellingtons.[3]

Delays in production of the equipment continued. The basic difficulty lay in the fact that the natural electric frequency of aircraft wings and fuselages often fell in the frequency bands in which H.F. loop cover was required, producing very great and not always regular and predictable errors. The incoming signal was liable to resonate with the metal structure of the aircraft, producing an effect of transmissions coming from any direction regardless of their true source. This feature necessitated experimental work in the actual types of aircraft to be used operationally, trials on one type of aircraft not necessarily giving any indication of what might happen on another. A further reason for delay was the lack of the necessary plugs and sockets for use with the Bendix equipment; they had been ordered from the United States of America but had not been delivered. There were similar delays with the Marconi equipment.[4] Other pressing problems concerned the training of wireless operators in the operation of the new equipment, and the provision of seating accommodation for an extra crew member, with the additional weight and loss of payload involved.[5] The production delays prompted comment from the Director of Telecommunications, who was particularly concerned that there seemed to be no reserve capacity for small projects which could be of vital importance for a short period. The R.1369 was only a simple frequency-changer, yet the gap between type approval and commencement of delivery was expected to be 30 weeks. The Director of Telecommunications classed the production demand as the sort which arises quickly and sometimes fades away altogether, '. . . but if only apparatus can be made available to deal with the situation quickly it puts us one up on the enemy . . .'[6]

[1] A.M. File CS.9931.
[2] A.M. File CS.15850.
[3] A.M. File CS.15850.
[4] A.M. File CS.9931.
[5] A.M. File CS.15850.
[6] A.M. File CS.17375.

On 3 October 1942, tests were carried out with a Catalina using modified Bendix equipment, and a Sunderland using modified Marconi, in homing to a captured U-boat transmitter installed in H.M.S. *Adrian*, at Holyhead. The tests gave hopeful indications, but failed to shed much light on the performance to be expected in operational conditions. The recorded results referred almost exclusively to homing as opposed to the taking of bearings, and the crucial question remained whether a sufficiently accurate bearing could be taken in the first instance to allow an aircraft to turn on to it with confidence.[1] On 28 October 1942, Headquarters Coastal Command requested the installation of suitably modified R.1155 receivers in Fortresses and Liberators, as the R.A.E. had found it impracticable to fit the R.1369 in those aircraft, and at the same time the requirement for installation in Whitleys and Wellingtons was withdrawn. At the end of the year the R.1369 installation, with the standard loop and Bendix radio compass, had been prototyped, approved and ground and air-tested. 250 R.1369 convertors were being produced, but only three had been delivered. These had been fitted to Catalina aircraft of No. 210 Squadron. For Sunderlands development was being undertaken of a modified R.1155 with a special H.F. loop. Early tests by Coastal Command had been unsatisfactory, and the R.A.E. was carrying out further investigations. A development contract for 50 modified receivers had been placed with the firm of Marconi. At the end of December the Halifax was added to the list of aircraft requiring extended D/F facilities, and it was possible that a Wellington installation might also be required in the future. But by January 1943, eighteen months after statement of the operational requirement, only four aircraft, all Catalinas, had been equipped, apart from those originally equipped as an interim measure with the modified R.1082.[2]

On 27 February 1943, following a review of maintenance, training, and availability within Coastal Command, the A.O.C.-in-C. informed the Air Ministry that he had reluctantly come to the conclusion that the H.F. homing equipment, while desirable, was no longer essential and should therefore be abandoned as an operational requirement. Several factors governed his decision.[3] The weight of the extra crew-member needed to operate the equipment, in addition to the weight of the equipment itself, could only be compensated for by a reduction in fuel with a consequent reduction in aircraft range. Installation and servicing of the additional equipment necessitated a larger establishment of personnel at a time when every effort was being made to conserve manpower. Development of the modified R.1155 was proceeding very slowly, and was a great deal more difficult than had been expected. Aircraft could not be spared from operations to permit installation, trials and modifications to be carried out. The reception of, and homing to, curtailed H.F. transmissions was more difficult than had at first been thought and would necessitate concentrated training in actual operational conditions. The scarcity of occasions when the equipment could be used did not justify its introduction. Ships equipped with better apparatus could pass on to escorting aircraft any information they gained. Final estimated dates for the earliest possible full-scale production of the modifications made it impossible to look forward to general installation in long-range operational aircraft before May 1943.[4] By then the U-boat pack-attack method used in the Atlantic had been decisively

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[1] A.M. File CS.9931. [2] A.M. File CS.9931. [3] A.M. File CS.17375.
[4] Coastal Command File CC/S.7010/10/6.

defeated, and the requirement lapsed.[1] The advisibility of leaving direction-finding to escort vessels and relying on them to pass on Intelligence to escorting aircraft had been considered but rejected in February 1942. It was apparent from the start that the provision of suitable equipment would be difficult, but the urgency was great and any addition to the power of aircraft to seek out U-boats was worth while. Nevertheless, due consideration of two factors only, the loss of range of the aircraft and the increased demand for personnel at a time when reserves of manpower were becoming exhausted, might have brought immediate acceptance of the proposal to concentrate on H.F. loop bearings taken by escort craft. However, at the height of the most successful period of the whole U-boat campaign against the Atlantic convoy routes, a useful means of U-boat detection was denied to aircraft of Coastal Command, in spite of the fact that an operational requirement had been declared over one year before the start of the period.

The necessity for some form of homing equipment other than V.H.F. R/T for aircraft of photographic reconnaissance units was first suggested in August 1940, installation of the Fighter Command V.H.F. system TR.1133 in P.R.U. aircraft being unacceptable to Headquarters Coastal Command, owing to the size and weight of the equipment. P.R.U. aircraft had a special need for a homing device in that the heights at which they operated added to the difficulties of accurate wind velocity forecasting. Rebecca was at first suggested, but the Telecommunications Research Establishment suggested as an alternative a simple beacon with a searchlight beam rotating clockwise, to be used in conjunction with a stopwatch and simple receiver in the aircraft; Fleet Air Arm aircraft used the system as an aid to returning to their carriers. The R.A.E. had designed the first receiver, the R.1110, and had recently developed a more advanced set, the R.1147, which was about to be produced in quantity and was expected to be available.[2]

In March 1941 the Admiralty was requested to make available two R.1147 receivers for trial installation in P.R.U. Spitfires. On 29 September 1941 installation of an R.1147 in a P.R.U. Spitfire had been completed by the R.A.E., ground and air tests of the equipment had been carried out, and the range and characteristics obtained were considered by the R.A.E. to be satisfactory for operational use. Retrospective installation in other P.R.U. aircraft was recommended. However, the O.C. No. 1 P.R.U., at whose unit the trials had taken place, thought the recommendations were premature, as the installation was still undergoing tests. A report on the results of further tests was made on 11 October. Successive homing bearings had varied by as much as 10 degrees, and had entailed considerable concentration by the pilot, which would not be possible when he was flying entirely on instruments during operations. Appreciable errors resulted from flying on an incorrect bearing for only a few minutes when letting down at a high groundspeed. Results obtained by a navigator in a Fulmar were far more accurate, partly owing to the lower ground speed, but mainly because of the increased concentration possible by the navigator. Headquarters Coastal Command considered that the object of the installation, to be an aid only in adverse weather, had been overlooked in the report, but the main objection remained that, in adverse conditions,

[1] A.H.B. Narrative 'The R.A.F. in Maritime War'.

[2] Coastal Command File CC/S.9110/46.

concentrating on instruments other than the normal flying instruments was impossible, or at least unwise. Nevertheless, Headquarters Coastal Command recommended that development should be continued and that provision should be made for installation of the equipment in all P.R.U. aircraft and for the installation of the necessary ground beacons. On 27 October it was confirmed that retrospective installation was required in all P.R.U. Spitfires to be followed by installation on aircraft production lines.

However, following further trials of the R.1147, and a trial installation of TR.1133 carried out in a P.R.U. Spitfire by unit personnel, on 16 December 1941 Headquarters Coastal Command requested the suspension of provisioning of the R.1147 until after completion of further TR.1133 trials. They were carried out at Duxford in the same month, after which the O.C. No. 1 P.R.U. reported that there was no difficulty in fitting the installations if the number of oxygen bottles carried was reduced from six to three.[1] On 6 January 1942, all instructions issued regarding the fitting of R.1147 were cancelled. Use of sector V.H.F. homing stations adjacent to photographic reconnaissance units was arranged with Headquarters Fighter Command and P.R.U. aircraft began to use the TR.1133 installation in April 1942, eighteen months after the original requirement had been raised, during which time they had been operated with no radio installation of any kind.[2]

Cathode-Ray D/F Organisation

Shortly after the outbreak of war, it was proposed that Bomber Command aircraft should make use of long-range cathode-ray D/F. It was argued that once aircraft had crossed the German border their presence was known and there was no further object in maintaining W/T silence. At that time two experimental C/R D/F equipments were available for Bomber Command and a further three for Coastal Command, and an order for thirteen more had been placed with the firm of Plessey. Their installation would make possible the provision of five baselines of 10 D/F stations in Bomber Command, and four baselines of eight stations in Coastal Command. Although doubts had been expressed whether the point had been reached where production of the sets was justifiable, the Director of Communications Development, Mr. R. A. Watson Watt, expressed his conviction that the cathode-ray direction-finder would give short and long-range results which could be obtained in no other way, and the order was approved. Negotiations for the acquisition of land for sites were already in progress, and delivery of the equipment was expected in three to four months ; although the exact siting in some instances had not been settled, landline arrangements were in hand. It was realised that relatively high-powered transmitters would be required to work aircraft at the ranges envisaged, and although delivery of S.W.B.8.B. transmitters was not expected for twelve months, a satisfactory alternative was found in the Type M.13 transmitter made by the Standard Telephones and Cables Company. Baseline linkage between transmitters was to be maintained by use of the T.1087, and tests of possible frequencies were carried out. In January 1940, sites for 10 C/R D/F stations had been settled, and in April 1940, the firm of Plessey informed the Air Ministry that the first of the C/R D/F equipments had undergone a series of tests and was

[1] There had been no occasion to use more than three bottles during operations.

[2] Coastal Command File CC/S.9110/46.

ready for transporting to the first D/F site.[1] The first three sets were installed at Butser (No. 1 Site), Dyce, and Acklington, range and calibration tests being carried out between 17 and 25 May by a Hampden flying between Upper Heyford, Aldergrove and the Hebrides. Tests were made during day-time on 7820 kilocycles per second, at night on 4077 kilocycles per second, and during the intermediate period on 6758 kilocycles per second ; ranges up to 600 miles were obtained on all frequencies. The errors shown on Butser were 0 to 2 degrees, the average error being 1 degree. On Dyce the error was from 0 to 9 degrees, the average being plus 6 degrees. The manufacturers considered that the error at Dyce was large because the station had only just been completed and there had been no time to check it over. On 7 September, as a further trial, an aircraft flew round Dyce on a 25-mile radius over eight known positions, transmitting on a frequency of 6025 kilocycles per second. At one position an error of 6 degrees was recorded, but on all other bearings the maximum error was plus 1·25 degrees.

Listening watches were kept on 4077 kilocycles per second for Bomber Command aircraft by Butser from 4 August 1940 and by Butser and Dyce from 18 September. Acklington also kept watch, but its bearings were not taken into account for the purpose of fixes. Over a period of about two months 730 fixes were requested, but reports made by operational aircraft detailed to request fixes from Butser when actually certain of their position indicated that serious errors were present. An average error of 40 to 50 miles in fixes at a range of 600 miles was reported, but investigation revealed that the report was based on a number of false or doubtful premises. Actual positions of aircraft, for instance, had been shown as ' nearest town ', rendering accurate analysis of the results impossible. A representative of Headquarters Bomber Command made a further investigation of Butser in October because large errors were still reported. His findings revealed that Butser, Acklington and Dyce had not been calibrated by an aircraft in flight ; the operators at Dyce were inexperienced ; the majority of bearings from Dyce were inaccurate ; generally bearings from Butser were reliable ; whenever bearings from Acklington were applied to those from Butser and Dyce, the error in the fix given by the two stations alone was reduced. Weather conditions during the winter months of 1940/41 restricted the distances at which aircraft had operated, thus reducing the need for cathode-ray D/F, but an attempt was made to assess the accuracy of fixes obtained from the Butser–Dyce section. The total number of fixes given in this period were 232, and of the 58 chosen for analysis, only 44 could be examined because of discrepancies ; some of the fixes reported by crews of Bomber Command were not given to any aircraft at the time and on the date stated. The general conclusions drawn were that bearings taken by Butser were twice as accurate as those taken by the other two stations ; that all large errors by Dyce and Acklington were positive ; that the differences were not confined to any particular region ; and that there would be no improvement were Dyce or Acklington to be withdrawn from the system.

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[1] 3 at Butser (near Petersfield). Parent station—Gosport.
2 at Perwinnes Moss (near Dyce). Parent station—Aberdeen.
2 at St. Eval.
1 at Widdrington. Parent station—Acklington.
1 at Low Mye (near Stoneykirk). Parent station—West Freugh.
1 at High Three Mark (near Stoneykirk). Parent station—West Freugh.
Arrangements for personnel and administration were the responsibility of parent stations, and gnomonic projection maps were prepared by the Maps Branch.

Meanwhile, the long-range cathode-ray D/F stations allotted to Coastal Command, St. Eval and Stranraer, had also come into operation. St. Eval reported that fixes given to aircraft on the day frequency seemed to be generally of good class; intersections of bearings received at the three stations (Dyce operated with Coastal Command also) were good, and ' cocked hats ' were small. No criticisms had been received, but no information was available upon which an assessment of the accuracy of the section might be based. Stranraer reported that no trouble had been experienced; reception was excellent and at distances over 100 miles bearings were accurate. Dyce reported that adjustments made to the aerial feeder system had greatly increased the percentage of first-class bearings and more clearly defined the image on the tube. Heavy interference from aurora borealis had been experienced in March. It was difficult to make recommendations for improvement until information was received about the standard of the existing service.

During the summer of 1941, when Bomber Command operations were confined to targets at short range because of the shorter nights, the Butser section closed, unless specifically requested, but when the service was resumed with the approach of the winter of 1941/42 the reliability of fixes given was again called into question, and in the course of the winter the service was used less and less by Bomber Command aircraft, the advent of radar systems largely removing the need for it.[1] In March 1942 a conference was held at the Air Ministry to decide the future employment of the cathode-ray D/F service, which was no longer required by Bomber Command.[2] It was agreed that, while fixes were liable to be inaccurate, there was no other equivalent radio aid to navigation available to aircraft of Coastal Command and No. 44 Group, and that retention of the service for their use was necessary. No. 44 Group required coverage from Malta over France, from Gibraltar via Cape Finnesterre to Lands End, and over the Newfoundland and Icelandic approaches. Coastal Command required coverage over the Western Approaches and the South-Western Approaches. The main No. 44 Group requirement was for assistance in homing to airfields in the United Kingdom, while Coastal Command required fixing facilities on patrol as a check on D.R. navigation. A common-user service was therefore introduced, with Coastal Command and No. 44 Group as the prime users. Existing equipment was repositioned and additional equipment provided to meet the requirements of the new service, the main repositioning being to Iceland and Northern Ireland.[3] It was by no means certain at first that the new service would continue indefinitely, but by the end of 1942 it had become apparent that for some time to come no alternative organisation could be provided which would meet the requirements of homing and fixing at long ranges. A survey carried out during 1942 by Headquarters No. 26 (Signals) Group, who had been given control of the new organisation, showed that bearings could be placed in different categories from the presentation on the cathode-ray tube, and that the system was capable of accurate and consistent working by day and night in the 3 to 9 megacycles per second frequency band if aircraft were more than 300 miles distant.[4]

The new organisation comprised three D/F sites at Sandgerdi (Iceland), Dyce, Ballywattick (Northern Ireland), and St. Eval, and two at Butser, with a central plotting control room situated at Old Boston (near R.A.F. Blackbrook, between

[1] A.M. File S.46691. [2] A.M. File S.59354. [3] A.M. File S.59354.
[4] A.M. File S.46691.

Liverpool and Manchester). The central plotting room replaced the old area controls at Prestwick (Transatlantic) and Gloucester (Overseas), and the loss of the area control facility at Prestwick for transatlantic aircraft worried Headquarters Transport Command. It was felt that the aim of the new system, involving a central plotting room, was sound, but that there was a danger of delays between aircraft transmissions and the passing of the position by Old Boston.[1] The previous system, whereby T.A.C. Prestwick and O.A.C. Gloucester plotted their own fixes from the individual bearings of the same cathode-ray stations, gave the area controllers facilities upon which they depended for the safe control of aircraft. It was felt that Old Boston was not fulfilling any function which was not better placed in the old area controls, both aircraft and control being robbed of essential requirements by the new system, which was considered clumsy. Tests showed that fixes took much longer to obtain, and that delays between aircraft transmission and the passing of positions under the new system had been up to 50 minutes. Headquarters Coastal Command also reported that the service was most unreliable and erratic, and that it took about 30 to 40 minutes to obtain a fix.[2] However, the advantages of a central control outweighed early minor disadvantages, which were mostly eradicated with experience, and with Old Boston remaining as the control station, the cathode-ray D/F organisation became :—[3]

Black Net. Sandgerdi, Ballywattick, St. Eval and Butser. For Transport Command (North Atlantic route).

Red Net. Sandgerdi, Dyce, Ballywattick, Butser. For Coastal Command.

Blue Net. Ballywattick and Butser. Later a third station at St. Eval was added. For Transport Command.

Green Net. Sandgerdi, Dyce, St. Eval, Ballywattick. Later a station in the Azores was added. For Transport Command.

This organisation remained in force until the end of the war, and with new-type Plessey equipment, RL.135, becoming available during 1944/1945, several stations were re-equipped, although installation was suspended after the end of hostilities in Europe. By this time, the service was being used largely for air/sea rescue purposes outside M.F. D/F cover, where there was no other means of obtaining a fix and thus determining a search area for an aircraft which had not been able to pass its position before ditching ; the best possible cover of the entire Atlantic area was required for this purpose. For routine navigation, the cathode-ray service was by then rarely used inside Loran cover, although south of 50 degrees north, where there was little Loran cover, it was still the only aid available when astro-navigation could not be used.[4]

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[1] Transport Command O.R.B., October 1943.

[2] A.M. File S.46691, Part II.

[3] Frequencies in kilocycles per second were :—

Black Net	6265
Red Net	6620/4575
Blue Net	8885/4575
Green Net	6500

[4] A separate cathode-ray D/F system for the U.S.A.A.F. was installed in 1944, stations being built at Dyce, Mullaghmore (Northern Ireland), St. Mawgan, Horsham St. Faith, and Meeks Field (Iceland). An interim scheme comprising four temporary stations came into being pending the completion of the full service. The introduction of a special system for the U.S.A.A.F. avoided the overloading of R.A.F. channels.

German Wireless Direction-Finding Systems

The capture of an enemy training school examination paper in navigation enabled deductions to be made as early as September 1940 on the German use of radio. The paper showed that complete reliance was placed on radio navigation, the aircraft D/F loop being used with specially placed and specially selected radio beacons and a conveniently placed broadcasting station. For an operational flight several beacons were selected, one and if possible two between the base and the target, and one well away on the beam of the aircraft, suitably placed for getting a good check on ground-speeds. From this paper and previous Intelligence reports it was clear that the *Luftwaffe* used track and other beacons as a check on ground-speed whenever possible. When it was not possible to use a beacon between the base and the target, aircraft flew on back bearings from two radio beacons, which were kept in line so as to maintain the required track. Bearings were obtained quickly by means of a navigator-operated D/F loop, the expected accuracy being of a high order. All the indications were that German aircraft were continually homing on a beacon or working on tail bearings so as to give a good track, while another station was used to check groundspeed. The navigator was thus chiefly a radio navigator, though he was also expected to be capable of D.R. navigation.[1]

The absorption with beam technology as an aid to navigation, and sometimes as a complete system of navigation, meant that the Germans were particularly susceptible to the effects of radio countermeasures, far more so than a Service in which D/F was regarded as one of several aids.[2] Countermeasures designed to confuse crews flying on a beam were more successful than were the attempts to interfere with the R.A.F. system of two-way communication with D/F ground stations. An instance in which an enemy ground station posed as a British station and attempted to work an R.A.F. aircraft occurred on the night 7/8 May 1941, when an enemy ground station copied the call-sign of Heston M.F. D/F station and attempted to work a British aircraft.[3] The effort was not skilfully conceived, but it showed how readily discrepancies in procedure and a strange method of operating could be recognised by a competent operator. Finding its efforts to work the aircraft unsuccessful, the enemy station called Heston on several occasions, using the aircraft's call-sign, but Heston declined to answer. The radio operator in the aircraft avoided any possibility of error by using the coded challenge each time he requested a fix. This interference was repeated on several subsequent occasions, the enemy station attempting on one occasion to pass incorrect fixes, but all such attempts failed because of incorrect procedure and the style of morse used.

River

By the winter of 1940 the *Luftwaffe* was using a special type of directive beam known as a *River* beam for accurate bombing at night or in conditions of bad visibility. The system consisted of a narrow approach beam which was laid over the target, and two narrow cross-beams which were made to intersect the approach beam at pre-determined points, enabling a precise calculation

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[1] No. 18 Group O.R.B., September 1940.

[2] *See* Royal Air Force Signals History, Volume VII : 'Radio Counter-Measures', for further details.

[3] A.M. File A.891009/46.

to be made of the actual moment of bomb release. The approach beam originated from transmitters situated in the Cherbourg peninsula, the width of the beam varying, according to target distance, between 200 and 400 yards. Only a limited number of German aircraft carried equipment enabling them to use this system, and they were used as pathfinders with the object of fixing the target in order to guide the following aircraft. Pathfinder aircraft belonged to the crack squadrons, and although they might avoid flying in the beam during most of the flight, they were bound to remain rigidly in the narrow cone during the last 20 miles of flight before the target was reached.[1]

Knickebein

The *Knickebein* beams transmitted a much wider ray than the *River* type, and apart from their considerably longer range were similar to the normal *Lorenz* landing beam. As with *River*, the Germans relied on this system to a greater or lesser extent according to the weather and the standard of navigational training of crews. Pilots tended to avoid following the continuous note indication in the centre of the beam for fear of finding fighters and A.A. fire concentrated along it, but they used the beam to check their navigation by occasional reference to the distinctive indications of the bands on either side of the continuous note. They usually used the starboard side of the beam on the outward flight and the port side on the return. Headquarters Fighter Command evolved several systems of using the beams as a guide to interception, and measures were taken to interfere with them to confuse the German crews.[2]

Sonne (Consol)

The *Sonne* or Consol system consisted of a series of M.F. beacons, located along the Atlantic and Mediterranean coastlines, which were capable of providing bearings of high accuracy, and which could be used in pairs to give fixes. They were primarily intended for use by U-boats and long-range reconnaissance aircraft. By suitable switching to three aerials in line a slowly rotating fan-shaped beam, 120 degrees in width, was produced. No extra equipment beyond a simple receiver capable of receiving M.F. transmissions was needed, and the system covered most of the North Sea and large areas of the Atlantic.[3] An aircraft wireless operator tuned in to the beacon signal, which consisted of a number of dots and dashes separated by a steady signal, and noted the number of dots and dashes heard from commencement of the keying cycle. Reference was then made to an appropriate lattice chart and the position line selected. Accuracy by day was plus or minus 0·3 degrees up to a maximum error of plus or minus one degree, propagation being due almost exclusively to the groundwave, providing very stable conditions. Bearings could be obtained at ranges up to 1,000 to 1,500 miles. Accuracy decreased as distance increased because as the field strength became less the liability to interference increased. At night the situation was essentially different because of the appearance of the skywave; a systematic displacement in the main beam pattern of radiation was capable of causing errors up to two degrees, but a correction for this displacement could be applied. However, scatter,

[1] No. 9 Group O.R.B., December 1940.

[2] *See* Royal Air Force Signals History, Volume VII: 'Radio Counter-Measures'.

[3] Coastal Command Signals Review, Volume 2, No. 7, July 1945.

ranging from plus or minus one to three degrees, although capable of being anticipated, was responsible for random deviation at night which could not be forecast.[1]

Great assistance was rendered to Coastal Command aircraft and later Transport Command aircraft by the *Sonne* beacon system, known to the R.A.F. as Consol, and it was estimated that in Coastal Command one fifth of all radio navigational assistance was obtained from this source.[2] Indeed, in 1944, when the Allied armies began to overrun the Continent, all possible measures were taken to ensure the continued operation of the *Sonne* system, but the difficulty was that whenever an area in which a *Sonne* beacon was situated was threatened with capture, the enemy naturally dismantled and removed or destroyed the equipment. The success of the Allied armies thus constituted an involuntary threat to the safety of Allied aircraft. The development of a British equivalent of *Sonne* was begun in November 1944, but no great progress was made up to the end of the war.[3]

Komet

In the course of long-range operations over the western Atlantic, the enemy raised a requirement for an accurate radio navigational aid with a range of at least 3,000 kilometres, and since beam technology had already been highly developed in Germany, it was natural to attempt to meet the requirement by the use of the beam principle. The *Sonne* system was already available for radio navigation for distances up to about 1,500 kilometres, and it was proposed to develop a similar system in the short-wave band, reaching ranges of between 2,000 and 4,000 kilometres by a choice of suitable wavelengths. It was thought that by constructing two installations, one in the south of France at Bordeaux and one in Denmark at Kolbi, it would be possible to obtain fixes in long-range aircraft over the entire Atlantic operational area. Up to the middle of 1944, however, trials with *Komet* were unsatisfactory, attempts to produce a beam concentration of adequate width proving unsuccessful. By this time, German long-range operations in the Atlantic had ceased and development of *Komet* was abandoned.[4]

[1] Air Scientific Intelligence Technical Translation No. 14.

[2] Coastal Command O.R.B., 1944.

[3] Coastal Command File CC/S.7512/7/4.

[4] A.I. 12/USAFE/TE 35.

CHAPTER 22

WIRELESS DIRECTION-FINDING IN OVERSEAS COMMANDS 1939–1945

Wireless direction-finding systems were required to fulfil two functions in overseas commands ; aids to navigation in operational theatres, and aids to navigation along aircraft reinforcement routes. The systems provided for operational theatres followed, in the main, the familiar pattern of those provided for operational commands based in the United Kingdom, but retained their importance until a later stage in the war because radar systems were not so readily available and in some instances were unsuitable. In no sphere of wartime flying was wireless direction-finding more widely used or of greater value than in the reinforcement flight organisation.

The outstanding requirement for direction-finding stations overseas was decided in July 1938 as six H.F. and five M.F. in the Far East, two mobile H.F. and two mobile M.F. in Egypt, two M.F. at Malta, one H.F. and one M.F. at Aden, one H.F. at Nairobi, and possibly one M.F. in Palestine. By the outbreak of war the only installations to have been completed were the M.F. stations in Malta and Egypt. Delivery of the remainder of the equipment was postponed in case it should be more urgently required in the United Kingdom.

The Far East 1939 to 1942

The chief requirement for D/F in Malaya, as envisaged before the war, was to fix the position of aircraft on reconnaissance patrols at distances likely to extend appreciably beyond 100 miles from Singapore Island.[1] It was known that the range and accuracy of M.F. D/F varied greatly in this area because of atmospherics, and that the normal operational range was about 100 miles (civil M.F. stations had been operating in the Far East for some years). While more modern M.F. stations might give better ranges, perhaps up to 150 miles, still greater ranges were wanted, and it was in an attempt to solve this problem of range that the provision of H.F. D/F stations was suggested, whilst the M.F. stations were to be used for homing. This was in complete contrast to the roles allotted to H.F. and M.F. systems in the United Kingdom, where H.F. was used for homing and M.F. for long-range fixing. The object in the Far East was to use H.F. beyond the skip areas, which normally extended from about 100 to 250 miles, as the effects of atmospherics were less on higher frequencies. The stations would still be made use of for short-range homing, supplemented by M.F. for short-range fixing and homing.

At the beginning of 1938 the only D/F stations in existence in Malaya were the civil M.F. stations at Singapore and Penang although an R.A.F. M.F. station was in the process of erection at Seletar. There was, however, a plan in existence for the provision of Service H.F. and M.F. stations at Tengah, Jesselton and Kuching (south-western Sarawak). A station was to be provided at Tengah by transferring the existing M.F. station from Seletar. Headquarters

[1] A.M. File S.45161.

Far East Command was by no means satisfied with the plan, and in March 1938 its limitations were brought to the notice of the Air Ministry.[1] The requirement, it was considered, was for the allotment of a second operational frequency and the erection of further suitable D/F stations. It was recommended that the Singapore reconnaissance area should be divided into two zones, each with a local operational frequency. D/F stations would be required at Tengah and Jesselton (British North Borneo) for the Northern Zone, and at Tengah, Kuching and either Kuantan or Sungei Patani for the Southern Zone. The Air Ministry made the following counter-proposals :—

Northern Zone. H.F. D/F stations at Tengah, Jesselton and Kuching.

Southern Zone. M.F. D/F stations at Tengah, Kuching and Kuantan, with use of an H.F. D/F station at Sungei Patani to combine with Jesselton in periods of bad M.F. reception.

It was thought that, if H.F. was used in the Southern Zone, difficulties would be encountered over a large part of the area because of skip effects. If M.F. was used, a fairly large proportion of the area would be covered, but since there was always the possibility that atmospherics might render the M.F. system inoperative just when it was most wanted, an H.F. D/F station could be sited at Sungei Patani, where D/F facilities would presumably be wanted in any event as squadrons were to be based there. When atmospheric conditions precluded the use of M.F., the northern area station at Jesselton could combine with Sungei Patani to cover the southern area, leaving the two remaining stations at Tengah and Kuching to cover the northern area. Normally, when Sungei Patani H.F. D/F was not required by the Southern Zone, it could be used as a homing and safety service for its own aircraft. Summarised, the Air Ministry proposals were :—

(*a*) H.F. D/F and M.F. D/F at Tengah and Kuching.

(*b*) H.F. D/F only at Jesselton and Sungei Patani.

(*c*) M.F. D/F only at Kuantan.

The possibility of extending the area covered by D/F by making use of French facilities on the south coast of Indo-China was considered at the Air Ministry, and as a result Headquarters Far East Command was urged to co-operate locally with the French authorities. But as far as was known in Singapore, there were no H.F. stations in French Indo-China, and no M.F. stations south of latitude 18 degrees.[2] Also, before any proposals were made to the French Indo-China authorities by Headquarters Far East Command for the use of D/F facilities, preliminary action at the appropriate level was essential, together with instructions on the scope of any such negotiations. No such preliminary action was taken and no approach to the French authorities in Indo-China was in fact made.

For a number of reasons the plan approved by the Air Ministry underwent many changes ; it underwent contraction due to the demands of other theatres of war, particularly of the United Kingdom after the outbreak of war in Europe, and expansion as a result of the planned transfer to Malaya of further squadrons. On 24 October 1938 Miri (Sarawak) was substituted for Jesselton, but was later deleted without any site being suggested in its place. A decision not to site the Singapore M.F. D/F station at Tengah was taken in April 1939, an alternative site at Sembawang having been proposed. M.F. D/F for homing

[1] A.M. File S.45130.

[2] A.M. File S.45130.

at Mergui, on the reinforcement route to Singapore between Bangkok and Victoria Point, was agreed in April 1939 but cancelled later, civil M.F. stations at Bangkok, 140 miles to the north, and Victoria Point 170 miles to the south, being left to meet the requirement. The revised plan at the outbreak of war in Europe was:—

H.F. D/F. Tengah, Kuching, Sungei Patani.

M.F. D/F. Singapore (site undecided), Kuching, Kuantan.

There were two other areas in the Far East where further D/F facilities were planned—Ceylon and Burma. In Ceylon, an H.F. and an M.F. station were planned for Trincomalee, and in Burma, an H.F. station was planned for Rangoon, where a civil M.F. station already existed.[1]

Immediately on the outbreak of war in Europe, M.F. D/F equipment earmarked for despatch to the Far East for the stations at Kuching, Kuantan, Mergui (not then cancelled) and Trincomalee, and H.F. equipment earmarked for Sungei Patani and Rangoon, was held back lest it should be more urgently needed in the United Kingdom. H.F. D/F equipment for Tengah, Kuching and Trincomalee had already been sent. On 22 September 1939, arrangements were made between the Air Ministry and Headquarters Far East Command for work to be started on H.F. D/F buildings at Tengah and Kuching directly a Marconi engineer arrived. He left the U.K. in November 1939, his brief being to complete the planned H.F. and M.F. stations at Trincomalee as first priority.[2] The M.F. equipment earmarked for Trincomalee and previously held back was despatched to Ceylon in the same month. Then Tengah and Kuching H.F. stations were to be completed in that order. The engineer arrived at Trincomalee on 24 November 1939, but found that very little progress had been made in anticipation of his visit, and that the site had not yet been cleared of jungle.[3] The delay in clearing the site was due to a misunderstanding, Headquarters No. 222 Group assuming that the site would be chosen by the Marconi engineer on arrival, and that no jungle clearing could therefore be begun meanwhile. By April 1940, jungle clearing had been completed and buildings were ready for the installation of apparatus, but remote control cable was not yet available and calibration could not begin until the cable was laid. Meanwhile, the Marconi engineer left for Malaya.

By the end of April 1940, specifications for the H.F. D/F station at Kuching were ready for despatch, and building was about to start at Tengah. The requirement for an M.F. station at Kuching had been cancelled in October 1939, as with the limited resources available in the Far East at that time, it was not possible to operate aircraft from Sarawak, and the station had been required largely for homing from the areas of H.F. skip. M.F. equipment for Kuantan was not despatched to the Far East until September 1940, as the airfield itself would not be ready until the end of 1941, and immediate provision was not therefore necessary. The H.F. station at Sungei Patani was no longer considered to be necessary, but at the request of Headquarters Far East Command its transfer to Alor Star was agreed in view of the planned increase in air forces in the Far East and the advisibility of a station in northern Malaya for the use of aircraft engaged on seaward reconnaissance.[4] Additional commitments were the provision of H.F. D/F at Seletar, to be installed on the M.F. D/F site when vacated, and at the new headquarters location at Bukit Timah.

[1] The Rangoon project was cancelled in September 1940.
[2] A.M. File S.45130.
[3] A.M. File S.45161.
[4] A.M. File S.45161.

By July 1940, all internal work on the Trincomalee sites had been completed, the masts had been erected, and there was a prospect of the station being in working order within a short time.[1] Both the H.F. and M.F. sites were completed and awaiting transmitting facilities by September, and all that remained was the actual installation of D/F equipment. The Marconi engineer was expected in January 1941, as soon as he had finished at Kuching. However, a serious setback was encountered in the shape of damaged feeder cable. Replacement cable was not received from the United Kingdom until October 1941 ; one reason for the long delay in its despatch was departmental confusion at the Air Ministry. Meanwhile, early in 1941, the Marconi engineer had decided, in view of the delay in obtaining the replacement cable, to complete the stations at Kuching, Kuantan, and possibly Alor Star, before proceeding to Trincomalee. He had already completed Tengah. The land at Tengah was not acquired until March 1940, and building commenced in May. By the end of June, it was expected that the buildings would be ready for occupation in four to six weeks. The first delay was caused by the contractor sloping the drains the wrong way, rains resulting in flooding. There were subsequent delays due to difficulties in the installation of the air-conditioning plant, but the station was working in October 1940 and calibration was completed by December.[2] By the end of June 1940 a contract for clearing the Kuching site and for the erection of buildings had been let, but due to the slowness of the contractor, building was not completed until February 1941. The equipment had not been installed, and no power supply was available. Power plant was not sent from Singapore until March 1941, and air-conditioning had then to be installed. The engineer was at Kuching in June 1941 supervising the installation of power plant, and the station opened shortly afterwards, but early results were not satisfactory and he had to visit it again later. By early 1941, building of the Kuantan M.F. D/F station was completed, power and control cables installed, and work was about to start on the erection of masts. This work was completed by the end of June, and the station was calibrated in October 1941.[3] Early siting difficulties were encountered at Alor Star but the land had been gazetted for purchase and building was about to start by December 1940, and the foundations had been completed and equipment installed by February 1941. Later, progress was delayed through works difficulties and the non-availability of earth plates, and this and other difficulties accounted for about eight months delay.[4] The installation of D/F equipment was completed in about October/November 1941, but so far as is known the station never operated.[5]

The installation of H.F. D/F at Trincomalee, Tengah, Kuching and Alor Star, and M.F. D/F at Trincomalee and Kuantan, completed the original brief, Alor Star having been substituted for Sungei Patani. Meanwhile, however, four other D/F commitments had arisen during the period, the transfer of Singapore M.F. station from Seletar to Sembawang, the installation of H.F. D/F at Seletar on the old M.F. site, the installation of H.F. D/F at Bukit Timah, and provision of an additional M.F. D/F station to serve Malacokjy. The erection of the H.F. D/F station at Bukit Timah was successfully completed by May 1941, but the Seletar M.F. station was still operating in September 1941, and so far as is known work on the H.F. D/F station at Seletar and the

[1] A.M. File S.45130.
[2] A.M. File S.45161.
[3] A.M.File S.45130.
[4] A.M. File S.45130.
[5] Narrator's interview with Wg. Cdr. T. R. Knight.

transfer of the M.F. station to Sembawang was never begun. The additional M.F. station to serve Malacokjy, with a suggested site at Machang, was proposed by Headquarters Far East Command on 25 September 1941 and subsequently agreed by the Air Ministry. A suitable site at Machang was selected in October 1941, but work was never begun. In March 1941, four transportable DFG. 12 sets were sent to the Far East to form the basis of an H.F. fixer service for fighters at Singapore.[1] Another new facility was the installation of an M.F. beacon, which came into operation at Singapore early in 1942, on a frequency of 1500 kilocycles per second.

