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THE SECOND WORLD WAR

1939–1945

ROYAL AIR FORCE

SIGNALS

VOLUME V

FIGHTER CONTROL AND INTERCEPTION

Promulgated for the information and guidance of all concerned.

By Command of the Air Council,

J. H. Barnes.

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

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ERRATA :

Page 97. *Insert* figure "1" *against* first footnote.

Page 204. Footnotes: *Alter* figure "5" *to* "3".
Alter figure "3" *to* "5".

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By Command of the Air Council,

J. H. Barnes

Preface

THE Royal Air Force methods of fighter control and interception which proved so successful during the Second World War were made possible by technical developments in radio communications and radar. The basis of the interception technique was the control of fighters in the air and plotting the courses of hostile aircraft; which thus enabled the fighters to be directed to a point of interception where they could engage the enemy. The events which led to the evolution of this fighter defence system took place over a period beginning some four years before the war, and continued under the pressure of enemy air attack during the war.

Radar provided a new method of detecting and locating aircraft and surface vessels, both from the ground and from the air. Radio communications in conjunction with radar, provided means for the control of our fighters, and the whole of the air defence organisation was operated by the use of an elaborate and extensive system of landline communications. The scope of this volume, however, is limited to deal specifically with fighter control and interception. The history of radar in raid reporting is more fully described in Volume IV, and the development of the radio and landline communications systems is related in Volume II—Telecommunications.

The technical developments which were applied to the progressive improvement of the fighter defence system were generally the result of deliberate scientific experiment to meet specific operational needs. In view of the complexities of these developments, this volume has been divided into four parts, each dealing with a separate aspect of the subject. There is a close operational relationship between the events described in each of the four parts. The events were to a great extent concurrent and complementary. It was, for example, the early failure of A.I. which accelerated the introduction of the first G.C.I., and eventually it was the combined use of both equipments which brought operational success. A slight degree of overlap between the four parts of this volume was therefore inevitable, but it will serve to correlate the different lines of development.

A Signals history deals inevitably with technical equipment, and the most important thing about technical equipment is the extent to which it helps to win a war. It is from this aspect that the account is written. Research and development are included because they were fundamental to the introduction of devices with war-winning qualities. How soon introduction into the Service took place depended largely on early operational demand and early appreciation of the possibilities of laboratory models. This was by no means entirely a matter for technicians, any more than was the development of methods of operational use. When these were worked out simultaneously with technical development, a great advantage was gained in the time saved, but this only occurred when there was understanding of the operational potentialities of technical features. The technical description of complete equipments has therefore been directed towards their salient characteristics, and to those details which had an influence or bearing on their operational and tactical performance.

The sequence of application of technical equipment to fighter operations during the war led to increasing reliance being placed on scientific devices, and scientific methods of investigation, in the solution of tactical problems. From the first constrained liaison between scientists and Service persons there grew wider contact and better mutual understanding. This progress was most noticeable at the time of the adoption of the ground radar station for night-fighter control in the winter of 1941/1942. By this time the universities and industrial laboratories were adding their research and development to that of Government establishments. Until this period, the radar reporting chain had been regarded from the operations room as something of a remote and secret entity, and the airborne set as a mysterious black box which gave the pilot indications of doubtful accuracy. Under the night bombing of that unpleasant winter, the need to make radar an integral part of the machinery of operational control, and the enthusiastic co-operation of the pilots and air operators, drove home the lesson that the scientist was not merely an inventor of equipment for the Royal Air Force : he was part of the team.

FIGHTER CONTROL AND INTERCEPTION

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PART I

Introduction

The invention of radar in 1935 revolutionised fighter tactics. Formerly, because good air intelligence was lacking, patrols and sweeps were the standard method of searching for the enemy, and onus of finding him was largely on the pilot. He was given no external aid for keeping track of his own position in the air and the probability of interception was little more than a matter of chance. The value of fighter defence showed signs of a rapid drop during the early 1930's when the ability of the bomber to get through, and back again, promised to improve out of all proportion as the result of faster speeds, operation at higher altitudes, longer ranges of action, and more facilities for flying effectively under cover of cloud and darkness.

The greatest advantage which radar gave was early warning, enabling the defence to dispense with standing patrols and economise in flying effort. To exploit this advantage, the defence required to be able to intercept with certainty. The first application of radar to this purpose was inevitably based on the Sector organisation then in existence, upon which the infant radar reporting organisation, with all its early limitations and inaccuracies, was grafted. The confidence of pilots in new methods of ground control and homing was gradually established. A remarkable feature in the development of forward interception was the undertaking and completion of the all-important first stage of the Biggin Hill experiments actually in advance of the building of the original five-station radar chain. To this early action was largely due the state of preparedness of air defence in time for the Battle of Britain.

The importance of the new sector control system in this battle can hardly be over-estimated. When the Germans concentrated their attacks on sector airfields between 24 August and 6 September 1940 it was 'not so much to destroy aircraft, or even to render areas unserviceable, but to destroy the nodal points of communication and control in the complex intelligence system that was, and always will be, the foundation of an effective air defence.'[1] During this period the whole structure of air defence was in the balance. 'Fortunately,' in the words of Air Vice-Marshal Park, 'the enemy switched his raids . . . to other objectives.'

[1] A.H.B. Narrative, A.D.G.B., Vol. II.

CHAPTER 1

THE BIGGIN HILL EXPERIMENTS

The initial sector organisation of fighter defence had its origin in the work of a joint War Office and Air Ministry sub-committee formed in 1923, and known as the Steel-Bartholomew Committee.[1] The main feature of the air defence plan was the Aircraft Fighting Zone. This was a prepared strip of country 15 miles wide and about 150 miles long, stretching from Duxford in Cambridgeshire, round the east and south of London to Devizes on the western edge of Salisbury Plain. It was to be illuminated by searchlights for night-fighting. The Aircraft Fighting Zone was to be divided into ten sectors, each having a front of about 15 miles and manned by one or more fighter squadrons. Along the forward edge of the sectors would be the Outer Artillery Zone, where anti-aircraft guns would indicate the presence of the enemy to aircraft by their fire, and would also assist by breaking up the hostile formations. London was to be directly defended by a ring of anti-aircraft guns and searchlights called the Inner Artillery Zone, sited clear of the rearward side of the Aircraft Fighting Zone.

The structure of the Aircraft Fighting Zone depended on a further factor, the length of the warning period provided by the raid intelligence organisation. The 35 miles gap between the Aircraft Fighting Zone and the coast was dictated by the time taken by fighter aircraft to climb to 14,000 feet (the altitude at which day-bombers would probably be flying) and the time interval between the receipt of a raid warning given at the coast and the arrival of the enemy over the Aircraft Fighting Zone.

Raid intelligence information was to be supplied in war by Observer Corps posts which were dotted about the country at roughly 5-mile intervals and organised in groups, each group covering an area of about one county. The posts would report by telephone the course and height of all aircraft seen or heard to their group centres, which in turn reported to Fighting Area Headquarters and to adjacent sector operations rooms. Observer post reports were naturally reduced in accuracy by cloud, darkness and by the height at which aircraft were flying. Raid intelligence was supplemented by reports from the acoustical mirror sections. Their equipment consisted of large concave sound-mirrors built of concrete. These were fitted with listening devices, capable of detecting the sound of approaching aircraft engines and of estimating the angle of direction of the noise. The average range of detection of the mirrors built at Hythe and Dungeness was about 7 miles, but if there was much wind or surf the aircraft could sometimes be seen before they were heard.

At Fighting Area Headquarters and at the principal airfield in each sector, operations rooms were developed and equipped as a result of the practice and experience gained in air exercises. Their main feature was a plotting room containing a large map-table. Signalling arrangements were rudimentary by

[1] C.I.D. 118A, 9 April 1923.

later standards. At each sector, in addition to plotting lines from the Observer Corps centres, telephones were provided to Area Headquarters and to adjacent sectors, and to anti-aircraft gunnery and searchlight headquarters. The sector commander was able to pass instructions to his aircraft in the air by means of a single-channel radio telephone link with each squadron, but the quality of communication was, until after about 1931, of extremely doubtful reliability.[1]

At the various operations rooms the reports of aircraft seen by observer posts were plotted by placing counters on the map-table. The counters were coloured red, blue or orange, as were also the successive 5-minute segments of the operations room clock. The colour of the counter indicated the time at which the report was received. Counters were removed every 5 minutes so that not more than two colours were on the table at the same time, and the information displayed was thus never more than 10 minutes old. Heights and numbers of aircraft were also shown by additional counters. Further information required by the controller, such as the ' state of readiness ' of fighter aircraft, performance of different types, cloud conditions and strength of wind were chalked on blackboards.

The T.R.9 radio telephone set installed in fighter aircraft during 1932 and 1933, was a great improvement on previous sets. It gave an increased range of 35 miles air to ground and 5 miles air to air, and its simplicity of installation gave ease of maintenance and improved reliability.[2] At that period the sector commander or controller in the operations room did not attempt to speak directly to the pilot by radio telephone. As a result of difficulties with earlier types of radio sets, this was still considered an art in itself. The long-winded R.T. procedure needed to ensure correct reception was spoken by an airman of the trade of R.T. operator, usually chosen for his clear enunciation, who sat in a special sound-proof compartment. Messages to pilots were written on slips of paper by the sector commander and passed to the R.T. operators for transmission. The lack of direct speech between operations controller and pilot did not encourage close understanding between the two. In 1934, switching arrangements were first made to allow direct speech between the pilot and his sector commander, and after successful trials the practice was adopted in all sectors.

The technique of fighter control was as follows. When warning of the approach of hostile aircraft was received, Headquarters Fighting Area ordered the appropriate sector operations room to send off fighter aircraft on patrol. The fighters were instructed to fly at a height slightly above that at which the raiders were reported, and to patrol a line (*e.g.*, sector right front to centre front) or over an area (*e.g.*, Sevenoaks) lying across their anticipated line of approach. Once the fighters had been detailed to their patrol line the sector operations room became responsible for giving them further information or orders by radio telephone. If the raiding aircraft changed course, a new patrol line would be given to the fighters. The task of the fighter patrol was to keep a sharp look-out and to prevent the enemy from passing by engaging him on sight. In

[1] The first use of wireless telephony to direct the movements of Home Defence aircraft in the air took place in June 1918. The transmitting station was at Biggin Hill aerodrome. (Short History of the R.A.F., 1929. A.P.125.)

[2] A.M. File S.30698, Encl. 42A. The set consisted of a two-valve transmitter and six-valve receiver both contained in one case, working on the high frequency band. It had three radio controls, send-receive switch, receiver fine-tuning and volume control, all operated by the pilot.

principle it was always intended that patrol lines at the forward edge of the sector area should be used. In practice there was a tendency to rely on the rearward patrol line, where the shorter distance to be covered gave the fighters a better chance of sighting the bombers.[1]

It was said with some justification that the fighter aircraft of the period were used as a sort of flying barrage into which it was hoped that the enemy would fly. Given clear weather in which observer posts could make accurate observations and fighter pilots could be sure of their positions, there was a fair chance that the enemy would be sighted. In cloudy weather, haze or darkness it was frequently otherwise. In such weather, observer posts could continue to give some warning of aircraft passing over provided that they were not at high altitude. But if the fighter pilot could not see the ground he was unable to find or keep to his patrol line. R.T. communication might supply him with orders, but it gave him no navigational aid. As a rule he was soon out of his reckoning, and relied on guesswork and good luck to regain his airfield.

Air Exercises 1934

The results of the Annual Air Exercises held in July 1934 emphasised the weakness of the interception system. Despite the deployment of fighters, roughly half the total number of bomber raids reached their targets without being intercepted. Of the daylight raids, more than two-fifths were not intercepted at all.[2] Several of the interceptions achieved were simply the results of sightings of raids from airfields, from which fighters were despatched in pursuit by their station or squadron commanders. These were shown later to have been successful only against bombers which were either very low or very slow.[3] Strange as it may seem, the percentage of interceptions against raids by night was slightly higher, but the relative performance of fighters and bombers made the figures patently unrealistic. The Virginia night-bomber aircraft cruised at 73 miles per hour and had a full load ceiling of about 7,000 feet. On the final night of the exercise a strong upper wind reduced their approaching speed to 35 miles per hour. The defence thus had a very great advantage. Even so, 48 per cent. of raids reached their targets without interception.

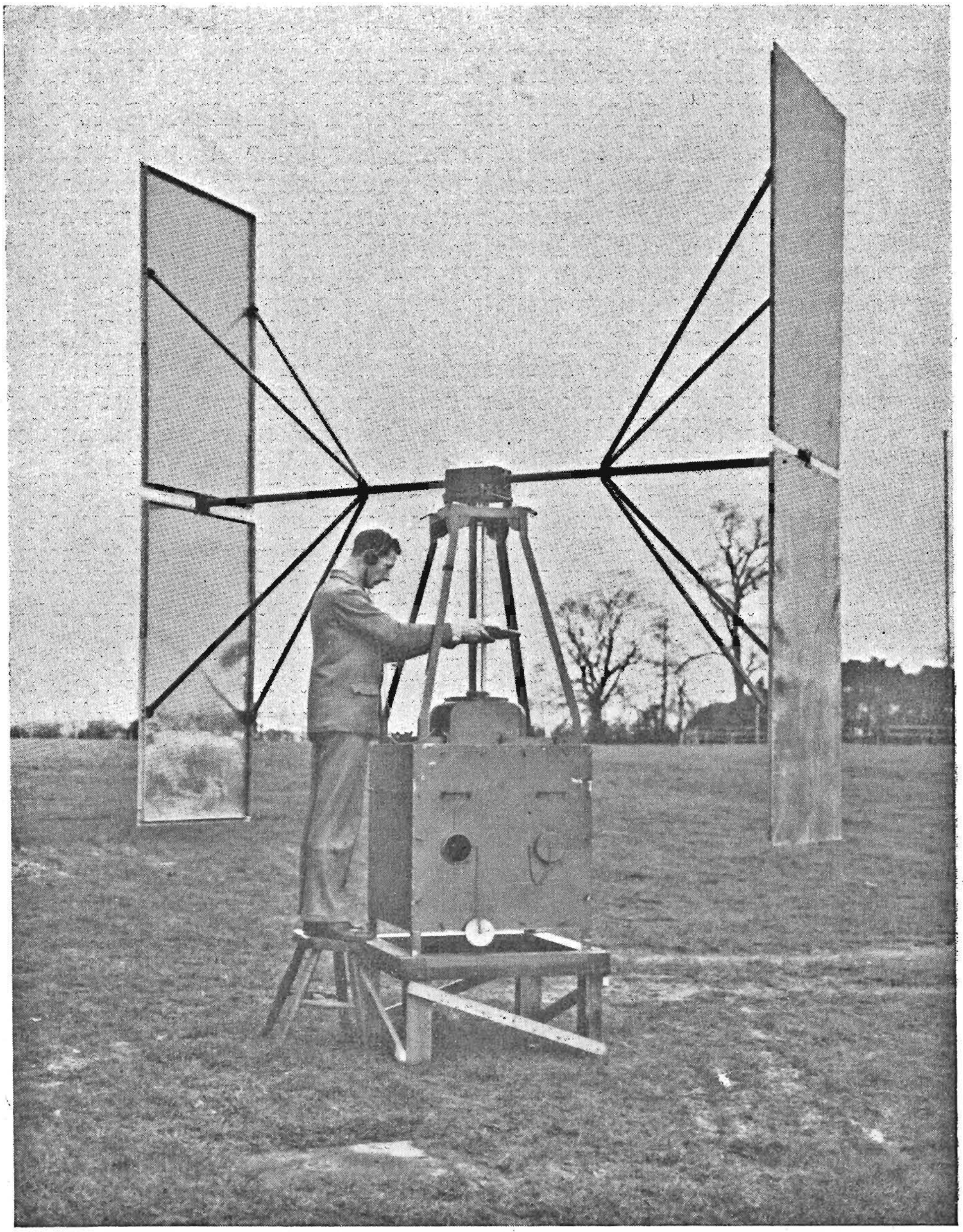
In the light of expectation that bomber development and design would enable aircraft to fly much faster and higher during the next few years, the results of the 1934 Air Exercises gave cause for grave concern at the Air Ministry. The speed of bomber aircraft promised indeed to become only slightly less than that of the best fighters. The problem of air defence was not merely an academic one. There was evidence in 1934 that the German aircraft industry was expanding, and that the threat of bombing might soon become a reality. In search of a solution, the Air Ministry turned to scientific possibilities.

On 12 November 1934, Mr. H. E. Wimperis, Director of Scientific Research, suggested to the Secretary of State for Air that a committee of independent scientists should be formed to conduct a survey of all technical methods which might be used to strengthen air defence. He stressed that the field of enquiry should be as wide as possible, and went so far as to suggest the possibility of a

[1] Fighter Command File S.15199/I, Encl. 54B.

[2] A.M. File S.34808, A.D.G.B. Report on Air Exercises.

[3] A.M. File S.35583, Encl. 13A.



Early Chandler-Adcock H.F. D.F. Station. R.A.F. Development of Naval Pattern

death-ray being of practical use. He proposed the name of Mr. H. T. Tizard, Rector of the Imperial College of Science and Technology, and a former Royal Flying Corps pilot, as chairman of the committee.[1] The Secretary of State for Air agreed to the formation of the proposed committee on 18 November 1934. Mr. Tizard accepted the invitation to serve as chairman, adding ' I am doubtful whether I shall be of real use, but I am very willing to try.'

[1] A.M. File S.34763, Minute 2. A copy of Mr. Wimperis' proposal is shown at Appendix 1.

The Committee for the Scientific Survey of Air Defence

The Committee for the Scientific Survey of Air Defence, as it was called, held its first meeting on 28 January 1935. It found itself in agreement that the problem of air defence was largely one of detection of aircraft. One of its first acts was to recommend the development of a scheme propounded by Mr. R. A. Watson-Watt for detecting aircraft by radio waves.[1] The second meeting of the Committee was held at Headquarters, Air Defence of Great Britain, where the existing scheme of fighter control was examined. Three months later, on 16 May 1935, after comprehensive inquiry into the means of air defence, including balloon wire barrages, anti-aircraft guns and the possibilities of radio beams, the Committee for the Scientific Survey of Air Defence issued its first Interim Report. The report stated that the major problem was to effect engagement of fighter aircraft with hostile bombers. It went on :—

> 'Fighter aircraft should be made more or less continuously aware of the positions of hostile aircraft relative to their own positions for a period sufficient for interception. The ideal would be to obtain, on the ground, a complete picture of the positions and movements of hostile bombers and defending aircraft for a time sufficient *to enable fighter aircraft to be directed, by radio telephony, towards particular hostile bombers.*[2] The Committee is aware of the procedure at Headquarters Air Defence of Great Britain, providing for the collection, co-ordination and dissemination of information obtained by visual and acoustic observations. It seems, however, that the ideal solution defined above is far from realisation.'

Achievement of this far-sighted glimpse of the future certainly seemed remote at the time, but the initial steps towards it were already being taken. Whilst preliminary investigations into the possibilities of detecting the approaching hostile bombers by radar were going on at Orfordness, the first high frequency direction-finding trials were coming to a successful conclusion.

High-Frequency Direction-Finding

Wireless direction-finding had been used in the Royal Air Force since 1924 on the medium frequency band, but it was not until 1934 that experiments showed that the same principle could be applied successfully to the high frequency band on which the fighter radio sets operated.[3] Successful trials by day were completed in January 1935 and by night in May of the same year. It was demonstrated that the direction of transmission from the standard fighter R.T. set, the T.R.9, could be determined with surprising accuracy, provided that the D.F. set was properly sited and well away from sources of metallic interference. Two Chandler-Adcock H.F. D.F. stations were installed at Biggin Hill and Hornchurch respectively in 1935.[4] They consisted essentially of a rotating aerial formed by two aluminium plates mounted on a vertical spindle, and connected to a modified receiver R.1084.[5]

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[1] *See* Volume IV 'Radar in Raid Reporting'. The technique was first known as R.D.F. and later as Radar.

[2] Narrator's italics.

[3] A.M. File S.34418, Encl. 33A.

[4] A.M. File S.34768, Min. 4. In the same year a D.F. station with cathode ray tube presentation was installed at Northolt. It offered advantages in greater freedom from interference and less strain on the operator, but shortage of tubes and technical difficulties in manufacture prevented general introduction.

[5] The R.1084 Receiver was a general purpose ground station receiver with a frequency range of 120 to 20,000 kilocycles and reception of both modulated and unmodulated signals was possible over the whole range.

Homing

Service trials and demonstrations of the H.F. D.F. apparatus in the autumn of 1935 showed its value, particularly as a homing device. General confidence in the equipment was not immediate, chiefly on the score of unreliability. Of the not uncommon scepticism the following story is told. A demonstration of homing a fighter aircraft was being given at Biggin Hill to a few senior officers. Interest grew in the D.F. cabin as the pilot's R.T. speech was heard getting louder and louder, indicating that he was homing correctly. So accurate was his course that he flew into the 'cone of silence' immediately above the D.F. aerials, causing his signals to fade suddenly and completely. The most senior officer was convinced that the radio had broken down, and said so in no uncertain voice. Not without misgiving, the station signals officer began to explain the phenomenon of the cone of silence, and to his relief the R.T. was again heard at its former intensity. The aircraft had passed directly overhead.

At a meeting held at Headquarters Fighting Area on 17 March 1936 it was decided that H.F. D.F. stations should be sited at all sector airfields for homing purposes.[1] By that time H.F. D.F. stations of the Marconi type had been installed at Duxford and North Weald, and a cathode-ray type station at Northolt. To a generation of pilots accustomed to climbing through a continuous layer of cloud to reach patrol height with the help only of a compass, turn and bank indicator, airspeed indicator and an insensitive altimeter, and to descending again with no better guide than dead reckoning could give as to their position, homing bearings soon proved their value. During a night of very bad weather in August 1936 the R.T. of a fighter pilot flying from a neighbouring airfield was heard on the Biggin Hill receiver. He was somewhere over Kent, but had no idea of his exact position, nor of how to find an airfield. The D.F. station gave him a series of homing courses to steer and shortly afterwards his navigation lights were seen to be approaching Biggin Hill through rain and low cloud. Even then he was heard to say that he could distinguish nothing on the ground. The message was heard on a portable R.T. set working on the airfield, and through the initiative of the Flight Sergeant operator who was able to have the airfield floodlight turned upwards, the pilot's attention was attracted, and he landed safely. The news of such incidents gradually travelled to other fighter stations, creating interest and confidence in the use of radio equipment.

Fixing

In addition to the homing aspect, the value of combining the bearings taken by two or more H.F. D.F. stations to 'fix' the position of fighter aircraft was realised. It is related that one fighter pilot scored a success in the Air Exercises of 1935 by arranging unofficially to be given cross-bearings from two D.F. stations. He was thus enabled to position himself accurately in his patrol area above the clouds by night, and by this hitherto impossible feat found himself more than once in a position to intercept bomber raids. In August 1936 fixing as well as homing had been developed sufficiently to be used in a Sector Training Exercise at Biggin Hill.[2] For this purpose, H.F. D.F. stations at Northolt and North Weald were connected directly by telephone to Biggin Hill, where bearings

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[1] A.M. File S.34418, Encl. 79A.

[2] A.M. File S.39190/I, Encl. 1c.

from all three stations were plotted on a map to give a point of intersection. The D.F. fix of the aircraft was recorded in the form of a map grid reference and transmitted to the pilot by R.T. Pilots' reports showed that in five out of every six cases the accuracy of the position was three miles or less, and in no case was it more than four miles. The time taken from request to receipt of fix by the aircraft varied between 45 and 75 seconds. The times were regarded as promising, but D.F. equipment on a scale of one per sector was inadequate to provide a permanent fixing service. For the time being, fixing could not be recognised as an operational function of D.F. stations.[1]

Anticipated Effect of Radar on Fighter Tactics

Meanwhile, since early in 1935, experiments and development in radio location had been going on at Orfordness and then Bawdsey Research Stations. By the middle of 1936 the range at which aircraft had been detected had risen to 75 miles. The system had not yet proved itself in trials as a useful aid to air defence, but the scientists had good reason to hope that its reliability in detecting and accuracy in locating aircraft could be improved sufficiently to make it so. Should the scientists' expectations be realised, the period of warning of hostile air attack would be greatly increased. It would be possible to send off fighter aircraft to gain height long before the raiders were sighted by the Observer Corps at the coast. The information would be more positive and precise than that obtained by visual means. Clouds, haze or darkness would not affect the accuracy of warning, and high flying aircraft would be detected as easily as those at moderate heights. To turn such warnings to full operational advantage the tactics of fighter defence would have to be revolutionised. A new interception technique would be required, one by which defensive fighters could be directed forwards to meet the enemy at the coast or over the sea, with a reasonably certain chance of finding and engaging him. Whether such a technique was practicable was by no means certain.

On 13 July 1936 a meeting took place at the Air Ministry, when Mr. Tizard suggested to the Deputy Chief of Air Staff that interception experiments should begin without delay. The aim of the experiments he proposed was to find out whether the degree of warning which radar was likely to supply, if it fulfilled its early promise, would enable satisfactory interceptions to be obtained. He required data on the percentage of occasions on which interception could be expected, and on the time which would elapse between receipt of warning and interception taking place. It was also to be determined how close to a bomber, whose approximate position and course had been found by radar, it was possible to direct a fighter by instructions from the ground. This information was needed to determine what range would be required of a radar set for installation in fighter aircraft for use at night or in poor visibility.[2] Mr. Tizard stated that he would like the experiments started as early as possible, and that he was prepared to devote two months to advising on their precise nature.

It was clear to the Air Staff that the experiments would absorb much effort from the sector and squadrons chosen to carry them out, to the extent of interfering seriously with training. The news that revolutionary experiments were

[1] A.M. File S.34961, Encl. 2A.

[2] A.M. File S.38638, Encl. 1A.

being made would inevitably be disturbing to sectors still training in the existing system. The radar equipment, on which the new method of interception would entirely depend, had not yet proved itself in large scale trials ; and even if it proved satisfactory a long period would still be required for manufacture of the equipment. Nevertheless, the bold and imaginative decision to proceed with the experiments was made.[1] Authority was given to the Committee for the Scientific Survey of Air Defence to guide the experiments on broad lines and to keep in direct touch with the airfield where they were to be made. Mr. Tizard emphatically disclaimed, however, any desire to be in executive control of the experiments, and the normal chain of command remained unaffected.

Experiments in Interception

At a conference at Headquarters, Fighter Command, on 7 August 1936, with the Air Officer Commanding-in-Chief in the chair, further details of the experiments were thrashed out.[2] Mr. Tizard said he wanted to see if raiders could be intercepted before they reached the coastline. Interception would be more difficult at a later stage and nearer the target, after the enemy had passed through the radar reporting zone which would stop short at the coast. He described the kind of warning information that radar would be able to give, and how much time would probably be available in which to send fighters into the air and to an interception point. The experiments would show time between the receipt of information about the location of the enemy and the issue of directions to fighters. It would be necessary to devise some kind of apparatus for working out course-lines with a minimum of delay. When questioned as to the probable duration of the experiments, Mr. Tizard thought that the two months he had previously mentioned would probably be too short a period. He guessed a year. The Air Officer Commanding-in-Chief, Fighter Command, thereupon took the precaution of asking the Air Ministry to retain the personnel concerned, not only the flying and operations room staff but also the D.F. operators at Biggin Hill, North Weald and Northolt, in their existing postings until the conclusion of the experiments. The Director of Staff Duties agreed that the experiments should continue until the end of the year and possibly during the early part of 1937.[3]

The choice of a sector in which to make the experiments fell on Biggin Hill, where trials of a similar nature were already being carried out. From the Service point of view the sector commander was in charge. No. 32 Squadron was to provide the fighter aircraft because it had already done well in radio and direction-finding work and was being re-equipped with Gauntlets. To ensure realism in the relative speeds of aircraft employed, the bomber aircraft chosen were Hinds, which would be only 30 or 40 miles per hour slower than the fighters.[4]

Plotting by Dead Reckoning

The first of the Biggin Hill Experiments began on 5 August 1936. Dr. B. G. Dickens of the Directorate of Scientific Development was attached as scientific

[1] A.M. File S.38638, Min. 9.

[2] Fighter Command File S.15199/I, Encl. 1A. The A.O.C.-in-C. was Sir Hugh Dowding.

[3] A.M. File S.38638, Encl. 41B.

[4] *Ibid.*, Encls. 2A and 3A.

adviser. In place of radar information which was not yet available, positions of bomber aircraft were initially supplied from fixes obtained from bearings taken by M.F. D.F. stations at Bircham Newton in Norfolk and Andover. Fixing accurately at that distance proved, however, to be too difficult. Fixing of fighters using D.F. stations of other sectors was unsatisfactory for the same reason. The experiments continued therefore using dead reckoning as the sole means of plotting the tracks in the operations room of both bombers and fighters.[1] As a result, a very high standard of accurate flying was required if satisfactory interceptions were to be achieved by this means.

The experiments took place over a period of several months, and can be broadly divided into five phases. In the first phase the bombers flew on a pre-arranged straight course from an agreed starting point at an agreed height. Fighter aircraft were despatched to intercept and given courses to steer by R.T. from the operations room. There was little difficulty, 27 out of 29 attempts being successful. The second phase was more realistic, and the difficulties of practical interception began to emerge. The bomber aircraft were allowed to vary their course at will and frequent re-direction of fighters became necessary. Several interceptions failed through delay while working out fresh courses. To work out each course a navigational calculation was necessary, involving the speed of the fighter, the wind velocity, and the track and ground speed of the bomber.[2] Every change of course by the bomber caused more calculations and more delay. A specialist navigation officer was attached from Bomber Command to assist and many intricate instruments were devised for solving the problem quickly. The manipulation of the calculating machinery still took too long, however, and fighters continued to overshoot the right place for turning towards the bomber. Eventually the sector commander, a seasoned fighter pilot and a helmsman of some repute, took a hand. During a particularly protracted interception one day he measured the angles on the plotting board with his eye, and broke in quickly with ' Tell him to fly 70 degrees.' Somewhat to everyone's surprise a most successful interception followed.

It was thus brought home that promptness was more important than precise accuracy. The calculating instruments were discarded. A quick method of finding a reasonably correct angle was devised during Mr. Tizard's next visit, as follows. A line joining the positions of bomber and fighter aircraft at the same instant was taken as the base of an isosceles triangle. The anticipated track of the bomber formed one side of the triangle, and a line drawn to form the opposite side gave a course for the fighter. A correction for wind was made by using a Type C arm fitted to the plotting board. The effect of different speeds of the aircraft was neglected for the time being. This method was simple and could be repeated in a few seconds whenever the bombers were observed to have altered course.[3] The use of the relative bearing method, as it was called, proved

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[1] A.M. File S.38638, Encl. 71B.

[2] Many methods were tried to obtain an accurate measurement of wind. The most successful was the ' smoke puff ' system in which an aircraft in R.T. touch with a sound locator operator flew to 20,000 feet and let off a smoke puff, at the same time informing the man on the ground that he had fired. He then flew over and round the puff, reporting each time he flew under it. In this way the movement of the puff was plotted by the sound locator operator at five minute intervals and the speed and direction of the wind could then be calculated. A.M. File S.36896, Encl. 64B.

[3] A.M. File S.3828, Encl. 84A.

very successful in subsequent attempts. The occasion of its invention was enlivened by the navigation officer, who immediately dubbed the equal angle the ' Tizzy Angle,' to the delight of all concerned.

In the third and fourth phases, the interceptions were made more complicated by introducing changes of height and course by the bomber. The problems were again overcome by practice until proficiency was obtained. It was then felt necessary to have a more realistic method than dead reckoning for plotting the bomber tracks, and the H.F. D.F. stations were brought into use for this purpose. The bomber aircraft made a continuous high frequency transmission during their runs, and the bearings taken were found to be accurate enough to give fixes suitable for plotting. The bomber W.T. set was, of course, more powerful than the fighter T.R.9. The plots were still not consistent enough at long range, however, and it was necessary to bring the interception area closer to the D.F. stations by the expedient of using a hypothetical coastline, drawn at a radius of 40 miles from Charing Cross.

In the fifth and last phase the bombers were allowed to vary course, height and speed to give them every chance of avoiding interception. By this time the plotting and controlling technique was well developed, and with the help of accurate flying by the fighters the success in interception was continued. In order to ensure accurate plotting even after several different courses had been flown, pilots learned to begin their turns to fresh courses at a given instant according to instructions from the operations room.

Attempts were subsequently made at the end of 1936 to use D.F. fixing with fighter aircraft in order to correct any errors in course-keeping and to eliminate the effect of inaccuracies and changes in wind velocity.[1] It would enable the sector commanders to despatch aircraft without first giving an exact course to steer, and time would be saved when two or more tactical units were sent off simultaneously.[2] For this purpose, the R.T. set of one fighter aircraft in each formation was made to transmit continuously, and D.F. bearings were taken at Northolt and North Weald. The fixes obtained were generally not more than three miles out, but they were too erratic to give a safe check on dead reckoning. Owing to the low power of the T.R.9 set, it was clear that D.F. stations were required to be sited closer to the area where cover was required. The Director of Signals agreed to supply two more D.F. stations for the Biggin Hill experiments, to be sited where they would give good fixes in the sector area.

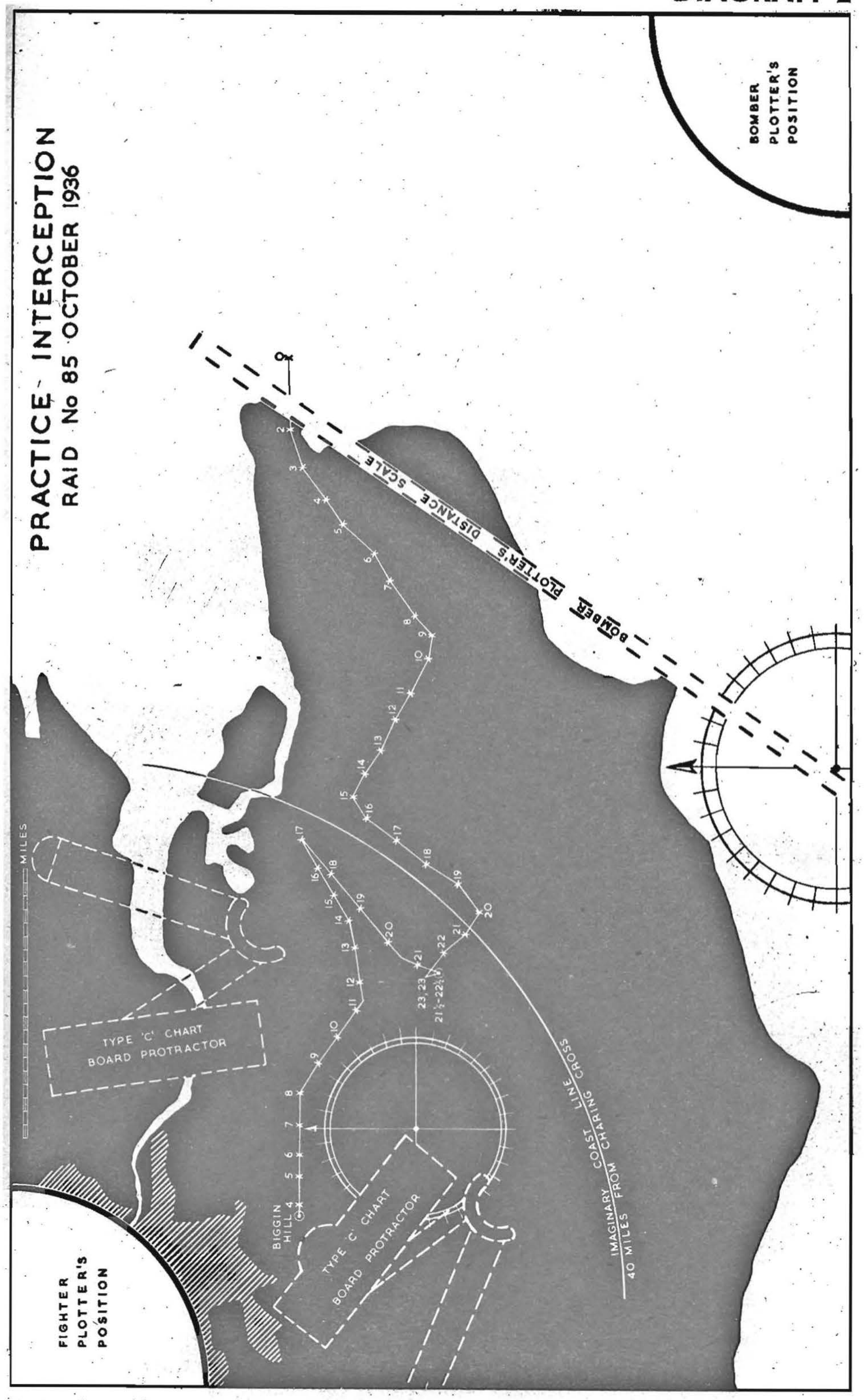
Results of the Biggin Hill Experiments

By the spring of 1937 the lessons learned in the Biggin Hill experiments were clear. Provided that the sector operations room could be supplied with the positions of bombers at one minute intervals, correct to within two miles, it should be possible to direct fighter aircraft to within three miles of them. This was sufficient to ensure interception in average conditions of visibility.

At a meeting held at the Air Ministry on 21 April 1937 the Biggin Hill Sector Commander reported the success achieved in each of the five stages of the experiments.[3] The Air Officer Commanding-in-Chief, Fighter Command,

[1] Fighter Command File S.15199/I, Encl. 34A. [2] A.M. File S.38638, Encl. 71B. [3] *Ibid.*

DIAGRAM 2



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informed the meeting that as each stage of the interception technique was perfected, it was adopted for practice at all other sector stations. Sir Henry Tizard said that the results had exceeded his expectations and that he was satisfied that they had a workable system.

Dead Reckoning Interception Procedure

The procedure for fighter interception, using dead reckoning for plotting purposes, was standardised as follows.[1] On receipt of orders to intercept a raid the sector commander brought the appropriate fighter aircraft to a state of readiness by telephone. When in radio communication with them he ordered them to take off and climb on a given course. They took off and set course when directly over the airfield, informing the sector by R.T. of the instant of setting course. From this moment the fighter plotters combined the course with the wind velocity to form a track which they drew on the plotting board as a thin chalk line. The line was thickened to keep up with the position of the fighters and the actual position at every minute was marked. As height, and so wind velocity, varied, the plotters corrected the track correspondingly. As the fighter's position approached that of the bombers, the sector commander gave any necessary re-directions in course or speed to the fighter flight leader by R.T. and the plotters made corresponding adjustments to the track.

The sector commander did not attempt to make a precise interception but rather to direct his fighters to a point about five miles ahead of the bomber formation, where they would circle. This method gave a safety margin to offset any lag in the plotting of the bombers, and provided against the latter making any last minute change in course. If this occurred it was then still possible to intercept without a long chase from astern. Similar considerations required that any re-direction of fighters should be bold and decisive. If the change proved too large, little harm would be done, but if a series of small changes were given the result would probably be a stern chase.

At the meeting on 21 April 1937 Sir Henry Tizard had mentioned that he was looking forward to further interception experiments using information from coastal and inland radar stations. The latter were not expected to be ready before September 1937 and the interim period was devoted to developing H.F. D.F. fixing technique. No firm decision had yet been made as to how far H.F. D.F. fixing would be needed, although on 31 March 1937 the Air Officer Commanding-in-Chief, Fighter Command, had already outlined his probable future requirements to the Air Ministry as three H.F. D.F. stations for each sector.[2] One was to be sited at sector headquarters and the other two about half-way between sector headquarters and the coast.[3] The three stations would lie roughly equidistant from each other and would provide the operations room with continuous tracks of fighter aircraft flying in the sector area.

In the Biggin Hill Sector, two additional H.F. D.F. stations were provided in May 1937 and sited at Chatham and Wittersham respectively. Special consideration was given to suitability of sites which had, for example, to be in

[1] A.M. File S.38638, Encl. 85A.

[2] A.M. File S.39190/I, Min. 7.

[3] A.M. File S.33016, Encl. 21A.

open flat country, free from obstructions such as buildings or clumps of trees and 200 yards from main roads and traffic.[1] The stations were first of all checked for performance against aircraft at long range and then calibrated precisely by taking bearings on aircraft flying immediately over positively identified landmarks and recording the differences between such bearings and those obtained on the Ordnance Survey map.

A firm requirement for three H.F. D.F. stations in every fighter sector was stated on 31 August 1937 by the Air Officer Commanding-in-Chief, Fighter Command. When referring the matter to the Chief of the Air Staff for approval, the Deputy C.A.S. pointed out the value of the Biggin Hill system of interception. Not only was it the best method of exploiting the advantages of radar, but it was the quickest method of concentrating airborne fighters from neighbouring sectors in order to deal with large formations. It enabled operations rooms to plot the positions of their fighters in the air. It relieved the fighters by day and night of navigational problems. It had always been a very difficult matter for fighters to know where they were, especially when above clouds or in darkness, because of their very limited navigational facilities. The Chief of the Air Staff approved in principle on 2 December 1937.[2] The decision was welcomed by the Director of Signals who had brought forward the question regularly every few months since 1 October 1936.[3] He was now able to take action with regard to selecting sites, applying for land to be leased, asking for financial approval and purchasing additional D.F. apparatus. He noted that delivery would probably not take place until 1939.[4]

Improvements in R.T. Equipment

The technical development and other work associated with the organisation of the H.F. D.F. fighter fixing system began during the Biggin Hill experiments and continued up to and after the beginning of the war. It was inevitably bound up with the improvement of fighter R.T. sets. The fighter aircraft of the near future would fly at higher speeds and would be required to make interceptions well beyond the limit of 35 or 40 miles imposed by R.T. range of the T.R.9. The need for R.T. sets of greater range had already been made known in January 1937 when a range of 100 miles at 5,000 feet was specified as a requirement. In the meantime, the range deficiency of the T.R.9 was overcome by using mobile ground R.T. relay stations, sited 30 or 40 miles forward of the sector R.T. Station.

Another weakness of the T.R.9 was a tendency to 'drift' off tune which reduced its power output and effective range, and had the effect of spreading the aircraft transmissions over a wide sector of the receiver tuning scale. An investigation by the Royal Aircraft Establishment showed that appreciable frequency drift could result from vibration and changes in temperature during even a short flight.[5] Frequency drift was overcome by a modification which introduced a quartz crystal to stabilize the frequency setting of the trans-

[1] A.M. File S.39190/I, Encl. 41B. [2] *Ibid.*, Min. 21. [3] *Ibid.*, Mins. 2, 6, 8, 12, 15 and 17. [4] *Ibid.*, Min. 23. [5] A.M. File S.44756, Encl. 11B.

mitter.[1] Crystal control was applied in April 1937 to the T.R.9, which then became known as the T.R.9C. Aircraft engaged in H.F. D.F. experiments were the first to be fitted with the modified sets, and the squadrons based at Biggin Hill were next to receive them.[2]

D.F. Fixing Problems

The need for one fighter aircraft in a formation to transmit continually for D.F. purposes produced another problem. The T.R.9C was a single-channel instrument. Either, therefore, normal R.T. communication between the ground and the formation leader would be interfered with by the D.F. transmission, or alternatively, the D.F. aircraft could work on a separate frequency and be out of R.T. touch with the leader and with the ground station. Since neither of these alternatives was acceptable, a new form of T.R.9 was developed in 1938. This had two frequency channels, one for operational R.T. and the other for D.F. It was called the T.R.9D.[3]

A further problem arose from the need for keeping track of several aircraft, or formations of aircraft, flying at the same time in the same sector. Simultaneous D.F. transmissions from two aircraft on the same frequency would result in no truly directional signal being received. The use of different D.F. frequencies for each aircraft was impracticable It was necessary to arrange, therefore, for the transmission from each D.F. aircraft to be sent at a different time, and for the timing of transmissions to be arranged in such a way that the signal from each separate aircraft could be recognised by the D.F. Stations on the ground. Experiments at Biggin Hill determined that D.F. station operators could take an accurate bearing on a signal of 14 seconds duration. This was a convenient period because it allowed for four different aircraft to make a D.F. signal during every minute, and for one second intervals between transmissions. Provided that stop-watches in aircraft could be synchronised, each D.F. aircraft could be allotted the first, second, third or fourth quarter-minute in which to transmit. Similar timekeeping in the D.F. stations would enable the operators to know which aircraft they were receiving. Synchronisation of stop-watches at the D.F. stations and in the aircraft was accomplished by an R.T. signal given by the sector controller as each aircraft or formation took off. At first, pilots of D.F. aircraft were responsible for switching on and off for the appropriate 14 seconds period of transmission, but the continual switching on and off engaged too much of a pilot's attention. An automatic time-switch known as a master contactor was devised and incorporated with the T.R.9D.[4]

This master contactor was driven by clockwork and was known as the 'pipsqueak' from the 1,000-cycle note which sounded in the pilot's telephones during the D.F. transmission. The pilot selected the appropriate quarter-minute for transmission by turning a knob on a remote control in his cockpit, and started the clockwork at a time signal given by R.T. from the operations

[1] Quartz crystal, when included in an electric circuit, responds with oscillation at one unvarying frequency, determined by the size and shape to which the piece of crystal is ground. This quality is known as piezo-electric effect.

[2] A.M. File S.38638, Encl. 71B.

[3] A.M. File S.34961, Encl. 15A.

[4] A.P. 1186A, Section 2, Chapter 1.

room. The mechanism then operated the frequency-changing relays in the T.R.9D without further attention during the remainder of the flight. The remote control contained a dial with a moving pointer which told the pilot when the 14-second D.F. transmission was taking place, and so enabled him to confine his R.T. transmissions to the remaining part of each minute.

It was thus made possible for four different aircraft flying in the same sector to send D.F. transmissions without interference from one another. At each of the three H.F. D.F. stations, bearings were taken on each aircraft transmission in turn and telephoned to a D.F. plotting room in the sector headquarters where the position of the fix was determined. To devise means for obtaining an accurate fix from three bearings once every fifteen seconds did not seem to be a difficult task, but it was not until after two unsuccessful attempts that a workable system was evolved. The first attempts failed because the designers were looking primarily for accuracy and they instinctively chose a large scale plotting map with hinged wooden arms for laying off bearings. In use, the map was too big for quick manipulation and the hinges wore loose and caused inaccurate bearings. The best size for the map was found to be that which operators could reach across easily, and the moving parts had to be so simple that there was nothing to go wrong.[1]

Eventually, a small circular map table was used for plotting with a thin cord, kept in tension by weight or elastic, drawn through a small hole at the position of each D.F. station. Three airmen sat round the table, each connected by telephone to one D.F. station. They plotted the bearings received by drawing the cord across the table from each D.F. station to the appropriate degree marking of the marginal protractor which ran all round the edge of the table. A fourth airman estimated the point of intersection of the three cords, which usually formed a small triangle or cocked-hat and told the position by telephone to a D.F. plotter in the operations room, using the fighter map grid procedure. The map tables were known as triangulators.[2]

Improvements in Signalling

Whilst the fighter fixing system was being evolved a large variety of other technical details received attention, all of which helped towards making fighter control machinery efficient. Special training was given to D.F. operators in the tuning of the R.1084 receiver, an effective but complex instrument. Vertical tuned aerials having coaxial feeders were introduced for use at ground R.T. stations to provide maximum radiating efficiency in all directions. Comparative clarity of tone in R.T. speech was obtained by improving the carbon microphone. Attempts were made to devise a method of plotting aircraft in the operations room on a vertical screen in order to improve the controller's view which was sometimes obstructed by the sprawling bodies of plotters. A ground glass screen was used on which a ray of light or a rubber suction disc applied to the back showed as a bright spot in front. Shortage of the materials required prevented this method from becoming standard in all sectors, or perhaps the simpler method of using counters was preferred. In October 1937 the Fighter Code was introduced for use in R.T. The code words used, such as

[1] A.M. Files S.39190/I, Encl. 31A and S.43172, Encl. 46A.

[2] A.M. File S.43172, Encl. 106A. *See* Plate 11, p. 58.

'angels' for height and 'bandit' for hostile aircraft, were easy to memorise because they bore some relation to their meaning. The code prompted rapid and clear communication.[1]

Installation of H.F. D.F. Equipment

At the time of the Chief of the Air Staff's approval of the interception method on 2 December 1937, three H.F. D.F. stations had been provided for both Biggin Hill and North Weald Sectors. A second Fighter Group, No. 12, had been formed in April 1937, and to equip all sectors in both groups required an additional twenty-three sets of D.F. apparatus. By the end of 1937, three more sectors, Hornchurch, Northolt and Duxford, were furnished with three H.F. D.F. stations each.[2] This was only the beginning, however, and the Air Officer Commanding-in-Chief, Fighter Command forecast that it would be two years before every sector would have three D.F. stations.[3] This proved only too true. Anxiety was repeatedly expressed at the slow progress of the programme. In addition to the equipment for fighter fixing, H.F. D.F. stations were now being asked for by Bomber and Coastal Commands each for their own special purposes, creating keen competition for priority.[4] The expansion scheme for the whole of the Royal Air Force was already well under way and pressure of work was felt in all branches, and by no means least in that responsible for the acquisition of land for aerodromes and other military purposes. The comparatively small patches required for D.F. stations gave much trouble because of the many stipulations in regard to location, surface and remoteness from sources of metallic or electric interference. The Director of Works complained that the Signals Directorates had only just realised exactly what they wanted, and expected priority over all other services in order to get their requirements complete by March 1939.[5] It was explained that policy approval had only just been received, and that at the present rate of progress it would be four years before the H.F. D.F. programme was finished. Additional Lands staff were appointed and private firms of land agents were also employed. To speed up installation and calibration of the equipment, civilian radio engineers were engaged. The urgency became so great that the Chief of the Air Staff and the Air Member for Supply and Organisation both gave personal attention to hastening the provision of H.F. D.F. stations by all possible means.

Value of the Biggin Hill Experiments

Although there had been a school of thought which considered the Biggin Hill experiments to be premature, such ideas were to be dispelled by developments of the international situation and the growth of the German Air Force. If the decision to proceed with these air interception experiments had not been taken in July 1936 it is doubtful whether Fighter Command could have been adequately prepared for the Battle of Britain. Apart from their value in developing the new interception technique, the Biggin Hill experiments brought

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[1] A.M. Files S.44002, Encl. 3A and S.38638, Encl. 112c. For details of full code *see* Appendix No. 2.

[2] A.M. File S.44002, Encl. 3A.

[3] A.M. File S.39190/I, Encl. 16A.

[4] A.M. File S.34418, Min. 87.

[5] *Ibid.*, Min. 101.

other advantages. The sector commander at Biggin Hill was emphatic that one of the benefits of the new system was the great confidence it gave to pilots in the air. They learnt the value of accurate flying. When a method was evolved, primitive at first, to ensure that pilots' positions were always roughly known to their commanders on the ground, they knew that they could always be brought home in difficult conditions. This was an essential part of the new tactics and had an immense moral effect.

An important feature of the Biggin Hill experiments was their freedom from undue guidance from higher authority. The operational flying problems anticipated on account of the development of radar were allowed to work themselves out in the hands of competent men at squadron and sector level. In consequence the results of the experiments were essentially practical and well fitted for adoption by those on whom the task fell in war.

CHAPTER 2

THE APPLICATION OF RADAR

The end of 1937 was a milestone in the development of fighter interception. Up to that time all experiments had been made with active co-operation from the target aircraft, which had either flown on pre-arranged courses or had transmitted signals to enable their tracks to be plotted in the operations room. The time had now come to find out whether fighters could intercept aircraft which gave no voluntary aid, as would be the case in war. The solution to the interception problem depended on radar stations being able to locate aircraft with sufficient accuracy, and at sufficient range, and to the clarity and speed with which the information could be represented at the sector headquarters.