Thus, after two years, only the H.F. station at Tengah and the M.F. station at Kuantan had been completed satisfactorily. The reasons for delay were innumerable. The role of the Marconi engineer was misunderstood; headquarters of commands abroad considered that he was to choose sites, and to supervise installation, and that any work undertaken in the clearing of jungle before his arrival might be wasted. This reasoning did not take into account the time taken to purchase land, let contracts, clear jungle, erect buildings, lay cable and provide supply services. Secondly, there was a serious shortage of supervisory signals staff; local contractors in overseas commands often needed far more supervision than was necessary in the United Kingdom.[2] Thirdly, the great distances between each site caused delays in transit. Nevertheless, the direction-finding organisation for the Far East was very nearly completed by the outbreak of the Japanese war, and possibly would have been completed but for the long delays in Trincomalee.

The Middle East

At the outbreak of war R.A.F. Bellini-Tosi M.F. stations were in operation at Heliopolis and Amman, and the Egyptian government operated Adcock M.F. stations at Mersa Matruh, Alexandria and the Dakhla Oasis.[3] There was also an Adcock M.F. station at Lydda, Palestine. There were, however, no H.F. D/F stations or M.F. beacons, and the shortage of R.A.F. wireless operators was such that squadrons were manned on the basis of one wireless operator per flight, until reinforcements were sent to Egypt from Palestine and Trans-Jordan, and from the United Kingdom.[4] With the entry of Italy into the war in June 1940, the need for improved D/F facilities became urgent, and a number of Marconi DFG. 12 equipments were sent to the Middle East. However, during the early months of the desert war radio navigational assistance was limited to the existing M.F. systems, and the stations were not worked until aircraft had crossed the enemy lines on the return flight. W/T silence was imposed except in emergency, and because only a few D/F stations were available all aircraft were expected to limit requests for D/F assistance to a minimum. In the Mediterranean area two M.F. D/F stations and an M.F. beacon were available at Malta, and two Greek Airgonio stations were available at Phaleron, one H.F. and one M.F.

The first three H.F. D/F stations installed in Egypt were sited at Maaten Bagush, Ismailia and Amiriya, the last-named operating R/T for fighters only; they began operating in November 1940.[5] In the same month, a system of M.F.

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[1] A.M. File S.45130. [2] Narrator's interview with Wg. Cdr. T. R. Knight.

[3] R.A.F. Middle East O.R.B. Signals Appendices, August 1939.

[4] R.A.F. M.E. O.R.B. Signals Appendices, August 1939.

[5] R.A.F. M E. O.R.B. Signals Appendices, November 1940.

beacons was put into operation. The beacons were situated at Maaten Bagush, Amiriya, Ismailia, Fuka and Heliopolis, and were organised to a schedule so that each beacon operated for not less than two five-minute periods per hour, with changes of call-sign every eight hours. The direction-finding organisation was still inadequate, however, and with the arrival of new equipment, many changes and additions were made to it in 1941. Combined with the shortage of equipment was the difficulty of constantly keeping pace with advances and retreats in the various campaigns.[1] In March 1941, Benina (Benghazi) was acting as H.F. D/F control with stations at El Adem, Mersa Matruh, Kabrit and Heraklion (Crete). The M.F. D/F organisation was then Heliopolis, Dekheila (Alexandria) and Eleeniko (Athens). A plan existed for the provision of further H.F. D/F stations in Greece and Crete but had not been implemented by the time of the withdrawal. The M.F. beacon organisation was extended in the same month, and in April 1941 three H.F. D/F stations were allocated to each of five fighter sectors, Heliopolis, Fayid, Port Said, Amiriya, and Haifa, the latter to assist with the air defence of Syria, Cyprus and Palestine. In July 1941 a sixth sector was added at Alexandria. The H.F. D/F organisation for bomber aircraft was changed in April 1941 as a result of the fall of Benghazi and El Adem, a station being re-established at Maaten Bagush. In June 1941 an H.F. D/F station began operating at Heliopolis. In spite of the improvements in overall D/F facilities, experience showed that a short-range navigational aid for homing to desert landing grounds was required, and to meet this requirement 30 Wellesley aircraft D/F loops were allocated for use with squadron pack-sets (T.1083/R.1082) to provide bearings and homing transmissions at all landing grounds.[2] The loops were all installed and working by September 1941.

From the start of the Cyrenaica campaign in September 1940 to the end of the Greek campaign in April/May 1941, the standard of operating was fairly high, but with the influx of newly trained operators, both as replacements and reinforcements, whose training had necessarily been reduced to a minimum, the standard deteriorated and soon became extremely low.[3] Aircraft were lost owing to the failure of aircrews to take advantage of the D/F aids to navigation provided, and to the inability of operators even to establish communication with their ground control stations.[4] The need was for signals leaders who could exercise disciplinary control and take over training programmes and signals briefing, and their establishment was requested. Meanwhile a programme of intense training for wireless operators was instituted. All operators were subjected to a full-scale test, and were employed for ten hours per month on W/T point-to-point watches at ground stations. Those who fell short of the required standard were attached to the school at Ismailia for refresher courses. Regular training programmes were thereafter carried out on all squadrons. An air/sea rescue organisation was brought into force in July 1941, consisting at first of two Wellingtons, with two launches, at Aboukir, Mersa Matruh and Port Said.[5] Each launch was equipped with a D/F loop. Aircrews were instructed to try to make transmissions on 294 kilocycles per second if forced

[1] R.A.F. M.E. O.R.B. Signals Appendices, January 1942.

[2] R.A.F. M.E. O.R.B. Signals Appendices, April 1941.

[3] R.A.F. M.E. O.R.B. Signals Appendices, September 1941.

[4] R.A.F. M.E. O.R.B. Signals Appendices, June 1941.

[5] R.A.F. M.E. O.R.B. Signals Appendices, July 1941.

down in the sea, to enable rescue launches to home to them. Rescue aircraft also made transmissions on 294 kilocycles per second to home launches to located aircraft. The service was greatly expanded during later campaigns.

The prime lesson of the early campaigns in the Western Desert was the importance of mobility; it was absolutely vital that W/T and D/F equipment should be readily transportable. Much equipment was damaged whilst being moved over rough desert tracks, and the importance of W/T and power vehicles being prime movers was stressed.[1] A suitable layout for vehicles was therefore designed and equipment was installed in them at base depots. Experience was gained in the method of control of aircraft in operations; each bomber group or wing needed and was given its own operational D/F station so that it could control its own aircraft until they were within 50 miles of the landing ground on the return flight. Responsibility was then handed over to squadron ground personnel, who used the pack-sets and portable loop. The vast superiority of Bendix and Marconi equipment over the R.1082/T.1083 was noted, and fighter pilots particularly were finding their wireless equipment inadequate, the combination of TR.9 and T.1087 being incapable of providing the R/T ranges required in mobile warfare.[2] Retrospective fitting of V.H.F. equipment did not begin until 1942, but by May of that year more and more areas and squadrons were changing over.[3] Supplies of ground equipment continued to arrive steadily, and three V.H.F. D/F fixer stations were operating by September 1942 at each of Haifa, Gaza, Port Said, El Arish, Shandur, Heliopolis and Alexandria sectors. Ground equipment was also being installed at Fayoum, Hurghada and Cyprus, and equipment was loaned to the Abadan and Shaibah areas in case they should be reinforced with V.H.F. R/T-fitted aircraft. In addition, a fighter group in the Western Desert was completely fitted with V.H.F. ground equipment. The aircraft equipment position was not so satisfactory, but, by the time of the attack at El Alamein, ten day and two night fighter squadrons had been fitted, seven of the day squadrons operating in the Western Desert.

On 18 October 1942, five days before the start of the El Alamein break-out, Headquarters R.A.F. Middle East outlined a signal plan based on the assumption that the enemy would be routed, and that Allied forces would be established as far west as Tripoli.[4] Staging posts were planned for Mersa Matruh, El Adem, and Benghazi, with H.F. D/F stations and M.F. beacons; and V.H.F. D/F for triangulation at fighter sectors was planned for the Mersa Matruh area, the Tobruk area, the Martuba area, and the Benghazi area. Later a further reinforcement staging post was established at Magrun, with H.F. D/F, V.H.F. D/F, and an M.F. beacon. The formulation of complete and detailed plans for navigational aid for an advancing air force before the advance had begun was an innovation in mobile warfare. The same planning technique was used again in January 1943, when plans were laid for the delivery of a further blow to the retreating Axis forces in North Africa, the objective being the establishment of Allied forces in Tripoli. Staging posts with H.F. D/F and M.F. beacons were planned for Marble Arch and Tripoli, with fighter sectors and V.H.F. D/F at Misurata and Tripoli. The taking-over of the civil M.F. station at Castel Benito

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[1] R.A.F. M.E. O.R.B. Signals Appendices, October 1941.

[2] R.A.F. M.E. O.R.B. Signals Appendices, May 1942.

[3] R.A.F. M.E. O.R.B Signals Appendices, May 1942.

[4] R.A.F. M.E. O.R.B. Signals Appendices, October 1942.

was also planned. These stations and many others were established in the course of the defeat of the enemy in North Africa. Radio ranges were established at Tripoli, Benghazi, Cairo, Habbaniyah, Abadan and Sharjah by the end of 1943. Operational training units were transferred to the Middle East from East Africa, and navigational aids were provided for them. In the eastern Mediterranean, H.F. D/F was established at Aleppo (Syria), Lydda (Palestine) and Nicosia (Cyprus), and an M.F. D/F service was also made available.

By the time of Operation Husky, and the subsequent invasion of Italy, the advances made in radar technique had been applied to the requirements of seaborne and airborne invasion, and for the amphibious assault against the Italian mainland, mounted from North Africa and Sicily, A.I. and A.S.V. beacons were installed on the islands of Ustica and Salina, and the Rebecca/Eureka system was employed to assist troop carriers in finding dropping zones. Fighter cover was mounted from airfields in Sicily, where V.H.F. D/F was available, and fighter directing ships equipped with V.H.F. D/F provided close control. H.F. D/F installations and M.F. beacons were provided in Sicily for the use of bombers, and in addition an extensive D/F organisation in North Africa and the eastern Mediterranean was available to aircraft of longer range. Although radar aids were introduced into the Middle East theatre of war, the continuing value of wireless direction-finding may be gauged from the extremely congested state of the Transport Command short-range guard frequencies even in 1944.[1] This reached such a point that operators were urged to make use wherever possible of navigational aids which did not involve transmission by aircraft. In addition, congestion on medium-frequencies caused by the number of beacon and radio range installations was such that it became necessary to stipulate that a frequency spacing of at least 10 kilocycles per second had to be maintained between beacons and ranges less than 1,000 miles apart, and of at least 20 kilocycles per second between beacons and ranges at the same location. In spite of the increased use of radar operationally, the basic navigational aids on transport and reinforcement routes continued to be H.F. D/F, V.H.F. D/F and M.F. beacons, and they were still extensively used by bomber and G.R. aircraft.

East Africa and Aden

In the East Africa Campaign of 1940/41, in which the Italian forces in Eritrea were contained and defeated, wireless direction-finding did not play a significant part. The only available radio aid to navigation was civil M.F. D/F, and this was little used, partly because many aircraft taking part in the campaign were not equipped with wireless or wireless operators, and partly because the nature of operations did not call for long-distance navigational assistance. But by 1942, following the entry of Japan into the war and the threat to Allied shipping in the Indian Ocean from German, Italian and Japanese submarines, Air Headquarters East Africa was formed in Nairobi, and a system of wireless direction-finding for G.R. and fighter aircraft operating within the East African area was planned in May 1942.[2] The existing civil M.F. organisation was inadequate for the scope of operations planned. The area of operational command was Kenya, Uganda, Abyssinia, Tanganyika and Northern Rhodesia on land, and seawards, eastwards as far as 60 degrees east north of the equator and 65 degrees east

[1] R.A.F. M.E. O.R.B. Signals Appendices, July 1944.

[2] R.A.F. M.E. O.R.B. Signals Appendices, May 1942.

south of the equator, northwards as far as 10 degrees north, and southwards as far as the operational range of aircraft permitted. The area of responsibility linked up with that of Aden Command in the north, while in the south, the neutral strip of Portuguese East African coastline separated it from bases in South Africa. The occupation of Madagascar in 1942 provided useful bases to the south-east, while to the extreme east was the reconnaissance area of No. 222 Group with headquarters at Colombo. The size of the area and the type of operations envisaged called for the maximum D/F coverage. The need was for the erection of H.F. D/F stations along the East African coast, in Madagascar, Mauritius and Seychelles, and on one or more of the islands between Madagascar and the mainland ; the erection of M/F beacons ; and the utilisation of civil M.F. facilities, both British and French.

Permanent reconnaissance bases were established at Mombasa, Dar-Es-Salaam, Diego Suarez, and Mauritius, including H.F. D/F, M.F. D/F (already in existence at all except Diego Suarez), M.F. beacons, and A.S.V. responder beacons. Temporary reconnaissance bases were established at Pamanzi, Seychelles, and Tulear, with M.F. and responder beacons, and H.F. D/F at Seychelles and Tulear. Advanced bases were established at Mogadishu and Lindi, also with H.F. D/F and M.F. and responder beacons, and a detachment was based at Rodriguez with an M.F. beacon. Flying-boat bases with full D/F facilities were established at Kisumu, Diego Suarez and Durban, and Fleet Air Arm bases were opened at Tanga, Plaisance (Mauritius), McKinnon Road, Voi and Andrakaka (Diego Suarez). Fighter sector facilities, on a care and maintenance basis, were provided at Mombasa and Diego Suarez. Considerable use was made of W/T equipment under French ownership in Madagascar, particularly of the M.F. transmitters, used as beacons, at Tulear, Diego Suarez and Tananarive, which had a range of 1,000 miles or more.[1]

The provision of these aids to navigation took place gradually, the first H.F. D/F stations being calibrated in April 1943. By November 1943, an H.F. fixer organisation for aircraft flying over the sea in the East African area included control stations at Mombasa and Diego Suarez, assisted by the stations at Dar-Es-Salaam and Seychelles. By February 1944 the stations at Mauritius, Lindi, Mogadishu and Tulear were ready to join this organisation, which was completed by the addition of Scuiscuiban, a station in British Somaliland under the operational control of Aden.[2] It was eighteen months before the first signals plan of May 1942 was translated into a signals service, but by the beginning of 1944 the D/F facilities in East Africa were on a par with those in other theatres.[3]

Air transport services in East Africa consisted largely of aircraft passing through *en route* to Egypt and South Africa. Traffic was considerable, U.S.A.A.F., S.A.A.F., B.O.A.C., Belgian and French aircraft all operating services, but as late as 1944 such services were still dependent on the civil M.F. organisation for direction-finding assistance, and it was not until mid-1945 that a Transport Command area control system, located at Nairobi, began operating.[4]

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[1] A.H.Q. East Africa O.R.B. Appendices, April 1943. Because of the nature of the terrain the French authorities in Madagascar made considerable use of W/T for the internal communications system of the island.

[2] A.S.V. was also widely used for navigation, in conjunction with responder beacons.

[3] A.H.Q. East Africa O.R.B. Appendices, February 1944.

[4] R.A.F. M.E. O.R.B. Signals Appendices, 1944. Another commitment in East Africa was the provision of H.F. D/F, M.F. D/F and M.F. beacons for No. 72 O.T.U. Nanyuki and No. 70 O.T.U. Nakuru, until 1943.

In addition to being an important staging post Aden was the centre of a G.R. organisation complementary to that of East Africa, with an area covering the northern Indian Ocean. The provision of direction-finding stations was planned in 1938 and completed in January 1941.[1] H.F. D/F was installed at Aden, Riyan, Salalah, Bandar Kassim, Socotra, Scuiscuiban and Masirah.[2] Siting of some of the stations had been carried out with little knowledge of technical requirements, and errors varied from 8 to 16 degrees. The stations at Salalah, Masirah and Riyan were categorised in August 1944 as good, that at Bandar Kassim as fair, and Scuiscuiban as poor, mainly owing to the proximity of other electrical plant, necessitating re-siting. The G.R. organisation at Aden was reduced in 1945.

India

Pre-war plans for the provision of wireless direction-finding stations in the Far East did not include India; Ceylon and Burma were the nearest areas in which equipment was to be installed. Early in 1942 it became apparent that provision on a large scale was required, since, after the retreat from Burma, it was possible that India might be the next battlefield in the war against Japan. The existing signals facilities, including a civil M.F. D/F service spread thinly over India, were hastily conscripted to aid communication and navigation, and an organisation designed to pool resources was formed.[3] The first need was for an early warning system to cover Bengal, and particularly Calcutta, and V.H.F. D/F was needed for the triangulation of fighters.[4] There was a similar urgent need for early warning and V.H.F. D/F in Ceylon. The development of V.H.F. facilities was, however, slow due to lack of equipment, and in the Bengal area three civil D/F stations were pressed into service as fighter fixer stations, and a further three such stations constituted the sole air-to-ground organisation for bomber and G.R. aircraft in the eastern area.[5] Because of the difficulty of obtaining either ground or aircraft equipment from the European theatre of operations, squadrons operating in Bengal and Burma were still without V.H.F. equipment at the beginning of 1943, except in the Calcutta area, where it was in use by the end of 1942. The fighter effort in the Bengal-Assam area was considerably impaired during this period by the lack of V.H.F. D/F facilities. The operational use of V.H.F. D/F was begun in eastern Bengal in May 1943, and in Ceylon in August 1943.[6]

Operational groups under the control of Air Headquarters India were No. 222 Group with headquarters at Colombo, No. 223 Group on the North-West Frontier and No. 225 Group with headquarters at Bangalore.[7] There were no D/F facilities at first in Ceylon, but an M.F. D/F station was nearly ready at China Bay, and H.F. D/F was in preparation. By February 1944, the G.R. fixing organisation for the Colombo area included H.F. D/F at Diego Garcia, Addu Attoll, Kelai, Koggala, Sigiriya, Trichinopoly, China Bay, and Cochin.[8] Two of the stations, Trichinopoly and China Bay, also operated in the Madras G.R.

[1] A.M. File S.45161.

[2] A.H.Q. East Africa O.R.B. Appendices, February 1944.

[3] Transport Command O.R.B. Signals Appendices, March 1944. The U.S.A.A.F. was at first included but later decided not to participate.

[4] A.H.B./IIJ/50/47/20.

[5] Transport Command O.R.B. Signals Appendices, March 1944.

[6] A.H.B./IIJ/50/47/49.

[7] No. 222 Group O.R.B., September 1941.

[8] A.H.Q. East Africa O.R.B. Appendices, February 1944.

area with Cholavarum, Vizagapatam, and Gannavarum. Three H.F. D/F stations were provided for No. 223 Group, and all groups by that time had been provided with adequate V.H.F. D/F facilities. Under the control of Air Headquarters Bengal were two operational groups; Headquarters No. 221 Group, Calcutta, controlled all offensive and defensive squadrons based in western Bengal, and Headquarters No. 224 Group, Chittagong, controlled all offensive and defensive squadrons along the entire Burma front from north-east Assam to the Mayu Peninsula. The headquarters controlled a G.R. fixing organisation with H.F. D/F stations at Cuttack, Calcutta, Vizagapatam, Chittagong, and Berhampur, and a group of H.F. D/F stations, to cover bomber operations, were installed at Fenni, Comilla, Agartala, Chittagong and Jessore by the end of 1942.[1] V.H.F. homer and fixer systems were established and in use in the operational areas of Bengal and Burma by the end of 1943.

The building up of a system of wireless aids to navigation in A.C.S.E.A. was a slow process, and although by the end of 1943 fairly comprehensive H.F. D/F, M.F. D/F and V.H.F. D/F systems were in existence, they never reached the standard of similar systems in the United Kingdom. Bearings obtained on H.F. and M.F. were apt to be unreliable at night.[2] Experience in meteorological forecasting in this area was almost negligible. Static interference on M.F. rendered it useless for D/F during the monsoon period, and the comparative freedom from static of V.H.F. made its speedy introduction of vital importance.[3] Navigation and blind bombing radar systems, not available until 1943, were disappointing when they were tried, generally losing in range and sensitivity due to high humidity.[4] There was no Gee system, but an East India Loran chain was in operation just before the end of hostilities, and further cover for the whole command was in the planning stage. Aircraft crews were not encouraged to use W/T D/F on operational sorties, emphasis being laid on the fact that use of H.F. or M.F. D/F revealed to the enemy the airfield to which aircraft were returning and the number of aircraft operating; the use of M.F. beacons was encouraged as it revealed neither. An energetic navigator could maintain a fair idea of his position by the use of astro-navigation and loop bearings, although generally speaking more use could have been made of loops.[5] In many instances the value of loops was limited owing to the distance from M.F. beacons at which operations were carried out, but navigators praised the assistance they got from beacons when flying over the Bay of Bengal, an error of not more than 18 miles being general at 250 miles range. Even these results might have been improved if regular checks of the loops for quadrantal error had been carried out. Some U.S.A.A.F. radio ranges were conveniently situated and gave useful service, and aircraft radio compasses were useful for homing.

Atlantic Ferry Routes

A decision to open air reinforcement routes across the North and South Atlantic was taken in October 1940, and Ferry Command was formed at Montreal on 20 July 1941 to organise and control the delivery of aircraft across the

[1] No. 224 Group O.R.B. Appendices, October 1942.

[2] A.C.S.E.A. O.R.B. Navigation Appendices, February 1945.

[3] A.C.S.E.A. O.R.B. Navigation Appendices, April 1945.

[4] A.C.S.E.A. O.R.B. Navigation Appendices, February 1945.

[5] A.C.S.E.A. O.R.B. Navigation Appendices, April 1945.

Atlantic.[1] The route followed was Montreal, Presque Isle, Goose or Gander, Nutts Corner, Prestwick: flying boats were routed through Boucherville, Botwood (Gander), to Largs, and through Bermuda and Botwood to Largs. Many aircraft using the North Atlantic ferry route refuelled in Iceland, and there was also a north-east staging route through airfields on islands on the west coast of Greenland and thence to Iceland and U.K.[2] Some flying boats flew from Bermuda to the United Kingdom via Gibraltar.

At first the most important radio aid on this route was long-range cathode-ray D/F, no other D/F system being capable of operating a fixing service at the distances involved. Radio ranges later came into general use, and M.F. D/F stations situated in western England and Scotland were also utilised, but the main aids, other than cathode-ray D/F, were Loran and Consol, which were not ideally situated to provide cover on the Atlantic routes. In September 1944, a flight was carried out by a Transport Command aircraft to compare, in operational conditions, the existing systems of radio aid to navigation as applied to trans-oceanic navigation.[3] The route followed was Prestwick, Iceland, Greenland, Newfoundland, Montreal, Toronto, Montreal, Newfoundland, Azores, United Kingdom. The report on the flight showed conclusively that Consol was superior to Loran and cathode-ray D/F in almost every way. It was at least as accurate, its reception was the most reliable, and its range was much the greatest. Where the cathode-ray system had a day range of 300 to 600 miles and Loran a day range of 700 miles, Consol had a reliable day range of 900 to 1,200 miles. The cathode-ray D/F organisation, however, retained its value for control purposes and as an aircraft safety organisation.

The South Atlantic route began at Miami and continued through Porto Rico, Trinidad, British Guiana, Belem (Brazil), Natal (Brazil), and thence across the South Atlantic to either Accra or Robertsfield (Liberia), medium-range aircraft staging at Ascension Island.[4] Having reached West Africa, aircraft then flew northwards to the United Kingdom or eastwards on the trans-African routes to the Middle East and beyond. H.F. D/F was available at coastal airfields from the Gold Coast to Gambia, and these stations also operated M.F. beacons.[5] American radio ranges were much used on this route, but the basic radio aid continued to be H.F. D/F. At times there were reports of inaccurate bearings, but such reports were seldom accompanied by documentary evidence, and H.F. D/F stations in West Africa gave a sound service to those operators who appreciated the limitations of this form of direction-finding.

Mediterranean Reinforcement Routes

By 1940, aircraft were already flying to Egypt via Gibraltar and Malta, and many other possible routes were open to development so long as France and her North African colonies held out against Germany. But with the collapse of France in June 1940, the only feasible air route for medium-range aircraft was United Kingdom–Gibraltar, Gibraltar–Malta, Malta–Egypt. The first two legs were too long for most fighter aircraft, and enemy air activity was liable to be encountered over parts of all three. Space at Gibraltar was extremely limited, so that its handling capacity restricted the potential flow of

[1] A.H.B./IIJ/15/5. Aircraft general arrangements including briefing and training of crews.

[2] A.H.B./IIJ/4/1. Reinforcement Routes.

[3] Transport Command O.R.B. Signals Appendices, September 1944.

[4] A.H.B./IIJ/4/1.

[5] A.M. File S.13293.

aircraft ; in addition an attempt by enemy forces to capture Gibraltar was a possibility, the outcome of such an attempt being uncertain. Malta, too, was extremely vulnerable to air attack from the moment Italy entered the war. Already, before the German *blitzkrieg* of 1940, a possible reinforcing route involving the movement of aircraft to Lagos by sea and thence, following assembly, by air through northern Nigeria, French Equatorial Africa and the Sudan, to Egypt, had been planned. A decision to open this route was taken in October 1940.[1] So by late 1940 the Middle East had two channels of reinforcement, one for twin-engined medium and long-range aircraft by air through the Mediterranean, flown by crews who would normally go with the aircraft to squadrons, and one for short, medium and long-range aircraft by sea to West Africa and thence by air, flown by crews specially chosen for a tour of ferry work.

The presence of the threat of enemy air activity over long stretches of the route from the United Kingdom to Egypt via the Mediterranean meant that W/T was used as little as possible. In any event, there were no intermediate stations for an aircraft to work with, although there were useful enemy and neutral beacons and broadcasting stations on the first two legs.[2] Navigational aids on this route were so few that the fullest advantage had to be taken of those that existed ; yet in April 1941, Air Headquarters Malta reported that a number of aircraft losses and many narrow escapes had been caused by lack of W/T communication, usually attributable not to technical failure but to inefficient operating, the inefficiency being due to either inexperience or incompetence. This report disclosed that even the most rudimentary aspects of an operator's task, log-keeping, ability to tune correctly, to change frequency, to interpret operating signals, and elementary fault-finding, were being done badly.[3] Signals briefing, too, was considered to be inadequate. Another important point was that many of the crews flying on this route had just completed O.T.U. training, and many navigational errors were due to the inexperience of pilots and navigators. Very few astro-navigation fixes were taken, and many navigators were unable to take drifts over water. Reliance on meteorological forecast information, encouraged by the accuracy of internal forecasts in the United Kingdom, was quite unwarranted in the Mediterranean area, where forecasting was extremely difficult due to lack of information.[4] These factors made competent operating of increased value, but, unhappily, operators suffered from the same defects of inexperience as other crew members. In addition, hampered by the reluctance of captains to sanction the breaking of W/T silence, and by the fact that their aircraft often flew at very little above sea level, and experiencing the same equipment difficulties as were general at that time, they were not always able to obtain navigational aid when the need arose.

The first major air activity at Gibraltar began early in 1940, when aircraft of Coastal Command began operating from there. From 1941 onwards, however, although Coastal Command continued to operate, the number of reinforcement aircraft passing through Gibraltar *en route* to Malta and the Middle East increased rapidly and constituted by far the greater part of all aircraft movements. At that time, radio aids to navigation were almost non-existent at Gibraltar. There was a Royal Navy H.F. D/F station, which had been installed in 1937, and R.A.F. aircraft used it for homing, but bearings were not accurate

[1] A.H.B./IIJ/15/5. [2] A.H.B./IIJ/4/23. Air Routes General Signals Instructions.
[3] A.H.B./IIJ/15/5. [4] A.H.B./IIJ/15/5.

enough to be wholly acceptable. There was also a ship's loop which had been installed by the Royal Navy before the war, and this was taken over by the R.A.F., who maintained a watch on 340 kilocycles per second. Bearings were greatly affected by coastal refraction and diurnal effects, and sense was unreliable, but nevertheless the loop gave useful service. However, it was obvious that a good H.F. D/F station was badly needed, although the topography of Gibraltar made the siting of a station on land impracticable; the only feasible location was in the bay itself.[1]

The bay to the west of the airfield was two to three fathoms deep and had a tidal rise of only six feet. It was protected in part by the North Mole and was subject to heavy swells only on occasion. It was at first proposed to build an island of wooden piles on which to erect the H.F. D/F station, but such a course was found to be impracticable owing to the heavy cost. When, therefore, in March 1942, rapid development of an extension of the runway into the west bay was begun, application was made for a small spit to be built on the north side of the runway in order that site possibilities might be tested. Permission was given and the tests were favourable, so a mole was subsequently built on the end of the completed runway, extending north of it for a distance of 250 feet. Late in April 1943 work on the D/F site itself began, and the station was completed and tested in June and July 1943. Good results were obtained up to a distance of 450 miles. Additional aids to navigation available at Gibraltar were an M.F. beacon, a Naval Broadcast M.F. beacon, and a responder beacon, and later a V.H.F. R/T ground station.

The first D/F station to be operated by the R.A.F. had been erected at Ta Silch, Malta, where the R.N.A.S. had sited D/F equipment in the First World War, in 1924, and it had provided a good service over the years. The provision of new equipment became essential and in 1938 the installation of twin M.F. channels, one Service and one civil, was planned. The new station began operating shortly after the outbreak of war.[2] Installation of the first H.F. D/F station in Malta was completed in May 1940, and subsequently three additional stations were erected; they were, of course, used as much by operational as by reinforcement aircraft. An M.F. beacon was also established, and V.H.F. D/F was introduced in 1942. The beacon was generally switched on two hours before the estimated time of arrival of aircraft, and it is notable that there is no evidence of enemy attempts to meacon its transmissions, although such a radio countermeasure presented no difficulties. In spite of the number of aids available, many aircraft failed to survive the Gibraltar–Malta leg of the route.

The fluid situation obtaining in the Western Desert for long periods made accurate navigation from Malta to Egypt essential. An H.F. D/F station located at Mersa Matruh provided an excellent service, and valuable assistance was provided by D/F stations sited in the Delta area. However, as late as May 1942 Headquarters R.A.F. Middle East was reporting that a considerable proportion of reinforcement aircraft were making no use of the D/F service, were failing to maintain a proper listening watch, and were not answering control signals.[3]

One of the advantages gained from the success of Operation Torch and the advance from El Alamein was that all types of aircraft could be ferried to the

[1] Coastal Command Signals Review, Volume I, No. 2, February 1944.

[2] A.M. File S.45161.

[3] A.H.B./IIJ/15/5.

Middle East and India along the North African coast, as soon as staging post facilities were ready. This relieved the pressure on Malta, where shortage of petrol for refuelling had restricted the flow of reinforcement aircraft, and also released shipping which had previously been used to carry aircraft to West Africa ; lack of suitable ships had made the shipping of twin-engined aircraft a most difficult problem. From December 1942, all aircraft, except Bisleys, Beaufighters, and Beauforts, were routed from Gibraltar direct to El Adem, landing at Malta in emergency only. A small number of Wellingtons flew direct from Gibraltar to Benina.[1]

West and North Africa Reinforcement Routes

It was decided to inaugurate a West African reinforcement route on 20 June 1940, to provide a means of supplying aircraft to the Middle East at a rate comparable with the accelerated wastage expected consequent upon Italy's entry into the war. The decision was also influenced by the knowledge that the Mediterranean route to the Middle East would be jeopardised by the collapse of France.[2] The first survey flight over most of the proposed route had been made in 1925, and further flights culminated in the inauguration of a weekly Imperial Airways service from Khartoum to Kano in 1936, which was later extended to Lagos and then Accra and Takoradi. By July 1940, when the advance party of the R.A.F. arrived at Takoradi, a primitive communications network connected Takoradi to Khartoum through Accra, Lagos, Oshogbo, Kano, Maiduguri, Geneina, El Fasher and El Obeid. An M.F. D/F service was available at only four stations throughout the route, at Accra, Lagos, Kano and Khartoum, consisting of Marconi-Adcock stations with DFG. 10 receivers and an assortment of transmitters. It was, of course, possible for W/T stations not provided with D/F equipment to transmit so that aircraft could obtain loop bearings. Such an organisation might have been adequate for the volume of pre-war air traffic, but considerable expansion was obviously necessary to maintain the flow of aircraft envisaged in the reinforcement scheme. The most pressing need was for increased D/F facilities between Kano and Khartoum, a distance of over 1,700 miles, then covered by a D/F station at each end only. A new signals organisation brought into force for the start of ferrying added M.F. D/F at El Geneina and Kosti, with aircraft installations to work on the ground as beacons at Maiduguri, El Geneina, and El Fasher.

The first despatch flight began on 19 September 1940, but for security reasons aircraft were instructed to maintain wireless silence throughout the flight, except in emergency, and the efficiency of wireless navigational aids along the route was not fully tested. However, in the meantime a request was made for H.F. D/F facilities at Kano and Geneina, and for a beacon at Lagos. The Air Ministry agreed to the provision of a beacon at Lagos but stressed that it was to be used sparingly, and H.F. D/F equipment was despatched for installation at Kano, Maiduguri and El Geneina. On 20 December 1940 this equipment was at Takoradi awaiting transport.

Meanwhile, one of the early convoys made a forced landing south of El Geneina following wireless failure. Of the seven aircraft in the convoy, four were completely destroyed ; one pilot was killed. It was later established that the wireless failure, which had been directly responsible for the forced

[1] A.H.B./IIJ/15/5.

[2] A.H.B. Narrative, ' The Middle East Campaigns ', Volume X—' The West African Air Reinforcement Route '.

landing, was due to inexperience on the part of the operator, and after this accident the importance of using only highly-experienced operators on the route was recognised. Great care had been taken in the selection and training of pilots and navigators, but the same care had not been taken up to that point in the choice of wireless operators.[1] In December 1940 Air Marshal Tedder, on his way to take up the appointment of Deputy A.O.C.-in-C., R.A.F. Middle East, surveyed the route. The key to the whole route, he thought, was efficient W/T and D/F ; maps over long stretches of the route were almost useless, and for some stretches, and particularly between Fort Lamy and El Geneina, there were practically no landmarks. The pilot of the aircraft in which Air Marshal Tedder travelled, who had been over the route a number of times, considered that without D/F the Fort Lamy–El Geneina leg was a gamble, and the Air Marshal endorsed this view. '. . . Further steps will have to be taken . . .' he said, '. . . to ensure that the wireless personnel in the aircraft are really experienced men . . .'[2]

A modified signals plan for the route was drawn up in April 1941, approved by the Air Ministry in May, and fully implemented by August. Main staging posts, at which H.F. D/F stations and M.F. beacons were installed, were established at Accra, Lagos, Oshogho, Kano, Maiduguri, El Geneina, El Fasher, Khartoum, and Wadi Halfa. Subsidiary staging posts, which were provided with H.F. D/F equipment with low-power transmitters Type P.3, were established at Ati, El Obeid, and Luxor. Civil M.F. D/F stations already existed at Accra, Lagos, Kano, El Geneina, Khartoum and Wadi Halfa, and a station was planned at Maiduguri. From then onwards D/F facilities on the route proved to be adequate, and with the establishment of a parallel route for aircraft operated by the U.S.A., installation of suitable radio facilities continued to increase.[3]

In view of the success of the Allied forces in North Africa, the Air Ministry decided in January 1943 that all twin-engined aircraft were to fly to the Middle East and beyond via the Mediterranean, and this meant a considerable reduction in assembly at Takoradi.[4] Later, in August 1943, it was also decided to route Hurricanes via the Mediterranean, and in consequence the number of aircraft handled at Takoradi decreased steadily and ceased altogether in October. However, American aircraft were still arriving at Accra, which became the major terminal in West Africa, and R.A.F. crews continued to ferry American aircraft to the Middle East and India. The organisation of staging posts remained in being, although there was some retrenchment since convoys of twin-engined aircraft were able to over-fly minor staging posts and even some of the major ones. A route of three legs, Accra–Maiduguri, Maiduguri–Khartoum, Khartoum–Cairo became commonplace ; but the importance of D/F facilities on this route was undiminished.

The North Africa route began in French Morocco at Rabat Sale, and continued through Ras el Ma (near Fez), Oujda, Biskra, Castel Benito, Marble Arch, El Adam, Mersa Matruh, to Cairo West. H.F. D/F, V.H.F. D/F, and M.F.

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[1] A.H.B. Narrative, 'The Middle East Campaigns', Volume X—'The West African Air Reinforcement Route'.

[2] A.M. File S.7580.

[3] By September 1941, British and American aircraft were being off-shipped and assembled at Port Sudan on the Red Sea, and a reinforcement route was opened to Egypt via Summit and Hurghada, and also through Atbara and Wadi Halfa. H.F. D/F and M.F. beacons were installed.

[4] A.H.B. Narrative, 'The Middle East Campaigns', Volume X—'The West African Air Reinforcement Route'.

beacons were installed at each staging post.[1] Some of the larger aircraft overflew one or more posts. There was a subsidiary route from Gibraltar via Cape Tenes, Maison Blanche, Biskra to Castel Benito and onwards with similar facilities. Later, a reinforcement route to Italy from North Africa was provided with major staging posts at Malta, Catania, Naples and Rome, and the navigational aids made available included H.F. D/F, V.H.F. D/F and M.F. beacons.[2]

India and Far East Reinforcement Routes

Aircraft destined for India were first ferried either by the West Africa route or the North Africa route to Khartoum or Cairo. From the Middle East there were two possible routes, both of which were used regularly ; a northern route through Lydda (Palestine), L.G.H. 3, Habbaniya, Shaibah (Basra), Bahrein, Sharjah, Jiwani, Karachi, and a southern route through Khartoum, Asmara, Aden, Salalah, Masirah, Jiwani, Karachi.[3] Short-range aircraft on the southern route followed the route Atbara, Summit, Bahdar, Massawa, Assan, Perim Island on the long leg between Khartoum and Aden. At first only a civil M.F. D/F service was available, but the installation of H.F. D/F had been completed by August 1943.[4] Major staging posts on both northern and southern routes were also provided with V.H.F. D/F and M.F. beacons.

The civil M.F. D/F service in India was used to form a reinforcement route in December 1941, when a number of Hudsons were ferried from the United Kingdom via the Mediterranean, Suez, Persia, across India, and then south-east through Rangoon to Singapore. Subsequently, poor lines of communication and the vast distances involved led the air forces to develop the potentialities of air transport vigorously, and eventually H.F. D/F and V.H.F. D/F equipment was installed at 18 staging posts. The new D/F organisation extended the number of stations operating on M.F., and provided an H.F. D/F service on the transit frequency on the trans-India and other internal routes, but development of V.H.F. D/F facilities was slow due to lack of equipment, and by the end of 1943 V.H.F. D/F was available, outside the operational areas, only at Jodhpur, Delhi and Allahabad.[5] Low-power M.F. beacons, and some U.S.A.A.F. radio ranges, were also available. This route, together with other internal Indian routes, was taken over by the newly formed Transport Command in 1943.[6]

The air route from Karachi over the Himalayas to China, the only practicable supply line to the Chinese Army following the loss of Burma, was known as ' The Hump '. It was operated by the U.S.A.T.C., and wireless aids were practically non-existent at first, later consisting almost entirely of radio ranges. The route traversed the most difficult terrain, crossed enemy-held territory, was liable to fighter interception, and yet approximated to an internal U.S.A. airline, aircraft flying down the radio range and being in continual R/T contact with the ground. R.A.F. flights over ' The Hump ' conformed to the American organisation.[7]

[1] A.H.B./IIJ/4/1. [2] A.H.B./IIJ/4/1. [3] A.H.B./IIJ/4/1.

[4] R.A.F. Middle East O.R.B. Signals Appendices, August 1943.

[5] Transport Command O.R.B. Signals Appendices, January 1944.

[6] Transport Command was formed on 25 March 1943.

[7] Transport Command O.R.B. Signals Appendices, March 1944.

CHAPTER 23

AIRCRAFT COMMUNICATIONS

All experience gained with aircraft up to the end of the First World War, in the R.N.A.S., the R.F.C., and later the newly formed Royal Air Force, combined to illustrate the enormous increase in operational scope and value of aircraft when they were equipped with efficient wireless communication equipment; in fact, the majority of aircraft were unable to fulfil adequately the role allotted to them without it. Wireless equipment was first used in Service aircraft in 1912, and the first battle in which aircraft radio became a major factor was that of Festubert in May 1915. Preparations for the engagement consisted of observation by aircraft for artillery whilst guns were registered against trenches and strong-points within the enemy lines, and for the first time aircraft were specially detailed to report progress of the land battle by wireless, four aircraft of No. 16 Squadron being used for this purpose. From those beginnings a system of close-contact patrols for reporting infantry movements was developed. By the end of 1916 the strength of wireless personnel in the R.F.C., 200 officers and 2,000 operators and mechanics, was greater than the total 1914 strength of the R.F.C., and it had been decided to erect permanent W/T ground stations at all important aircraft bases in the United Kingdom. In 1918 the W/T research establishments of the R.N.A.S. and R.F.C. were amalgamated to form the R.A.F. W/T Establishment at Biggin Hill.

Design of Aircraft Radio Equipment 1919–1923

At the conclusion of the First World War it was evident that, owing to the great increase in use of wireless by aircraft, employment of the spark system of transmission in congested areas would have to be abandoned, because of the wide band of interference it caused and its flatness of tuning, in order to allow the requirements of all three Services to be met. In 1919, therefore, a series of inter-Service conferences was held, at which it was decided that all future equipment used by the R.A.F. and the Army in the field should be designed on a system calculated to reduce considerably interference caused by the spark system and so enable more individual communication to be carried on in a given area. As the decisions involved complete re-design of nearly all Army and R.A.F. apparatus, a scheme of apportioning wavelengths to the various Services was adopted, allowing for an overlap to cater for inter-Service co-operation.

T.25 and R.31 equipment was designed for the transmission and reception of R/T messages between close reconnaissance aircraft and Army units, and for R/T communication in the air between aircraft.[1] Unlike its wartime equivalent, the Telephone Wireless Aircraft Marks II and III, the installation worked on fixed aerials, thus doing away with the trailing aerial, which had been one of the greatest disadvantages in the use of R/T in operational aircraft. The apparatus

[1] A.H.B./IIA/1/53.

was operated by the pilot by means of a mechanical remote control system. The ranges obtained varied, but in the Bristol Fighter the average ranges were 25 miles air-to-ground, 5 miles air-to-air, and 8 miles ground-to-air. The first production models, 80 in number, were delivered by the contractors in 1924. The weight of the total installation was approximately 83 pounds.

The T.23 transmitter was designed to meet the needs of artillery co-operation, for the transmission of gunfire corrections to battery receiving stations. It radiated I.C.W. (interrupted continuous waves), which caused far less interference than the spark type, and the installation weighed 65 pounds. The pilot was provided with remote control located on his instrument dashboard and a morse key. The transmitter operated with a 200-foot trailing aerial. The wartime equivalent of this transmitter was the spark transmitter (Nos. 1 and 2). The T.23 was tested at Aldershot in 1921 and later introduced in all army co-operation squadrons.

The T.21A and Tf installation, designed during the war for continuous-wave transmission and reception, primarily for naval co-operation purposes, proved so efficient that it was quickly adopted for long-distance reconnaissance purposes. There was originally an attachment for radio telephony but this fell into disuse. The installation was subsequently introduced into all bombing and army co-operation squadrons, at home and overseas, and had become standard equipment in them by 1923. The total weight of the installation was 75 pounds. Range varied in different types of aircraft, but averaged 300 miles air-to-ground, 40 miles air-to-air, and 200 miles ground-to-air. The transmitter T.21A was one of the most efficient wireless sets of similar power and size in existence at the time, and although considerable skill was needed on the part of the operator to obtain good reception with the Tf in the air, remarkable results were achieved with the installation, which was still in use in the Service until a few years before the Second World War.

At the end of 1923 trials of the T.22 transmitter were about to commence. It was intended as a replacement for the T.21A, and it had been designed with the advantage of several years experience gained with this type. The waveband was extended, and the telephony attachment was expected to give better results than had been obtained with the T.21A. It was expected that future modifications would enable the apparatus to be used not only for air-to-ground W/T and R/T but also for short-distance air-to-air R/T on a fixed aerial.

Air Staff Policy 1924 and 1928

At the beginning of 1924, future policy with regard to the installation of W/T, R/T and D/F equipment was considered by the Air Staff, and although it was felt that a comprehensive statement of policy was premature in view of limited experience of the subject, it was decided to formulate a course of action with a view to finding out what results could be obtained with existing apparatus and what line future development should follow.[1]

As a result of Air Staff decisions, every aircraft of one squadron, No. 207 Squadron, was equipped with the necessary wiring and fittings to enable it to carry a W/T installation with trailing aerial, and an R/T installation with fixed aerial, but only sufficient equipment was provided to enable the leader and

[1] A.H.B./IIA/1/53. *See* Appendix No. 11.

deputy-leader to use two-way W/T and R/T, all other aircraft being provided with R/T reception only. This meant that, with D/F equipment, leader and deputy-leader aircraft carried wireless installations weighing 140 pounds and all other aircraft equipment weighing 40 pounds. Two W/T ground stations were erected to work with this squadron. Other Air Staff decisions made at this time were that the first new day-bombing squadron was to be equipped in the same way as No. 207 Squadron, except that all aircraft were to be equipped with two-way R/T to enable formation flying tactics and drill to be practised; other two-seater day-bombers were to be suitably modified to enable similar installations to be made. All aircraft of No. 7 Squadron were equipped with two-way W/T, and as each of the next three new night-bombing squadrons was formed it was equipped in the same way.[1] The Air Staff was particularly concerned with three problems of the future: the outmoding of the trailing aerial in all aircraft which might have to fly in formation, the extending of the receiving range of apparatus without any increase in weight, and the design of a set which would combine the functions of telegraphy and telephony.[2]

Progress in the next few years was disappointing, and there were many delays in the supply and fitting of equipment.[3] Most of the trials carried out during this period concerned D/F methods, some of which, such as wing coils and the rotating beacon, did not depend on two-way W/T communication, but all aircraft equipped with two-way W/T made use of the two ground stations at Eastchurch and Worthy Down, and W/T communication was good. However, an equipment policy which resulted in aircraft being liable to carry two transmitters (one for W/T, one for R/T) and three receivers (W/T, R/T and wing coil) could obviously be only temporary, and by 1927 the most urgent need was for the design of a general-purpose transmitter-receiver which would fulfil all necessary functions. In army co-operation squadrons, whose functions depended mainly on the effective employment of aircraft radio, a three-panel system of installation was used. Short-range reconnaissance involved the use of T.25 and R.31, long-range reconnaissance the use of T.21A and Tf, and artillery co-operation the use of T.32, a development of T.23. Although the removal and installation of each separate panel was comparatively simple and normally took only a few minutes, the functions of aircraft were restricted, and the loss of flexibility was uneconomic.

In February 1928 the Air Staff reviewed the experience of previous years, and found that installation of all the individual sets required at the time was so complicated and cumbersome as to interfere with other duties of the aircraft crew.[4] It was therefore decided to introduce a fresh interim policy, to be proceeded with until sufficient experience had been gained with improved apparatus to enable a final policy to be declared.[5] The main points of the interim policy were that a combined set for day bombers, capable of providing two-way W/T or two-way R/T, to operate on a fixed aerial, was to be produced for Service trials as soon as possible. Pending production and trials of this apparatus, no definite decision on the tactical use and employment of wireless in day bombers was made. All day-bomber aircraft were wired to take, and three aircraft per squadron were fitted with, two-way W/T, to enable squadrons to

[1] Provision was made for 100 per cent spares to be held in each instance.
[2] A.H.B./IIA/1/53. [3] A.M. File S.23185. [4] A.M. File S.23185.
[5] A.H.B./IIA/1/53. *See* Appendix No. 12.

practise D/F navigation by the Bellini-Tosi method and two-way W/T communication with ground stations and with other aircraft. One flight of No. 100 (Bombing) Squadron was equipped with two-way R/T of the same type as that already in use in fighter aircraft, to enable experience to be gained in the tactical handling of bomber formations using R/T. In specifications for future day-bomber aircraft, details of the wireless equipment to be carried were to be omitted, but a space of specified dimensions was to be reserved for wireless apparatus. The dimensions were to be arrived at by the R.A.E. and were to be of a size to ensure that new apparatus under development could be carried. A new W/T receiver for night bombers, capable of use for two-way W/T or wing coil reception, was to be completed at an early date and given Service trials in a night-bomber squadron with a view to its general introduction when proved satisfactory. All future night-bomber aircraft were to be fitted with wing coils. All night-bomber aircraft were to be fitted with two-way W/T to enable them to practise D/F navigation by the Bellini-Tosi method and two-way W/T communication with ground stations and other aircraft.

Development and Production 1928–1935

In the next few years research and development were continued, but operationally there were very few developments, policy being governed by the Air Staff statement that definite decisions on the tactical employment of wireless in aircraft could not be made on the basis of results with the existing obsolete equipment. The second experimental receiver for night-bomber aircraft, for long-wave reception and wing-coil D/F, was still undergoing modification in 1929, and delay in its production was made the subject of investigation and report.[1] Production of six Service trial models was given the highest priority, but still no delivery date could be given. Finally, one receiver was ready for installation in February 1929, and was subsequently styled the R.68. The requirement that W/T equipment was to be capable of use with both rotating beacons and D/F ground stations was confirmed in June 1930, but the new experimental transmitter-receiver, the TRX.3, which weighed 130 pounds, was adjudged to be too heavy for day bombers. Although only two aircraft in each formation were fitted with W/T in day-bomber squadrons, the speed of the whole formation was reduced, and the external wind-driven generator was another source of loss of airspeed. In addition, the bomb load was also unacceptably reduced. The TRX.3 was therefore rejected for use in day bombers, and a conference was called at the R.A.E. to discuss W/T and R/T requirements in those aircraft.

As a result of the conference, held on 22 December 1930, specifications were formulated, for development in 1931, of a day-bomber transmitter/receiver with a range of up to 300 miles, and of a battery-operated transmitter/receiver of lower power known as the TRX.9, which was the prototype of the TR.9 used by Fighter Command in the Battle of Britain. Service trials of the TR.9 began in 1932. At 5,000 feet R/T ranges were 30 to 40 miles air-to-ground and 10 to 12 miles air-to-air. In June 1931 a clear requirement for new W/T equipment for night bombers was stated, to include D/F by the Bellini-Tosi method and the rotating beacon up to the maximum range technically possible with existing ground equipment, estimated at 500 miles.[2] The weight of the equipment was to be restricted to 120 pounds, but it was found that this requirement was not compatible with a range of 500 miles, and in order to keep the weight down

[1] A.M. File S.26997.

[2] A.M. File S.29124.

range was sacrificed and was finally agreed at 300 miles. This equipment was given its first trials at Worthy Down and Boscombe Down in March 1935, and as a result there emerged a new general purpose W/T installation, the R.1082/T.1083. The R.1082/T.1083 and TR.9 installations contained many faults and limitations, and, as might be expected, were obsolescent by September 1939, but they represented the results of a long struggle for improved wireless equipment at a time when the importance of aircraft radio was not universally accepted or understood.

The years 1919–1935 were difficult years in the Service for the development of wireless equipment, as may be gauged from the fact that the Tf receiver and the T21.C transmitter, a modified version of the T21.A, used in the later stages of the First World War, were still in general use at the end of the period. Three main considerations had determined the policy of provision of aircraft radio ; the number and variety of operational requirements, the necessity of financial economy, and the swiftly-changing process of technical development. They made any long term production programme impracticable ; the requirement for each different function was therefore reviewed at fairly short intervals of time, and provision was made on the smallest possible scale on each occasion. As a result of the necessity for a short-term policy, forced upon the Air Staff by the three main factors, the requirements of bomber, fighter, army co-operation squadrons, of general purpose squadrons overseas, of reconnaissance squadrons, flying-boats, and Fleet Air Arm units, had to be considered separately and no form of standardisation was possible. Interference caused by the spark method of transmission had resulted in the development and introduction of continuous-wave transmission. Congestion on medium frequencies was followed by the exploration and use of higher frequencies. The ever-increasing use of H.F. telegraphy and telephony by all nations necessitated close adherence to allotted frequencies and the development of transmitters of sufficient power and stability to overcome increasing interference. This increasing interference was a great stimulus to the development of equipment designed to operate in the very high frequency, or V.H.F., bands.

In 1928 research into the general properties of V.H.F. for wireless communications was provisionally recommended for inclusion in the R.A.E. research programme, but before this the Air Ministry had become interested in a scheme proposed by Mr. R. C. Galletti for generating a parallel beam of short wireless waves.[1] After a preliminary demonstration in March 1927 it had been suggested that the R.A.E. should make a thorough investigation of the proposed system but no suitable personnel could be made available for the project. The Signal School of the Royal Navy conducted an investigation and reported adversely on the proposed scheme. The matter was therefore dropped but in 1929 interest was revived, and flight trials carried out in May 1930 produced such encouraging results that further investigation was included in the research programme of the R.A.E., where a super-regenerative receiver and mobile transmitter were designed and made for experimental use.[2] In May 1931 it was decided that the method was not sound fundamentally and development of the project was abandoned. During the course of the investigations progress was made with the design of a complete low-power transmitter and a receiver for use on the 150 to 100 megacycles per second frequency band, and in March 1931 the first

[1] A.H.B./IIE/249. 'The V.H.F. R/T System' by Jay.

[2] The highest frequency used in the experiments appears to have been 100 megacycles per second.

of a long series of experiments was begun with the aim of gaining more knowledge of the properties and characteristics of such frequencies. The experiments formed the basis for development of V.H.F. wireless equipment.

By the end of 1932 flight tests of improved equipment enabled the R.A.E. to arrive at certain broad conclusions. Frequencies between 109 and 120 megacycles per second were suitable for many ground-to-air, air-to-ground and air-to-air communication purposes. Range was about equal to the optical path between transmitter and receiver : it was considered that this effective limitation of range would be valuable in certain circumstances. Vertical polarisation was preferable and super-regenerative receivers were unlikely to be suitable for Service use because they were not sufficiently selective and were not easy to tune.[1] Until 1935 research and development were devoted mainly to improving the design of transmitters and receivers, and no fundamental circuit modifications were included. Some improvement in transmitters was made possible by the introduction of special V.H.F. transmitting valves, but development of receivers was very much hampered by the lack of really suitable valves ; the first samples of ' acorn ' valves, for example, were not received at the R.A.E. until the end of 1934. Consequently only super-regenerative receivers were available for experimental use ; such a receiver, the R.1110, was developed for aircraft of the Fleet Air Arm to enable them to home to beacons on a frequency of 210 megacycles per second.

During 1933 it had become apparent that Service requirements and technical development had at last reached a stage which made it possible to visualise some degree of standardisation in the immediate future, and in 1934 a line of policy was decided which marked a big advance in this direction.[2] Discussions centred around the possibility of reducing the aircraft sets in use to two only, an R/T set for fighters, day bombers and trainers, and a general-purpose set for all other types of aircraft. However, owing to the fact that the Hart type of aircraft then in use for army co-operation (Hart, Audax, Osprey, Hardy) would not accommodate a general-purpose set of the type visualised, it was realised that the standardisation aimed at must be attained in at least two steps, and it was therefore decided to reduce the number of sets under development to three, an R/T set for fighters and light bombers, an interim general-purpose set for all squadrons other than army co-operation, and an army co-operation installation. Later, upon the replacement of the Hart type of aircraft for army co-operation, the requirement would be reduced to two main installations. There was, however, one qualification ; the replacement for TR.9 would include facilities for modulated C.W., listening through, and coil D/F in the receiver, to make it meet the requirement in light bombers for a ' pocket ' general-purpose set.

Improvement of Equipment 1935 to 1939

The operational requirement for radio in fighter and bomber aircraft was consequently defined as :—[3]

Fighters. Two-way H.F. R/T for tactical control of fighter formations, at ranges up to 50 miles, with frequency-changing in the air and an increase in range to 80 miles to be aimed for ultimately. The necessity for the transmission of wireless signals by the aircraft for D/F was accepted. Intercommunication was necessary between pilot and air gunner in two-seater fighter aircraft.

[1] A.H.B./IIE/249. [2] A.H.B./IIA/1/53. [3] A.H.B./IIA/1/53.

Light Bombers. Three aircraft in each squadron were to be equipped for W/T and normally in a squadron formation two aircraft were to carry W/T, capable of a range of up to 300 miles on M.F. and greater ranges on H.F. H.F. R/T with an air-to-air range of 5 miles was also needed for fire control, co-ordination in wing formation, and pattern bombing. Intercommunication between pilot and air gunner was required.

Medium and Heavy Bombers. All aircraft were to carry W/T, capable of ranges of up to 300 miles on M.F. and up to 500 miles at 5,000 feet on H.F., and intercommunication between pilot and crew was required.

The situation in 1935, therefore, was that day and night fighters, which were both allocated the 4,286 to 6,667 kilocycles per second frequency band, were being fitted with the TR.9, whilst a replacement set of similar design but improved performance was planned for introduction in about 1938/39. Light bombers, which were allocated the 3,000 to 4,620 kilocycles per second frequency band, were being fitted with the TR.11, an R/T set of similar design and performance to the TR.9 but operating on a lower frequency range, the replacement set being the same as that being developed for fighter aircraft. Light bombers also carried W/T, operated on the same H.F. range as their R/T, and on the M.F. band of 143 to 400 kilocycles per second, and were using the T.21C and Tf, which was to be replaced by the interim G.P. set in 1936. Eventually this interim set would be replaced either by a more up-to-date G.P. set, developed to specifications drawn up by the Directorate of Signals, which was expected to be ready by 1939/40, or by the ' pocket ' G.P. set produced from the new R/T replacement set. Medium and heavy-bombers, which were allocated the 3,000 to 4,300 kilocycles per second H.F. band and the 143 to 400 kilocycles per second M.F. band, were using the T.21C and R.68, which was to be replaced by the interim G.P. set in 1936. This in its turn was to be replaced by the new G.P. set in 1939/40. The installation in bomber aircraft of separate R/T equipment, the TR.11B, was begun in 1939, for inter-aircraft communication and local control. However, the rapid expansion of Fighter Command made it impossible to provide sufficient TR.11 equipment for Bomber Command without adversely affecting production of other equipment, and it was decided in March 1939 to equip all bomber aircraft with the TR.9D.[1]

There were two other operational requirements for aircraft radio communication; army co-operation and coastal defence. The equipment in use in army co-operation squadrons hitherto had been complicated by two factors: first, three types of air reconnaissance had been required, close, medium, and artillery, and considerations of suitable frequencies for the distances involved necessitated the provision of three types of apparatus; and secondly, the necessity for carrying an air gunner who could devote all his attention to defence made it desirable for the W/T and R/T in close reconnaissance and artillery spotting to be suitable for operation by the pilot. A three-panel system had been evolved to cover the three different reconnaissance requirements, in which three interchangeable sets were fitted according to the requirements of the individual flight, but by 1932 this system had been superseded by a combination of the three transmitters and two receivers of the old system into one transmitter/receiver, the TR.2. This apparatus marked a big advance in ease of maintenance and handling on the old three-panel system, but there were still several shortcomings, and replacement apparatus was therefore designed. Service

[1] A.M. File S.4669.

trials were carried out and contract action taken in 1935. One of the most striking lessons of Army exercises of the early thirties was the gradually increasing difficulty of differentiating between close and medium reconnaissance areas, the development of mobility as a result of the mechanisation of ground forces causing the close reconnaissance area to be extended. A new transmitter, the T.1090, was produced to meet the Army requirement of R/T communication from ground to air, and four of these transmitters, mounted in Morris six-wheelers with improved layout and accommodation, completed Service trials in 1935. In addition, a general-purpose wireless tender, using the standard Albion two-ton chassis, was under construction, and the first of these vehicles was ready in 1937. It was thought that the interim G.P. set would meet all the coast defence requirements for multi-seater aircraft, with the TR.9 or TR.11 for all R/T requirements. Flying boats were operating with the TR.4, and coastal reconnaissance aircraft taking the place of flying boats were to use the TR.4 initially followed by the interim G.P. set when available. Spotter aircraft were operating with the T.21C and Tf, which was to be replaced by the interim G.P. set. Torpedo-bombers were to use the interim G.P. set and TR.9.

The performance of aircraft radio was improved by the introduction of engine-driven generators and more effective ground equipment. Engine-driven generators had been made necessary by the increasing drag effects on high-speed aircraft of air-driven generators, and with the general introduction of the interim G.P. installation the latter were withdrawn from service. The provision of receiving and transmitting apparatus installed at ground stations was governed by a replacement programme laid down in 1933/1934. The replacement transmitters were the T.70 and the T.77, which were due for introduction in 1936, and the T.1087, which was due for introduction in 1937. The T.70 was an interim set for R/T communication with aircraft pending the introduction of the T.1087. The T.77 was a low-power transmitter for M.F. and H.F. W/T communication with aircraft and for point-to-point working. R/T could be added where required. The T.1087 was a general purpose, low-power H.F. transmitter for W/T and R/T working to aircraft, point-to-point and general standby. The replacement receiver was the R.1084, a general purpose W/T and R/T receiver covering all R.A.F. frequencies. Other transmitters, used particularly for working with aircraft at long distances overseas, were the Standard Telephones and Cables Type M.13 and the Marconi S.W.B.8.B. The importance of inter-communication between crew-members was recognised, and an amplifier Type A.1134 was developed for use in all multi-seater aircraft where the number of positions to be covered was greater than the capacity of the G.P. set.[1]

The comparatively large number of R/T and interim general-purpose sets required, especially under the expansion programmes of 1936, resulted in a departure from the previous practice of hand-production in the wireless industry. The TR.9 was made on quantity-production lines, and although delays in securing initial supplies resulted, valuable experience was gained, as a result of which the industry was soon in a position to produce large quantities of this particular set at short notice. The R.1082/T.1083, too, was made partly by quick-production methods, and it was decided that in future all sets would be designed for quantity production.[2] Production of wireless equipment was by then going

[1] A.H.B./IIA/1/53.

[2] A.H.B./IIH/241/10/16. Bomber Command File Signals Policy.

some way towards meeting the increased operational requirements caused by the greater speed and ranges of aircraft and their need to fly in unfavourable weather conditions. The Bellini-Tosi M.F. D/F system had been greatly improved by the substitution of new direction-finding equipment using Adcock-type aerials, and the whole service had been extended. H.F. D/F trials had been successful, and as a result the homing and fixing of fighters using the modified TR.9 had become a fundamental factor of fighter tactics. The installation of a network of H.F. D/F stations for fighter and bomber aircraft was in progress. W/T procedure for the identification of returning bombers, pending the design of equipment which would give automatic identification on ground radar screens, was under consideration. The installation of R/T equipment in all types of aircraft became approved Air Ministry policy in 1936. The limitations of the TR.9, coupled with growing interference on the H.F band in use, had stimulated the design and production of V.H.F. equipment.[1] The two basic wireless equipments with which R.A.F. aircraft began the war, the R.1082/T.1083 and the TR.9, were in quantity production. An inter-communication amplifier was being produced. Procedure for the use of W/T and R/T communication to assist landings in conditions of poor visibility and low cloud, and the testing and production of radio equipment specially designed for such landings, was in hand.

Inauguration of Regional Flying Control—1938

Progress in the design of aircraft since 1919, and recognition of their strategic and tactical potentialities, had indicated that air power would play an important and even a decisive part in any future conflict. The lessons of the early use of aircraft in the First World War, coupled with subsequent experience, suggested that for the proper conservation and efficient application of air power, radio communication with the ground for reporting, control, and navigational assistance was a fundamental need. That this aspect was recognised by the Air Staff in the inter-war years is evident from the decisions made to carry radio in all aircraft, in spite of the additional weight and space involved, and to rely on radio as the basic navigational aid. Yet, although the loss of payload involved was accepted, as well as the loss of security attendant upon the use of all forms of D/F, the value of W/T and R/T communication for general control purposes was not fully appreciated.

The use of aircraft radio for control purposes was far more advanced in civil aviation. The function of the civil aviation signals organisation was classified in two categories: provision of navigational assistance, inter-airport communication, and supply of meteorological information; and regulation of the movements of aircraft to minimise risk of collision.[2] A high proportion of communication between ground and air consisted of meteorological reports, and to avoid congestion a system of broadcast reports was instituted in 1936. But one of the two main functions of the organisation, assuming an importance equivalent to that of furnishing aircraft with navigational assistance, was the establishment of measures to prevent the possibility of collision as a result of the growing density of air lines. A standard organisation was devised to meet the need for a central control station regulating the movements of aircraft, and short-range stations whose function was to supervise and assist the approach and landing of aircraft were established. This organisation involved the creation

[1] A.H.B./IIE/249.
[2] A.H.B./IIH/241/10/16.

of main radio communication areas, normally about 150 to 200 miles square, arranged in an interlocking or honeycomb pattern to cover the entire country.[1] Each area was provided with a central station controlling radio traffic and regulating the movements of aircraft in its area. Within a main area were established, at the important airports, short-range stations on a different frequency from the main area station. The short-range stations were equipped with D/F equipment and low-power transmitters, and besides relieving the pressure on the main area D/F stations, they regulated the movements of aircraft in the controlled zone established round busy aerodromes, and were able to provide series of homing bearings to aircraft approaching to land.

The possibility of controlling aircraft tracks by some method of D/F first occurred to the Air Ministry in 1933, at a time when the risk of collision between aircraft flying on converging courses in cloud was causing much concern. Models of a visual azimuth indicator were produced for Service trials but the hope that the equipment would provide an efficient warning system was not fulfilled. An alternative suggestion for a W/T ground organisation to keep track of the position and height of aircraft formations and to control them so that collisions were avoided was put forward, but the idea was not followed up for some years.[2] It was not until 1937 that firm proposals were made for the incorporation of a new system of control for R.A.F. aircraft, and these proposals came from the Director of Training, following a visit to the U.S.A. in the summer of 1937 in which he was impressed by the methods of control of aircraft there, both on the ground and in the air. On his return the Director of Training recommended that the methods in use in the R.A.F. should be thoroughly overhauled. Up to 1937 the duties of control at airfields had been undertaken from a small watch hut by a duty pilot, usually a member of the squadron detailed for the day, with an airman of the watch, and sometimes a meteorological assistant.[3] The Director of Training recommended that the watch hut should be completely re-designed and enlarged into a control building, to be manned by an officer of at least flight lieutenant rank, who should be vested with authority to redirect aircraft in the air, to prevent the departure of aircraft if in his opinion weather conditions were unfavourable, to recall aircraft if the weather deteriorated after their departure, and to re-route aircraft if, through congestion or other causes, the route selected became dangerous.

The proposals of the Director of Training were given an added impetus in December 1937, when the A.O.C.-in-C., Bomber Command outlined measures he considered necessary for the organisation of regional airfields for the assistance of aircraft in emergency. The measures included :—

(*a*) A weather information service for conditions prevailing at airfields in different regions.

(*b*) A communications system whereby aircraft might contact control for general information and instructions.

(*c*) Homing devices.

(*d*) Aids to safe landings by night and in bad weather.

A Regional Control Committee was formed to consider the proposals, the first meeting being held on 12 January 1938, and as a result of a series of meetings, and reports from the commands, nine regional control stations were provided,

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[1] A.H.B./IIH/241/10/16. [2] A.M. File 149335/31. [3] A.M. File 668431/37.

at Leuchars, Linton-on-Ouse, Waddington, Wyton, Abingdon, Boscombe Down, Mildenhall, Manston and St. Eval. They were selected primarily for their geographical locations so as to cover the greater part of England and southern Scotland. Each of the airfields was equipped with all available devices to enable an aircraft to land safely either in bad weather or when in difficulties, including H.F. D/F, *Lorenz* beam approach, night landing lights, and visual beacons. Control officers were specially trained and staffs were established to operate and maintain the various radio and electrical aids. Qualified meteorological staffs were also established to advise the control officers, and each station kept a record of the current weather conditions obtaining in its particular area, so that pilots could be kept informed in the air and either homed to one centre or diverted to another. Each centre was responsible for assisting any aircraft within its area by means of weather reports, information as to landing grounds, homings, controlled approaches, and diversions. Mildenhall, Abingdon, Boscombe Down, Linton-on-Ouse, and Wyton were completed by the end of 1938, and the remaining stations were completed shortly afterwards. In May 1939, agreement was given for the provision of a second H.F. D/F station at each regional control station.[1]

Before the outbreak of war, there was no continuous radio control of the actual landing of aircraft. The duty pilot was responsible for ensuring that the correct signals were displayed in the signal square on the airfield, including the wind direction and any special regulations in force, but A.P. 1460 (' Flying Regulations for the Royal Air Force ') promulgated in March 1938 with the object of forming a collection of all current orders and instructions directly concerning pilots and crews of aircraft when engaged on flying duties, contained no mention of any kind of control of landings, the only regulation concerned with the actual process of landing being an instruction to pilots to see that the landing area was clear of obstruction. Pilots were responsible for complying with pyrotechnic and light signals at all airfields. This system was satisfactory only for individual aircraft in favourable weather under peacetime conditions; it was totally inadequate to meet wartime requirements. In war conditions whole squadrons might be expected to return to their bases within a short time, perhaps in bad weather, with most of the aircraft near the limit of their endurance and some damaged by enemy action. In such circumstances the individualism of pre-war days only added to the dangers, particularly when aircraft were jockeying for position on the approach. However, no control system to meet the problem had been developed up to the war.[2]

Operational Use of Aircraft M.F. and H.F. Communication Systems 1939 to 1942

Long-range communication with aircraft had been recognised as a requirement in Coastal Command as a result of experience gained during 1935, when the war between Italy and Abyssinia created international tension, and a high-power transmitter was installed at Mount Batten. It was used to work Bomber Command aircraft in the course of a series of training flights to France in July 1939, and the results encouraged Headquarters Bomber Command to urge the provision of a similar installation at High Wycombe. On the training flights the R.1082/T.1083 was used for maintaining two-way communication at distances of 400 to 500 miles.[3] However, a lack of discipline amongst operators

[1] A.M. File S.38120.
[2] For full details *see* A.H.B. Monograph ' Flying Control '.
[3] A.H.B./IIH/241/10/24(A).

was revealed, messages being sent mostly in an insecure and uneconomical manner. The flights were the first occasion on which 'Syko' was used, and on some of the later flights a distinct improvement in its use was noted.[1] They brought a sharp reminder of the absence of security of wireless transmissions, the German news broadcast in English giving a concise review of the exercises by a high-ranking *Luftwaffe* officer.

Many of the early operations of Bomber Command were long-range reconnaissance in the Heligoland Bight and North Sea areas, at ranges up to 500 miles, and in those areas aircraft were required to send weather and reconnaissance reports the importance of which was sometimes so great that the success of operations depended upon them.[2] This circumstance gave added weight to the demands for long-distance communications, but there was some disagreement whether the need was as real as suggested. It was contended at Headquarters Bomber Command that the wireless operator was manning a gun throughout the period when long-distance communication was a possibility, and the likelihood of any appreciable volume of W/T traffic being passed to and from aircraft was thought to be remote. However, early in 1940 the Air Ministry authorised the provision of high-power transmitters at all bomber group headquarters locations, and by mid-1940 it had come to be appreciated that the ability to communicate with aircraft at long range was a necessity. At the same time the general opinion was that provision of the new Marconi W/T installation in aircraft would meet whatever operational requirement arose, but this set was still a long way from general introduction.

The expansion of the Royal Air Force which took place between 1939 and 1942 threatened, and in fact produced, a heavy overload on aircraft communications, which began to assume serious proportions in 1941. Several M.F. D/F sections were occupied in the identification of returning bombers, throwing an extra burden on the rest. H.F. D/F stations, although increased to a total of two at most operational bases, were liable to be overloaded on nights when Bomber Command operated in strength, especially if the weather deteriorated. The transmissions of routine messages on group operational frequencies soon built up to a considerable volume of traffic, and the landing of large numbers of aircraft in a short space of time presented exceptional problems of airfield control. Efforts to relieve congestion on D/F frequencies centred around the provision of an M.F. beacon system and the use of directional beams, and the problem resolved itself on the introduction of radar aids in 1942, but the danger of congestion on W/T and R/T communication channels remained. There was, in addition, a second ever-present danger in the use of W/T and R/T for whatever purpose; the danger that signals might be intercepted and the information extracted from them used by the enemy for operational purposes and to deduce the order of battle.

The main remedy for both dangers was the restriction of all aircraft communications to an absolute minimum. Indeed, prior to the outbreak of war it had been generally assumed that aircraft would maintain W/T silence until entering the identification zone on the return journey, except when requiring D/F for navigation purposes or in emergency, and it was not visualised that communications would be required on operational frequencies beyond the identification area. However, soon after the outbreak of war, operational groups felt the

[1] Syko was a cypher system for use in aircraft. [2] A.H.B./IIH/241/10/24(A).

need for the control of individual aircraft at long range, and considerations such as the testing of equipment and the need for quick communication in emergency encouraged operators to make frequent use of their transmitters. Routine transmissions from aircraft such as requests for ' W/T Go ', ' Operation completed ' on leaving the target, or ' Operation abandoned ' in some circumstances, and the transmission of operational messages by group headquarters for individual acknowledgment by aircraft, all contributed to overloading, besides providing a fruitful source of information to the enemy. And although at first all aircraft were not fitted with R/T, and the use of R/T for local control purposes was not general, this form of communication soon became popular for marshalling aircraft prior to night operations and for landing control. It was thought at first that the short range of the TR.9 would not render its use liable to general interception by the enemy.[1]

By mid-1941, it became apparent that control of individual aircraft on group operational frequencies, which was then customary, would soon become impracticable. Adequate communication became increasingly difficult, particularly on occasions when a high percentage of the bomber force was diverted on the return flight, and, from a security aspect, the growth of two-way communication between aircraft and ground stations for largely routine purposes had reached alarming proportions. The A.O.C. No. 5 Group informed Headquarters Bomber Command that, in the interests of security, aircraft in his group were maintaining virtually complete wireless silence until they returned to their bases, except in emergency.[2] ' Operation completed ' and ' Operation abandoned ' signals, for so long regarded by group operations rooms as essential to enable them to follow the course of operations, had been abolished, and with them had gone all frequency checks, W/T tests and W/T ' Go ' signals. Q.D.Ms. were used only in emergency, and the use of the TR.9 for the marshalling and despatch of formations had been stopped, although No. 5 Group stations were still using R/T for bringing in aircraft returning from raids. It was decided in July 1941 that, for the time being at any rate, the value of R/T in the control of landings, especially in view of continued expansion, outweighed the disadvantage that the enemy might use the intelligence he gained from intercepting these signals to mount intruder operations.[3] The instances of interception and intrusion by German fighters in No. 5 Group were studied to see whether they showed any significant drop since the restriction of the use of W/T and R/T, and were found to be lower than those occurring in Nos. 1 and 3 Groups, but it was not thought that any safe conclusions could be drawn owing to various complementary factors.

It was assumed, and subsequent intelligence proved the assumption to be correct, that all W/T and R/T signalling, even with the TR.9, was capable of being received, logged and correlated by the enemy. The Air Staff was particularly concerned to prevent the enemy from obtaining, during the progress of a raid, indications of the extent of activity from the volume of W/T traffic, and another form of signalling known to be giving away valuable information was the practice of aircraft making frequency checks just before and just after take-off. This practice had four dangers : it indicated the airfields from which aircraft

[1] R/T was used continually in Fighter Command, but in the prevailing conditions the lack of security had, to some extent, to be accepted.

[2] A.H.B./IIH/241/10/32. Bomber Command File ' Security of Wireless Traffic '.