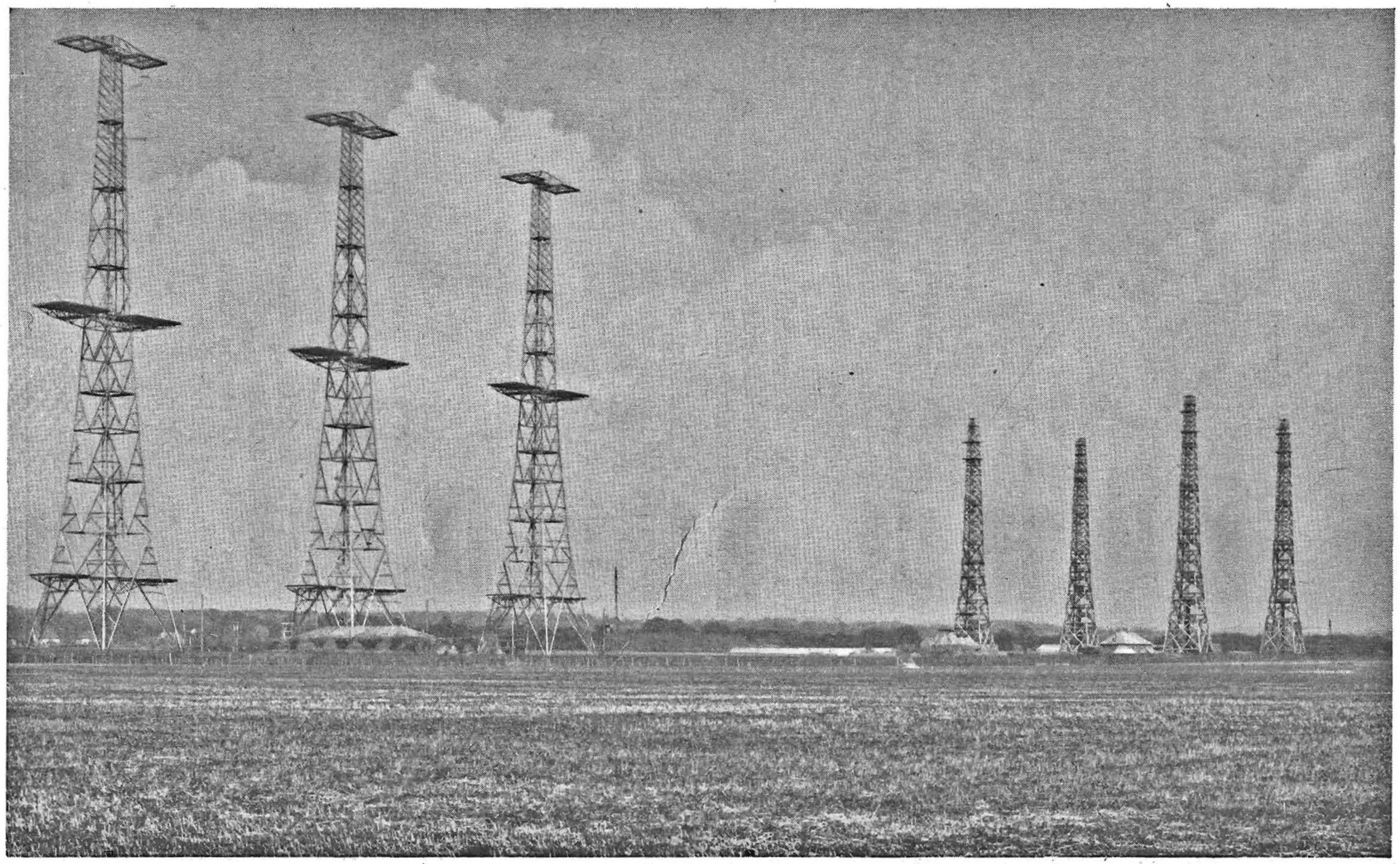
Judging from the results of radar trials held between 19 and 30 April 1937 the prospects were not particularly bright. Attempts made at Bawdsey Research Station to locate aircraft flying on pre-arranged courses over the North Sea had resulted in tracks which mostly bore no recognisable resemblance to the true positions. The Air Officer Commanding-in-Chief, Fighter Command, agreed that greater value would probably be extracted from radar in the future, but for the present he regretted that he could not accept the information in the state as it appeared for use in his operations rooms.[1]

The useful cover of a radar station of that time lay within an angle of about 120 degrees. Indications of aircraft could be obtained up to eighty miles range, but beyond about thirty miles the accuracy of position was poor. Measurement of the distance or range of aircraft from the station was accurate enough, but the bearings were frequently wide of the mark. Tracks of aircraft as plotted on the basis of such information were therefore too erratic to be of use. Heights could be measured fairly well above 8,000 feet, but below that they deteriorated, and below 5,000 feet were unreliable.

There was general agreement after the trials in April that an improvement in tracking would result if radar stations were sited close enough together along the coast to ensure that every part of the observed area could be covered by at least two stations. In this way a ' range cut ' could be obtained. Positions of aircraft would be determined by the intersection of two accurate range measurements ; unreliable bearings might be used to provide an approximate check. Greater accuracy would result. The method would require a reporting, or filtering, centre where the observations of several stations could be combined. The most accurate information would be filtered out and passed to operations rooms for use in interception.

Radar stations were by that time working at Bawdsey and Canewdon, on the Suffolk and Essex coasts respectively, and at Dover. The general plan had been to site the stations along the coast where they could operate most effectively

[1] A.M. File S.40260, Encl. 37A.



C.H. Station—East Coast Type

over the level surface of the sea, and where the earliest warning of enemy approach would be obtained. Since the radar information of enemy aircraft would cease when they crossed the coast, it was most desirable that interception should be achieved before the raiders reached the coast.

The First Filter Centre

An experimental filter centre was installed at Bawdsey in July 1937.[1] Its main feature was a map-table covering the approaches to the Thames Estuary, on which were plotted reports of aircraft positions as received by telephone from radar stations at Bawdsey, Canewdon and Dover. The information was at first reported from stations in the form of readings of range and bearing. This method proved too complicated for the filter centre, and in November the stations reverted to reporting the map-grid co-ordinates of aircraft positions, calculated from their readings of range and bearing. When positions of the same aircraft given by two stations were combined, greater reliance was placed on the range element of the position than on the bearing. Similarly, greater reliance was placed on reports of such positions as were known to be well within the technical capabilities of the station reporting, and less on reports made, for example, at extreme range. By taking judicious advantage of the most reliable factors in all the information received, the filter room staff overcame many of the technical shortcomings of radar stations and were able to produce more reliable tracks.

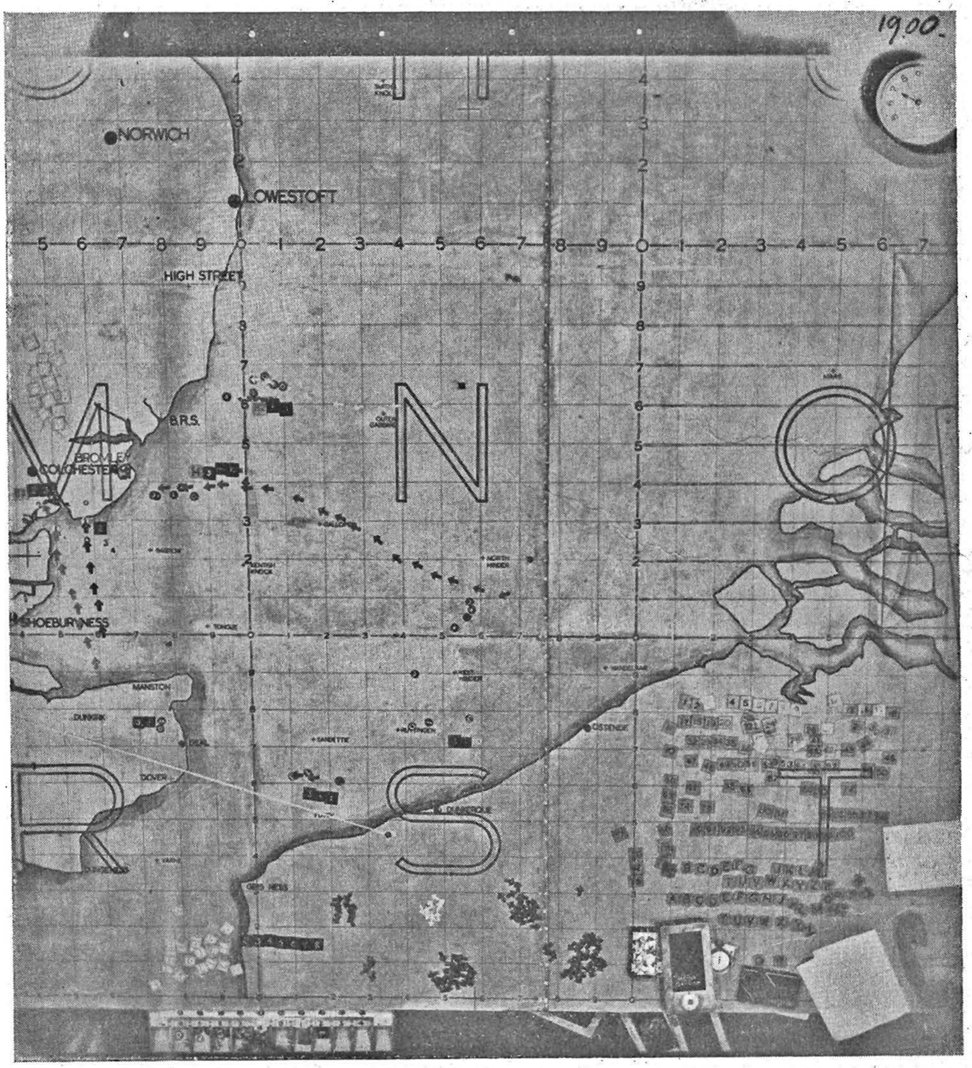
In the filter centre reports received were plotted on the map-table by m ean of counters, coloured to correspond with the coloured ten-minute segments of the clock, but the ten-minute intervals used soon had to be reduced to five to prevent the map from becoming too congested. By the end of November 1937 the tracks obtained by filtering were being passed by telephone to the operations rooms at Headquarters Fighter Command, Headquarters No. 11 Group and Sector Headquarters, Biggin Hill. Radar information was also being obtained from the new inland station at Dunkirk, near Canterbury, which had just been brought into operation to discover whether radar could be used to observe inland as well as out to sea. Two months later the filter centre equipment was moved into fresh quarters at Bawdsey, known as No. 2 Filter Room, which had been specially designed as a result of the experience already gained. It was lined with sound-absorbing material and a larger map-table covered the coastal area from Dover to Norwich. Thus began the filter organisation which was later to extend over the greater part of England.

Interception of Civil Air Liners

Previously, at the meeting held at the conclusion of the Biggin Hill experiments on 21 April, 1937, Sir Henry Tizard had suggested that new experiments in the interception of aircraft located by radar might suitably begin by attempts against Dutch K.L.M. and other civil air liners which regularly approached London by way of the Thames Estuary. He thought it might have a salutary effect on the Continent when it was realised that aircraft approaching on independent courses were being systematically encountered before crossing the

[1] A.M. File S.40260, Encl. 43A.

coast.[1] The air liners were already being tracked by operators at the Bawdsey radar station as part of their normal training. Such exercises formed part of interception experiments using radar information, the first of which was made on 20 December 1937. Bawdsey and Canewdon provided information and fighter aircraft based on Biggin Hill were employed. Another section of the experiments included tests of the Dunkirk inland radar station, by comparison of aircraft positions which were plotted simultaneously both by radar and by



Bawdsey Filter Room Table, Home Defence Exercise, 1938

means of fixes obtained by H.F. D.F. In another phase of the experiments, attempts were made to intercept Anson aircraft making mock raids within radar range of Dover and Dunkirk stations.[2]

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[1] A.M. File S.38638, Encl. 71B.

[2] A.M. File S.43174/I, Encl. 4A.

The experiments were then delayed by storms which severely damaged the aerials at Dunkirk. They were resumed about the middle of January 1938 and continued during the next three months, but apart from fair success with the Ansons, the results were not encouraging.[1] The air liners defied interception, and their tracks were repeatedly lost by the radar stations. Bad weather continued to cause much loss of time. The radar at Canewdon was frequently unserviceable through valve failures, and the operators at the Dunkirk inland station had great difficulty in distinguishing the target aircraft amongst permanent echoes and those caused by aircraft flying from Manston and Eastchurch. On some occasions R.T. communication with fighter aircraft failed. The telephone between Bawdsey and Biggin Hill also failed repeatedly; this line was so notoriously bad that no rent was being paid for it.[2]

At the 38th meeting on 22 February 1938, the Committee for the Scientific Survey of Air Defence recorded their concern at the failure to intercept air liners. They called for a report from the Bawdsey Research Station and pointed out that the routine approach of air liners should be comparatively easy to detect and report, and suggested that this problem should be concentrated on, even at the sacrifice of progress in other aspects.[3] On preliminary investigation, the failure to intercept air liners was attributed to the aircraft reducing height near the Estuary and thus flying below the coverage of the radar stations in the area where frequent plots were most needed for interception. The courses they flew varied widely and sometimes changed abruptly.[4]

Shortcomings in Radar Tracking

The Biggin Hill Sector Commander was called to attend the 40th meeting of the Committee on 26 April 1938. He summarised the difficulties in effecting interception as follows:—[5]

(*a*) Lack of height information;

(*b*) Erratic nature of information supplied and long intervals between plots; and

(*c*) Cessation of information before the coast was reached.

The stage of development of radar was still such that the stations at Dover and Canewdon were not equipped to measure heights, although modifications to enable this to be done were then in progress. At Dover there was the complication that the height scale varied with azimuth to an extent depending on the topographical features in front of the station. It was not then realised that the state of the tide could also affect height readings. The shortcomings in reporting were to some extent due to deficiencies in the training of radar operators, and to their lack of experience. Their ability in observing was at first noticeably less than that of the scientific staff, who, however, took no active part in the interception experiments. But whatever the cause, the cessation of information short of the coast was most serious because it made interception at the coast dependent on extrapolating the track on the assumption that the

[1] A.M. File S.43174/I, Encls. 9A and 12A.
[2] *Ibid.*, Encl. 16A.
[3] Minutes of 38th meeting C.S.S.A.D.
[4] A.M. File S.43174/I, Encl. 16A.
[5] Minutes of 40th meeting C.S.S.A.D.

course, height and speed of the aircraft would remain unchanged.[1] Such assumptions might lead to successful interception in exercises, but would be an unsatisfactory basis in war.

To overcome the cessation of radar information at the coast it was proposed to make experiments using a rather cumbersome procedure by which the target aircraft would first be intercepted by a 'shadow' aircraft. The latter would be a fast, preferably twin-engined, type, based near the coast. For the purpose of interception, locations of both the target and the shadow aircraft would be given solely by radar. Having sighted the target aircraft, the shadow aircraft would follow it, transmitting continuously in order that the sector headquarters could track it by H.F. D.F. fixing throughout the sector area. Fighter aircraft could then be directed towards it, and the target aircraft would be attacked. Preparations for experiments along these lines were made, but the scheme appears to have been abandoned as a result of the failure of attempts to intercept using radar location only.[2]

Renewed attempts to intercept air liners and Anson aircraft were made under improved arrangements recommended by the Committee for the Scientific Survey of Air Defence on 26 April 1938. The work of the radar operators was henceforth to be supervised by members of the Bawdsey scientific staff. The intense amount of flying round Eastchurch and Manston airfields was restricted for certain periods of the day to give the radar operators a better chance of observing close to the coast. Experiments with the Dunkirk station were discontinued as unlikely to be of value because of excessive interference experienced inland.[3] Part of the difficulty in the interception experiments using radar was undoubtedly a lack of understanding between the Service element represented by Biggin Hill and the scientists engaged in radar research. Division of responsibility between the two had not been well defined and the rigid security measures surrounding radar tended to isolation. Both Biggin Hill sector and the scientists had for a long time been experimenting independently but they were now working in harness together, and interchange of experience could not be achieved overnight.

Scientific Analysis of the Tracking Requirement

The experiments as a whole remained under the direction of the Biggin Hill Sector Commander, but the Superintendent of Bawdsey Research Station now found himself responsible, in addition to his normal radar research work, for advising on the interception experiments from the technical angle. The Superintendent had not been concerned in the original Biggin Hill experiments using dead reckoning. He was handicapped by lack of interception data and had no means of assessing, for example, what maximum range of radar was required to enable interception at the coast to be effected. He needed, in fact, the benefit of the experience of the previous Biggin Hill experiments in order that he might shape the technical performance of the radar equipment and the detail of operating in such a way as to secure the best chance of interception.[4]

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[1] A.M. File S.43174/I, Encl. 20A.

[2] *Ibid.*, Encl. 27A. *See* 'Lamb' experiments in Chapter 11.

[3] At Biggin Hill, another squadron took over the flying side of the experiments. A.M. File S.43174/I, Encl. 31A.

[4] A.M. File S.43174/I, Encl. 24A.

This information was difficult to supply in comprehensive form because of the large number of variable factors. Distance of fighter airfields from the coast, speed and rate of climb of fighters, speed and height of bombers, maximum range of radar stations, and the time necessary to put the machinery of interception into action were all involved. The task fell to Dr. Dickens, the scientific adviser in the earlier Biggin Hill experiments, who drew up five tables of data in a paper entitled 'Interception with Radio Location'.[1]

Table I gave the distance from the coast at which a raid must be reported to enable fighters to intercept at the coast. This was called 'sector warning'. An estimate of the strength, as well as the position and direction of the raid was needed when sector warning was given, in order that when the raid was allotted to a particular sector, the sector commander could decide the appropriate strength of fighters to be despatched. Various heights of interception and various distances of airfields from the coast were taken into account in producing the data. One minute was allowed for passing the aircraft report to the operations room and five minutes for fighters to take off. The calculation was based on the speed and rate of climb of fighter aircraft then available.

Table II gave details of the type of reports and the frequency with which they were required at different stages of the approach of the raid. Until the raid was within 30 miles of the coast, position reports every two minutes and height reports every four minutes were sufficient. Within 30 miles of the coast, accurate position reports every minute were vital. At this stage a single inaccurate plot might cause the fighter controller to assume that the raid had altered course, and to change the fighters' course appropriately. The degree of accuracy desired was within one mile in plan position and within 2,000 feet in height in clear weather. For the purpose of Table II, the ground speed of the raid was taken as 240 miles per hour.

Table III gave a comparison between the range of sector warning required to enable a raid approaching at 240 miles per hour to be intercepted at the coast, and the normal maximum range of detection of existing radar stations. It showed that provided the fighter airfields were not more than 40 miles from the coast, interception of raids at any height was theoretically practicable.

Table IV assumed that the direction and identification of a raid could be established during the 12 miles following initial detection at the maximum radar range. On this assumption, it showed where interception would probably take place under various conditions in relation to the coast.[2]

Table V gave an estimate of the sector warning which would be required when the speeds of bomber and fighter aircraft had increased to the degree expected in three to five years time. Only a proportionately small increase of sector warning would be required.

The paper on Interception with Radio Location was welcomed by the Air Staff and scientists alike. It gave precise information of what was required from observers at radar stations, and clarified the relationship between the

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[1] Appendix No. 3 shows the five tables.

[2] An approximate formula for determining the position of interception for given conditions is quoted in Appendix No. 4.

many different aspects of the interception problem. It gave reassurance concerning the adequacy in range of the existing radar equipment. When reviewing the paper, the Air Staff agreed with the general picture it presented. They stressed the importance of reports containing early details of the strength of raids, and also the desirability of detecting low flying raids 80 miles from the coast, but low cover at long range was impossible owing to the curvature of the earth's surface.[1]

Further Experiments in Interception

Meanwhile the interception experiments were continued with steady persistence and increasing success until the month of September 1938. The quality of the tracks was by then approaching the high standard laid down in Dr. Dickens' paper. The majority of them continued at least near enough to the coast to ensure interception at that point, and many extended several miles inland. The average distance from the coast at which warning of an established track was given was 55 miles and the maximum 85 miles, but preliminary indications could often be given at even greater range. Disconnected tracks resulted from gaps in the radiation field of the radar station, and when these had been eliminated a high percentage of satisfactory tracks could be provided. Height readings were generally correct to 500 feet. Over the last four months the fighter had sighted the target aircraft on three out of every four occasions, usually at a range of one mile or less. But for clouds, the percentage would have been higher. Civil air liners were being intercepted without difficulty. The improvement in the standard of warning was such that when the flying restrictions at Manston and Eastchurch were removed there was little or no deterioration in aircraft tracks.[2]

Home Defence Exercise, 1938

The first large scale test of the interception system took place during the annual Home Defence Exercise in August 1938. Radar stations at Dover, Dunkirk, Canewdon, Great Bromley and Bawdsey were working, passing their reports to the filter centre at Bawdsey. Filtered plots were told simultaneously from Bawdsey to Fighter Command and No. 11 Group Operations Rooms, and to Sector Headquarters at Biggin Hill, Hornchurch and North Weald. The filter centre succeeded in handling the increased information, regulating the efforts of the various radar stations and telling them which tracks to concentrate on and which to disregard. The radar stations worked well, the only shortcoming reported being their inability to detect low flying raids which were below the cover of their radiation.

The plotting of information in most operations rooms was not very successful, their staffs lacking the practice and experience of those who had been concerned with the experiments.[3] Observer Corps reports added to the mass of information and operations room tables were often covered with disconnected plots. Fighter controllers were frequently at a loss. The passage of 'enemy'

[1] A.M. File S.43174/I, Encl. 42A. [2] *Ibid.*, Encls. 37A and 51B.

[3] At this period, no special establishment for operations rooms was allowed. The officers and airmen of the headquarters unit were supposed to be able to man the operations room continuously in addition to their other duties.

bombers flying through the area on their outward 'neutral' journey increased the confusion. In consequence, fighter aircraft were largely employed in the old tactics of standing patrols which would be uneconomic in war.[1] Attempts at controlled interception made in the Biggin Hill and North Weald sectors were frustrated by bad weather and abnormal electric storms which interfered with R.T. and H.F. D.F. Nevertheless the squadrons were able to operate throughout the bad weather and the air defence did not break down.

The Home Defence Exercise 1938 crystallised ideas in planning the new interception organisation in Fighter Command as a whole. Decisions were made on which the aircraft reporting and fighter control system began to take definite shape. The Bawdsey Filter Centre was to be moved to larger accommodation in Fighter Command Headquarters. Special telephone lines were to be provided for reporting aircraft information. Operations rooms were to be better staffed, and the staffs were to have more frequent practice, shorter shifts and better ventilation. To enable fighters to intercept over the coast, forward R.T. relay stations were to be provided in greater numbers to overcome the inadequate R.T. range. In addition, greater priority was given to the development of I.F.F. equipment for identifying friendly aircraft to radar stations observing them.

Building of Operations Rooms

There was also the urgent question of building an underground operations block for Headquarters Fighter Command which was more important than formerly by reason of the network of communications which would lead into it, and the centralisation there of the whole system of aircraft reporting and air defence control. Previous conceptions had been modest. Between 1925 and 1936 a wooden hut opposite Hillingdon House, Uxbridge had sufficed, and in June 1936 a sum of £500 had been sought to construct an experimental layout in the ballroom of Bentley Priory.[2] During the next two years plans for a permanent building were held up in anticipation of the outcome of the interception experiments. Early in 1938 the Air Ministry displayed concern at the lack of secure centres from which air defence could be conducted.

Operations room research was added to the responsibilities of the Directorate of Communications Development and a section of the Research Group at Bawdsey was formed to study the problems. Some progress was made in May 1938 when new sites were selected for operations rooms for Nos. 11, 12 and 13 (Newcastle) Fighter Groups, but still no final plan had been agreed on for Fighter Command operations room, while the outlook in Europe became more and more threatening. On 2 June the Deputy Director of Plans recommended that a definite order should be given that command and group operations rooms should be completed, underground, and all sector rooms, by 31 March 1939 at latest.[3] He said that 'there had been twenty years to decide what operations rooms should be, and that they could not wait any longer'. There was reason, however, in the delay in 'going underground'. Whilst the operations and filter rooms were above ground, alterations could still be made to their dimensions as the rapidly growing experience with the new reporting

[1] Report on Home Defence Exercise 1938, A.H.B. II H1/95.

[2] Station File Bawdsey Research R.S.21/Air.

[3] A.M. File S.38423, Encl. 38A.

system demanded. Once installed underground it would have been difficult to make any minor alterations. The temporary layout was, of course, not merely experimental but fully serviceable and effective.

As a result of the experience of the Home Defence Exercise, 1938 a decision was made and on 23 September the building of a permanent underground operations block at Bentley Priory was sanctioned at a cost not exceeding £45,000.[1] Building proceeded in great haste, but there was a limit to the speed with which the vast amount of signalling equipment could be installed. Concern was expressed in March 1939 when it was found impracticable to install the signals apparatus in the as yet damp and unventilated underground concrete building along with other less delicate equipment.[2] Metallic corrosion and loss of insulation would have been the inevitable result of introducing delicate signals apparatus into the high humidity of the still sweating concrete structure. Some idea of the need for dryness can be gathered from the fact that in a space eight feet by five, the air raid warning signalling map alone carried about 4,000 soldered connections. Once the insulation of switchboard cables was degraded it could never have been brought back again to its former value. In the circumstances, therefore, there was no alternative but to delay fitting, regardless of urgency, until the ventilation plant was working and the air reasonably dry.

In the plan of the underground operations block, accommodation for a filter room was to be provided but the Munich crisis in September had called for immediate improvisation. In the basement of the Headquarters a temporary special intelligence room was prepared where the minimum of aircraft reports necessary to conduct operations could be filtered. By the end of the year the temporary arrangements were being elaborated to include a complete telephone system, and a map-table covering the east and south coasts of England, the North Sea and the English Channel for the purpose of filtering radar information over the main areas of the air defence system.[3]

Manning of the Filter Room

There was much difficulty in manning the special intelligence or filter room. The art of filtering had been evolved by a small team of men at Bawdsey who had built up the system by trial and error with the help of the research staff. The work consisted of receiving the reports of aircraft positions from all the radar stations, of sifting the successive reports until definite tracks of hostile or unidentified aircraft became recognisable, and of passing on an intelligible air picture to the operations rooms. The large number of reports received from the expanding radar chain had now grown beyond the capacity of the small staff and the accommodation at Bawdsey, and a similar but more complex organisation was to be set up on a larger scale. There were three types of work to be done in the filter room, plotting, filtering and telling. The first two were more difficult to do well than appeared at first sight.

The plotter's duty, basically, was to place counters on the filter-table in the positions told to him by the various radar stations. The positions he received were, however, not always accurate because the radar stations were technically

[1] A.M. File S.38672, Min. 10.

[2] A.M. File S.38423, Min. 75.

[3] A.M. File S.42503/I, Encl. 55c.

incapable of giving first class bearings. If the plotter merely registered the reports as he received them, it was often impossible to decide whether they referred to an aircraft previously plotted, or to another aircraft a short distance away not previously reported, or perhaps to another track approaching in the vicinity. The plotter had therefore to be constantly on the watch for inaccurate plots. By interrogating a radar station at the right moment to ask for a check of position, or a confirmatory height, he could do much to keep the picture clear. At the same time he had to be careful not to hold up the work of the stations by undue interrogation, or other aircraft might go undetected.

The filterer's work was still more responsible. His duty was to decide the moment when a few successive plots, with all their possible inaccuracies, might be considered as a reliable track, fit for the operations room to act on for fighter interception. He indicated such tracks by placing an arrow on the table showing the position and direction of the raid. He was constantly on the horns of a dilemma, whether to put down an arrow on the strength of his first guess, or to wait for another plot in the hope that it would confirm or confound his suspicions. The first course of action gained valuable time but might result in fighters taking off on false information. The second course might reduce the chance of interception.

The teller's duty was to describe the filtered air picture to all the operations rooms simultaneously by telephone. Promptness, and clearness of language and diction were essential because time did not permit of repetitions. Plotters, filterers and tellers worked as a team. The speed and accuracy of their work went a long way towards obtaining interceptions, and in times of much air activity, great concentration and quickness of thought were called for.[1]

The establishment of personnel issued in response to Headquarters Fighter Command letter dated 15 October 1938 authorised the employment of aircrafthands Group V for filter room duties. It was soon evident that some upgrading of the posts of the filter room staff was required. The best of the aircrafthands were constantly being posted away for training in a skilled trade. In the meantime, the work of the filter room deteriorated. The situation was reported to the Air Ministry by Headquarters Fighter Command on 3 January 1939. No attempt appears to have been made at that time, however, to assess the degree of intelligence required to do the work adequately. Four months later, on 5 May, the Officer in Charge of Records was directed urgently to substitute Clerks Group IV in place of Group V airmen in the filter room as a temporary measure.[2] On this basis, under the supervision of a filter room Controller, radar filtering was carried out for over a year. On these men lay the responsibility for transforming the raw radar reports into the information of hostile aircraft on which the fighter squadrons operated.

Fighter Operations Rooms

Fighter operations rooms, whether at command, group or sector level, had much in common. Their main purpose was, like that of any operations room, to maintain a clear picture of the tactical situation and deployment of forces. The rapidity of movement in air warfare always calls for a very high degree of

[1] A.M. File S.49884, Min. 2.

[2] *Ibid.*, Min. 17. The trade of Clerk (Special Duties) was introduced to cover these and miscellaneous similar duties on 1 August 1940.

promptness and clarity in displaying information, and in fighter operations most of all. The general layout of the fighter operations rooms at the beginning of the war owed something to the original design of the pre-1936 days, but had made great strides to meet the increased complexity and organisation of the new technique.

In the body of the room lay a gridded map-table showing only the elementary geographical features. On the table, plotters connected by telephone to the filter room and Observer Corps centres placed indicators showing the position, strength, height and direction of hostile and unidentified aircraft. Fighters were plotted from information gained by triangulation. Details of fighter forces available in various states of readiness, records of orders given and other essential data were displayed on wall panels. In a raised position from which all information was clearly visible sat the controller, representing the commander, with telephones at hand to other fighter operations rooms and anti-aircraft commanders, as required. Controllers requiring to speak to fighter aircraft had radio telephones also. One assistant, 'Operations A,' helped him to manipulate the means of communication. Another assistant, 'Operations B,' usually seated below, listened in to all telephone conversations, recorded orders and compliances, and dealt with confirmatory teleprinter messages.

The extent of the operations room map-table and the degree to which information was displayed on it varied at command, group and sector levels according to function. At command, interest lay in the most general picture and in the disposition of forces as between Groups. At group level, hostile raids were allocated to particular sectors and allocation of squadrons was made accordingly. Prominence was therefore given at command and group to display of the strength and direction of hostile and unidentified aircraft incoming to their respective areas. In sector operations rooms, where direct control of fighter aircraft was exercised, display of their positions was essential. But in all operations rooms it was a general rule to display positions of all friendly aircraft flying over the sea, and of any friendly aircraft believed to be in distress overland.

Signals Equipment and Personnel, Spring 1939

In the spring of 1939 there were still many gaps in the air defence system. Only twelve of the planned chain of nineteen radar stations were yet working. None of the underground operations rooms had been completed. H.F. D.F. stations to give triangulation in each sector were still being installed. Additional forward R.T. relay stations to extend the range of fighter communication were being added. Telephone and teleprinter lines and equipment were being installed to link the ramifications of the new air defence system together. A sense of emergency prevailed, the Munich crisis of September 1938 having provided clear warning of events to come. There was an acute shortage of signals staff, caused by the expansion of Fighter Command and the increasing number of radio installations to be provided, aggravated by the demands of the steadily lengthening radar chain.[1] By May 1939 the radar stations and the filter room were operating 24 hours a day in order to be at full efficiency the moment war was declared. The widespread deployment of the stations caused a more than proportionate increase in the staff required to supervise and maintain liaison.

[1] A.M. File S.47071, Encl. 30A.

Review of the Interception Problem, June 1939

The progress made in fighter interception came under criticism at a conference held at the Air Ministry on 28 June 1939. From the air exercises he had seen, Sir Henry Tizard felt that raids were being handed over by groups to sector control too late for fighters to intercept near the coast. On certain occasions they had actually been retained on patrol over their own airfields. Such tactics would inevitably lessen the chances of interception. Changes in the course and height of enemy raids could not be reported by radar once they had crossed the coast, and it was there that interception should be attempted. The Commander-in-Chief, Fighter Command, attributed the tactics mentioned to lack of forward R.T. relay stations and to lack of H.F. D.F. fixing. Controlled interception was impossible out of R.T. range.

The installation of these equipments had been agreed over two years previously, but despite great efforts by all concerned, and priority from the highest level, the work was not yet complete. A careful survey, made three days later, showed that only nine out of eighteen sectors had D.F. fixing stations in operation, and only five out of the twenty-nine forward R.T. stations projected were connected by landline. Of course, some sectors had only been recently planned, and many installations were nearly complete, but the long time taken to reach this stage was symptomatic of the inertia to be overcome when preparing defence measures in time of peace.

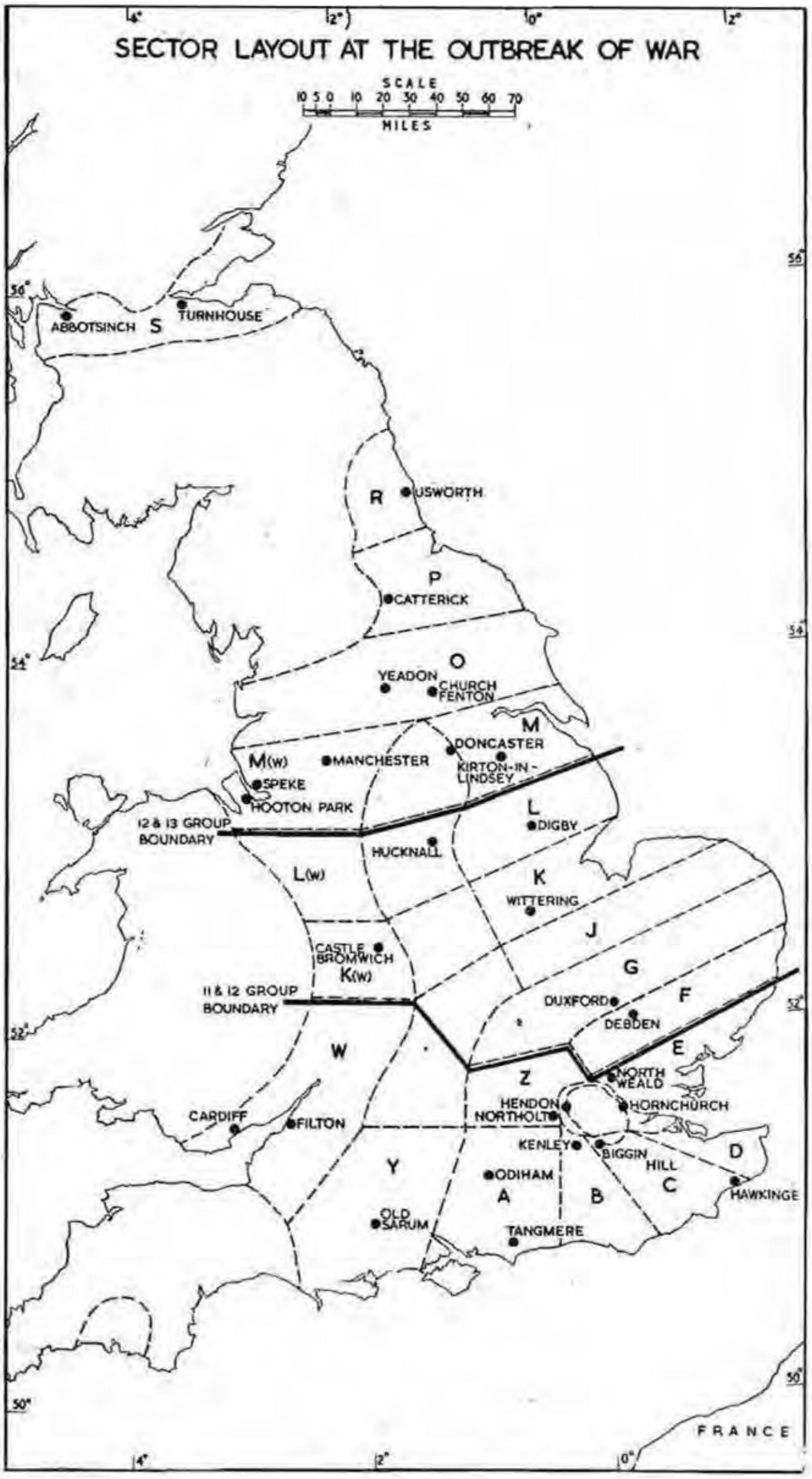
The Commander-in-Chief, Fighter Command, mentioned another cause of tardy attempts to intercept. Although aircraft were being detected 50 or 60 miles from the coast, identification was not established until they had travelled another 30 or 40 miles. When identification equipment was installed, there would be an immediate jump in the distance at which interception took place. Mr. Robert Watson Watt reported that sets of I.F.F. apparatus should be ready in time to be tried out in the air exercises in August.

Aerial Mines

At the same meeting the long-standing project to use aerial mines in air defence was reviewed. The suggestion had been made to the Committee for the Scientific Survey of Air Defence during the early meetings of 1935. Much time and effort had been spent on development, which included experiments at the Royal Aircraft Establishment in which aircraft collided with dummy aerial mines at high speeds. The type of mine evolved was estimated to have a one-in-three chance of destroying the aircraft striking it. On the other two-thirds of occasions the mine would either slip off the wing tip, or the cable break or be cut by an airscrew. Development had now reached the stage where it had ceased to be primarily a research problem and became one of development to be handled by the Service.

The mine consisted of 2,000 feet of piano wire with a bomb at one end and a parachute at the other, the whole being supported by a second and larger parachute which gave it a rate of fall of 900 feet per minute.[1] On collision between the mine and the wing of an aircraft, the larger parachute broke away and the other pulled the bomb up to the wing. The mine weighed 12 lb. and

[1] A.M. File S.1525, Encls. 3B and 37A.


SECTOR LAYOUT AT THE OUTBREAK OF WAR
SCALE
10 5 0 10 20 30 40 50 60 70
MILES
4°
2°
0°
2°
56°
54°
52°
50°
S
ABBOTSINCH
TURNHOUSE
R
USWORTH
P
CATTERICK
O
YEADON
CHURCH FENTON
M
DONCASTER
KIRTON-IN-LINDSEY
M(W)
MANCHESTER
SPEKE
HOOTON PARK
12 & 13 GROUP BOUNDARY
L
DIGBY
HUCKNALL
L(W)
K
WITTERING
J
CASTLE BROMWICH
K(W)
G
F
DUXFORD
DEBDEN
11 & 12 GROUP BOUNDARY
W
E
NORTH WEALD
Z
HENDON
NORTHOLT
HORNCHURCH
CARDIFF
FILTON
KENLEY
BIGGIN HILL
D
Y
ODIHAM
A
B
C
HAWKINGE
OLD SARUM
TANGMERE
FRANCE

the bomb contained about 8 oz. of explosive. Filled bombs had not yet been tested, neither had a satisfactory minelaying mechanism been evolved. Harrow or Lockheed-14 aircraft would carry about 100 mines. Interception at night would preferably be made out to sea and be guided by radar. Mines would be laid about 200 feet apart across the anticipated track of the enemy. During minelaying, the aircraft would dive at the same rate of descent as the falling mines so as to leave a horizontal curtain.

Calculations based on the accuracy of interception with radar and on the various probabilities in operation showed that the overall efficiency of the minefield as a lethal weapon might be of the order of one in twenty. That is, a minelayer would have to go up loaded on twenty separate occasions before it brought down an aircraft flying by itself. An improved chance of success was given if the minefield were laid in front of a formation, according to its shape and size. If the formation were in line astern, however, the chance would be about the same. By day a fighter aircraft operating under the same conditions as the minelayer would have a good chance of bringing down one enemy aircraft on each flight. Minelaying would therefore be unprofitable in good visibility. But by night or in bad weather when fighters would have less chance of sighting their quarry, it was considered that minefields might prove a deterrent. The development therefore went on. Hitherto the Biggin Hill Sector had taken a large part in the minelaying interception experiments. To give relief to this hard-pressed station the work was transferred to a bomber station, and there the aerial mine experiments continued under the direction of Headquarters No. 11 Fighter Group.

Home Defence Exercise, August 1939

The last full-scale rehearsal of the air defence system before the war took place from 8 to 11 August 1939. Fighter Command operated for three days continuously during the Home Defence Exercise. The defended line was from the Humber to the English Channel. It was clear that a great advance had been made since the previous annual exercise in which standing patrols had been freely employed. This year, on the third day especially, daylight raids were tracked and intercepted with ease. The radar stations and the filter room had got into their stride. The preliminary report on the Exercise conceded that ' the system, although doubtless capable of improvement as the result of experience, might now be said to have settled down to an acceptable standard '.[1]

The confused mass of information which previously filled the group and sector operations room tables had been eliminated. Observer Corps reports were now co-ordinated with radar tracks before they reached the operations table. The method of co-ordination used, said the report, ' implied a complete trust in the radar system.' The order was given that Observer Corps centres were to pass no plots unless they could clearly refer them to the raids already detected by radar, and identified and numbered by the filter room. For this purpose, radar information of the approach of enemy raids over the sea was given to the coastwise Observer Centres. It was possible that such a drastic measure might cause a few raids not to be reported inland. To minimise this

[1] A.M. File S.1659, Encl. 10A.

risk a Lost Raid Office was instituted at each Group Headquarters to notice the cessation of tracking of any raid inland, and to endeavour to pick it up again and re-identify it. The Lost Raid Office showed promising results. As an exception, until low cover radar stations were installed, a temporary organisation allowed coastal Observer Posts to report the approach of low flying raids from seaward, using a subsidiary numbering system.

A spurt had been made in the installation of H.F. D.F. fixing and forward R.T. relay stations. The technical equipment of the interception system was largely complete, although only one operations room was as yet underground, that of No. 11 Group.[1] One important handicap persisted; the identification of raids was still unsatisfactory. By the strenuous efforts of the Bawdsey Research Staff a few I.F.F. sets were tried out during the Exercise. There had been no time to make Service trials previously, however, and technical failures occurred on a large scale. Some additional development was required before the sets could be used operationally.

Despite the reserved tone of the preliminary report on the Home Defence Exercise, 1939, there was an unmistakeable note of confidence in it; at least so far as the daylight air battle was concerned. The ability of the air force to operate in bad weather was a strong point. Acceptance of the principle of interception at the coast was confirmed by the decision to use two advanced landing grounds for fighter squadrons whose sector airfields were too far inland to allow them to reach the Norfolk coast quickly. In a public broadcast on the eve of war, the Air Officer Commanding-in-Chief, Fighter Command, discussed the exercise and expressed his satisfaction with the results.

[1] The underground operations room at H.Q. No. 11 Group was opened for use ten days before the declaration of war.

CHAPTER 3

THE BATTLE OF BRITAIN

From the beginning of the war until the end of 1939, aircraft of Fighter Command intercepted and engaged a total of 51 enemy aircraft, of which 31 were reported as destroyed. The destruction of 13 was confirmed. The comparatively light scale of hostile air activity continued in the new year until the heavier raids began in the middle of 1940. These sporadic raids provided Fighter Command with much useful experience and gave an opportunity to improve the interception organisation. One source of constant concern was the time lag between detection of an aircraft at the radar station and the appearance of a corresponding plot on the operations room table. The increasing speeds of new types of aircraft made rapid plotting, filtering, identification and telling all the more important. One of the first steps taken was to move the liaison officers, who provided information on flights by Bomber, Coastal and French Air Force aircraft, from the operations room to the filter room. The work of identification could then be done simultaneously with the filtering, instead of afterwards. Responsibility for deciding the identification of raids fell on the operations controller of the filter room. The filtering process was still giving much trouble, and the radar officer who had previously been in charge of the filter room thenceforward gave his undivided attention to supervising filtering. His knowledge of the capabilities of radar stations was invaluable in sorting out erratic plots.

Complications in Filtering

The number of stations reporting to the filter room increased steadily as the radar chain was extended along the south and east coasts. The number of plots to be dealt with multiplied as the filter room staff were collected and trained. Constant instruction was necessary by members of the Research Section who had moved from Bawdsey to Headquarters Fighter Command for the purpose. Concentration of instructional effort shifted from position filtering, which was becoming better understood, to height filtering, which was even more complex. Height reports of aircraft received from two different stations sometimes conflicted widely. To strike an average between heights reported variously as 3,000 and 17,000 feet was clearly of no value in interception. The filterer had to make up his mind which of the two readings was more likely to be correct. To come to some dependable conclusion he had to take into account both the range and the bearing at which the readings were taken on the aircraft by each individual station, and to assess which station had the better chance technically of being accurate. In an attempt to clarify this process and reduce it to the simplest form, a pamphlet entitled 'Height Reading Without Dizziness' was produced by the Research Section. Another important requirement, much stressed by the Air Staff, was the number of aircraft in a hostile formation. Skill in estimating numbers depended entirely on experience of having seen formations of similar strength, and few even moderate sized formations were seen in the first months.

A further filtering complication appeared with the opening, on 1 November 1939, of the first of the low-looking radar stations, known as a C.H.L.[1] The earlier stations, which were of the C.H. type, employed a transmission technique akin to flood-lighting. The transmission of the new C.H.L. stations was in the shape of a searchlight beam, a property which enabled them to detect aircraft closer to the surface of the sea at longer range than could the C.H. To the confusion of the filterers, positions of aircraft reported by the early C.H.L. stations were accurate in bearing but less accurate in range, characteristics exactly opposed to those of the C.H. plots to which they had just accustomed themselves. It was now no longer sufficient for filterers to think of plots as positions variable along the curve of a range-arc drawn from the respective radar stations. It was necessary to consider which type of station was reporting each separate plot, and to remember the possibility of inaccuracy along either a range-arc or a bearing-line drawn according to the position of the particular station. All this had to be done at top speed.

Fortunately the range reading of the C.H.Ls. was soon improved and the element of direct contradiction in the possibilities was removed. The C.H.L. thus became fairly reliable in both range and bearing, but since its cover was restricted to low altitudes, the C.H. station remained the main source of information and the filterers task was still confusing even to the most agile wits. The most trying factor was the ever-present need for lightning decisions and the knowledge of the grave consequences of a miscalculation. Varying probabilities of error had to be assessed in strictly limited time if filtering was to keep pace with the constant appearance of fresh plots in different tracks on the filter table.

No effort was spared to make as much information as possible clearly available. Specially shaped counters and arrows distinguished the C.H.L. plots from the rest. Every item used was appropriately coloured, marked or shaped until the filter table was a display of bewildering variety to the uninitiated. Silent signalling devices reduced the distraction of noise and talking but could not altogether eliminate the atmosphere of feverish bustle during the busier periods. With all the supervision and aid that could be given, the clerks employed on filtering continued to struggle with their task. In January 1940 the late arrival of filtered tracks in the operations rooms was still a cause for concern. It had become the practice not to tell tracks to the operations room until they were fairly well developed. In the light of filtering difficulties this was understandable but it nevertheless reduced the chance of interception. The order was given that tracks were to be told immediately the first directional arrow had been placed on the filter table.[2] This measure enabled fighters to be despatched some few minutes earlier but it made the importance of the filterer's first decision more critical than before.[3]

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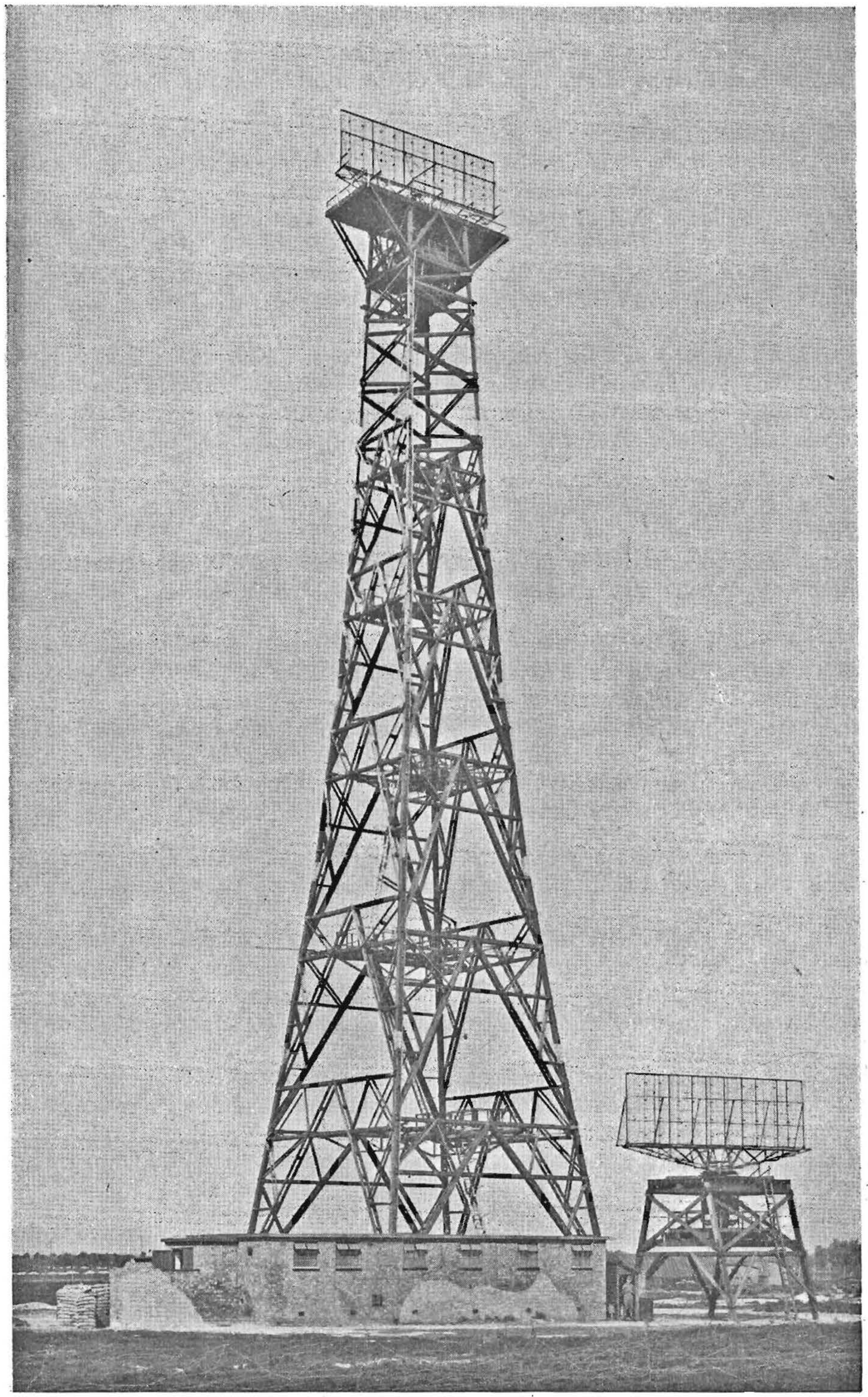
[1] Chain Home Low.

[2] A.M. File S.3377, Encl. 1A.

[3] Fighter Command O.R.B., January 1940.



C.H.L. Station with Aerials on Tower 185 ft. and Gantry 20 ft.