[3] A.H.B./IIH/241/10/32.

were operating and the strength of the effort; it enabled the enemy to signal his intruder patrols that aircraft were taking off from a particular airfield; it enabled him to gauge the most suitable time to put up his interception fighters; and it gave him foreknowledge of the airfields to which his intruders could most usefully be sent to intercept returning aircraft. The Air Ministry issued instructions covering these points, and on 2 December 1941 Headquarters Bomber Command issued a general directive on the restriction of signalling by W/T and R/T.[1] This directive closely followed the existing practice in No. 5 Group. The main points covered by the directive were that every message sent by wireless gave the enemy information of some kind, and for this reason it was clearly important that signalling to and from aircraft should be restricted to the minimum necessary for the success of the mission and the safety of aircraft. Moreover, it was equally important to ensure that all channels were kept free of non-essential traffic, so as to facilitate the passing of urgent operational messages such as recalls and diversions, and improve and speed up communication with aircraft in real and immediate need of assistance. Radar aids to navigation were developed, and use of them materially reduced the need for breaking wireless silence for navigational purposes. At the same time it was decided to introduce the broadcast method on group operational frequencies, and the congestion resulting from large numbers of aircraft acknowledging and being called upon to acknowledge group messages was obviated. Use of R/T for marshalling, however, was not wholly prohibited, and use of R/T for landing control was standardised. An abbreviated pre-flight check procedure was introduced which it was believed gave very little useful information to the enemy. The use of W/T over the target was not re-introduced until the master-bomber technique was evolved in 1943.

The fact that the enemy had only to listen out on the frequencies used by Bomber Command to obtain a great deal of information about operational plans was responsible for the introduction of wireless deception or 'spoof'. In July 1940 it was decided to set up an organisation for that purpose.[2] The deception schemes operated in Bomber Command after August 1941 were simulation of signalling normally carried out by aircraft in the course of night-flying tests, simulation of aircraft returning to base, and spoof transmissions to conceal special operations and movements of squadrons. All involved the use of an attachment to aircraft W/T installations designed to modify the characteristic of the note transmitted when the sets were on the ground so that it sounded like the note transmitted when they were airborne. Effective use of wireless deception was complicated by the changeover from R.1082/T.1083 to T.1154/R.1155, the characteristic note of which was very different. The reduction in air-to-ground signalling brought about by the introduction of Gee lessened the need for deception. A close analysis of daytime signals traffic on H.F. channels revealed that transmission made during daily inspections of equipment and on air tests gave no certain indications of impending operations. To some extent this was the result of instituting a system in which aircraft letters only, and not call-signs, were used for practice transmissions and each aircraft worked with at least one other station in addition to that at its own base. There were occasions, however, when, because of weather conditions, the lack of wireless

[1] A.H.B./IIH/241/10/32.

[2] A.M. File S.5686. An organisation to study enemy radio transmissions was also set up with the object of deducing preparations for operations.

signalling during the day revealed a general stand-down throughout Bomber Command. The use of aircraft letters did not prevent the enemy from obtaining information unless they were frequently changed. A wireless deception organisation was still required, especially in order that the R.A.F. should be able to play its part in inter-Service plans for the liberation of Europe.

One of the principal duties of Coastal Command aircraft was to pass to area combined headquarters the reports and information which they required, especially of enemy forces.[1] Generally speaking, in such instances, the enemy was aware that he was being shadowed, so the question of security could be ignored, but for nearly all other types of operation, W/T and R/T silence were essential. The onus of breaking silence for air-to-ship communications rested with the ship, except in certain special circumstances such as the sighting by aircraft of a U-boat. Reports of this nature were passed direct to the commanders of the convoy on the convoy R/T frequency of 2,410 kilocycles per second.[2] Aircraft engaged on reconnaissance, anti-submarine or escort duties maintained continuous W/T watch on the appropriate frequency. Aircraft on reconnaissance or similar duties, and on convoy escort in the Atlantic, were controlled by the appropriate area combined headquarters, or sometimes by their base station. Very-long-range aircraft operating in the North Atlantic used either Iceland or Liverpool A.C.H.Q., or St. John's, Goose or Gander. When the use of other equipment such as A.S.V. precluded the use of W/T simultaneously, aircraft listened out to the routine broadcast periods, which occurred twice an hour.

Experience during the first winter of the war indicated the magnitude of the problem of assisting operational aircraft to return safely to their bases. Navigation over long distances, particularly at night, proved extremely difficult, and there were frequent fatal accidents caused by errors in navigation or by the inability of crews to find their bases, especially in bad weather. The problem was aggravated by the need for all aircraft in the air to be identified to the fighter defence organisation.[3] The regional control organisation, the first stations for which were completed in 1938, was taken over from Bomber Command by the Air Ministry shortly after the outbreak of war, and was then expanded and reorganised to bring it into closer relationship with the other commands. However, with the expansion that took place in the first two years of war the new system was shown to be inadequate, and in November 1941 a new co-ordinated plan for the landing of large bomber forces in bad weather was introduced.[4] The previous system, in which the task had been undertaken by the individual groups, suffered from a lack of a central control, and frequently led to a situation in which aircraft were kept waiting for instructions, and many crashed through lack of petrol. There were, in addition, many accidents occurring in the vicinity of airfields, such as collisions on the approach and with ground obstructions, taxying accidents, and aircraft under or overshooting when coming in to land, and as a result of a thorough investigation in 1941, standard regulations were formulated for the local control of aircraft, covering their movements from the time of leaving dispersal point until after take-off, and again on their return from the time of handing over to local control till their return to dispersal.

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[1] Area Combined Headquarters were located at Gibraltar, Plymouth, Liverpool and Iceland.

[2] Manual of Coastal Command Operational Control, May 1943.

[3] A.M. File S.2704.

[4] A.M. File CS.10503.

By the end of 1942, the facilities necessary for the efficient control of aircraft from the ground were beginning to take shape, and it was clearly established that Flying Control was an essential and permanent feature of the Royal Air Force. But the most important ingredient of an efficient system of controlling aircraft on the ground and in the air, high-quality radio-telephony, was still lacking. The TR.9 was not replaced by the TR.1196 until 1943, and even then the quality of two-way R/T communication left much to be desired. Meanwhile, incidents such as the loss of eight aircraft out of 43 diverted on the night of 26/27 November 1943 continued to focus attention on the need for good speech communication with heavy bomber aircraft. It was not until 1944, however, that standardised fitting of V.H.F. R/T in Bomber Command became practicable, and even then the fitting programme could not be completed for many months.

Improvement of Aircraft H.F. Equipment

On the outbreak of war the standard of aircraft communications achieved was not regarded as satisfactory, and indeed a comparison of operating standards in the Royal Air Force and the *Luftwaffe* showed that general efficiency and manipulation in the R.A.F. compared unfavourably. In the R.A.F., secret call-signs were often compromised, operating signals were misused and sometimes entirely dispensed with, unnecessary transmissions were frequent, a slackness of W/T discipline was evident, and manipulation was generally poor.[1] However, within a few weeks of the outbreak of war a marked improvement in operating and discipline in the R.A.F. was noted, whereas in the *Luftwaffe* a deterioration took place, enabling us to obtain much valuable intelligence. The training and technical knowledge of wireless operators in the R.A.F. was probably better than at any other stage of the war, all operators on operational squadrons being peacetime-trained; thus they were quick to adapt themselves to the needs of war. Again, the comparative size and performance of the two air forces at this time bred caution in the one and carelessness in the other. Similar fluctuations of this kind continued. The influx of war-time aircrew entrants whose training schedules had of necessity been telescoped resulted by 1941 in an extremely low standard of operating in the R.A.F. in all theatres. Then, as these operators gained experience, and as counter-methods of continuation training and incentive were applied, the standard of operating rose steadily.

Another factor affecting the standard of aircraft communications was the equipment in use. In Bomber and Coastal Commands, this comprised the R.1082/T.1083 for W/T, the TR.9D for R/T, and in multi-seater aircraft the A.1134 for inter-communication amongst the crew. The R.1082/T.1083 was an interim general-purpose 'receiver' whose replacement by a more up-to-date apparatus had been planned some years before the war, and the TR.9D operated in the noisy high-frequency bands and had other limitations. The R.1082/T.1083 in particular could not be operated successfully in all conditions by anyone but a highly-skilled operator, and this lent added urgency to the early introduction of the new Marconi equipment.

Introduction of the replacement for the R.1082/T.1083, the Marconi T.1154/R.1155, was not expected to begin until April 1940 because development of equipment to fulfil the operational requirement had not been started at the R.A.E. although specifications had been drawn up in 1935/36. In view of the

[1] A.H.B./IIH/241/10/5. Bomber Command File, 'No. 67 Wing Signals arrangements including R.D.F.'

urgent need of this improved equipment, it was arranged for the firm of Marconi to provide fitting parties, under the supervision of No. 26 Group. However, production of the equipment did not begin until August 1940, when trial installations were made by the firm in a Wellington, Whitley, Hampden and Blenheim. It had been found some time previously that the electrical power supply originally provided in these aircraft was insufficient to supply the input required by the new set, and it was decided that either a larger or an additional generator must be provided. However, since it was anticipated that supplies of the new generator could not be made available in time for the T.1154/R.1155 installation programme, it was decided as a temporary measure to provide an additional accumulator to give the power required, until such time as the extra generator could be fitted. Unfortunately, when the first installations were tested it was found that the accumulator was unsatisfactory and that the radio equipment could only be installed and used when the larger or additional generator was provided.[1] It was therefore necessary to arrange fitting parties to fit an additional generator at the same time as the new Marconi equipment was installed.

By November 1940, the additional electrical supply in Whitleys, Wellingtons and Hampdens had been arranged, and fitting began, but installation in the Blenheim was still held up as the Bristol Aeroplane Company had been unable to supply the fitting party or fittings to install the additional generator. Even more disturbing was the situation with the new heavy-type bombers, the Stirling, Halifax and Manchester ; they were leaving the aircraft production line wired for the old layout.[2] For the rest of the winter 1940/41 the majority of aircraft in Bomber Command, and nearly all the aircraft in Coastal Command, were equipped with R.1082/T.1083, and there were occasions when heavy losses in Bomber Command were attributed largely to the failure or inadequacy of the existing W/T equipment, and to the continued absence in some groups of a regional control organisation. It was believed, in particular, that eleven Wellingtons which were lost on the night of 11/12 February 1941 could have been guided in to airfields which were not unserviceable through bad weather if they had had efficient wireless facilities. Everything was being done to speed up the general introduction of T.1154/R.1155, and indeed at the time progress of production and installation was regarded as satisfactory ; 1,000 sets had been delivered and a further 1,500 were due for delivery in March. However, Air Ministry satisfaction was not shared by the C.-in-C., Bomber Command, who regarded the situation not from the aspect of the numbers of new equipments being produced but from the numbers of operational aircraft equipped. On 22 February 1941 only 60 Hampdens had been completed, of 272 operational Wellingtons only 15 were fitted, about 25 per cent of Whitleys were equipped, and in nine Blenheim squadrons not one aircraft was fitted. The situation had greatly improved by the winter of 1941/42, but it was not until 1943 that the last R.1082/T.1083 was replaced in Coastal Command.[3]

A large number of different versions of the basic T.1154/R.1155 installation were eventually produced to meet different requirements for frequency coverage and containers, and to meet manufacturing problems such as shortage of

[1] A.H.B./ID/2/125. C.I.D. Home Defence Committee Reorientation of the Air Defence system of Great Britain. Memo. by the Home Defence Sub-Committee of the C.I.D.

[2] A.H.B./ID/2/125.

[3] Coastal Command Signals Review, Volume I, No. 3, March 1944.

materials and tooling difficulties. By August 1944 the number of variants had been reduced to :—

T.1154 H — for all Halifax and Sunderland aircraft as well as for types of aircraft which required aluminium container versions to lessen interference with the compass.

T.1154 L — for air/sea rescue marine craft and wireless trainers.

T.1154 M — for general use.

R.1155 A — for Halifax bomber aircraft.

R.1155 F — for all bomber aircraft other than Halifax and for types of aircraft which required aluminium container versions.

R.1155 L — for general use (aluminium container version of R.1155 N)

R.1155 N — for general use except in bomber aircraft.

To meet the requirement for a general purpose installation of the same dimensions as T.1154/R.1155 but much lighter, and with an overall performance approximately equal to that of T.1154/R.1155 but operating on a considerably reduced power input, the T.1528/R.1529 installation was developed. The power input was effectively reduced by employing a single power unit for H.T. supply to both transmitter and receiver and by connecting all valve heaters (both transmitter and receiver) in a series-parallel arrangement, supplying them from the aircraft 24-volt batteries through a carbon pile regulator. Transmitter design was based on the T.1154 H although the circuit differed considerably, whilst the receiver was basically the same as the R.1155 L. Service trials were completed by December 1944. However, although the installation fulfilled requirements satisfactorily the concensus of opinion was against its gradual introduction at that stage of the war because the advantages gained in reduced input power and weight did not compensate for the fact that special training in its operation would have to be given and a new fault-finding technique would have to be evolved and learnt. Further development was therefore stopped.[1]

A decision to install R/T equipment in all R.A.F. aircraft was made in 1936, but the demands of Fighter Command delayed general introduction of the TR.9. R/T was thought to be of use in bomber aircraft largely for the tactical control of formations by the leader and to assist in the concentration of fire-power. Its use for airfield control was not at first considered but by the outbreak of war duty pilots at many R.A.F. airfields were using H.F. R/T to control aircraft movements although no standard procedure existed until 1941.[2] Because of Admiralty insistence on the maintenance of wireless silence during fleet exercises and operations before the war, when reliance was placed on visual signalling methods, no R/T communication equipment had been specifically designed for aircraft of Coastal Command. Developments to meet the requirements which arose soon after the war began were consequently made on an *ad hoc* basis. Complications were added by the many different types of aircraft with which the command was armed, fitted with different types of wireless equipment, both British and American. It was soon found that the efficacy of anti-U-boat escorts operating with convoys was considerably lessened by dependence on Aldis lamp communication, and escort vessels were equipped with H.F. R/T equipment. The convoy frequency, 2,410 kilocycles per second, had to be used,

[1] A.H.B./IIE/44.

[2] An aircraft installation was usually adapted for use on the ground.

and was not very suitable for R/T communication.[1] TR.9 equipment, suitably modified, was installed in Coastal Command aircraft, but was far from satisfactory for air-to-ship communication. The technical limitations of low ranges, poor quality of speech, high noise to signals ratio and frequency congestion were increased by the lack of understanding of each others' difficulties which sprung from inexperience of operating conditions, for there had been no opportunity for practising air-to-ship R/T communication. The inadequacy of the TR.9 installation was emphasised in the summer of 1943, when the U-boat Command began the use of group sailing tactics in the Bay of Biscay. Once a group had been located the sighting aircraft orbited beyond gunfire range until joined by reinforcing aircraft. The sighting aircraft then became responsible for controlling the ensuing attack, and for this purpose effective air-to-air R/T communication was essential. Because the performance of the TR.9 was inadequate many promising anti-U-boat attacks were spoilt by lack of co-ordination.[2] The efficacy of aircraft, and particularly of aircraft radar, was being lessened to some extent by the inefficiency of aircraft communications equipment, but by that time the TR.1196B and similar American equipment was being installed in Coastal Command. The TR.1196 made available four spot frequencies, with selection by remote control, in the band 4·3 to 6·7 megacycles per second.[3] The transmitter and receiver were crystal-controlled (eight crystals per installation) and worked from a self-contained power unit, the total input being approximately 60 watts from the aircraft supply. Its introduction considerably improved the efficiency of aircraft communications, in spite of the inherent limitations of H.F. R/T, and early in 1944 one convoy commander reported '. . . from experience of last four months . . . R/T communications with Coastal Command aircraft have been excellent and difficult to improve . . .'[4]

Development of V.H.F. R/T System—1935 to 1939

The development of V.H.F. equipment was formally added to the R.A.E. development programme in January 1935, when at a wireless development conference it was stated that research should be initiated and '. . . it seems possible that a practical set should be forthcoming in five years time . . .'[5] Transmitters and receivers for aircraft and ground use were to be developed and consideration was to be given to direction-finding on the V.H.F. band. Because of the urgent requirement for improved R/T performance in fighter aircraft, longer ranges being required for homing and vectoring than could be provided with the H.F. equipment in use, the development programme was amended in 1936 so that the whole fighter R/T organisation could be made to work in the 100 to 120 megacycles per second frequency band. It became possible to apply considerably more resources to the development of V.H.F. equipment. Suitable personnel were recruited and progress was made in the development of measuring equipment, the lack of which had retarded progress in the previous years. However, some time elapsed before crystal-controlled transmitters and superheterodyne receivers were considered to be practicable

[1] Extra coils had to be provided for the R.1082/T.1083 installation.

[2] *See also* A.H.B. Narrative 'The R.A.F. in Maritime War'.

[3] About 300 TR.1196 installations were modified to meet Transport Command requirements and were known as TR.1518.

[4] Coastal Command Signals Review, March 1944.

[5] A.H.B./IIE/249.

and considerable effort was expended on less efficient types of equipment which were inadequate for the complete communications system required. The R.A.E. was made responsible for the specifications of buildings, their internal layout, and their inter-station line communications as well as the design and development of radio units and the selection of sites. This was probably the first occasion on which the R.A.E. radio engineering staff had been given complete responsibility for planning in addition to technical development, and early development of the V.H.F. R/T system was in that respect analogous to that of R.D.F.

In the meantime the shortcomings of the H.F. R/T communications system were becoming more obvious. Some improvement was effected by the introduction of crystal control in the TR.9F but the system was quite inadequate. Apart from the increase of serious interference, especially at night, on the H.F. band, the number of communication channels made available was insufficient, and the ease with which transmissions could be intercepted at long ranges was giving rise to anxiety.[1] The interference and vulnerability to interception were unavoidable because of the fundamental properties of the ionosphere at the frequencies in current use, but the use of very high frequencies offered some alleviation. It was known that wireless waves of very high frequency normally penetrated the ionosphere and were not deflected by it so that long-range jamming was not possible. It was expected that the range of communication on V.H.F. would be limited to the optical horizon and, although experience showed that anomalous conditions which resulted in greater ranges being obtained could exist, in practice the expectation was broadly realised. More channels were required partly because of the expansion of the fighter organisation and partly because of changes in the technique of fighter control made necessary by the successful development of R.D.F.

With the growth of tension in the international situation the need for improvement of fighter communications was emphasised, and the improvement could not be made without the full-scale introduction of V.H.F. R/T. Development of a complicated V.H.F. R/T system was bound to take a comparatively long time and consequently the possibility of suitable alternatives was examined. When information was received, early in 1938, that the Royal Netherlands Air Force had been operating a V.H.F. R/T system for some eighteen months to two years, two signals officers were sent to Holland to inspect it at the invitation of the head of the wireless section of the air force. They reported that '. . . the V.H.F. R/T installation is a sound, practical, working proposition although no attempt to introduce any great measure of advanced technique has been made . . .'[2] However, when purchase of an installation was suggested, it was pointed out that the estimate of five years made in 1935 was for the provision of a complete V.H.F. R/T system for Fighter Command, including ground stations, aircraft installations and direction-finding facilities. The difficulties involved in the provision of 80 adjacent R/T channels were emphasised by the Director of Communications Development, who added that, at the time when research at the R.A.E. was begun, equipment to meet the requirement could not have been produced by any organisation in any country. The Dutch equipment was very similar to that which the R.A.E. or any competent radio firm could have produced some five or six years earlier; it could not provide the number of

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[1] A.H.B./IIE/249.

[2] A.M. File S.44756. The officers were Wing Commanders O. G. Lywood and R. S. Aitken.

channels or the stability and selectivity required by the R.A.F.[1] At that time V.H.F. R/T development at the R.A.E. had reached the stage where '. . . the technical features of a crystal-controlled ground transmitter (TX.62) to include instantaneous electrical remote control to any of six spot frequencies had been established, and the transmitter was being made in the workshops. A complete aircraft transmitter/receiver (TRX.25), incorporating electrical remote control to any of four spot frequencies, the transmitter being crystal controlled and the receiver being provided with automatic fine-tuning, is being made . . . single-frequency prototypes . . . are now in operation both in the air and on the ground . . .'[2]

Perhaps partly as a result of the stimulus given by the investigation to progress with development, the Director of Signals was able to inform the C.A.S. in January 1939 that a substantial proportion of Fighter Command, eight sectors and sixteen squadrons, could be equipped with V.H.F. R/T by September 1939 if installations slightly inferior to those originally planned and initially produced on a limited scale were acceptable to the Air Staff.[3] The proposal was not without an element of risk, since it was always possible that war might begin before the changeover from H.F. to V.H.F. had been completed, and the resultant difficulties were obvious. It meant going ahead on a considerable scale with equipment which had not been given Service trials, but the risk was minimised by the design of the aircraft installation. Its shape, size and means of fitting in aircraft were to be similar to those of the TR.9 so that, if the worst came to the worst, squadrons could change from V.H.F. to H.F. or H.F. to V.H.F. R/T equipment in about ninety minutes once the necessary wiring, generating and voltage control systems had been installed in the aircraft. The scheme, which had been formulated with the aid of the Director of Communications Development, was summarised by the A.C.A.S. for the C.A.S. as '. . . the question at issue is whether we should go straight away for V.H.F. in our fighters. As you know the great advantage of V.H.F. is that it cannot be jammed, whereas there would be no great difficulty in jamming our present fighter R/T sets. We thought that it would take several years to produce a satisfactory V.H.F. set. So much so that, until recently, we were contemplating going into production on an improved model of the present fighter R/T set.[4] . . . Thanks however to strenuous efforts on the part of the Director of Communications Development and the R.A.E. it now appears that we can get into production straight away on a hand-made V.H.F. set which, in the opinion of the D.C.D., has every chance of being successful. This means that we shall be able to get 200 to 300 fighter aircraft equipped with V.H.F. sets by September of this year. The Director of Signals proposes to build up the V.H.F. R/T ground organisation alongside the present organisation and to arrange for the V.H.F. equipment to be interchangeable with the present R/T sets, so that even if V.H.F. is not so successful as we anticipate we shall still have the present organisation and equipment to fall back on . . . The scheme is of course a bit of a gamble but . . . I strongly

[1] The Dutch system worked in the 60 to 70 megacycles per second frequency band. The transmitter was a modulated self-oscillator with an output of 20 watts. The receiver was super-regenerative with six pre-set frequency spots. Crystal control was not used.

[2] A.M. File S.44756.

[3] Sectors to be equipped were Debden, Biggin Hill, Hornchurch, North Weald, Duxford, Wittering, Catterick and Digby.

[4] An H.F. R/T installation was being produced by the Standard Telephones and Cables Company, designed by the firm with modifications added by the R.A.E.

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recommend that you approve these proposals . . .'[1] The C.A.S. replied that he was satisfied that the proposals were sound and directed that their fulfilment was to be treated as a matter of first importance in view of the international situation. '. . . If you are held up by the " machine " please let me know . . .'

The V.H.F. R/T installation plan was divided into two stages. In Stage I, which it was intended should give place to Stage II in May 1940, the aircraft installation was the TR.1133, and consisted of a crystal-controlled transmitter and a superheterodyne receiver with automatic fine-tuning; four spot-frequencies were available. The ground transmitter was the T.1131, a single-channel master-oscillator capable of rapid frequency-change, and the ground receiver was the R.1132, a superheterodyne with single-knob tuning. In Stage II all Fighter Command aircraft were to be equipped with TR.1143, in which the receiver was crystal controlled as well as the transmitter. The ground receiver was also to be crystal controlled and the output power of the ground transmitter was to be increased.

Rapid progress was made with Stage I. By July 1939 all sites had been obtained, buildings were to be completed by mid-August, and the provision and erection of masts had been almost completed. Delivery of equipment from the manufacturers began in August. Suitably modified Spitfires were due to leave the aircraft factories in mid-August at the rate of 11 or 12 per week, but delivery of the first modified Hurricane before the end of October could not be promised; it was expected that the rate of delivery would then be 5 per week rising to 12–15 by the end of the year. Since 10 of the 16 squadrons which were to be equipped with the TR.1133 were armed with Hurricanes this raised a serious problem.[2] The question of aircraft modifications gave rise to another appeal to the Chief of the Air Staff. In August 1939 the Directorate of Communications Development asked that the new, modified aircraft should be issued to all the squadrons which were to be equipped with V.H.F. R/T and their old aircraft withdrawn. On the grounds that such an arrangement would result in another period of re-equipping fighter squadrons the request was strongly opposed by the A.M.S.O., who contended that approval for the introduction of V.H.F. equipment had been given on the assumption that there would be no aircraft modifications because the equipment would be interchangeable with the TR.9 installation; he recommended that the modified aircraft should be put into reserve and not into front-line squadrons.[3] The A.C.A.S. pointed out that the interchangeability could not be construed to mean that there would be no aircraft modifications; the Director of Signals had stated that there would be some in his original proposals. The C.A.S. appreciated the point of view of the A.M.S.O., but as the matter was of prime importance to effective air defence of the country he ruled that Fighter Command was to be provided with modified aircraft as quickly as possible.

Meanwhile good reports had been received of V.H.F. R/T equipment being used by the French Air Force and it was thought possible that the technique used in the French equipment, developed largely by radio firms to the specification of the French Air Ministry, was far in advance of that used in the equipment being manufactured for the R.A.F. However, the D.C.D. informed the C.A.S. in August that he had made a detailed investigation of the sets in December 1938 and again in May 1939 and had ordered, for trial purposes, one

[1] A.M. File S.44756. [2] A.M. File S.49038. [3] A.M. File S.49038.

D/F ground installation, which was the only equipment which seemed likely to have any advantages. '. . . As I have frequently informed the Director of Signals, he could have had a V.H.F. R/T set as bad as the Dutch and French sets years ago, but his own requirement specification and our technical standard alike very properly excluded it from proposals for introduction . . .'[1]

Service trials of TR.1133 took place at Duxford on 30 October 1939, with six Spitfires of No. 66 Squadron. The results exceeded expectations. An air-to-ground range of as much as 140 miles was obtained at 10,000 feet, and an air-to-air range of over 100 miles. The Director of Signals reported that '. . . there can be no doubt that even Mark I V.H.F. equipment opens up a completely new chapter of aircraft R/T communication. Telephony was in every case far better than anything previously heard and the whole of the ground arrangement as laid out by the R.A.E. seemed to fit completely the operational requirement. Direction-finding, both for plotting and homing, was instantaneous and exceedingly accurate. . . . it is a matter of great satisfaction and reflects the greatest possible credit on all concerned, particularly No. 10 Department of the R.A.E. who have evolved in a matter of ten months a completely new scheme, which previously had taken four or more years to produce . . .'[2] A few days later the Chief of the Air Staff approved the general introduction of V.H.F. R/T in Fighter Command. An important consequence was that the decision to limit the hand-made TR.1133 to Stage I was changed. TR.1143 was not yet ready and TR.1133 was put into quantity production.

V.H.F. R/T in Fighter Aircraft

Once the Chief of the Air Staff had approved the general introduction of V.H.F. R/T in Fighter Command in October 1939 rapid and effective action was taken to implement the sector station installation programme.[3] By the beginning of December Headquarters Fighter Command was able to inform the Air Ministry of the requirement and sites for ground stations. It involved the installation of 20 new stations together with an increase in the equipment of the existing eight stations. Sixteen of the new stations (11 of them sector stations) were to be completely fitted and tested by the end of September 1940 and the other four by the end of the year. It was decided that two types of mobile ground equipment was required; one using the T.1131 for homing, direction-finding, and relay station purposes, and one using the aircraft installation TR.1133 for ZZ landings. The former was to be provisioned on the scale of one per sector station, 15 for relay stations, and 15 for satellite stations, spares and training; the light, mobile equipment was required at every Fighter Command airfield. Installation of the 20 new stations was completed by September 1940, but in the meantime more sectors had been added to the command and the requirement for equipment was consequently increased. In June 1940 Headquarters Fighter Command requested that all R.D.F. stations affiliated to sector stations should be equipped with single-channel V.H.F. R/T. V.H.F. R/T equipment was also installed in G.C.I. stations when they began operating early in 1941; effective close control of night fighters required installation in the aircraft of 8-channel V.H.F. R/T.

[1] A.H.B./IIE/249. One year later the French Air Force found that their V.H.F. R/T system did not provide sufficient communication channels, and asked for supplies of R.A.F. equipment.

[2] A.M. File S.44756.

[3] Installation of eight sectors as specified in the original plan was completed in January 1940.

Production in quantity of aircraft installations was complicated by delays in the development of TR.1143. Provisioning action for aircraft equipment was taken in November 1939 but it was not then possible to forecast when TR.1143 would be ready for quantity production. Consequently, from a provisioning aspect, no distinction was made between TR.1133 and TR.1143. The total requirements were calculated and requisitions were raised to cover a definite number of TR.1133 installations and an additional number of equipments which were to be TR.1133 or TR.1143, according to the progress made towards completion of development of TR.1143. The total number of sets originally requisitioned was 13,260, to be delivered by the end of March 1941.[1] In July 1940 deliveries from the first contract for 6,000 TR.1133 placed with the General Electric Company were expected to begin in the following month, and completion of the contract by March 1941 was anticipated. Production of TR.1143 was evidently not going to begin in time and therefore a contract was placed for an additional quantity of 5,200 TR.1133. By the end of 1940 the total requirement had increased and requisitions were raised for another 8,775 equipments. The continued delay in reaching the production stage with TR.1143 resulted in a proposal being made early in 1941 to secure some of the benefits of the newer design by providing a crystal-controlled receiver unit, R.1225, for use with the transmitter unit of TR.1133; the new combination eventually became TR.1133 G and TR.1133 H.[2] Incorporation of the new receiver considerably extended the number of possible frequency channels beyond the 86 of TR.1133. Contracts were placed for 5,000 receivers R.1225 and were later increased to cover the period between the end of production of TR.1133 and the delivery of TR.1143.

By May 1940 installation of hand-made TR.1133 had been completed in eight squadrons.[3] During that month many fighter aircraft were lost in air battles during the evacuation from Dunkirk, and on 26 May 1940 the squadrons were ordered to change back from V.H.F. R/T to H.F. R/T, an eventuality which had been foreseen in January 1939. The A.O.C.-in-C. Fighter Command informed the Air Ministry that '. . . I have found it necessary to suspend indefinitely the further use of V.H.F. equipment by fighter aircraft. I appreciate fully, and I know my views will be shared by the Air Ministry, that to have to abandon the use of our most successful form of fighter communications at the present time is a deplorable necessity. The result must be to reduce the operational efficiency of this command. The necessity which has forced me to resort to such drastic action is due entirely to inadequacy of supplies and the need for conserving our available reserves so that the equipment shall be on hand for use in its proper sphere and to the best advantage when the occasion demands. At the present time I am required to operate fighter patrols over the Channel and parts of France and Belgium from bases in the south-east of England : losses are unavoidable and, apart from the initial issue of 25 sets of V.H.F. equipment to each of the eight squadrons which have been fitted up to date, and also 40 additional sets suitable for Hurricanes only, I am informed that no further equipment of this sort will become available until the late summer. A further complication which arises is due to the fact that I must

[1] 7,680 were to be 12-volt and 5,580 24-volt installations.

[2] Because the receivers in TR.1133 were not crystal-controlled they were subject to frequency shift due to temperature variations. It was therefore desirable to allow as much as 450 kilocycles per second separation between channels in the band covered, 100 to 120 megacycles per second, compared with the 250 kilocycles per second separation in TR.1143.

[3] Nos. 41, 54, 66, 611 (Spitfire) and Nos. 17, 32, 56, 213 (Hurricane).

maintain complete flexibility in the operation of all my squadrons under the present exceptional conditions. In some cases it is necessary to operate composite squadrons, when it is obvious that the aircraft concerned must be fitted with the same type of apparatus to permit of air-to-air communication. Although every squadron equipped with V.H.F. equipment is in possession also of complete H.F. equipment, it is not practicable for a squadron to keep changing from one type of equipment to another, neither is it practicable to maintain proper ground organisation. By reverting to H.F. R/T communication throughout the command my Chief Signals Officer considers it probable that he will be able to compete with all likely communication problems but the continued use of the admixture of H.F. and V.H.F. is unworkable . . .'[1]

Deliveries of TR.1133 from quantity production began, as had been anticipated, in August 1940, when Headquarters Fighter Command decided to restart the changeover to V.H.F. R/T, beginning with squadrons based at stations where ground equipment and suitably trained personnel were available.[2] It was emphasised that approval for the changeover to begin immediately was given only on the assumption that the manning situation at the selected stations was such that both V.H.F. and H.F. R/T could be operated in conjunction, and H.F. R/T equipment was to be kept in a state of readiness. Although by the end of September 1940 sixteen single-seater fighter squadrons and six Blenheim fighter squadrons had been equipped, the TR.1133 installation programme was not sufficiently far advanced to enable Fighter Command to take full advantage of the superiority of V.H.F. over H.F. R/T, but its use by even a limited number of squadrons was of considerable assistance to pilots and controllers especially at long ranges.[3] Thereafter Fighter Command demands for V.H.F. R/T equipment rapidly and considerably increased and large-scale production and installation programmes were put in hand, those for TR.1143 beginning in 1942.

In order that ground controlled night fighters equipped with A.I. could be made more effective, eight readily available V.H.F. R/T communication channels were required. An installation based on the design of TR.1143 but with twice the number of channels was therefore developed and was known as TR.1430. Until it was ready for operational use night-fighter aircraft were equipped with a twin-TR.1143 installation. By March 1944, when 100 TR.1430 equipments had been produced, the requirement had risen to 12 channels, so the TR.1430 was installed retrospectively in aircraft of three night-fighter squadrons as a replacement for one of the TR.1143 sets. When deliveries from quantity production began, twin-TR.1430 installations were fitted on the aircraft production lines in Mosquito and Welkin night-fighter aircraft thus providing them with 16 readily available communication channels.[4]

The advent of high-performance single-seater day-fighter aircraft called for a new design of V.H.F. R/T equipment, and the light-weight TR.1464 installation was developed. Compared with the TR.1143 it represented an overall saving in weight of 50 pounds and provided eight channels. Flight trials were undertaken in March and April 1944 when air-to-air ranges of 175 miles at 400 feet and air-to-ground (T.1131/R.1132) ranges from 90 miles at 2,000 feet to 150 miles

[1] A.M. File S.44756. *See also* Royal Air Force Signals History, Volume V: 'Fighter Control and Interception'.

[2] Nos. 19, 41, 54 (Spitfire) and 17, 32, 46, 56, 229 (Hurricane).

[3] *See also* Royal Air Force Signals History, Volume V: 'Fighter Control and Interception'.

[4] A.H.B./IIE/44.

at 8,000 feet were obtained. Without waiting for type approval and full Service trials production of a limited number of equipments was begun in August 1944 for installation in Meteor aircraft. A new problem was encountered when it was discovered that the whine peculiar to jet aircraft could be transmitted through the V.H.F. R/T installation. This was serious since it might provide the enemy with important information. The difficulty was to some extent overcome by inserting a filter in the microphone circuit but it was only a partial solution of the problem as the noise was still distinguishable unless the pilot's oxygen mask fitted perfectly.[1]

The Royal Navy first became actively interested in the R.A.F. V.H.F. R/T system in 1941. Convoys sailing off the east coast were then being provided with fighter escort operating under the normal R.A.F. control system. It was found that fighter pilots were not always aware of the position of German aircraft which could, however, be seen from the ships.[2] It was therefore suggested that the escort surface vessels should be equipped with V.H.F. R/T so that direct communication with air escorts would be possible. An experiment with an installation in a cruiser, consisting of T.1131 and R.1132, was very successful. Accordingly all escort vessels of east-coast convoys were equipped with V.H.F. R/T but owing to the limited space available TR.1133 was used. In 1942 V.H.F. equipment was installed in two cruisers engaged on convoy escort duties in the Mediterranean so that they could control the operations of escorting R.A.F. fighters. The results encouraged the Naval Staff to arrange for the installation of V.H.F. equipment for fighter control in all major ships. In December 1943 trials were begun of installations consisting of adapted T.1131 and R.1132 equipment in aircraft carriers. The results obtained were so satisfactory that it was decided that all Fleet Air Arm fighter aircraft should be equipped with suitable V.H.F. R/T.[3]

V.H.F. R/T in Bomber and Strike Aircraft

The possibility of using V.H.F. R/T in Bomber Command aircraft for local flying control was first considered in March 1940, and provision of equipment working in the 126 to 146 megacycles per second frequency band was proposed. By December 1940 work on the design of TR.1226, to be interchangeable with TR.1143 but with a different frequency coverage, for installation in Bomber Command aircraft had begun.[4] However, experience with TR.1133 in Fighter Command had shown that R/T ranges considerably in excess of optical ranges were frequently obtained and it was feared that such occurrences would mar the effectiveness of a V.H.F. Darky system. In any event Bomber Command would be faced with the necessity for a more elaborate organisation than it could then deal with. The position was further complicated by the large demands for V.H.F. equipment made by Fighter Command and the consequent absorption of production capacity to meet them. In addition, the most urgent Bomber Command requirement for V.H.F. R/T in 1941 was for day bombers of No. 2 Group.

[1] To meet a requirement for V.H.F. R/T in flying-boats of A.C.S.E.A. in July 1945 trial installations of TR.1464 were begun and arrangements made for general fitting to take place retrospectively and on aircraft production lines.

[2] *See also* A.H.B. Narrative ' The R.A.F. in Maritime War '.

[3] An adaptation of SCR.522 (TR.5043) was installed in H.M. destroyers.

[4] Also on the design of T.1227 and R.1228 for use on the ground.