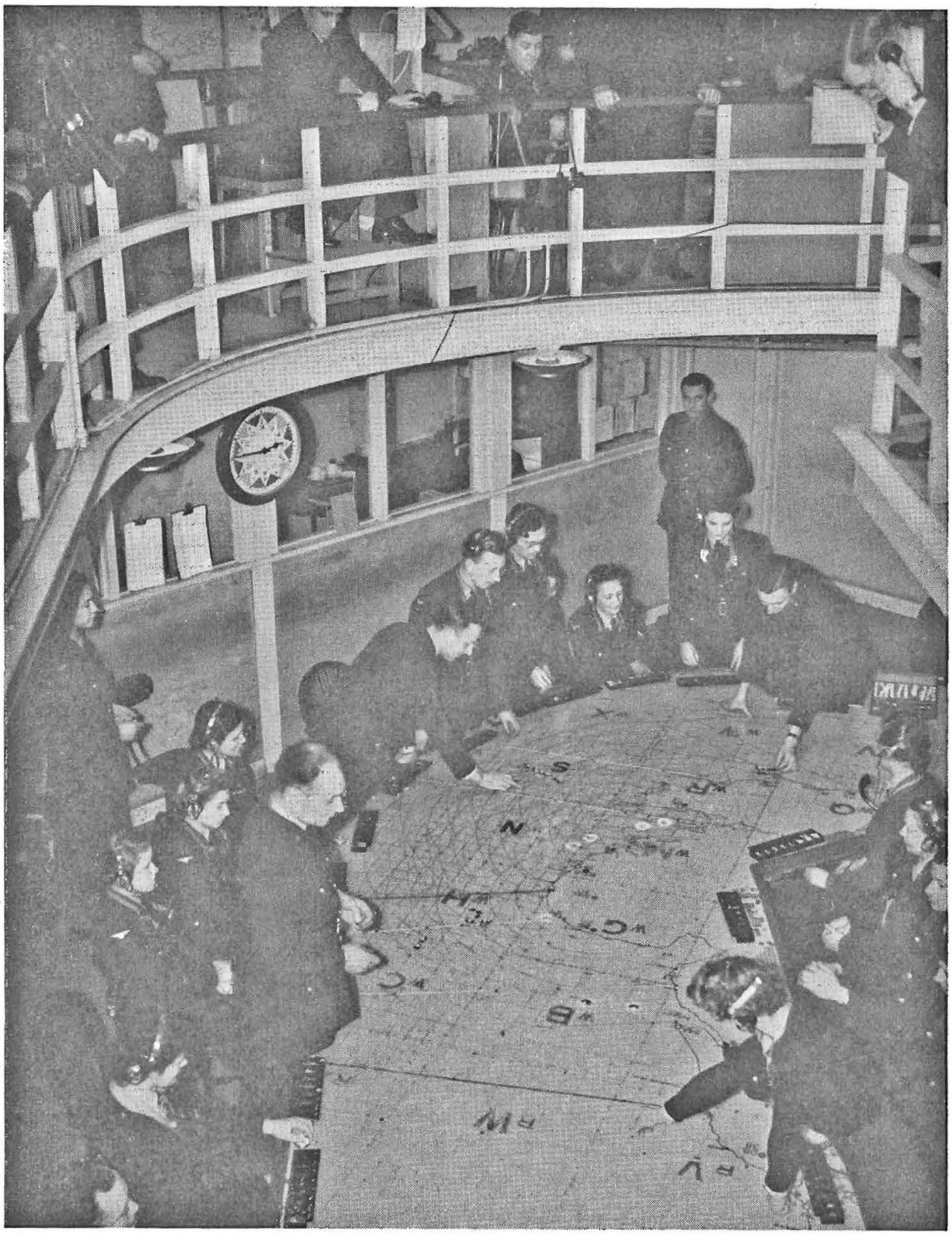
Scientific Analysis of Filtering

It was acknowledged early in 1940 that the results of the fighter control system were disappointing. The cause of the trouble was not clear. Most of the previous causes for complaint had been removed, the quality of radar and other equipment had become much better and there was no shortage of personnel; yet the results were worse than before. A scientific analysis was therefore made of the work of every class of individual employed in fighter interception. The analysis disclosed that the weakest link lay in the filter room. Detailed examination of the process of filtering followed. Records of all plots made by the various radar stations during selected periods were collected together, and from the plots, tracks of raids were accurately reconstructed. The reconstructed tracks were compared with the tracings of tracks as plotted originally in operations rooms while the raids were in progress. The comparison proved beyond all possible doubt that some of the tracks produced during operations had been grossly incorrect. The air picture given had been so misleading as to preclude any chance of successful interception.

Some radical improvement was clearly essential. As an experiment, three Technical Assistants of science degree standard were given a short period of training in the principles of filtering. They then manned the filterer posts. Despite their inexperience, the tracks they produced under operational conditions were much nearer the accuracy required for interception, and a great improvement in reliability was observed. Only after this convincing demonstration was it generally accepted that men of special mental ability were required as filterers. A knowledge and appreciation of the capabilities and limitations of radar stations was also necessary. In his minute to the financial authorities, presenting the case for the establishment of commissioned filterer officers, the Wing Commander 'Operations', Air Ministry, summed up the situation and made perfectly clear what the result would be if the importance of the filtering process continued to be under-estimated.

'In the early days when radar was just beginning, the whole system from radar station to filter room was in the hands of hand-picked enthusiasts, each selected for his particular suitability for the work . . . In the Air Exercises of 1938 it produced excellent results . . . Since those days there has been rapid expansion and consequent dilution of experience and technical aptitude amongst radar personnel . . . Today . . . the results obtained from the radar system are markedly inferior . . . Fighter Command have always had difficulty in finding filterers capable of replacing the original men. You will remember how N.C.Os. of all trades were misemployed as filterers in the endeavour to get efficiency, then how the best of the plotters were selected and regraded as filterers, then how Fighter Command suggested the taking in of the higher clerical grade of civil servants as direct entry N.C.Os. for the purpose . . .'

'The whole work of a filterer has been described by the officer entrusted with the investigation and analysis as "the assessing of a probability". The most accurate assessment of this probability depends on many factors, comprehension of which will never be found in the ordinary airman, nor indeed to the highest degree in the average officer. You know as well as I do the vital importance of accurate filtering. At only one point in the whole vast network of the radar



Filter Room, Headquarters Fighter Command system does the information collected and forwarded by the radar chain assume tangible form on which fighter action may be taken. At that point stands the filterer and it is his responsibility and his alone that this tangible data is the most accurate which it is possible to obtain. Unless he has the peculiar knowledge and the ability to profit by the experience which is ultimately the medium through which a filterer becomes an expert, we shall never get good filtering and the maximum number of interceptions. Without such filtering the whole of the fighter defence of this country will be most severely handicapped, and the ten and a half million pounds of capital sunk in the radar organisation itself will never give the results of which we know it should be capable'.[1]

Financial approval of the appointment of Pilot Officers or Flying Officers to filterer posts in lieu of Corporals was given on 19 February 1940. It thus became possible to select men for filtering duties from amongst those with the special mental qualifications for the task. Usually they were university graduates in scientific or mathematical subjects. Whilst it cannot be said that all filtering troubles ceased with the appointment of the first fifteen trained officer filterers on 10 June 1940, there was undoubtedly thenceforward a much better chance that the accurate air information essential to fighter operations would be forthcoming. Officer filterer posts were later filled by members of the Women's Auxiliary Air Force, who had been, in fact, employed as plotters in the filter room since 20 September 1939. It should be mentioned that the majority of both filter and operations room duties were ultimately carried out by women with conspicuous success.

Underground Operations Rooms

Anxiety persisted until 9 March 1940 regarding the vulnerability to bombing of Fighter Command Headquarters, the destruction of which would reduce the highly developed air defence organisation to chaos. On that date the Filter and Operations Room moved into the newly completed buildings underground. In order to preserve as far as possible the continuity of control, the change-over of 167 external telephone lines to the new building was completed in the short space of two and a half minutes.[2] The internal telephone exchange comprising 250 extensions and 70 exchange lines and private wires was changed in one minute. As a precaution against bomb-damage to outgoing lines, three separate cable feeds were carried for the first 200 yards in steel pipes six feet below the surface. Concrete-protected interconnection panels provided alternative routeing for all lines in the event of one cable feed being cut or damaged. At the end of March, No. 13 Group Operations Room moved to underground accommodation, and No. 12 Group Operations Room on 31 May.

Introduction of V.H.F. R.T.

The range of the T.R.9 high frequency R.T. set was too short and its performance too variable to give efficient air to ground communication for the new interception system. The expedient of using forward R.T. relay stations made speech possible between aircraft over the coast and their sector operations room, but the short range for D.F. fixing still restricted the area over which fighter aircraft could be positioned. The limitations of the T.R.9 had

[1] A.M. File S.47071, Min. 68.

[2] Fighter Command O.R.B., March 1940.

been recognised for a long time and as early as January 1937 the requirement for a fighter R.T. range of 100 miles had been formally stated. A high frequency set of such performance could doubtless have been produced at that time at the expense of greater electric power and weight, but there were other considerations to be taken into account. The number of users of the high frequency band had increased enormously since it was first adopted by the Royal Air Force twelve years before, and interference from civil, military and foreign stations had become serious. The number of channels available for simultaneous use was limited, and the expansion of the Royal Air Force to war strength would necessitate the use of more channels than could be obtained. A further danger in the continued use of high frequencies was their vulnerability to intentional jamming from stations two or three hundred miles away, the distance of Germany from the United Kingdom.[1] For these reasons it was most desirable that the next R.T. equipment for the Royal Air Force should work in another frequency band.

Development of very high frequency (V.H.F.) R.T. had been going on at the Royal Aircraft Establishment since 1935 when it was hoped that a set would be available in five years time.[2] In July 1938, however, it appeared that still another four years' work would be required before V.H.F. equipment having the performance specified by the Air Staff could be produced. It was true that the Dutch Air Force was already using V.H.F. R.T. but an examination of the equipment showed that it was no better than could have been produced by the Royal Aircraft Establishment some years previously. The techniques employed certainly could not give the frequency stability, nor the selectivity, nor the number of channels which the larger Fighter Command organisation would require.

The Air Staff were much concerned at the prospect of waiting until 1941 or 1942 for a new set to replace the inadequate T.R.9. In the circumstances there seemed to be no alternative to the retrograde step of placing a large contract for an interim high frequency set which, although vulnerable to jamming, would give some advantage in greater power and range and increased frequency-changing facilities.[3] This state of affairs was a challenge to the scientific resources of the Royal Aircraft Establishment. As a result of accelerated progress and a somewhat unexpected degree of success in early trials, the Director of Communications Development and the Director of Signals were able to announce jointly on 9 January 1939 that, if an apparatus slightly inferior to that eventually contemplated and produced on a limited initial scale would be acceptable to the Air Staff, then they could offer a very much earlier change-over to V.H.F. If special approval were given and provision action taken, it should be possible to equip eight sectors in Numbers 11 and 12 Fighter Groups with ground transmitters and receivers, including D.F. stations, and some 200 to 300 fighter aircraft with V.H.F. sets by September 1939.

The proposal was not without an element of risk. If war occurred before re-equipment was complete, there would be difficulties in operating a fighter force using partly H.F. and partly V.H.F. R.T., especially when reinforcing one sector with squadrons from another. Furthermore, because the testing

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[1] A.M. File S.49038, Encl. 1B.

[2] A.M. File S.35037, Encl. 22A.

[3] A.M. File S.44756, Encl. 16A.

period would be limited, the new set might well develop some serious fault after being put into service. These risks were minimised by the design of the set. Its shape, size and means of attachment in the aircraft were made similar to those of the T.R.9, and a squadron would thus be able to change to V.H.F. sets or back again to H.F. in about an hour and a half, once the new wiring, generating and voltage control systems were installed in the aircraft.

The Assistant Chief of Air Staff said the scheme was a bit of a gamble, but he strongly recommended it.[1] The Chief of Air Staff approved on 16 January 1939. When giving instructions to put the scheme into force with all speed, he added 'If you are held up by the "machine", let me know'. Layout of buildings and inter-station line communications, as well as technical design, were made the responsibility of the Royal Aircraft Establishment. Eight sectors were to have V.H.F., four in each of Nos. 11 and 12 Groups.[2] Hornchurch, North Weald and Debden were to work H.F. and V.H.F. simultaneously. Spitfire and Hurricane aircraft were modified for the installation.[3] By 24 July 1939 all sites had been obtained, buildings were to be finished during the following month, and masts were practically complete.[4] Delivery of sets from manufacturers began in August. There was some little delay because the aircraft aerial installation turned out to be beyond the scope of Service units, but by October the first aircraft were ready for test. Technical trials had already given promise of fulfilling operational requirements and Service trials took place at Duxford with six Spitfire aircraft of No. 66 Squadron, using the T.R.1133, on 30 October 1939. The results exceeded expectations. An air-to-ground range of as much as 140 miles was obtained at 20,000 feet and an air-to-air range of over 100 miles.[5] Speech was clearer, pilots' controls simpler and quicker to operate, direction finding was sharper; in every way the T.R.1133 was beyond comparison with the T.R.9. A few days later the Chief of Air Staff approved the general introduction of V.H.F. and gave great credit to all concerned.[6] Greatly improved sector control became possible as the squadrons were equipped. Fighters could be accurately fixed and could intercept over much wider areas. Advanced D.F. stations and V.H.F. R.T. relay stations in each sector facilitated interception at the coast and out to sea.

The first stage of the plan of installation of V.H.F. equipment did not work out, unfortunately, as quickly as had been hoped. It was to have given place in May 1940 to a second stage in which the whole of Fighter Command was to be equipped with an improved version of V.H.F. equipment, the T.R.1143, embodying crystal control in the receiver as well as the transmitter.[7] In the

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[1] A.M. File S.44756, Min. 21.

[2] Sectors to be equipped with V.H.F. in No. 11 Group were Debden, Biggin Hill, Hornchurch, North Weald: in No. 12 Group Duxford, Wittering, Catterick and Digby, in that order as far as practicable.

[3] The modifications included the fitting of new electrical generators, a carbon pile type of voltage regulator, a filter for suppression of radio interference, and a whip type aerial. A.M. File S.49038, Min. 36.

[4] A.M. File S.49038, Encl. 60A. There were eight double (transmitting and receiving) and 24 D.F. receiving sites.

[5] A.M. File S.44756.

[6] *Ibid.*, Min. 44.

[7] The disadvantage of the lack of crystal control in the receiver of the T.R.1133 was made clearly apparent during the initial fitting of the V.H.F. set in aircraft of one squadron. The weather was extremely cold and the tuning and setting up of the instruments had been done inside the well-heated hangars. When in the air, all aircraft failed to communicate, the change of temperature having been sufficient to put the receivers off tune. Thenceforward tuning was done in the open air.

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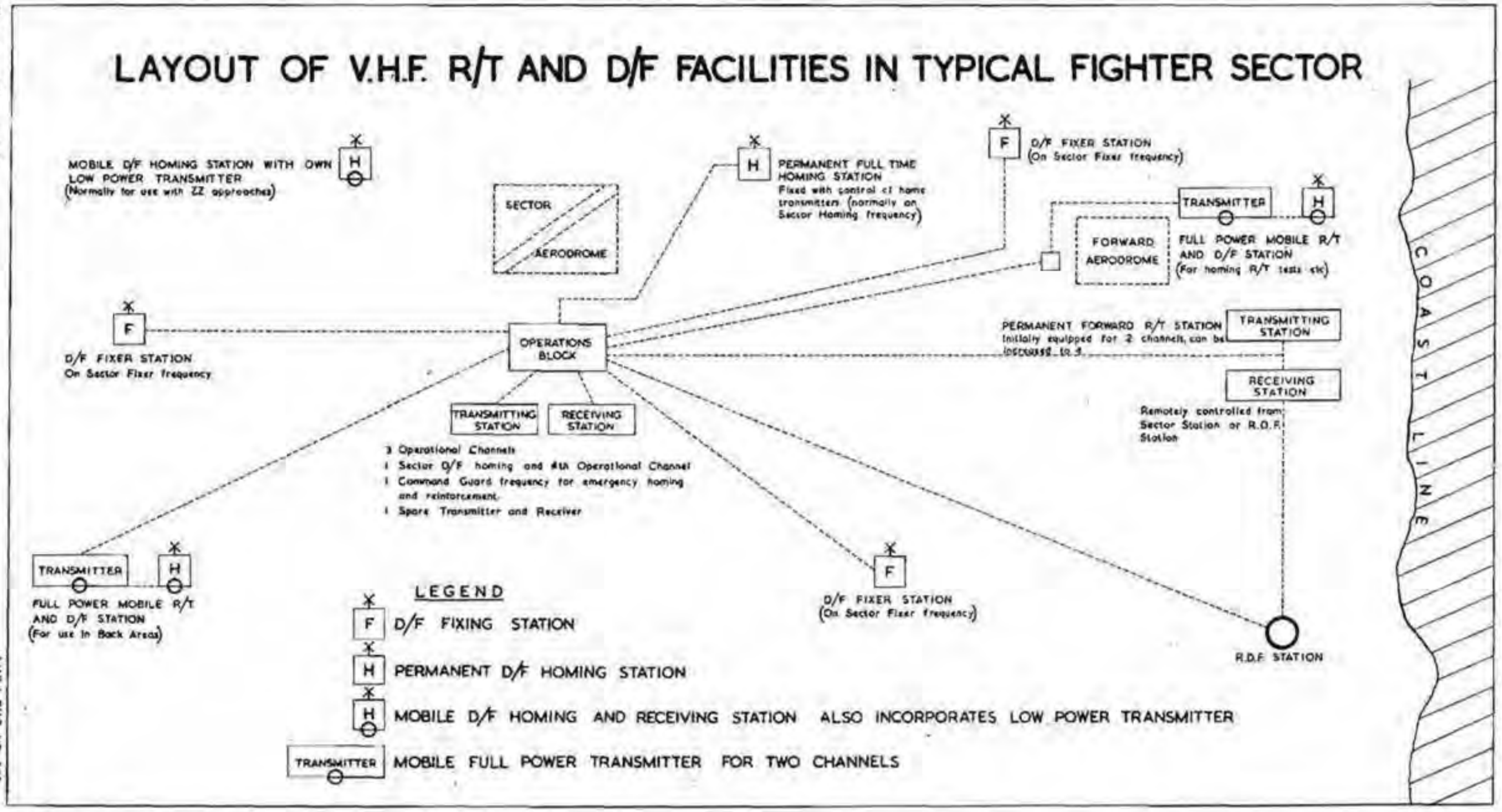

DIAGRAM 8

endeavour to achieve technical perfection combined with economy in production, however, the satisfaction of operational demands fell between two stools. Production of the T.R.1133 was tardy and supplies inadequate to meet the demands of fighter operations. Apart from the initial issue of 25 sets to each of eight squadrons, and 40 additional sets suitable for Hurricane aircraft only, it was found that no further equipment could be expected to become available until the late summer of 1940.

Postponement of V.H.F. Installation

During the evacuation of Dunkirk in May 1940 the shortage of V.H.F. equipment was keenly felt. Only a proportion of the fighter squadrons were equipped with V.H.F. and the operation of a force partly equipped with one and partly with another type of R.T. equipment proved unworkable. The Air Officer Commanding-in-Chief, Fighter Command, signalled as follows :—[1]

> 'To : 11, 12, 13 Groups repeated Air Ministry.
>
> In view necessity for maintaining flexibility in operation of all Fighter Squadrons at present time and limited wireless apparatus available all V.H.F. equipment in aircraft is to be replaced by H.F. T.R.9D sets forthwith. V.H.F. equipment is to be retained in reserve by V.H.F. sector stations. Squadrons concerned to report as change-over completed. V.H.F. ground personnel to remain in their sectors but employed to best advantage pending return to V.H.F.'

In a letter to the Air Ministry on 1 June 1940, the Air Officer Commanding-in-Chief, Fighter Command, deplored the inadequacy of supplies which had forced him to abandon this most successful form of fighter communication.[2] He felt it necessary to prevent the loss of V.H.F. equipment over Belgium and the Channel at that distressing time in order that it should be to hand when the occasion demanded. Moreover, flexibility in the employment of squadrons was required. Composite squadrons sometimes operated and R.T. communication between aircraft was essential. It was impracticable for squadrons equipped with V.H.F. constantly to change to H.F. and back again. Only by reverting to H.F. throughout the Command could a workable R.T. organisation be maintained. To lose the advantages of V.H.F. in this manner was a great disappointment. The only consolation was the ease with which reversion to H.F. could be effected. The additional work entailed in design to secure interchangeability had been fully justified. After the Dunkirk evacuation, production of the T.R.1133 improved.

The Beginning of the Battle

The fighter control and interception system which had been evolved and built up during the previous four years was put to the test in the Battle of Britain, between July and October 1940. Fighter Command was fortunate in that the comparatively light scale of air attack on the United Kingdom during the first ten months of the war had allowed the system to be improved with greater resources and under added incentives. On the other hand the test was to be much more severe than that envisaged during the years of preparation. It was no longer merely a question of whether unescorted long-range enemy

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[1] A.M. File S.44756, Encl. 113A.

[2] *Ibid.*, Encl. 115A.

bombers could destroy the cities and industries of the nation. The fall of France had brought enemy airfields within short range of the south and east of England, and the Germans could deploy both bomber and fighter aircraft against the defence.

The German aim in the Battle of Britain was primarily to wear down the strength of Fighter Command, not only in the air but also in its ground organisation, to the point of achieving air supremacy. Bombers were to be employed in the first instance to ensure that the Royal Air Force came up to fight, but the greater part of the German bomber force was to be kept in reserve until a good measure of air superiority had been gained. In their task the Germans had a clear advantage in numbers of aircraft. Against the British force of 603 single-engined fighters, as on 15 July, they could dispose about 1,200 long-range bombers and 760 single and 220 twin engined fighters.[1] Not only that, for while the Germans could distribute or concentrate their effort as they wished, the defending force was necessarily extended behind the length of the coastline to enable it to oppose attack in any area.

Being outnumbered, Fighter Command was required to operate with strict economy in the use of aircraft and pilots, whilst at the same time to inflict more than proportionate losses on German bombers and fighters. To this difficult task the radar early warning and fighter control system was ideally suited. It was possible for the defending fighters to remain on the ground until the approach of a raid was imminent, and then to engage it at or near the coast with little waste of time or effort. During July and the first half of August the daylight attacks were chiefly directed against shipping, and towns and airfields near the coast. The German intention appears to have been to test and tire the defence by bombing a variety of widely separated targets. It is noteworthy that few, if any, unescorted bomber attacks were made. The ability of the defending fighters to meet attacks on the coastal fringe made fighter escort essential if heavy losses were to be avoided, even in tip-and-run raids on seaside towns.

The Fighter Code

For giving instructions to fighters by R.T., the simple code invented in 1938 was still in use. For example, ' scramble ' meant take off, ' orbit ' meant circle, ' vector 230 ' meant fly on a course of 230 degrees. The risk of giving the Germans useful information thereby was slight, except in one or two cases such as when giving the height at which fighters were to fly and the order to ' pancake ' or land. For these instructions special arrangements were made. When giving height a false quantity was introduced, and ' angels 18 ' really meant fly at 21,000 feet and not 18,000. On more than one occasion German fighter formations intending to dive on our patrols were themselves attacked from above. In the place of ' pancake ' a number of synonyms were used in turn, the meaning of which was not readily apparent to the enemy.[2]

A shortcoming in fighter directing during the early period of the battle was in the matter of height. British fighters sometimes found themselves too low to be able to attack effectively. Height measuring by radar was admittedly

[1] A.H.B. Monograph. *The Rise and Fall of the German Air Force*. A.M.P. 248. German Intelligence estimated the British fighter force at 675 aircraft.

[2] Despatch by Air Chief Marshal Sir Hugh Dowding. A.H.B. IIH1/18.

sometimes faulty at first; the equipment was difficult to operate and the operators inexperienced. Moreover, German raiders often continued to gain height until a late stage in their approach. Any delay in the reporting and control system would therefore make the reported heights seem more inaccurate to pilots than they had been at the time they were taken. Reported heights improved considerably in accuracy during the battle and by 7 September it was found necessary to warn controllers and formations against disregarding the height information given to them.[1] Again on 9 September, as a result of a failure to comply with patrol height instructions, pilots were reminded that 'orders given by the group controller are based on accurate information which is available.'[2]

German Assessment of the Fighter Control System

In the preliminary stage of the battle the Germans realised, through interception of R.T. messages, that British fighters were being directed towards their formations with great accuracy. They had known of the British radar system some time before the war but not of the highly developed plotting system linked with fighter control. Nor had they themselves experimented in the tactical employment of radar, although their technical development of it had reached an advanced stage. Their assessment of the British fighter control system, as circulated by German Intelligence to operational commands on 7 August 1940, showed a serious misconception. 'Since', the appreciation ran, 'British fighters are controlled from the ground by R.T., they are tied to their respective ground stations and thereby restricted in mobility, even taking into consideration that the ground stations are partly mobile. Consequently the assembly of strong fighter forces at determined points and at short notice is not to be expected. A massed German attack on a target area can therefore count on the same conditions of light fighter opposition as in attacks on widely scattered targets. It can, indeed, be assumed that considerable confusion in the defensive networks will be unavoidable during mass attacks, and that the effectiveness of the defences may thereby be reduced.'[3] The conclusion arrived at was in fact the opposite of the truth. One of the advantages of the fighter control system was the ease with which threatened areas could be reinforced from other sectors and also from other groups.

Attacks on Sector Stations

By 18 August, when the attacks ceased for a period of five days, it was clear that the defence was still an effective fighting force and had not been materially weakened by the German tactics hitherto employed. Deeper penetration would be necessary to bring about a decisive result. On 24 August large scale attacks began to be directed against such airfields in south-east England as were part of, or likely to be part of, the defensive organisation of Fighter Command. Between 4 August and 7 September no fewer than six of the seven sector stations in No. 11 Group were extensively damaged. The Germans attacked airfields not so much to destroy aircraft or even to render areas unserviceable, but to destroy the nodal points of communication and control.[4]

[1] A.H.B. Narrative A.D.G.B., Vol. II, Appendix 12.

[2] No. 11 G.I.B. No. 49, 9 September 1940. A.H.B. IIM/B11/1A.

[3] A.H.B. Monograph. *The Rise and Fall of the German Air Force.* A.M.P. 248, p. 80.

[4] A.H.B. Narrative, A.D.G.B. Vol. II.

Thus, it was damage to telecommunications and operations rooms which were above ground, rather than to landing grounds and hangars, that most interfered with the proper working of No. 11 Group. Kenley, and later, Biggin Hill operations rooms were put out of action and forced to move to emergency rooms which had been prepared beforehand. They were not, however, large enough to contain all the staff required nor equipped with the full scale of landlines to enable three squadrons to be controlled. A beginning was made towards the end of August of building alternative operations rooms, fully equipped in all respects, within five miles of each sector station.

Even when operations rooms escaped serious damage, as at North Weald on 3 September, important operational landlines were frequently and internal communications invariably severed. The work of repairing the first was carried out by the General Post Office (War Group), while that of repairing station lines was chiefly done by station signals sections and the Royal Corps of Signals. During the period of repairs, essential communications were kept going by virtue of the flexibility of the operational keyboard system. When, for example, all lines between Headquarters No. 11 Group and Biggin Hill were cut in a particularly heavy raid, operational control was continued by means of lateral lines through the neighbouring sector station at Kenley. It is difficult to say how long this sort of improvisation could have continued.

'There was a critical period between 28 August and 5 September,' wrote the Air Officer Commanding No. 11 Group, 'when the damage to sector stations and our ground organisation was having a serious effect on the fighting efficiency of squadrons . . . The absence of many essential telephone lines, the use of scratch equipment in emergency operations rooms and the general dislocation of ground organisation was seriously felt for about a week in the handling of squadrons to meet the enemy's massed attacks. . . . Had the enemy continued his heavy attacks against (Biggin Hill and) the adjacent sectors, and knocked out their operations rooms or telephone communications, the fighter defences of London would have been in a perilous state during the last critical phase when heavy attacks have been directed against the capital. . . . Fortunately the enemy switched his raids from aerodromes on to industrial and other objectives . . .'[1]

Interception Difficulties

It might be supposed that when the Germans began their intensive raids on sector airfields around London, the task of interception would be easier than it was when raids were made on widely separated coastal targets. However, this was not so, because the concentration of enemy aircraft reduced the period of radar early warning. The continued air activity over the Straits of Dover frequently prevented the radar stations from giving early warning of individual raids. Out of a maze of plots in that area there would suddenly emerge anything from three to six formations, rarely less than four, heading for the coast of Kent. The period of warning was often reduced to something considerably less than twenty minutes before the enemy crossed the coast. This time was inevitably reduced further by the delay in telephoning the information to the filter room and onwards to operations rooms, and by the intermediate

[1] No. 11 Group, 11G/S.493, 12 Sept. 1940. A.H.B. IIM/B11/1A.

processes of filtering and identification. It was therefore difficult for fighters to intercept at proper height near the coast unless they were already in the air at the time of warning.

Once the German formations had crossed the coast, accurate tracking became impossible except in clear weather when the aircraft were flying within visual range. The Observer Corps could not be expected to see through cloud or haze, nor could they observe high flying aircraft against a bright cloudless sky. The information available to controllers was often scanty or confused and effective fighter direction suffered. 'There had been occasions recently,' said the Group Commander on 30 August, 'when strong squadrons had been left sculling around the sky breathing fire, when other squadrons had been fiercely engaging superior numbers.' As a result of the failure of many squadrons to intercept overland, the Air Officer Commanding No. 11 Group ordered formation leaders to transmit by R.T. reports of enemy aircraft sighted, giving to controllers the strength, height, course and approximate position of the enemy. The transmission of a sighting report involved the possible loss of surprise in attack, but this disadvantage was outweighed by the value of the information received. Nevertheless interceptions were still not numerous enough. During 6 September only seven out of eighteen squadrons despatched succeeded in engaging the enemy on one occasion, and on another, only seven out of seventeen. These were admittedly among the worst examples. Previously there had been occasions when every squadron despatched had engaged.

Shortcomings of H.F. R.T.

In addition to the lack of complete air information overland, another reason for failures to intercept was undoubtedly the poor standard of R.T. communication given by the T.R.9. On 18 August only one section of a squadron had come into action against a German formation near Chelmsford. The other sections failed to hear an order addressed to them by the squadron commander owing to loud interference by the Germans in which conversation between the enemy pilots could be plainly heard. There had been a similar experience over Swanage on 15 August. There are many examples of poor R.T. communications recorded in the operational narratives, and from these it is evident that despite the provision of forward R.T. relay stations and the attention devoted in other ways to getting the last ounce out of the H.F. R.T. organisation, it was still not satisfactory. Sometimes it worked well, but in general too much of pilots and controllers time was occupied in the effort of passing and receiving messages. Interference was a frequent distraction. Communication was not sufficiently positive.

Re-introduction of V.H.F. R.T.

As a result of improved production of V.H.F. equipment and of the urgent need for better R.T. communication, it was decided on 18 August to put into force once again the replacement of H.F. sets by V.H.F., beginning with the squadrons previously equipped which had the installations and trained personnel already available.[1] Later, priority of installation was given to No. 11 Group to facilitate inter-squadron communication in the air. The need for alternative working on H.F. or V.H.F. was still regarded as important. By the

[1] A.M. File S.44756, Encl. 130A.

end of September sixteen day-fighter squadrons had been fitted with V.H.F. Six Blenheim night-fighter squadrons had also previously been fitted.[1] The vastly superior performance of the V.H.F. equipment in providing perfect R.T. communication was reflected in the results of operations conducted by the squadrons which received it. Unfortunately, despite its excellent technical qualities, V.H.F. came to Fighter Command too late and in too small a quantity to be a major factor in the Battle of Britain. Only a few squadrons were able to use it, and lack of uniformity of equipment imposed an operational disadvantage. Nevertheless, operated in the spearhead squadrons it gave great help to pilots and controllers at long range and over the sea.

At times when No. 11 Group squadrons were heavily engaged, it was necessary for them to call on neighbouring groups for reinforcement. Reinforcing aircraft then patrolled No. 11 Group airfields, or other vulnerable targets, to prevent their being attacked. Special arrangements were made for such occasions to provide R.T. communication on the appropriate frequency. The R.T. station of each sector which might be reinforced always held quartz crystals for adjacent group frequencies in order that it could control reinforcing aircraft on the frequency to which their sets were normally tuned. In addition, each sector airfield kept two spare R.T. sets with the fixer channel tuned to the frequency of the sector to be reinforced. These were clearly labelled and kept ready for immediate installation in aircraft of the reinforcing squadron. Facilities for fighter control in all circumstances were therefore readily available.[2]

Interception during the Attacks on London

On 7 September the German bomber attack was switched from airfields to the mass bombing of London. It was simpler to intercept large forces converging on the capital than smaller forces operating against a number of targets at shorter range, but the increasingly cloudy skies of September caused a deterioration of Observer Corps plotting. During the month the German raiders showed a tendency to fly at still greater altitude, some being too high for the coastal radars to detect reliably. To overcome the inability of controllers to direct fighters reliably in such circumstances, the Air Officer Commanding No. 11 Group decided in favour of definite patrol lines which would be taken up by squadrons on the warning of approach of a large raid. The task of the controller was confined to keeping the squadrons on their respective patrol lines and to giving them such information as he had about the attack. Squadron commanders were then largely responsible for searching for and locating the enemy among the clouds. When, however, in good weather clear tracks of German aircraft were available, squadrons would be despatched to intercept direct.

From the second week in September attempts to supplement radar warning of high flying raids were made in the shape of single reconnaissance aircraft from squadrons at Biggin Hill and Hornchurch, despatched to patrol at maximum height on the usual enemy routes across the coast. Sighting reports were transmitted by R.T., but this valuable information usually failed to reach the Group operations room in time to be effective. During the third week in September the Air Ministry was asked to form a special reconnaissance flight, No. 421,

[1] Fighter Command, O.R.B., July 1940. [2] No. 12 Group, O.R.B., January 1941.

for the purpose, and instructions to this effect were given on the last day of the month. The Spitfire aircraft were to be equipped with V.H.F. R.T. and to report direct to Group Headquarters where V.H.F. equipment had been installed.

Large scale bomber attacks on London continued during the second, third and fourth weeks of September until heavy losses compelled the Germans to cease this type of offensive. They then reverted to their previous aim of wearing down the fighting strength of the defence, this time using a proportion of their fighters as bombers. The increasing height and speed of the attacks called for constantly changing tactics on the part of the defence to meet every new situation. It was necessary, for example, to keep standing patrols just below oxygen height, about 15,000 feet, from where they could climb to higher altitudes to intercept as warnings were received. A description of the various tactics employed is not within the scope of this narrative, but it may be noted that these departures from the original conception of the interception system do not detract from the value of the four years of preparation. The essential features were still in evidence: radar early warning and tracking of the enemy made quickly available for use by the fighter pilot; ability to keep track of defensive fighters in the air, to position them when necessary on patrol lines over cloud and direct them as required, and to enable pilots to regain their airfields in bad visibility. Reinforcement of heavily engaged sectors was also facilitated.

Interception during Raid on North-East England

Throughout the whole of the battle, Fighter Command could and did react immediately to attacks at any point of the coast whilst simultaneously dealing with the main and heaviest threat against the south-east of England. Diversionary attacks made in the Portsmouth-Weymouth area were always intercepted effectively, and the surprise attack on the north-east coast on 15 August was countered in an exemplary manner. This raid consisted of two forces, which approached the coast near Newcastle and Scarborough. Radar warning of the first was given at 1208 hours. It was attacked before reaching the coast, and subsequently, by five separate fighter squadrons at 1245, 1300, 1307, 1315 and onwards from 1315 hours. Such bombs as fell on land caused insignificant damage. Warning of the second force was given at 1239 hours. It was first intercepted ten miles out to sea at 1315 hours by one squadron, and later by another squadron and a flight. The only part of the whole fighter force available which did not intercept was on patrol duty elsewhere. The fighters which intercepted were unfortunately not numerous enough to break up the bomber force which attacked Driffield airfield and an ammunition dump near Bridlington. The damage caused was small although a force of about 140 bombers was engaged. This was due to the raiders being roughly handled by the fighter force. No British fighters were lost and, taking the raid as a whole the enemy suffered considerably. It must have been very discouraging for the Germans, after approaching over four hundred miles of sea, and probably hoping for complete surprise, to be set on by entire squadrons even before reaching the coast. At all events, the experiment was not repeated.

German Impressions

A tribute to the effective and economical way in which the comparatively small number of fighters in the south of England was employed was made by *Generalleutnant* Galland who commanded '*J.G. 26*' during the Battle of Britain.

After the war he stated that during the battle he was continually being assured that only a hundred or so fighters would be met in any operation over the south-east, but in his experience anything from two hundred to three hundred might be found.[1] The fact was, that even including the squadrons from Duxford (No. 12 Group) and Middle Wallop (No. 10 Group), there were rarely more than three hundred British fighters available in the south-east at any time; and it would be surprising if all of them were ever seen in the air at the same time.

The impression which Galland gained of a stronger fighter force than actually existed in the south is curiously in accord with a rumour current in the Royal Air Force at the end of 1940. This was to the effect that the Germans, notwithstanding all their intelligence as to the modest numerical strength of Fighter Command, had come to the conclusion towards the end of the battle that the perfidious English had deceived them once again, having with the greatest secrecy built up an innumerable and quite inexhaustible force of aircraft and pilots.

Decentralisation of Filtering

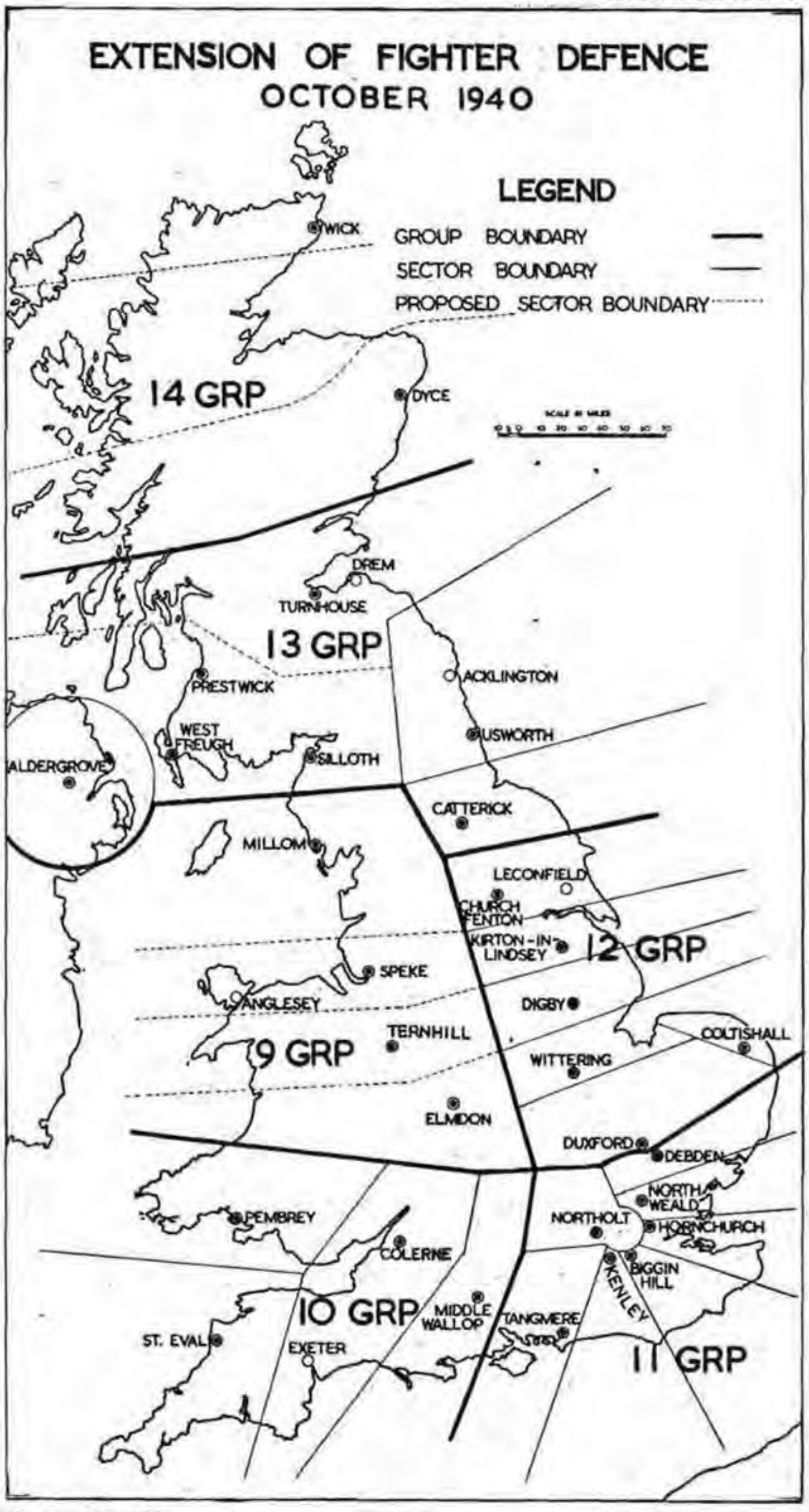
One sign of the sure foundation on which the fighter control system was built up was the remarkably slight degree of modification necessary as a result of the experience of the Battle of Britain. The most noticeable, and practically the only, change made in the general organisation was the decentralisation of the functions of the Command Filter Room to Fighter Groups. Congestion in plotting and filtering had certainly been evident during the more intense periods, and the resulting delay had an adverse effect on fighter control. These weaknesses had been forecast in January 1940, seven months before the battle, and the Chief of the Air Staff had been persuaded that experiments in radar plotting direct to group and possibly sector operations rooms were desirable. By this means congestion and delay would be minimised and much greater tactical use could be made of radar information. The Commander-in-Chief, Fighter Command had successfully resisted these proposals. He felt, at that late stage, that it was more important for the whole system to settle down and achieve efficiency in the methods already carefully arrived at by trial and error over a long period. He was also influenced by the knowledge of the numerical inferiority of his force in the face of the approaching trial of strength. Filtering and identification centralised at his headquarters would give him greater measure of control and economy in the use of aircraft. Direct plotting by groups and sectors would inevitably increase the number of fighter sorties.[2] The filter room therefore remained at Fighter Command Headquarters at Bentley Priory during the battle.

Throughout 1940, and especially in the latter half, the radar chain was greatly extended, and C.H.L. stations were also added to improve the low cover. Two difficulties arose, and increased. In the first place, it became impossible to provide the number of long distance telephone lines required for a centralised filter system. A compromise was made when a small subsidiary filter room

[1] The German Chief of Intelligence assessed R.A.F. fighter strength towards the end of August as 350. Operational strength on 23 August was 672. A.H.B. Monograph. *The Rise and Fall of the German Air Force*, p. 85.

[2] A.M. File S.3377, Encl. 10A.

DIAGRAM 9



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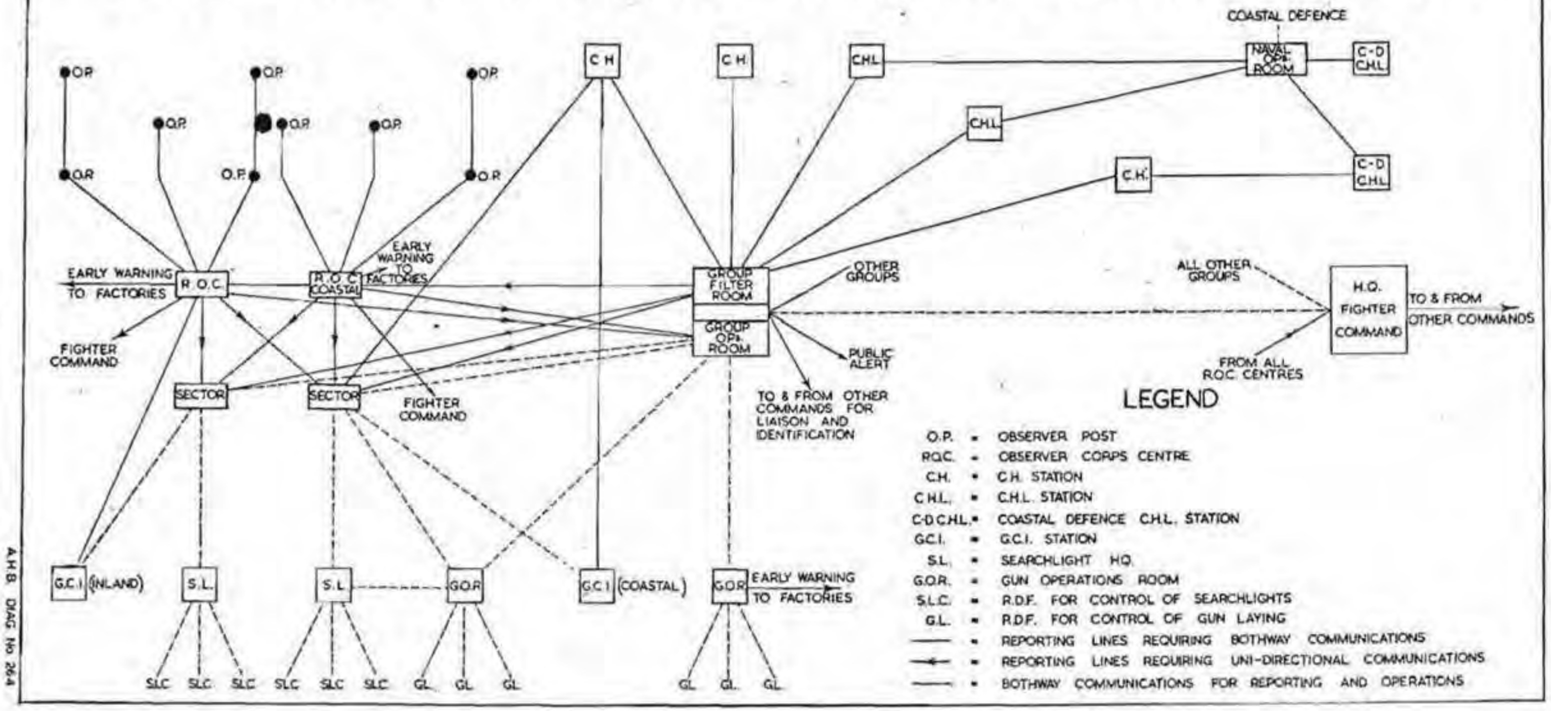
LAYOUT OF AIR MOVEMENT REPORTING COMMUNICATIONS



A.H.B. DIAG No 264

to deal with reports from the recently added radar stations in the south-west was set up at Plymouth in June 1940, and moved to Headquarters No. 10 Group at Rudloe, near Bath, at the end of the month. For similar reasons a temporary filter room was opened at Headquarters No. 9 Group at Preston in September.

At the same time the profusion of plots pouring into the Fighter Command Filter Room, including those from the newly added C.H.L. stations, began to cause congestion and delay. A short-term remedy was applied when C.H.L. stations were made to pass their plots to their neighbouring C.H. stations, instead of passing them to the filter room. A simplification of work was certainly observed in the filter room, but the bottleneck had merely been transferred to the C.H. stations, which now tried unsuccessfully to pass twice the former amount of information along a telephone line previously found barely adequate for their own reports. Instead of the congestion being eliminated, the flow of plots was being dammed up nearer the source. Well might the Air Officer Commanding No. 11 Group complain on 28 September that the radar system was giving shorter warning than during mid-summer.[1]

By the end of 1940 the volume of radar information was still greater and promised to increase further. The physical limitations of the filter room at Stanmore already made it impossible to accommodate more people around the filter table. The research section considered that the existing staff would all be fully employed in dealing with the No. 11 Group area alone whereas they were attempting to cover the areas of Nos. 11, 12 and 13 Groups.[2] Under pressure of these inescapable facts the decision was made in December 1940 to decentralise the filtering process to fighter group headquarters. The task of reorganising the landline system was inevitably complicated and protracted, and the group filter rooms were not all working separately until September 1941. The filter room at Stanmore continued to operate but for the No. 11 Group area only.

Change-over to V.H.F.

Another development which occurred after the Battle of Britain was the completion of the V.H.F.R.T. fitting programme, with the equipment then becoming available. The end of the year saw forty-one fighter squadrons completely re-equipped, and in addition seventeen sector stations were equipped partly with mobile apparatus and partly on a permanent basis, but all capable of operating fighters on V.H.F. This represented just over half of the Home fighter strength. After the increase in production of V.H.F. sets had taken effect, the Air Officer Commanding-in-Chief, Fighter Command gave instructions for the remaining squadrons in the command to be changed over to V.H.F.R.T. by 1 March 1941, allowing sector stations to be equipped primarily with mobile ground equipment.

With the completion of the first V.H.F. re-equipping programme and the inauguration of group filter rooms, the period of intense development of the fighter control system came to an end. Many improvements and additions to the machinery of fighter control continued to be made, but these were embellishments of the accepted system rather than the primary development of an organisation for applying radar and other radio techniques to Home Defence.

[1] No. 11 Group Instructions to Controllers No. 20, A.H.B. IIM/B11/1A.

[2] A.M. File S.41234/II, Encl. 92A.

CHAPTER 4

SECTOR CONTROL OVERSEAS

The transformation which took place in Fighter Command in the three years just before the war was barely completed in time for war. During the preparation no effort had been spared and every resource and facility available in a highly developed industrial country was immediately to hand. Land lines from the generously scaled G.P.O. network were ready laid; for the manufacture and maintenance of technical equipment the radio industry was there to be drawn on. No problem of mobility was set; the line of defence was fixed inevitably at the coast for military and naval reasons as well as for those of air operations. To defend this line large radar stations could be set up in permanent form on sites overlooking the sea; inland radar was impracticable at this early period of development. Even more important, the length of the defended line was short enough to be commensurate with the possibility of continuous radar cover; the degree of air warning available could therefore be generally complete.

The fighter defence organisations set up overseas lacked most of the advantages in respect of equipment, partly as a natural result of their less importance and lower priority, and partly because the need for transportation brought in the factors of delay and sometimes of loss. The shortage of landlines, in particular, was the most important point of difference. Nowhere abroad, even in important and permanent base defence areas, were they to be had in anything approaching the quantity available at home. The laying of a skeleton network was a project which took a long time, even after the bulky equipment and cable had safely arrived. Laying cables and subsequent maintenance of efficient circuits were often hindered by topography, violent extremes of weather, floods and hurricanes, and the depredations of animals and the inhabitants. Stand-by wireless sets were in constant demand. The sector control system did not lend itself to mobile campaigns chiefly on account of the impossibility of providing landlines for temporary use.

The overseas theatres of operations were so vast in area that the concept of air defence and the fighter control system as developed for the United Kingdom could not possibly be applied. Moreover, in the Middle East alone, the amount of technical equipment available in the early years of the war was totally inadequate to provide for the efficient air defence of all important vulnerable points. Not only was the communications problem magnified by the great distances, but it was out of the question to provide continuous radar cover in and around every operational area. The very meagre quantities of radar and communications equipment sent abroad had to be disposed to the best advantage at a few individual vital centres. The overlapping radar cover necessary to provide range cuts by readings from adjacent stations of the 'floodlighting' type, as in the Home Defence system, was rarely possible. The result was that radar information was generally useful only for the purpose of giving air raid warnings. It was not until much later that controlled interception methods could be introduced.

The supply of radio equipment to the overseas theatres improved considerably in 1942 and thereafter. By that time, the standards of radar reporting and the interception technique developed by experience in the United Kingdom had gradually become more widely known and accepted. There is a great contrast, for example, between the frail defence organisation attempted in France in 1939 and 1940, and the rapidly constructed sector and night defence systems set up in India in 1942 and 1943. The provision of landline communications, however, on anything more than a local basis, in all the oversea air defence systems, presented great difficulties which were only partially overcome by the use of radio.

The Campaign in France, 1939–1940

It was foreseen that there would be two separate roles for fighter aircraft in France ; the first to operate under the control of the Air Component in forward battle areas and the second to defend the base areas, guarding ports and industrial centres in co-operation with the French.[1] Aircraft employed in the latter role could be operated on similar lines to the Home Defence squadrons and would need a similar method of control. It was hoped that the final static organisation could be left behind on the advance of the Allied forces into Belgium.[2] Aircraft in advanced positions would be operated under mobile conditions and would consequently need some sort of control system which could keep up with their movements.

At the outbreak of war in September 1939, the French aircraft warning organisation consisted of the *System de Guet* which was similar to the Royal Observer Corps, backed rather ineffectively by a radio device called *Detection Electromagnétique*. This formed the entire air defence intelligence organisation. Some potentialities of radar had been disclosed to the French in April 1939 and plans drawn up for a chain of radar stations to extend from Dunkirk to Strasbourg. By November 1939 the first eight mobile radar stations were sited. Each station was to be linked by landline with its neighbour and with one of the two filter centres to be sited at Arras and Rheims.[3] Lateral telephone links between the filter centres and with Headquarters Fighter Command and the War Room in Paris completed the communications of the air information system. For fighter control purposes, Headquarters No. 14 Group was to receive information from Arras and Headquarters No. 67 Wing from Rheims. One H.F. D.F. station was to be provided for the use of each squadron.