Installation of TR.1133 in selected aircraft of No. 2 Group so that they could communicate with fighter escorts was first proposed by the A.O.C.-in-C. Fighter Command in August 1941, and early in 1942, the supply of TR.1133 still being very limited, two Boston and three Blenheim squadrons were provided with enough equipment to enable aircraft of formation leaders only to be fitted. However, in practice it was found that there were serious drawbacks arising from the fact that the bomber leader when using V.H.F. R/T was unable to communicate with other bomber aircraft in his formation or with his crew. On 20 June 1942, Headquarters Bomber Command and Headquarters Fighter Command asked for the fitting of all No. 2 Group aircraft, then Bostons and Venturas, with TR.1133 and amplifier A.1219.[1]

Meanwhile, development of the TR.1356, a small two-channel V.H.F. transmitter/receiver, had reached a stage at which it was necessary to decide on the uses to which it was to be put and the qualities which would be required. A conference was therefore held at the Air Ministry on 14 August 1942 to discuss these points, with particular reference to the use of TR.1356 by No. 2 Group. However, it was agreed that, since aircraft of No. 2 Group were to be employed almost entirely under the operational control of Headquarters Fighter Command, they would need to be equipped with TR.1133 and subsequently TR.1143. At the same meeting it was decided that medium and heavy bombers would be unlikely to operate in conjunction with fighters and that installation of TR.1356 in them was unnecessary.

On 1 October 1942, the Air Ministry made final proposals for the fitting of aircraft in No. 2 Group, which by then included Mosquitos, Bostons, Venturas, and Mitchells. The two-way W/T installation was to be discarded, and V.H.F. R/T and Gee were to constitute the basic radio aids to navigation. The proposals were at first agreed by Headquarters No. 2 Group who, however, on 19 December 1942 decided not to discard the installation of two-way W/T in aircraft manufactured in the U.S.A., preferring for various operational reasons to keep the W/T facility at the expense of Gee.[2] Gee, however, was retained in the Mosquito on account of its greater radius of action. W/T equipment in the Boston, Ventura and Mitchell aircraft was American. The V.H.F. R/T fitting programme allowed for the fitting of Mosquito and Boston aircraft by 1 March 1943 and Ventura and Mitchell aircraft by 1 April 1943. No comprehensive ground organisation could be allotted to No. 2 Group because of the acute shortage of frequencies, and as a result frequencies and organisations were shared with other commands. There were considerable technical difficulties in the employment of British V.H.F. equipment side by side with American W/T installations, especially in the Mitchell, but these were overcome by various compromises.

It had been realised by the U.S.A. authorities early in the war that the R.A.F. V.H.F. R/T system was considerably in advance of anything then available to them. Consequently in 1942 one of the first TR.1143 prototypes was sent to the U.S.A., where the basic scheme was copied, details being modified to suit American components and methods. By agreement with the U.K. authorities the new set, SCR.522 (TR.5043), was made mechanically and electrically interchangeable with TR.1143, but it was arranged to have increased frequency coverage, from 100 to 156 megacycles per second, to meet operational requirements. It was supplied to the R.A.F. in considerable quantities to supplement TR.1143 production in the U.K.[3]

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[1] A.H.B./IIH/241/10/38(A). [2] A.H.B./IIH/241/10/38(A). [3] A.H.B./IIE/249.

The need for better quality R/T in bomber and Coastal Command aircraft made it necessary to consider the general introduction of V.H.F. R/T in heavy and medium bombers and possibly general reconnaissance and training aircraft. There were three possible courses of action ; the employment of TR.1143 (100 to 124 megacycles per second), the employment of SCR.522 or a similar installation (100 to 156 megacycles per second), or the development of a new installation which would meet all requirements. One main factor to be considered in the choice of a method was availability of frequencies. Until the summer of 1943 the frequency band 124 to 146 megacycles per second had been reserved for possible V.H.F. R/T equipment in aircraft other than fighters. The claims of the Fleet Air Arm and the United States Army Air Force had, however, to be met, and frequencies were allocated as :—

100 to 124 megacycles per second :	Royal Air Force.
124 to 128 megacycles per second :	Fleet Air Arm fighters.
128 to 131 megacycles per second :	Fleet Air Arm fighters (at sea only).
131 to 135 megacycles per second :	Fighter reconnaissance aircraft when SCR.522 installed in Mustang aircraft.
135 to 145 megacycles per second :	U.S.A.A.F. bombers and fighters.

Channel requirements of home commands were considered to be :—

Fighter Command	110
Bomber Command	120
Coastal Command	11
Tactical Air Force	11
Total	252

Receiver components of TR.1143 and SCR.522 were not capable of discrimination between signals less than 180 kilocycles per second apart. Consequently TR.1143 provided only 133 frequency channels in the 100 to 124 megacycles per second band. The General Electric Company was developing a multi-channel frequency-modulated installation which provided 288 channels, with 90 kilocycles per second spacing, in the 124 to 150 megacycles per second band. An experimental version of the equipment was given flight tests in July 1943. It was possible to modify it so that it would make available 266 channels in the 100 to 124 megacycles per second band, but extension of the frequency coverage up to 130 megacycles per second was suggested in order that Fleet Air Arm requirements might also be covered.

When considering its adoption it was possible to visualise its introduction into Service use in two stages. The first was retrospective installation in Fighter Command. This would be necessary as Fighter Command was already using all the channels available at 180 kilocycles per second spacing in the 100 to 120 megacycles per second band. When all aircraft had been equipped the command could be allotted the band from 100 to 110 megacycles per second in which the requirement of 110 channels could be met with 90 kilocycles per second separation. The second stage would be to install the equipment in aircraft of Bomber Command, Coastal Command and the Tactical Air Force. The Bomber Command requirement of 120 channels could be met between 110 and 121 megacycles per second, that of Coastal Command between 121 and 122, and that of the Tactical Air Force between 122 and 123 megacycles per second. This would leave 123 to 130 megacycles per second, approximately 77 channels, for the Fleet Air Arm.[1]

The G.E.C. equipment offered advantages other than a greater number of channels. A simple controller in the pilot's cockpit enabled remote selection to be made of all available channels. The remote control was achieved by means of two click-stop dials. The stops on the dials were given letters of the alphabet. Frequencies were selected by turning the dials to a particular combination of two letters. The installation employed four crystals which were the same in every set so that provisioning of crystals was not complicated, and since the crystals were permanent fixtures and channel selection automatic there was no need to set up frequencies before flight. However, there were certain research problems still to be overcome in the frequency modulation technique, particularly with the close channel spacing envisaged, and since the technique was very much of an unknown quantity, especially in connection with aircraft installations, there was a great element of risk in changing over to it during wartime. The chief advantage of frequency modulation over amplitude modulation was its improved signal to noise ratio, but a disadvantage was that direction-finding was difficult and the incorporation of beam approach facilities in a frequency-modulated receiver might not be possible.

In July 1943 the operational requirements of home commands were reviewed. In Fighter Command TR.1143 was meeting requirements satisfactorily except that the need for more channels was ever-increasing, and until more could be made available the flexibility of operations was becoming somewhat constricted. The problem of crystal distribution was already complicated and it was fairly certain that in the near future night fighters would require from 12 to 16 channels and day fighters 8, to be selected at will. In Coastal Command there were two separate requirements, one for general reconnaissance aircraft and the second for strike aircraft. The major need in reconnaissance aircraft was long-range R/T communication with escort vessels ; a range of 100 miles at low heights was required, and this was not likely to be obtained with V.H.F. equipment. Another need was for R/T control in co-ordinated attacks against U-boats for which an air-to-air range of 10 miles was essential.[2] The main requirements for strike aircraft were good tactical control, R/T communication with fighter escorts, and long-distance W/T communication with base. The first two were being met with TR.1143 but it was considered that eight channels, to be selected at will, would ultimately be needed. Strike aircraft might also be employed on controlled interception of E-boats and other light surface craft in which case they would be placed under the control of the appropriate fighter organisation.

Bomber Command required an R/T system for airfield control at ranges up to 75 miles when aircraft were at 3,000 feet, short-range air-to-air R/T for formation control, R/T communication between bombers and fighter escorts, and air-to-air R/T at ranges of 30 to 50 miles for the new Master Bomber

[1] A.H.B./IIE/44.

[2] In 1943 development of an airborne R/T relay station was begun in order that the ground-to-air range of V.H.F. R/T might be extended. The project was considered to be of particular value for increasing the range of communication with low-flying aircraft ; effective range between ground stations and aircraft at 500 feet was normally only about 30 miles. To overcome the limitations imposed by the use of very high frequencies the airborne relay station was equipped with a combination of TR.1196 and TR.1143. TR.1196 was used for communication between relay aircraft and ground and TR.1143 between relay aircraft and forward aircraft.

technique.[1] Successful application of this new technique was dependent upon efficient R/T communication between the master bomber and aircraft of the main force when in the target area. The technique was applied in two forms, one in which the master bomber exercised only loose control over the main force, limiting his instructions to those necessary to ensure that the attack was carried out as planned, and a second and more rigid system in which the master bomber assumed direct and close control of the main force, and varied the method and/or time of attack at his discretion. Various methods of putting the technique into practice were being tested. The main ones were use of T.1154 in the controlling aircraft and R.1155 in the other aircraft for R/T communication on a frequency near 7,000 kilocycles per second, when ranges of up to 25 miles were obtained, and use by the master bomber of a modified TR.1143 transmitting on about 36 megacycles per second, the remainder of the aircraft receiving his instructions by using S.B.A. receivers. The methods were not entirely satisfactory and in August 1943 use of TR.1196 on the Darky frequency was decided.[2] In the course of raids against Turin on 7/8 August and Milan on 12/13 August good results were obtained, but effective interference was expected on the Darky frequency over Germany. It was therefore decided to use both T.1154 and TR.1196 in the pathfinder aircraft and R.1155 and TR.1196 in the rest of the bomber force in order that the strength of signals and range of reception might be improved and to provide two communication channels. This method became standard practice, but the efficiency of the system was often impaired by too much talking and interruption by main force aircraft and by the lack of clear-cut concise instructions from the master bomber.[3]

The effectiveness of bombing raids was greatly increased by employment of the Master Bomber technique, but it was considered in No. 5 Group, which provided the master bombers for attacks against multiple objectives, that the effectiveness could be doubled by use of V.H.F. R/T.[4] Interference experienced when TR.1196 was used was too great to permit anything like maximum efficiency being attained, and control by W/T was too slow and cumbersome. Unless the master bomber was able to pass his instructions instantly it was possible for the centre of the whole attack to shift appreciably within a minute or so. The ideal solution was installation of V.H.F. R/T equipment in all aircraft of Bomber Command, but it was thought that until that could be brought about its installation in aircraft of No. 5 Group would result in improvement of bombing results since information could be passed accurately and quickly between aircraft of the marking force. Consequently, in April 1944 Headquarters Bomber Command asked for special provision to be made for squadrons of No. 5 Group. In May 1944 it was decided that sufficient TR.1143 installations could be made available for that purpose, but the remainder of the command would have to be equipped with SCR.522. In June 1944 aircraft

[1] A.H.B./IIE/44. V.H.F. R/T had been employed for air-to-air communication during the attacks against the Moehne and Eder dams.

[2] A.H.B./IIH/241/3/838. The Master Bomber technique was developed to provide the bomber force with minute-to-minute information of the progress of a raid, to issue warnings of misplaced markers, to give the position of decoys, and generally to assist the bomber force to attack the correct aiming-point. The master bomber stayed in the immediate vicinity of the target during the whole period of attack, and reserves were briefed to take his place if necessary.

[3] A.H.B./IIH/241/3/838. A memorandum on this subject was sent to all Bomber Command groups on 3 May 1944.

[4] A.H.B./II/70/373.

of No. 5 Group were fitted with TR.1143, and in the following month those of No. 1 Group were fitted with SCR.522, installation of which in all heavy bombers of Bomber Command had been completed by April 1945, when the fitting of TR.1430 in Mosquito bomber aircraft was begun. Despite the large measure of success achieved with V.H.F. R/T, a W/T communication channel was also made available. It provided an insurance against poor R/T communications at low altitudes, enemy jamming, enemy spoofing and failure of V.H.F. R/T equipment.[1] It also provided a means for keeping group headquarters informed of the progress of an attack and thus enabled the A.O.C. to make the best use of his reserve aircraft and to cancel an attack if necessary.

Further Development of Aircraft Communications Equipment

On 3 August 1943 a conference was held at the Air Ministry to discuss aircraft R/T communication requirements. It was decided that it was not possible to meet future V.H.F. R/T requirements of the Royal Air Force with existing equipment and that the development of new equipment was necessary. It was considered that a single equipment to meet the requirements of both R.A.F. and the F.A.A. could not be developed, and it was agreed to produce the G.E.C. installation to meet all R.A.F. requirements other than those of Coastal Command and to develop another equipment to meet the needs of the Fleet Air Arm and Coastal Command. The time factor was important and delay in the development and production of the G.E.C. project in order that frequency modulation might be incorporated in addition to amplitude modulation could not be accepted. The new requirement was to be based fundamentally on amplitude modulation but provision of frequency modulation for air-to-air working, selection of either being made by a switch, was to be considered. The installation was to be the same size as, and interchangeable with, TR.1143 and TR.1196. Six models of an interim version, known as TR.1407, covering about 100 to 130 megacycles per second, were to be ready for Service trials in September 1944. The final version, providing full frequency coverage from 100 to 156 megacycles per second with 622 frequency channels, was to be known as TR.1533.[2]

Six TR.1407 installations were made ready in September 1944 as planned, but Service trials showed that further development was necessary before production could be started, and the sets were returned to the General Electric Company for improvements to be included. By May 1945 renewed Service trials of installations in Wellington, Beaufighter and Lancaster aircraft had been completed by the Signals Flying Unit at Honiley and the Bombing Development Unit at Feltwell. In general it was considered that air-to-ground performance with amplitude modulation was adequate but performance with frequency modulation was unsatisfactory.[3] The principle of frequency selection employed was satisfactory but many improvements were recommended for inclusion in the equipment before production could be started.

Also well under development before the end of the war was a pilot-operated installation, TR.1501/1502, designed to meet the requirements of Coastal

[1] A.H.B./IIE/76A.

[2] Difficulties encountered with the design of fully tropicalised components were one cause of delay in development of TR.1533.

[3] A.H.B./IIE/44.

Command and the Fleet Air Arm. It was planned to provide reliable multi-channel V.H.F. R/T, and two-channel pre-set H.F. R/T and W/T, for air-to-air, air-to-ship, and air-to-ground use. The method of channel selection employed was the same as that used in TR.1407, and the V.H.F. unit, TR.1501, was built on the same lines as that installation, but covered the full frequency band from 100 to 156 megacycles per second with 180 kilocycles per second separation. Progress of development was hindered by difficulties encountered with frequency selections and other technical problems. The H.F. R/T–W/T unit, TR.1502, covered from 2 to 7 megacycles per second. Both sets used a common power supply and were built to standard dimensions and weighed about 55 pounds.

Design had also been completed of equipment A.R.I.5332, projected to replace the existing general purpose aircraft installation, which was intended to be suitable for use in any part of the world. It was built in three main sections comprising V.H.F., H.F. and M.F. units which were rack-mounted and readily removable, somewhat reminiscent of the three-panel system used in army co-operation squadrons shortly after the First World War. The installation consisted of five units, V.H.F. transmitter/receiver (incorporating features of TR.1407), H.F. transmitter, H.F. receiver, M.F. transmitter and M.F. receiver, and was so designed that one or more could be fitted in an aircraft according to requirements. Ability to receive on M.F. whilst transmitting on H.F., and to receive on H.F. whilst transmitting on M.F., was a specification, but simultaneous transmission on H.F. and M.F. was not; simultaneous transmission and reception on V.H.F. and H.F. was to be possible. The V.H.F. transmitter and receiver had a separate power supply. The M.F. and H.F. transmitter units operated from a common power supply, but the M.F. and H.F. receiver units were given a separate supply so that use of the transmitter supply was avoided during prolonged listening-out periods. The frequency range covered was 200 to 1,200 kilocycles per second, 1·5 to 17·5 megacycles per second, and 100 to 156 megacycles per second. An intercommunication system was associated with the installation and, consequently, production of A.1342 was cancelled, although its development, as a replacement for A.1134, had been completed. No aircraft requiring the simultaneous operation of more than eight intercommunication positions were likely to be in production before A.R.I.5332 was available.[1]

During 1944 development was also begun of an automatic radio compass, A.R.I.5428, principally for use in transport aircraft. To a large extent it was developed in parallel with A.R.I.5332, as the H.F. receiver was common to both. The radio compass was to be effective at ranges up to 400 miles from a 300-watt transmitter with accuracy of plus or minus 2 degrees. It was designed to provide measurement and indication of the bearing, relative to aircraft heading, of a selected transmitting station, automatically or by manual operation (when an aural minimum was used), and standby communication reception of both modulated and unmodulated signals, including those from radio ranges.

An airborne voice-recording system was made an operational requirement in the summer of 1944. One reason was a desire to obtain more accurate and detailed information, in correct chronological sequence, of observations made

[1] A.1342 was a two-stage amplifier which was designed to be stowed in any convenient position and used in conjunction with a control unit installed at the wireless operators station (A.H.B./IIE/44).

and events which occurred during operational bombing sorties. It was considered that much useful information was being lost because of excitement, forgetfulness and fatigue of crew members. Similar facilities were required for recording tactical reconnaissance observations. No existing equipment fulfilled the requirement, which entailed five to six hours recording time, 'press to record' operation, and high-fidelity reproduction. Suitably modified Model 2ON magnetic wire recorders were being used by the United States Navy for recording sono-buoy transmissions, and Headquarters Coastal Command considered that Model 2ON would meet the urgent requirement of that command for recorders to be used with sono-buoys.[1] Investigation revealed that the Bomber Command requirement could be met with the same equipment until such time as equipment suitable for universal use throughout the R.A.F. could be produced. Requisitioning action was therefore taken to permit installation in about 500 aircraft and maintenance for about 18 months whilst a recorder was developed at the R.A.E.[2] A development contract for recorders and associated play-back units was also placed with the radio industry.

Beechnut

As the effectiveness of fighter and close-support operations became increasingly dependent on the efficiency of aircraft communication, the vulnerability of the V.H.F. R/T system to jamming became more important. It was considered that the enemy might choose the time of an assault on the Continent to attempt to render the system ineffective by jamming, and after the merits of various proposals had been closely studied, the Air Interception Committee decided on 3 September 1943 to adopt a measure known as 'Beechnut' which was recommended by the Director-General of Signals as being the most suitable.[3] Beechnut, a form of impulse signalling, did not interfere with normal two-way R/T working but provided a transmission, proof against jamming, which conveyed information, from ground to air only, in the form of ideographs, and enabled automatic or semi-automatic acknowledgment to be made from air to ground. This was achieved with the aid of additional equipment, both in the aircraft and on the ground, working in conjunction with the V.H.F. R/T equipment.[4]

The ground equipment consisted of a control unit and a sender. The control unit contained a keyboard, manipulated in a similar manner to a typewriter, and incorporated 66 ideograph buttons arranged in six columns of eleven each, a call-sign selector switch, control buttons and signal lamps. The sender, which controlled the V.H.F. R/T transmitter, served two purposes. It stored a message containing the six ideographs (one from each column of buttons) which was set up on the control unit, and sent the message, in the correct sequence and prefaced by the appropriate call-sign, when the 'send' button on the control unit was pressed. Provision was made at the control

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[1] *See also* Royal Air Force Signals History, Volume VI: 'Radio in Maritime Warfare'.

[2] A.H.B./IIE/44. About 250 Model 50 play-back units were also ordered.

[3] A.H.B./IIE/28/24(A). Meetings of R.C.M. Board. A.1420, a one-kilowatt amplifier for use with a V.H.F. R/T ground transmitter, was also developed. When used in conjunction with a high-gain aerial system ranges up to 375 miles with aircraft at 30,000 feet could be obtained, and V.H.F. R/T could be operated in spite of considerable jamming.

[4] A.H.B./IIS/110/9/5A. A.E.A.F. File S.14068.

unit for sending to any one of 40 aircraft on one V.H.F. R/T channel by means of a call-sign selector switch. By pressing the 'send all' instead of the 'send' button, the message could be sent to all aircraft which were listening-out to Beechnut on that channel. Acknowledgment signals from aircraft could be received both aurally and by means of a signal lamp on the control unit.

In aircraft, the V.H.F. R/T receiver fed into a selector unit which discriminated against wrong call-signs, unwanted signals, and incorrect messages, and operated an indicating unit in the pilot's cockpit. The indicating unit consisted of six independently rotating drums around the peripheries of which were painted various ideographs. The selector unit caused each of the six drums to rotate in turn so that a row of six symbols was displayed to the pilot, who, by means of a simple code, could read off the message. Also mounted in the pilot's cockpit was a control unit consisting of an on/off switch, an acknowledgment button, and a red and a green lamp. The red lamp glowed whenever a Beechnut transmission was being made on the channel to which the receiver was tuned, and so warned the pilot not to transmit. The green lamp glowed when the Beechnut transmission was directed to his own aircraft and so called his attention to the indicating unit. When the message reached the aircraft and had been correctly set up on the indicating unit, the V.H.F. R/T installation was automatically switched over to 'transmit' and radiated an acknowledgment signal in the form of a 'pipsqueak' tone for 2·2 seconds. The acknowledgment button in the pilot's control unit was not used for this automatic acknowledgment, but the pilot could be briefed to use it when, for instance, he fulfilled the instructions displayed on the indicating unit. When he did use it, the acknowledgment signal was not transmitted immediately, but a circuit was set up such that the signal was transmitted at the request of the ground station. This function was set in motion when the appropriate button on the ground control unit was pressed. This caused a part of the aircraft call-sign to be transmitted, which, when received by the aircraft installation, completed the circuit so that the signal was sent.

Provision was made for scrambling the message on the ground and reversing the process in the aircraft. This was brought about by changing the order in which the drums in the indicating unit were actuated. As there were six drums there were 720 ways of arranging them. The order of actuation was governed by the wiring on the W-plugs fitted in the selector unit and the ground sender. It was therefore important that all ground stations, and all aircraft required to work with them, were initially fitted with the same scramble plug. In the same way that the frequency of the Beechnut channel had to be decided before a flight, so had the scramble combination to be determined before the system was employed.

On the ground the call-sign of the aircraft to which a message was to be sent was set up by rotation of a switch on the control unit. In an aircraft the call-sign was determined by a W-plug, similar to the scramble plug, inserted in the panel of the selector unit. It was therefore very necessary to emphasise that call-signs were applied to aircraft and not to pilots. If a pilot had to change aircraft, he used the Beechnut call-sign of the new aircraft unless special measures were taken before he left the ground.

The efficiency of Beechnut depended largely on the length of time for which it could be employed before the enemy found means to neutralise it and on the thoroughness of organisation for ensuring that the right message reached the right aircraft. There were three variables in the aircraft installation which required rigid control in order that the desired results could be achieved; call-sign, scramble combination, and 'supersonic' frequency channel.

Arrangements were made, with most stringent security measures, to provide enough equipment for installation in all aircraft of night-fighter squadrons, in three aircraft of each fighter and fighter/bomber squadron, and in one aircraft of each day-bomber squadron, and for the appropriate ground stations to be suitably modified. The necessary modifications were made to aircraft V.H.F. R/T installations but the Beechnut equipment was held ready for fitting until such time as enemy jamming of V.H.F. R/T made its employment necessary; in the event the emergency did not arise. Neither Beechnut nor the high-power amplifier, A.1420, was required on D-Day or subsequently, since the enemy made no serious attempt to interfere with the V.H.F. R/T system.

TABLE No. 1

OPERATIONAL CHARACTERISTICS—OBOE MARK I STATIONS. December 1943

Station and Number	Position and Aerial Reference Numbers	Height of Aerials above Mean Sea Level Feet	Radio Frequencies			Baillie Beam Positions Azimuth Arc
			Transmit	Transmit	Receive	
TRIMINGHAM I 9121	52° 53′ 36·34″ N. 01° 24′ 11·64″ E.	246	216	228	232	
TRIMINGHAM II 9131	52° 53′ 24·27″ N. 01° 24′ 41·37″ E.	212	228	236	232	Caistor 078–140 degrees
WINTERTON II 9161	52° 42′ 27·472″ N. 01° 42′ 01·508″ E.	56	212	220	236	
HAWKSHILL DOWN I 9132	51° 11′ 27·843″ N. 01° 23′ 53·219″ E.	160	216	228	232	
HAWKSHILL DOWN II 9162	51° 11′ 30·081″ N. 01° 23′ 53·398″ E.	131	212	220	236	Oldstairs 0–360 degrees
SWINGATE 9122	51° 08′ 07·050″ N. 01° 21′ 24·233″ E.	397	228	236	232	
WORTH MATRAVERS I 9142	50° 35′ 42·370″ N. 02° 03′ 07·850″ W.	416	216	228	232	Worth Matravers 070–230 degrees
WORTH MATRAVERS II 9152	50° 35′ 41·496″ N. 02° 03′ 09·436″ W.	412	212	220	236	
SENNEN 9141	50° 03′ 56·690″ N. 05° 40′ 14·053″ W.	304	216	228	232	Constantine 070–230 degrees
TREEN 9151		326	212	220	236	

TABLE No. 2

OPERATIONAL CHARACTERISTICS—OBOE MARK II (FIXED) STATIONS

December 1943

Station and Number	Position and Aerial Reference Numbers	Height of Aerials above Mean Sea Level Feet	Baillie Beam Positions Azimuth Arc
WINTERTON I 9211	52° 42′ 30·619″ N. 01° 41′ 59·293″ E.	86	Caistor 078–140 degrees
HAWKSHILL DOWN II 9212	51° 11′ 25·913″ N. 01° 23′ 49·370″ E.	170	Oldstairs 0–360 degrees
WINTERTON III 9221	52° 42′ 25·146″ N. 01° 42′ 03·101″ E.	54	Caistor 078–140 degrees
HAWKSHILL DOWN IV 9222	51° 10′ 57·532″ N. 01° 23′ 42·509″ E.	221	Oldstairs 0–360 degrees

TABLE No. 3

OPERATIONAL CHARACTERISTICS—OBOE MARK III STATIONS

January 1944

Station and Number	Position and Aerial Reference Numbers	Height of Aerials above Mean Sea Level Feet	Baillie Beam Positions Azimuth Arc
CLEADON III 9313	54° 58′ 07·363″ N. 01° 22′ 57·579″ W.	275	Cleadon 090–140 degrees
	54° 58′ 07·855″ N. 01° 22′ 56·760″ W.	275	
CLEADON IV 9323	54° 57′ 58·835″ N. 01° 22′ 49·884″ W.	265	
	54° 57′ 59·318″ N. 01° 22′ 49·022″ W.	265	
WINTERTON IV 9311	52° 42′ 19·960″ N. 01° 42′ 05·830″ E.	52	Caistor 078–140 degrees
	52° 42′ 19·547″ N. 01° 42′ 06·684″ E.	52	
WINTERTON V 9321	52° 40′ 59·101″ N. 01° 42′ 59·270″ E.	49	
	52° 40′ 58·644″ N. 01° 42′ 58·431″ E.	49	
HAWKSHILL DOWN V 9312	51° 10′ 55·285″ N. 01° 23′ 41·595″ E.	225	Oldstairs 0–360 degrees
	51° 10′ 55·595″ N. 01° 23′ 41·604″ E.	225	
HAWKSHILL DOWN VI 9322	51° 10′ 52·342″ N. 01° 23′ 35·939″ E.	221	
	51° 10′ 51·683″ N. 01° 23′ 35·644″ E.	221	
TILLY WHIM 9314	50° 35′ 42·035″ N. 01° 57′ 21·718″ W.	282	Worth Matravers 070–230 degrees
	50° 35′ 41·501″ N. 01° 57′ 22·407″ W.	284	

NOTE: 3150–3180 and 3210–3240 megacycles per second.

TABLE No. 4

OPERATIONAL CHARACTERISTICS—OBOE MARK II (MOBILE) STATIONS

April 1944

Station Type and Number	Radio frequencies in megacycles per second	Baillie Beam Positions Azimuth Arc
Tilly Whim II (W.M.) 9411	3,150–3,135	Worth Matravers 070–230 degrees
Tilly Whim III (S.M.) 9412	3,240–3,225	Worth Matravers 070–230 degrees
Tilly Whim IV (S.M.) 9412	3,195–3,180	Worth Matravers 070–230 degrees
Beachy Head I (S.M.) 9421	3,195–3,180	Oldstairs 0–360 degrees
Beachy Head II (S.M.) 9421	3,240–3,225	Oldstairs 0–360 degrees
Beachy Head III (W.M.) 9411	3,150–3,135	Oldstairs 0–360 degrees
Hawkshill Down II (S.M.) 9212	3,240–3,225	Oldstairs 0–360 degrees
Hawkshill Down IV (S.M.) 9222	3,195–3,180	Oldstairs 0–360 degrees

TABLE No. 5

STATISTICS OF OBOE SORTIES

1942–1945

	R.A.F.					U.S.A.A.F.				
	Raids	Total Oboe Sorties	Successful Oboe Sorties	Percentage	Main Force Sorties	Raids	Total Oboe Sorties	Successful Oboe Sorties	Percentage	Remarks
1942										
Dec. ..	13	25	15	60	8					
1943										
Jan. ..	18	35	28	72	623					
Feb. ..	40	55	34	71	945					
March	45	84	57	68	1,883					
April ..	7	50	36	72	1,609					
May ..	7	78	58	74	3,984					
June ..	10	84	55	65	3,949					
July ..	8	64	42	65	2,400					
Aug. ..	9	76	44	63	2,218					
Sept. ..	11	66	43	65	1,223					
Oct. ..	26	150	86	59	783	1	?	—	—	Jamming
Nov. ..	29	210	101	47	731	1	2	—	—	Jamming
Dec. ..	29	192	102	51	54	3	3	—	—	Jamming
1944										
Jan. ..	57	318	185	58	256	4	6	2	33	
Feb. ..	65	257	147	57	12	—	—	—	—	
March	121	447	267	60	2,141	8	10	6	60	
April ..	72	346	214	62	4,693	4	14	9	64	
May ..	107	553	300	54	6,089	14	36	29	80	
June ..	138	745	519	69	12,218	54	112	65	58	
July ..	140	699	493	71	8,647	72	163	131	80	
Aug. ..	165	720	532	74	7,941	36	73	59	80	
Sept. ..	130	773	486	63	6,720	3	3	2	67	
Oct. ..	114	623	330	53	9,210	16	34	8	23	
Nov. ..	67	546	227	41	7,083	42	157	90	57	
Dec. ..	61	471	222	45	7,480	69	146	52	35	
1945										
Jan. ..	32	223	142	64	2,626	61	118	39	33	
Feb. ..	64	464	252	54	5,895	99	204	95	47	
March	75	551	362	66	9,283	122	471	262	55	
April	95	569	391	69	6,688	17	107	43	40	
May ..	36	152	133	88	2,548	1	4	1	25	

TABLE No. 6

DEPLOYMENT OF TYPE 9000 CONVOYS

1 March 1945

Unit	Site	Convoy	Channel	Cabin
No. 1/9000	Molsheim	9422	12A	15
		9431	13A	14
		9451	11C	9
		9452	11B	12
No. 2/9000	Laroche	9442	13A	6
		9442	11B	7
		9431	11C	13
		9412	12	62
No. 3/9000	Florennes	9432	13A	1
		9432	11B	2
		9452	11C	11
		9421	12	64
No. 4/9000	Commercy	9441	11B	3
		9441	13A	5
		9451	11C	10
		9421	12	63
No. 5/9000	Rips	9411	11B	51
		9411	13A	52
		9412	12	61
		9422	11C	16
No. 6/9000	Tilbourg	9461		17
		9461		18
		9462		19
		9462		20

TABLE No. 7

OBOE ACCURACY DATA

Type of Operation	Height in feet	Period	Average error in yards
Bombing Operations with Oboe Mark I	—	December 1942–February 1943	650
Bombing Operations	—	March and April 1944	600
Bombing Operations	26,000	May 1944	300
Bombing Trials—Oboe Mark I ..	12,000	April 1945	227
Bombing Trials—Oboe Mark II ..	12,000	April 1945	176
Bombing Trials—Oboe Mark II ..	28,000	April 1945	274

TABLE No. 8

STATISTICS OF GEE-H SORTIES

October 1944

Date	Target	Gee-H Sorties		Failures			Missing
		Used Gee-H	Bombed on Gee-H	Technical	Not Gee-H	Unclassified	
14	Duisberg ..	31	6	3	3	19	—
18	Bonn	41	20	7	1	12	1
22	Neuss	26	18	1	—	7	—
23	Essen	18	14	3	—	1	—
26	Leverkusen ..	34	29	3	—	2	—
30	Wesseling ..	34	30	4	—	—	—
31	Bottrop ..	35	31	2	—	2	—
	TOTALS	219	148	23	4	43	1
	Excluding Duisberg TOTALS	188	142	20	1	24	1

Note.—On the Duisberg raid crews were briefed to bomb visually although they were to operate Gee-H. The majority of the 19 unclassified failures used Gee-H for tracking but did not continue with its use because the releasing pulse was weak. Six navigators reported that they could have bombed on Gee-H. If the Duisberg raid is excluded, 142 of 188 aircraft, that is 75·5 per cent, successfully bombed on Gee-H.

TABLE No. 9

DETAILS OF GEE-H RAIDS

October 1944

Target	Time over Target	Height in Feet	Tracking Station and Range	Releasing Station and Range	Angle of Cut	Weather
					Deg.	
Duisberg	0845	18,000	Commercy 191 miles	Florennes 124 miles	032	Layers of cloud, tops 8–14,000 feet.
Bonn	1100	17,000	Florennes 111 miles	Commercy 149 miles	046	Clear, visibility good.
Neuss	1600	17,000	Antwerp 105 miles	La Roche 77 miles	056	Nine to ten-tenths cloud, tops 8–10,000 feet.
Essen	1930	16,500	Antwerp 121 miles	La Roche 99 miles	047	Ten-tenths cloud, tops 10,000 feet.
Leverkusen	1530	16,500	Commercy 165 miles	La Roche 76 miles	025	Ten-tenths cloud, tops 10,000 feet.
Wesseling	1200	16,500	Commercy 152 miles	La Roche 68 miles	032	Ten-tenths cloud, tops 9,000 feet.
Bottrop	1500	16,500	Volkel 55 miles	La Roche 104 miles	064	Ten-tenths. cloud, tops 9,000 feet.

TABLE No. 10

STATISTICS OF SHORAN SORTIES

9–18 April 1945

Method of Bomb-aiming	Sorties		Failures							Average percentage of bombs within 600 ft. of target
	Airborne	Effective	Weather	Dust, Haze, Smoke, etc.	Human Errors	Enemy Opposition	Shoran Equipment	Other aircraft equipment	Other causes	
Shoran Number	443	378	8	—	32	3	22	—	—	
Percentage	—	85·3	1·8	—	7·2	0·7	5	—	—	80·1
Visual Number	1,097	886	41	41	59	18	—	27	25	
Percentage	—	80·8	3·7	3·7	5·4	1·6	—	2·5	2·3	72·1

APPENDIX No. 1

SURVEY OF GERMAN CENTIMETRIC RADAR RESEARCH AND PLANS, FEBRUARY 1944

Extracts from a translation of a lecture given by Dr. Brandt at a meeting presided over by Field Marshal Milch in the *Herman Goering Saal* on 8 February 1944.

. . . The centimetric waves, as compared to those used to date, have certain advantages in that they can be more clearly focused. A fact, which up to now has not been generally known, is that they possess greater reflecting properties against aircraft. *Staatsrat* Esau has always maintained that this was the case and in the meantime it has been in fact recognised. They are also less easy to jam and are obviously less liable to Window interference and have afforded, for the first time, the possibility of producing a ground scanning apparatus, that is, they have brought a television-like picture into the aircraft. The enemy has recognised these facts and has introduced a 'ground scanner' to ensure success in his attacks against our cities and U-boats (H2S and A.S.V.). He has already introduced this equipment on a large scale. The enemy has also clearly recognised that these waves have other important spheres of usefulness and has equipped his south coast with these sets as a defence against our ships ; he also uses them in aircraft and we assume that they have also been installed further inland for defence against our aircraft. We are firmly convinced that they are used on his ships against our naval units.

Up to a year ago, we had—with the exception of research and development—done very little work in the centimetric sphere. In the past year we have tried to make up the deficit as far as was possible with the means at our disposal. It was necessary to collect new data and then to copy the British 'ground scanner' (H2S). We then had to determine the reflective properties against aircraft and what diffusive properties over water were obtainable. We are now in a position to state that the necessary data has been collected and that the successful completion of the task is now only a question of the manpower available for its completion. In the study of these problems, over the past few months, we have enjoyed, both in the *Luftwaffe* Technical Control Office (*Technisches Amt*) as well as in all departments of the Navy, the closest, I may say the friendliest, co-operation of all concerned. We have co-operated in tackling each problem that has arisen and thus achieved the clarity which is ours today. . . . The British H2S (*Rotterdam*) cannot, on account of its size, he built into a German aircraft. We have therefore constructed a smaller set, the *Berlin*, details of which will be explained. It can be broken down into five main components : the high-frequency head, the pulse and intermediate frequency parts, the presentation unit and the control unit. The aerial system used on this set will have a performance at least equal to that of the British H2S. The British have scored a success with the H2S. In the early stages they worked with comparatively incomplete equipment. They used equipment which was very much in its early experimental stages and had to overcome all kinds of 'teething troubles' connected with equipment and technique. In the early stages, technicians were sent out on flights because the fundamental significance of the project was fully appreciated. They recognised that radar was the eyes of the fighting units and that these sets were at their best when their wavelengths were nearest to light waves.

We must realise that in the course of introducing the *Berlin* equipment, we shall also have to employ an increasing number of technicians ; we are in complete agreement with the *Luftwaffe* Technical Control Office that failure in this respect would be a grave mistake, the result of which would be reluctance on the part of our forces to introduce this equipment, whereas, it is, in fact, our aim to introduce something entirely new. The British have recognised how this equipment can be further improved. One can obtain a clearer picture when used for ground scanning and the diffusive properties at sea, particularly against U-boats, can be improved.

(C50782)   Y*

With this object in view they have developed a set that works on the 3-centimetre wave-band of which the angular resolution is three times as great. Unfortunately, we know nothing regarding the diffusive properties over sea but, in view of the rule that range is dependent upon the amplitude (*Aufstellungshoehe*) in wavelengths, we can expect advantageous results.

In the course of our work together over the past year it has become clear to us that our technical research in the field of the shorter waves must be carried on and we discussed this problem with *Staatsrat* Esau some weeks ago. On the same day that the first enemy 3-centimetre set was discovered it was possible to produce a German valve with the same frequency band. It is essential that we should, first of all, copy this set and, secondly, that we equip our *Berlin* set with a 3-centimetre head in order to gain the information already in possession of the British.

The next important question is to what extent the other radar equipment will have to be switched over to these wavelengths. I have already mentioned that the decisive experiments into the reflective properties of aircraft first gave us the incentive to work in other fields on 9 centimetres. Opinions on this matter differed but the opinion of *Staatsrat* Esau that aircraft reflected considerably better than had been thought was accepted. As a result we must now go into the question of the 3-centimetre wavelength for other radar equipment. . . . The normal viewing equipment of our aircraft is the *Lichtenstein SN.2* with which an approach is made. The spotting of the target over the last few hundreds metres is done by the pilot with the naked eye. In addition, in conjunction with the technical control office, fire-control equipment is being developed which will make it possible, as in the case of A/A control equipment, to fire merely from indicator readings or dots on the cathode-ray tube. This fire-control equipment is being developed on 50 centimetres in two types : one is the *Pauke A*, an excellent type, the other is *Li.C2B*, a less efficient type. We hope that the question as to which of these two techniques is the right one for fire-control equipment will be answered by the end of the month and is dependent on the result of our experiments. It is essential that we should already be thinking about a successor to the *Li.SN 2* as there is a danger that it will be jammed in the near future. For this reason spot frequencies have been introduced, but these can also be jammed. In addition we still have the *Neptune V* which can also be jammed and is susceptible to Window interference.

We must therefore produce some new kind of equipment. We have at our disposal the *Berlin* which can be taken over practically unaltered, merely needing another type of aerial system. There are two possibilities with regard to viewing equipment for the *Berlin* ; firstly an aerial system such as that of the *Li.SN 2*, built into the turret of the aircraft, which does not give an all-round view but only 70 degrees each way, but which gives a complete panoramic picture of the aircraft present within that arc (*Berlin N1*). The other possibility (*Berlin N2*) is important where the turret cannot be used ; it is to use a simple aerial rod coming vertically out of the wave-front (*Wellenfront*), fixed in front of the turret and capable of swivelling horizontally and vertically by mechanical means, thus attaining the same results as those achieved electrically on the *Li.SN 2*. These are in fact routine experiments requiring no new developments. The *Berlin* set can be taken over in its entirety for the *Berlin N1* and for the *Berlin N2* parts from the *Li.SN 2* will probably have to be used.

Now to the question of firing equipment (*Pauke S*). What is required is an apparatus with a parabolic reflector which can be large or small according to the range required, and with a high-frequency head and intermediate-frequency component of the *Berlin* set. The other parts could be taken from the *Pauke A*. Here again, no new development of equipment is necessary, a combination of these two sets being all that is required. There are a number of technical questions concerning this which will have to be investigated.

Both the basic problems created by airborne fire-control and viewing equipment can therefore be solved on the centimetric wave-band. At the same time, we must consider testing the *Berlin* set as a ground scanner on the 3-centimetre wave-band, to discover what the new enemy technique against aircraft can accomplish. It is obvious that by using an aerial array of the same size one obtains a much sharper focus and better angular resolution of the aircraft. Furthermore, if the improvement shown in the reflective properties of aircraft between 50 centimetres and 9 centimetres continues in the same proportion, it might be possible to use smaller aerial arrays. This is important because of the question of using the turret. As soon as the high-frequency head is available, we must, without undertaking any further developments, apply this knowledge to the 3-centimetre wave-band in order to ascertain whether it would also be possible to switch fire-control equipment over to 3 centimetres at a later date. Thus a much smaller reflector would be possible. This will be particularly important in the problem of controlling the movable guns in bombers by radar, for then for the first time we would have reflectors small enough to be fitted into a bomber.

We must remember that the enemy is working with great intensity in the 1-centimetre field. He certainly realises the importance of this frequency and I am firmly convinced that his laboratories are paying a great deal of attention to 1-centimetre research. I even suspect that he is already testing it at his experimental stations. Consequently we in Germany must allocate strong forces to this field of research. The problem here is not that we are unable to solve it, but rather that if we do not assign sufficient manpower to the task, the enemy will, one day, give us a big surprise. . . .

. . . One may question whether this or that particular piece of active radar equipment is really necessary, but the development of passive radar equipment, that is observation sets, is absolutely essential since, if one does not possess them, one is delivered defenceless into the enemy's hands. We have, unfortunately, experienced what it means to be without this equipment for some time. We must therefore produce a ground radar observation set operating between 2·5 and 12 centimetres and we must seriously consider what is needed on this frequency band to avoid finding ourselves in the same situation again. As a foundation, we already have the first-rate *Korfu* set and to back it up the organisation of the *Blaupunkt* works. The set is already adapted for a frequency band of 8·5 to 12 centimetres and the plans for 2·4 to 4 centimetres are almost complete. It is of the utmost necessity that we should fill the gaps which still exist and develop and produce prototypes of other sets. The next most essential step in the field of development is to replace the hand-operated direction-finder on the *Korfu* set with an automatic direction-finder. This field of ground radar observation must be fully covered between 2·5 to 12 centimetres as quickly as possible, as we already know that the enemy is using equipment on this frequency band.

We come now to airborne passive radar equipment. Here we have the *Naxos Z* set for homing on to a target, which enables the enemy to be located and shot down. This equipment has, so far, only operated on the 8 to 12-centimetre wave-band. Should the enemy use the 3-centimetre wave-band on his raids, we do not possess a *Naxos Z* set which can operate on this frequency. We know that such equipment has already been used and it may be assumed that increasing use will be made of it, and we are unable to provide airborne warning equipment in this wave-band. Intensive work has already been started to convert the *Naxos Z* to this frequency and it is hoped that receivers will be available very shortly. However, we have not yet closed the gap between the new field of 3 centimetres and the old one of 8 to 12 centimetres. It is a matter of great urgency that we should produce a rotary direction-finder to cover the whole frequency band of 2·5 to 12 centimetres as a final solution to this problem. This puts us in a very unpleasant position, for without previous planning and without the necessary manpower, we are faced with the necessity of producing an immediate solution to this problem. We cannot expect new technicians for this task and we must therefore take them from other duties and switch them over to this work. Our rate of progress in this work does not depend upon us, but is dictated by the enemy.

. . . There are of course other spheres in which centimetric radar is of particular importance. For instance, its importance for I.F.F. has not yet been fully ascertained. It is recognised that the interrogation and responder waves must be kept separate from the main station wave, so that interference with the latter does not take place. Most of our I.F.F. sets work on a wave-band of 2·4 to 1·9 metres independent of normal radar waves. The disadvantages of these waves is that, on account of their much greater length, focusing is far less accurate than focusing on 50 centimetres or 9 centimetres. One would then to be faced with a situation where the radar would have a comparatively small range and the I.F.F. a very coarse focus. In particular, however, very good radiation can be achieved when locating over the sea because of the centimetric waves, whilst relatively bad radiation is obtained on the associated I.F.F. working on the longer wavelengths. It is therefore necessary to develop an I.F.F. set which operates in the centimetric sphere so as to achieve the desired degree of focusing and radiation.

We now come to a special field which arises mainly through the use of the ' ground scanner ' (H2S). There are, scattered about the countryside, a variety of visual signals to mark airfield boundaries, cross-country routes and the like. What we now have to consider is whether these signs can be treated so as to make them visible on a radar screen. For this purpose we would require a transmitter/receiver on the appropriate wave, that is to say, a sort of I.F.F. set which would not be called upon to fulfil the duties of an I.F.F. set. This type of equipment would be grouped under the name *Gluehwuermchen.* One would, from a purely radar point of view, be able to see airfield boundaries and special air-lanes on the ground scanner. By erecting such a set in the middle of an airfield, one would obtain a simple blind-landing aid. One could also equip warships similarly and in the same way indicate the coastline and the entrances to harbours. The *Gluehwuermchen* is not very complicated and would not require any major plans for development. The enemy is sure to adopt these measures as the advantages are obvious and they do away with the present visual method. Furthermore, the *Gluehwuermchen* technique could be used in formation flying, whereby each aircraft would be equipped with a *Gluehwuermchen* and the leader of the flight with a *Berlin* set. The *Gluehwuermchen* could also be used as a transmitter for agents and here fear must be expressed that the enemy is already exploiting this angle although nothing positive is known to this effect. . . . . . . I would like to come to the camouflage of the countryside. For this purpose large triple reflectors are being erected on the lakes which give a particularly good reflection on airborne radar sets. Up to now these *Triberg* work only on 9 centimetres and their introduction on the 3-centimetre wave is an urgent necessity otherwise there is a danger that our widespread camouflage measures will afford no protection whatsoever against 3-centimetre radar. We must therefore undertake the necessary research in order to acquire the requisite knowledge.

. . . The question of the use of Window and its influence on our own and enemy radar must also be investigated. All these problems are still practically unsolved in the 9 and 3-centimetre field, not to mention the 1-centimetre field. Furthermore, we must give our attention to the question of jammers, although we do not yet know how successful our jamming of enemy radar on these wavelengths is. It has, however, been established that the width covered by a jamming transmitter in cycles per second is not in proportion to the wavelength but has a definite frequency width. For this reason it is necessary to use considerably more jamming transmitters against centimetric radar than against metric radar in order to cover the whole band. We must not fail to give attention to centimetric jamming transmitters, but must experiment with them on all wavelengths so that we can find out how our own radar is likely to react to enemy jamming. This is an extremely large field which must be covered in addition to active and passive radar. The German Post Office is developing high-powered jamming transmitters fitted with klystron valves. In addition, *Siemens* have developed a jamming transmitter equipped with magnetron which, of course, is not so high-powered. . . .

. . . It is worth while considering what else can be achieved by the use of this technique outside the field of pure radar and radar search. The country which, at an early stage, succeeds in fusing this technique and those closely related to it into an intelligent and useful combination will undoubtedly have a great advantage over those countries which fail to plan along these lines. Particular benefit would be gained from allowing experts in these different technical spheres to work in close co-operation, in order to achieve surprising results. We have only considered a few of the possibilities, and we must maintain constant and comprehensive research in order to deal completely with this subject. I wish to stress one aspect in order to illustrate how necessary it is that we should give these closely related spheres our attention : as an example I would like to draw your attention to bomb-release apparatus. The enemy is already using H2S for bomb-aiming instruments ; we know that he has already considered automatic altimeters. In the navigational sphere it is important that we should decide whether to use split direction-finding (*Schnittpeilung*) or angle beam direction-finding (*Winkelflimmerpeilung*). We must further consider to what extent the *Berlin* equipment may be used for formation flying, in an emergency without the *Gluehwuermchen*, since it is possible to recognise neighbouring aircraft through the ' ground scanner '. It is still questionable whether this formation flying technique offers any special advantages. Further we must consider the possibilities of its combination with the dead reckoner. An important question is that of rapid location ; for just as we have the *Naxos Z* set, the enemy will also develop an appropriate homing receiver, so that we shall only be able to switch on our ' ground scanners ' for short periods or they will be picked up by the homing receivers. However, we must hope that the enemy has not previously developed rapid location so that our warning and homing traffic will not be unduly hindered. Another question is that of short-wave modulation, especially for ships' radar. Admiral Stummel has pointed out that it is in no way necessary to view the whole horizon from a ship, but usually only that particular section required, and that under no circumstances should the beam be revealed in other directions. Another matter which will have to be thoroughly examined is that of low-level aircraft detection possibilities, that is to say, that we must ascertain how low it is possible to fly with a ' ground scanner ' and still perform useful work. In this respect the British H2S is very unsatisfactory since the quickly changing pictures of the ground cannot be clearly reproduced in the afterglow valve. This aspect must be gone into with regard to the *Berlin* set and we feel confident that we shall achieve more satisfactory results in the matter of low-flying aircraft.

The question of balloon barrages and long-distance location by means of the *Gluehwuermchen* also requires our attention. We must also consider whether we should develop a receiver/transmitter with greater sensitivity and power for long-range location. We suspect that the enemy is using such means, as the Technical Control Office informs us that, when taking off, the H2S set always points to the rear without the reflector having been turned. We must furthermore turn our attention to the question of D/F equipment for aircraft. It should be possible, by the introduction of a second aerial array which would point upwards, to cover the whole area. The importance of height direction-finding in the panoramic equipment must also be realised. The control of swivel-mounted weapons by aircraft panoramic equipment is not simple. In this sphere the co-operation of all concerned with this technique is essential. The question of a joint aerial array for radar and radar search on aircraft and shipping must also be gone into. Another important question is that of signal mixing on panoramic equipment. And finally an interesting task before us is that of combining the *Berlin* set with a rear-looking warning set, since up to now a special set has been needed for rear warning.

A very wide sphere which we will have to think over very carefully in connection with the centimetric waves is that of remote control and remote steering. We have not yet given serious consideration to this problem. The question requires the close co-operation of the Technical Control Office and it is certain that centimetric equipment will play a major part in the field of remote control technique. I have endeavoured to give you a short survey of the complete field of centimetric radar and I would like to say that all departments concerned with these matters, the Technical Control Office, and the industry have given their unstinting and friendly co-operation. But the manpower with which we are called upon to manage at the moment is much too small. We need considerably more men to do all that has to be done. The speed and the scope with which this technique will be introduced will be decided by the manpower situation and not by technical ability to carry it out. . . .

APPENDIX No. 2

NOTES ON GERMAN H2S

Extracts from Milch Documents (Volume 59, pages 3930 to 3932)

. . . Shortly the *Rotterdam* set (German copy of H2S) will be celebrating its first anniversary. It was on 12 February last year (1943) that the industry received the set from a shot-down aircraft. In ten weeks we had copied the H2S and had it functioning. It was demonstrated early in June. In the meantime a number of these sets had been built and, in addition, we had developed the *Berlin* set which was to serve the same purpose. There is very little difference between the *Berlin* and H2S. The H2S scanner was too large for our aircraft to carry. The scanner was so redesigned, that whilst retaining its electrical efficiency (focusing), it was now possible to install the *Berlin* set even in the *Ju. 88.*

H2S operates in the completely blacked-out cabins of enemy four-engined bombers. It works on an indicator system with afterglow effect and demands the concentration of the human eye for a period of ten minutes. The use of afterglow effect was impossible under German conditions. It was necessary for the operator in a German aircraft to be able to remain in his seat and watch the viewing apparatus with normal light conditions and in a normal aircraft. An indicator instrument without afterglow effect was produced by stepping up the rotation speed of the scanner to 400 per minute, whereas the British scanner revolved at 80 per minute. This was only made possible by the construction of a new scanner. In addition to the scanner and the new indicator method, our main achievement was the reduction in the size of the set. The H2S set had a volume of over 21 cubic feet, whilst the German set, which has the same technical performance, has a volume of under nine cubic feet. The weight of the H2S was 235 kg ; the German set although made entirely of steel in order to avoid using materials in short supply, weighs only 180 kg. When comparing this to other German airborne radar equipment, one must bear in mind that nearly all these are constructed of light metals. Since the same performance was desired, the number of valves could not be reduced ; about 50 valves have been retained, but they are practically all normal radio valves.

The German set is constructed in such a manner that no fitting or bench assembly (*Leerenbau*) is necessary and thus large numbers can be produced without difficulty. We have produced an experimental series of ten sets, five of which have been tested and are ready for use. The prototype, after having had its ground tests, has been installed in an aircraft in the past few days and is now ready for flight tests. Furthermore, an initial series of 100 sets has been planned and production of these will begin in March (1944).

The problems of reproducing the British set in the form of the *Berlin* set taxed the combined efforts of our technicians and industry to the utmost in order to make the complicated H2S set both portable and capable of operating under German requirements. Instead of the 14 component parts, we in Germany have managed with four main parts which, with the exception of one, do not require operating. Instead of the 60 cable leads to connect up the various pieces of equipment, we have 11 multi-plugs. Everything has been done to retain the performance and potentialities of the set whilst adapting it to German requirements. It must be mentioned that the performance of the set is dependent on the personnel being able to extract from this ground scanner its full potentialities. We in the industry fear operators will be disappointed when they receive the first sets. They just have to learn to interpret the pictures obtained. The presentation on the British and German sets is certainly the same, the German one may be slightly better. The exploitation of the military possibilities which these pictures provide is exclusively in the hands of the personnel operating the sets.

APPENDIX No. 3

FLOWER CODE FOR GEE STATIONS, JULY 1942

Code	Meaning
Buttercups and Daisies	General Operations
Deadly Nightshade	Single Target Concentrations
Snowdrops	Mine-laying
Forget-me-not	Sea-rescue
Double Daisy	Combined Operations
Love-in-the-Mist	Blind Bombing
Wallflowers	Unclassified Operations
Red-hot Poker	Nuisance Raids
Lilies of the Valley	Aircraft
Orchids	Gee-Aircraft
Rock plants	Heavy Bombers
Sweet William	Medium Bombers
Pansy	1–50
Carnation	50–100
Begonia	100–200
Chrysanthemum	200–300
Hollyhock	300–400
Sunflower	400–500
Princes Feather	500–1000
Crown Imperial	Over 1000
Lupin	Target Correction—Stenigot
Crocus	Target Correction—Gibbet
Bluebell	Target Correction—West Prawle
Clarkia	Target Correction—Truleigh
Rose	0·01
Lily	0·02
Tulip	0·03
Pink	0·04
Iris	0·05
Poppy	0·06
Stock	0·07
Aster	0·08
Geum	0·09

APPENDIX No. 4

DETAILS OF THE OBOE SYSTEM

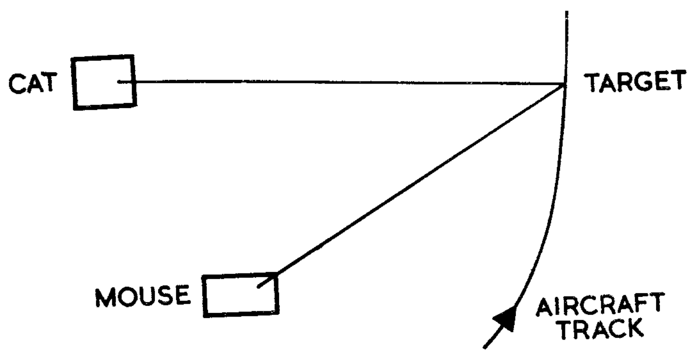
1. The Principle

Oboe was a system of blind bombing whereby an aircraft was controlled by range measurements from two ground stations. Each ground station transmitted pulses on different pulse recurrence frequencies and the aircraft carried a pulse repeater to provide adequate signal strength at the ground station over great distances. The controlled aircraft flew at constant range measured by normal R.D.F. means from one station, the Cat, such that the track took it directly over the target. At another ground station, the Mouse, usually located about 100 miles from the Cat, the aircraft's range and the component of groundspeed along the line joining the Mouse with the target were measured, and from this, in conjunction with a knowledge of the ballistic data of the bomb, the point at which the aircraft must release its bomb was determined and a signal given to the aircraft accordingly.

Signals were transmitted on the same R.F. channel as that used for range measurement

(*a*) to the pilot to assist him to keep on track ;

(*b*) to the bomb-aimer to indicate the moment of release.



2. Development of Oboe

Oboe was developed along a number of different lines, the main ones being as follows :—

(*a*) *Frequency.* Two main frequency bands were used :

(i) $1\frac{1}{4}$ metres : 211 to 236 megacycles per second.

(ii) Centimetre : 3,150 to 3,240 megacycles per second.

(*b*) *Modulation.* Two types of modulation were used :

(i) Space modulation of alternate pulses.

(ii) Width modulation of all pulses.

(*c*) *Range*

(i) The ground stations could directly control the bomber up to ranges a little in excess of optical.

(ii) The range of the bomber could be extended by flying a repeater aircraft along a line between each ground station and the target. This repeater aircraft received modulated pulses from the ground station and retransmitted them to the bomber. It also received unmodulated pulses from the bombers and retransmitted them to the ground station. The system called for at least two radio frequencies to be used alternately in successive links of the chain.

(*d*) *Control of Repeater*

(i) by means other than Oboe.

(ii) by splitting the original ground transmission in a *Lorenz* manner.

(*e*) *Development of K System*

(i) Normally reception and transmission took place on only one frequency but this was found to be susceptible to interference on the lower frequency band.

(ii) Transmission from ground to bomber could take place on two frequencies simultaneously ; this was the K system. The bomber had two receivers, one on each frequency, which fed to a coincidence valve which did not conduct unless the outputs of the two receivers occurred simultaneously. This reduced the interfering effect produced by spurious pulses on a single frequency. The channel bomber-ground station was on single frequency only.

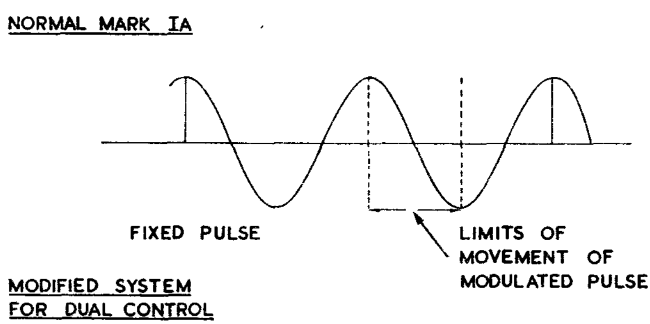
(*f*) *Control of More Than One Aircraft Simultaneously*. (This section should be read only after section 4.)

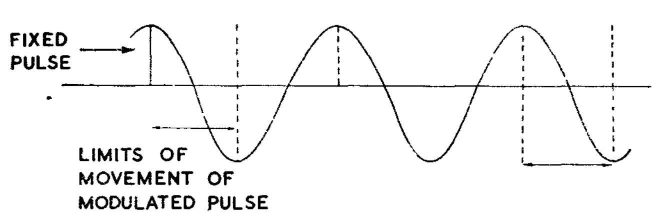
(i) This could be done by erecting further pairs of ground stations, each pair being on a different radio frequency or, as in the K system, on a different pair of frequencies. Thus, with four available frequencies A, B, C and D :

the first pair transmitted on A and B and received on B ;
the second pair transmitted on C and D and received on C ;
the third pair transmitted on A and D and received on D ;
the fourth pair transmitted on A and C and received on A.

(ii) It was possible to develop the K system in the following way :—

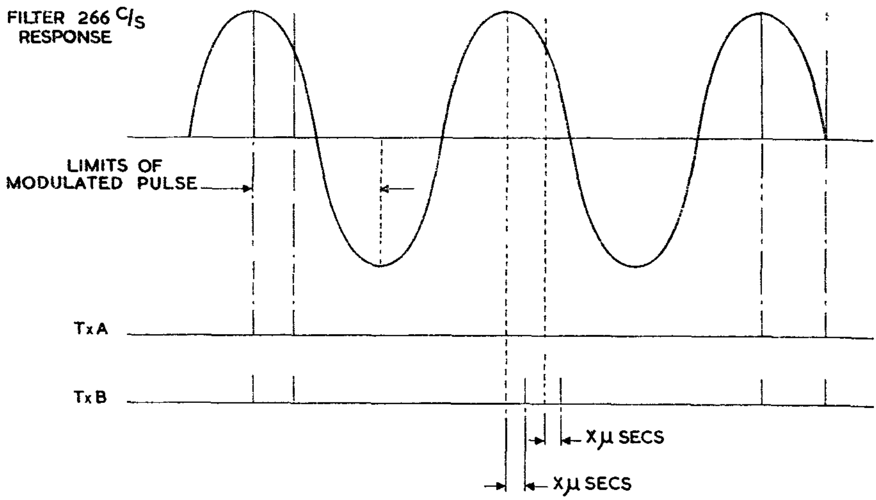
Each fixed pulse was transmitted 133 times per second. The modulated pulse varied in space in the first quarter of the cycle instead of, as in Oboe Mark IA, in the third quarter thus :





These pulses were transmitted on the normal K system, *i.e.* on two radio frequencies simultaneously.

At the half cycle a second fixed pulse was transmitted on the two transmitters, not simultaneously but separated by x microseconds, and the modulated pulse was transmitted on two transmitters separated by x microseconds within the third quarter of the cycle. An aircraft, carrying two receivers, between the output of one of which and the coincidence valve was an x microsecond delay, would receive only the pulses in the second half cycle.



The ground transmitter was therefore being pulsed at 2 by 266 cycles per second (Cat) or 2 by 194 cycles per second (Mouse), but only alternate half cycles were being received by each of the two aircraft under control, *i.e.* one aircraft was fitted with the normal K system to receive, interpret and retransmit the A pulses while the other had a K system with an x microsecond delay in one receiver output to deal with the B pulses.

The ground displays were duplicated, each displaying only alternate half cycles, *i.e.* each display control led one aircraft. Both the long and short time-bases were displayed on one tube but later the layout was redesigned so that each display system could be mounted in one rack instead of three.

(iii) A scheme similar to (ii) above was possible utilising one radio frequency only, but necessitating two ground transmitters H, K. In the first half cycle, transmitter K was fired y microseconds after transmitter H. In the second half cycle K was fired z microseconds after H. The output of the aircraft receiver was split, one going direct to one grid of a coincidence tube, the other through a y or z microsecond delay to another grid of the same coincidence tube. Thus the coincidence tube did not conduct, and therefore did not pass the pulse to the filter and transmitter, unless the pulses which were received were displaced by the time interval of the particular delay in the aircraft.

(iv) Several pairs of ground stations could be used all on the same radio frequency, but each using a different pulse recurrence frequency. This called for a pulse recurrence frequency selector in the aircraft whereby four such pairs of ground stations could operate simultaneously on the non-repeater system. Thus with four radio frequencies, 16 pairs of ground stations and 16 aircraft could be controlled at the same time.

(v) A number of separate displays, each associated with a particular aircraft by reason of a different pulse recurrence frequency as in (iii), could share the same radio frequency equipment, viz. transmitter and receiver. All pulse recurrence frequencies were derived from a common calibrator.

(*g*) It should be noted that apparatus for Marks IA, IK, IB and IIA was largely hand-made, each unit being constructed and set up individually, and therefore unsuitable for production. Marks IIB and III were designed with a view to production.

3. The Apparatus

(*a*) *Ground Station.* Each ground station comprised a pulse transmitter (in Mark IK there were two pulse transmitters firing synchronously on different radio frequencies) and a receiver. The ground ray and aircraft signal were displayed on a time-base on to which calibration pips could be switched at will. A strobe could be positioned along this time-base such that any fifteen miles or less could be taken and displayed on a second and very fast time-base, the speed being such that a ' mile ' could be displayed as a length of trace up to 5½ inches long. The target range was defined on this very fast time-base as a blacked-out spot. The ground station also included a modulator which modulated the pulses and conveyed information to the aircrew to enable them :

(i) to keep at constant range from one ground station (Cat)

(ii) to release the bombs at the correct instant according to signals from the other ground station (Mouse).

Each ground station worked on a different recurrence frequency from the other, this frequency being controlled by a crystal-controlled calibrator. The crystal-controlled calibrator oscillating at 93·120 kilocycles per second gave rise to a pip at each oscillation, the time between any two consecutive pips corresponding to one mile when displayed on a time-base. These mile pips were passed through a ' series ' of counting stages such that either :

(i) each 700th pip occurring 133 times per second or

(ii) each 960th pip occurring 97 times per second

gave rise to the pulse recurrence frequency controlling :

(i) the transmitter

(ii) the time-base.

(*b*) *Bomber Aircraft.* Each bomber carried a receiver, the pulse from which triggered a transmitter. The pulses from the receiver or from the trigger unit were fed to a double filter, each portion of which was tuned to the recurrence frequency of one of the ground stations (one to the Cat P.R.F., the other to the Mouse P.R.F.). The outputs of the filters were fed as an aural indication to the pilot and the observer respectively. In Oboe Mark IK, the aircraft carried two receivers which were fed to a coincidence valve and which conducted, passing pulses to the trigger unit and filter, only when pulses were received simultaneously by the two receivers.

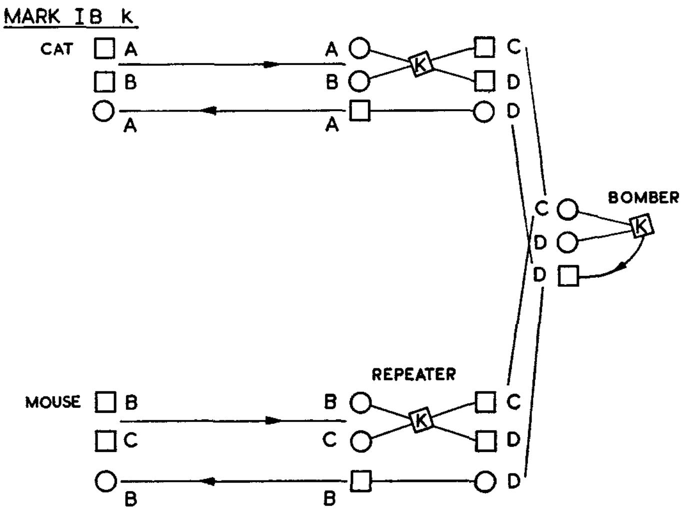
(*c*) *Repeater Aircraft.* Each repeater aircraft carried two transmitter and receiver sets, one set dealing with pulses from ground station to bomber, the other set dealing with pulses from the bomber to the ground station.

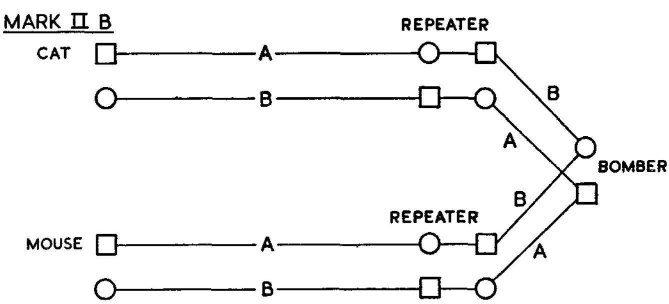
In the Mark IK system the set dealing with pulses from ground station to bomber was doubled and comprised two receivers feeding a coincidence valve which fired two transmitters simultaneously. In all cases the receiver of the outgoing set was suppressed when the transmitter of the incoming set was fired.

In Oboe Mark IIB and Mark III the repeater aircraft carried a demodulator to detect the information conveyed by the *Lorenz* split-beam system at the ground station.

In Oboe Mark IB, however, the repeater aircraft carried a receiver peculiar to the frequency of the Baillie beam and this was quite independent of the Oboe apparatus.

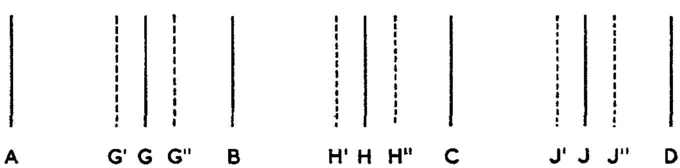
(C50782) Z





4. The Communication System

(*a*) *Space Modulation.* Alternate pulses were sent out at regular and fixed intervals at a recurrence frequency of 133 cycles per second for a Cat, and 97 cycles per second for a Mouse station. Intermediate pulses were sent out at between $\frac{1}{2}$ and $\frac{3}{4}$, and normally at $\frac{5}{8}$ of the time-interval between the fixed pulses thus :



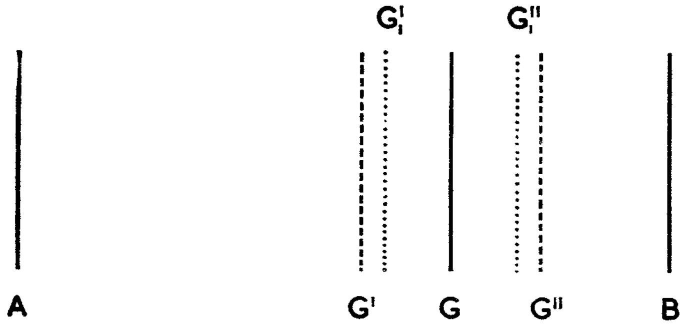
A B C D were fixed pulses

G H J were variably spaced pulses, varying between G′ and G″, H′ and H″ respectively such that

$$A\,G = \tfrac{5}{8}\,A\,B$$
$$A\,G' = \tfrac{1}{2}\,A\,B$$
$$A\,G'' = \tfrac{3}{4}\,A\,B$$

These pulses were received in the aircraft through filters tuned to 266 cycles per second and 194 cycles per second respectively.

When G was in the position G′ it arrived in phase with the oscillation of the filter already excited by A and maintained the 266 cycles per second oscillations, the fourth harmonic of which was passed to the pilot's headphones. When G was in the position G″, however, it arrived completely out of phase with the filter, and the oscillations were immediately damped out and no more was heard in the filter.



If G was at G′ for say 8 pulses and at G″ for 56 pulses then dots would be heard in the phones, but when G was at G′ for 56 pulses and at G″ for 8 then dashes were heard.

If G was made to vary between G_1' and G_1'' then dots or dashes were heard such that difference in intensities between mark and space was less than when G occupied positions G′ and G″. The percentage modulation under these conditions was defined as $\frac{G_1'\,G_1''}{G'\,G''} \times 100$. When G′ and G″ coincided with position G then a constant tone was heard in the phones of half the maximum dot or dash intensity—this was the equi-signal note which the pilot endeavoured to maintain and which indicated that he was flying at the correct range.

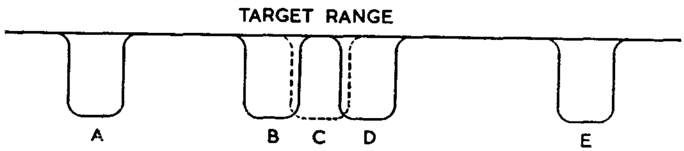
The output of the 266 cycles per second filter worked in this way and was connected to the pilot's phones. The 194 cycles per second filter was connected to the navigator's phones and on this channel pulses G H J etc. always occupied the position G′ H′ J′. Executive signals were sent by cutting the ground transmitter and keying it on and off in a morse manner—' on ' for mark and ' off ' for space.

(*b*) *Width Modulation.* All pulses were equally spaced in this system and were transmitted at a regular 266 or 194 cycles per second (or at half those rates in the repeater system). The pulses were, however, variable in width between 2 and 4 microseconds. The energy of each pulse was proportional to the product of width and amplitude, but since the amplitude of the pulses was limited at the aircraft, the energy which was fed into the filter was a measure of the width. The filter output was proportional to the energy put in and consequently wide pulses rang the filter more violently than narrower ones and a louder note was produced. In practice the first 2 microseconds of each pulse were cut off so that a series of 2 microseconds pulses did not ring the filter at all, whereas a series of 4 microsecond pulses were arranged to ring the filter to maximum amplitude. Thus a series of pulses consisting of 8 at 2 microseconds, 56 at 4 microseconds, 8 at 2 microseconds etc., gave rise to a filter output maximum depth of dashes. A series comprising 8 at 2·25 microseconds, 56 at 3·75 microseconds, etc., gave rise to a dash output, the depth of modulation being less than the earlier example. When all pulses were of 3 microseconds width, a constant level of output from the filter was produced—the equi-signal which the pilot endeavoured to maintain indicating that he was at the correct range. On the navigator's channel pulses were sent normally at a regular 3 microsecond duration, but when morse or release signals were sent the pulse width was reduced to 2 microseconds for space and increased to 4 microseconds for modulation. In either method of modulation, and on both pilots' and navigators' channels, full depth of modulation could be keyed in a morse manner by operating a morse key.

(C50782) Z 2

5. Control of the Aircraft at the Cat Station

Oboe Marks I and IIA. On the very fast time-base (the magnified time-base) was displayed that portion of the time-base on which the aircraft signal appeared when flying at the correct range designed to take it over the target. This range was defined as the centre of a 1 microsecond gap between two associated strobes each 4 microseconds long. The coincidence of the aircraft signal with either or both of these strobes gave an output to the modulator which was a measure of the displacement of the aircraft from its correct track. The aircraft signal displayed



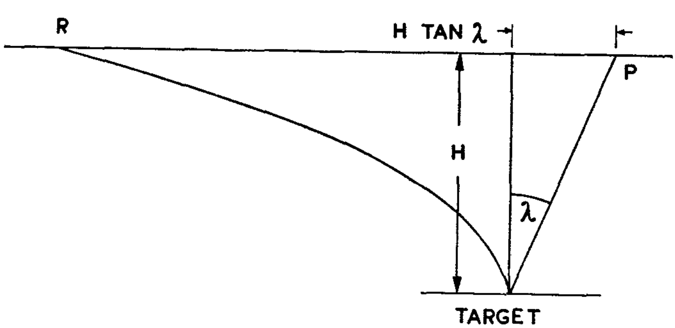
on the time-base was derived from a ringing circuit triggered by the direct signal from the aircraft, in order that a symmetrical pulse was used for action with the double strobe.

When the signal was in position B it was coincident only with one of the strobes, and 100 per cent dot modulation was sent to the aircraft. As the signal moved to the right (*i.e.* the aircraft increased in range) the depth of dot modulation decreased until with the signal at C there was no modulation at all and the pilot heard an equi-signal note. As the signal moved further to the right, the depth of dash modulation increased up to 100 per cent dash when the signal was at D. When the signal was to the left of B or to the right of D, a switch was operated so that the modulation became 100 per cent dot and dash respectively. Thus the aircraft appreciated changes in modulation from 0 to 100 per cent within less than $\frac{1}{4}$ mile of the track that it should fly.