Two Air Formation Signals Units had been established to provide limited line communications for the Air Component and the Advanced Air Striking Force.[4] The second echelon (No. 2 Group) of the latter force was never

[1] H.Q. British Air Forces in France, File 7158/Sigs, A.H.B. IIH2/189, Encl. 8A.

[2] H.Q. British Air Forces in France, File 7180/Sigs, A.H.B. IIH2/198, Encl. 18A.

[3] Radar stations at Dover, Boulogne, Calais, Lille, Arras, Cambrai, Aresne and Sedan were to report to Arras and those at Verdun, Mount Haut, Bas le Duc and Troyes were to report to Rheims.

[4] H.Q. British Air Forces in France. File 7180/Sigs, A.H.B. IIH2/198, Encl. 23A.

despatched with the result that the line equipment and personnel intended for it was applied to provide a better scale of communications than had been expected. Even so, this reserve was soon exhausted and it became increasingly difficult to provide additional communications for the new units which were arriving. From December 1939 the position became gradually worse until in April 1940 it was impossible to add any signals facilities to those already existing. The telephone facilities were inadequate, both in quantity and quality, in contrast with the generous and efficient provision made by the General Post Office in England for Fighter Command. Circuits were frequently noisy and most of the lines were laid overhead on poles, vulnerable to damage by enemy action or by sabotage.

To reinforce the sources of aircraft information a wireless intelligence screen was improvised. The screen consisted of mobile visual observation posts manned by Army observers and Royal Air Force W.T. operators, at first reporting by wireless to No. 14 Group and No. 67 Wing Operations Rooms. In order to co-ordinate and supervise the operation and administration of the various aircraft reporting units, No. 5 Signals Wing was formed and moved to France in January 1940.[1] By 21 April the first filter centre was completed and opened at Arras, receiving aircraft plots from the wireless intelligence screen and six radar stations. One mobile radar station was installed at Bar le Duc in the advanced Air Striking Force area to report to the second filter room at Rheims. As the building of this filter centre had been delayed by frost and snow the radar station plotted directly to No. 67 Wing Operations Room. Little value was obtained from it because the performance of a single station at that time was too erratic to produce a continuous track.[2]

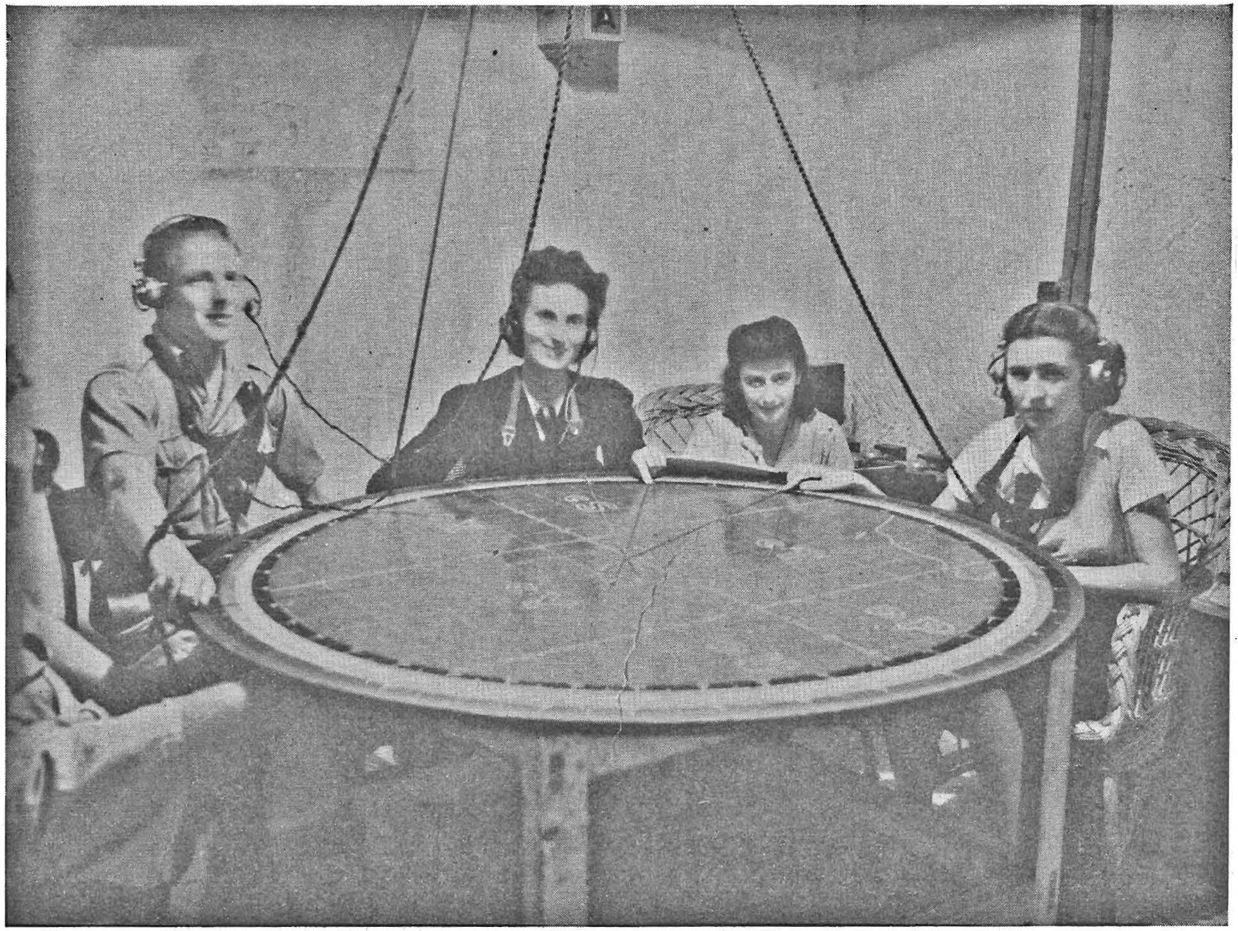
During the winter of 1939/1940, control was limited to occasional operations against single high-flying reconnaissance aircraft.[3] When the Battle of France began in May 1940, results from the fighter control system were disappointing. Apart from the visual observations from the Wireless Observer Units the information of hostile aircraft was poor and of little value. Plots of aircraft near the French coast were sometimes reported from the Fighter Command Filter Room when no information had been given by the radar screen in France.[4] Inland stations did not give satisfactory height estimations and their performance was generally poor. The French expressed their dismay at the performance of the radar sets and it seemed that until the equipment could be made to work more satisfactorily, it was impossible to rely upon its information for fighter direction. A serious disadvantage in the reporting system was the difficulty of obtaining information of movements of French aircraft, which added to the problem of identification, there being no I.F.F. apparatus or D.F. system in operation for identifying friendly aircraft. Lack of information of hostile aircraft, lack of identification of friendly aircraft, poor communications and the inexperience of controllers were all contributing to

[1] The various air movement reporting units to be co-ordinated under No. 5 Signals Wing were :—the R.D.F. screen, the Wireless Intelligence Screen, the Air Movement Liaison Unit, the Air Raid Reporting Liaison Section and the D.F. Identification Service (the latter not yet in existence). H.Q. British Air Forces in France File 4349/Org. 1, A.H.B. IIH2/178.

[2] H.Q. British Air Forces in France. File 7180/Sigs, A.H.B. IIH2/198, Encl. 17A.

[3] Air Marshal Barratt's Despatch on B.A.F.F. 15 January–18 June 1940, A.H.B. IIH2/414.

[4] H.Q. British Air Forces in France. File 7158/Sigs, A.H.B. IIH2/189.



Sector Operations Triangulator Room—Malta the failure of fighter control in France. Little record remains beyond the bare facts of the withdrawal to England in May and June of the personnel of the control organisation.[1]

Sector Control in Malta

The story of the successful air defence of Malta is well known. The air attacks began in June 1940 and continued throughout 1941 but the tempo of attack was intensified in 1942 and reached a peak in April. During that month the heavy enemy bombing affected all communications on the island. Major interruptions of main cables, remote control wires and telephone lines occurred. The signals organisation was badly strained as a result of the damage but the essential parts of it were kept going under emergency conditions. All available telephone lines were commandeered for fighter control. Wireless power supplies were dependent for a time on portable electrical charging plants and accumulators until replacements for damaged equipment were brought in by air from Egypt. During this critical period alternative communications were improvised between the fighter operations room and the aerodromes, V.H.F. R.T. aircraft sets being used in the place of telephones, with satisfactory results. The task of trying to maintain essential telephone links in the face of the weight of attack then being received was a very difficult one, many lines having to be relaid or repaired two or three times a day. Nevertheless, a complete breakdown of communications was never allowed to develop.

The fighter controlling organisation, essential in defence, was of greater value in the next phase when the number of fighter aircraft increased and a forward interception policy was inaugurated in the second half of 1942. Enemy aircraft were detected by the radar stations from the moment of take off from some of the airfields in Sicily and the repeated interception of bomber formations over the sea forced the enemy to abandon the use of heavy bombing after his losses in October 1942, and to limit his air activity to fighter sweeps.

The third phase came in the following year when the fighter control facilities of Malta were greatly enlarged to the extent that they were able to provide control for Allied aircraft during the early stage of the landing in Sicily.[2] Throughout the operations in and around Malta, the fighter operations room was unlike those in the United Kingdom in that it combined the functions of a group and sector headquarters.

Sector Control in the Mediterranean Area

The task of providing a fighter control system in the base areas of the Middle East Command during the first three years of the war was characterised by an acute shortage of signals equipment. At the outbreak of war only one radar station, and that of doubtful efficiency, was operating in the whole Middle East Command. To provide warning of the approach of hostile aircraft, chains of Wireless Observer Units, each consisting of a number of posts of three or four men with a wireless set, were stationed at intervals of ten or twenty miles along the coast of Egypt and Palestine, and across the deserts to the east and west of the Delta area.[3]

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[1] Information concerning the radar stations and No. 5 Signals Wing is given in Volume IV, Chapter 7.

[2] Volume IV, Chapter 20.

[3] Appendix No. 5. Organisation of Wireless Observer Units.

During 1940 and 1941 the number of radar stations was gradually increased to provide something approaching continuous cover at medium height along the coast from Haifa to Mersa Matruh, and round Cairo and the Suez Canal area, reinforced with low cover at the most important points. For a long time, however, the number of radar stations was too small to allow the combining of reports in filter rooms by means of range cuts in order to build up accurate tracks. The information the stations gave was therefore of little use for interception purposes and the only value extracted from it was the advance warning of an approaching raid. Local telephone lines only were available for passing plots to the fighter operations rooms, built up at Alexandria, Ismailia, and Haifa, and the more remotely sited radar stations reported their plots by wireless, in code. Such a method imposed additional delays on the reporting system, and attempts at interrogating the stations to obtain specially important data were so slow that the information was of little value by the time it arrived. At those stations where a telephone was available, periods of landline unserviceability made stand-by wireless a permanent necessity. The very important link between the operations rooms at Alexandria and Ismailia consisted of a wireless channel only because a telephone circuit could not be spared for this purpose; in consequence the eastern and western sides of Egypt were defended by two fighter forces, each to a great extent independent of the other in operations. Even wireless equipment for plotting purposes was so scarce as to be allocated on the lightest possible scale, and until the end of 1941 many aircraft information circuits worked at a disadvantage because only the lowest power type of wireless set was available.

No. 202 Group was formed with headquarters in Cairo at the end of April 1941 to control and co-ordinate the air defence of the Delta area, which was then divided into two fighter wing zones. No. 252 Wing, which was already in existence, defended the areas of Alexandria and Cairo, and No. 250 Wing was formed to defend the Suez Canal zone. A new operations and filter room was established at Ismailia for No. 250 Wing with sector operations rooms in the north and south Canal areas. A sector operations room was also established in the Alexandria area to take over the local control of fighters, such control having been carried out previously by the wing operations room. During the early period the scale of German air attack on the base areas was fortunately slight, except for night bombing and mine laying in the Canal area in the summer of 1941, and sporadic attacks on the naval base at Alexandria. The threat nevertheless was continuous, and efforts were made to use every scrap of equipment available to the best advantage.

With the loss of Greece and Crete to the Germans and the taking of Syria from the Vichy French in 1941, came the need to extend the air defence system along the eastern coast of the Mediterranean as far as the Turkish frontier, and over Cyprus. The air defence of Palestine, Syria and Cyprus was treated as one single problem, and placed under the control of Headquarters No. 263 Wing, Beirut. Sector operations rooms were constructed in Beirut and Nicosia. Some use was made of captured French wireless equipment, and with the help of radar and land-line equipment, which towards the end of 1941 began for the first time to be available in larger quantities, it was possible to provide a fighter control system on a workable, if modest, scale. Standby wireless was still essential for plotting, however, in such emergencies as the destruction of parts of the overhead telephone routes by storms, and the pilfering of considerable lengths of telephone cable by the inhabitants of the more remote parts for manufacturing beds and making other domestic equipment. In Cyprus arrangements were made to switch over the entire scanty civil trunk telephone system of the island to air defence purposes whenever a hostile aircraft was seen to approach. The manipulation of a few switches placed coastguards and other observer posts in direct communication with the fighter operations and filter rooms. Aircraft information was exchanged by wireless between the sector operations rooms at Beirut and Haifa, and Headquarters No. 25 Sector, Cyprus which controlled all the radar stations on the island. Arrangements were made to make use of the civil submarine cable between Larnaca and Haifa for aircraft reporting purposes in emergency only. Wireless communication was notoriously unreliable in the Levant as a result of the close juxtaposition of sea, high mountain and desert. Fighter defence organisations were set up in Iraq at Habbaniya and at Basra, the latter being extended after the move of British armed forces into Persia in order to cover the approach from the north to the oil refineries at Abadan and the ports at which American lease-lend equipment was disembarked and despatched to Russia. Teheran and other centres in Persia were protected similarly on a lighter scale.

During 1941 the task of aircraft reporting in Egypt and Palestine increased in complexity as a result of the reinforcements of friendly aircraft and additions to the radar stations. Filtering and aircraft movement control became more important and the lack of experienced filterers and controllers was seriously felt. In May the Air Ministry was asked to send out twenty sector controllers by the end of the month. Fighter Command was already forty-seven controllers below establishment and was faced with the prospect of the deficiency rising to one hundred with the completion of the G.C.I. programme. Nevertheless nine controllers were sent for duty at static sectors and a further four wing controllers for service in the Western Desert. A school for filter officers was opened in the Middle East and additional officers were trained locally in filtering.

During 1942 the air defence telephone system in Egypt became at least comparable in efficiency with Fighter Command standards. Demands for telephone cable, which in the earlier years of scarcity had authoritatively been deemed astronomical in quantity, had been met. V.H.F. radio equipment, also, was fitted in the same year in sector headquarters and fighter squadron aircraft, giving greater range of control and increased efficiency. The improvement in the land-line situation made it possible to reorganise the air defence system on a more centralised and economical basis. In December 1942, two fighter groups were formed under the command of Air Headquarters Egypt. Headquarters No. 219 Group was opened at Alexandria on 6 December to take over the responsibilities of No. 234 Wing (Mersa Matruh), No. 252 Wing (Alexandria) and No. 250 Wing (Ismailia), thus bringing the air defence of Egypt from the Palestinian frontier to the area of Western Desert operations under one command. The filtering organisation remained unchanged, however, with centres at Ismailia and Alexandria. In December 1942, Headquarters No. 209 Group was opened at Ramleh, moving soon afterwards to Haifa, to replace Headquarters No. 263 Wing, Beirut. The new group was generally responsible for the fighter defence of the whole area of Palestine, Syria and Cyprus, and in particular of the naval base at Beirut and the harbours and oil installations at Haifa and Tripoli. The filter rooms which existed at Ramleh and Beirut were merged into one in underground accommodation at Haifa.[1]

An important part of the responsibilities of Nos. 209 and 219 Groups was the protection of shipping within forty miles distance of the coast of the land area they defended. This role entailed accurate plotting of all surface craft within the sea area and keeping the naval authorities informed. The escort naval forces and coastal convoys placed a high degree of discretion concerning the protection of the vessels in the hands of the escort patrol leader who received, by radio telephone, information of hostile aircraft from the sector operations room and from naval vessels equipped with radar equipment. Destroyers and small ships confined their communications to information of hostile aircraft only. Cruisers and larger ships fitted with long-range radar and carrying a trained fighter direction officer might use the directive method and assume full control, directing the fighter escort's operations in accordance with naval fighter direction procedure. A similar responsibility for combining the roles of fighter defence with convoy protection devolved on groups and sectors of the North-West Africa Coastal Air Force in the Western and Central Mediterranean, and on other formations and units in other theatres of war.

After the advance of the Eighth Army from El Alamein westwards, it was as much for the protection of coastal shipping as for the air defence of Cyrenaica that No. 212 Group was re-formed on 1 December 1942, with headquarters in the Gazala area. The headquarters moved a few days later to Benina, near Benghazi, and sector operations rooms were subsequently established at Driana, Cyrene and Bu Amud. No. 212 Group thus became, with Nos. 209 and 219 Group, the third static fighter defence group under Headquarters Air Defence of Eastern Mediterranean, Cairo.[2]

A further extension of the air defence and shipping protection cover occurred in January 1943, when No. 243 Wing was transferred from the command of Air Headquarters Western Desert, to that of Air Headquarters Egypt, for employment under Headquarters No. 212 Group in the static defence of Tripolitania. Filter and sector operations rooms were established at Misurata and Tripoli.[3] On 11 February 1943 No. 243 Wing was replaced by the formation of No. 210 Group, directly responsible to Air Headquarters Egypt, a change necessitated by the need to provide a large administrative organisation for use in the forthcoming landing in Sicily.

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[1] The filter and operations room at Ramleh was built underground.

[2] A.H.Q. Egypt O.R.B. Appendix No. 6 gives Air Reporting Organisation in Libya. A.H.B. IIM/A32/2C, 2J.

[3] *See* Volume IV, Map No. 6, for scope of radar cover in central and eastern Mediterranean area.

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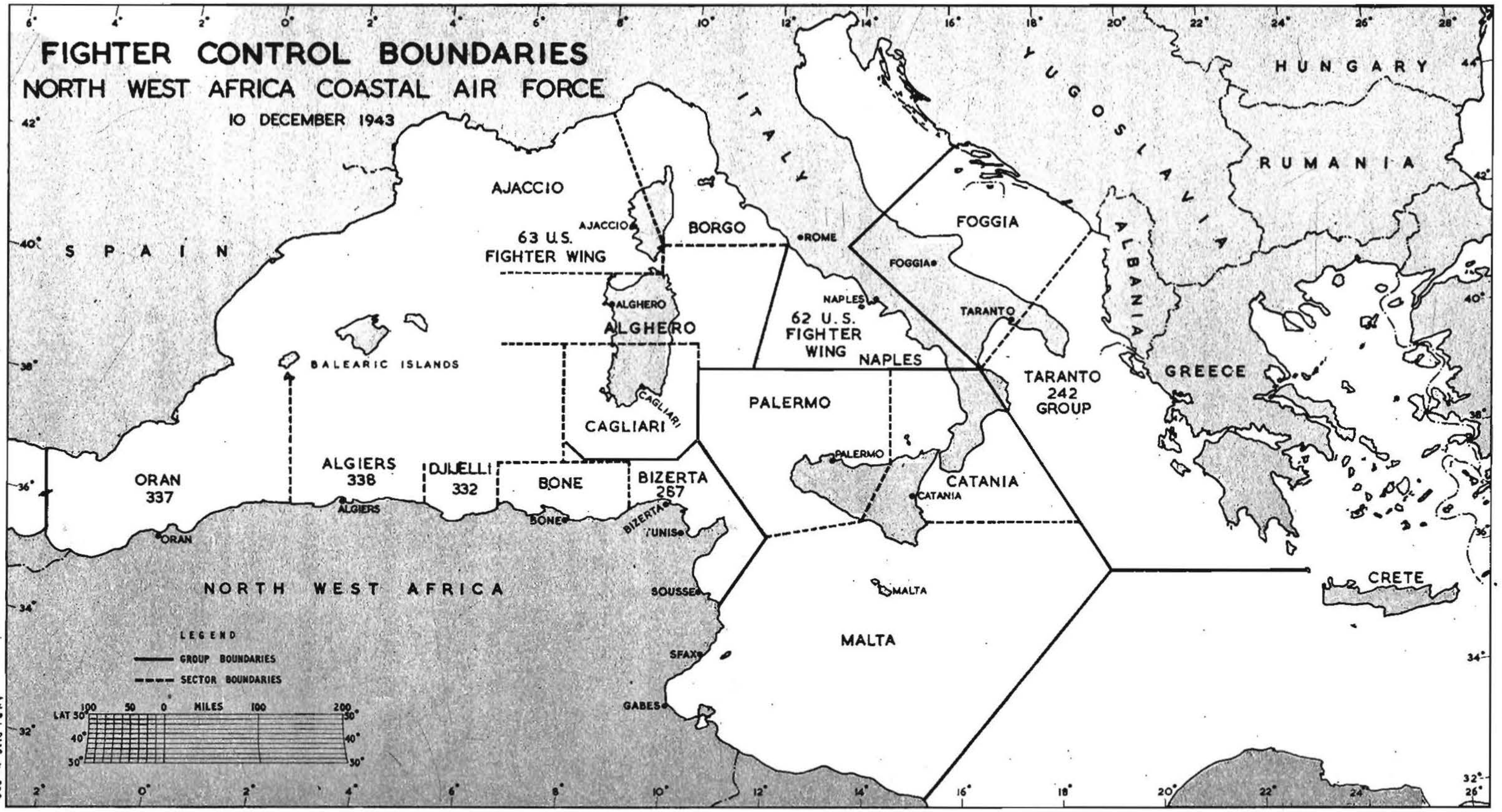

DIAGRAM 12

The setting up of the static fighter defence organisations just described, for the purpose of protecting the lines of communication and supply of the advancing Eighth Army and Desert Air Force, were projects needing much adaptability on the part of the signals units. Such equipment as could be made available on the spot from the mobile forces was used immediately in its mobile form and gradually transformed into static installations. As much use as possible was made of captured material, especially electric power plants. Deficiencies were gradually made good by supplies brought up from Egypt. Fixed equipment was thinned out from the rearward areas where the value of its operation was becoming less, and moved forward to areas where its operation would be of greater use.

Aircraft reporting links were all, except for the shortest, composed of wireless circuits initially, as were the long lateral links between sector and group headquarters. Consideration of the distances involved shows the impossibility of considering the laying of telephone lines quickly for these purposes. Duplex wireless channels, which may be described as pairs of single channels used for plotting one in each direction simultaneously, were used between sector operations rooms when the volume of plotting required it. The transmitting operator was connected by telephone to the filter teller and the receiving operator to the operations room plotter.[1] Economy in men and equipment was obtained by siting sectors and headquarters, where possible, in conjunction with the local signals centre. This provided a single static communications centre to serve the administrative and operational needs of all Royal Air Force units in the area.

Fighter Control in South East Asia

The first air attacks to be made on the base areas of South East Asia were made on Colombo and Trincomalee on Easter Day, 5 April 1942, and on 9 April 1942 respectively by strong forces of Japanese carrier borne aircraft. The radar organisation failed to detect the raid on Colombo, with the result that no warning was given until the raiders were sighted.[2] The raid was not unexpected, however, because reconnaissance aircraft had previously sighted the Japanese force, and Hurricane pilots were already in their cockpits. But although there was no delay in 'scrambling' the fighters, the advantages of early warning in time to gain height and controlled interception had been lost. By contrast, the first radar plots of the raid on Trincomalee were obtained at 91 miles range and a positive track was established by the time the raiders were between 35 and 40 miles away. The strength of the Japanese raids appears to have been similar on both occasions and a numerical comparison between the losses inflicted is interesting.

[1] Appendix No. 7: Air Headquarters, Egypt Signals Instruction on the Air Defence of Tripolitania. A.H.B. II J1/105/18.

[2] The technical equipment A.M.E.S. No. 254 (M.R.U.) reached Colombo from Great Britain on 23 March 1942 and was working by the evening of 25 March. The plotting line was serviceable two days later. The failure to detect the raid on 5 April was attributable in part to the very troublesome permanent echoes and to gaps subsequently discovered in the vertical polar diagram of the station. Another contributory cause of the failure was an unequally divided watch-keeping roster resulting in operators continuing on watch with diminished alertness. A.M.E.S. No. 272 was installed at Trincomalee. The R.D.F. personnel of both stations arrived on 18 March 1942. (No. 222 Group O.R.B., A.H.B. IIM/B.222/IA.)

Raid on Colombo, 5 April 1942

British fighters.			Japanese aircraft.	
	Airborne.	*Losses.*	*Assessed Losses.*	
Hurricanes	36	15	Destroyed	19
Fulmars	6	4	Probables	7
	—	—	Damaged	9
	42	19	By A.A. guns ..	5

Raid on Trincomalee, 9 April 1942

British fighters.				Japanese aircraft.	
	Airborne.	*Losses.*	*Damaged.*	*Assessed Losses.*	
Hurricanes ..	17	8	2	Destroyed	15
Fulmars ..	6	3	—	Probables	17
	—	—	—	Damaged	5
	23	11	2	By A.A. guns ..	9

The figures quoted admittedly cannot take into account all the relevant factors, as, for example, the excellent cloud cover available at Colombo, of which full advantage was taken by the Japanese. Considering the much smaller number of fighters available at Trincomalee, however, the figures give a good indication of the advantage which accrues from radar warning and a system of fighter control.[1]

At the time of the raids no filter room had yet been established in Ceylon and the two radar stations reported direct to the temporary Fighter Operations Room at Colombo and the Gun Operations Room at Trincomalee respectively. Filter rooms were opened at Trincomalee on 27 April 1942 and at Colombo on 1 June. Telephone lines were used for telling by radar stations, but inter-filter room telling was done by wireless. Information was supplemented by a number of Wireless Observer Units.[2] By the end of 1942 filter rooms had also been established at Calcutta, Imphal, Comilla, Bombay and Madras. During the month of December 1942 the Japanese raided Calcutta successfully on five occasions by night with the loss of only one aircraft. As a result of the raids and of enemy radio propaganda, refugees began to leave the city in thousands. To stiffen the night fighter defence which up to that time was composed only of Hurricane aircraft, four A.I.-equipped Beaufighters of No. 176 Squadron were flown from Egypt, arriving on 14 January 1943. Two nights later one Beaufighter intercepted a formation of three Japanese bombers before they reached the city and shot them all down in the space of a few minutes. Four nights later, on 20/21 January, a Japanese formation of four aircraft attempted to bomb the city. At least two and probably three of these were shot down by a Beaufighter and the raid achieved neither damage nor casualties.[3] During the first approach one engine of the Beaufighter was set on fire by defensive fire from the Japanese aircraft, but the crew carried on to inflict the losses described before being compelled to descend by parachute,

[1] No. 222 Group O.R.B., Encls. A and B. A.H.B. IIM/B222/1A. [2] *Ibid.*, Encl. D.

[3] A.V.M. Williams' Despatch on Bengal Command, A.H.Q. Bengal O.R.B., A.H.B. IIM/A42/1a, Appendix D, August 1943.

which they did safely. As a result of these decisive successes, not only did the returning confidence of the civil population prevent a mass exodus from the city, but the Japanese made no further attempts to bomb targets west of the Brahmaputra River for nearly a year.

The installation of the air defence organisation in India continued in 1943 on the principles evolved earlier in the United Kingdom. An outstanding feature of the organisation was the remarkable speed with which it was formed, considering the difficulties of transport and shortage of experienced personnel. A warning system consisting of chains of observer posts had been built up before the War by the Indian Government. Its communications depended at first upon the civil telephone system, but this proved too slow in operation to be of practical value. Observer posts equipped with wireless sets were introduced to overcome the slowness of communication. The Royal Air Force personnel who operated the wireless sets were found to suffer from a high rate of sickness, living as they were in isolated locations out of ordinary reach of the administrative services. They were therefore replaced later by Indian Air Force personnel as soon as a sufficient number could be trained as wireless operators and observers. These men proved to be less vulnerable to the climatic conditions and provided an efficient service.

Radar stations within reasonable distance of filter rooms were connected by telephone as soon as lines could be laid by detachments of Air Formation Signals personnel. Wireless remained a necessary standby, however, to provide for the inevitable and frequent periods of interruption which occurred during and immediately after the monsoon seasons.[1] V.H.F. radio equipment replaced the H.F. radio equipment during the latter part of 1942 and 1943. An idea of some of the local conditions under which the air defence system in India was built up can be gained from extracts from a letter written by the officer in charge of the delivery of V.H.F. radio equipment from Bangalore to the Vizagapatam Sector during November 1943.[2]

That the weight of air attack on India did not develop into something heavier was due in no small degree to the effectiveness of the fighter organisation. In more than one locality the installation was completed only a few days in advance of the first operational success. After a period of reduced activity during the monsoon of 1943 the Japanese made several reconnaissances by flying boats. On 4 October a Dinah aircraft was, rather surprisingly in view of its superior speed, intercepted by Hurricanes over Calcutta and claimed as probably destroyed. A flying boat was intercepted by a Beaufighter under G.C.I. control over Ceylon and shot down in flames into the sea off Trincomalee on the night of 11/12 October. Exactly a month later a four-engine flying boat attempting to raid Madras was intercepted fifteen miles off shore at 18,000 feet by a Beaufighter of No. 89 Squadron under G.C.I. control. In the ensuing combat the flying-boat was damaged and was seen just over an hour later by the tanker Saidja, 'flying at 400 feet, heading east, losing height, with

[1] In his Despatch on Air Operations in Bengal, 21 June–15 November 1943, the Air Officer Commanding wrote, 'The behaviour of all ranks of R.D.F. and W.O.U. is beyond praise for the magnificent manner they have carried on their duties during the monsoon. . . . Many posts were completely isolated for long periods and had to be supplied by air.'

[2] A.H.B. Narrative, Far East, Volume III (India Command). *See* Appendix No. 8.

engines working irregularly.' It was later deemed probably destroyed.[1] On 5 December 1943 the Japanese again raided Calcutta, the bombers being detected by radar as far away as over Akyab. Interceptions were made over the sea by Hurricanes and Beaufighters, and although the defence was handicapped by lack of the faster Spitfire, it is noteworthy that on that occasion the Indian population showed no tendency to leave the city as a result of the raid.[2]

The importance of good telephone communication in an air defence system has already been stressed. The provision of landlines for the Royal Air Force in oversea theatres was a responsibility of Army Signals, and the necessary construction and maintenance work was done by Air Formation Signals which were attached to the Royal Air Force for that purpose. It would be unfitting to conclude this chapter without mentioning these units which played a most important part in the creation of air defence organisation overseas.

[1] No. 225 Group O.R.B.

[2] A.H.Q. Bengal O.R.B., A.H.B. IIM/A42/A-C.

Part II

RADAR IDENTIFICATION

PART II

Introduction

The need to distinguish friend from foe has always been a pre-requisite in any military encounter. In the early days of air warfare a knowledge of aircraft silhouettes and markings sufficed, supplemented by pre-arranged signalling with such means as Verey lights. Such procedures were termed recognition, and their use has persisted. Long range identification became necessary with the organisation of an observer system for use in air defence. When it was shown that radar could detect the approach of an aircraft at long range, the need arose for means to discover at once whether it was hostile in order that the advantage of economy in flying hours gained by early warning should not be frittered away by chasing unidentified friendly aircraft. The means of identification provided by radar had many shortcomings. It showed that certain aircraft were friendly and left the operations controller to make the doubtful assumption that all others were hostile. But whatever the deficiencies of the system, it was of great value in defence and particularly in night interception. Its limitations became clear during the later stages of the war when large numbers of friendly aircraft dominated the situation.

CHAPTER 5

EARLY DEVELOPMENT AND I.F.F. MARK I

Between the years 1937 and 1939 the method of long-range identification employed by the Royal Air Force was a radio transmission from friendly aircraft received simultaneously at two or three geographically well-separated, ground wireless direction-finding stations. Each D.F. station obtained a bearing on the aircraft transmission and passed it to the control station, where the bearings were quickly plotted, and their point of intersection indicated the location of the aircraft at the instant it made its transmission. The location or fix was passed to Fighter Command Operations Room and plotted on a gridded map as the position of a friendly aircraft.[1]

In many cases the knowledge of the position of friendly aircraft was supplemented by information from Air Movements Liaison Officers who had full knowledge of the intended movements of aircraft of Bomber, Coastal and Fighter Command. Aircraft employed on long-range flights, such as bomber and coastal reconnaissance aircraft, were given lanes of approach along which to fly on their return towards the coast of England, but they were often so far off course that movements liaison information had little value. The fixing transmissions of these aircraft for identification purposes were therefore important.

The method of transmission and the radio frequency on which it occurred varied with the type of aircraft. Returning bomber and coastal aircraft made their fixing transmissions on the medium frequency band, the aircraft wireless operator giving a short manual W.T. transmission when approximately 100 miles from the coast. In Fighter Command aircraft, the pilot was too fully occupied to keep making special manual transmissions for fixes. An arrangement known as 'Pipsqueak' was therefore developed to transmit automatically on high frequency.[2]

On 5 August 1938, the annual Royal Air Force Home Defence Exercise began, planned primarily to test the efficiency of the air defences. For the first time there existed a chain of radar ground stations, five in all, to give warning of incoming hostile raids. The organisation for the identification of friendly bombers by medium frequency D.F. was also tested.[3] The exercise opened in very bad weather, continuous thunderstorms producing excessive atmospherics, so that the D.F. stations had great difficulty in receiving signals. During the whole of the first twenty-four hours only one aircraft was heard. Later in the Exercise, when the duration of aircraft transmissions was doubled, fixes were passed to Headquarters, Fighter Command, well within one minute of the aircraft transmitting, but there was a considerable delay, amounting in some cases to ten minutes, in getting the information to the Bomber Movements Liaison Officer. This was because the Bomber Liaison Section required the grid reference positions converted to latitude and longitude.

[1] A.M. File S.40818/I, Encl. 25A.

[2] *See* Chapter 1 of this volume.

[3] A.M. File S.40818/I, Encl. 25A.

The partial failure of the medium frequency D.F. identification system in this Exercise was referred to by the Air Officer Commanding-in-Chief, Fighter Command, at a conference at Fighter Command Headquarters, Stanmore, on 11 October 1938. He stressed the urgent necessity for some successful method of identifying returning aircraft, and stated that the most suitable device was one which would indicate directly on the cathode ray tube at the radar ground stations.[1] Radar was relatively free from the influence of heavy atmospherics which interfered with the D.F. system. Although the D.F. fixing systems, on medium frequency for Bomber and Coastal Command aircraft and high frequency for the Fighter 'pipsqueak' system, continued to be developed and were subsequently employed to good effect during the war, attention was focused in 1938 on the development of a system of identification of friendly aircraft at the radar ground stations.

Principles of Radar Identification

Three years earlier, in his first memorandum on radar to the Committee for Scientific Survey of Air Defence, Mr. Robert Watson Watt had suggested on 27 February 1935, that the problem of the interception of enemy bombers by British fighter aircraft would involve some method of identifying the fighters on the cathode ray tube.[2] He suggested that the interval between detection and engagement might best be reduced to a minimum by having interceptor aircraft fitted with a resonating keyed array so that whilst being readily located by the same methods as those used for enemy bombers, they could also be discriminated and identified by intermissions in their 'reflected' field.

An aerial resonating at wavelengths of about 50 metres which was then envisaged for the radar Home Chain would have to be long and awkward, and detrimental to the aircraft's performance. An alternative method, which obviated the necessity of the bulky aerial system, was elaborated by Mr. Watson Watt on 15 September 1936,[3] and was essentially the same as that subsequently developed and known as I.F.F. (Identification Friend or Foe).

The principle to be employed was as follows. All friendly aircraft were to be equipped with a radar transmitter-receiver, a type of equipment which became known as a transponder. The pulse transmissions from the ground radar stations would be picked up by the receiver portion of the transponder when they would trigger the transmitter portion. The radio pulse thus transmitted to the ground from an aircraft with a transponder would have a much greater amplitude than that of the radar echo normally reflected from the structure of the aircraft. Hence, an aircraft fitted with a transponder could be recognised as different from one which was not fitted and could thus be assumed to be friendly.

The problem was not quite as simple as this brief description suggests. A transponder or I.F.F. set could produce its identifying signal at the ground station only if both were operating on the same radio frequency. The Home Chain radar ground stations worked on different wavelengths in order not to

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[1] A.M. File S.40818/I, Encl. 36A.

[2] This memorandum is given in full at Appendix No. 1 of Volume IV.

[3] Patent Specification No. 25133/36 dated 15 September 1936.

interfere with each other and thus any one I.F.F. set would provide identification only at the ground station to which it was tuned. But it was required that any one aircraft set should be able to identify itself at every radar ground station. The task of arranging for the identification signal to be given on more than one wavelength was, however, simplified by the fact that the early radar ground stations worked on a group of wavelengths which were all in the same small waveband. The method adopted may be appreciated from everyday experience: if the tuning-knob of a broadcast radio receiver is turned slowly through its full range, all the broadcasting stations on the wave-band are received in turn. Similarly, the I.F.F. set was arranged to have its receiver tuned-circuit varied automatically and continuously by an electric motor, sweeping up and down the band of wavelengths used by the ground radar stations, and each station was tuned-in in turn. The aircraft transponder then received radio pulses from any one ground station and automatically replied only for the short interval of time during which it was tuned to that ground station's wavelength.

An aircraft transponder thus produced at each ground radar station an identifying signal which had two distinguishing characteristics :—

(*a*) Its maximum amplitude was much greater than that of the normal aircraft echo or blip seen on the cathode ray tube.

(*b*) It appeared and disappeared at regular intervals of time.

The rate of sweep of the transponder could be varied by changing the speed of the electric motor, so the rate at which the identifying signal appeared at the ground station could also be changed. By arranging for a different rate of sweep to be used from day to day, an elementary form of coding could be brought into the signal. Coding offered decided operational advantages, firstly because it would give a method of discrimination in the event of the enemy discovering and imitating the system. Secondly, radar stations would be able to distinguish between friendly aircraft engaged in different operational activities if special codings were given to bomber, fighter, and other types.

For technical reasons, variation of the sweep rate was an unsatisfactory method of coding, and a better method was to be had by varying the width of the pulses. When this was done the identifying blip seen by the radar ground station observer was not only longer than the normal echo but also wider. By providing three readily distinguishable widths and by arranging that alternate pulses could, when required, have different widths, a number of codes were developed.

Development of I.F.F. Mark I

Although research work on radar had begun at Orfordness[1] during May 1935 and had been continued at the Bawdsey Research Station from 1936 onwards, the urgency of the need for developing radar ground stations and the lack of sufficient scientific staff precluded the undertaking of any research on a radar identification system until late in 1937. From that time until the autumn of 1938, a long series of experiments was made on the original suggestion of a keyed aerial system. The results obtained, though lacking in consistency,

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[1] *See* Volume IV, Chapter 1.

were encouraging from the point of view of a radio technician, but the extensive aerial system required to resonate at the frequency of a ground radar station was viewed with disfavour as being detrimental to the performance of the aircraft. In spite of this drawback, the Air Officer Commanding-in-Chief, Fighter Command, was impressed with the necessity to achieve some radar method of identifying aircraft. As a result of the experience gained in the Home Defence Exercise of 1938, which had demonstrated the weakness of the M.F. D.F. identification system, he reported to this effect and was responsible for stimulating Air Ministry interest in identification experiments.[1]

In September 1938, work on the original project of the keyed aerial was abandoned in favour of the more positive method of employing a sweeping receiver and transmitter. Incorporated in the equipment was a quiescent oscillator valve circuit which improved the reliability of working.[2] The extraneous aerial system gave place to the use of part of the aircraft structure (initially the main-plane, and later the tail-plane). Experimental work proceeded at the Bawdsey Research Station along these lines for the remainder of the year, and eventually the apparatus was made to work satisfactorily. Improvements were made during January and February 1939, and the equipment, involving no outside aerials or structure, was installed in a Harrow aircraft.[3] It produced a rhythmic amplification of the radiated pulses at the radar ground station and thus made it possible to distinguish a friendly aircraft. At a range of five miles from the ground station the ratio of amplitude distinguishing the transponder signal from the ordinary echo was not more than 2 to 1, but very large ratios were obtained at long range, so there was no difficulty in identifying friendly formations in which only one aircraft was fitted with the I.F.F. equipment. Indeed, a friendly aircraft could be identified at probably twice the range possible with a normal echo because an identification blip of 3 centimetres length was obtained when a normally produced echo was not visible at all.

By 6 March 1939, sufficient progress had been made for the equipment to be demonstrated to the Air Officer Commanding-in-Chief, Fighter Command, at Bawdsey.[4] So very much impressed was he with this ' outstanding exhibit ' that as a consequence of his representations to the Air Ministry the highest priority was accorded to the further development of the equipment to make it quickly available to the Service. Work on the I.F.F. set at Bawdsey continued, so that when he again visited the Research Station on 8 May 1939, the apparatus, though the same in principle, was quite different electrically. It then weighed only 10 lb. and had overall dimensions of 6 by 9 by 15 inches. Air tests had been made with I.F.F. in Anson, Blenheim, Wellington, Hampden and Whitley aircraft.[5] The major need was for an early full-scale operational trial. Conscious of this, and afraid of inordinate delays in the normal channels of

[1] A.M. File S.40818/I, Encl. 25A.

[2] The valve behaved as a quiescent oscillator—that is, it was normally just not oscillating, but on the arrival at the aircraft of a radio pulse from the ground radar station, the valve was forced into oscillation for the duration of the pulse. A magnified pulse was therefore radiated from the aircraft and returned to the ground station where it was observed as friendly. Originally the device consisted of a simple oscillator, but in December 1938, a quench oscillator was added to increase the sensitivity.

[3] A.M. File S.46286, Encl. 11A.

[4] A.M. File S.47404, Encl. 6A.

[5] A.M. File S.46286, Encl. 17B.

specification, production, distribution and installation, the Air Officer Commanding-in-Chief urgently requested that 30 sets of the equipment should be hand-manufactured and fitted to a proportion of the 'friendly' aircraft to be employed in the Home Defence Exercise due to start in August 1939.[1]

The Home Defence Exercise—August 1939

The May 1939 version of the I.F.F. device, which had been modified to give one of three characteristic identification signals to provide coding facilities, became the prototype of the transponder which later came into service as I.F.F. Mark I.[2] Arrangements were made with the firm of Ferranti of Manchester to copy the Bawdsey Research Station model and to produce 30 hand-made sets. The first set was supplied by Ferranti, tested and found satisfactory at Bawdsey, by 20 June 1939, and delivery of the complete order was made by 30 June. Meanwhile, three fitting parties, each under the supervision of a scientist from the Bawdsey Research Station, had been busily engaged in wiring some 90 aircraft to take the equipments so that the I.F.F. sets would not be idle because of unserviceability of particular aircraft. The wiring was completed by 20 July 1939. However, on being tested, some of the I.F.F. sets failed to work correctly and only a limited number were available for the Exercise.[3] The remainder of the sets required minor modifications.

The performance of I.F.F. (RX2900) in the Exercise of August 1939 was not altogether satisfactory. Certain condensers failed because the voltage of the aircraft electrical supply was not well regulated and rose beyond the limits previously applied in the bench tests. Moreover, the operators at some radar stations failed to report I.F.F. signals correctly. They were in fact similar to effects caused by aircraft flying in formation and also by ill-adjusted ground transmitters of the M.B. type, and lack of experience led not inexcusably to confusion between the three.[4] The merits of the I.F.F. system of identification of friendly aircraft were nevertheless apparent. The Air Officer Commanding-in-Chief, Fighter Command was satisfied that the system could be perfected, and he recommended that preparations should be made at once for large-scale production.[5]

Production and Fitting of I.F.F. Mark I

The question of provision had in fact already been discussed by the Inter-Services R.D.F. Committee in June 1939 and preliminary estimates of requirements had been made.[6] After Air Chief Marshal Sir Hugh Dowding's report, the Committee decided that the total estimate of I.F.F. Mark I requirements should be related to the total aircraft production rates. Treasury approval was obtained and orders placed during October 1939 with Ferranti for 1,000 sets of the type which had been tested during the August Exercises.[7] The mass production of these was to be completed as soon as possible.[8] The first 100 I.F.F. Mark I sets were to be available early in November. At the

[1] A.M. File S.47404, Encl. 15A.
[2] A.M. File S.52197, Encl. 4A.
[3] A.M. File S.1270, Encls. 4A, 6A and 16A.
[4] A.M. File S.52197, Encls. 33A, 35A.
[5] A.M. File S.1659, Encl. 10A.
[6] Inter-Services R.D.F. Committee, 3rd Meeting on 13 June 1939, Min. 29.
[7] The mass-produced sets were given the Royal Air Force numbers :—R.3000 working on 12 volts, R.3001 working on 24 volts.
[8] A.M. File S.52197, Encl. 37A.

same time an order was placed for 2,000 sets of a type still under development[1] which would also give a response to the G.L.[2] ground radar equipment, and the contractors were requested to provide the materials for a further 10,000 equipments for future production. The magnitude of the identification programme was just beginning to demonstrate itself.

As the result of experience gained in operating the Home Chain ground radar stations during the early days of the war, Headquarters, Fighter Command, in October 1939, proposed that initial priority for fitting I.F.F. Mark I should be given to certain aircraft of Coastal Command and to Bomber Command aircraft operating from the United Kingdom. After these, fighter aircraft and aircraft of the Fleet Air Arm were to be fitted, and certain French aircraft operating in the English Channel, North Sea and Bay of Biscay. The order of fitting British army co-operation and bomber aircraft of the Field Force and Advanced Air Striking Force in France was dependent on how quickly the mobile ground radar stations were provided in France.

Fitting commenced during the first week of December 1939 at No. 32 Maintenance Unit, St. Athan.[3] By the second week of December, bombers were being fitted at the rate of 5 per day, increasing to 20 per day by the end of the month. There was a temporary delay in the fitting of Coastal Command Hudson aircraft because they had a 24-volt electrical system and only 12-volt I.F.F. Mark I sets were coming off production.[4] At the end of December some 24-volt sets were produced by modification of the 12-volt equipment.

Emergency destruction facilities

The success of the radar system of identification depended on only friendly aircraft being fitted with the I.F.F. set. If the secret of this apparatus were to fall into enemy hands the whole I.F.F. system would be in jeopardy. It was therefore imperative that no I.F.F. set should remain intact in any aircraft which crashed or made a forced landing in enemy territory. At the first meeting of the Committee for the Scientific Survey of Air Warfare on 27 September 1939, it was recommended that experiments should be made to evolve a device enabling the I.F.F. apparatus in aircraft to be destroyed, both automatically and manually, in the event of an aircraft descending in enemy territory.[5] Experiments were made at the Royal Aircraft Establishment and at Woolwich Arsenal on the destruction of the vital parts of the I.F.F. set by electric detonators and by a thermite destruction unit.

After comparison of the two methods on which research had been carried out, a representative of the Director of Communications Development considered that the damage caused by two electrical detonators was sufficient.[6] By blanking off vent-holes in the base-plate of the set and fitting a steel protecting band round it, adequate protection was afforded to both the personnel

[1] The development type is dealt with fully in the next chapter.

[2] G.L. ground radar equipment was being introduced into Army A.A. Units. The G.L. set was for gun-laying purposes, employing radar to obtain the range, bearing and elevation of an aircraft.

[3] A.M. Files S.52197, Encl. 62A, and S.2004, Encl. 14D. Prototype installations were made for the following aircraft :—

Whitley, Blenheim (Fighter), Anson, Wellington, Blenheim (Bomber), Swordfish, Hampden, Hudson, Skua.

[4] A.M. File S.1270, Min. 32.

[5] R.A.E. File Arm S.548 WDB/64.

[6] A.M. File S.1270, Encl. 48A.

and the aircraft from fragments penetrating the case of the I.F.F. set. The explosion took place close to two feed-back condensers and quench coils; destruction of these obscured the super-regenerative nature of the set so that its transponder action could not be recognised. Provision was made for the deliberate destruction of the I.F.F. set by the pilot operating a switch if he anticipated a landing in enemy territory. Since however it might be necessary for the aircrew to bale out, an automatic deceleration-operated switch, capable of destroying the set if the retardation of the aircraft exceeded any chosen figure, was also fitted.[1] Thus every contingency was allowed for and there was in theory no reason why the equipment should ever fall intact into enemy hands.

Servicing of I.F.F. Equipment

A very high degree of secrecy had been maintained in regard to I.F.F. equipment. As a result, only the Signals Officer on an airfield had any knowledge of its technical details; Signals tradesmen had not been trained in its adjustment and servicing. In January 1940 it was decided to form a new trade of Wireless Electrical Mechanic (R.D.F.) for the purpose of servicing the equipment, and the establishment of each squadron fitted with I.F.F. was increased by 1 W.E.M. (R.D.F.).[2] For ground testing at an airfield it was necessary to have a signal generator (or small pulse transmitter) which would radiate pulsed signals to be received by the I.F.F. set, thus triggering the transmitter portion. A test receiver was also designed to enable the ground mechanic to check that the I.F.F. set was actually transmitting. The Air Ministry Research Establishment had investigated the best method of providing test signals generators and receivers during October 1939, and these were manufactured during November and December.[3]

The method of operation of the test equipment was as follows. The small pulse transmitter was placed on the tail-plane of the aircraft near the tapping point of the I.F.F. aerial lead-in, and the receiver portion then adjusted so that it ceased sweeping through the C.H. waveband and operated continuously on a chosen frequency. The test receiver (or field strength measuring set) was taken some 25 yards from the tail-plane behind the aircraft and tuned to receive the signals. Adjustments were then made to the I.F.F. set until maximum output was obtained. Daily ground testing consisted of plugging wireless headphones into a socket in the I.F.F. control panel, and adjusting until the meters were reading satisfactorily and until the whistling sound heard became just inaudible.[4]

Operational Use of I.F.F. Mark I

The introduction of I.F.F. Mark I into the Royal Air Force was a gradual process, chiefly because there was a shortage of skilled radar mechanics for the fitting parties which started work at St. Athan at the beginning of December 1939. By the end of February 1940 the aircraft fitted were :—

Coastal Command	..	16 Hudsons, 1 Sunderland,
Bomber Command	..	226 aircraft of various bomber types,
Fighter Command	..	13 Blenheims, 1 Hurricane, 1 Spitfire,

making a total of 258 aircraft altogether. The installation in the single-seater

[1] A Graviner impact trip-switch.

[2] A.M. File S.1270, Encls. 58A–61A.

[3] A.M. File S.52197, Encl. 37A.

[4] A.M. File S.1270, Encl. 48A.

fighter aircraft was not working well, giving a range of some 30 miles only. No adjustments were possible to the I.F.F. set while the fighter aircraft was in flight, whereas in the larger aircraft the wireless operator was able to check the I.F.F. control panel meter-readings and make any necessary readjustments occasioned by the varying state of the aircraft accumulators. The responsibility for checking I.F.F. lay on the radar personnel, but the captain of the aircraft was to ensure that the self-destruction detonator cartridge was in place before take-off. The captain was also to give orders that I.F.F. was switched on when the aircraft was approximately 100 miles from the British coast on the return flight of an operation.[1]

The coding system available with I.F.F. Mark I was introduced in January 1940. Three codes, B, C and D were available, based on the width of the I.F.F. response seen on the cathode ray tube of the radar ground stations. D was a combination of B and C. The instructions stated that I.F.F. was to be brought into use by any unit which had full equipment; Bomber Command aircraft to use code B, Coastal Command code C, and Fighter Command code D.[2]

The operation of I.F.F. Mark I was not as good as was expected. Although the sets were monitored correctly and appeared to work satisfactorily when checked both aurally and visually during flights, it was found on many occasions that the I.F.F. pulses had not been observed by the Home Chain radar stations. Operational records for the last two weeks of February 1940 indicated about 50 per cent. identifications at the ground stations:—[3]

Command.	Flights.	Radar Tracks.	I.F.F. Observed.
Bomber	80	63	31
Coastal	46	21	8
Fighter	10	10	9

The partial failure of the I.F.F. Mark I system could not be accounted for by any single reason. It was a combination of faulty pre-flight setting up of the equipment, the failure of some captains of aircraft to switch on the set, and above all the failure to recognise the I.F.F. signal at some ground radar stations where the operators were unaccustomed to its appearance. The short duration of the response probably contributed.