Oboe Marks IIB and III. On the very fast time-base the target range was displayed as a black-out pip. Also on the time-base was a small 'walking' strobe which when free moved across the trace from left to right with a velocity V. When a signal appeared on the trace, however, the 'walking' strobe could be placed on the loading edge of the signal, on to which it locked ; the strobe then moved only with the velocity v of the signal. There existed a certain sponginess between the strobe and the signal proportion to $V \pm v$ and therefore to v. If the voltage proportional to v was integrated with reference to the voltage given by the position of the black-out pip, a voltage proportional to the displacement of the signal from the black-out pip was obtained. This could be positive or negative with reference to the black-out pip and was passed to the modulator which controlled, in accordance with this voltage, the depth of dot or dash modulation to be transmitted.

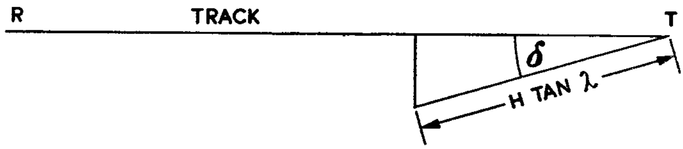
6. Control of Release of Bombs from Mouse Station

Bomb Ballistics. When a bomb is released from an aircraft its horizontal velocity is initially that of the aircraft, but the effect of air resistance causes the bomb to lag behind the aircraft so that at the moment of impact the aircraft is at P and beyond



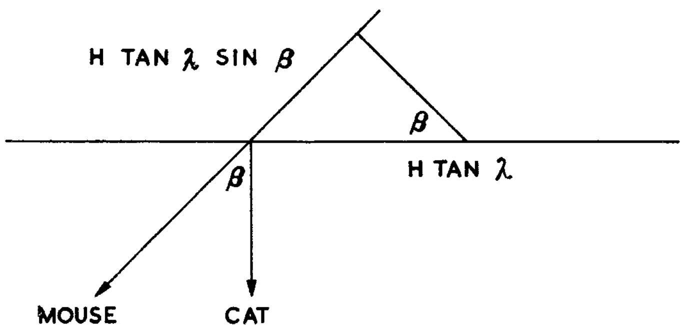
the target by a distance H tan λ (called ' the trail distance '). The distance P R (where R is the point of release) is given by G x t where
G is the ground speed of the aircraft
t is the time of fall of the bomb.

It should be noted that H tan λ is dependent only upon air speed, height and the type of bomb, all of which factors are pre-arranged, and that the trail distance is always along the reciprocal of the heading of the aircraft. The Mouse station was



δ IS THE ANGLE OF DRIFT

required therefore to give the release signal to the aircraft at a point R which was t seconds flying time away from position T. The point T appeared at the Mouse station to be in excess of the target range by a distance H tan λ sin β, where β was the angle subtended at the target by the two ground stations.

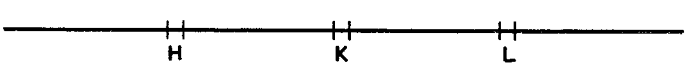


Oboe Marks I and IIa. On the fast time-base were displayed a number of black-out pips generated by a ringing circuit and therefore equally spaced. One of these, L, was placed at a range in excess of the position of the ground ray by the sum of

(i) calculated distance from ground station to aircraft at given height vertically above target;

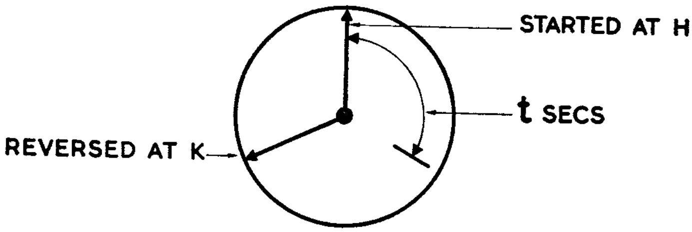
(ii) delay in airborne pulse repeater;

(iii) H tan λ sin β. (This was negative if the aircraft was to approach the target from a range in excess of the target range.)



Two further pips H, K, were selected such that H K = K L, H and K being on that side of L from which the aircraft would approach.

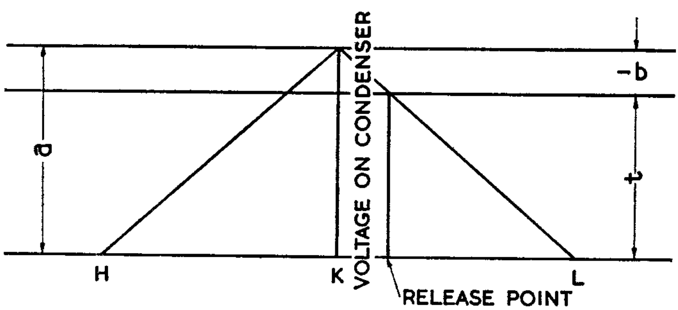
When the aircraft signal passed H, a clock was started and when the signal passed K the clock was reversed. If a constant groundspeed was maintained, the clock should have returned to zero when the signal reached L, but t seconds before reaching L the bomb had to be released, therefore a contact was placed on the clock at t seconds so that when the pointer after reversal touched this contact a



signal was sent automatically. The distance H K had to be such that the aircraft would take at least t seconds to cover it.

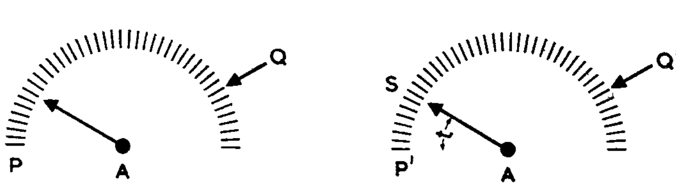
Average Velocity Mouse

The A.V.M. consisted of a large condenser charging through a large resister and discharging through a similar one, the voltage proportion to t being set as a bias to



a valve. The charging was effected through a feed-back time-constant so that it was effectively linear, and the apparatus was set up so that for all values of a, $a = b + t$ and so that t was the required value. A signal was given automatically to the aircraft when the voltage on the condenser fell to a value corresponding to t.

A second type of A.V.M. consisted of two banks of uniselectors each supplied with impulses at a constant rate of 10 per second. At the moment corresponding



to the position of the aircraft signal at H the uniselector A was started and ran from P to say Q, this latter position corresponding to the position of the aircraft signal at K. At this moment uniselector A was stopped and uniselector B was started from a position S where P′S was t seconds (t was the time of bomb-fall) and where P′ on B corresponded to P on A. Uniselector B moved until it found the position Q′ corresponding to Q on A. When it found Q′ a signal was given automatically to the aircraft. This type of A.V.M. was used solely with Mark I and IIF stations.

Instantaneous Velocity Mouse used in Oboe Mark IIM and III

On the fast time-base was displayed a black-out pip which could be set at such a range as to be in excess of the ground ray by the sum of

(*a*) calculated distance from ground station to aircraft at a given height vertically above the target;

(*b*) delay in airborne pulse repeater ;

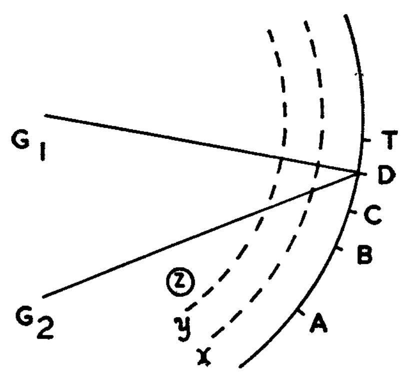
(*c*) $\pm$ H tan λ sin β (as above).

On one side of the trace was a 'walking' strobe (brightness intensified) which, if free to move, travelled across the trace at velocity V. When a signal from the aircraft appeared on the trace, this 'walking' strobe could be placed on the landing edge of the signal, on to which it locked. The strobe then moved only with the velocity v of the signal. There existed a certain sponginess between the strobe and the signal proportional to V $\pm$ v and therefore to v. If the voltage proportional to v was integrated with reference to the voltage given by the position of the target black-out pip, a voltage r proportional to the displacement of the signal from the black-out pip was obtained.

The ratio $\frac{\text{displacement}}{\text{velocity}}$ had the dimensions of time so that an arrangement was made whereby when the ratio of voltage proportional to displacement and velocity respectively was equal to the t b f, a signal was sent to the aircraft. The value of velocity thus measured was almost instantaneous and was only dependent on the integrating time-constants.

Alternatively the target black-out pip could be set beyond the ground ray by an amount equal to the sum of only (*a*) and (*b*) above. The trail could then be fed into the Mouse as a time, the time, in fact, for the aircraft to cover the trail distance at an assumed ground-speed. In this case aircraft could be brought in from either side without involving any movement of the black-out pip.

7. The Operation



Each aircraft navigated itself to within an area Z with its Oboe receiver switched on but its transmitter off. The first aircraft of a series switched its transmitter on at a pre-arranged time, but subsequent aircraft switched on transmitters only in response to a call-sign associated with each particular aircraft. The aircraft then flew in a direction approximately at right angles to A T and morse signals were sent to the aircraft as it passed through arcs Y and X at 10 to 5 miles range arc respectively. The aircraft ultimately turned on to the arc at A T and signals were given at A, B, C and D corresponding to pre-arranged distances or times from the target. The distances were such that an aircraft flew from Z to T in less than 10 minutes.

Multi-Channel Control

The limitation of one aircraft over the target every 10 minutes was too severe for target marking when each marker lasted only for 6 minutes and when one faulty aircraft resulted in a gap of 14 minutes. Alternative channels, as discussed in 2 (*f*), were provided, working independently so that with n channels one aircraft could be brought in every $\frac{10}{n}$ minutes on the average.

Essential Data for Operations

(*a*) *Geographical distance.* The arc distance between each ground station and the target were provided by the Air Warfare Analysis Section (A.W.A.S.) together with a correction to be applied for the height of an aircraft vertically above the target.

(*b*) *Bomb ballistics.* The time of bomb-fall and the trail distance of the bomb to be used were supplied in tables provided by A.W.A.S. together with the height of the target above mean sea level.

(*c*) *Bomb load.* Data regarding the type of bomb, number of bombs in the stick, and spacing of bombs within the stick, were furnished by the squadron operating.

(*d*) *Meteorological information.* In order that the apparatus could be set up for greatest efficiency according to the most probable conditions prevailing, the latest available meteorological information was utilised.

Corrections

A correction was applied to both Cat and Mouse ranges because of the fact that the aircraft was travelling along the arc of a circle whereas the bomb was thrown out tangentially. A correction was also applied to both Cat and Mouse ranges to compensate for the cross-trail effect due to components of cross-wind, and, when a stick of bombs was used, a correction was applied to the time of the bomb-fall such that the middle of the stick would hit the target.

APPENDIX No. 5

NOTES ON OPERATIONAL USE OF REPEATER AIRCRAFT WITH OBOE, 31 MARCH 1943

1. Object of Repeater

At present the use of Oboe is limited to attacks on targets within some 270 miles of the ground stations with the bomber at about 28,000 feet. Owing to the straight path along which the signals travel, tangential to the surface of the earth, the range is limited by the height at which the bomber can operate as well as by the height of the ground station. With both the ground station and bomber at their maximum practicable altitudes nothing further can be done to increase the range on any given radio frequency, without introducing an intermediate stage between the ground station and the bomber to relay the signal. This relay system is being introduced by carrying suitable radio relay equipment in a Mosquito aircraft which will require to fly between the ground station and the bomber aircraft.

2. Technical Considerations

This proposed repeater has not yet been flown, but there is every reason to hope, from the radio point of view, that the project is technically practicable. To ensure accuracy in the range measurements and to conform to the propagation path of the signal, the repeater aircraft will be restricted in space to fly to and fro on a certain fixed track between two points. The position of this beat is determined mainly by three variable factors :—

(i) Radio frequency of system

(ii) Heights of repeater and bomber aircraft respectively.

(iii) Distance to target.

For the purpose of this paper, the third factor, distance to target, is assumed to be the maximum possible range of the system, and, therefore, figures for the first two factors only will be given.

The length of the repeater's beat should be sufficient to ensure that it is at the beginning of one of its runs as the bomber commences its own approach to the point of release. The timing must be precise to avoid any possibility of the repeater reaching either of its turning points while the bomber is running up to the target. It cannot effectively relay a signal while turning. If it is intended to continue the present Oboe policy, and aim at an evenly spaced series of bomber runs, 15 minutes spacing would seem practicable at the ranges considered ; bearing in mind the fact that the bomber will be out of range of all precise aids, such as Gee or Baillie Beams, which it has at present, and which facilitate the timing to ensure even spacing. Thus 15 minutes has provisionally been selected for the length of beat of the repeater aircraft between its turning points, or 60 miles at 240 m.p.h. It must also remain at a constant height for the whole period of its runs while an operation is in progress.

The repeater must not approach the ground station closer than 100 miles, and its extreme outward limit is governed by the point at which signals fade. This varies with its height and the radio frequency used. Three possibilities are considered :—

(i) Wavelength 1½ metres, repeater and bomber aircraft at 28,000 feet.

(ii) Wavelength 1½ metres, repeater and bomber aircraft at 25,000 feet.

(iii) Wavelength 10 centimetres, repeater and bomber aircraft at 35,000 feet.

(If Mosquitos with Merlin 61 engines can be provided, a height of 35,000 feet should be practicable, and it is hoped that these will be available at any rate by the time the 10-centimetre Oboe project is developed.)

In the case of (i) above, the maximum certain range between the ground station and repeater aircraft is 250 miles, and between the repeater and bomber aircraft is 400 miles. Thus, allowing for the repeater's beat of 60 miles, we get a total range of 590 miles. In the cases of (ii) and (iii) the total ranges are 620 and 570 miles respectively. Figures 1, 2 and 3 attached illustrate graphically these three cases. It must be emphasised that these figures of range are theoretical, but they have been arrived at after careful investigation of the propagation theory, and any error will probably be an under-estimation.

3. Practical Considerations

Examination of the arrangements of height and wavelength shown in the attached figures indicates that it will be necessary for the repeater to maintain a constant track and height, and carry out its turn at each end of the beat at the correct place, since the range computations for any given target will have to assume a fixed beat. If Berlin is the target, the repeater working with the station at Dover would have to maintain its beat roughly over the Ruhr, and it is a matter for Air Staff decision as to the practicability of this at 28,000 feet. No doubt at 35,000 feet the problem will present a different aspect. Although it has been said that the repeater is restricted to this constant track and height, the following figures may be helpful in planning tactical details. If the repeater aircraft is displaced by as much as 4 miles to one side or the other of its track, and taking into consideration also the additional error due to the possibility of its being at one or other end of its run, the resulting error in range measurement at the target will only amount to between plus 75 yards and minus 45 yards. If the repeater varies its height by 1,000 feet about its mean height of 28,000 feet this will produce an error at the target of plus or minus 26 yards. These figures are again only approximate but serve to indicate the magnitude of errors likely to arise as the result of inaccuracy in navigation on the part of the repeater aircraft.

The aim has been to convey to those concerned with the planning of operations in which the Oboe system will be used, essential facts regarding the use of a repeater aircraft. It is clear that the repeater will possess considerably greater freedom of movement about its assumed track than has hitherto been supposed, but the major problem will be the accurate navigation of the bombers, out of range of Gee or Baillie Beams, to ensure their arrival, at the correct point for running in to the target, every 15 minutes, to synchronise with the repeater's beat.

Regarding the repeater itself two important points emerge. First, because a considerable deviation from its mean track or height introduces so small an error, it will be free to take violent evasive action, provided its turns to port or starboard do not exceed some 20 degrees from the mean track. This turn limitation is necessary because of the aerial arrangement—which is directional. Secondly, for the same reason, navigation of the repeater aircraft could well be undertaken accurately with Gee, which is standard in the Mosquito. At no place, up to the maximum range of the repeater from the ground stations, is Gee less accurate than plus or minus 4 miles, and over most of the area is far more accurate, with possible errors of less than 2 miles.

FIGURE 1

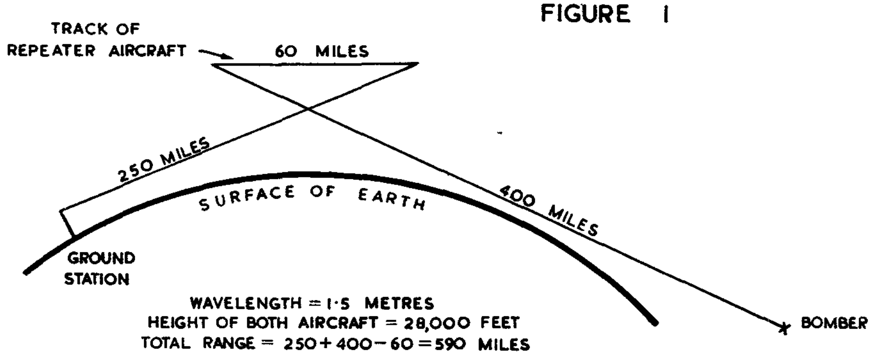


FIGURE 2

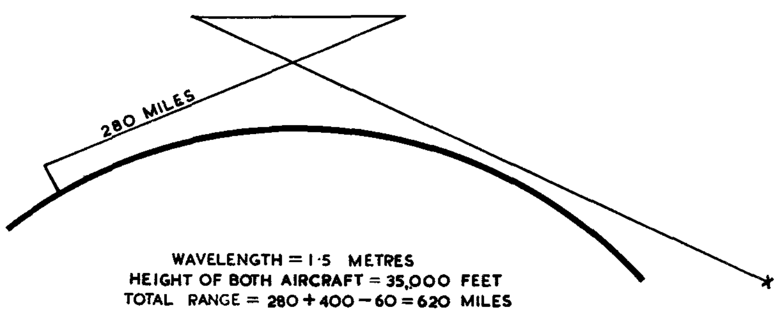
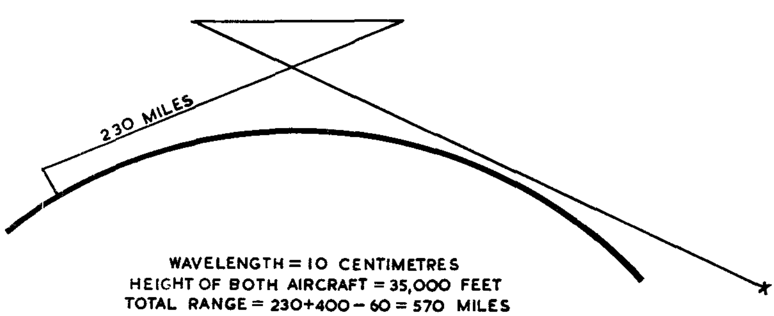


FIGURE 3



APPENDIX No. 6

GERMAN ATTEMPTS TO JAM OBOE

Extracts from Translations of German Documents

1. The 'Holzhammer' Method

After the middle of 1943, German Observation Posts in the Ruhr had recognised the employment of Oboe procedure in air attacks over that area. From August 1943 onwards, 500-watt jammers (continuous dash performance) were set up in the Ruhr and on each English penetration were switched on to the 210–240 megacycles per second band. In January 1944 additional jammers of a similar type, with aerials set eastwards, were erected on the left-hand bank of the Rhine, and by April 1944 the number of jammers set up to protect the Ruhr had risen to 80. At the same time, apparatus for fixing the frequency of the airborne Oboe receiver began to be employed so that each time the greatest number of jammers would be tuned in to this frequency, thus increasing their effectiveness. The Krefeld area was not covered with jammers until April 1944, so that the series of Oboe attacks against the Krefeld *Edel* steel works, which lasted from January to the end of March, were for the most part highly successful. By means of the *Holshammer* method, jamming was carried out in the 200–250 megacycles per second wave-band until the end of 1944, with constant improvements in apparatus and organisation. During a heavy attack against a *Hydrier* works near Recklinghausen on 15 June 1944, all the Oboe pathfinders seem to have been jammed with great success. Apart from this, for a time an attempt was made to jam the receiver frequencies of the Oboe ground stations in England, from Calais.

On the evening of 21 March 1944, at 1815 hours, a short time before the Oboe flights started, the following morse signal was sent out in German from the English Oboe ground stations by keying the Oboe pulse signal '. . . Hallo, you are a *schweinehund*. . . .' This was received by Calais and accepted as confirmation on the German side of the effectiveness of jamming.

2. The Ball

By this method all impulses radiated from airborne Oboe transmitters and received by the jamming stations were adjusted, synchronised with the Oboe ground receiver frequencies, and re-radiated. A test of this method was successfully carried out on 8 July 1944 during an Oboe flight to a target on the Rhine between Duisburg and Cologne. After several tests in the Arnhem area during August and September, approximately 30 *Ball* jamming equipments were by degrees set up in the Erfurt and Bremen areas and between Utrecht and Mainz, from the middle of October 1944 to March 1945. Although during the setting up of Oboe ground stations in France and Belgium, very few Oboe flights were carried out and the use of *Ball* jammers rendered necessary quite a few tests, the number of successfully-jammed Oboe flights in the northern *Reich* rose from the middle of December 1944. As examples of the jamming results established, the following two days should be mentioned :—

(*a*) On 11 November 1944, four Oboe aircraft flew to Gotha. All were jammed by *Ball* jammers in the neighbourhood of Gelderu and no bombs found their mark in the town area. Some were 30 kilometres away and the course of the aircraft was for the latter part very uncertain. During several previous Oboe attacks and one attack some days later against the same target, jammers were not switched on this direction and practically all bombs found their mark.

(*b*) On 17 December 1944, six Oboe aircraft flew to Salzgitter. Five of them were completely and one partly jammed by *Ball* jammers in the Gelderu and Hamelin areas. No bombs hit the mark and three bomb-loads were 5–20 kilometres wide of the mark. The remainder could not be found. The headings of the aircraft were very erratic and half of them far wide of the *flak* zone. During all previous Oboe attacks until 3 December, no jammers were set up for the protection of the *Salzgitter* works and nearly all bombs found their mark in the works area. Only one aircraft could be partly jammed from Gelderu on 3 December.

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The increase in Oboe flights during the first quarter of 1945 (the increase in flights from February to March was about 100 per cent) and other simultaneous air attacks rendered more difficult the establishment of the successful jamming of single penetrations. Of Oboe flights to Bremen 50 per cent were jammed and of those to Wurzburg 25 per cent.

APPENDIX No. 7

JAMMING OF GEE-H, DECEMBER 1944

Extracts from Translations of German Documents

1. It is necessary to render the enemy Gee-H systems so ineffective that it would make target pin-pointing and navigation an impossibility, at least over all home territory, and even over enemy territory.

2. As long as no better plans are submitted, the following is proposed :—

(*a*) Through the use of higher pulse production jamming transmitters the Gee-H ground receivers are to be made to respond at such a high 'frequency' that the Gee-H transmitter must either fail through overloading or merely transmit a mass of jammed signals in which none of the answering pulses from the enemy aircraft is easily recognisable. The transmitters must be tunable to frequencies on which the Gee-H ground transmitter can work. In order to increase the degree of reliability of Gee-H ground receivers responding, in spite of the jamming transmitters being out of optical range of the Gee-H ground stations, the beam can be concentrated and directed against the Gee-H ground receivers.

(*b*) Through one or several monitoring stations

(i) A continuous check must be kept on the effectiveness of every single jamming station.

(ii) Frequency-modulation on the part of the enemy must be confirmed as soon as possible.

By means of this proposed jamming system all navigation by Gee-H over home territory and even over enemy territory (for example, an approach to front-line targets) would be made impossible. A further advantage is that only a comparatively weak jamming signal strength is required on the enemy ground receivers, as it only needs to match that of the weak aircraft transmitter.

3. The jamming or deception of aircraft Gee-H receivers, in a similar manner to the jamming or deception of Gee, demands transmitters in western Germany with an extraordinarily high maximum and average output. Otherwise, because of the characteristics of Gee-H, jamming does not seem to be 100 per cent effective. Nevertheless, an investigation of the following questions is requested :—

(*a*) Whether high-powered jamming transmitters (*Feuerstein* or *Feuerzange*) could be converted to a jamming or deception modulation against Gee-H in order to accomplish effective jamming as outlined in paragraph 2, and whether they hold any promise of success if used in adequate numbers in the form in question.

(*b*) Whether a more effective and quicker method of jamming than that proposed in paragraph 2 is possible on a comparable scale.

4. The necessity for ground and aircraft monitoring equipment, already demanded in order to make possible up-to-date identification of enemy aircraft and ground frequencies, is once more emphasised.

APPENDIX No. 8

MEMORANDUM OF GERMAN CONFERENCE ON JAMMING TRANSMITTERS, 9 JANUARY 1945

Extracts from Translations of German Documents

Present :	Minister Speer	Chairman
	Dr. Heine Dr. Lubeck	Industrial Advisers to Goering
	President Kehre President Gerwig *Oberpostrat* Dr. Scholz	German Post Office
	Dr. Luschen	Radar Committee
	Dr. Gauzenmuller	Secretary of State for Railways
	General Martini General Burckhardt Colonel Knemeyer Major Harmening Major Buchmann Captain Hurner	

1. The subject of the conference was stated by Minister Speer to be :—

How and against what are jamming transmitters to be employed ?
What further measures can be taken to improve the jamming organisation ?

2. The effectiveness of various navigation methods, and the importance of jamming them, was discussed. For pin-pointing a target the enemy prefers to use Oboe. Gee-H is also frequently used. Speer considers it to be of vital importance that these two methods should be jammed. On the other hand Gee-H is much less accurate, even in the front line, for, according to Intelligence reports, it is no longer to be used for bombing main German front-line positions, because of the danger to their own positions. The ' ground scanning ' type of radar has the advantage of having a constant proportionately good degree of accuracy for the whole of Germany and is used in bombing raids taking place now.

The immediate jamming of all radar navigation methods is acknowledged to be an absolute necessity. Moreover, jamming of the centimetric wave-band, and therefore of ' ground scanning ' equipment, is considered to be of the utmost urgency for, as the Director-General of Signals pointed out, there is a steady changeover by the enemy of frequencies to the centimetric wave-band, and the operational use of centimetric Gee-H is to be expected in the near future. The Director General of Signals states further that the radio interception service is now, to a large extent, able to predict, from radio traffic, the time and place of Oboe-controlled bombing raids up to 20 minutes beforehand. Moreover, Speer reports that a higher percentage of hits have been confirmed on Oboe-controlled raids than on raids using equipment of the ' ground reflection ' type, for example, Gee-H. The Signals Staff, General Headquarters, credits this however to the higher standard of training of aircrews of Oboe squadrons.

3. To increase the protection of industrial plants and road and rail junctions in the west, an increase in the use of jamming, or a speed-up in the delivery of transmitters, is essential. Industrial areas in the Ruhr must take top priority in places to be protected by jamming. Following that comes the area stretching southwards as far as Frankfurt and then areas lying to the east. The delay in construction and use of high-powered transmitters is blamed by the Technical Air Supplies department on transport difficulties.

In answer to the Director General of Signals' query as to whether the modulation of high-powered jamming transmitters was now free of faults, Colonel Knemeyer replied that the defects discovered to date could be overcome immediately. Major Harmening stated that the high-powered transmitters would be ready for operations in sufficient numbers in three months' time and at full operational strength in five months. The importance of delivering two completed anti-Oboe jamming transmitters each week, as Goering had demanded, is stressed. The Director General of Signals pointed out that there might be a hold-up in the output of anti-Oboe equipment due to all available stocks of *Kumark* rotating cabins being used up. The Technical Air Supplies department states that a suitable substitute is now available.

The Post Office representatives then made a statement on jamming transmitters used against the ground scanning type of radar (H2S). They expect three transmitters to be produced in the very near future for use in close co-operation with the industrial plants to be protected. *Oberpostrat* Dr. Scholz presented a method of stepping up the jamming power in the protected area by using a large number of extremely low-power centimetric *Ball* jamming transmitters. To cover the Laubfrosch zone, he estimates that four of these transmitters should be installed at one point. This increase in effectiveness would give a better protection of industrial plants, extending right up to the maximum effective range. General Burckhardt objected that such stepping-up would, after a time, provide the enemy with navigational assistance, as had centres of A/A concentration. Dr Scholz denied that this was possible. Dr. Luschen stated that, in order to step up the output of jamming transmitters, technicians were needed.

The Director General of Signals felt that the definite and constant lag of German jamming measures behind the new developments of the enemy would have a lasting and detrimental effect on the German war effort in the field of radio engineering. In order to remove this serious disadvantage the Director General of Signals demands that all possible means are devoted to the development and manufacture, in sufficient numbers, of jamming transmitters with wavelengths down to one-tenth of a millimetre.

4. The following measures are to be introduced to improve the jamming organisation :—

(*a*) Transport difficulties are to be overcome through the personal intervention of the Secretary of State for Railways.

(*b*) Labour difficulties are to be overcome through the mediation of President Kehrl.

(*c*) The time taken to build jamming stations is to be shortened through the co-operation of the Speer organisation with assistance from the industrial plants to be protected.

(*d*) A commission on jamming is to be set up, under Dr. Heine, to deal with any further difficulties and to discuss in detail the measures proposed at (*a*), (*b*) and (*c*). There is a strong possibility that fresh difficulties in production may arise, as a total of 240,000 skilled workers is being withdrawn from the industry at the rate of 80,000 every three months.

APPENDIX No. 9

GERMAN NOTES ON USE OF AIRBORNE JAMMING TRANSMITTERS, JANUARY 1945

Extracts from Translations of German Documents

1. Use of Airborne Jamming Transmitters by the Enemy

With reference to the use of airborne jamming by the enemy the following facts must be borne in mind. It is known that the enemy uses a large number of jamming aircraft against German high-frequency signal transmissions when large-scale flights are made over Germany. This fact leads one to consider whether the same method could not be used on our own operations. There is, however, a fundamental difference between our own and enemy airborne jamming. The enemy must carry airborne jamming transmitters when flying over *Reich* territory, since no effective jamming system from ground stations against German radar devices is available to him. Jamming from our own aircraft would mostly take place over the *Reich*, an area in which an extensive jamming system from ground stations exists, and which has far more effective means at its disposal. It is evident, therefore, that airborne jamming is only necessary when no ground jamming system is available, as in flights over front-line territory or over enemy territory.

2. Possibility of the Enemy Homing to Airborne Jamming Transmitters

By using suitable homing receivers the position of all airborne jamming transmitters can be plotted. This greatly increases the danger of the jamming aircraft being shot down. This can be reduced, however, by installing the transmitter in very fast aircraft, the *Arado 234* for instance. Due to the limited space of such aircraft, however, they can be fitted only with jamming transmitters of limited output. The danger of jamming aircraft being shot down could be reduced still further if the transmitters are used for short periods only. In order to produce sufficiently effective jamming this measure necessitates employment of a much larger number of jamming aircraft.

3. Airborne Jamming against Enemy R/T

The successful employment of airborne jamming against enemy R/T can be achieved only if jamming transmitters can be installed in fighters. It should be used only in daylight hours. It is also essential that operation of jamming transmitters is simple enough to enable it to be carried out by the pilot of a single-seater aircraft. The jamming transmitter must be capable of jamming on all frequencies used by the enemy.

4. Airborne Jamming against Gee

The following technical possibilities exist in the use of airborne jamming against the Gee system :—

(*a*) The *Wolke* jamming transmitter, to be ready in three months' time, has, owing to its limited range, no advantage over the established ground stations.

(*b*) The *Kettenhund* transmitter is even less effective because of its low power.

(*c*) The *Heinrich* jamming transmitter, already in operation as a ground jamming station, possesses a much greater jamming range because of its greater power. It would, however, be difficult to install in aircraft because of its weight and need of a large power supply.

It is technically impossible to install the large jamming transmitters, which, because of their high power, would have an effective jamming range, in aircraft. The limiting jamming range of an airborne jamming transmitter demands the employment of a number of jamming aircraft in order to jam effectively an enemy bomber formation, even if it is only to achieve an effect approximating to that of the ground jamming station.

5. Airborne Jamming against Gee-H

According to the latest information on Gee-H one must differentiate between metric Gee-H and centimetric Gee-H (micro-H).

(*a*) The same considerations are applicable to the airborne jamming of metric Gee-H as to its use against Gee. As with Gee, jamming or deception of the aircraft Gee-H receiver requires the construction in western Germany of jamming transmitters with a very high maximum and average output. However, because of the characteristics of Gee-H, this method does not appear to be completely effective. It could only be made effective, and even then its success is doubtful, if a jamming or deception modulator were fitted. This type of equipment could not, however, be installed in aircraft. The answering of the ground transmitters with a pulse recurrence frequency so high that it would cause the transmitters to break down appears to be the most effective method of jamming at present.

(*b*) Jamming transmitters suitable for use against centimetric Gee-H have not yet been built and production of such transmitters in the near future seems unlikely.

6. Airborne Jamming against Loran

The considerations for the airborne jamming of Loran are similar to those for the jamming of Gee.

7. Airborne Jamming against Oboe

(*a*) Against metric Oboe only jamming transmitters which are fitted with search devices would be suitable for use in aircraft. Because of the short time taken to make the approach to a target—it lasts only eight minutes, in which time the frequency must be determined, transmitted from a ground station to the jamming aircraft, and the aircraft transmitter tuned accurately to this frequency—it appears that the use of airborne jamming does not hold much promise of success. Because of its comparatively short jamming range, the jamming aircraft would have to orbit the actual area to be protected in order to be effective. If the enemy should attack a target other than that protected by the jamming aircraft it would be impossible to switch the latter to the new target because of the high speed of the attacking aircraft (Mosquito).

(*b*) Since suitable jamming apparatus for use against centimetric Oboe is not available and is not to be expected in the near future, the demand for it must remain of secondary importance in favour of the speeding up of the construction of ground jamming stations (the *Ball* system) already in hand. The use in aircraft of the *Ball* jamming system is technically impossible.

8. Airborne Jamming against Enemy Radar Ground Stations

Aircraft jamming enemy radar ground stations can use only low-power transmitters (*Wolke* or *Kettenhund*) the small power units of which can be housed in the aircraft itself. Because of their short jamming range the jamming aircraft would have to be used in front-line areas and even over enemy territory itself if they are to prevent the detection of our own aircraft on flights over the enemy *hinterland.*

9. Airborne Jamming against Metric-wave Searching Sets

The use of airborne jamming transmitters against enemy airborne search equipment on the metric wave-band (night fighter search equipment *Luchs*) is no longer worth while because of a great reduction in the use of such equipment. Jamming transmitters have not yet been produced for use on the centimetric wave-band (night fighter search equipment *Frankfurt* and *Grille*).

10. Airborne Jamming against Centimetric-wave Ground Scanning Equipment

An essential for the effective jamming of enemy ground scanning equipment (H2S) operating on the centimetric wave-band is a highly directional jamming beam. This is a possibility where suitable jamming transmitters are established on the ground. It is absolutely impossible, however, to transmit a highly directional beam from an aircraft.

11. Conclusions

To sum up, it must be stated that, apart from jamming enemy R/T traffic, consent cannot be given for the use of airborne jamming transmitters over the *Reich,* both on tactical and technical grounds. Moreover, consent can only be given for the use of airborne jamming equipment against enemy R/T on the condition that the jamming transmitter is fitted only in fast aircraft, capable of higher speeds than the enemy fighter cover. On flights over enemy territory or in front-line areas airborne jamming is only possible when very fast and suitable aircraft are used. At present suitable jamming transmitters are not available.

NOTES ON WIRELESS DIRECTION FINDING

From the earliest days of wireless telegraphy, the directional properties of aerials were known and the practical application of these properties soon became an important factor in marine and air navigation. In the absence of radio communication, a ship or aircraft could determine or keep track of its position by dead-reckoning, map reading, or astronomical observation. But in aircraft, D.R. navigation might easily become inaccurate owing to unknown or changing winds; map reading was only possible in clear weather when flying below cloud; and astro-navigation was also dependent upon good weather conditions, as well as being really applicable only to long flights. Similar hazards were always present in marine navigation, but their danger became many times greater with the infinitely greater speed and shorter endurance of aircraft.

In ships, then, direction-finding by wireless was little more than a check on the older methods of navigation—valuable and universally employed, but not perhaps imperative. With aircraft it became of vital importance, and the organisation of civil and military flying between the wars became dependent upon the existence of an efficient D/F service.

Frame Aerials

The frame aerial, which was the basis of all wireless D/F apparatus, was simply a pair of spaced open aerials given a common earth lead and coupled and connected to form a 'frame' or 'loop' aerial. In using this type of aerial the frame is rotated about a vertical axis and the position of minimum signal strength noted. The plane of the frame is then at right angles to the direction of the signal, and a scale of degrees enables the bearing to be read. The maximum position, when the frame is in line with the signal, could just as readily be used, but the human ear is not always able to detect small differences in the intensity of a signal, whereas it is well able to choose the point where a signal is weakest, or inaudible. Since all early D/F was done by aural methods, the principle of the minimum signal for D/F purposes became established.

Bellini-Tosi

A very high degree of amplification was required with rotating loop D/F because of the smallness of the loop diameter compared with the wavelength. High amplification inevitably resulted in an increase in the general noise-level of the receiver, with a consequent tendency to mask the minimum position of the frame, and large frame aerials became unwieldy, making the D/F process slower and more laborious. About 1907, the research workers Bellini and Tosi developed a D/F system using fixed frames, and for many years this system was practically standardised for all D/F ground stations. The chief advantage of the system was that, because the frame aerials were fixed, they could be made much larger than the rotating loop. The D/F process was carried out by a small swinging search coil in an instrument called a radiogoniometer, which, in conjunction with the two frame aerials, constituted the complete Bellini-Tosi system.

The Radiogoniometer

This had two fixed or stator coils which were mounted at 90 degrees to each other, each stator coil forming a part of one frame aerial circuit. Mounted centrally in the space between the stator coils was a small coil called the search coil, which was connected to the receiver. The search coil was in effect a small frame aerial within the electric field of the two stator coils. As it revolved, the E.M.F. induced in it varied as the E.M.F. induced in the two fixed frame aerials would vary if they could be rotated. A scale and pointer associated with the search coil spindle completed the action of the radiogoniometer.