The fact that the production programme for the I.F.F. Mark I set was limited to 1,000 equipments was not due, however, to lack of success during the first two months of operation, but to the appearance of more ground radar stations working on new wave-bands. I.F.F. Mark I had been designed to respond on the wave-band of C.H. stations only, on frequencies between 22·20 and 27·65 megacycles per second. By the time it came into service, G.L. radar sets were also in use. There were, in addition, firm proposals to set up other early-warning radar stations (A.C.H.) on another wave-band, for which identification would also be needed. I.F.F. Mark I did not respond to either G.L. or A.C.H. radar stations and was therefore inadequate to fulfil its purpose in entirety. The weakness had been recognised, however, even before the first set was produced. The small-scale production was intended as an interim measure only, to fill the gap until a more effective set could be developed and manufactured.

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[1] A.M. File S.1270, Encls. 50A, 73A, 100A and 101A.

[2] These instructions were given in an Air Ministry Secret Publication, S.D.164, issued through commands to all units concerned.

[3] A.M. File S.52197, Encl. 166A.

CHAPTER 6

I.F.F. MARK II

The development of an I.F.F. set which would respond to all three types of radar ground stations then envisaged, C.H., G.L. and A.C.H., was started at Bawdsey Research Station in the spring of 1939.[1] The principle employed in the new set was the same as that of the original Mark I equipment, but arrangements were made to switch the transponder automatically from one wave-band to the next so that identification signals would be obtained at any of the radar ground stations.[2] The development of this new aircraft equipment, I.F.F. Mark II, was continued jointly by the Telecommunications Research Establishment, the Royal Aircraft Establishment and the manufacturers, Ferranti, throughout the remainder of 1939.

Even though Ferranti's production line was already running, opinion was by no means unanimous in March 1940 that I.F.F. Mark II was ideal for its purpose of radar identification. It was pointed out at a conference at the Royal Aircraft Establishment on 6 March that the efficiency achieved by I.F.F. Mark I was less than 50 per cent., and that its failure operationally could not be definitely attributed either to the apparatus or to personnel, but might be bound up with the short duration of the I.F.F. signal appearing at the ground radar station.[3] When it was revealed that the duration of the I.F.F. response was to be fractionally shorter in the Mark II equipment, the conference doubted whether the new apparatus would be satisfactory and suggested modifications to increase the signal duration. The meeting was warned that any modification of Mark II equipment at that time would entail three months delay at the contractors. Nevertheless a signal was sent to the Assistant Chief of Air Staff (Radio) recommending immediate airborne trials of I.F.F. Mark II.

Acceptance tests were held between 11 and 16 March 1940 with sets fitted in Wellington, Whitley, Hampden, Blenheim and Hudson aircraft. A report on the tests was submitted to the Air Ministry by Headquarters, Fighter Command.[4] Although enquiries amongst the radar ground station operators revealed that there was a feeling that the I.F.F. pulse duration of 1/10th second was too short, the consensus of opinion was that the responses were unmistakable and easily seen under normal operating conditions.[5] The greatest difficulty appeared to be in recognising the 'narrow' I.F.F. pulse amongst interference, where a response of longer duration would have been an advantage.[6] The I.F.F.

[1] Bawdsey Research Station File 4/4, Encl. 449A dated 16 June 1939.

[2] The three frequency bands to be covered by the new set were :—
83–56 Mc/s—the A.A. No. 1 or G.L. frequency band
51–39 Mc/s—the A.C.H. frequency band
30–22 Mc/s—the C.H. Station frequency band.
The original frequency coverage of the I.F.F., Mark I, set had been 27·65–22·2 Mc/s.

[3] A.M. File S.1270, Encl. 112B.

[4] A.M. File S.4084, Encl. 4A.

[5] A.M. File S.1270, Encl. 99A.

[6] A.M. File S.4084, Encl. 3A.

responses received at the G.L. radar posts of Anti-Aircraft Command were a decided advantage to the gunners, and the filter room at Fighter Command was satisfied with the results obtained at Home Chain stations. Headquarters, Fighter Command therefore recommended that a sufficient number of sets of I.F.F. Mark II should be produced and installed to meet all immediate requirements.

Even at that stage, in March 1940, before the general introduction of I.F.F. Mark II into Service use, the limitations of the equipment were apparent. C.H.L. stations to counter low-flying raiders and A.I. for night-fighter aircraft were both being rushed into production, and I.F.F. Mark II did not respond to their frequency-bands. The Mark II equipment, though in large-scale production, could therefore only be regarded as an interim set. A Mark III was already envisaged, giving a pulse of longer duration and covering all ground station frequencies, and even a Mark IV equipment was recommended for design, with the same performance as Mark III but covering also the wave-band 5–20 centimetres to be employed by airborne search equipment.

The time-lag between the beginning of design and the large-scale introduction into use of Service equipment was generally so great, that to wait for an ideal I.F.F. set was not a practical policy. Fitting of Mark II into aircraft therefore proceeded.[1] The Aircraft Equipment Committee at its 113th meeting on 11 March approved the introduction of I.F.F. Mark II in all aircraft, other than elementary trainers, of Home commands and of the air forces with the British Expeditionary Force in France. Although the first models of I.F.F. Mark II were promised for 30 March 1940, it was not until 14 May that the first 50 hand-made sets were completed, and even then they were still at the manufacturers awaiting certain valves.[2] Not only were the valves not available; a hold-up in mass-production was occurring because a certain plug was cancelled in one contract and then omitted from embodiment loan contracts. Fitting of aircraft was also held up at No. 32 Maintenance Unit, St. Athan by the non-availability of special 7-core cable.

It is worthy of note that the gap between the delivery of I.F.F. Marks I and II raised the whole question of the procedure for ordering radar equipment. Plans were made to ensure that in future the full requirements would be realised and catered for.[3] The matter was thrashed out between the Directorates of Signals, Equipment and Communications Development at a meeting on 1 May 1940. It was agreed that all future requests for requisitions should be from D.C.D. or D. of S. to D. of E., specifying the parts required, types of aircraft to be fitted or the number of stations to be erected. The Directorate of Equipment would then calculate the actual numbers of the equipments to meet the demand and cover the spares policy then in force. It was also agreed that it had been a blunder to abandon the manufacture of I.F.F. Mark I without ensuring that there were adequate spares available for fitting I.F.F. Mark I until sufficient quantities of I.F.F. Mark II were delivered.

Another source of delay in the mass-production of Mark II equipment was the ineffectiveness of the six codings specified. The Director of Radio Production at the Ministry of Aircraft Production advised that serious delay would

[1] A.M. File S.4084, Encl. 13A.

[2] Valves Type S.V.T. 61A.

[3] A.M. File S.4084, Encl. 46B and Min. 40.

follow any further attempt to change the specification, and so in order to relieve the situation three codings only were used instead of the original six.[1] By setting a switch on the I.F.F. control panel in the aircraft to one of three positions, the coded response on the cathode ray tubes of the radar ground stations could be either narrow, wide or very wide ; the ground operator could easily discriminate between the three codes.

Fitting of I.F.F. Mark II

Although Bomber and Coastal Commands had been given priority in the first installation programme, the fall of France made the fitting of Fighter Command aircraft with I.F.F. Mark II of greater urgency, and installation in Spitfire and Hurricane aircraft began in earnest at the end of July 1940.[2] By October 1940, practically all operational aircraft had been fitted, though those aircraft originally fitted with I.F.F. Mark I were not all converted to Mark II until February 1941.[3] Some idea of the scale of installation of I.F.F. equipment may be gained from the production effort. In all, 21,000 Mark II equipments were manufactured.[4] The Royal Navy had some of these because it was making increasing use of I.F.F. for identifying friendly shipping, but the lion's share was absorbed by the Royal Air Force.

Operational Instructions

During the period of conversion from Mark I to Mark II the instructions for switching on I.F.F. Mark II were similar to those for Mark I, using the Mark II 'narrow' pulse.[5] In February 1941 it was decided that I.F.F. Mark II could be employed not only for identification, but also as a means of indicating an aircraft in distress, amounting to a radar S.O.S. The instructions to aircrew were therefore issued under two separate headings, 'Identification by I.F.F.' and 'Identification of Aircraft in Distress.'

Identification by I.F.F.

All aircraft fitted with I.F.F. Mark II were to keep the device switched on under the following conditions :—

(*a*) On the outward flight, from the time of take-off until the aircraft was more than 50 miles out to sea.

(*b*) On the return flight or when approaching to land at a destination in Great Britain, from the time the aircraft was 100 miles from the coast until it had landed.

(*c*) Whenever an aircraft fitted with the device was flying over Great Britain.

(*d*) When Royal Air Force aircraft were co-operating with the Royal Navy.

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[1] A.M. File S.4084, Min. 84. [2] *Ibid.*, Encl. 163A. 5 August 1940.

[3] Trial installations had been made at No. 32 M.U., St. Athan, 15 man-hours per aircraft being required. Converting a Mark I installation to Mark II was a simple matter and took only two man-hours per aircraft.

[4] The Mark II equipments were termed—
R.3002—for 12-volt working,
R.3003—for 24-volt working.

[5] A.M. File S.40818/II, Encl. 85A, giving Amendment List No. 1 to S.D. 158(4).

Since I.F.F. Mark II did not respond on the C.H.L. station frequency-band, all aircraft were to approach the coast of Great Britain, whenever possible, at a height exceeding 2,000 feet so that the C.H. stations would be able to observe them. Provided Bomber and Coastal Command aircraft were above 2,000 feet during their return to Great Britain there was no need to identify themselves by W.T. to M.F. D.F. stations. The Code 1 position of the I.F.F. control panel switch was used by all aircraft under normal conditions, giving the 'narrow' pulse response at the radar ground stations.

Identification of aircraft in distress

When in distress, in addition to sending S.O.S. by W.T. or a 'Mayday' R.T. call, all aircraft were to change the I.F.F. panel switch from the No. 1 position to the No. 3 position. This changed the I.F.F. response at the radar ground stations from the 'narrow' to the 'very wide,' or 'broad' coding. Ground stations kept a special watch on any aircraft showing the broad pulse and all details of its track were passed immediately to the Air Movements Liaison Section. The latter was then able to set the Air-Sea Rescue Organisation in action if required, giving more accurate information of the position of the distressed aircraft than had hitherto been available.

Operational Performance

On the whole, Mark II identification equipment gave extremely good service. As many as 96 per cent. of returning bombers were identified on some occasions, while the average figure for the Stanmore filter room was of the order of 80 per cent. for all aircraft.[1] At filter rooms other than Stanmore the percentage of identifications was, however, seldom more than 60 per cent.[2] The causes of these failures were not quite clear in July 1941, but from the evidence available the majority of failures was due, not to the airborne gear, but to failures of the radar chain as a whole, either in the west coast chain stations or alternatively in the filter room. Although the pulse duration of 1/10th second was rather short for the ground observer, when air activity was small identification was generally excellent. When large numbers of aircraft, both friendly and enemy, were operating, identification was more difficult for the ground station operator. In such circumstances the large number of aircraft to be tracked made it impossible to concentrate on individual aircraft long enough for positive identification.

I.F.F. Mark II was just being taken into service when Headquarters, Fighter Command drew the attention of the Air Ministry Radar Panel to the fact that Mark II equipment did not respond to the C.H.L. stations which were being erected and aircraft flying over the coast at low heights were seldom identified.[3] To overcome this difficulty it was decided at the third meeting on 10 September 1940 of the Air Ministry Radar Panel that C.H.L. stations should be equipped with special transmitters to trigger I.F.F. Mark II.[4] Three of these were made by modifying G.L. sets for the purpose but while they were awaiting Service trials the decision to use them was cancelled because of an even more urgent requirement. G.C.I. stations had been introduced to counter the enemy night

[1] A.M. File C.16090, Encl. 52A. [2] A.M. File S.6430, Encl. 13A.

[3] Air Ministry R.D.F. Panel, 1st Meeting, 15 July 1940.

[4] T.R.E. File 4/27, Part V, Encl. 36B.

bombing during the winter of 1940, and defensive night-fighter aircraft required to identify themselves to G.C.I. and G.L. sets. At a meeting at T.R.E. on 29 September 1940, attended by the Assistant Chief of Air Staff (Radio), it was recommended as an interim measure that special I.F.F. sets should be provided for night-fighter aircraft, covering the G.L. and G.C.I. bands of wavelengths only, since G.C.I. stations then worked on nearly the same wave-band as C.H.L.

The deficiencies of Mark II equipment were given in detail by Mr. R. A. Watson Watt in a paper to the Inter-Services Committee on R.D.F. as follows. ' It could not respond to all wave-bands then in use, to say nothing of those shortly to be introduced ; the operation of identification interfered with that of location, the coding facilities were unsatisfactory in several respects, and there was disquieting evidence to show that the enemy might be able to copy the system and thus simulate the rudimentary coding methods.'[1] Taken out of its context, this statement could have given serious cause for alarm, but following it, the Scientific Adviser on Telecommunications outlined a new I.F.F. system then under development, which was designed to overcome the shortcomings described.[2] It was hoped that the new system would be ready for the Service late in 1941, but in the meantime every effort was made to minimise the disadvantages of I.F.F. Mark II by modification and improvisation.

Identification of Night Fighters—I.F.F. Mark II G

A special I.F.F. set, enabling night-fighter aircraft to identify themselves at G.C.I. and G.L. ground stations, and on A.I. aircraft equipment, was produced by modifying I.F.F. Mark II, removing the C.H. waveband circuits and substituting a circuit on the C.H.L./G.C.I. waveband of 190–210 megacycles per second.[3] The modified equipment was known as I.F.F. Mark II G. The proposals for it were approved by the Inter-Services Committee on R.D.F. at its 15th meeting on 20 November 1940 when the Committee directed that 1,000 Mark II sets, subsequently increased to 3,000, should be modified to meet Mark II G requirements. A contract was placed with Ferranti on 4 December 1940 and type approval given on 23 February 1941. But this modification did not provide identification at C.H. stations.[4] Experience with night-fighter aircraft operating under G.C.I. control showed that they frequently crossed the coast at heights at which they could be seen by the C.H. stations, and identification of all friendly aircraft by C.H. stations was essential because they were the main source of air warning for the whole fighter system. An attempt to provide identification of night fighters was made by giving special radar equipment to certain C.H. stations,[5] and its function was to trigger the I.F.F. Mark II G sets, and to feed the response received from them into the C.H. receiver.[6] The special equipment comprised a transmitter and receiver which were called an ' interrogator ' and ' responser ' respectively.

[1] Inter-Services Committee on R.D.F. 17th Meeting, 18 March 1941.

[2] This was I.F.F. Mark III.

[3] R.A.F. Nomenclature :—R.3077 for 12 volts, R.3078 for 24-volt sets.

[4] Inter-Services Committee on R.D.F. 15th Meeting, 20 November 1940.

[5] The C.H. Stations selected were the south-eastern portion of the Home Chain, where the night activity was most intense :—

Worth Matravers, Rye, Swingate, Canewdon, High Street, Stenigot, Poling and Pevensey.

A.M. File C.S.8092, Encl. 55A.

[6] A.M. File C.16090, Encl. 52A.

The principle of separating the function of identifying an aircraft from that of determining its location, and providing separate interrogating equipment solely for identification, had already been proposed for a new I.F.F. Mark III system in which it was later employed, but its use in July 1941 was the first occasion on which it was applied in practice. The interrogators and responsers employed at C.H. stations were hand-made copies of the prototype of a set which was later manufactured in large numbers for I.F.F. Mark III ground equipment. Ground interrogation with Mark II G equipment could not be considered a satisfactory system, however, because the sensitivity of the normally-adjusted I.F.F. Mark II G aircraft set was insufficient for working with the ground interrogator, the peak power of which was too low.[1] The expedient was eventually abandoned in April 1942, when the C.H. stations were modified to work with the Mark III system, which was about to be introduced.

I.F.F. Mark II N

For co-operation with the Royal Navy, Coastal Command aircraft required I.F.F. equipment which would respond to naval raid warning sets on 5·8–7·9 metres wavelength as well as to C.H.L. Stations. The requirement was a necessity for Fleet Air Arm aircraft too, and also for aircraft being ferried across the Atlantic from the United States of America. Another modification to I.F.F. Mark II was therefore authorised, and a set covering the frequency bands 39–51 and 196–220 megacycles per second was produced, I.F.F. Mark II N. Deliveries of this equipment started in August 1941.

Operational requirements were thus met for the time being by I.F.F. Mark II but only by resorting to *ad hoc* modifications of the Mark II G and Mark II N type. It was clear that such measures could not be tolerated indefinitely. Any one aircraft installation could respond to only two of the many wave-bands then being used by radar, making the scope of identification limited and the system inflexible. It was visualised that the radar frequencies, extending in the middle of 1941 from 22 to 214 megacycles per second would soon cover a range of 20 to 10,000 megacycles per second. Any attempt to extend the Mark II system to cover all these frequencies would be impracticable ; the equipment to be carried in the aircraft would be too cumbersome, and the coding cycle would occupy a period of some two minutes instead of the 12-second cycle of I.F.F. Mark II. The useful days of the Mark II system were numbered and a new system, using a common identification frequency band separate from all the radar location bands, would have to take its place.[2]

Extension of the use of Mark II G and Mark II N

Originally, when the I.F.F. Mark II system was introduced, it was thought that it would have to operate only until the end of 1941, when the separate-band I.F.F. Mark III equipment was to be available to replace it. It was apparent by the summer of 1941 that the Mark III system would not be available for general introduction into the Services until at least a year later than had been anticipated. It was therefore necessary to make the best use of the Mark II equipment throughout the remainder of 1941 and 1942.

[1] A.M. File C.S.8092, Encl. 86A.

[2] Accounts of the use of I.F.F. equipment as a radar beacon, and as a radio countermeasure, are given in Volumes III and VII respectively.

Fighter Command had been employed in the main on the defensive during 1941, but after that year daylight operations became largely a matter of offensive sweeps over enemy-occupied territory in the Low Countries and Northern France. G.C.I. equipment was used on the south-east coast of England to keep track of the progress of sweeps and of the movement of German fighters in their vicinity. A system of day-fighter control, leading later to the introduction of Fighter Director Stations, developed. Identification of friendly fighter aircraft was necessary at these ground stations, but Fighter Command day-fighter aircraft, being fitted with I.F.F. Mark II, did not give an I.F.F. response on the G.C.I. waveband. Accordingly, it became necessary to convert the I.F.F. equipment for day-fighter aircraft from Mark II to Mark II G.

The Aircraft Equipment Committee notified the Air Member for Supply and Organisation on 7 November 1941 of their approval of the introduction of Mark II G as an alternative to the existing Mark II in all Royal Air Force day-fighter aircraft. An order of priority of fitting had to be laid down because of the limited quantity of sets then available.[1] The Director of Radio gave this as :—

(*a*) All night fighter aircraft.

(*b*) Beaufighter aircraft flying out to the Middle East.

(*c*) Beaufighter aircraft packed for the Middle East.

(*d*) Other aircraft of Fighter Command.

At the same time, Mark II N was being used by all Coastal Command aircraft in order that ships of the Royal Navy could identify them as friendly. Although Royal Air Force aircraft had specific instructions not to fly directly over naval vessels when on patrol, instances were continually occurring of naval anti-aircraft guns engaging friendly aircraft. There had been a cleavage of opinion between the air force and naval authorities on ship anti-aircraft defence. At the beginning of the war, before opening fire, the ships had to recognise the aircraft markings as being hostile. With the development of radar G.L. control of naval guns and the extended use of I.F.F., the Admiralty felt that ships should open fire by radar G.L. control even when the aircraft could not be seen.[2] The Air Ministry opposed this, two arguments being employed :—

(*a*) I.F.F. failures resulting from enemy action or technical faults prevented I.F.F. from being regarded as an infallible means of identification, and

(*b*) Aircraft operating over the sea with I.F.F. not working and being unaware of the disposition of H.M. ships might fly inadvertently within their blind-controlled artillery zones.

It was not until July 1941 that permission was given for blind firing of naval anti-aircraft guns. Then, in all waters, H.M. ships fitted with radar to which I.F.F. would respond, or vessels in close company with ships so fitted, might engage aircraft which were both unseen and unidentified with radar-controlled blind fire up to 6,000 yards range, standard barrage fire and close-range weapon fire, if the position and method of approach of the aircraft indicated hostile

[1] A.M. File C.S.22208, Encl. 25A.

[2] A.M. File S.47871/IV, Encls. 88A, 163B and 178A.

intent. From 15 July 1941 onwards therefore, the responsibility devolved on Royal Air Force pilots to keep away from the shipping, and to keep Mark II N or G equipment switched on whilst over the sea.

I.F.F. Used with Rotating Aerial Radar Stations

I.F.F. had originally been designed to be interrogated by fixed aerial radar stations. The rotating aerials of C.H.L. and G.C.I. stations made it more than ever necessary to separate the identification function of radar stations from their prime work of aircraft location. Before a rotating-aerial radar station could receive an I.F.F. response, the beam of the station had to be directed towards the aircraft at the moment when the aircraft I.F.F. set was sweeping through the frequency of that particular ground station. At G.C.I. stations this was not a very great disadvantage because a G.C.I. operator was usually following the movements of particular aircraft. At a C.H.L. station, however, the aerial system was normally in rotation. When establishing the identity of a particular aircraft it was necessary to stop the all round search whilst the operator 'inched' for the 12-second I.F.F. response. During such periods the value of the station was lost.

The Telecommunications Research Establishment gave some thought to this and a special attachment was devised for Mark II N equipment to enable it to give a fixed frequency response.[1] The device could also be fitted to Mark II G equipment. It fulfilled the requirement for a method of identifying a particular aircraft at one beam-type ground radar station, and also of identifying it from several aircraft within a few miles of each other. This, it was thought, would greatly enhance the value of I.F.F. as an aid to interception, particularly of the low-flying enemy raider. Unfortunately it was not until August 1942 that the attachment was tested successfully in aircraft. It was then too late to introduce yet another variant of the Mark II system, for new Mark III separate-band identification was expected to be available for Service use within three months.

The Human Factor with I.F.F.

In addition to the technical inability of Mark II equipment to respond to all radar search stations which were operating in 1942, there were shortcomings even at ground stations where it should have been observed. The failure of I.F.F. Mark II in this respect was not due to any one particular factor, but sprang from three possible causes :—

(*a*) Failure of the ground radar station operator to see the 1/10th second I.F.F. response.

(*b*) Faulty servicing of I.F.F. equipment on the ground, resulting in the I.F.F. set not working correctly in the air.

(*c*) In some cases, aircrew not complying with instructions on the use of I.F.F.

The three causes were not accepted as inevitable. I.F.F. failures from each of them could be reduced by continued instruction and enlightenment of the personnel involved. To assist operators at the radar stations a double filter was

[1] A.M. File C.16090, Encl. 144B.

provided for use in observing the cathode ray tube. The portion of the filter for use over the lower portion of the trace was green, which allowed the afterglow of the I.F.F. response to be seen more clearly than previously, when operators had tended to use the amber filter.

Despite careful instruction of radar operators, identification of every aircraft was not possible. Sometimes hostile aircraft came in at the same time as a returning friendly bomber force. The latter, showing I.F.F., masked the echo of the enemy intruders. A similar effect occurred when a friendly aircraft showing I.F.F. was in the back-beam of a C.H. station at approximately the same range as an enemy aircraft flying in on the line-of-shoot of the station. In such circumstances the enemy aircraft would either not be observed or be identified as friendly, at least for a time, by the ground station operator.

In the effort to ensure that I.F.F. Mark II was operated always in accordance with the instructions laid down, aircrew were briefed regularly in the correct routine when airborne. In such briefings, emphasis was placed on the purpose of I.F.F. equipment and possible results of its incorrect use. Captains of aircraft were reminded of their responsibilities with regard to the destruction of the I.F.F. set before abandoning aircraft over enemy or neutral territory.[1]

Instances occurred during 1941 of aircraft showing ' broad ' I.F.F. instead of ' narrow ', caused by the switch on the I.F.F. Control panel being in position 3 instead of position 1.[2] As a result the whole emergency organisation for an aircraft in distress had been set in motion. To reduce the incorrect use of the I.F.F. coding, a small but effective modification to the I.F.F. control panel was introduced on 25 January 1942. The movement of the code switch knob was restricted to the Code 1 position by a piece of thin copper wire secured with sealing wax. The knob could be turned easily to the distress position on the orders of the captain of the aircraft but the stretched or broken wire revealed that the action had been taken. This modification reduced considerably misuse of the distress signal.

As a means of speeding up improvement and increasing knowledge, command I.F.F. parties were formed.[3] These consisted of one radar officer and three sergeants (Radar Mechanic) who toured the stations in the command, supervising and checking efficiency of I.F.F. maintenance and servicing. Although these parties were small, by co-operation with station signals personnel they had a marked effect in increasing the efficiency of the ground servicing of I.F.F., Mark II. A check on I.F.F. operational efficiency during the summer of 1942 gave an average efficiency of 90 per cent. for Bomber Command, despite the fact that returning bombers were instructed to fly across the sea at low altitude, causing difficulties at the Home Chain stations in seeing them.[4]

There is no doubt that during 1942 the Royal Air Force was getting a high degree of identification from Mark II equipment, as far as was technically possible within the limitations of the system. Identification by ground radar

[1] Similar destruction facilities existed for Mark II equipment as for Mark I.

[2] A.M. File C.16090, Encls. 102A and 101B.

[3] A.M. File S.4389, Encl. 15A.

[4] ' War in the Ether—Signals in Bomber Command.' A.H.B. IIE/76A, para. 70.

stations within the frequency band swept by the I.F.F. sets was good. But as soon as the groups of aircraft increased to 50 plus, the identification system became congested. Where, say, some 100 bomber aircraft were operating at one time, they were recognised as friendly in a general way, but there was no reliable individual identification. By sending aircraft in company with returning bombers, the enemy was able to infiltrate his night fighters undetected over Bomber Command bases. On the few occasions when the Germans adopted these tactics, they obtained very good results. The Germans never exploited the possibility of infiltration fully, so the operational weakness of the I.F.F. Mark II system was never completely revealed.

CHAPTER 7

I.F.F. MARK III

I.F.F. Marks I and II became prematurely obsolescent because the number of wavebands on which they were required to work steadily increased. Neither of the sets was faulty in its design or manufacture ; they both did all that they were intended to do at the time of their development. But as the number of wavelengths, and wavebands, on which they were required to respond, increased in accordance with rapidly developing radio techniques, so the size and complexity of any equipment capable of giving response over such a wide range became far too great to be acceptable for airborne use. When the method of responding to each ground radar station on its own particular wavelength was first devised, the process of identification became an integral part of the location technique. Later the increased complexity of the expanding radar systems made it necessary to provide an independent arrangement for identification.

The new system, for it was more than merely a new mark, was known as I.F.F. Mark III. The principle involved setting aside a band of wavelengths, and providing special ground equipment exclusively for the purpose of identification. The waveband 1·6–1·9 metres was selected and a new I.F.F. set, a transponder sweeping this waveband only, was designed for use in all aircraft, ships and even vehicles which might have to be identified.[1] All radar search stations, whether ground, airborne or shipborne, were provided with an interrogator and a responser, together with appropriate aerials, solely for the purpose of interrogating the aircraft transponder. Suitable arrangements were made to display the received I.F.F. pulses at the search radar station separately from the normal echoes, in such a manner that they could be related without ambiguity to the aircraft carrying an I.F.F. Mark III transponder.

Initial consideration of the problem of putting I.F.F. Mark III into service suggested that it would be less complicated than I.F.F. Mark II, since it was to sweep through one comparatively narrow band of wavelengths, whilst the latter had to switch from one waveband to another. The interrogators and responsers were also much simpler than the ground radar search sets with which they were associated. Nevertheless, the implementation of the proposal involved a programme of great complexity and magnitude, arising more from the large numbers and varieties of the equipments required than from the technical complexities of the individual sets. The greatest technical complication of the whole Mark III system was to be in the matter of display, which had to be adapted to all the various methods of displaying radar echoes in the different search equipments already in use at radar ground stations, in aircraft and in ships of the Royal Navy.

[1] Inter-Services Committee on R.D.F., 17th Meeting, 18 March 1941. Paper on 'The New I.F.F. System'.

Development of I.F.F. Mark III and Mark III G

Separate band identification was first discussed at Bawdsey Research Station in 1939. The development of it had not been considered practicable at that time by the Air Ministry because of the additional ground interrogator/responser equipment required.[1] Nevertheless, experimental research work on separate band identification was started at the Telecommunication Research Establishment early in 1940. In the course of this work the technical soundness of the scheme was confirmed. In September 1940 the Air Ministry Radar Panel had decided that the development of separate band identification should proceed. I.F.F. was, however, of importance to all three Services and a universal identification system could only be evolved and its development proceed at an adequate pace if it were approved on an inter-Service basis.[2] The Air Ministry Radar Panel therefore referred its decision to the Inter-Services Radar Committee. The Committee gave consideration to the identification problem at its meetings in October and November 1940 and duly agreed that separate band identification was desirable at all search radar installations.[3] A technical sub-committee of representatives of the research establishments of the three Services was set up to examine the interrogator requirements of each of the Services and to produce prototypes for trial. The W.T. Board approved the allocation of the frequency band of 157–187 megacycles per second to be set aside for I.F.F. purposes, and the development work proceeded.

Meanwhile, the Inter-Services Radar Committee discussed the estimated scale of provision of Mark III equipment which would be necessary on conversion from the Mark II to the Mark III system.[4] The requirement at the first assessment of the programme was given as 1,000,000 aircraft sets, 1,000 pairs of the largest type of ground interrogator and responser equipments and 10,000 pairs of the smaller types. This excluded the requirements of the Royal Navy. Since the Committee had to consider the inter-Service aspects of all radar equipments, it was felt that the details of the gigantic Mark III requirements merited the formation of a sub-committee on I.F.F. with representatives of all three Services 'to consider what is required to enable identification to be satisfactorily achieved' on the basis of the estimates already produced, and to ascertain whether the objective so agreed was capable of attainment.[5]

The sub-committee considered the requirements of the three Services and the separate requirements of individual commands. At that time, the summer of 1941, the I.F.F. Mark III scheme appeared satisfactory to Headquarters, Bomber Command, and it met Army requirements. The Admiralty did not feel able to commit itself definitely; its agreement was to depend on whether or not the interrogator/responsers could be fitted in ships. However, the Admiralty agreed to endeavour to conform with the suggested policy of a universal identification system by the beginning of 1942, that being the rough target date suggested by the sub-committee for the change from Mark II to Mark III.

[1] T.R.E. Progress Report, May/June 1940.

[2] Minutes of Air Ministry R.D.F. Panel, 3rd Meeting, 10 September 1940.

[3] Minutes of Inter-Services Committee on R.D.F., 14th Meeting, 3 October 1940 and 15th Meeting, 20 November 1940.

[4] Inter-Services Committee on R.D.F., 17th Meeting, 18 March 1941.

[5] A.M. File S.8213, Encl. 19B.

Fighter Command representatives expressed satisfaction with the Mark III system for general use but pointed out that a special I.F.F. would be required to show a response in G.C.I. stations on the Plan Position Indicator.

It was necessary for the G.C.I. controller to be able to identify echoes appearing on the P.P.I. tube and to do this he had to be able to see the I.F.F. responses on the tube itself. This requirement had been satisfied partially by I.F.F. Mark II G but there had always been the difficulty that the rotating aerial had to be orientated towards the aircraft at the same instant as the sweeping I.F.F. set was tuned to the right frequency. The Mark III responded to the interrogator on what became known as the 'A' Band (157–187 megacycles per second). For display on the P.P.I., a response was also required on the 'G' frequency band (200–210 megacycles per second). A special I.F.F. transponder, Mark III G, was therefore designed to respond either to normal interrogators on the 'A' band, or on the frequency in the 'G' band of the G.C.I. station. In meeting this special requirement of Fighter Command for direct interrogation on a frequency which was outside the special band reserved for identification, it was demonstrated that the ideal of a single equipment for universal use in all three Services was not a practical proposition on the allocated waveband.

Demonstrations of the Mark III system

The decisions of the sub-committee on I.F.F. had constituted some degree of approval of the Mark III scheme and, with the even greater inter-Service co-operation, development proceeded with more confidence.[1] A demonstration of separate band identification was given at Poling C.H. Station on 1 August 1941 to the Director of Radio. He recommended adoption of the Mark III aircraft set and interrogation equipment, and pressed for an early demonstration with C.H.L. and G.C.I. equipments which was also to be witnessed by naval and military authorities. The Aircraft Equipment Committee gave authority for the introduction of I.F.F. Mark III in all aircraft on 20 August 1941.[2] Six pre-production models of I.F.F. Mark III were delivered during August and fifty hand-made production models were then being made by Ferranti.[3] But whilst the main consideration in pressing on with the I.F.F. Mark III programme was the urgent need for a more certain and more universal identification system than the Mark II had proved to be, another factor had to be taken into account. This was the possibility of the United States of America coming into the war, in which event it would be invaluable to have an I.F.F. system common to both British and American forces.

Prior to conversations between the two countries on the subject of identification, the Americans had been developing a system by using pulses on a spot-frequency of 473 megacycles per second and a response from aircraft on the spot-frequency of 492 megacycles per second.[4] Such single channel interrogation imposed a much lower limit on the permissible number of interrogators which could act on one airborne transponder than the British Mark III system with its approximately ten channels in a band sweep of 30 megacycles per second

[1] A.M. File S.8213, Encl. 20B.
[2] A.M. File C.S.11600/I, Encl. 2A.
[3] A.M. File C.S.10374, Encl. 12B.
[4] *Ibid.*, Encl. 5B.

between 157 and 187 megacycles per second. In addition, the spot-frequency working of the American system was much more vulnerable to jamming. There were other features too which made the American system undesirable from the British point of view for both operational and technical reasons. Nevertheless the Americans were very much concerned with I.F.F. policy in June 1941 and hoped to introduce their own I.F.F. system in 1942. It was possible that they might develop a system which could not easily be co-ordinated with the British radar organisation, unless a clear indication of British policy were given to them at once.[1]

The I.F.F. Sub-Committee was agreed that the British were already definitely committed, and accordingly that nothing should be allowed to hold up the development of what appeared to be the best identification system so far evolved. In September 1941 a meeting was attended by representatives of the United States Army and Navy and the three British Services, at which Sir Robert Watson-Watt described the British Mark III system.[2] It was pointed out that considerable technical difficulties were likely to be encountered if ever it were necessary to attempt to use both the British and American systems together. In particular, if the United States entered the war, the naval forces of the two countries would presumably be operating in the same waters. It was therefore suggested that the United States Navy might find it possible to use British Mark III in their ships. The meeting, not qualified to decide in this matter, recommended that it should be discussed between British and American experts. In the meantime a T.R.E. scientist had flown to the United States with a model of the airborne I.F.F. Mark III set, and further models of that set and two models of the ground interrogator/responsers were being despatched to America at the end of September 1941. It had already been decided that a large-scale Service trial of the Mark III system was necessary, and in August 1941 the I.F.F. Sub-Committee agreed that the trials should be held in Pembrokeshire as soon as possible[3]. Added importance was now given to this practical demonstration of the efficiency of I.F.F. Mark III by the need to show a working system to the Americans.

The Pembroke trials of I.F.F. Mark III held in December 1941 rank among the most elaborate of their kind. They were devised to test the C.H., C.H.L. G.L., S.L.C. and A.S.V. interrogation of the airborne I.F.F. set[4]. Eleven ground installations of interrogator/responsers for every sort of ground search radar then in use with the Army and Royal Air Force were set up, and six different types of aircraft were fitted with the Mark III transponder.[5] In addition, a

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[1] A.M. File S.6738, Encl. 44A. Minutes of meetings on 18 and 19 June 1941.

[2] A.M. File C.S.10374, Encl. 17A, Annex. 8. Meeting, 20 September 1941.

[3] *Ibid.*, Encl. 1A.

[4] Report on I.F.F. Mark III Trials in Pembrokeshire, 15/18 December 1941. A.M. File C.S.10374, Encl. 30B.

[5] The following equipments were fitted with interrogator/responsers and displays :— Warren C.H. Station and a mobile radar unit (Type R.M.3B), St. Twynnels C.H.L. Station, Ripperstone G.C.I. Station, three G.L. sets and an S.L.C. set, together with three additional interrogator/responsers at Manorbier A.A. School. Aircraft employed were Spitfire, Blenheim, Wellington bomber, Sunderland, Coastal Wellington and Beaufighter. The latter was fitted with Mark IIIG. Sunderland and Coastal Wellington were carrying L.R. A.S.V.

sloop of the Royal Navy was fitted with I.F.F. Mark III to test the identifications of friendly ships at C.D./C.H.L. Stations and on the A.S.V. search equipment in aircraft.

Representatives of the three British Services, the Royal Canadian Air Force, the Royal Australian Air Force, and the United States Navy and Army all witnessed the four days' trials. The results were generally satisfactory, though owing to the experimental nature of some parts of the equipment, minor technical difficulties were encountered. The Director of Radio reported to the I.F.F. Sub-Committee that 'all observers agreed that the trials amply demonstrated that the I.F.F. Mark III system should be made the basis of a universal identification system.' The Americans, no longer neutral observers, were enthusiastic about the success of I.F.F. Mark III. To quote from the report submitted by the observers from the U.S. Embassy, 'It has been urgently and jointly recommended that this system be adopted in its entirety by the U.S. War and Navy Department in all geographical areas.'

Acceptance of I.F.F. Mark III by British and U.S. Services

The Director of Radio's report, summarising the general agreement that the Mark III system was practical and should be accepted, was endorsed by the Radar Policy Sub-Committee in January 1942.[1] It was agreed that the new identification system should be brought into service as quickly as possible, modifications being introduced in the production line if necessary and practicable. Later, on 16/17 July 1942, in Washington, the Combined Chiefs of Staff Radar Committee's Sub-Committee on Identification considered Allied I.F.F. policy and came to the following conclusions :—[2]

(*a*) The adoption of a common identification system by the Allies was essential.

(*b*) The British Mark III equipment was to be adopted as standard equipment for U.S. and British forces.

(*c*) Replacement of one identification system by another was in future to be made by areas. American and British aircraft were to be equipped simultaneously in each area.

(*d*) The development of a new and universal identification system to supersede the British Mark III was to be initiated forthwith by American and British scientists working in collaboration.

This was the final stage in the acceptance of the Mark III system for use in all the Allied Services. Certain weaknesses of I.F.F. Mark III from the point of view of both universality and technical performance could, however, be visualised ; hence the development of yet another universal identification system was recommended. It would take at least three years, possibly longer, from the research stage to re-equip the whole Allied forces with another Mark of I.F.F. The Mark III programme, now well advanced, was destined to be the identification system with which the Allies were to operate for the remainder of the war. Contracts were placed with Ferranti, Ericsson, Plessey and Ultra Radio for the production of I.F.F. Mark III, the initial quantity of the sets ordered being 49,885. The immense task of introducing I.F.F. Mark III

[1] A.M. File C.S.10374, Encl. 33A.

[2] A.M. File S.47871/V, Encl. 117B.

into the Royal Air Force was by no means restricted to a huge aircraft installation programme. An essential pre-requisite was the installation at each radar search station of the interrogator and responser. The new ground equipment could not be accommodated in existing buildings and additions were necessary at each station.

The Royal Aircraft Establishment was made responsible for the ground interrogator and the airborne interrogator programme. The Chiefs of Staff policy for the introduction of Mark III laid down zones of fitting as :—[1]

(*a*) England.

(*b*) The remainder of the United Kingdom, North Atlantic and Western Mediterranean.

(*c*) South Atlantic.

(*d*) Indian Ocean.

(*e*) Eastern Mediterranean.

The conversion to I.F.F. Mark III, even in any one zone, required a very high degree of co-ordination ; of the zones laid down, the first in priority presented the most complicated problem.[2] The change-over had to be carried out in such a manner that identification was continuously possible, whether on Mark II or Mark III, otherwise the enemy might have detected a weakness in the raid reporting organisation and exploited it to the full.

The long-range early warning system was dealt with first. It was hoped to have nineteen of the more important C.H. stations on the south and east coasts of England fitted with interrogators by mid-November 1942.[3] In a similar manner, all G.C.I., C.H.L., G.L., and S.L.C. ground search radar stations had to be included in the programme, concentrating as before first on the principal Home Defence areas in the south and east and then continuing the installations throughout the rest of the country. It was hoped that all ground interrogators would be fitted by March/May 1943. Co-ordinated with the ground installation programme, it was possible to plan for British and American bombers to start the change from Mark II to Mark III about the same time as the Home Chain stations in the south and east of England, namely the end of November 1942.[4] To avoid the possibility of interception of Allied bombers fitted with I.F.F. Mark III by British night-fighter aircraft using A.I. search radar, the latter aircraft required the installation of their airborne interrogator/responsers about the same time.[5] This was planned to start early in December and all night fighter fitting was to be completed by February 1943.[6]

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[1] A.M. File C.S.12578, Encl. 222A.

[2] A.M. File C.S.11600/I, Encl. 75A.

[3] The British interrogator was given the type number T.3117 and the associated responser was R.3118.

[4] The Mark III aircraft sets had the following type numbers :—

	British	*American*
12-volt installation	R.3067	A.B.K. S.C.R.595
24-volt installation	R.3090	A.B.K. S.C.R.595A

[5] These had the type numbers :—

(*a*) T.R.3171 for Beaufighter and Mosquito aircraft equipped with A.I. Marks IV and V.

(*b*) The American S.C.R.729 for A.I. Mark X, later replaced by the American AN/APN-I equipment.

[6] A.M. File C.S.11600/I, Encl. 75A.

In retrospect, it is very difficult to gain a true impression of the large scale of the task of this conversion from Mark II to Mark III in the British Services. The United States forces were also equipping with Mark III, and the production resources of the two nations were utilised to the full to meet identification requirements. The mass-production facilities of the radio factories in U.S.A. assisted in the Royal Air Force conversion to Mark III. Between the end of December 1942 and February 1943 10,000 American-built sets arrived in the United Kingdom.[1] Although the designs of British and American Mark III transponder were similar, neither detonators nor valves of the two types were interchangeable.[2] This would have created difficulties if both types of set were used in the same unit, so Royal Air Force wings kept to one or the other type of set to avoid maintenance troubles. By the time American Mark III sets had arrived in this country, British contractors had delivered 5,000 equipments and were trying to maintain a production rate of 2,000 sets per month.[3]

The I.F.F. Mark III G aircraft set, designed to give a direct response to G.C.I. stations as well as to the normal Mark III interrogation, was never produced in quantity in the United Kingdom. An American version (SCR.695) was manufactured as a direct copy of the British prototype, and some 4,000 sets were supplied to the British Services in the first six months of 1943. Instead of the Mark III G, a British model called the Mark III G (R)[4] was produced, which gave 'G' band G.C.I. response and also, with a slight modification, could be used as an aircraft radar beacon called a 'Rooster' beacon. Details of the 'G' and 'Rooster' applications of this equipment are outlined later in connexion with its operational use.

Introduction of I.F.F. Mark III

By the end of December 1942, firm dates for introduction of I.F.F. Mark III into Service use had been laid down.[5] Although the fitting programme proceeded well it was impossible to meet these dates in all the areas concerned.

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[1] A.M. File C.16278, Encl. 65A.

[2] A.M. File C.S.22208, Encl. 40A.

[3] The following requirements of the Royal Air Force and Royal Navy in February 1943 give some impression of the magnitude of the aircraft fitting programme.

Bomber Command	4,000 ..	300 already supplied.
Fighter Command	5,000	
Coastal Command	2,000	
Flying Training Command	4,000	
Army Co-operation Command	1,000	
Eastern Air Command	1,000 ..	1,000 ready for despatch.
Middle East Command	3,000	
Royal Navy	1,000 per month with 1,000 already supplied.	

A further 21,000 sets were required to be manufactured in the next six months.

[4] The Mark III G (R) had the R.A.F. type numbers :—

12-volt—R.3120 24-volt—R.3121.

These numbers were originally assigned to the Mark III G and assumed by the Mark III G (R) when Mark III G did not go into production.

[5] It was hoped to change over to I.F.F. Mark III in the various types of aircraft on the following dates :—

Home .. All Bomber aircraft from 1 February 1943.
All G.R. and Naval aircraft from 15 May 1943.
All Day Fighter aircraft from 1 February 1943.

Overseas .. M.E. Theatre as from mid 1943.
N. African Theatre from 1 April 1943.

It was therefore left to the discretion of the respective area commanders to fix the exact date of termination of the employment of the Mark II system and the date of introduction of Mark III.[1] The operational use of I.F.F. Mark III in the United Kingdom was authorised with effect from 15 April 1943 for such aircraft as were modified and whose region of flight passed over the south and east coasts of England or over the North West Atlantic Approaches. At that date approximately 2,000 Bomber Command aircraft started using Mark III; the whole of the American VIII Bomber Command were also employing the new identification system, but Fighter and Coastal Commands failed to meet the target date because airframe kits and connectors were not available. Night fighter aircraft were fitted with the American Mark III G equipment (S.C.R. 695) by 1 June. At ground search radar stations the policy for installation of interrogator/responser equipment on the south and east coast stations had been well implemented. At the end of April 1943 30 C.H. stations were operational with interrogators, ranging from Middlesbrough to Land's End, with 5 in the North West Approaches area: 20 C.H.L. stations between the Wash and Dartmouth and 7 G.C.I. stations in the area between the Wash and Isle of Wight were also fitted.

Operational Use of I.F.F. Mark III

When I.F.F. Mark III was first authorised for operational use on 15 April 1943 the instructions for employing it were identical with those for the Mark II model as far as switching on and off were concerned. An important improvement in Mark III, however, was the elimination of all manual adjustment of sensitivity. The coding of Mark III was different from Mark II and the I.F.F. control panel slightly more complicated.[2] Six codes were available as well as a special distress code. The six codes used for identification purposes were obtained from transmitter pulses of two widths. These were 'Narrow' (N) of 5–9 microseconds and 'Wide' (W) of 15–35 microseconds. Variations of these and the spacing between them made up the six codes which were easily recognised at the ground radar stations.[3] The minimum recognition time for any code was of the order of 9 seconds as the responses recurred every 2·8 seconds.

In the Mark II system the third position of the coding switch was reserved for distress signals. In Mark III aircraft equipment there was a special Distress switch on the Control panel, separate from the coding switch. When S.O.S. conditions obtained in an aircraft fitted with Mark III, the pilot or other member of the crew ignored the coding switch and merely depressed the Distress switch. This gave a very wide or 'broad' distress code of 60–120 microseconds in width in the ground station cathode ray tube. A report of this to the filter room brought the Air Sea Rescue organisation into action if the distressed aircraft was over the sea at the time.

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[1] A.M. Files C.S.12578, Encl. 232A and C.16084, Encl. 156A.

[2] A.M. File C.S.21736, Encl. 4A.

[3] The codes available for the six positions of the coding switch were :—

(1) N N N N ———	(4) NNWWNNWW ———
(2) N–N–N–	(5) N–W–N–W–
(3) NNN–NNN–	(6) NNW–NNW–NNW–

The dash between indicates a spacing.

When Mark III equipment was first introduced operationally, all aircraft employed code 1. No use of the remaining five codes was permitted for security reasons except by Inter-Service agreement to allow for distinction between friendly aircraft under special conditions.[1] This general policy was formulated by the Combined Communications Board, which had been established in Washington on 16 July 1942 to be the sole body supporting the Allied Chiefs of Staff on Communications matters. After two months experience with all aircraft operating on Code 1, it was decided that Code 6 should be introduced for use by all land-based fighter aircraft in June 1943.[2] Large forces of bomber and fighter aircraft were operating in the summer of 1943, often with the fighters in support of the bomber offensive by day, and distinctive identification in this manner of the different types of aircraft was valuable.

Use of I.F.F. Mark III G

The requirement for a direct identification response on the Plan Position Indicator of the G.C.I. station in addition to the normal Mark III interrogator response has already been mentioned. British night fighter aircraft were initially fitted with the American Mark III G (S.C.R. 695) equipment. The Mark III G set responded either to the normal interrogators or directly to the G.C.I. stations, at that time working on a frequency of 209 megacycles per second in the ' G ' band. Normally the set swept the ' A ' band of identification frequencies in the usual way, but the pilot could, when requested to do so by the G.C.I. controller, press a button which temporarily put the set into a state known as ' G working '. It remained in this state for about twenty seconds, during which time it gave direct responses on the G.C.I. frequency and then automatically reverted to the normal identification frequency A band sweep.

While in a condition of G working, the I.F.F. set did not entirely abandon its identification A band working. It continued to sweep the A band but gave ' chopped ' A and G responses in such a way that the A band operation continued for 1/10th second and was followed by G band working for 1/25th second. Thus, for a period of 20 seconds after the pilot had depressed the G button, the set gave a rapid succession of short pulses on the G.C.I. frequency, and meanwhile it continued to respond to A band interrogation. From the pilot's view point, the major difference between Mark III and Mark III G was the introduction of a G band panel in the cockpit, the button of which was pressed on instructions from the G.C.I. controller. One other difference was that the Distress switch on the normal I.F.F. Control Panel was not used, the Distress switch on the G band panel being employed instead.

Controllers at the G.C.I. ground stations spoke by R.T. to the pilot in a simple code which had been introduced for operations with I.F.F., Mark II, and amplified for use with Mark III. The principal code words were ' Cockerel ' for the I.F.F. set and ' Canary ' for the G band. Thus, ' Make your Cockerel crow ' meant switch on I.F.F., and ' Strangle Cockerel ' was the order to switch it off. ' Canary please ' was the G.C.I. controller's request for the pilot to push the G band button-switch.

[1] A.M. File S.47871/V, Encl. 117B.

[2] A.M. File C.S.21736, Encl. 20A.

Use of I.F.F. Mark III G (R)

The British Mark III G (R) set had all the facilities of the American Mark III G but could also be used as a Rooster beacon, this being the term given to an airborne radar beacon.[1] It was used mainly by aircraft of Coastal Command and the Fleet Air Arm which were engaged in searching for enemy submarines and surface craft and wished to be reinforced by other aircraft when they sighted an enemy vessel. Previously, the Mark II G set had been modified for this purpose, working on a fixed frequency of 176 megacycles per second so that it would respond to A.S.V. Mark II and to Coastal Command and Fleet Air Arm 'Lucero'.[2] The Mark III G (R) set was designed to operate either as an I.F.F. transponder or as a Rooster beacon, eliminating the necessity to carry separate beacon equipment. The Mark III G (R) could be used either as a Rooster beacon or for G working, but not both, in addition to its I.F.F. function. This was no disadvantage, since G working was required only by fighter aircraft, and Rooster working was required only by maritime reconnaissance aircraft. For Rooster working the transponder used the G band circuit, re-tuned to give continuous responses on a pre-set frequency in the Rooster band (172–182 megacycles per second), normally 176 megacycles per second. The responses were not shared with the A band but were continuous. When set for Rooster working, I.F.F. Mark III would give either normal identification band sweeping or continuous response on the Rooster frequency.[3] The change-over from identification to Rooster working was effected by a remote control switch, the R-switch. When this switch was depressed the set ceased to give any identification responses and went over entirely to Rooster working. When operating as a Rooster beacon, it was possible to interrupt the transmission by means of a morse key and thereby to communicate with the aircraft which were homing to the airborne beacon.[4]

The Mark III G (R) set was an attempt to increase the degree of universal application of I.F.F. equipment. The various operational requirements which occurred after production of the original Mark III resulted in modifications on the production lines in both the United Kingdom and the United States of America, a total of eight variants of Mark III being produced.[5] This led to non-standardisation, with consequent loss of ease of maintenance and flexibility in operations.

Operational Performance of the Mark III System

By the end of June 1943 it was possible to gain some impression of the performance of the I.F.F. Mark III identification system from its operational use. Its most important advantage was the degree of universality it made possible.[6] It provided a means by which any ground radar equipment or any aircraft or ships, equipped with the requisite interrogator/responser facilities,

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[1] The type numbers given to this set in the Royal Air Force were :—
12-volt—R.3120 24-volt—R.3121.

[2] 'Lucero' was an interrogator/responser designed as an adjunct to centimetre radar airborne search equipments to enable I.F.F. and 1½-metre wavelength radar beacons to be interrogated, and to present the responses on the indicator of the main radar equipment.

[3] 'Notes on I.F.F. and Radar Beacons', A.H.B. IIE/181, p. 32.

[4] For operational application of Rooster see Volume VI.

[5] Appendix No. 9 gives a list of these I.F.F. sets and a brief description of their use.

[6] A.M. File C.S.15052, Encls. 10A and B.

could identify any aircraft or ship carrying I.F.F. Mark III or III G. The range at which I.F.F. Mark III in an aircraft could be observed at the C.H. stations was unfortunately not more than 100 miles, even with high-flying aircraft. This was substantially less than the maximum search range of the stations concerned and was therefore a handicap, but the same disadvantage fortunately did not apply to C.H.L. and G.C.I. stations. The difficulty of identifying aircraft in areas containing strong concentrations of activity was a much more serious deficiency in the system, for in 1943 the Allies were employing large numbers of aircraft over North-West Europe. The over congestion of the Mark III system was most evident during periods of great activity. The ground and ship-borne interrogator/responsers received so many I.F.F. responses that the trace of the I.F.F. display tube showed one continuous mass of echoes through which it was impossible to recognise any one individually. This appearance of the crowded responses on the display was known as I.F.F. clutter.

The first and chief factor in producing clutter was over-interrogation. With a large number of aircraft operating in one area with their I.F.F. transponders switched on, all would be triggered by one ground interrogator and clutter was the inevitable result. This was not always important because C.H. and C.H.L. stations were frequently unable to observe individual echoes when plotting large Allied bomber raids leaving or returning to the coast. One single hostile aircraft which happened to be present among the others could not be distinguished in any case. I.F.F. clutter was still troublesome, however, when the concentration of aircraft was not sufficiently great to congest the main radar search display. This suggested that there were factors other than simple interrogation which caused clutter on the I.F.F. display.

One such factor was mutual triggering or ringing round. It was possible for one I.F.F. set to trigger another in its neighbourhood. Because I.F.F. aircraft transponders had a band width of some 6 megacycles per second, this could happen if two sets were tuned to slightly different frequencies. It was therefore possible for the transponders to interrogate one another independently of the ground stations, thereby causing a cumulative interference which ceased only when the aircraft moved out of range of each other. The possibility of this effect had been considered during the development of the set at the Telecommunication Research Establishment. The matter had obviously grave implications; in fact the T.R.E. scientist in charge said that it was 'enough in itself to condemn the whole of the Mark III system as at present contemplated.'[1] It was considered during development that the trouble had been eliminated by reducing the sensitivity of the transponder without seriously affecting the overall performance.[2] Nevertheless, when a large number of I.F.F. sets were working in one neighbourhood, complex mutual triggering effect occurred. A further cause of clutter on the I.F.F. displays of the ground search stations was the triggering of I.F.F. sets by C.H.L. stations working on 193 megacycles per second. Although this was 6 megacycles per second away from the identification band, it appeared that the band spread of the C.H.L. transmitter and the I.F.F. aircraft transponder were sufficient to permit overlap. There was also evidence that aircraft engine ignition systems had caused random triggering of the I.F.F. transponder.

[1] T.R.E. File D.1203/1, Encl. 61c.

[2] A.H.B. IIE/181, p. 41.

Whatever the causes, the problem of clutter was so serious when air activity was fairly high that it often rendered the Mark III system virtually useless. It was therefore necessary to reduce interrogation at the search stations to a minimum, keeping the interrogators switched off when not required in order to prevent the clutter caused by over-interrogation.[1] Meanwhile efforts were made to reduce the beam width of the ground interrogators to its finest practical limit. This was not just a problem of producing the finest beaming system possible, because the airborne I.F.F. responder had to remain in the beam of the interrogator at least for the time interval of its own frequency sweep if a response were to be ensured. An alternative method of reducing clutter on the ground I.F.F. displays was to reduce appreciably the number of I.F.F. transponders switched on at any time, that is, by strictly controlling the occasions of its use by aircraft and ships. It was subsequently essential to adopt such control during the early phases of operations covering the Normandy landings in 1944.

Security

There were two main security problems arising from the operational use of I.F.F. Mark III: [2]

(*a*) The possibility that the enemy might interrogate the Mark III airborne transponder and use the responses to detect and identify Allied aircraft, and

(*b*) the possibility that the enemy might manufacture copies of the set and fit them in his own aircraft, or ships, which could then pass as friendly. The fitting of detonators in I.F.F. sets did not in practice entirely remove the risk of the set falling into enemy hands.

To offset the first risk, Bomber Command requested permission on 7 July 1943 to switch off I.F.F. when its aircraft were proceeding towards enemy territory, to prevent the interception of I.F.F. Mark III signals giving early warning of raids to the enemy.[3] Fighter Command, operating the radar home chain for the defence of the United Kingdom, raised no objection and the Air Ministry accordingly amended the I.F.F. regulations so that aircraft of Bomber Command were permitted to keep I.F.F. switched off when flying by night to enemy-held territory, so long as they remained above 5,000 feet.[4]

The second danger was felt to be imminent early in 1943 when a British I.F.F. Mark III equipment fell into German hands, and the prospects that use might be made of it caused grave concern in the United States.[5] Proposals were made to abandon the Mark III programme in favour of the American system, I.F.F. Mark IV, for fear of enemy airborne interrogation of I.F.F. Mark III. It was pointed out, however, that Mark IV was equally vulnerable operationally and that a new system, Mark V, already being designed, would be introduced just as soon as the scientists had solved the complex problems involved. The possible use of I.F.F. Mark III in enemy aircraft and ships was considered to be a very real danger because it would have caused confusion to the whole

[1] A.M. File C.S.15052, Encls. 26A and 42A.

[2] A.H.B. IIE/181, p. 44, para. 2(*a*) and (*b*).

[3] A.M. File C.S.3062/II, Encl. 72B. [4] S.D.158. [5] A.M. File C.S.22208, Encl. 51A.

identification system. It was felt that the six codes available were insufficient to guard against such a situation ; something offering more permutations was required so that the code could be changed from day to day or even from hour to hour.

The two major limitations of the Mark III technique at the end of 1943 were its weakness in congested conditions and its lack of security.[1] There were two remedies, either to patch up the existing Mark III system or to devise an entirely new method of interrogation. Both these courses, were, in fact, adopted. All feasible steps were taken towards reducing clutter, and in Great Britain development work continued at the research establishments on new variants of the Mark III aircraft transponder.[2] In the United States, with British assistance, efforts were concentrated on research and development of the new Mark V system.

I.F.F. Mark III in the Mediterranean Theatre

Air activity was generally on a smaller scale in the Mediterranean area than over North-West Europe and the south and east coastal areas of England. During April and May 1943 Mark III ground interrogator/responsers and aircraft I.F.F. sets were being received in North Africa and Malta for fitting to Mediterranean Air Command ground search stations and aircraft for use in the invasion of Sicily.[3] Naturally, with new equipment in a theatre remote from the United Kingdom, teething troubles were experienced, but later, as experience was gained with the equipment, some assessment of the efficiency of the system became possible.

A series of observations was made during the period 27 February to 17 March 1944 at radar stations and I.F.F. monitoring units in No. 338 Wing of the Mediterranean Allied Coastal Air Force by the Operational Research Section.[4] Conditions were static and units far from the tactical area. For checking the performance of aircraft I.F.F. equipment special airfield ' snoop ' sets were installed.[5] The efficiency of the Mark III aircraft installation was found to be between 85 per cent. and 90 per cent. when interrogated. The loss of more than 10 per cent. was therefore attributed to pilots forgetting to switch on, and to unserviceable I.F.F. sets. In order to check the efficiency at the radar stations, six selected ground stations kept special records of all their I.F.F. interrogations during the same period. Analysis of their results gave an operational efficiency of 75 per cent. for these ground stations in conjunction with the airborne efficiency of 85–90 per cent. It would appear therefore that there was a further loss of approximately 10 per cent. by the ground radar stations, attributable either to poorly adjusted interrogator/responser equipment or to peculiarities of the I.F.F. radiation pattern. The analysis was carried a stage further by a check of the reports received at the filter room from all stations in the area. From a large number of daily observations the overall

[1] A.H.B. IIE/181, p. 46. [2] A.M. File C.S.15052, Encl. 20A.

[3] A.H.Q. Malta File MS.5491/Sigs. R.D.F., A.H.B. II J5/113/1/10, Encl. 31A.

[4] A.M. File C.S.15052, Encl. 53A.

[5] The airfield snoops consisted of either A.S.V. Mark II sets suitably installed to monitor the I.F.F. Mark III equipment in aircraft, or Light Warning sets sited near airfields for the same purpose.

efficiency was estimated at about 60 per cent. It is of interest to note that a loss was also occurring in the various reporting links from the radar search stations to the filter room.

From these analyses it can be seen that the Mark III system was by no means perfect in 1944, even in the Mediterranean theatre. Under the best circumstances aircraft efficiency did not quite attain 90 per cent, while the ground interrogator equipment could obtain an average of 75 per cent under this aircraft efficiency.[1] There is no doubt that the losses of approximately 10 per cent airborne and 10 per cent ground efficiency were due largely to the human element. What this inefficiency of the Mark III system meant in terms of practical air defence may be gained from consideration of its reaction on Allied fighter defences. Over the period 24 November 1943 to 29 March 1944 the Mediterranean Allied Coastal Air Force made 2,300 fighter sorties, of which 925 or 40 per cent were sent against aircraft subsequently recognised as friendly. This effort was wasted solely because of poor identification in circumstances which were favourable to good I.F.F. working.

I.F.F. Mark III in the Landings in North-West Europe

In planning the assault on the Normandy coast it was foreseen that indiscriminate use of I.F.F. Mark III would cause a complete breakdown of the entire system because of simultaneous operation of interrogators and transponders by naval, air and ground forces in Southern England, the English Channel area and the assault area of the Normandy coast.[2] Had general use of I.F.F. Mark III been permitted it would have resulted in the complete obliteration of all I.F.F. displays by clutter. Stringent restrictions on the use of I.F.F. were therefore issued. The restrictions, imposed primarily in order that the important identification requirements of the Royal Navy might be met, were such that I.F.F. was virtually unused by the Royal Air Force during the first nine weeks of the operation, except by aircraft operating independently of the main air concentrations. The necessity for such restriction of the radar identification system was in itself an indictment of the Mark III technique.

When the Normandy bridgehead expanded, the concentration of transponders and interrogators decreased and some relaxation of the restrictions on the use of I.F.F. Mark III was possible. Minor relaxations were introduced on 12 August 1944 and regulations for the use of I.F.F. for the North-West European theatre of operations as a whole were brought into force during November 1944. Further issues of these regulations, three in number, eased the restrictions still more before the end of the war, but nevertheless certain limitations still remained.[3] Over-interrogation was prevented by allowing only one ground search radar station in each group to act as I.F.F. interrogator guard station. This station was permitted to interrogate continuously with the beam type interrogator aerial system, on a frequency ordered by Headquarters, Allied Expeditionary Force, to prevent mutual interference. Other ground search stations operated their I.F.F. interrogators for the briefest possible periods consistent with operational requirements.

[1] M.A.C.A.F., ORS/5/2/2, 7 April 1944.

[2] S.H.A.E.F. Air Signals Report on operation 'Overlord' Section XXV, A.H.B. IIE/159.

[3] A copy of the final regulations in operation for the last month of the war gives some idea of the limitations imposed on the use of I.F.F. Mark III. It is included in Appendix No. 10.

For the Base Defence Group, No. 85 Group, the task of picking out a hostile aircraft was formidable. From a sample of records of No. 24 Sector of the Base Defence Group between 15 October and 30 November 1944, some idea of the preponderance of friendly air traffic may be gained. During this period of, 16,609 filtered tracks 99·23 per cent were categorised as friendly; of the remainder 0·5 per cent were hostile and the balance 0·27 per cent unidentified. The number identified as friendly, however, reflected little credit on the I.F.F. Mark III system. From a sample taken in November for one week, only 1 per cent were identified by I.F.F., 46 per cent from movement information, 18 per cent were recognised by fighter aircraft under G.C.I. control, and the remainder by the dubious method of track behaviour, almost guesswork. From October 1944 to March 1945, 54 per cent of the attempted interceptions controlled by G.C.I. stations of No. 85 Group were wasted on friendly aircraft. The ground-to-air interrogators on the G.C.I. mobile stations available during most of the campaign were practically useless despite determined efforts on the part of the Post Design Service to devise improvements to the equipment.[1]

The night fighter aircraft of No. 85 Group relied almost entirely on Canary for individual recognition by their ground controller. In the case of the G facility, the pilot was genuinely interested in its success, whereas in the ordinary I.F.F. system the user might be uninterested. As a result, the efficiency of ordinary I.F.F. Mark III was never up to the level of efficiency of the G facility. During one week in December 1944 only 68 per cent of requests for Canary from ground stations met with satisfactory response. After this low figure was pointed out to the squadrons, a second week's check also in December showed an advance to 81 per cent indicating, as in the examples taken from the Mediterranean area, that the human element played the largest part in reducing the efficiency of the Mark III system of identification, although its technical shortcomings would have prevented it from being infallible.

The experience of the campaign in North-West Europe showed that the requirement in identification had not been met. During the campaign itself, when it could be accepted that the failure of the identification system would not materially lengthen the war, the assistance that the radar screen could give without perfect identification was welcomed. But the expanding applications of search radar during the war, and the steady increase in the numbers of ships and aircraft to be identified, caused many complications in the problems of identification which were never resolved. The Mark III system was used on many occasions to good advantage, but it was far from perfect. The Allies were working on the development of a more satisfactory system, the Mark V, but it was not available during the war period.[2]

The need to distinguish between friendly and hostile aircraft presents a permanent problem which is continually being complicated by developments affecting air warfare. Improvements in the operational range, speed and height of aircraft, have multiplied the difficulties of interception whilst the devastating effects of atomic bombs have made it vitally necessary to prevent even isolated raiders from reaching their targets. The risks are now so great that there cannot

[1] 2nd T.A.F. O.R.S. Report No. 41. A.H.B. IIF/101/1.

[2] Some details of the essentials of the Mark V system are given in Appendix No. 11.

be any alternative to the need for the earliest possible destruction of every unidentified aircraft in time of war. Hostile aircraft, however, offer only fleeting opportunities for interception and attack and it is therefore essential to provide at least for the positive and instantaneous identification of our own aircraft. This should avoid wasting the resources of the air defence system in any methods of attack against friendly aircraft. It is doubtful whether the I.F.F. system of the Second World War would be adequate for future requirements, since the need is for a secure method of identification which cannot be reproduced by an enemy, even though he may be in possession of the airborne equipment used.

Part III

AIRCRAFT INTERCEPTION

PART III

Introduction

After the London air raids of the 1914–18 War, the importance of searchlights was continually emphasised as the sole means of attempting to make good the limitations of the pilot's vision by night. In 1935 the Defence Policy Requirements Committee stated, 'Without searchlights, the operation by night of fighter aircraft and anti-aircraft guns would be severely crippled, and the interception of the enemy bomber would become a matter of chance.'[1] The force of this pronouncement became unpleasantly clear during the next five years as the capabilities of bomber aircraft rapidly improved, and as their greater operational height placed them beyond the reach of illumination. In July 1939, the Air Officer Commanding-in-Chief, Fighter Command[2] was receiving most discouraging reports of the inability of searchlights to pick up and hold aircraft painted matt-black at heights over 10,000 feet. 'This gives additional urgency' he said 'to the need for pressing on with the new method of night interception.'[3]

The main feature of the new method was an airborne radar set which would enable the night-fighter pilot to locate and pursue the bomber in the dark. It was hoped that Sector Control, or some modification of it, would be sufficient to guide the fighter close enough to the bomber for the airborne set to be used. For a whole year, successive versions of the set failed to provide the range and scope necessary to give operational success in conjunction with existing methods of ground control. In common with many other radar devices, the urgency of its requirement for operational use led to its introduction into the Service in a form which was known to have technical and operational limitations. During the last six months of 1940 another improved version was introduced together with a faster and more heavily armed night fighter. With the help of more accurate ground control, and assiduous practice by aircrews to master the new technique, heavy losses were inflicted on German night bombers in the spring and summer of 1941. Thereafter, in the same and in more advanced form, the airborne equipment was successful in the Mediterranean theatre, in India and in North-West Europe.

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[1] Defence Policy Requirements Committee, 1935, Paper No. 2.

[2] Air Chief Marshal Sir Hugh Dowding.

[3] Fighter Command File S.16638, 10 July 1939.

CHAPTER 8

EARLY DEVELOPMENT OF A.I.

The first memorandum on radio pulse technique for the location of aircraft, as submitted to the Committee of Scientific Survey of Air Defence by Mr. R. A. Watson Watt on 26 February 1935, contained no suggestion of developing airborne radio-location equipment. Attention was focussed at that time on exploiting the new technique for long-range location of aircraft at coastal ground stations. Not many months passed, however, before it was realised that the radio pulse technique might also be applied to the location of bombers directly from the defending aircraft and on 25 February 1936, at the 16th meeting of the Committee for Scientific Survey of Air Defence, Mr. Watson Watt made proposals for airborne radar, giving theoretical details of the technical approach to be made to the problem.[1]

Bawdsey Research Station opened in January 1936 as a centre for research work and headquarters for the organisation of a chain of radar ground stations. The ground radar research was given the nomenclature R.D.F.1 and the airborne research R.D.F.2. With the small scientific staff available, work could only proceed on R.D.F.2 at the expense of the higher priority long-range location experiments. Work on the airborne side continued to receive attention however, and a team of three scientists studied the applications of radar principles to aircraft equipment for the detection of other aircraft.[2] The 'airborne group'[3] had not been working long before they were interrupted to help with ground radar which had failed to give a completely convincing demonstration during the first R.D.F. Air Exercise in September 1936, and it was only in November 1936 that research started in earnest.[4] The experiments with radar ground equipment had been conducted on a wavelength of 26 metres using relatively wide pulses (20 micro-seconds). Such a system was unsuitable for airborne equipment because the 26-metre wavelength required aerials much too large for fitting in aircraft and the pulse-width required reduction for shorter range work. In addition, methods of homing both in azimuth and elevation which would be operationally practicable were required. Perhaps the most formidable task was that of reducing the cumbersome mass of the ground station radar equipment of that time to the small size and weight which would be acceptable in a fighter aircraft.

During the first half of 1937, research continued with little tangible result. A survey of all the existing types of transmitter valves in the frequency region about 50 megacycles per second was undertaken and several were tried out in the various forms of transmitters designed, but without success. Some

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[1] A.M. File S.42439, Encl. 1A. [2] *Ibid.*

[3] The group consisted of Dr. E. G. Bowen, P. A. Hibberd, A. G. Touch (and for a short time, S. Jefferson) in 1936.

[4] Radar Papers—Airborne, Dr. A. G. Touch, p. 1. A.H.B. IIE/187.

progress was made when a modulator giving pulses of approximately two microseconds duration was made, but the size and weight of the whole transmitter was still too great for an aircraft installation. Less difficulty had been encountered in producing a receiver, and when in June 1937 no practical solution had yet been found to the airborne transmitter problem, experiments were made with a system which was known as R.D.F. 1½.

In this technique the aircraft carried a radar receiver only: its time-base was locked to the pulse received direct from a C.H. station ground transmitter. Provided that the disposition of the target aircraft was favourable in relation to the locations of the C.H. station and of the searching aircraft, the radar echoes reflected by the target aircraft could be picked up and displayed. The method had obvious tactical limitations and it also had a technical one, for although the target aircraft could be detected by radar means, no direct range measurement could be made. Nevertheless, the achievement of radar reception in the air gave great encouragement to the research party, and revived their flagging confidence that the airborne project was practicable, particularly when it was found that the maximum air to air range amounted to as much as eight miles. A renewed attack on the major research problem produced a self-modulating or 'squegging' transmitter which, not requiring a modulator, was simple and light in weight. Although the original model was unstable in performance, it served as a basis of design for all the early airborne transmitters.

Using a new triode valve, a squegging transmitter was built during July 1937 giving nearly 100 watts peak power on a wavelength of one metre. In August, the crude equipment was hopefully installed in an Anson aircraft. The transmitter aerial was poked through the escape hatch, while the receiver aerial was fitted inside. To the great joy of the experimenters, radar echoes up to 5 miles range were obtained from a 2,000-ton freighter.[1] Thereafter for more than a year, attention was focussed largely on developing the airborne radar equipment for use in ocean search, a method which became known as A.S.V., but many valuable lessons were learned which were applicable to A.I., as the airborne radar search equipment was termed.[2] No A.I. equipments were yet built specially, but research continued steadily throughout 1938.

Research scientists were handicapped in those days by the need to use aircraft on short-term loan from Service units. These were fitted with the experimental and highly secret equipment which needed to be extracted and refitted whenever the aircraft were changed, and research and development suffered. In addition, it was most desirable for security reasons that the nature of this very secret work should not be disclosed to the personnel of the units from which the aircraft were loaned. A special flight was therefore formed at the Aeroplane and Armament Experimental Establishment at Martlesham Heath in May 1938, comprising one Harrow, two Battle and two Anson aircraft, to provide air co-operation with the Bawdsey Research Station in much the same way as Flights had been provided for co-operation with Coast Defence

[1] 'Central Radio Bureau preparation of material for disclosure to the public'.—The Harley narrative, Part 10. A.H.B. IIE/90.

[2] A.H.B. IIE/187, p. 3. Further details of the development of A.S.V. are given in Volume VI.

Artillery.[1] With the provision of the special flight, research flourished and good progress was made although facilities at Martlesham were far from adequate for the scientific staff, who had very little laboratory space for making pre-flight checks and modifications to the apparatus.

Methods of radar direction-finding with airborne equipment were showing promise of success towards the end of 1938. One method, known as 'lobe-switching,' may be regarded as another milestone in the early development story, ultimately becoming the basis for all the first A.I. and A.S.V. sets. In this method, a mechanical switch connected the port and starboard aerials alternately to the receiver, and synchronously controlled the signal obtained so that it was displayed on opposite sides of the cathode ray tube vertical time base. The difference in signals received at the two aerials in this manner gave an indication of the direction of the target observed. Almost simultaneously with this development, another method of direction-finding emerged from research using a rotating half-wave dipole aerial common to both transmitter and receiver. This method also employed a C.R.T. for the display of impulses reflected from the 'target aircraft.' These impulses were superimposed on a rotating radial timebase synchronised with the aerial. The afterglow on the tube gave a rough bearing of the target.[2] This technique was only partially successful because the rotating aerial was too large for air installation, and it was decided to concentrate on the lobe-switching method. By the middle of 1938 a general idea of the requirements for both the transmitter and receiver had been decided, and the first specifications were drawn up at Bawdsey Research Station. They were re-drafted in October, and during the autumn of 1938 contracts were given to Cossors for the receiver and to Metropolitan-Vickers for the transmitter. By February 1939, eighteen transmitters had been delivered but the receivers were never satisfactory, and were not accepted.[3]

The first three months of 1939 were a period of great activity in the development of the airborne search radar equipment. Greatly improved receivers resulted from the use of the Pye television chassis. Effective radio frequency switches were developed, but perhaps the greatest step forward was in the work on pulse transmitter valves which led to the evolution of a suitable valve for Service use.[4] The increasing tempo of scientific research was matched by the flood of practical applications of airborne radar. In aircraft fitted with this early equipment it was demonstrated that towns could be distinguished, air navigation by contours was a possibility, and that bombs falling from aircraft could be tracked in their fall.[5]

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[1] A.H.B. IIE/90, Part 10. In August 1938, the Experimental Co-operation Flight was re-named 'D' Flight, Aeroplane and Armament Experimental Establishment (A. and A.E.E.).

[2] The method was revived and improved later for use with centimetre wave A.I. technique.

[3] Dr. A. G. Touch described these receivers as 'out of date, very heavy, did not work, useless.' A.M. Files S.45970, Encl. 2A and S.48456, Encl. 2A. Inter-Service Committee on R.D.F., 2nd Meeting.

[4] This work at G.E.C. on a thoriated tungsten filament valve for pulse working resulted in the V.T.90 valve. This gave a saving of 150 per cent. in the transmitter input power required—an extremely important development because the power requirements had to be reduced to a minimum to keep down the weight and size of the aircraft generators.

[5] From such experiments came H2S and the pulse radio altimeter.

The several possible practical applications of the airborne search radar equipment were not allowed to distract attention from the main air defence requirement of A.I., and during May 1939, the first experimental A.I. equipment was fitted in a Battle aircraft. A 50-cycle power supply was used; the transmitter was housed in the port wing and fed a half-wave horizontal antenna placed along the leading edge. Four receiving antennae completed the aerial system, two quarter-wave elements were fixed on either side of the engine (with the leading-edges of the wings acting as reflectors) for search in azimuth, with two half-wave elements one above and one below the starboard wing for search in elevation. At first, the search for targets was made in azimuth and elevation separately, since it was necessary to switch alternately from one pair of aerials to the other in order to search in the horizontal and vertical planes. By mid-June 1939, a suitable four-way switch had been produced and both the azimuth and elevation of the target could be determined. Two cathode ray tubes were used with the receiver in the well of the aircraft for the simultaneous observation of azimuth and elevation.

On 16 June 1939, Mr. A. P. Rowe, the Superintendent, Bawdsey Research Station wrote of research progress on A.I. :—[1]

'This week, for the first time, equipment has been successfully demonstrated in a Battle aircraft using a Harrow as a target. The equipment shows the range of the target and indicates clearly the direction in which the defending fighter needs to turn in azimuth and elevation in order to home to a hostile aircraft which is somewhere in a wide zone in front of it: no indications are received if the hostile aircraft is behind the defending aircraft. In its present form, two 3-inch observing tubes are necessary, one giving range and elevation and the other range and azimuth; it is therefore unsuitable for a pilot's use. Technically, the demonstration with the Harrow as a target is most striking, but more power is needed to provide similar results with small targets. (Smaller targets are not however of first importance.) When over land, indications are only given when the range of the target is more than 1,000 feet and less than the height of the defending aircraft above the ground; this latter limitation does not apply over the sea, which is a further argument for interception at sea . . . It is felt that the two-tube equipment now available in a Battle should be demonstrated to a number of experienced Service pilots whose views should be obtained; few civilians have the experience necessary to assess the value of the equipment to the Service in its present form.'

The installation was demonstrated in the air to certain members of the Air Defence Research Sub-Committee of the Committee of Imperial Defence[2] and to the Air Officers Commanding-in-Chief, Fighter and Bomber Commands during the first week in July 1939.[3] Air Chief Marshal Sir Hugh Dowding reported to the Air Ministry on 10 July, after his flight with a scientific officer in a Battle aircraft in which he had acquainted himself with the progress of A.I.[4] 'I was very much impressed' he wrote 'with the potentialities of the apparatus (although of course it was installed only in a "lash up" form). The range

[1] A.M. File S.46286, Encl. 17B.

[2] These were Sir Henry Tizard, Professor Lindemann (later Lord Cherwell and the Rt. Hon. Winston Churchill.

[3] A.M. File S.1619, Encl. 1A.

[4] D.H.O. Folder, R.D.F. Stations, A.H.B. IIH/148, Encl. 53A.

and approximate position of the target aircraft were clearly indicated, and I formed the opinion that an approach in the dark could be easily effected after a small amount of training and practice, provided that an astern position within range of the target could be attained.' He went on to confirm two limitations of the apparatus; first, that the maximum range was dependent upon the height of the operating aircraft above the ground because the echo from the target aircraft became lost in the echoes from the ground, and secondly, that the echo from the target aircraft became lost in the indications of the emitted rays at a range of 900 feet. He desired a much closer minimum range.

It is interesting to note in view of later developments that the Air Officer Commanding-in-Chief, Fighter Command showed great foresight in his comments on the possibilities of installing A.I. in single-seater fighter aircraft. Having heard that the research scientists at Bawdsey were contemplating an A.I. presentation on a single cathode ray tube to make the apparatus available for single-seater fighters, he was strongly of the opinion that there was little possibility of a pilot being able to fly his machine, look at a radar tube, and search for a target aircraft in a single seater machine, and he advocated a specialised type of 2-seater night fighter. He thought the Defiant aircraft would be unsuitable owing to the gunner's tightly wedged position, and suggested the Blenheim aircraft would make an admirable 'test bench' for the apparatus. He favoured the Beaufighter aircraft (then not off production) but recommended that three or four sets of the apparatus as it then existed should be provided for use in Blenheims in Fighter Command so that the Air Staff could, as soon as possible, determine and issue a specification for a radar-fitted night-fighter aircraft.

The development of night fighter tactics for aircraft fitted with A.I. was uppermost in the thoughts of the Air Staff. The report from the Commander-in-Chief, Fighter Command, led to the highest priority being given to the provision of sufficient A.I. equipment to enable selected Royal Air Force fighter aircraft to be fitted with equipment very similar to the experimental installation in the Battle aircraft.[1] On receiving Sir Hugh Dowding's report on the A.I. demonstration, the Deputy Chief of Air Staff wrote in a minute on 14 July 1939:[2] 'In view of the promising nature of the recent trials of the R.D.F. air to air sets installed in the Battle at Martlesham and in view of the present relative weakness of our night defence, it has been decided that Fighter Command should proceed with the development of R.D.F. air to air tactics on the highest priority and that we should be prepared at short notice to equip one Blenheim 5-gun fighter squadron with this equipment.' Instructions were thereupon given that 21 A.I. sets were to be constructed by hand, six to be delivered to Fighter Command and the remainder held against any emergency that should arise. Blenheim aircraft were to be prepared electrically to receive the sets and the first four of them to be delivered to No. 25 Squadron, Hawkinge.

[1] The change of installation from Battle to Beaufighter was unfortunately to have serious repercussions on the direction-finding qualities of the aerials, due to the more irregular frontal profile of the twin-engined aircraft in comparison with the single-engined one.

[2] This question of the speedy implementation of the policy for A.I. equipped night fighter aircraft had also been raised by Mr. Winston Churchill on 11 June 1939 at a meeting of the Air Defence Research Sub-Committee of the Committee for Imperial Defence, when he had demanded the highest priority for this development. A.M. File S.45970, Encl. 46A.

Although sufficient transmitters and generators were available to fit the first ten aircraft, and contracts for the remainder had been placed with Metropolitan-Vickers, the receiver position was not even thus far advanced.[1] Only the experimental types existed. Pye Radio had already produced a prototype receiver in their research department and an order for 30 receivers was given, delivery to be effected in nine weeks. Financial concurrence for this programme was granted on 19 July 1939, and the work was given priority over everything at the contractors except C.H. station radar equipment. The production of this equipment in nine weeks was considered a very creditable achievement, since speed was the governing factor.[2]

The Royal Aircraft Establishment was to undertake the electrical screening of the aircraft, the fitting of alternating current generators and modification of oil filter units on absolute priority over all other work. Construction of the equipment, brackets and couplings was already in hand. The aircraft were then to fly from R.A.E. to Martlesham for the installation of the A.I. transmitters, receivers and aerials which was to be done under the direction of Bawdsey scientific personnel, who would also supervise the air testing of each installation and train the pilots. The hurried nature of this programme made it impossible, however, to install the apparatus in such a way that it could be readily transferred from one machine to another. It was therefore decided that the 21 sets should be installed in their respective aircraft and not held in reserve for unit installation. Six aircraft were to be allotted to No. 25 Squadron to enable tactical development to be undertaken and the remaining 15 Blenheims were to be held in store at an Aircraft Storage Unit.

Fitting began at Martlesham just before the war.[3] The equipment consisted of :—

(*a*) A pulse transmitter operating at a frequency of 200 megacycles per second giving a peak output of one kilowatt. This transmitter was installed forward in the navigator's position in the perspex nose. Its output was fed into a single half-wave dipole aerial fixed horizontally on the nose of the aircraft.

(*b*) A superheterodyne receiver with radio frequency and mixer stages operating on 200 megacycles per second and a 45 megacycles per second intermediate frequency amplifier with a band width of 3 megacycles per second. The azimuth aerials were two quarter-wave horizontal aerials fitted to the outer sides of the port and starboard engine nacelles in front of the leading edge of the main planes, the latter acting as reflectors. For searching in elevation, two horizontal half-wave aerials were placed above and below the starboard mainplane. The input signals were fed to the receiver from these four receiver aerials in turn, and the output signals to two cathode ray tubes. These tubes gave measurements of the range, azimuth and elevation of aircraft in the vicinity.

(*c*) An alternator of ingenious light-weight design provided power for the whole installation, rated at 500 watts output at 80 volts between 1,200 and 2,400 cycles per second. A carbon pile voltage regulator was employed.

[1] A.M. File S.45970, Encl. 24A.
[2] A.M. File S.54690, Min. 2.
[3] A.M. File S.1572, Encl. 7A.

The switches, cathode ray tube indicators, receiver and associated power unit were all mounted on a plywood board fixed vertically on the side of the pilot's dashboard. The indications of the range and position of other aircraft were given on the cathode ray tube between a minimum range of 500 feet and a maximum range which was equal to the height of the A.I.-fitted aircraft in flight. The accuracy of the range measurement was of the order of hundreds of feet, whilst the bearings in azimuth and elevation were within 5° when the target aircraft was in a head-on position.

At the outbreak of war the three Blenheim Mark IV aircraft fitted with A.I. were in No. 25 Squadron at Northolt. On the night of 3 September 1939 one of the Blenheims was flying in the London region with a Bawdsey Research Station scientist acting as the A.I. observer.[1] At Northolt, Group Captain A. H. Orlebar carried out extensive tests on the A.I.-equipped aircraft and his comments indicate the haste and inexperience of installation work at that time :—

(*a*) The wrong aircraft had been chosen for the A.I. installation ; they should have been the short-nosed (Mark I) and not the long-nosed (Mark IV) Blenheims.

(*b*) The pilot could not use the A.I. indicators, and the equipment should have been fitted in the observer's compartment.

(*c*) The glow from the aircraft could be seen for many miles at night because of the bright illumination from the transmitter valves.

During October 1939 the indicator board was transferred to the observer's position, in order that he could tell the pilot, over the inter-communication system, the courses to steer in order to effect an interception. Modifications were also introduced to obviate the transmitter glow. A series of tests was made to see whether Royal Air Force operators could use the equipment and to investigate the possibility of making interceptions from various angles of approach. The Air Officer Commanding-in-Chief, Fighter Command was particularly anxious to get the right kind of men into the back seat of the Blenheim aircraft to operate the radar sets.[2] He wanted Voluntary Wireless Corps personnel if possible, and asked the Director of Signals at the Air Ministry to take up this point. The Commander-in-Chief of Fighter Command followed the progress of the development, both technical and tactical, with the closest attention and was supplied with daily reports on the operational tests. In addition, he visited the Bawdsey Research Station at least once a week in this period to observe progress.[3]

Although A.I. was in Service use for tests and trials during the first autumn months of the war it was not yet being employed against the enemy. Nevertheless, early development of this airborne radar equipment had reached a stage which was considered suitable to embark on production. The orders for the hand-made A.I. Mark I equipment had been increased to 144 and the manufacturers were warned that about 1,000 production models would be required. It was intended to fit all Blenheim fighter aircraft, and later the Beaufighter as soon as it was available.[4]

[1] A.H.B. IIE/90, Part 10.
[2] A.M. File S.45970, Encl. 82A.
[3] A.H.B. II/E187, p. 5.
[4] Inter-Service Committee for R.D.F., 4th Meeting, 19 September 1939.

CHAPTER 9

$1\frac{1}{2}$ METRE A.I.

Introduction of A.I. into the Royal Air Force was anticipated enthusiastically. At a conference at Fighter Command on 23 September 1939 the Air Officer Commanding-in-Chief, spoke of the remarkable progress made with A.I. 'A new chapter in night-fighting has started,' he said. The new chapter was, however, destined to open in slow tempo.

A.I. Mark I

The initial impact of war set back the fitting of the first 21 Blenheim aircraft with hand-made models of A.I. Mark I, and the delay was further aggravated by the decision that Bawdsey was too vulnerable a location for a research station in war. The 'airborne group' of scientists was therefore moved to Perth on 7 September 1939. So far north they found themselves too distant from the A.I. fitting parties at No. 32 Maintenance Unit at St. Athan, South Wales, and another move was made on 5 November 1939 to that station. It was consequently November 1939 before even six Blenheims were fitted with A.I. apparatus and transferred for operations to Fighter Command airfields.[1] The tactics of their employment and the facilities required by their crews were already being given consideration, but at a meeting held at Headquarters, Fighter Command on 30 October 1939 the shortcomings of the hurried installation were revealed. Aircraft were coming off the production line without the necessary fittings to hold all the radio apparatus to be installed and the construction of the fittings and installation of the equipment were beyond the scope of the operational units. In addition, the various radio installations for A.I., for identification, and for radio telephony, caused difficulties with the aircraft electrical power supply system, and interference between them occurred.[2]

The jamming of the R.T. set then in use, the T.R.9D, by A.I. transmission was so serious that it was possible to use only one of the two radio equipments at a time. It was, of course, highly desirable that R.T. communication between the night-fighter and the ground control station should be continuous during each operational flight, but some compromise was necessary until a technical solution to the interference problem could be found. During the first stages of an attempted interception, therefore, when R.T. communication was essential for directing the aircraft to the neighbourhood of an enemy bomber, the A.I. set remained switched off except for the valve filament circuits. During the later stage when A.I. search was required there was no alternative but to dispense with communication with the ground station.

Technical examination showed that it was impossible to eliminate A.I. interference with the T.R.9D, which was a high frequency set, but fortunately the new V.H.F. equipment was about to come into service. This was also

[1] Two at Martlesham, three at Hornchurch and one at Debden, A.H.B. IIE/187, p. 6.
[2] A.M. File S.1572, Encl. 7A.

affected by A.I. interference but to a smaller degree, and by a slight modification and careful selection of operating frequencies the interference could be removed. During the first winter of the war, therefore, the Blenheim night fighters had to operate under the disadvantage described. Apart from a few enemy reconnaissance aircraft, the nights during the initial period of the war were singularly free from hostile activity. Enemy night operations started in mid-November 1939, when the German Air Force began mine-laying, particularly around the mouth of the Humber, off Harwich, and in the Thames Estuary. The raids were made at low level and were therefore often below the radar coverage of the C.H. stations.[1] One result of the raids was the urgent production of C.H.L. low-looking radar stations; but these were not available until many months later. The first attempt to intercept a mine-layer was made in an A.I.-fitted Blenheim from Martlesham Heath on the night of 22 November 1939. Unfortunately the aircraft left the ground with the A.I. set incomplete. A successful interception resulted, but it was made entirely by visual means.

It was evident from trials that the range of A.I. Mark I was too short to enable fighters to locate enemy aircraft by independent search, and that a considerable measure of control from the ground would be required to direct them into close proximity with hostile raiders. The method of Sector Control used in daylight interception was not accurate enough to enable fighters to establish A.I. contacts. Experiments were being made to discover whether a radar officer could direct aircraft with greater accuracy by operating the C.H. radar set himself, measuring the range and distance of both fighter and bomber from the station, and giving instructions by R.T. to the fighter pilot. The technique was known as All-R.D.F. Interception.[2] Some success was achieved but a large amount of intelligent guess-work and imagination was required.

By December 1939 a method of ground radar control had been evolved and the instruction of ground sub-controllers began at Bawdsey. By night, however, attempts to intercept German minelaying aircraft with A.I.-equipped Blenheim fighters were unsuccessful although they were continued for three months. The failures revealed that the limited range of early A.I. equipment was not the only weakness. The shortcomings of ground radar apparatus, with its inaccurate height-finding facilities, made accurate ground control impossible. Added to this, the immaturities of a yet undeveloped system of direct control and of untried tactics hardly provided the circumstances in which experimental airborne radar could be successful. The failure of the anti-minelayer operations emphasised the need for more accurate control from the ground, but how this could be provided was still to be discovered. The problem of accurate ground control was referred by the Air Staff to the scientists, who were required to make systematic experiments and to devise equipment for giving continuous following of aircraft at all altitudes. From these experiments grew a year later the special radar equipment for ground controlled interception (G.C.I.) using night-fighter aircraft fitted with A.I. But for the time being, the problem was apparently insoluble until a greatly improved A.I. set could be produced.

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[1] A.D.I.K. Report 12/1940. A.H.B. II G/29.

[2] Until 1942, radar was known as R.D.F. Chapter 11 describes the All-R.D.F. Experiments. A.M. File S.43174/I, Encl. 61c.

Even if the ground control had been able to produce accurate juxtaposition of the night-fighter with the enemy bomber aircraft, A.I. Mark I was still incapable of low-level interception because its maximum range was limited to the height of the aircraft above the ground. Addressing the Chief of the Air Staff in December 1939, Sir Henry Tizard, his Scientific Adviser, wrote: 'The Director of Communications Development and I have been having a discussion about the interception of low-flying aircraft at night, and I think you might like to know our conclusions. We agree that the A.I. apparatus now being fitted to machines is quite unsuitable for the purpose. It was not designed to meet these conditions and we do not think you ought to rely on it in the least.'[1]

Another criticism of A.I. Mark I was the excessive minimum range. At short ranges the echo from the target aircraft was invisible because of interference on the cathode ray tube caused by the transmitter. It was considered that the pilot could not get close enough to the enemy aircraft by means of A.I. to enable him to make visual contact until this interference had been reduced. The operational life of A.I. Mark I was therefore quite short. On 10 January 1940 the Air Officer Commanding-in-Chief, Fighter Command, commented: 'The A.I. equipment of the "First 20" or Mark I type has now been tested in squadrons. As was expected, the Mark I equipment is of no operational value, but the sets are being used for training.'[2]

A.I. Mark II

After the extensive tests of A.I. Mark I at the beginning of the war, experimental work continued in the research laboratories of the 'airborne group.' It had been decided to develop a production model of A.I., a Mark II, similar in design to Mark I.[3] In October 1939 it was anticipated that some 300 sets would be manufactured by Christmas. E. K. Cole had begun work on an improved transmitter and Pye Radio were making the receiver embodying better time-base circuits and other improvements.[4] Of these, the most important was an attempt to reduce the minimum range of the equipment by 'suppressing' the receiver during the transmitter pulse. This tended to reduce the distance at the beginning of the time-base on the cathode ray tubes over which the transmitter pulse spread, thereby enabling the A.I. operator to read to a smaller minimum distance.[5] It was reported that a minimum range of as little as 400 feet had been obtained, but this was under laboratory conditions. The maximum range obtained still fell considerably short of Fighter Command's requirement of ten miles.

In January 1940 Dr. E. G. Bowen, the scientist in charge of airborne radar research and development, reported difficulties with the first installation. The suppression stage in the new type of equipment was found to be unsatisfactory when installed in aircraft and practical tests showed that the minimum range was still over 1,000 feet. Attempts at improvement were made, but a reduction beyond 800 feet could not be obtained. Dr. Bowen therefore suggested that the St. Athan fitting programme, initially planned for 300 aircraft, should be

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[1] A.M. File S.3081.

[2] A.M. File S.1572, Encl. 17A.

[3] Inter-Service R.D.F. Committee 5th Meeting, 26 October 1939.

[4] A.H.B. IIE/187, p. 6.

[5] A.M. File S.B.2141, Encl. 20A.

restricted to six and that the position should be reviewed when further experience had been gained. Fitting of the six aircraft began towards the end of February 1940, and five of the aircraft fitted were despatched to Nos. 25 and 600 Squadrons for test.

In February 1940 the Assistant Chief of Air Staff (Radio) urged the Air Officer Commanding-in-Chief, Fighter Command, to continue the use of A.I. in night-fighter Blenheim aircraft.[1] His argument was that despite the failure of A.I. against low-flying enemy aircraft, the modified equipment could still be useful for fighting at heights above 5,000 feet. This letter resulted in authority for three aircraft of each of Nos. 23, 25, 29, 219, 600 and 604 Squadrons being fitted with A.I. Mark II. The A.I. was simply to be used as much as possible for training purposes without interfering with operational commitments. Squadrons were advised that in spite of the shortcomings of the equipment they would gain valuable experience with the A.I., which would prove of great worth when a better type of apparatus was put into service. The aircraft fitted were not exempted from normal operational duties and little or no value seems to have been gained from this sprinkling of equipment.

To co-ordinate all the efforts being made to solve the night-interception problem, and to link up research and development to the stage of practical trials, a special committee termed the Night Interception Committee was set up in March 1940 under the Deputy Chief of Air Staff.[2] The terms of reference of the Committee were 'To co-ordinate all work on the problem of night interception, to initiate action as necessary to this end and to keep a close watch on progress in each line of development.' The proposals before the Committee at its inception covered a very wide field. They included interception by C.H.L. station control (which was abandoned after several trials), guidance of night fighter aircraft with C.H.L. controlled searchlights (also abandoned), detection of aircraft magneto radiation, infra-red detections, and other possibilities. Among these, A.I. took its place and was considered the most promising field for further development.

The Night Interception Committee decided at its first meeting on 14 March 1940 that there was a need for special aircraft within Fighter Command to carry out technical and operational trials, and continuous systematic experiments in interception.[3] The organisation of such a unit was put in hand forthwith, and it was formed at Tangmere on 10 April 1940 under the command of Wing Commander G. P. Chamberlain. It was initially named the Night Interception Unit, later changed to Fighter Interception Unit (F.I.U.). The Chief of the Air Staff was most anxious that the unit should start work 'as quickly as possible' and that 'the provision of the necessary aircraft and personnel should be on the highest priority, the provision of Blenheims taking equal precedence with the re-equipment of the operational fighter squadrons.' The unit was initially equipped with six Blenheim fighters. In addition, a scientific staff was

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[1] A.M. File S.3848.

[2] Night Interception Committee Papers, 1st Meeting, 14 March 1940. This Committee was renamed the Interception Committee in July 1940 and the Air Interception Committee in July 1941.

[3] A.M. File S.4211, 30 March 1940 and F.I.U. O.R.B.

attached to the unit, and laboratory and workshop accommodation was provided so that modifications to instruments could be done efficiently at the station. F.I.U. started the operational testing of A.I. immediately.

The Fighter Interception Unit played an important part in the introduction of A.I. and other technical equipment. The apparatus could be brought up to a certain stage of development by scientifically trained research teams, but the use of the equipment in Service squadrons inevitably brought in many new factors. These included the difficulties connected with tactical application, the operation of the instrument by inexperienced and comparatively unskilled persons, and the problems of day-to-day maintenance and 'tuning-up.' It was important that such difficulties should occur first of all in an organisation where the means were at hand to overcome them by modification of the equipment, scientific advice and sympathetic control. The F.I.U. provided the essential Service testing ground where technical apparatus could be finally developed for general introduction to squadrons.

At the date of formation of the Fighter Interception Unit, tests on A.I. Mark II were already being carried out for Fighter Command by No. 600 Squadron at Martlesham. In the squadron report, the minimum range was given as 1,000 feet and the maximum (using a Blenheim aircraft as target) was between 5,000 and 6,000 feet. The figures quoted, however, gave an optimistic idea of the capabilities of the equipment. The tests were carried out under almost ideal conditions, with an A.M.R.E. scientist acting as A.I. observer and making any necessary adjustments to the transmitter while in flight.[1] Such advantages could not be obtained during day-to-day operations, and the average level of A.I. performance in squadrons was necessarily inferior to these standards. In addition, the maximum range of A.I. quoted did not by any means give to a pilot the same advantage as an equivalent range of daylight visibility. The effective field of A.I. vision was restricted to a fairly narrow cone directly in front of the aircraft and unless the fighter found himself between 6,000 and 1,000 feet behind the enemy aircraft, and flying in the same direction at roughly the same height, he had very little chance of completing the interception. Outside this small cone of vision the direction-finding qualities were poor and it was almost impossible to hold an A.I. contact at wider angles. There was also a chance of ambiguous indications, caused by the irregularities in the field strength in different directions within the radiation pattern obtained with the Blenheim. It was quite possible for an A.I. operator to deduce that a target aircraft was in front and above, when in fact it was behind and below his own aircraft. It was clear that interceptions using the A.I. Mark II would be few and far between.

The question of the importance of a low minimum range caused a controversy at this stage between the scientists and Headquarters, Fighter Command.[2] The scientists were tackling the problem by modifying the existing equipments, but they did not share the view of Headquarters, Fighter Command, that excessive minimum range was the gravest shortcoming. In their opinion, it was more important to increase the maximum range and, perhaps most

[1] A.M. File S.4233, Encl. 21B.

[2] Part of the cause of the controversy, at least, was the difficulty of estimating accurately in the air the distance between the two aircraft.

important of all, to improve the reliability of the set. F.I.U. continued testing A.I. Mark II during May 1940 under varying conditions of visibility at night including moonlight, to estimate how many interceptions would fail through inability to obtain visual contact at the minimum A.I. range of 1,000 feet. The trials showed that when the A.I. operator brought the fighter to minimum range in bright moonlight with the moon behind, the target was plainly visible in silhouette although its exhaust flames were not so clearly defined. With the moon ahead, however, the pilot was unable to pick out the target aircraft visually when the A.I. operator had closed to the minimum distance of 1,000 feet. It was emphasised, too, that conflicting indications were frequently obtained because of the unstable performance of the equipment. Consistent results were difficult to obtain, and heartening successful practice interceptions were often speedily followed by complete failures.[1]

A.I. Mark III

Meanwhile, in February 1940, assistance had been requested from the main body of the Air Ministry Research Establishment in Dundee. Hitherto all the work had been done by the hard-pressed and isolated group at St. Athan, who were out of touch with the main stream of research. The transmitter of A.I. Mark II was discarded and replaced by one which was very similar (except that it was on a different frequency) to the A.S.V., Mark I transmitter, already in limited production for use in ocean search by Coastal Command. The new set, then termed A.I. Mark III, had an increased maximum range of 17,000 feet but contained flaws in the matters of minimum range, excessive pulse width, and cross-over in direction-finding or ' squint,' at certain angles of elevation. Some twenty sets were produced and fitted in short-nosed Blenheim aircraft.[2] The minimum range difficulty was tackled first by the Air Ministry Research Establishment which suggested two possible solutions, both based on modification of the same transmitter :—[3]

(*a*) By minor modifications to the transmitter and major ones to the receiver used in A.I. Mark III it was hoped to obtain a minimum range of 800 feet. This modification ultimately became A.I. Mark IIIA.

(*b*) By a major modification to the transmitter, using a second transmitter connected across the tuned circuit of the first to damp the tail of the pulses, it was hoped that the minimum range could be reduced to 600 feet. Only minor modifications to the receiver were required. This modification became known as A.I. Mark IIIB.

At the 4th meeting of the Night Interception Committee on 2 May 1940 it was decided to fit 100 Blenheim fighter aircraft with A.I. equipment on the highest priority, and production was begun.[4] The chairman of the Night

[1] A.M. File S.4579, Encl. 7A.

[2] A.H.B. IIE/187, p. 7.

[3] A.M. File S.B.2141, Encl. 37A. By April 1940 research and laboratory development of A.I. were expanding into several different channels. It had been recognised that to overcome the range problems of A.I., both at the minimum and maximum ranges, the radiation should be ' beamed '. This implied shorter wavelengths and a scanning technique. Dr. Bowen wrote a paper describing a television type picture which later became the basis for the United States A.I. system from which were produced the SCR.520 and SCR.720.

[4] Night Interception Committee Papers. 4th Meeting, 2 May 1940. A.M. File S.B.2136, Encl. 20A.

Interception Committee felt that preference must be given to A.I. over A.S.V., since countering night raiders was then the more urgent problem, and 80 of the 140 A.S.V. transmitters then available were taken over. The firm of E. K. Cole were asked to make 70 more transmitters.[1] This plan aimed at equipping 60 aircraft with A.I. Mark IIIA and 40 aircraft with A.I. Mark IIIB. The engineering aspect of A.I. became a Royal Aircraft Establishment (R.A.E.) responsibility.