Sensing and Fixing

Bearings taken by rotating loop or goniometer D/F were subject to a 180-degree uncertainty. If a minimum occurred at 135 degrees there was a second minimum at 315 degrees, the loop or search coil having then turned a half-circle. Generally an aircraft requesting D/F assistance knew its approximate position, the ground station knew its rough course and destination, and the 'sense' of a bearing was apparent. But for D/F stations to be able to give a reliable safety service to an aircraft in distress or uncertain of its position, it must be possible to determine which of the two bearings is the correct one. This determination of the correct bearing was known as 'sensing'. The 180-degree doubt arose through the symmetry of the figure-8 radiation pattern of the aerial, essential to direction-finding. Sense was obtained by switching in the E.M.F. induced in an open vertical-wire aerial to the same receiver and combining it with the loop or goniometer E.M.F., after the bearing had been taken. The two E.M.Fs. from the open aerial and the loop aerial or goniometer were then aiding one another for one position of the loop and in opposition for the other, the combination of the two giving one maximum and one minimum position instead of the two equal maxima and minima in the case of the loop or goniometer alone. When this process had been completed, the bearing was said to have been 'sensed'.

Fixing was the use of bearings from two or more stations to form an intersecting point at which the aircraft's position was said to be fixed. When three ground stations were used the intersecting point never coincided in practice, and the size of the triangle formed at the intersecting point represented the possible error of the fix. This triangle was sometimes known as the 'area of doubt', or the 'cocked hat'.

Errors in Direction Finding

The main sources of error, which affected both D/F loop work and bearings received from ground stations, were 'site error' (generally known as quadrantal error) and 'night effect'. There were other sources, such as coastal refraction and polarisation error, but these were the main ones which affected the development of direction finding between the wars. Solution of site error in ground stations lay mainly in the choice of a site as free as possible from all possible interference from conductors The only method of dealing with site error once it was found to exist was the preparation of an error chart from which observed bearings could be corrected. This was always done in aircraft, the chart being permanently attached to the loop scale. The compilation of this from observed bearings was known as calibration. The presence of night effect was known very early in the history of D/F. It was noticed that the apparent bearings of fixed stations went through astonishing variations, sometimes being more than 90 degrees out. On medium wavelengths these phenomena were found to occur during the period between dusk and dawn, the daylight hours being comparatively free from any irregularity. The errors coming under the heading of night effect could be attributed to one main cause—the spurious E.M.Fs. induced in the horizontal members of a frame aerial by ionospheric reflections. A long series of trials and experiments between the wars was aimed at the elimination of 'night effect'.

There were several other causes of error, most of which were associated with the fact that two rays might be received at the receiving station, one direct and the other reflected from the ionosphere. These errors were due to fading, skip distance, and scatter. But in most cases where D/F errors appeared, an experienced operator could judge the conditions and select the right moment for taking a bearing, or at least recognise that a bearing was unlikely to be accurate.

The Adcock Aerial System

This system was first proposed by Adcock during the First World War, and was later practically standardised for permanent ground D/F stations. The principle of the Adcock aerial was the removal of the top horizontal limb of the frame so that it was not affected by the received wave. This principle was applied to the Bellini-Tosi aerial system with radiogoniometer, and it greatly reduced night effect.

Civil Aviation D/F Development Plan 1934

In 1934 there were four permanent civil aviation D/F stations, those at Croydon and Manchester being Bellini-Tosi and those at Lympne and Pulham being Marconi-Adcock stations. Croydon was to be converted to Marconi-Adcock in due course and so in all probability was Manchester. The civil aviation development programme for 1935 was for nine mobile stations, sites for which would depend on the development of air routes. The probable sites were Portsmouth, Hull and Newtownards (which was already in position and operating), Plymouth, Birmingham, Aberdeen, the Orkneys, and Bristol. Other possible sites were Renfrew, Newcastle, Cardiff, Wick and the Shetlands. Eight new permanent stations were to be erected by 1938–1939, three of which would be converted mobile stations. The sites of the permanent stations would depend on the course of internal airline development, but one station was to be erected at Heston early in 1935, and other likely permanent sites were Portsmouth, Hull, Newtownards, Plymouth and Renfrew. In addition the Channel Islands' authorities intended to erect a Bellini-Tosi station in Jersey, and the installation of a station on the Isle of Man was planned by the local government. The final position in 1938/39 was to be twelve permanent stations and six mobile stations. All these stations were to be of the Adcock type, working on M/F. Abroad, D/F facilities on the civil air routes were greatly expanded during this period.

The trend of European opinion in civil aviation was against the use of long-range track beacons. They were not considered suitable for complicated networks of routes, and insufficient frequencies were available for an extensive beacon organisation in addition to the channels required for normal two-way communication. Civil D/F ground stations economically combined two-way communication with navigational assistance on the same wireless channel.

It was proposed, however, to experiment with ultra-high-frequency short-range beacons to facilitate the approaches to airfields from distances of 15 to 30 miles. Experience showed that the bulk of congestion on D/F channels was due to the number of bearings required by aircraft in the last stages of approach before landing. A short-range beacon was already in existence at Croydon, and if experiments were successful other civil airfields were to be similarly equipped.

APPENDIX No. 11

AIR STAFF MEMORANDUM No. 15, 1 JANUARY 1924

The Use of Radio Communication by Home Defence Bombing Squadrons

1. This very complicated and difficult subject has recently been receiving the attention of the Air Staff, and it has been decided that any comprehensive statement of policy would at the present time be premature, in view of the limited experience of the subject which has been gained.

It has, however, been decided to proceed on the following lines, with a view to finding out what results can be obtained from present-day apparatus in existing aircraft, and what line future development should follow. The position will be reviewed at the end of 1924.

2. One squadron, namely No. 207, is to be equipped as follows :—every aeroplane will be equipped with ' Wing coils ' and the necessary wiring and fittings to enable it to carry simultaneously Wireless Telegraphy sending and receiving, with trailing aerial, and Radio Telephony sending and receiving, with fixed aerial. The instruments which will be provided for the squadron will be two-way wireless telegraphy for the leader and deputy leader, and radio telephony reception for all other aeroplanes. In addition, 100 per cent reserve of instruments on the above scale will be held, so that the squadron can carry on, in spite of crashes and damaged instruments, for 18 months.

The above decision will mean that the leader and deputy leader will carry wireless installations weighing 140 lb. and all other aircraft 40 lb.

The personnel establishment of this squadron must allow the leader and deputy leader to carry wireless operators who are also trained as aerial gunners.

When the squadron has been equipped it is to practise formation flying with the two aerials down, and also navigation by means of sending signals to the ground and receiving positions from the ground. It is also to practise navigation by means of the wing coils only.

Two W/T ground stations will be necessary to work with this squadron, and these will be at R.A.F. Stations.

3. The first of the new day-bombing squadrons which is formed complete, *i.e.*, does not have to train its own pilots, will be equipped as follows.

All aeroplanes will have wing coils and the wiring and fittings to enable them to carry simultaneously wireless telegraphy sending and receiving with trailing aerial, and radio telephony sending and receiving with fixed aerial. Instruments will be provided for this squadron to enable the leader and deputy leader to carry wireless telegraphy sending and receiving and radio telephony sending and receiving, and all other aeroplanes radio telephony sending and receiving. In addition, 100 per cent reserve of instruments on the above scale is to be ready by the time the squadron forms.

The squadron is to use its radio telegraphy to practise formation flying tactics and drill, and its wireless telegraphy in the same way as No. 207 Squadron.

Both No. 207 and the new squadron will report on the effects of the trailing aerial, and on navigation by both methods open to them, *i.e.* by wing coils and by sending to the ground stations.

4. In addition to the two squadrons mentioned in paragraphs 2 and 3 above, all two-seater day bombers are to be capable of carrying the instruments laid down for the new squadron in paragraph 3, and enough instruments are to be held in reserve to enable two additional day-bombing squadrons to be equipped on the same scale and with the same reserve as the new squadron.

5. From 1st June 1924, all aeroplanes of No. 7 Squadron will be equipped with wireless telegraphy sending and receiving and also with rotating coils for direction finding, if the Vickers Vimy will take them. Instruments will be provided for all aircraft in this squadron, and 100 per cent reserves will be held in addition.

6. As each of the next three new night-bombing squadrons is formed, it will be equipped in the same way as No. 7 Squadron, except that rotating coils will not be used. A reserve of 100 per cent of wireless telegraphy transmitters and receivers will be formed for each of these squadrons as it completes forming, but no more rotating coils will be ordered until further reports on the revolving beacon have been received.

7. For the future, every effort must be made to improve wireless apparatus in the following directions :—

(i) The trailing aerial must be done away with in all aeroplanes which may have to fly in formation.

(ii) The receiving range of instruments must be extended without increasing their weight.

(iii) The ' revolving beacon ' method of direction finding must be pushed on with.

(iv) Telephony and telegraphy must be combined in one instrument if possible. Aeroplanes of the future must be designed to carry the combined set.

AIR STAFF MEMORANDUM No. 40, FEBRUARY 1928

THE USE OF RADIO COMMUNICATION BY HOME DEFENCE BOMBER SQUADRONS

(Air Staff Memorandum No. 15 on the same subject issued on 1 January 1924, is hereby cancelled)

1. From the experience gained in radio communications in Home Defence Bomber Aircraft during recent years, it is clear that the apparatus required by Air Staff Memorandum No. 15 to be fitted to these aircraft is not altogether satisfactory. While the individual items could be made to carry out their correct functions, the installation of the whole was so complicated and cumbersome as to interfere with the other duties of the crew of the aircraft.

It has been decided, therefore, to proceed on the following lines, until sufficient experience has been gained with the improved apparatus as to enable the final policy on this subject to be declared.

2. **A. Day Bombers**

(i) *New Apparatus.* A combined set capable of providing two-way W/T or two-way R/T, to operate on a fixed aerial, is to be produced for Service trials as soon as possible.

(ii) Until this apparatus is produced and given trials in a Service squadron, no definite decision as to the tactical use and employment of wireless in day-bomber aircraft can be made.

(iii) For the present all day-bomber aircraft are to be wired to take, and three per squadron fitted with, two-way W/T only, to enable the squadrons to practise D/F navigation by ground D/F (Bellini-Tosi) and two-way W/T communication with the ground and with other aircraft.

(iv) In addition to (iii) above, one flight of No. 100 (B) Squadron is to be equipped with two-way R/T of the same type as that now in use in No. 41 (F) Squadron to enable experience to be gained in the tactical handling of bomber formations using R/T.

(v) In specifications for future day-bomber aircraft, details of the wireless to be carried is to be omitted, but a space of specified dimensions to be allowed in the aircraft for wireless apparatus. These dimensions are to be arrived at now by the Royal Aircraft Establishment and are to be of a size to ensure that the new apparatus ((i) above) under development for this type of aeroplane can be carried.

B. Night Bombers

(i) A new W/T receiver capable of use for two-way W/T or wing coil reception is to be completed at an early date and given Service trials in a night-bomber squadron, with a view to its general introduction when proved satisfactory into all night bomber aircraft.

(ii) All future night-bomber aircraft are to be fitted with wing coils.

(iii) All present night-bomber aircraft are to continue to be fitted with two-way W/T to enable practice to be carried out in navigation by ground D/F method (Bellini-Tosi) and two-way W/T communication with the ground and other aircraft.

MEMORANDUM ON THE USE OF D/F AS AN AID TO NAVIGATION AND DISSEMINATION OF INFORMATION OBTAINED FROM D/F SOURCES, 24 MARCH 1940

PART I

D/F as an Aid to Navigation

General

1. Successful air navigation is based upon Dead Reckoning, which consists of calculating the track and ground speed of an aircraft. Accurate navigation over long distances cannot, however, be maintained by Dead Reckoning alone, due primarily to the inability of meteorologists to forecast accurately wind velocities over wide areas.

2. Although Dead Reckoning must remain the basis of all navigation, navigators can resort to assistance from one of the following navigational aids :—

(i) Observation of objects on the ground.

(ii) Calculation of position lines obtained from the observation of celestial bodies.

(iii) Position lines or fixes obtained from radio.

(iv) The combination of any of the above.

3. Experience has shown that the mastery of any one of these aids alone is not enough accurately to conduct the navigation of an aircraft in all circumstances. It is therefore essential that navigators should appreciate the advantages and disadvantages of all possible aids to navigation. It is essential to bear in mind that the value obtained from astronomical position lines or radio bearings, or a combination of both, is almost invariably dependent upon the accuracy of Dead Reckoning navigation.

4. In astronomical navigation, Dead Reckoning positions may be comparatively inaccurate, but recent experience has shown that positions and bearings obtained by D/F methods are liable to grave inaccuracies, and that unless the D.R. navigation is carefully conducted, crews may easily be led into difficulties.

Necessity for Checking D/R by Loop Bearings, Astro and D/F

5. The navigator may frequently receive fixes and bearings which appear to show his D/R navigation grossly in error. These incorrect bearings or fixes may be due to misleading transmissions from the enemy, night effect, coastal refraction or the distance from the ground station combined with the height of the aircraft. Where efficient D.R. navigational methods have been followed, a navigator will be confident of his approximate position. He can then use D/F information with reserve, and reject such information as is manifestly inconsistent with his D.R. reckoning.

6. The navigator should constantly check his track and ground speed by observation of the ground where possible, or alternatively by astronomical means and by D/F, when these are available. He will then have a fair knowledge of the reliability of his sextant, of the reliability of the various D/F stations and beacons, of the W/T set, of the calibration of the loop and of the static condition of the atmosphere.

Errors likely to be Experienced when using D/F

7. The degree of error likely to be experienced on M/F D/F is dependent upon the efficiency of the ground personnel in obtaining a well-defined minimum, but experience has shown that a high degree of accuracy can be expected up to 250/300 miles, so long as the aircraft is high. It must be remembered, however, that one degree of error in the bearing will mean an error of approximately one mile at sixty miles range, the error increasing in proportion to the range. Similarly, the error in a fix when both bearings are incorrect will increase with the range. On the other hand, the H/F D/F system is only accurate up to a distance of 100 miles.

8. Loop bearings are generally not as accurate for a given distance as are those of ground stations. The order of accuracy is certainly not more than plus or minus 2 degrees at 200 miles. They are especially affected by night effect during sunrise and sunset periods at distances over 50 miles from a beacon. It is important to bear in mind that the accuracy of the bearing is dependent upon accurate course keeping at the time of taking the bearing.

Availability of D/F Methods

9. It will therefore be appreciated that under certain conditions useful assistance from D/F may not be available. Consequently, the necessity for accurate D/R navigation is paramount, and all other means of navigation, especially for operational flying over enemy territory and over sea, must be considered as aids only to the accurate navigation of the aircraft.

PART II

DISSEMINATION OF INFORMATION OBTAINED FROM D/F SOURCES

Information regarding Position of Aircraft

1. The safety of aircraft, particularly in bad weather, will be enhanced if Groups and Stations are in possession of information regarding their movements. The position of aircraft is known

(*a*) from fixes or bearings given by D/F stations,

(*b*) from knowledge of the tracks flown out and home.

2. Stations should keep a listening watch on M/F D/F frequency whilst their aircraft are operating, and similarly on the M/F D/F identification frequency. Fixes intercepted on either frequency should be passed from the W/T receiving station to the Station Operations Room, thence to the Group Headquarters. Such fixes should be plotted at Stations and checked against the estimated D/R position.

3. Should doubt arise in the Operations Room as to the accuracy of a fix given, or if for any reason it is believed that the D/F Station is not answering aircraft transmissions, the Operating Station concerned should inform the Group. The Group Staff should then refer the query to the D/F Safety Section, or to the M.L.O., as appropriate. It should be noted that, in accordance with existing procedure, the M.L.O. passes all fixes obtained by the identification stations to the Group concerned.

4. If the safety D/F service is likely to be overloaded, the Group should communicate with the D/F Control Station, and indicate the order of priority to be observed in answering requests from aircraft of that Group. Similarly, Bomber Command Operations Room should be informed of any situation demanding that the Radio Beacon organisation may be brought into force, vide S.S.I., Part VI, Section 3.

5. In order that information is readily available, it is essential that known positions and estimated tracks are plotted. Only by such means will it be possible to make early decisions as to the best methods of assisting aircraft should this become necessary. In addition, such records will enable advanced information to be given to Regional Control Centres concerned, so that the latter may be prepared to accept aircraft at short notice.

Division of Responsibility between Groups and Stations

6. The responsibility for taking action and initiating queries rests with the Group and Station concerned. Stations must assist their own aircraft with the means at their disposal and a careful check is to be kept on the accuracy of their H/F D/F stations and the ranges at which their aircraft ask for bearings from them.

7. Group Headquarters are to start the Regional Control machinery when required, *e.g.* bad weather conditions, overloading of H/F D/F, or its failure to give efficient service. Stations should report immediately to the Group Headquarters if their H/F D/F system is unsatisfactory, or if the number of aircraft to be 'homed' is such that some may be delayed to the limit of their endurance.

Information obtainable from the Fighter Command Organisation

8. When aircraft are lost over this country and are unable to make use of D/F, for example owing to W/T failure, information as to their position may be obtained from Headquarters Fighter Command. If, therefore, it is known or may be assumed that an aircraft has crossed the coast under these conditions, the M.L.O. should be informed by the Group concerned. He will be able to keep the Group informed of the aircraft's position, as shown by the Observer Corps' plots, and will also take such action as the Group consider necessary for the lighting of aerodromes. Since the aircraft will be flying a left-handed triangular course it should be possible to determine that it is one of our own aircraft and to predetermine its track.

9. Advance information regarding the approach to the English Coast of aircraft which have failed to identify themselves may also be obtained from the M.L.O., but such information should be treated with reserve until the Observer Corps' plots are received.

Reliability of H/F/ D/F Organisation

10. Bearings given to aircraft by H/F D/F stations at distances over 100 miles are unreliable. All bearings given by these stations should be telephoned to the Station Operations Room, where they should be checked. If scrutiny shows a greater distance than 100 miles, the D/F station should be instructed to inform the aircraft that the bearing is unreliable, and a bearing or general direction passed to the aircraft on the instructions of Station Operations Room.

11. In addition to this known fault of H/F D/F stations, other circumstances, such as minor technical faults, may arise which will affect the accuracy of bearings given by them. To ensure a continual check on the accuracy of the D/F receivers, Groups are to arrange snap bearings by each D/F station on a known transmission, at intervals of not more than one hour.

Use of D/F Safety Services as Communication Channels

12. Existing orders lay down that aircraft engaged on night operations shall change to M/F from operational frequency when a point 100 miles from the English Coast is reached on the outward journey. Unless arrangements are made for aircraft to revert to operational frequency for short intervals and at predetermined times, this D/F channel is the only means of communication. It must, however, be realised that transmissions will interfere with the safety and navigational functions of the D/F Service.

Use of M/F D/F as an Aid to Navigation Outwards

13. When over 100 miles from the coast, a fix may be obtained from the M/F D/F Service allotted to the Group as a check on D.R. navigation. Care should be taken to ensure that interference is not caused to aircraft making use of the M/F D/F Service for safety purposes.

BC/S.20768/88/SIGS.

ALLOCATION OF M.F. D/F SECTIONS, JUNE 1940

Section 'A.' *Inverness*—Sumburgh. (330 Kc/s)
Combined Security and Identification duties.
Identification Front :—57° 30′ N.–61° N.
Inverness connected by telephone to No. 14 Group M.L.S.

Section 'B.' *Renfrew No. 1*—Kirkwall–Sollas. (363 Kc/s)
Combined Security and Identification duties.
Identification Front :—55° 30′ N.–59° N.
Renfrew connected by telephone to No. 9 Group M.L.S.

Section 'C.' *Manchester No. 1*—Newtownards. (356 Kc/s)
Combined Security and Identification duties.
Identification Front :—55° N.–56° N. extending westwards to 8° W.
Manchester connected by telephone to No. 9 Group M.L.S.

Section 'D.' *Heston No. 1*—Hull No. 1–Newcastle No. 1. (348 Kc/s)
Security duties No. 5 Bomber Group aircraft.
Heston connected to Fighter Command M.L.S. by direct telephone.

Section 'E.' *Plympton*—Southampton (Old Netley). (314 Kc/s)
Combined Security and Identification duties.
Identification Front :—50° 30′ N.–48° N. and between 1° and 5° W.
Plympton connected to No. 10 Group M.L.S. by direct telephone.

Section 'F.' *Sealand*—Andover No. 1–Leuchars. (340 Kc/s)
Identification duties No. 4 Bomber Group aircraft.
Identification Front :—52° 45′ N.–56° 30′ N.
Sealand connected to Fighter Command M.L.S. by direct telephone.

Section 'G.' *Bircham Newton*—Lympne No. 2–Newcastle No. 2. (326 Kc/s)
Security duties No. 4 Bomber Group aircraft.
Bircham Newton connected to Fighter Command M.L.S. by direct telephone.

Section 'H.' *Tangmere No. 1*—Pulham No. 2–Carlisle No. 2. (273 Kc/s)
Identification duties No. 3 Bomber Group aircraft.
Identification Front :—50° N.–54° N.
Tangmere connected to Fighter Command M.L.S. by direct telephone.

Section 'J.' *Pulham No. 1*—Lympne No. 1. (257 Kc/s)
Identification duties No. 5 Bomber Group aircraft.
Identification Front :—50° 45′ N.–53° N.
Pulham connected to Fighter Command M.L.S. by direct telephone.

Section 'K.' *Hull No. 2*—Heston No. 2–Renfrew No. 2. (294 Kc/s)
Security duties No. 3 Bomber Group aircraft.
Hull connected to Fighter Command M.L.S.

Section 'L.' *Bristol*—Manchester No. 2–Tangmere No. 2–Exeter. (370 Kc/s)
Combined Security and Identification duties.
Identification Front :—50° N.–53° N. extending westwards to 8° W.
Bristol connected to No. 10 Group M.L.S.

Section 'M.' *Andover No. 2*—Manchester B/T–Western Zoyland B/T. (440 Kc/s)
Practice Group for use of Bomber O.T.Us., Coastal Command O.T.U. and School of A.A. Day watch (0800–1800 hours) only.

NOTE 1.—Stations in italics indicate Control Stations.

HEADQUARTERS No. 1 GROUP SIGNALS INSTRUCTION No. 8, 25 May 1942

Signals Procedure for Aircraft on Operational Flights

1. The following procedure is to be used when aircraft of No. 1 Group are engaged on operational flights for which no special instructions have been issued.

Information to be carried in Aircraft

2. The wireless operator is responsible that the following are available in the aircraft :—

(i) F.398—W/T Operator's Log Book, which is to show a clean sheet at the start of each flight.

(ii) A.P. 982—Aircraft Operating Signals.

(iii) S.D. 0182/H.1—Aircraft and Ground D/F Verification Signals with sufficient extracts for the maximum possible duration of each flight only.

(iv) The schedule of operation of the British M.F. Beacons for the period covered by the flight.

(v) The operational call-sign allocated for the particular operation, the aircraft letter, and the M.F. D/F Section specifically allocated to the aircraft for the flight.

(vi) Standard destructible paper giving the following details :—

(*a*) The call-signs and frequencies of H.F. D/F stations in Bomber Command, and other stations to which the aircraft might be diverted in an emergency, viz. : those included in the Diversion Schedule.

(*b*) The call-sign of Group Headquarters, the collective call-sign of all Group aircraft in flight, and the Group Operational Frequency.

(*c*) The call-signs and frequencies (both D.F. and Guard) of Flying Control Centres.

(*d*) The diversion numbers set out in the Diversion Schedule for the period in force at the time.

(*e*) The call-signs and frequencies of the various M.F. D/F Sections, including their constituent stations.

(*f*) The station aircraft call-sign.

(*g*) The call-signs and frequencies of selected continental wireless stations.

3. The wireless operator is responsible that the transmitter click-stops are set up on the following frequencies :—

(i) High Frequencies :—

Base H.F. D/F.
Group Operational.

(ii) Medium Frequencies :—

M.F. D/F Sections E, F, G, H, J, and N.

The remaining click-stops may be set up according to local requirements.

4. The navigator is responsible that the following are available in the aircraft :—

(i) S.D. 02—Syko Machine with the correct card for the day.

(ii) A.P. 1927—Air Force Code.

(iii) An outline map showing pictorially the details of the Beam Approach Installations which are available on each stud setting on the receiver.

(iv) Location of British M.F. Beacons and continental wireless stations. These are to be on destructible paper.

Calibration Signals by Ground Stations

5. Station H.F. D/F will transmit call-signs for a period of 3 minutes at intervals of 15 minutes commencing at the clock hour, throughout the 24 hours. If, however, at the 15-minute intervals aircraft are being worked, call-signs will not be sent.

6. At every hour and half hour, commencing at the clock hour, throughout the 24 hours, the Group Medium Power Transmitter will transmit signals on the Group Operational Frequency in the following manner :—

(i) Where there is a message to be passed to aircraft :—

(*a*) Call-sign of all Group aircraft in flight or the Operational call-signs of the aircraft concerned (3 times).

(*b*) " V ".

(*c*) Call sign of Group (3 times).

(*d*) Text of message (twice).

(ii) Where there is no message to be passed to aircraft :—

(*a*) Call-sign of Group (3 times).

(*b*) Short Break.

(*c*) Identification numeral (once).

(*d*) Short Break.

(*e*) " V " (6 times).

Note.—The last sequency signal is to include a time signal and will be concluded by " VA ".

These signals will be transmitted for a period of at least three minutes, the sequence being repeated as necessary.

In order that there shall be no confusion with diversion numbers, only the numerals 1–9 are to be used as the identification numeral.

7. The control station of each M.F. D/F Section will transmit its call-sign for 3 minutes at 15 and 45 minutes past the hour daily, the first of such transmissions being at 11.15 B.S.T. and the last at 13.45 B.S.T. The transmissions will not be allowed to interfere with the operational function of the M.F. D/F Service, and if, at these intervals, aircraft are being worked, the call-signs will be curtailed or omitted as necessary.

Ground Control of Aircraft

8. The use of R.T. for the control of take-off is to be restricted and where other means of control are possible R.T. is not to be used. If, however, it is used, a short drill of essential signals only is to be employed and such practices as, for example, pilots requesting permission to take off before they have been instructed to do so, which only result in additional and unnecessary signalling by the control station, are forbidden.

Security

9. Strict W/T silence is to be observed at take-off and no W/T or R/T checks necessitating transmission are to be carried out.

10. It is emphasised that in the interests of security, transmissions from aircraft, either W/T or R/T, must be kept to the minimum consistent with safety.

11. All W/T transmissions to and from aircraft (with the exception of Diversion Signals and Recall Signals, which will be sent as laid down in paragraph 22 below) must be in SYKO, except in emergency upon the express instructions of the captain of the aircraft.

12. Radio Aids to Navigation should normally be obtained by means of D.F. Loop Bearings, Radio Track Guides, and Station Beam Approach Systems. Navigational aids requiring W/T transmission should only be used when absolutely necessary.

13. In addition to the loss of security caused by W/T or R/T transmissions, it is to be impressed on all crews that as the numbers of operational aircraft increase, the amount of navigational aid that can be given to aircraft using transmitters will be strictly limited, while on the other hand navigational aid obtainable by D.F. Loops and Beams is unlimited.

Navigational Aids Requiring W/T Transmission

14. (i) M.F. D/F Section F has been allotted to No. 1 Group and this is the section to which wireless operators should normally make distress calls, requests for assistance, and identification signals. In an emergency or when the aircraft is flying in an area in which their own section is unsuitable, wireless operators may work any other appropriate section.

(ii) Whenever S.O.S. calls, requests for D/F fixes, or identification signals are made, the control station of the appropriate section is to be worked. Bearings may, however, be obtained from any station in the M.F. D/F organisation.

15. (i) Short-range H.F. D/F stations are situated at most airfields and are available for homing purposes from distances up to 100 miles.

(ii) Normally aircraft should be at heights of not less than 4,000 feet when requesting bearings at ranges of more than 50 miles.

(iii) On no account are bearings to be obtained by aircraft which are more than 100 miles distant from the D/F station, since at these distances the D/F station is liable to lie in the skip area of the aircraft transmitter and the risk of large errors and reversed sense is very great.

16. Wireless operators must be prepared to give the correct verification signal from S.D. 0182/H1 should they be challenged by a ground station. Similarly, wireless operators should challenge a D.F. station if the transmission is considered to be of doubtful authenticity.

17. (i) The emergency R.T. Organisation " Darky " exists to enable the pilots of aircraft to obtain immediate R.T. communication with the ground.

(ii) All Bomber Command aerodromes and certain other aerodromes maintain continuous watch on a common frequency from dusk to dawn, and can establish immediate communication with any aircraft calling " Darky ", so that assistance and information can be passed direct to the pilot.

(iii) These ground stations have an approximate range of 8 miles.

Balloon Barrage Warning Signals

18. Transmitters are installed at the majority of balloon barrages for the purpose of radiating a signal which produces an audible note in the aircraft R/T receiver similar to the warbling note of an air raid siren, to warn aircraft of the presence of a balloon barrage. The transmitter has a range of approximately 10 miles, but owing to various local conditions this may be considerably exceeded or reduced. Pilots of aircraft are to switch on the R/T receiver at all times when there is any possibility of their being in the vicinity of a balloon barrage.

Operational Control of Aircraft

19. Operational control of aircraft will be by Group Medium Power Transmitter and all aircraft are to listen on the Group Operational Frequency at the hour and 30 minutes past the hour for control signals, unless the aircraft is homing on H.F. D/F. If one half-hourly period is missed it is imperative that watch is kept at the next period.

20. These control signals will be broadcast and should not be acknowledged unless specific instructions to acknowledge are included in the address of the message. This instruction will consist of the insertion of the procedure signal " Y ".

21. It is essential that the aircraft transmitter is accurately set up on the Group Operational Frequency.

22. Diversion and Recall Signals will not be put into SYKO but will be sent in the following form :—

(i) Diversion Signals.—Diversion signals will consist of BFX followed by the number of the airfield, taken from the current diversion schedule. Should it be necessary to divert aircraft of this Command to an airfield which is not included in the diversion schedule, the name, call-sign, frequency etc. of that airfield will be transmitted in clear.

(ii) Recall Signals.—Recall signals will consist of one of the following sets of groups from A.P. 1927 :—

NLW BBA—Abandon Operations and land at the Base.

NLW (Diversion Number)—Abandon Operations and land at (airfield indicated by diversion number).

NLW BJV (Diversion Number)—Abandon Operations and land at (airfield indicated by diversion number) or at any suitable airfield *en route* which will accept you.

Safety Precautions Over the Sea

23. During the period when aircraft are over the sea transmitters are to be adjusted to the appropriate M.F. D/F frequency (normally Section F) in order that no time may be lost should it be necessary to transmit a distress signal. This refers to transmitters only, and operators should change to the receiver frequency as necessary either to obtain navigational aid or to listen to the Group Routine Broadcasts.

Emergency Reports

24. The following self-evident code is to be used for the reasons indicated by the code if it is doubtful whether the aircraft will regain British territory :—

(i) FTR—Damaged by enemy fighter.
(ii) FLK—Damaged by enemy flak.
(iii) BAL—Damaged by enemy balloons.
(iv) ICE —Icing.
(v) ENG—Engine failure.
(vi) PET—Fuel shortage.
(vii) LLL—Lost.

25. The message should normally be addressed to Group and passed if possible on the Group operational frequency but may be passed on any medium D/F frequency or station D/F frequency. The message is to be given Emergency priority. In circumstances requiring the sending of S.O.S. the appropriate code group should if possible be added to the distress call.

26. It must be clearly understood that the use of this code must not jeopardise the passing of S.O.S. calls, either from the aircraft concerned or from other aircraft using the same frequency.

Identification by I.F.F.

27. All aircraft which are fitted with I.F.F. are to keep the device switched on using No. 1 Setting (Narrow) :—

(i) On the outward flight, from the time of take-off until the aircraft is 50 miles out at sea.

(ii) On the return flight from the time the aircraft is 100 miles from the coast until it has landed.

(iii) When within visual range of H.M. ships at sea or when H.M. ships are known or believed to be sailing in the area over which the aircraft is operating.

28. Aircraft fitted with I.F.F. are, whenever possible, to approach the coast of Great Britain at a height exceeding 2,000 feet above sea level.

29. Provided that the wireless operator has satisfied himself by tests that the I.F.F. device is working satisfactorily, identification by the procedure outlined in paragraph 32 below may be dispensed with if the aircraft is flying higher than 2,000 feet.

30. The attention of all wireless operators is to be drawn to the test to be carried out on the I.F.F. equipment during flight as laid down in A.P. 1766G, Volume 1, paragraph 14.

Identification by M.F. D/F Signals Procedure

31. The identification procedure detailed in paragraph 32 below is to be carried out by aircraft :—

(i) Which are not fitted with I.F.F.

(ii) Whose I.F.F. sets are not working correctly.

(iii) Which are flying below 2,000 feet above sea level ; or

(iv) Whose direction of approach is one which would not normally be followed, but which is occasioned by an error in navigation, or by orders received whilst airborne.

The identification signal described should be transmitted when the aircraft is as nearly as possible 60 miles from the coast on the return flight.

32. The identification procedure consists of sending a signal, in the form indicated below, on M.F. D/F Section F, or other appropriate section :—

(i) Call-sign of D/F Control Station—" V "—call-sign of aircraft.

(ii) Total number of aircraft in formation (if more than one).

(iii) A long dash of 15 seconds.

(iv) Call-sign of aircraft made once only.

33. When requiring a D/F fix or bearing from an M.F. D/F section aircraft are to use the same procedure as laid down in paragraph 32 (i) above, followed by the appropriate operating signal, a long dash of 15 seconds, and the call-sign of the aircraft made once only. For example :—

(i) Call-sign of D/F Control Station—" V "—call-sign of aircraft.

(ii) Operating signal requesting fix or bearing.

(iii) Long dash of 15 seconds.

(iv) Call-sign of aircraft made once only.

34. The Control Station will :—

(i) Answer the aircraft with letter " R " in the case of identification only ; or

(ii) Transmit the bearing of the aircraft, if a bearing has been asked for ; or

(iii) Answer the aircraft with the letter " R ", if a position has been requested, and then, after a short pause, transmit the position of the aircraft ;

(iv) If the identity of the aircraft is in doubt, challenge by means of the S.D. 0182/H.1 procedure. If there is no reply to the challenge or if an incorrect reply is received, the Control Station will refer the matter to the appropriate M.L.S. for further instructions.

Identification of Aircraft in Distress

35. Aircraft in distress, that is to say, aircraft incapacitated either structurally or by weather conditions and in danger of failing to reach a base, are to make a distress call to the M.F. D/F Organisation, as indicated in sub-paragraph (ii) below, and, simultaneously, in aircraft fitted with I.F.F. the Code Switch is to be moved from No. 1 Setting (Narrow) to No. 3 Setting (Very Wide). A breakdown on either the aircraft W/T transmitter or the I.F.F. set should not prevent the other set from being used for this purpose.

36. A distress call should normally be made on the M.F. D/F section allotted to this Group, i.e. Section F, but may be made on any of the M.F. D/F Sections should congestion occur on Section F. Whenever such calls are received the resultant fixes and the particulars of the aircraft concerned will be passed immediately to the

M.L.S. to which the Control Station of the Section is connected. The Control Station concerned will thereafter give priority facilities to the aircraft in distress. An aircraft after transmitting its distress message is to endeavour to send its call-sign for a period long enough to permit D/F Stations to determine its position.

37. A special watch will be kept on the track of any aircraft showing " Very Wide " I.F.F. (No. 3 Setting), and all details of its track passed to the M.L.S. The M.L.S. will take action as laid down in the instructions for the Air/Sea Rescue Organisation, in addition to informing Group Headquarters to which the aircraft belongs.

Identification of Aircraft being Shadowed by the Enemy

38. Warning that the aircraft is being shadowed by enemy aircraft is to be given by adding a special code group to the identification signal which is transmitted in accordance with paragraph 32 above. The code groups concerned are given in A.P. 1927 and are as follows :—

GCN—Enemy aircraft in company with me.
GCB—Unrecognised aircraft in company with me.

Whenever one of the above groups is used it is to be followed by the number of aircraft to which it refers, e.g. :

H7X —Aircraft call-sign.
6 —Total number of aircraft covered by the signal.
GCN9 —Nine enemy aircraft in company with me.
H7X —Long dash of 15 seconds followed by call-sign made once only.

Note.—When making the above transmission extreme care is to be taken not to interfere with other aircraft transmitting.

39. The D/F Control Station will acknowledge receipt of the transmission by sending the letter " R ". If the first transmission is not acknowledged by the D/F Control Station a second transmission is to be made at the first opportunity.

Landing Signal

40. On arrival in the vicinity of the parent station or any other station to which an aircraft has been diverted, the pilot is to establish communication with the Watch Office by R/T for the purpose of obtaining permission to land or receiving any instructions from the airfield Control Officer.

41. After landing, the pilot is to inform the Watch Office by R/T that he has landed, in order that the airfield Control Officer may know exactly what aircraft are still airborne.

42. In the interests of security NO signal of any description is to be made by W/T which would indicate that the aircraft is about to land, either by " X " signal (X195) or by local arrangement (such as VA VA).

43. Weather reports when passed by R/T must be confined to the terms " FIT " " FIT ZZ " " UNFIT ". The definition of these terms is given in A.M.C.O. A.20 of 1940.

44. The decision whether barometric pressure should or should not be given on any particular occasion is to rest with the Station Commander concerned.

Responsibility of Wireless Operators

45. No signals are to be made at any time without the permission of the captain of the aircraft. Operators are to keep captains of aircraft informed at all times of the stations with which they are in communication or with which they are able to establish communication.

46. *The Captain of the aircraft is to be informed immediately should a W/T failure occur.*

(Signed) Group Captain
Senior Air Staff Officer,
Headquarters, No. 1 Group

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