A.I., Mark IIIA and IIIB

On 22 and 23 May tests were made at F.I.U. with A.I. Mark IIIA. Improved ranges, with a minimum of 900 feet and a maximum of 9,000 feet were obtained using a Blenheim aircraft as target. The equipment was most unreliable, however, in Service use. The mains transformer was liable to burn out on switching on and the cathode ray tubes were being seriously over-run. Only one in ten of the tubes as supplied by the makers was of any use in the set, and satisfactory ones had to be chosen by the radar mechanics by process of trial and error. Even then, the life of a tube was only between six and ten working hours.

The decision to equip night-fighter squadrons with A.I. Mark IIIA, and Mark IIIB, was not without its critics. 'I have come to the conclusion,' the Director of Signals reported towards the end of May, 'that A.I. in any form in which it exists at the time of writing is unsuitable for operational use by Service squadrons.' He stressed that the greatest danger with A.I. was that its premature introduction into Service use in an unreliable and unfinished form would create prejudice against it in the minds of pilots, who were 'notoriously conservative.' On the other hand, the report showed that the Director of Signals clearly recognised the need for a reliable A.I. equipment. When A.I. could be demonstrated even as a moderately reliable method of interception, nothing should be allowed to delay its introduction into the Royal Air Force by even a single day. He pointed out that the claims which had been made for A.I. so far had been too optimistic and the dates for production and installation given from time to time had invariably proved incorrect. In the summer of 1940 it was essential to conduct proper Service trials to ensure that A.I. had operational value before it was issued to squadrons.

Sir Henry Tizard expressed his views in a paper written for the 5th meeting of the Night Interception Committee on 23 May 1940. He recommended that the F.I.U. experiments should be directed to solve the practical problems of night interception, flying by day until they had mastered the A.I. technique. 'Let them forget about the minimum range' he wrote 'and concentrate on getting the equipment right and reliable, and develop the right flying technique.' He thought that in A.I. operational practice, Service personnel were trying to run before they could walk. 'The principles of design and construction of the present A.I.' wrote Sir Henry, 'are perfectly sound. What is wrong is that it is an inferior engineering job. The firm entrusted with the manufacture did it badly; it breaks down too often; and it has minor imperfections which make it difficult to use in the air.'[2]

[1] A.M. File S.B.2136, Encl. 20A.

[2] Night Interception Committee Papers, 5th Meeting 23 May 1940.

There was tremendous activity in research and development of A.I. during 1940, and perhaps too many authorities were attempting to direct and advise. In June, Air Marshal Sir Philip Joubert pointed out the confused situation to the Vice-Chief of the Air Staff.[1] The Secretary of State for Air was being advised on the development and usage of A.I. by no less than five different authoritative sources.[2] There was, to make matters worse, no consensus of opinion amongst these authorities on the best policy to be adopted. Opinions varied between two extremes. Some thought that development should go on until those who were responsible for it were satisfied, while from the Service side, operational use was wanted as soon as possible. It was difficult to choose the middle way between unending development and immediate use.

By the end of June 1940, 31 fully fitted A.I. Blenheim aircraft had been transferred to night-fighter squadrons from No. 32 M.U., St. Athan. At the same time these aircraft were fitted with V.H.F. R.T. to reduce the interference difficulty and to give better ground to air communication. At the beginning of August, 69 out of the 72 night-fighter Blenheims were fully equipped[3] and by the end of August the number had risen as high as 140, mostly with Mark IIIA.[4] The Mark IIIB scheme did not go far because of its complexity. The whole effort of production and installation was very considerable, but to thrust the equipment into service in this manner was of little value.

In the squadrons the difficulties of operating with the hastily made equipment were aggravated by a shortage of competent servicing and operating personnel.[5] Each squadron had about three or four mechanics who had had no training with the new set. There was a lack of test gear. Worst of all, many of the air observers were previously aircrafthands who had in general neither the qualifications nor an aptitude for the work. The aircrews disliked having a third man in the Blenheim fighters because of the difficulty of abandoning the aircraft quickly in emergency, but the addition of a radar observer to the original crew of pilot and air gunner was thought necessary because the watching of the fluorescence of the cathode ray tube might impair a man's night vision for looking outside the aircraft.[6] The lack of suitable radar observers was a disappointment after the need for observers of adequate mental calibre, with a background of radar knowledge, had been foreseen by the Air Officer Commanding-in-Chief nearly a year previously. It was difficult to obtain such men because of their scarcity in the Service. The need for some method of more accurate ground control was again prominent. The average error under Sector Control of between three and five miles was a negligible

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[1] Folder on A.I. by A.M. Joubert. A.H.B. IIE/198, Encl. 14A. A.M. File S.45970, Encl. 169B.

[2] These were :—

(a) The Ministry of Aircraft Production ;
(b) Professor Lindemann of the Imperial Defence Committee ;
(c) Sir Frank Smith, Controller of Tele-communications and Equipment at M.A.P. ;
(d) Sir Henry Tizard, Scientific Adviser to the Air Ministry ; and
(e) The Under Secretary of State for Air.

[3] Twelve aircraft per squadron were authorised. Six short-nosed Blenheim Mark I squadrons were fitted, namely, Nos. 23, 25, 29, 219, 600 and 604 Squadrons.

[4] S. of S. Scientific Progress Meeting, 9 August 1940, A.H.B. IIK/45/112, Part II.

[5] Interview with Sqn. Ldr. J. Hunter-Tod.

[6] A.M. File S.1572, Encl. 7A.

factor during daytime; but by night when the maximum radar search range of the aircraft was limited to 9,000 feet, or less than a mile and a half, A.I. contacts were still little better than a matter of chance. And at lower altitudes than 9,000 feet the A.I. range was correspondingly reduced.

There was also an inferiority in aircraft performance, on which the combat reports are illuminating.[1] Two experiences of the operational use of A.I. during June 1940 were reported to the Night Interception Committee. In one instance, a Blenheim of No. 29 Squadron, Digby, on night patrol on 18 June, was vectored into the vicinity of enemy aircraft. A.I. was switched on and from the indications on the cathode ray tube the enemy was followed until the pilot could see the flame of his exhaust. But before the pilot could align his sights the enemy opened fire with a single burst and rapidly drew away. The other incident, equally interesting, concerned the Commanding Officer of No. 23 Squadron, Wittering. On night patrol with A.I. switched on, his operator reported that they were rapidly approaching another aircraft. A hostile aircraft having been reported in the vicinity, the pilot executed a stall turn. By means of A.I. the enemy was followed until the pilot found that he was in its slipstream. He obtained a visual, but before he could get into position for attack, the enemy drew rapidly away and was lost.

Further evidence of lack of speed was the A.I. operator's report after an attempted interception controlled by the F.I.U. controller at Tangmere on the night of 14/15 July 1940. Information of the track of a returning enemy bomber was supplied by the Home Chain radar station at Poling. By the time the bomber was approximately 10 miles south of Selsey Bill, the controller had vectored the Blenheim into position and instructed the pilot to start A.I. search.[2] 'Less than one minute after switching on, an excellent response was obtained, the height of A.I. aircraft being 8–9,000 feet and range of target approximately 11,000 feet; the echo was clearly discernible within the sea returns.[3] Indications were that the target was well below, and instructions were given to the pilot to dive, and increase speed. Range then very slowly decreased to about 6–7,000 feet as the A.I. aircraft dived. Two starboard turns (20° and 10°) and one 10° port correction sufficed to put target in a good position for interception—dead ahead and the same height (2,000 feet) range 6,000 feet. Our own lack of altitude hampered operations somewhat, but the response was very clear and of excellent amplitude, despite being within the ground return most of the time. The pursuit was continued but we were unable to approach nearer than 4,000 feet owing to lack of speed, and eventually range commenced to increase again very slowly. The pursuit was finally abandoned when approximately over the French coast. It is respectfully pointed out and emphasised that in the opinion of the writer, only lack of speed prevented a successful and comparatively easy interception, as A.I. indications were excellent and continuously maintained until abandonment of pursuit.'[4]

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[1] Night Interception Committee Papers, 8th Meeting, 4 July 1940.

[2] A.H.B. IIE/198, Encl. 64B.

[3] The density of sea returns varied according to the state of the sea. When it was smooth, echoes were sometimes visible within the interference.

[4] The report is signed E. L. Byrne, A.C.1. The maximum level speed of the Blenheim was about 190 knots.

First A.I. night interception

The continuous and zealous practice in the use of A.I. and the attempts of the F.I.U. ground controllers at Poling C.H. station to provide successful contacts did not pass wholly unrewarded. On the night of 22/23 July 1940 a Blenheim aircraft of F.I.U. shot down a Dornier 17 aircraft into the sea off Bognor Regis. The combat report recaptures some of the impressions of the crew on this occasion.[1] 'Our aircraft was patrolling at 10,000 feet as Raid No. 9, composed of six aircraft at 6,000 feet, appeared. As the sub-controller at Poling was providing good information on this raid the F.I.U. controller directed the Blenheim to intercept it, but the raid turned south-east and as there was little chance of an interception the Blenheim was vectored to Selsey Bill. The raid again turned north, and the Blenheim was ordered to vector 180° and to switch on A.I. At approximately two minutes from crossing the coast after first vector of 180°, the A.I. operator reported a contact, but below. Height was lost and after four corrections, each of 5° starboard, " Bandit " was reported at range of 5,000 feet, height of fighter being 5/6,000 feet.[2] Shortly afterwards, the observer reported " Bandit to port ". Through the side windows the pilot saw the enemy silhouetted against the moon at an angle of about 45° and about 200 feet above the Blenheim. By the silhouette it was ascertained to be a Do.17. Distance was closed, and our aircraft took up position about 200 feet below and dead astern. The " Bandit's " track was approximately 150° and our aircraft could hold him at the first gate. Back sight was brought into position, and though pilot could not see his fore-sight he closed to approximately 400 feet and opened fire. A grand firework display was observed from tracer and incendiary striking home. No return fire was noticed and firing button was pressed to an approximate range of 100 feet. The enemy aircraft lurched to starboard and the nose dropped. Our pilot attempted to follow, pressing firing button, when the whole of the cockpit perspex was covered with oil and, from sensations experienced, the crew found themselves on their backs. By the use of instruments the aircraft was brought back to a level keel at 700 feet, but had lost complete contact with the enemy aircraft. Our aircraft called for homing bearing which was received from Poling, and having flown on 30° for approximately six or seven minutes, aircraft crossed the coast somewhere near Littlehampton. As our aircraft crossed the coast the observer reported a big blaze astern, and a glow was seen on the water. The observer pin-pointed the fire on the water about five miles south of Bognor. . . . Enemy casualty one Dornier 17 unconfirmed—our casualties, nil.'[3]

Development Work on A.I. Aerials

During June and July 1940, F.I.U. continued testing A.I. Marks III, IIIA and IIIB apparatus installed in Blenheim aircraft.[4] The direction-finding ambiguities in azimuth and elevation were investigated in relation to the aerial systems which were still similar to the original experimental aerials devised on a research basis before the war. They were not easy to make mechanically and the matching between them and the feeders was difficult to achieve and to maintain. A Royal Aircraft Establishment report dated

[1] A.M. File S.3848, Encl. 23A.

[2] 'Bandit' was the radio code-name for a hostile aircraft.

[3] The destruction of the Dornier 17 was later confirmed.

[4] A.M. File S.4916, Encl. 1B.

10 June made an important point when it stated, ' The first major improvement to be expected will be when a less critical aerial system can be produced.' This summed up their diagnosis of the prevailing trouble of squint, or the incorrect radar indication of the direction of the target aircraft from the A.I. equipment, the chief cause of which was the irregular frontal profile of the Blenheim, aggravated by difficulty in keeping the aerials in adjustment. When squint occurred, the radar observer might think he had the enemy aircraft dead ahead when in fact it was some way out on the beam. This fault may well have been overshadowed previously by too much concentration on the problem of minimum range. Directly attention was vividly called to the major problem, which in its turn was linked with the importance of getting shorter wavelengths, further development gave more successful equipment.

In August a Blenheim fitted with vertical aerials was flown to F.I.U. from R.A.E. for testing. Up to this date all A.I. aerials had been horizontal. Reporting on the vertical aerials, F.I.U. stated that interceptions were much easier to direct because there was no ambiguity in azimuth D/F indications, while the elevation indications were good up to a limit of 50°, the latter limitation not prejudicing the operational value of A.I. in any way.[1] The eradication of the direction finding ambiguities was a big step forward. Owing to the structural alterations involved it was impracticable for the aerials fitted to Blenheim aircraft in service to be changed, but vertical aerials were to be adopted for all new fittings.

With the approach of longer nights in the autumn of 1940 the prospect of heavy night bombing grew imminent. Experience thus far, using A.I. Mark III-equipped night fighters, gave little grounds for optimism that the night defence would be effective. A number of contacts had been obtained at night using A.I.; hostile aircraft had been chased by the slower Blenheim night fighters, but kills were not being made. There was, however, a hope of improvement. A faster and more heavily armed night fighter aircraft, the Beaufighter, was just beginning to come off production; a radar station for direct ground control of these aircraft was under development, and A.I. Mark IV was being evolved.

A.I. Mark IV

From April 1940 onwards much research effort had been devoted to overcoming the various defects of A.I. Mark III.[2] The resources of the Air Ministry Research Establishment had been brought in to reinforce the airborne group of scientists which had been depleted by the splitting off of a portion of the staff to work on A.S.V. The Royal Aircraft Establishment helped with the engineering side of A.I. A very important step, which was to have far-reaching effects, was the use of the radio industry resources in the research and development of airborne radar. Renewed progress resulted from the combined efforts, and in particular from a development contract given on 17 May to Electrical and Musical Industries (E.M.I., Ltd.) which played a large part in producing the greatly improved Mark IV.

[1] A.M. File S.4579. F.I.U. Report No. 30.
[2] A.H.B. IIE/187.

In A.I. Mark IV, the squegging principle was abandoned and the transmitter was modified to work with an external modulator, in which for the first time high voltage pulses were obtained by passing a heavy current through an inductance. In addition the vexed problem of excessive minimum range was at last solved. In order to reduce the large patch of interference at the lower ranges caused by the transmitter pulse, the receiver was suppressed by a pre-pulse from the new modulator which automatically rendered it insensitive for the period of the main pulse. To ensure that the receiver became sensitive again at the right moment, when the direct pulse was just dying away, an 'oscillator bias' control was provided. This was adjusted by the operator in the air until the back edge of the direct pulse was just showing; he could experiment with the control to find the best setting by flying close behind an aircraft during the day. When the oscillator bias control was correctly adjusted, the minimum range of A.I. Mark IV was as little as 400 feet.[1] This principle was applied to all subsequent metre wave A.I. receivers.

On 30 June and 1 July 1940 the new A.I. Mark IV underwent its first trials at F.I.U. It appeared to be a decided improvement on the earlier equipments except that the echoes on the cathode ray tubes were not steady, making it difficult to read the D.F. indications. After modifications had been made, the apparatus was refitted into a Blenheim aircraft at Christchurch and, after flight trials there, was returned to F.I.U. at Tangmere where further trials were carried out during 17–26 July 1940.[2] F.I.U. reported that the brilliance of the picture was now satisfactory. The set had greater maximum and lower minimum range than the Mark III, and the need for switching off the R.T. receiver during an A.I. approach had finally been removed, conferring a great tactical benefit on both pilot and ground control. The first trials were carried out with the old type of horizontal aerials, but as soon as the equipment was tried with vertical aerials F.I.U. reported a marked improvement over any previous system.[3]

At the 11th meeting of the Interception Committee the Air Officer Commanding-in-Chief, Fighter Command said he was in favour of going ahead with this apparatus with a view to using it in the new Beaufighter.[4] This recommendation was eventually accepted and on 10 September 1940 authority was given by the Air Ministry to discontinue the fitting of Blenheims; all efforts were to be diverted to equipping Beaufighter aircraft with A.I. Mark IV as replacements. No time was lost, for the Fighter Command Operations Record Book for September records, 'This month Beaufighter aircraft fitted with A.I. Mark IV were introduced in small numbers into the Command'.

The Salmond Committee

The first heavy German night attacks occurred during September 1940, before either the Beaufighter or A.I. Mark IV were available in any quantity. The very few which had reached the squadrons could not affect the issue; in fact not a single enemy bomber was claimed as shot down by A.I.-equipped

[1] Radar Equipments Manual Section 11, A.I. issued by T.R.E. (M.A.P.) in 1943.

[2] A.M. File S.4579, F.I.U. Report No. 31. Mr. Blumlein and Mr. Houchin, of E.M.I., who had been mostly responsible for the development, were present at the trials.

[3] A brief description of the installation of A.I. Mark IV is given at Appendix No. 12.

[4] A.M. File S.6210, 11th Meeting, 15 August 1940.

fighters during the month.[1] There was much anxiety and the Minister of Aircraft Production suggested that Marshal of the Royal Air Force Sir John Salmond should be called in to advise concerning the preparation of night fighters. The Chief of the Air Staff recommended that the enquiry should be extended to cover the whole field of operation of night fighters as well.

A committee, under the chairmanship of Sir John Salmond, began its consideration of the subject during September 1940. From its findings, the Air Council instructed the Air Officer Commanding-in-Chief, Fighter Command to take certain action and his reply to these injunctions was considered on 1 October 1940 at a meeting of the Night Air Defence Committee which the Secretary of State for Air and the Chief of the Air Staff attended.[2] Among the several courses of action accepted were :—

(*a*) Acceleration of production of A.I. Mark IV and Beaufighter aircraft.

(*b*) Control of interceptions from coastal radar stations, including those at Poling, Pevensey, Swanage and others on the East Coast.

(*c*) Additional radio aids for night-fighters. A.I. beacons[3] would have to be installed at airfields in addition to Lorenz blind landing apparatus.[4]

(*d*) Specialised night-flying training for aircrews was desirable, probably at a night-fighter operational training unit.

But there was a limit to the amount by which production of Beaufighter aircraft and A.I. Mark IV could be speeded up. Immediate reaction to the Salmond Committee's proposals in this direction was not possible in any marked degree. By November 1940 47 Beaufighters had been fitted, but the conversion from Blenheim aircraft was obviously going to be a gradual process.[5] Nevertheless, the combination of the faster aircraft better suited for navigating by night, heavier armament, and an improved A.I. installation raised the hopes of the night-fighter squadrons, though for some time without operational effect. The Salmond Committee's recommendations that interception to seaward should be more actively attempted had also proved abortive in practice. The C.H. station at Pevensey was employed on sixty-nine occasions between mid-September and mid-October.[6] On only ten of these were the instructions to aircraft accurate enough for A.I. contacts to be obtained, and no enemy aircraft was claimed as shot down. Similar lack of success attended the attempts from other coastal radar stations. As a result of this unsuccessful night activity, however, many early mistakes made in operating the equipment and in approaching to attack hostile bombers were uncovered and rectified.

Operation of A.I. equipment in the air and its maintenance on the ground required more personnel of higher technical qualifications, and steps were taken to increase the number of experienced technicians working on Service radar.

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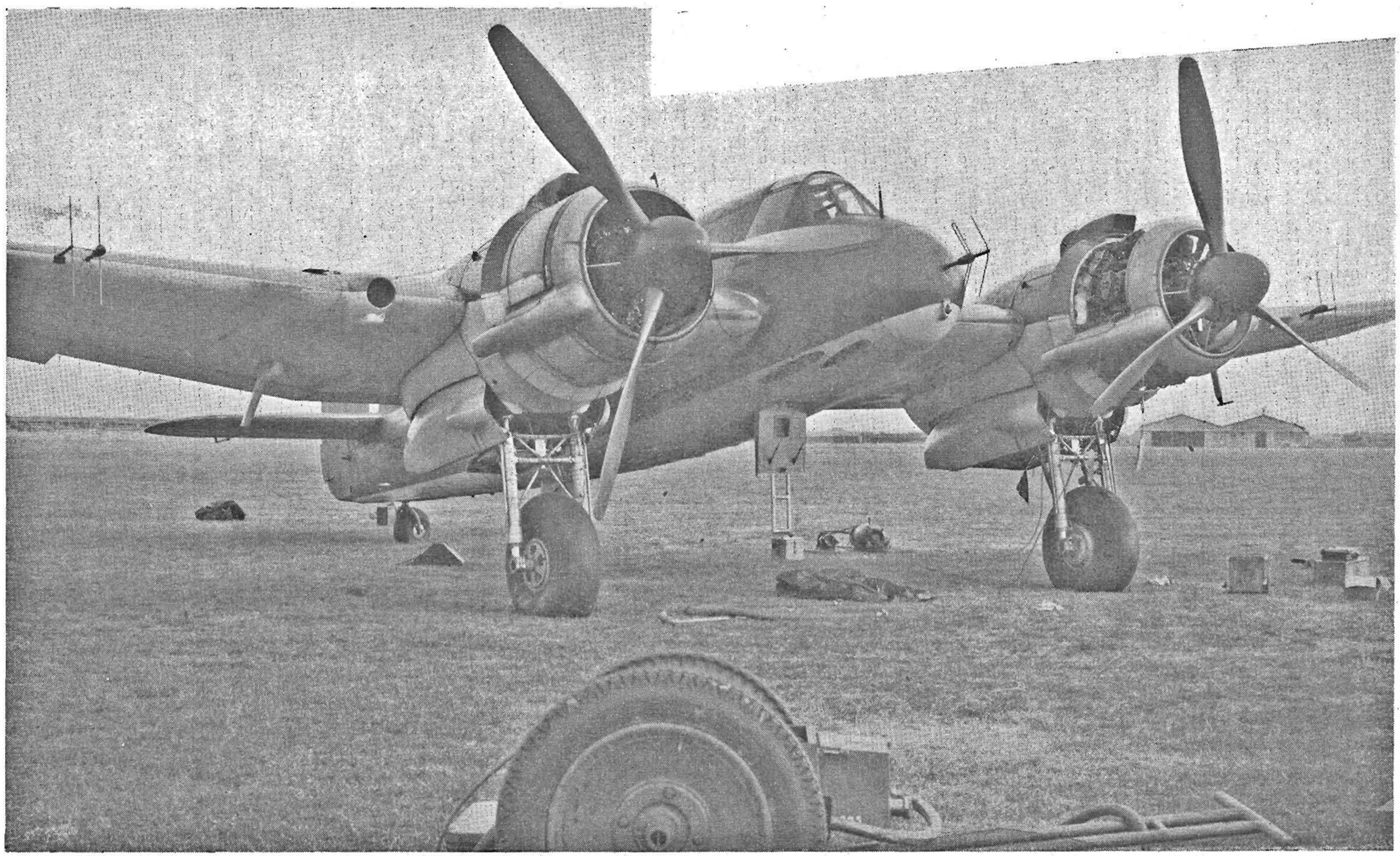
[1] A.M. File S.6287. [2] A.C.47 (40).

[3] A.I. Beacons were transponders working on the A.I. frequency band of 188–198 megacycles per second. These could be interrogated by the A.I. set in the aircraft, the transmitted response being coded so that the A.I. operator could identify the airfield on which the beacon was operated.

[4] Lorenz Beam Approach is described in Volume III.

[5] Fighter Command O.R.B., November 1940.

[6] A.C.A.S.(R) Folder on N.A.D.C. A.H.B. II/55, Encl. 17.



Beaufighter showing A.I. Mark IV Aerials

Ground radar operators trained at No. 2 Signals School, Yatesbury, had been posted to squadrons for air training, but their numbers were inadequate for the requirements of the expanding night-fighter force. Accordingly, a school for Radio Operators (Air) was started at Prestwick as No. 3 Radio School in December 1940 to provide operators with air training before they arrived in the squadrons.[1]

A proposal of the Salmond Committee to establish a night operational training unit was agreed by the Air Staff and on 11 November 1940 orders were given for the formation of No. 54 (Night) O.T.U. The unit began its work at the end of December 1940 at Church Fenton, near York.[2] In order to provide night-fighter squadrons with fully trained crews, the radio operators from Prestwick joined up with their pilots at the O.T.U. and they completed air training together. For successful operation of the A.I.-equipped night-fighter aircraft, a most intimate co-ordination was necessary between radio operator and pilot. The final training together at the O.T.U. did much to produce this close understanding.

First Interception using A.I. Mark IV

The Beaufighter had several teething troubles ; unserviceability was initially high, and the output from production did not come up to expectations.[3] To supplement the small numbers of A.I.-equipped aircraft three single-seater Hurricane squadrons had to take their place among the night fighters during October 1940 as a stop-gap until adequate numbers of Beaufighter aircraft were available. The Deputy Chief of Air Staff obtained assent for three Defiant squadrons also to specialise in night interception. The Air Officer Commanding-in-Chief, Fighter Command, ' with the greatest reluctance,' chose Nos. 73, 151 and 85 Squadrons for this purpose, for he held other views on standing night patrols.[4] He felt that to employ aircraft not equipped with A.I., particularly single-seater aircraft, wholly on night duty was dangerous and unsound. It was his emphatic opinion that ' if the whole air force were relegated to night duty on these lines, the number of interceptions would not suffice to check the night-bomber menace.'[5] He was convinced that night interceptions could best be achieved by fighters equipped with A.I. and controlled closely by radar devices on the ground, and declared : 'An A.I. sight must eventually be developed, capable of being laid and fired without seeing the enemy. . . . Our task will not be finished until we can locate, pursue, and shoot down the enemy in cloud by day and by night, and A.I. must become a gun sight. . . . Nothing less will suffice for the defence of the country. Every night I spend watching attempts at interception confirms me in my belief that haphazard methods will never succeed in producing more than an occasional fortunate encounter.'

Some idea of the difficulty of the problem of night interception without the use of radar aids can be gained from the striking example of the German attack on Coventry in which about 437 enemy aircraft took part. A total of 119

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[1] R.A.F. Station Prestwick O.R.B., December 1940.

[2] A.M. File S.5218. No. 54 O.T.U. and R.A.F. Station, Church Fenton O.R.B.s.

[3] A.H.B. IIE/198.

[4] A.M. File S.5566, Minute D.C.A.S. to C.A.S., 28 October 1940. [5] *Ibid.*, Encl. 19A.

defensive patrols were flown by night-fighters but only seven ' visuals ' were obtained on enemy aircraft and not a single decisive interception resulted. At a cursory glance such lack of success would seem almost impossible, and considering that the enemy aircraft, flying on radio beams, crossed the British coast almost in single file, moving in parallel tracks confined to a narrow belt often not more than ten to fifteen miles wide, the chances of interception seem enhanced. But in a so-called ' crocodile ' of raiders, one aircraft crossed the coast about every four minutes, and the aircraft flew at varying heights between 10,000 and 20,000 feet. A simple mathematical analysis gives an average of one aircraft per 345 cubic miles of space.[1] The proverbial parallel of looking for a needle in a haystack comes immediately to mind.

On the night of 19/20 November the first claim was put forward by Fighter Command for an enemy aircraft destroyed by an A.I. Mark IV-fitted night-fighter. A Beaufighter pilot engaged what he took to be a four-engined enemy aircraft flying at 18,000 feet near Brize Norton. Instructions from the A.I. operator enabled contact to be maintained and searchlight concentration on clouds improved visibility. According to the pilot's report, the result of the combat was inconclusive. Nevertheless, a JU.88 aircraft crashed in flames at East Wittering and the crew, who had baled out and were taken prisoner, reported that they had been fired on by a fighter aircraft shortly before reaching Birmingham. Fighter Command Intelligence Section considered that this was the machine engaged by the pilot concerned who saw its four exhausts and presumed it to be a four-engined aircraft.[2] This success was the only one recorded for A.I. Mark IV during the remainder of 1940.

Notes made by the Deputy Director of Air Tactics, Air Ministry, on 26 November 1940 throw light on some of the weaknesses in the operation and maintenance of A.I. at that time. 'Although the A.I. operators at the Fighter Interception Unit are specially selected,' he wrote, ' those in units earmarked for night-fighting are not. It is of the greatest importance that the A.I. operator should be intelligent, keen, and of a patient and painstaking disposition. He is, after all, the brains of the aircraft up to the moment when the pilot actually sees the silhouette of the enemy aeroplane and opens fire. . . . Up to the present insufficient attention has been given to the carrying out of interceptions in daylight. This is essential in order to convince pilots and A.I. operators that A.I. really works, and to allow them to see how the blips on tubes correspond to the movements of the target aeroplane.'

' It is evident,' he went on, ' that in certain aircraft the A.I. installation has never been properly calibrated. For example, during a daylight test it was found that two Beaufighters showed the target aircraft as being dead ahead according to the tubes, when it was actually some 40° on either bow. Lack of knowledge of a fault of this nature would account for several failures to intercept by night when, as the attacking aircraft closed range, the target appeared to suddenly " flick " away and disappear from the tubes. Apparently no testing gear has, as yet, been provided to discover faults such as those described above, or to check A.I. sets for functioning immediately before flight.' The importance of daylight practice was also mentioned at the Secretary of State's Scientific Progress meeting on 22 November 1940.

[1] This analysis is given in Chapter 11 of Volume IV.

[2] Fighter Command O.R.B., November 1940. The pilot was Flt. Lt. J. Cunningham.

None of the weaknesses described nor the recommendations made was new, and it appeared that some form of closer liaison between the scientists and squadron personnel concerned with the introduction of a new and untried equipment into the Service was urgently required. Nothing short of a direct link between the scientists concerned with the development of the new equipment, and the air and ground crews of all the squadrons being equipped with it, would give the best results. The Air Officer Commanding-in-Chief, Fighter Command, recommended that a scientific officer should be posted to each squadron to ensure that the complex airborne radar equipment was properly maintained.[1]

It was not, however, until effective radar ground control equipment came into use that reliable night interceptions were achieved. The first six sets of ground control interception (G.C.I.) equipment were put into service at the beginning of 1941. They made it possible to direct the night-fighter towards the enemy bomber with such accuracy that A.I. contact could be obtained from a good tactical position astern of the enemy, thus reducing subsequent manoeuvring during the A.I. approach to a minimum. Success was not immediate. The G.C.I. and A.I. equipments were involved in the night battle before fully adequate exercises had been held ; experience had to be gained and the technique of ground control assimilated before tangible results in terms of enemy aircraft destroyed were forthcoming. Although the number of A.I. contacts increased during January 1941, only one enemy aircraft was destroyed and one damaged by A.I.-equipped night-fighters ; flying conditions were very bad during the month.[2]

Greater effectiveness in the use of A.I. was due in a generous measure to the arduous and strenuous efforts of the night-fighter squadrons in their persistent development of the tactical application of airborne radar. No. 219 Squadron at Redhill, for example, had striven for months with the troubles of the new Beaufighter aircraft, with a new type of engine and with the new A.I. apparatus, all simultaneously, working at dispersed sites on a wet and soggy airfield. Airfield lighting and other night-flying and navigation equipment were far from adequate by later standards. Practising during the day and operating by night, the aircrews spared no effort in their attempts to master the peculiarities of the new interception equipment. Much of the credit for subsequent night successes was due to all those concerned in this preliminary struggle with the new techniques, particularly to the small band of pilots and radio operators of whom Flight Lieutenant J. Cunningham and his operator Sergeant I. Rawnsley of No. 604 Squadron, by dint of great application and prolonged practice, achieved the first and the most numerous successes. Furthermore, they were able to put their technique down on paper for the benefit of other Fighter Command crews.

On 19 February a Heinkel 111 was destroyed by Squadron Leader H. Little, commanding No. 219 Squadron, another leading exponent of the night interception technique. Still more encouraging results came during the heavier night raids on 12, 13 and 14 March when fifteen enemy aircraft were claimed as destroyed, with four probably destroyed and three damaged.[3] In April the number of successful A.I. combats mounted still further ; twenty-nine

[1] Then Air Marshal W. S. Douglas. Fighter Command File S.22104.

[2] Fighter Command O.R.B.

[3] *Ibid.*, March 1941.

destroyed, four probables, and twelve damaged. The total number of enemy aircraft destroyed by A.I.-equipped night-fighters under G.C.I. control from the beginning of operations in January 1941 reached 100 during July of that year. From December 1940 to May 1941, pilots claimed 178 enemy bombers destroyed, with more than that number probably destroyed or damaged.[1]

These figures cannot be taken, of course, as being proportionate to the efficiency of the G.C.I./A.I. interception technique. Many other factors were involved, including the magnitude of the German night effort from time to time, and also the size of the night-fighter force available. Moreover, there were only six twin-engined night-fighter squadrons equipped with A.I. Mark IV by 22 March 1941. Eight squadrons of single-engined fighter aircraft were also operating at night and achieved numerous successes in the special conditions favourable to their employment. Some idea of the relative effectiveness of both A.I. and 'cats-eye' squadrons may be gained from the following table of results obtained during the three months of the spring of 1941.

	A.I. Fitted Squadrons.			*'Cats-eye' Squadrons.*		
1941.	Sorties.	A.I. Contacts.	Combats.	Sorties.	Visuals.	Combats.
March	270	95	21	735	34	25
April	542	117	50	842	45	39
May	643	204	74	1,345	154	116
Totals	1,455	416	145	2,922	233	180

A noticeable feature is that twin-engined squadrons fitted with A.I. made nearly the same number of combats with the enemy in about half the number of sorties. The results of the A.I.-equipped squadrons are all the more striking when it is borne in mind that the 'cats-eye' fighters were only profitable in areas of concentrated enemy activity during periods of bright moonlight and clear weather, such as occurred in exceptionally good measure during May 1941. It is doubtful whether there was a single occasion during the war on which a 'cats-eye' fighter shot down an enemy bomber when the moon was below the horizon. On the other hand, the A.I.-equipped night-fighter could operate in all kinds of weather and could intercept isolated raiders.

After May 1941, enemy pre-occupation with the Russian front caused a reduction in the bombing force employed against the United Kingdom. Enemy aircraft began to resort to vigorous evasive action, beginning with a very low approach over the sea and varying both course and height frequently overland. As a result, A.I. Mark IV was not so effective, the echo usually being lost in the sea returns when the enemy aircraft flew low. The combined effect of the reduction in the German night effort and the evasive action of bomber pilots resulted in a decrease in the number of enemy aircraft shot down. The totals reached in May 1941, when approximately 100 enemy aircraft were claimed as destroyed by night-fighters, were never repeated.

[1] An analysis of the results claimed by defensive night-fighters between November 1940 and December 1941 is given at Appendix No. 13, A.H.B. Narrative, A.D.G.B., Volume III.

The Pilot's Indicator

During the early A.I. operations the pilot depended entirely on guidance from the A.I. operator in making his approach. Unless there was a very close understanding between pilots and observers using A.I. Mark IV, there was a tendency for the aircraft to weave, and it was thought that this might be caused by a time-lag in passing the information from observer to pilot. A number of schemes were tried during the year 1940 to obviate it. The first practical system resulted from experiments carried out at the Telecommunications Research Establishment; a Pilot's Indicator was produced on which A.I. indications could be observed directly by the pilot on a small cathode ray tube. The target aircraft showed initially as a spot on the tube and the fighter pilot flew in such a way as to keep the spot in the centre. An A.I. observer was still necessary for tuning and other adjustments to the A.I. apparatus. The Director of Communications Development notified the Air Interception Committee at its 9th Meeting on 18 July 1940, that the Pilot's Indicator had been developed.[1] He pointed out that it would be unsuitable for use in single-seater fighter aircraft because a radio observer was still necessary.

The first instrument was received at the F.I.U. for trial in October 1940.[2] Preliminary tests showed that the absence of range indication on the Pilot's Indicator necessitated constant reference by the pilot to his observer, and it was recommended that the instrument should be developed to show range. In December 1940, a greatly improved equipment was ready for trial. The response from a target beyond 10,000 feet appeared as a spot of light on the pilot's cathode ray tube.[3] As the range decreased the spot extended on each side into a line, and extensions or ' wings ' steadily increased in size until the minimum range was reached. The Pilot's Indicator tube had a U-shaped mark in the middle and two vertical lines or ' goalposts ' on each side, thus | U |. At a range of 5,000 feet from the target aircraft the ' wings ' were just touching the sides of the U-shaped mark; at 4,000 feet they reached the outside of the mark. As range decreased the wings spread steadily until at minimum range (normally 300–400 feet) they were just touching the goalposts. To show elevation the indications rose or fell and in a correct approach the pilot kept the spot of light in the middle of the top of the U, until the wings extended to reach the goalposts.

To bring a target indication on to the Pilot's Indicator tube, the radio observer selected an echo on his range tube and adjusted a control to bring a ' strobe spot ' along the horizontal time-base until it coincided with the echo. This manual operation, known as ' strobing ', had to be continued by the observer as the pilot approached his target. The pilot was only called upon to look at his Indicator (or ' G ' scope) during the final stages of an interception; up to that point the observer gave instructions to the pilot as formerly.

A.I. Mark IVA

From October 1940 until the end of the year F.I.U. carried out tests with a Pilot's Indicator in Blenheim and Beaufighter aircraft.[4] Reports were favourable. At the 19th meeting of the Interception Committee on 12 December

[1] A.M. File S.3984, Encl. 55A.
[2] F.I.U. O.R.B., October 1940.
[3] A.M. File S.7832, Encl. 51A.
[4] F.I.U. O.R.B., November/December 1940.

1940 it was agreed that twelve hand-made Pilot's Indicators which were being constructed by T.R.E. should be installed in Havoc aircraft, and that T.R.E. would construct a further thirty-six instruments to enable fitting to begin in eleven Beaufighter squadrons, pending the delivery of factory-produced Pilot's Indicators.[1] The A.I. Mark IV together with the hand-made instrument was known as A.I. Mark IVA. The first dozen hand-made indicators were constructed at the Air Defence Experimental Establishment and a contract for the remaining thirty-six was let to the Dynatron Company. Mark IVA was installed in Havoc aircraft during February and March 1941.

The factory-produced equipments were termed A.I. Mark V. The transmitter and modulator of the Mark IV equipment were relatively unchanged and the principles of Mark IVA were applied to a completely re-engineered receiver and indicator made by Pye Radio under R.A.E. supervision.[2] During the production period, Mark IV was used successfully in Beaufighter aircraft in the spring and summer of 1941, and Mark V was not unduly hurried into operational use.

Simultaneously with the development of A.I. Marks IVA and V, another set, A.I. Mark VI, was also being developed by the teamwork of the Telecommunications Research Establishment, the Royal Aircraft Establishment and Electric and Musical Instruments. Although the new set worked on the 1½ metre waveband it employed wandering automatic strobes and was technically the most advanced equipment of its type. It was completely automatic and since no radio operator was required, was suitable for installation in single-seater fighter aircraft. This promised to be a great advantage because the shortage of twin-engined aircraft suitable for night fighting in 1941 could then be overcome by using single-engined aircraft, provided only that A.I. Mark VI was a success.

During 1940, 2,000 sets of A.I. Mark VI were ordered ; production in quantity was to begin in June 1941. This order was given despite the fact that design was not quite cleared. Tests on an experimental model during the same month showed that it suffered from serious limitations ; chiefly poor minimum range and the lack of A.I. beacon facilities.[3] With production programmes for Marks IV, IVA, V and VI running concurrently, there appeared to be a certain lack of liaison between the Ministry of Aircraft Production and the Directorate of Signals in their interpretations of Air Staff policy, both with reference to the functions of the various Marks of A.I. and the types of aircraft to be fitted with those marks. In December 1940 the radio programme included orders for :—

(*a*) The original contract of 600 A.I. Mark IV, expected to be completed by January 1941.

(*b*) 48 hand-made Pilot's Indicators, to be made to T.R.E. requirements. A.I. Mark IV sets were to be modified to take these, the combination being known as Mark IVA.

(*c*) 600 semi-automatic Pilot's Indicators from Pye Radio, to be used in conjunction with A.I. Mark IV.

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[1] A.M. File S.3984, Encl. 69A.
[2] A.H.B. IIE/187, p. 9.
[3] A.M. File S.7741, Encls. 1A, 3A, 9A, 11A, 11B and 16A.

(*d*) 2,000 sets of A.I. Mark VI from E.M.I. with a ' stop ' at 200 for modifications to be introduced to give A.I. beacon homing facilities and I.F.F. interrogation. The modified set was to be termed A.I. Mark VIA.

Although Mark VI was expected to replace Mark IV for all purposes, it had still to be accepted as suitable after flight trials.[1] To limit the production of A.I. Mark IV to 600 sets was felt to be gambling too high on the immediate and complete success of Mark VI and on its production by a promised date. The earlier decision to produce only 600 sets of A.I. Mark IV was therefore amended to 1,000 to give adequate supplies over the transition period.

For the sake of clarity it is necessary in this narrative to consider the implementation of the Marks V and VI programmes separately ; but in point of fact development, production, prototyping of installations in aircraft and indeed the fitting of the equipments, were taking place concurrently. Furthermore, despite the introduction of these new marks of A.I., Mark IV equipment continued in general use throughout 1941 and 1942, and proved to be the most reliable equipment of the night-fighter force for a much longer period than had been originally anticipated.[2]

A.I. Mark V

The first hand-made A.I. Mark V set received from the manufacturers was tested at F.I.U., first in a Havoc and then in a Beaufighter aircraft during May 1941, and the results were favourable, especially in the latter aircraft.[3] It appeared a good omen for the future of the new equipment when, on the night 25/26 June, A.I. Mark V was flown operationally by an F.I.U. crew and made radar contact with a Heinkel 111, resulting in its destruction.[4] It was, however, a very difficult matter to estimate what the reliability of A.I. Mark V would be under operational conditions, because the set was much more complicated than Mark IV.[5] In order to determine its reliability, it was decided to fit one flight of Beaufighters of No. 219 Squadron as soon as the first fifty production models became available. This was begun in October 1941, but production faults in the equipment caused the work to extend over two months. Meanwhile, a double range scale giving separate scales for interception and A.I. beacon working had been devised and sent to F.I.U. for tests. A setback occurred when the Beaufighter aircraft carrying the first production model of A.I. Mark V crashed at the end of the flight trial on 3 September 1941, damaging the new equipment beyond repair and killing the crew.[6]

By December 1941 the flight of Beaufighter VI aircraft in No. 219 Squadron were flying on night defence operations with A.I. Mark V. Apparently the quick success achieved at F.I.U. with this equipment had flattered to deceive.

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[1] A.M. File S.7741, Encl. 13A.

[2] Amongst the welter of new Marks of A.I., of both $1\frac{1}{2}$ metre and centimetric wavebands, which follow in this narrative, A.I. Mark IV remained in use until the end of the War.

Theatres in which A.I. Mark IV was used :—

United Kingdom ..	September 1940–April 1945.
Malta and Egypt ..	September 1941–August 1944.
India	April 1942–April 1945.
The North African Campaign.	

[3] F.I.U. O.R.B., May 1941.

[4] A.M. File S.6848, Encl. 59A.

[5] A.M. File C.S.9487/41, Encl. 21A.

[6] F.I.U. O.R.B., September 1941.

No. 219 Squadron's experiences indicated several faults; indicator spot swinging, sluggish spot movement, and a limited angle of interception. The fitting of further Beaufighters was therefore held up.[1] During the 1941 Christmas period Pye Radio staff worked day and night to produce 100 sets before the end of the year. Efforts were made to speed up production, so that the new Mosquito night fighter expected to be in Service use in the spring of 1942 could be fitted with A.I. Mark V. Prototyping of the fitting of the equipment was completed and when the first Mosquito aircraft were available in April 1942, No. 157 Squadron was the first to have the A.I. Mark V/Mosquito combination. Eight further Mosquito squadrons were similarly equipped and the Mark V set was in use from the beginning of May 1942 until September 1943, in the United Kingdom only.[2] Operationally, by comparison with Mark IV, the success of Mark V was somewhat disappointing in terms of enemy aircraft shot down. During the period April–July 1942 the results were as follows:—[3]

Type of A.I.	*Destroyed.*	*Probably Destroyed.*	*Damaged.*
Mark IV	50½	15	32
Mark V	13	3	7

Although technically a fine instrument, A.I. Mark V was very complicated and demanded a correspondingly high standard of maintenance, a standard not immediately obtainable in the squadrons.[4] There was, therefore, a high unserviceability rate for the first months of operation and, coupled with it, a prejudice of aircrews in favour of Mark IV which persisted for some time.

A.I. Mark VI

A.I. Mark VI, a very well-engineered equipment, was put somewhat hastily into production as the only A.I. suitable for single-seater fighter aircraft.[5] Although A.I. Mark VI had fully-automatic strobing and therefore did not require an operator, it was suitable for use in twin-engined aircraft also, the set being adjustable for manual strobing by the radio observer when required. It was therefore regarded for a time as the eventual replacement for the Mark IV equipment. The policy towards A.I. fluctuated considerably, partly due to the rapid technical progress made in the centimetric waveband equipment and partly to the tactics of the enemy. In April 1941 the Vice-Chief of the Air Staff ruled that A.I. was not to be fitted in single-seater fighter aircraft and that the priority of fitting of A.I. was Defiant II, Mosquito, Havoc, Beaufighter, in that order. A.I. Mark VI was ultimately selected only for Defiant and a few dual control Mosquito aircraft. Although 2,000 sets were originally ordered, 200 would now have been more than ample.

A delay in the production of A.I. Mark VI during May 1941, when the Defiant II aircraft were becoming available, caused the Air Officer Commanding-in-Chief, Fighter Command to comment, 'I trust that all these aircraft may be issued with Mark VI and that every possible effort will be made to that end'.

[1] A.M. File C.S.9487/41, Encls. 97A and 105B.

[2] The squadrons fitted were Nos. 25, 85, 151, 157, 264, 305, 410, 456 and 488.

[3] A.M. File C.S.22408, Encl. 125A.

[4] A.M. File C.S.9487/41, Encl. 110A.

[5] Eight single-seater fighter squadrons were operating on night defence in March 1941.

Despite this reminder, the first forty-five hand-made sets were not available from production until 5 December 1941, when the fitting of the Defiant II Squadrons, Nos. 96 and 264, was undertaken. It had been the intention to fit a third squadron of Defiant II aircraft (No. 151 Squadron) with A.I. Mark VI. Before any of the squadrons were fully fitted, however, the Air Staff decided on 2 May 1942 that Defiant aircraft were no longer to be employed as night-fighters. A.I. Mark VI had thus a very brief and unsuccessful operational span of life of only four months, as far as the defence of the United Kingdom was concerned.[1] Very little success was achieved by the A.I. Mark VI/Defiant II combination. The first claim was made by a pilot of No. 264 Squadron from a sortie on the night of 17/18 March 1942, and the destruction of a Heinkel 111 was confirmed.[2]

Earlier, in December 1941, Hurricane and Typhoon aircraft had been selected to be prototyped for A.I. Mark VI. The trial installation for the Hurricane was completed on 3 March 1942 and the aircraft went to F.I.U. for tests. With the decision to abandon the use of Defiant aircraft as night fighters, the whole policy for A.I. Mark VI became dependent on this trial installation in the Hurricane; if it were successful, then installation in Typhoon aircraft was also to proceed.[3] Technically, the Hurricane installation was a success under test in May 1942 and further possibilities opened up for the employment of A.I. Mark VI. By this time, however, A.I. equipment operating on centimetric wavelengths had begun to challenge the 1½-metre waveband A.I. and the Mark VI equipment thus became obsolescent even before it was used operationally. During July work began on fitting one squadron of Hurricane aircraft with A.I. Mark VI. This proceeded on low priority and the aircraft were never flown operationally in the United Kingdom. The squadron was eventually despatched to India and employed there, operationally, from April 1943 until March 1944.

On the production side, the order for 2,000 sets was reduced to 1,125. It had been intended to modify the set for A.I. beacon facilities and also I.F.F. interrogation, the new model to be known as Mark VIA.[4] A development contract for only twelve sets was given to Electric and Musical Industries but the set did not come up to expectations and work was suspended. The 'break clause' in the production of Mark VI was not exercised and the full number of 1,125 sets was produced. They were subsequently made use of in Bomber Command aircraft as a tail-warning device against German night fighters.[5]

Value of 1½-metre A.I.

The numbers of German aircraft shot down by A.I.-equipped night fighters in conjunction with G.C.I. control in the spring of 1941 were not maintained during the last six months of the year. The scale of the enemy night bomber effort against the United Kingdom declined substantially as a result of the transfer of the bulk of his air forces to the eastern front for employment in the

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[1] A.M. File S.7741, Encl. 66A.

[2] A.M. File S.6848, Encl. 86A.

[3] A.I.C. 95. A.M. File S.7741, Encl. 69A.

[4] A.M. File S.7741, Encls. 65A, 67A, 70A and 71A.

[5] This is dealt with as Monica in Volume III.

invasion of Russia, which began on 22 June.[1] The comparatively small number of German aircraft retained in the west offered less opportunity to the defence than before, not merely because they were fewer but also because they concentrated their attacks on shipping and coastal targets, enabling them to operate for the most part at low altitude and thus to evade the zone of effective G.C.I. control, and to some extent the early warning radar screen. The adoption by the Germans of low-flying tactics also gave them protection against the direct use of A.I. by night-fighters because of the diminished range of the instrument at low altitude caused by ground or sea returns.[2] There was no doubt in 1942 that 1½-metre waveband A.I. Marks IV, V, and VI, were becoming out of date for home defence purposes. In addition to their limitations at low altitude, they were vulnerable to interference by enemy jamming aimed specifically at airborne equipment or at ground radar location apparatus. Without radical re-design, it was not possible to counter this disability.

The desirable maximum detection range for A.I. was of the order of ten miles. The maximum range of Mark V, the best of the 1½-metre equipments, was less than half of this. In 1942 the enemy was vigorously adopting evasive tactics; his aircraft never flew on a straight course, never kept a constant speed, and never remained at the same height for more than a minute or two.[3] Thus greater range over a wide angle of vision was required from the A.I. apparatus.

Although the effectiveness of 1½-metre A.I. was minimised by the German night tactics of the winter of 1941/42, Marks IV and V had by no means outlived their usefulness. Indeed, Mark IV, the original successful A.I. of the 1940–41 night battle over the United Kingdom, was to continue in use until the end of the war. The increasing raids by the Royal Air Force on Germany early in 1942 stung the enemy into retaliation. The minelaying policy was temporarily abandoned from the night of 23/24 March 1942 when spasmodic bombing raids on coastal objectives began. Later, between 23/24 April and 8/9 May, attacks were made on towns such as Bristol and Bath, within 50 miles of the coast. During these fourteen nights of the so-called Baedeker raids, night fighters destroyed 37 enemy aircraft, with 36 more probably destroyed or damaged. Altogether, between April and August 1942 there were 1,304 attempts at interception, of which 971 were made with A.I. Mark IV. Of the 250 combats which ensued, more than half were fought by Beaufighters fitted with Mark IV equipment.[4] The 1½-metre A.I. was still giving yeoman service. Every combat report and every radar ground station report made it perfectly clear that evasion was the rule for the night bomber squadrons of the German Air Force.

Long Aerial Mines

Two devices which were used in conjunction with 1½-metre A.I., without marked success, were the Long Aerial Mine (L.A.M.) and the Turbinlite. Long Aerial Mine operations were attempts to lay a screen of air mines in the path of enemy bombers.[5] Experiments had been continued at Martlesham

[1] A.M. File S.6848, Encl. 80A.

[2] A.I.C. 95, para. 10.

[3] A.M. File S.6848, Encl. 86A.

[4] Fighter Command, O.R.S., Report No. 374. A.H.B. II/39/2.

[5] A.M. File S.6728. *See also* Chapter 2.

since March 1940 with dummy aerial mines. At that time, tests were carried out without the use of A.I. Harrow bombers and slow transport aircraft were employed, and radar information from the C.H. stations was used by the ground controller in attempts to put the mine-laying aircraft in the path of target aircraft simulating enemy bombers. A report by Headquarters, Fighter Command, on these trials was circulated at the 6th meeting of the Night Interception Committee on 13 June 1940.[1] The chairman remarked that long aerial mines had never been an Air Staff requirement and felt it was not an economical way of using the country's resources. If there was to be any possibility of success, however, the mine-laying aircraft must be faster than the enemy bombers. In July 1940 the original plan to use obsolescent bombers or civil aircraft was abandoned, and it was proposed to use the D.B.7 aircraft, of which there were some forty available.[2] A prototype installation for A.I. Mark IV was made for the D.B.7, and the fighter version of the aircraft was renamed the Havoc.

While awaiting the fitting of A.I. Mark IV the Havoc aircraft were flown in trials by No. 93 Squadron, but the results were so unfavourable that the tests were suspended, and the project was turned over to the Fighter Experimental Establishment for further study. With the introduction of the A.I. Mark IV and G.C.I. ground control, the Havocs were again flown on 'Mutton' operations.[3] Two enemy aircraft were claimed as destroyed during April and May 1941. The efficiency of the L.A.M. technique, using Havoc aircraft fitted with A.I. Mark IVA, can best be gauged from the Chief of the Air Staff's minute to the Prime Minister on 11 May 1941, 'The A.O.C.-in-C., Fighter Command, is not yet satisfied that the "Mutton" method will ever be as efficient as the G.C.I.-controlled A.I. fighter. Statistics since 29 March credit "Mutton" with 1·3 successes per 100 sorties and the Beaufighters with 8·3 per cent., G.C.I. being used for both. The technique for interception with "Mutton" is far more difficult, and though it may eventually be mastered I believe that the airborne searchlight will eventually provide the answer for dark nights.'

Because of the great effort which had gone into the L.A.M. scheme it was thought undesirable to drop the subject until further experience had been gained. No. 93 Squadron continued to operate; Headquarters Fighter Command gave the 'Mutton' operations equal priority of G.C.I. control with A.I. night fighters on moonlight nights and priority over A.I. fighters on dark nights, but no further enemy aircraft were claimed as destroyed. In August 1941 a last attempt to make 'Mutton' a success was tried using both forward and sideways-looking A.I. It was thought that this would greatly decrease the time taken by interceptions, and that a mine-laying Havoc aircraft so equipped could continue to operate as a night-fighter after laying its mines. No improvement was achieved with this new installation. A.I. could not bring success to a night defence scheme which was apparently fundamentally impracticable.

The only L.A.M. squadron, No. 93, ceased to function as such at the end of October 1941, and both aircraft and personnel were converted to more profitable use. On 13 November the Assistant Chief of the Air Staff (Training) wrote a

[1] A.M. File S.3984, 6th Meeting and N.I.C. 14.

[2] The D.B.7 was an American-built aircraft contracted for by the French but taken over by the British after the collapse of France in June 1940.

[3] No. 93 Squadron O.R.B., April/May 1941. 'Mutton' was the code name given to Long Aerial Mine Operations.

fitting epilogue in a minute to the Controller of Research and Development at the Ministry of Aircraft Production : ' The L.A.M. has today received last rites of burial and may henceforth be regarded as frozen meat.'[1]

Turbinlite (September 1941—January 1943)

Turbinlite was the name given to the airborne searchlight referred to in a minute from the Chief of the Air Staff to the Prime Minister on 11 May 1941. It had been found that A.I. Mark IV night fighter aircraft lost contact with enemy aircraft more frequently on dark nights than on moonlight nights. To overcome this, an aircraft fitted with A.I. was modified to carry a searchlight and, controlled by G.C.I., it was to be accompanied in the air by two Hurricane or Defiant aircraft. The Turbinlite aircraft had no armament and its sole function was to illuminate the hostile aircraft with the searchlight beam after obtaining contact with A.I. The single-engined fighters were then to go in for the kill.[2]

The Havoc was the best available aircraft in 1941 for the installation, though doubts existed as to whether it was fast enough for the purpose when carrying the immense weight of the searchlight and its storage batteries. During trials in September 1941 it was reported that the A.I. was below standard ; serious fading and lack of range were common faults. The cause of the trouble was the introduction of the searchlight into the nose of the aircraft, which affected the aerial efficiency. Twin transmitter aerials were therefore fitted resulting in an improvement in the radiation.

Experiments were carried out in Fighter Command at the end of September on the most effective methods of co-operation between single seater fighters and the searchlight aircraft, and an opportunity for trials against the enemy was awaited. Ground control was the same as that used in normal G.C.I./A.I. interception at night. At first it was found that intercommunication between the searchlight aircraft and the satellite Hurricane fighters interfered with the sector R.T. control, but this difficulty was overcome by cutting down intercommunication to a minimum and using R.T. code words.[3]

Turbinlite development had been carried out in No. 93 Squadron and the personnel and aircraft required became No. 1458 Turbinlite Flight. The remainder of the squadron was diverted to building up two further flights. By the beginning of October 1941 five ' Turbinlite ' flights were in existence with twenty searchlight aircraft and two more flights were forming. Eventually the number of flights increased to ten. By this time, A.I. Mark V had been introduced into Service use and it was decided that this should form the basic A.I. equipment for all future Turbinlite aircraft, although no retrospective installation was attempted.

During the latter part of 1941 the Air Officer Commanding-in-Chief, Fighter Command, had ordered that the Turbinlite was not to be used on operations until the enemy night bombing effort justified the introduction of this new weapon. The technique of a parent aircraft directing its satellite fighter was practised in operations, but the light was not exposed until April 1942, when

[1] A.M. File S.6728, Encl. 75A.

[2] I.C. 68, 12 September 1941.

[3] *Ibid.*, para. 6.

permission was given for Turbinlite flights to go into action. Perfect exposure of the light occurred in the initial operations, but the enemy aircraft adopted violent evasive action and got out of the beam before the satellite aircraft could 'kill' it. However, success came soon afterwards, on the night of 30 April/1 May, when the first enemy aircraft was claimed as destroyed using the A.I. Turbinlite method.

Havoc searchlight aircraft continued to be used until the end of 1942. In bad weather the satellite aircraft had difficulty in keeping close enough to the parent aircraft; the whole combination proved extremely unwieldy.[1] On some occasions when the light was exposed the pilot of the Turbinlite aircraft was unable to see the target even though it was illuminated, the light having been exposed at too great a range. In addition, the Havoc aircraft proved to be too slow. Although A.I. performance was satisfactory, no great success attended the operations.[2]

[1] Turbinlite Operations, A.H.B. II/54/83, Encls. 5A and 11A.

[2] A.H.B. Narrative A.D.G.B., Vol. III, deals with the operational technique of Turbinlite aircraft.

CHAPTER 10

CENTIMETRIC A.I.

The $1\frac{1}{2}$ metre technique employed in A.I. Marks I to VI imposed a common disadvantage on all those types of equipment ; 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. The restriction of A.I. range was a bearable disadvantage when operating at a height of, say, over 6,000 feet where the maximum range was of the order of a mile or more, but against low-level bombing and minelaying raids the effective range of $1\frac{1}{2}$ metre A.I. was so short as to make A.I. contact virtually a matter of chance. Efforts were therefore made in 1940 to develop an equipment which could operate effectively at low altitude. 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 night fighter, 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 airborne use.[1] A method of producing radiation of sufficient power was accordingly sought among the shorter wavelengths for which a correspondingly smaller aerial could be used.

The possibility of using wavelengths of about one centimetre for radar purposes had been mentioned by Mr. R. A. Watson Watt at the 16th meeting of the Committee for the Scientific Survey of Air Defence on 25 February 1936.[2] The technical difficulties in the way of generating such wavelengths in adequate transmitting power were formidable at that time. Theoretical studies made before the war had shown that efficient oscillatory circuits could be made by using metal cavities proportioned to resonate electrically at the centimetric wave frequency concerned. Similarly, the general nature of aerials and feeders most suitable for working on centimetric wavelengths had been established theoretically, but these theories were largely academic, not well co-ordinated, and certainly outside the field of most radio engineers at the time. In the matter of valves, the position was rather more advanced. It was known that ordinary radio valves could not be used and special valves had been developed, though the power generated was too small for radar purposes.[3]

Initially the 10 centimetre waveband was not used because of the many immediate technical difficulties involved; attempts were first made in the late spring of 1940 to develop a new A.I. system on 25 centimetres wavelength. Before the 25 centimetre A.I. had progressed beyond the research laboratory stage, however, a

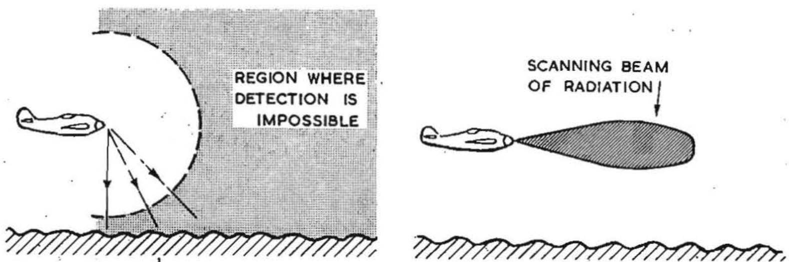
[1] For example, to produce a beam of 12° width on $1\frac{1}{2}$ metres wavelength, an aerial system about 20 feet wide would be required.

[2] Minutes of C.S.S.A.D., 25 February 1936.

[3] The Split Anode Magnetron Valve and the Klystron Valve. The former gave a peak pulse power of 1 kilowatt at a wavelength of 40 centimetres but the power output dropped rapidly as the wavelength was reduced to the 10 centimetric region. The Klystron Valve was complicated, and gave a continuous power of about only 100 watts at wavelengths around 10 centimetres.

CENTIMETRIC A.I.

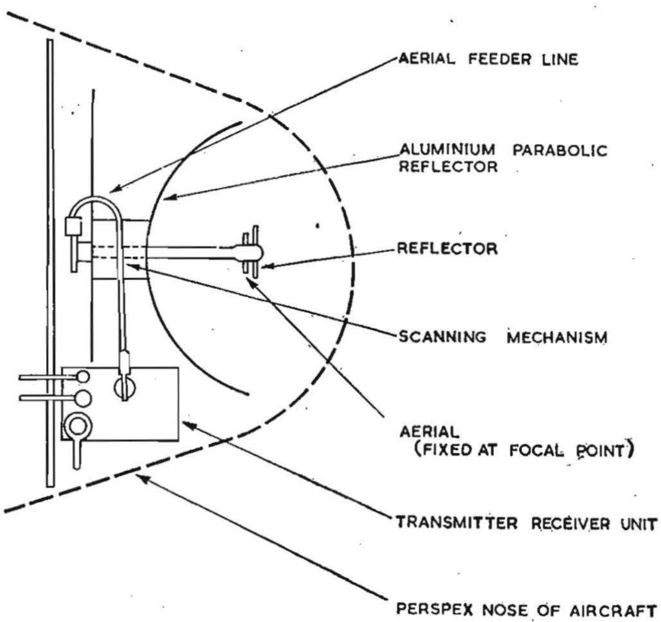
COMPARISON OF RADIATION PATTERNS ON METRIC AND CENTIMETRIC WAVELENGTHS



1½ METRE 9 CENTIMETRE

AERIAL SYSTEM

MOUNTED ON NOSE OF BEAUFIGHTER OR MOSQUITO AIRCRAFT



revolutionary development occurred which stabilised airborne radar firmly on a frequency of 3,300 megacycles per second (9·1 centimetres wavelength). This was the Randall-Boot cavity magnetron valve and the improved design of it which was produced in the General Electric Company Research Laboratory.[1] A twenty-fold increase in power over previous valves resulted ; the pulse output was of the magnitude of 10 kilowatts.

At the same time, work on the receiving valve side had been continued at the Clarendon Laboratory, Oxford, and by the Admiralty Signals Establishment team at Bristol University. The research laboratories of Electric and Musical Instruments and Standard Telephones and Cables also contributed. Ultra-high frequency circuits had been studied since early in 1940 by the Air Ministry Research Establishment team at Dundee, whilst the 'airborne research group' at St. Athan studied the beam scanning methods for centimetric A.I. The culminating point in the basic phase of centimetric development was reached at the Telecommunications Research Establishment at Worth Matravers, Dorset, on 13 August 1940.[2] Using centimetric equipment on the ground, echoes were obtained from a Battle aircraft up to a range of about six miles. All that then remained, in the optimistic words of one of the research scientists working under Dr. Dee, was to 'put it in an aeroplane.' The broad outlines of the ultra-high frequency radar system were decided upon, but the process of converting a 'lash-up' bench set operated by men with scientific knowledge into an aircraft equipment capable of reasonably high serviceability under active service conditions was essentially a long one.

The engineering and manufacturing of all kinds of new equipment was already straining the production capacity of the British radio industry to the limit in 1941, and the benevolent neutrality of the United States offered a radio production field of apparently unlimited capacity. The cavity magnetron valve in particular and many of the British ground and airborne radar techniques were highly secret, but, after President Roosevelt's express wish to co-operate and at the direction of the Prime Minister, a British technical mission under the leadership of Sir Henry Tizard went to the United States at the end of August 1940.[3] Its purpose was the exchange of secret technical information. Dr. E. G. Bowen, who had worked on airborne radar from the first experiments, accompanied the mission, representing the Ministry of Aircraft Production as a technical adviser.[4] Perhaps the most important single British disclosure to the Americans was the cavity magnetron valve, which opened the field to microwave development. United States equivalents of the cavity magnetron valve were soon manufactured and progress on centimetre wavelengths continued in the American research departments.[5]

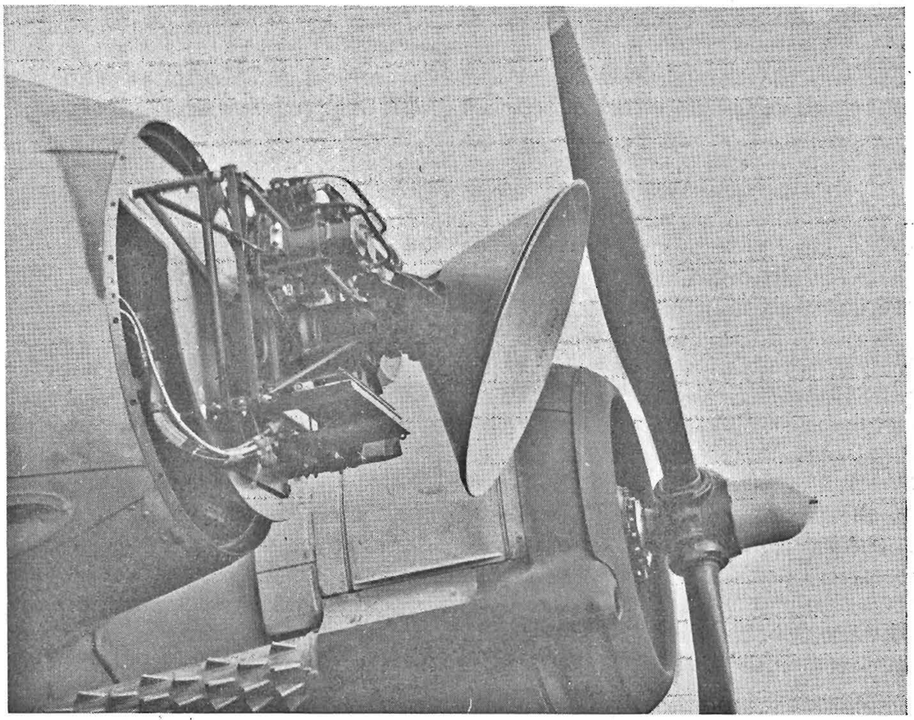
[1] C.V.D. Report, May 1941, 'Magnetron Development in the University of Birmingham' and G.E.C. Report No. 8717, C.V.D., 30 August 1945. The story of the magnificently co-ordinated effort which led to the development of the high-power, pulsed, cavity magnetron valve and the ultra-high frequency radar technique is given at Appendix No. 8 to Volume IV.

[2] Air Ministry Research Establishment became Telecommunications Research Establishment on moving from Dundee to Worth Matravers on 5 May 1940.

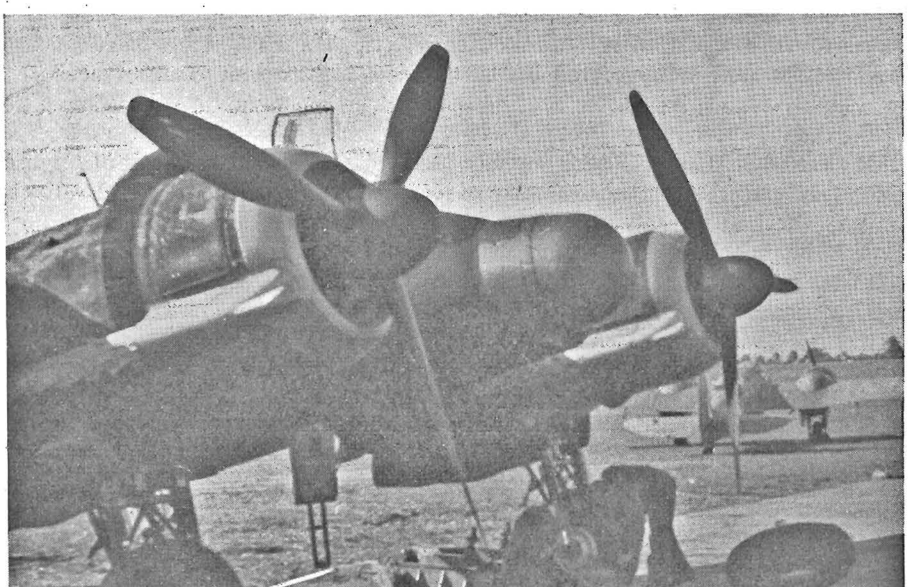
[3] A.M. File S.4471, Encl. 152A.

[4] A.M. File S.5799, Encls. 38B, 48A and 68B. War Cabinet North American Supply Committee N.A.S. (40) 33.

[5] H.M.S.O. Reprint—'A Report on Science at War', 1945. S.O. Code Nos. 59—85.



Scanner.



Perspex Nose Housing the Scanner

A.I. MARK VIIIA—INSTALLATION IN BEAUFIGHTER MARK VI

On 12 October 1940, Dr. Bowen discussed with the American Microwave Committee the specific project of 10 centimetre A.I. development, which it was suggested should be undertaken by the United States. A microwave laboratory under the Massachusetts Institute of Technology was opened in November 1940 and became an important factor in the advancement of centimetric radar technique. Dr. Bowen remained in the United States, at first attached to the British Purchasing Mission there and later under the British Central Scientific Office in the U.S.A., continuing his work on centimetric A.I. in collaboration with American scientists.[1]

Meanwhile in the United Kingdom, despite the suggestion that centimetric A.I. was a suitable field for American research and development, there was no slowing up in basic research at the Telecommunications Research Establishment. Dr. Dee and Dr. Lewis, with a small group of scientists at Worth Matravers, continued to improve their original microwave equipment and to re-design it suitably for installation in night-fighter aircraft. Overcoming the limitations of weight and bulk, vital factors in equipment design for fighter aircraft, the first centimetric A.I. set in experimental form was flown in a Blenheim aircraft in March 1941. Ranges of just over two miles were obtained on a target aircraft flying at 5,000 feet, and it was thus apparent that the new A.I. had overcome the range limitation in relation to height.

The radiation from the new A.I. transmitter was confined by means of a parabolic mirror to within a beam of 12°. The beam scanned the sky in front of the aircraft, moving around and outwards in a spiral path up to a limiting angle of 45° after which it moved inwards in a similar spiral path. In this manner all the space in front of the aircraft within a cone of angle 90° was searched continuously. The spiral scanner,[2] driven by an independent hydraulic system from the port engine, was designed by the firm of Nash and Thompson. The whole scanner system was built into the nose structure of the aircraft, much work having been done on the design and supply of a suitable type of perspex nose for the Blenheim and Beaufighter aircraft. Two such scanning systems, one for transmission and the other for reception, were employed in the original experimental work but such duplication made too great a demand on space in the aircraft. Efforts were made at the G.E.C. research laboratories, the Clarendon Laboratory, and T.R.E. to make one scanning system perform the functions of both transmission and reception. This last major difficulty was overcome in May 1941 by the use of an ingenious form of automatic switch, which enabled the same aerial system to alternate with great rapidity between transmission and reception.

The presentation of the information to the radar operator was on a single cathode ray tube, using a rotating time-base synchronised with the movement of the scanning mirror. Each time-base started at the centre of the cathode ray tube and travelled outwards towards the edge of the tube so that successive time-bases were radial lines slightly displaced, due to their rotation.[3] Any

[1] A.M. File C.S.13467, Encls. 21B and C.

[2] The diagram shows this aerial system, in which the aerial remained stationary at the focus of the parabolic reflector and the axis of the mirror rotated rapidly with a continuously varying inclination to the dead-ahead position so that the centre of the mirror actually traced out a spiral path.

[3] The Radial Time-Base. *See* C.D.0515.

aircraft within the range of the equipment and coming into the path of the scanning beam reflected the transmission. This reflection was received, amplified, and applied to the cathode ray tube where it appeared as a spot of light on the time-base. In operation, the brilliance control of the set was turned down to a position where the time-bases were not visible; the incoming signal was then indicated as an isolated spot of light, the distance of which from the centre of the tube was a measure of the range to the target aircraft. There were 150 time-bases for each revolution of the mirror and the revolving scanning mechanism was designed to work at up to 1,000 revolutions per minute. The spots of light, whose number depended on how long the target was held in the beam, appeared at an equal distance from the centre of the tube. Because of the speed of rotation, instead of appearing as a series of spots, they merged together in the form of a luminous arc. From this display, the following interpretations could be made:—

(*a*) The distance from the signal arc to the centre of the cathode ray tube indicated the range of the target.

(*b*) The position of the middle of the arc relative to the centre of the tube gave the relation of the target's position to that of the night fighter aircraft.

(*c*) The angular length of the arc also indicated the angle at which the target was lying off the axis of the fighter, that is, the amount by which the target was off centre.

During June 1941, two experimental A.I.S. equipments fitted in Blenheim aircraft showed great promise; in fact there was every reason to believe that ranges of the order of eight miles would be attained.[1] Twelve hand-made sets of more elaborate apparatus were ordered, manufacture of the principal parts being undertaken by the General Electric Company. Beaufighter aircraft were to be fitted as soon as the new microwave A.I. sets were available.[2]

Enemy low-flying tactics, especially with minelaying aircraft, and the possibility of German jamming of the 1½-metre (200-megacycles per second) equipment caused Air Marshal Sir Sholto Douglas, Air Officer Commanding-in-Chief, Fighter Command to press for A.I.S. equipment to be fitted in two Beaufighters and to be sent to the F.I.U. for trials.[3] Provided the trials were successful, he wished to recommend the making of 100 hand-made sets by G.E.C. as soon as possible so that they could be used to intercept enemy aircraft making a low approach over the sea. The sets (known originally as A.I.S. Mark I and later as A.I. Mark VII) were ordered in August 1941 even before tests at F.I.U. had been carried out. The urgency of the requirement, and the success of the demonstrations by T.R.E. scientists of A.I.S. in Blenheim aircraft at Christchurch airfield, had convinced the Air Ministry representatives that such action was justified. Meanwhile, the centimetre equipment was being developed to include beacon and I.F.F. working and the new set, to be known as A.I. Mark VIII, was to be let out to contract for large-scale production.

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[1] *i.e.* A.I. in the centimetre or 'S' wave band.

[2] A.M. File S.6879, Encl. 12A. Air Interception Committee 26th Meeting.

[3] *Ibid.*, Encls. 13A, 44A and 71A.

American A.I.S.

Just at the time when British A.I.S. had shown promise and the Service was awaiting the manufacture of A.I. Mark VII, Dr. Bowen returned to the United Kingdom from the U.S.A. to be present when an American experimental A.I.S. equipment was given special trials by the F.I.U.[1] The apparatus was rather heavy and was installed in a 'flying laboratory', a Canadian Boeing 247-D aircraft which had been shipped from America and reached F.I.U. on 14 August 1941.[2] The reasons for bringing the equipment over to Britain were two-fold: to obtain a direct comparison in performance with the British 10-centimetre A.I. set and to get a statement from the F.I.U. on operational requirements so that American production could start in a form suitable to British needs.[3]

The American scanner system was driven electrically and the scan motion was helical. The presentation was in the form of a television picture, approximately five inches square, on a cathode ray tube. An echo from a target aircraft appeared as a horizontal bright line about half an inch in length. Although both range and direction could be determined from the position of this indication on the tube, they could not be read at the same time, and the range indication was of little value operationally. The whole equipment was too large and too heavy to be installed in a Beaufighter aircraft, but the necessary modifications to reduce bulk and weight were in hand. Despite the disadvantage mentioned, the equipment showed the greatest promise and the F.I.U. reported that it would 'offer a weapon of the highest operational value against the night bomber'. The United States Army Air Corps had considered it equally promising and had turned it over to one of the large American industrial concerns at the end of May 1941 to be engineered for production. It was given the U.S. Signal Corps nomenclature SCR.520.[4]

A decision had to be taken in the autumn of 1941, whether the hand-produced A.I. Mark VII programme and the development and production of A.I. Mark VIII were to continue, or alternatively, whether it was advisable to await the improvement and production of the American centimetre set, SCR.520, by Western Electric Company (U.S.A.). The estimated delivery date of the American equipment was May 1942.[5] Acting on the advice of the Directorate of Signals, the Air Staff decided that the British design, A.I. Mark VII, would be available first for operational use and would fill the gap until the improved production model, A.I. Mark VIII, appeared. Only two hundred American centimetric equipments were therefore ordered. The American attitude towards British A.I. requirements was extremely helpful, enabling the Ministry of Aircraft Production to formulate its own specifications for the sets, though broadly they were to be on the same lines as the U.S. Signal Corps SCR.520. The sets for the Royal Air Force were to be known as the SCR.520 (U.K.). One of these was fitted into a Beaufighter, specially shipped from England, in December 1941, but the excessive size of the equipment and its heavy power requirements presented installation difficulties.[6] Eventually, in March 1942,

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[1] A.M. File C.S.13467, Encl. 12A.

[2] F.I.U., O.R.B., August 1941.

[3] F.I.U., Report 85, 21 August 1941. A.H.B., IIm/fA140/1.

[4] 'Radar—A Report on Science at War'. H.M.S.O. Reprint, 1945. S.O. Code No. 59-85.

[5] A.M. File C.S.13467, Encl. 55A.

[6] *Ibid.*, Encls. 85B, 89A.

a fairly satisfactory arrangement was made, but by that time the British programme of microwave A.I. was so far advanced that it was considered not worth while pressing the United States to go ahead with the SCR.520 (U.K.) and the order was cancelled.

Hand-made A.I.S. sets were fitted in two Beaufighter aircraft in September 1941 by the Telecommunications Research Establishment at Christchurch.[1] This was a change from previous practice. Formerly the responsibilities of the Telecommunications Research Establishment had ended with the production of the first set of new equipment, but the difficulties experienced in introducing technical equipment into the Service after only the barest minimum of test and trial had made clear the need for special arrangements. An organisation was required to bridge the gap between scientific development and operational use. It was necessary to ensure that technical installation work was competently supervised, that adequate test gear and spares were made available, that radio mechanics were given comprehensive training and that the problems inevitably encountered during the first operational use of the equipment could be solved by personnel possessing the necessary understanding of the set. To do this work the first Service Liaison group, jocularly referred to as the 'After Sale Service', was formed at the Telecommunication Research Establishment in September 1941.[2] Because they were not all physicists, some were, for example, biologists, they were not imbued with the idea that the best remedy for any failing was re-design, but tackled the job of getting the best out of the set in the squadron as it stood. Their slogan, which was belied by the quality of their work was, 'Something in time, however bad!'[3]

A.I. Mark VII

On 27 November 1941 the two Beaufighters flew from Christchurch to the F.I.U. at Ford for operational trials.[4] A Service Liaison party and a G.E.C. representative accompanied the aircraft, to instruct Royal Air Force personnel and to service the equipment. In addition to operational trials, the two aircraft were to remain at the F.I.U. for use in investigating the serviceability of the new apparatus and in developing methods of maintenance.[5] After initial demonstrations, flying locally with target aircraft, the trials took the form of active operations against German mine-laying patrols over the Thames Estuary. During the first trial on 7 December 1941 the F.I.U. crew located an enemy aircraft with the A.I.S. equipment, chased and damaged it, recognising it as a Ju.88.[6]

The experimental equipment in the Beaufighter aircraft proved very useful for training both aircrew and ground servicing crews in the new centimetric technique. Radio observers rapidly adapted themselves to the radial time-base presentation, and maximum ranges of 3½ miles were obtained.[7] In view of the

[1] A.M. File S.6879, Encl. 62A.

[2] The History of T.R.E. Post Design Services, 1941–1945. A.H.B. IIE/244.

[3] In November 1942, Service Liaison groups expanded to all R.A.F. Commands and the name was changed to 'Post Design Services'.

[4] F.I.U., O.R.B., November 1941 to April 1942.

[5] T.R.E. Report T.R.E./25/1, 17 May 1942. A.H.B. IIE/193/1.

[6] F.I.U., O.R.B., 7 December 1941. [7] F.I.U. Report No. 105. A.H.B. IIm/fA140/1.

experience obtained at the F.I.U. with all previous Marks of A.I., their report that the new apparatus ' gave far less trouble than any other prototype A.I. set ' augured well for the future. The experimental equipment proved unsuitable for operations above 8,000 feet because of internal ' arcing ', but even so, it was considered that it warranted early introduction into two night fighter squadrons for use against enemy low-flying aircraft.

A Service liaison section gave courses of instruction to squadron maintenance personnel in basic centimetric technique and special points of A.I. Mark VII.[1] Between January and May 1942 officers and airmen from four squadrons,[2] and also technical officers from Headquarters Fighter Command and Fighter Groups, were given initial training in centimetric technique. Two more T.R.E. Service Liaison sections were set up at Christchurch in December 1941, one to deal with installation and the other with maintenance in squadrons. Forty Beaufighter aircraft were to be fitted as quickly as possible. One hundred sets of A.I. Mark VII were shortly due off the main production contract.[3] Royal Air Force radio mechanics were attached to the installation section during the period of fitting Mark VII, so that they would later be competent for the Mark VIII fitting, which was to be done at maintenance units. Installation, begun during the last week in February 1942, proved more troublesome than had been anticipated, and the first two aircraft were not completed until 18 March. Thereafter an average of three aircraft every week was maintained, despite a move from Christchurch to Hurn during the fitting programme.[4] The first squadron to receive A.I. Mark VII-equipped aircraft was No. 29 Squadron. A Service Liaison party went to West Malling airfield to give assistance until the squadron radio mechanics were sufficiently experienced. Similar parties went to No. 68 Squadron at Cottishall, No. 141 Squadron at Acklington, and No. 604 Squadron first at Middle Wallop and later at Predannack, where A.I. Mark VII was introduced during April and May 1942.

The F.I.U. had been the first to secure operational successes with A.I. Marks III, IV and V. Mark VII was no exception to the rule. One of this unit's pilots took off in a Beaufighter on 5 April against enemy minelaying aircraft and established A.I. contact at 4 miles range under C.H.L. station control. A ' visual ' was obtained on a German Do.217 aircraft and, closing to about 300 yards, the night fighter shot it down in flames.[5]

From its initial introduction A.I. Mark VII was outstandingly successful. Even before the four squadrons were fully equipped, seven enemy aircraft had been claimed as destroyed by the few available aircraft before 15 May 1942, in addition to several damaged and ' probables '. A.I. Mark VII was the only centimetric A.I. in service with the Royal Air Force until December 1942, when the first squadron was equipped with A.I. Mark VIII. During this period enemy air activity was relatively small, consisting mostly of low-flying raiders and minelayers. It is significant that this type of enemy operation had

[1] The History of T.R.E. Post Design Services, 1941–1945. A.H.B. IIE/244.

[2] Nos. 29, 68, 141 and 604 Squadrons were selected as the night-fighter squadrons to be equipped with A.I. Mark VII.

[3] A.M. File CS.13884, Encls. 1A and 12A.

[4] The History of T.R.E. Post Design Services, 1941–1945. A.H.B. IIE/244.

[5] F.I.U., O.R.B., April 1942.

formerly been almost immune from night interception. In the United Kingdom and later in the Mediterranean theatre, A.I. Mark VII was instrumental in the destruction of just over one hundred enemy aircraft, more than one for every set of equipment made.[1]

The A.I. Mark VIII Series

The A.I. Mark VII system was a hastily produced centimetric equipment designed to meet the pressing need for the night interception of low-flying enemy aircraft. Its limited production was intended to fill the gap until the arrival of the A.I. Mark VIII. The Mark VIII programme was a major production and installation effort to re-equip almost the whole of the night-fighter force with centimetric A.I., incorporating A.I. beacon and I.F.F. facilities which it had been impossible to include in the Mark VII apparatus owing to the speed of its production. Development work at the Telecommunications Research Establishment on A.I. Mark VIII during the hurried Mark VII production programme was so satisfactory that a three-stage production plan for the Mark VIII system was undertaken.

(a) *A.I. Mark VIIIA* was limited to an interim programme for 500 hand-produced sets ordered from G.E.C.[2] Manufacture was to begin immediately the limited production of Mark VII was completed. Though engineered in a similar manner to Mark VII, this set was of higher power and gave direct interrogation facilites of centimetre responder beacons and blind approach beacons (BABS Mark I), and I.F.F. Mark III.[3] A rather optimistic target date for the contract to be fulfilled was given initially as the end of the year 1942. In an effort to achieve this, the G.E.C. prototype set was to be accepted on the basis of T.R.E. type approval and factory inspection. No operational trials at the F.I.U. were to be held.

(b) *A.I. Mark VIII* equipment was to be the main line of production, and a contract for 1,500 sets was given to E. K. Cole. The set was similar to Mark VIIIA but was of improved engineering technique, theoretically of higher power, and was to incorporate any modifications subsequently found necessary as a result of experience with Mark VIIIA.[4]

(c) *A.I. Mark VIIIB* was to complete the production programme of the series. It was to be a variant of Mark VIII in which 'Lucero'[5] facilities were available for I.F.F. responder beacons, and beam approach, thus enabling night-fighter squadrons so equipped to use the 1½-metre responder beacon chain.

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[1] Fighter Command O.R.S. Reports Nos. 374, 416. A.H.B. II/39/2. T.R.E. Journal, A.H.B. II E/184, July 1945, p. 93.

[2] The contract was later increased to 1,000 sets. A.M. File S.12460, Encl. 5A.

[3] Centimetre responder beacons and blind approach beacons are described in Volume III.

[4] A.M. File S.12460, Encl. 69A.

[5] A.M. File S.18801, Encl. 104B. Lucero was the name given to an interrogator responser designed as an adjunct to centimetre airborne radar equipment to enable 1½-metre responder beacons and I.F.F. to be interrogated, and to present the responses on the indicator of the main radar equipment. Details of Lucero are to be found in Volume III.

A.I. Mark VIIIA

German jamming of the 1½-metre band in June and July 1942 made it all-important to put the new centimetre equipment into service without delay and the Telecommunications Research Establishment was again called upon to take charge of the introduction of A.I. Mark VIIIA into the Service.[1] The diversion of scientific effort from the primary duty of research was unfortunate, but knowledge and experience of centimetric radar was still very limited in the squadrons, and might easily lead to incorrect adjustment of the equipment and to minor but important points being overlooked in servicing and maintenance. Such shortcomings had in fact been responsible for many of the difficulties in the introduction of the 1½-metre A.I. equipment. It was therefore expedient that the T.R.E. staff should undertake the early work of fitting, adjustment, instruction and supervision of maintenance alongside the Service maintenance and aircrew personnel.

The Service liaison sections were expanded, but even so their Special Installation Unit at Defford was too small for the large programme which the Mark VIII series was to involve. Plans were therefore made for the first six Beaufighters to be fitted at Defford by Service liaison personnel with Royal Air Force mechanics assisting under instruction. Two of the completed aircraft were then sent to No. 32 and No. 218 Maintenance Units as prototypes, and all subsequent installations of A.I. Mark VIIIA were undertaken at these units. The rate of output ultimately reached eighty aircraft a month.

The first pre-production model of A.I. Mark VIIIA was delivered by G.E.C. in July 1942. Flight trials for type approval began on 25 August under the supervision of T.R.E. and Service representatives, and lasted for two weeks. Although the power output rating of the new set was greater than that of previous Marks, its effective range was somewhat disappointing, being of the order of 4 miles at 10,000 feet. Arcing occurred at 22,000 feet, necessitating an altitude limitation on the use of the equipment.[2] After recommendations for minor improvements had been made, production was approved and G.E.C. began work on the first 500 Mark VIIIA equipments. It was the end of the first week in December 1942 before the first ten production models were available, delays having been caused by technical difficulties in production. Eight Beaufighter squadrons were selected for Mark VIIIA installation after the first two aircraft fitted had been sent to the F.I.U.[3] Aircraft fitted with Mark VIIIA reached No. 219 Squadron on 21 December 1942.

Meanwhile the organisation for training both air and ground personnel in centimetric radar had to be expanded to take in larger numbers. The small-scale instruction of maintenance unit and squadron personnel by the T.R.E. Service liaison group at Defford was inadequate to deal with the intended increasing use of centimetric equipment, so in mid-January 1943 Technical Training Command took over all responsibility for A.I. Mark VIII maintenance training. The equipment used for instruction at Defford was removed to No. 7 Signals

[1] A.M. File S.12460, Encl. 120A.

[2] *Ibid.*, Encls. 123A and 203A.

[3] The squadrons selected were Nos. 219, 68, 125, 29, 406, 604, 141 and 488 in that order of priority. A.M. File CS.17599, Encl. 2A.

School at the Science Museum, South Kensington, and the larger courses began there at the end of January. After the delivery of the first A.I. Mark VIIIA-equipped aircraft to No. 219 Squadron, aircrew radio operators rapidly became adept in their new equipment. Maximum ranges of 4½ miles were obtained, and the greater coverage of the Mark VIII scanner gave a decided advantage over the Mark VII in its ability to follow jinking targets. The squadron was fully equipped during January 1943, as was No. 68 Squadron in February. From March to May three other squadrons, Nos. 125, 29 and 604, received their A.I. Mark VIIIA-equipped Beaufighters.

Initially, serviceability was better than that of the Mark VII set, but after a few hours running many breakdowns occurred. The principal troubles were in the modulator, with overheating and arcing of the CV57 valves (which were being over-run) or breakdown of the pulse transformer. It was found that by careful 'running in' the life of the valves was increased, but there were three CV57 valves in parallel in the modulator, so running in was only a palliative. Modifications to the set itself were made to relieve the strain on these valves, but it was not until late in 1943, when the final type of CV57 valve was produced, that the serviceability of the modulator improved to a reasonably high standard.[1]

In spite of such technical difficulties, A.I. Mark VIIIA was very successful operationally. The first enemy aircraft to fall a victim to the new A.I. was a Do.217, shot down on 3 February 1943 by a night-fighter of No. 219 Squadron. During the first seven weeks of its use in this squadron nine enemy aircraft were claimed as destroyed. The second squadron to receive Mark VIIIA, No. 68, claimed five enemy aircraft destroyed during the first full week of operations. One of the enemy aircraft destroyed was contacted at 7 miles range.[2]

Analysis of the numbers of enemy aircraft shot down during March 1943 shows that A.I. Mark VIIIA was instrumental against seventeen of the total of twenty-seven destroyed, notwithstanding that only two squadrons were as yet fully equipped with the new sets. Probably the best standard for comparison in relative efficiency of the various A.I. systems is the ratio between the number of attempts to intercept and the number of destructions achieved. The ratio between destructions and attempts was appreciably higher for A.I. Mark VIIIA than for any other marks of A.I. equipment which had been in Service use up to the spring of 1943.[3] Increased range was probably the most important factor in the improved effectiveness. A prototype installation of A.I. Mark VIIIA in a Mosquito aircraft was made during October 1942, using a pre-production prototype model of the equipment. In March 1943 fitting in Mosquitos began, and No. 85 Squadron was equipped.[4] After installation problems had been cleared up, the A.I. Mark VIIIA-equipped Mosquito showed an effectiveness on night operations similar to that of the Beaufighter.

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[1] A.M. File S.18801, Encls. 37B and 88A.

[2] No. 219 Squadron and No. 68 Squadron O.R.B.s.

[3] Fighter Command O.R.S. Reports Nos. 446, 455 for March and April 1943. A.H.B. II/39/2.

[4] A.M. Files C.S.14774, Encl. 16B and C.S.18957, Min. 2.

A.I. Mark VIII

A pre-production model of A.I. Mark VIII installed in a Beaufighter arrived at the F.I.U. for Service trials on 23 December 1942 and the new equipment was subjected to tests lasting 120 flying hours. The maximum range averaged only four miles, and since the Mark VIII transmitter was designed to radiate ten times the power of the Mark VII, this was disappointing. Occasionally ranges of six to eight miles were obtained but modifications were necessary to improve the range.[1] The general serviceability and reliability of the Mark VIII equipment was good, although troubles with the C.V.57 valve occurred as with the Mark VIIIA. The F.I.U. was of the opinion that the efficiency of the night fighter defences would improve out of all recognition with the general introduction of this new Mark.

The firm of E. K. Cole ran into serious technical difficulties with Mark VIII sets before large-scale production was undertaken. Although the chief difference between Mark VIIIA and Mark VIII was the improved lay-out and better engineering of the latter, many important modifications were introduced to improve serviceability, notably the introduction of oil-filled pulse transformers to overcome the weakness which had manifested itself in the modulator of the Mark VIIIA set.[2] The first of the new Mark VIII sets was delivered to No. 218 Maintenance Unit during May 1943 and installation on Mosquito aircraft began immediately. No. 151 Squadron received its first A.I. Mark VIII equipped Mosquito on 11 June 1943 and began training with the new equipment. During July and August this squadron devoted a good deal of flying time to comparing the performance of the Mark VIII with the Mark VIIIA equipment and found no appreciable difference in the maximum ranges achieved.

The first success with A.I. Mark VIII was claimed on 15 September 1943 by the second squadron to be equipped, No. 488 at Drem, one of its night-fighters intercepting and destroying a German Dornier 217 aircraft which was making a low-level attack on the north-east coast.[3] In September and October, enemy minelaying operations by aircraft were greater than at any time during 1943. During those two months, all Fighter Command successes at night were obtained with A.I. Mark VIII, and thirty-one of the thirty-seven combats during October and November were made with the A.I. Mark VIII/Mosquito combination. But although centimetric A.I. was rapidly supplanting 1½-metre equipment, the latter was still used successfully on operations. In December 1943, during the course of one night, the pilot of a Mosquito fitted with A.I. Mark V made four interceptions and destroyed three enemy aircraft.

The conversion of the Home night-fighter force to centimetric equipment proceeded gradually under the guidance of a Fighter Command special servicing party which took over the responsibility from the post design service groups. Nos. 29, 256, 307, 409, 96, 406 and 264 Squadrons were all using A.I. Mark VIII by early 1944. Conversion would have proceeded much more rapidly if it had not been for the night-fighter aircraft requirements overseas, which were making increasing demands upon the production of both aircraft and A.I. equipment during 1943.

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[1] F.I.U. Report No. 181. F.I.U. Report No. 188, A.H.B. IIM/f.A140/1.

[2] A.M. File S.12460, Encl. 208B.

[3] Fighter Command O.R.S Reports, September–December 1943. A.H.B. II/39/2.

Overseas Use of 1½-Metre A.I.

Three factors had restricted the early provision of A.I. to oversea theatres:

(*a*) The priority of the night defence of the United Kingdom.

(*b*) The need for mobile G.C.I. stations before the A.I. technique could be exploited overseas.

(*c*) The security aspect. A.I. was only to be operated in areas where there was no risk of it falling into enemy hands.

Two squadrons of Beaufighter aircraft fitted with A.I. Mark IV were transferred to the Middle East during 1941 and 1942 where they took part in the night defence of both Malta and Egypt.[1] Although the total numbers of aircraft shot down were perhaps not comparable with those reached in the United Kingdom against heavier and more numerous raids, the squadrons were an effective deterrent against night-bombing in the important base areas of Alexandria and the Suez Canal.[2] The overseas requirement for A.I. increased after the landing in North Africa on 8 November 1942. It was decided during the planning stage that two squadrons of Beaufighter aircraft, Nos. 255 and 600 Squadrons, would provide the night fighter cover, but it was found that the demand for shipping space precluded the night-fighter squadrons from being brought into use before D + 28.[3] For security reasons the Air Ministry ordered that A.I. Mark IV equipment should be removed from the Beaufighter aircraft flying out from the United Kingdom via Gibraltar and should be taken to North Africa by sea with the ground parties. As a result of the rapid advance of the British First Army after the landing and the difficulties of securing forward airfields, the Air Officer Commanding, Eastern Air Command decided to call in the two Beaufighter squadrons early and employ them as long-range fighters by day without A.I. No. 225 Squadron arrived on D + 7 and No. 600 Squadron on D + 10. This attempt to operate the Beaufighter aircraft before their ground servicing parties arrived resulted in poor serviceability and an excessive rate of wastage.

When on 20 November 1942 the first German night attacks were made on Algiers, an attempt was made to use the Beaufighters in their proper role of night-fighters. They carried no A.I., however, because the equipment was still *en route*, and were consequently of little value. To forestall hostile reaction by the local population as a result of night bombing, assistance was requested from Headquarters, Royal Air Force, Middle East, and one flight of No. 89 Squadron was flown in from Egypt.[4] In addition, twelve sets of A.I. Mark IV were despatched from England by air and efforts were made to fit them in some aircraft

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[1] These were :—

No. 89 Squadron—Arrived in the Middle East during December 1941. Had a detached flight on Malta from 23 June 1942.

No. 46 Squadron—Ground personnel arrived Middle East 9 July 1941. Some aircraft and pilots operated from Malta on the way out so it was 8 May 1942 before squadron operated in Middle East.

[2] Nos. 46 and 89 Squadrons O.R.B.s.

[3] Fighter Command O.R.B., October 1942.

[4] This flight of No. 89 Squadron remained in North Africa until January 1943. Early that month it returned to the Middle East. During its six weeks operations in the North African theatre it destroyed nineteen enemy aircraft. (Eastern Air Command, O.R.B., December 1942.)

of both No. 255 and 600 Squadrons, a difficult task because the specialist ground personnel were still at sea and until they arrived the aircraft were being serviced by their aircrews and the ground personnel of a Hudson squadron.[1]

The few A.I.-equipped aircraft available paid a rich dividend on their first night of operations on 28/29 November 1942. Five enemy aircraft out of eight approaching Algiers were destroyed. Subsequently a further fourteen enemy aircraft were destroyed during their operations against the port of Bone on three nights in the first week of December.[2] It is of interest to note that in the early night raids on North African objectives, the German aircraft approached in straight and level flight, with an interval of several minutes between each aircraft. Such tactics were most advantageous to the radar-equipped night-fighters. Apparently the lessons learned by the *Luftwaffe* in the night assault against England, which had led to the adoption of jinking tactics and low-level approach, had to be re-learned in the Mediterranean theatre. The decision to separate the Beaufighters from their A.I. equipment had further unfortunate repercussions.[3] The ship carrying the ground parties reached Algiers punctually on D + 28 but there was no time to land the Royal Air Force personnel and equipment because certain Army elements on board were urgently required to disembark at Bone. There the Royal Air Force personnel were also put ashore, a proportion of the A.I. equipment for No. 255 Squadron being lost in the unloading.[4] Eventually the ground personnel of No. 600 Squadron returned to Algiers by sea and joined their aircraft on D + 35.

During its first month of operating with A.I. Mark IVA, No. 255 Squadron was very successful; eighteen enemy aircraft were claimed as destroyed at night.[5] Night fighter strength over the North African base area was increased towards the end of December by the arrival of No. 153 Squadron from the United Kingdom.[6] Personnel and spare equipment for this squadron were at first inadequate and it was only by assistance from Nos. 255 and 600 Squadrons that it could operate effectively. To co-ordinate night defence, all three squadrons were placed in a special night-fighter wing (No. 325) with headquarters at Setif. The squadrons and flights were then stationed at several different airfields to increase the area of night fighter operational cover.[7] No. 153 Squadron quickly made its presence felt in the theatre, claiming twelve enemy night raiders destroyed in January 1943.[8]

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[1] A.M. File C.26023/45, Report on Operation 'Torch', para. 133, *et seq.* Fighter Command O.R.B., November 1942. The Hudson squadron was No. 608.

[2] *Ibid.*, para. 136, *et seq.*

4th December	..	3 destroyed out of 20 enemy aircraft.
5th December	..	5 destroyed out of 15 enemy aircraft.
6th December	..	6 destroyed out of 15 enemy aircraft.

[3] Owing to the limitations of shipping space and the need to give priority to aircraft which could be used for offence, the night defence of bases was to have been an A.A. responsibility during the first four weeks. There was no delay in organising the Royal Air Force night defence; on the contrary, a night fighter organisation was set up with limited equipment and personnel well ahead of the time planned. In the Air Ministry view these 'Night fighters are obviously paying an excellent dividend'. (A.M. File C.S.17571, Encls. 26A and 51A.)

[4] Nos. 255 and 600 Squadrons O.R.B.s, November 1942.

[5] No. 255 Squadron O.R.B., December 1942.

[6] No. 153 Squadron O.R.B., December 1942.

[7] Night flying detachments operated from Casablanca, Oran, Algiers, Bone, Souk-el-Arba, Souk-el-Khemis and Tebessa. A.M. File C.S.17572, Encl. 130A.

[8] No. 153 Squadron O.R.B., January 1943.

Introduction of Centimetric A.I. Overseas

By the end of 1942 five squadrons of Beaufighter aircraft equipped with 1½-metre A.I. were operating in North Africa and the Middle East, including a flight in Malta. The need for centimetric A.I. was felt when the Germans in Sicily began to jam the A.I. frequency (200 megacycles per second) affecting the area of Malta, and there seemed every likelihood of the jamming extending to the North African ports.[1] The re-equipment of the night-fighter squadrons with centimetric A.I. offered a timely solution to the jamming problem. In spite of the shortage of centimetric A.I. equipment, the change was not altogether inconvenient because the supply of suitable Beaufighters equipped with A.I. Mark IV was running out. The only ones available had already seen service in Fighter Command squadrons and even after overhaul were reaching the stage when they were unfit for a prolonged campaign overseas. The new type of Beaufighter was already being supplied complete with the perspex nose and electrical wiring designed for use with centimetric A.I. The change-over to centimetric A.I. sets in overseas theatres of war was, however, no easy task. The rate of flow of the new equipment from production was insufficient to meet the immediate requirements both at home and overseas. In addition, ground personnel and aircrews overseas were out of touch with the developments of the centimetric technique, and a considerable amount of instruction was necessary before effective operation and maintenance could be assured.

The first centimetric A.I. equipment to be sent overseas was despatched to Malta towards the end of July 1942 from the scanty resources available in the United Kingdom. There were only forty Beaufighters fitted with A.I. Mark VII, but when Air Headquarters, Malta, reported that their 1½ metre A.I. was being jammed during the latter part of June 1942 it was decided that a special flight of five Beaufighter aircraft fitted with A.I. Mark VII and five spare sets of equipment should be despatched to Malta immediately.[2] A technical officer, two radar mechanics and one hydraulic fitter (for servicing the scanning mechanism), all experienced in Mark VII equipment, were to accompany the flight.

For security reasons, the aircraft were stripped of their equipment and four of them flown out via Gibraltar.[3] The A.I. equipment and ground personnel were transported over the same route in two Sunderland flying-boats, arriving in Malta during the first week in August 1942. Aircrew of the flight of No. 89 Squadron which had been operating in Malta with A.I. Mark IV were trained and began night flying with the new Mark VII sets. It was not suitable for high-altitude operations in its original form, so modifications to prevent flash-over were undertaken to enable it to be used against high-flying bombers up to a height of 20,000 feet. Nevertheless, in the six weeks following 1 September 1942 fifteen A.I. contacts with enemy aircraft were made at night leading to six visual sightings. These resulted in five enemy aircraft destroyed and one

[1] A.M. Files C.S.17132, Encl. 2A and C.S.18667, Encl. 3A. Some impression of the scope of the night fighter problem in North Africa may be gained from the extent of the coast to be covered—a front of over 250 miles, involving the protection of five vital ports through which the ground forces were supplied.

[2] A.M. File C.S.17132, Encls. 2A and 5A.

[3] *Ibid.*, Encl. 56A.

'probable.'[1] The fact that all these combats took place between 19,000 and 22,000 feet, much above the A.I. Mark VII designed altitude figure, speaks well for the local modifications to the equipment. Within two months of the beginning of operations with centimetric A.I. in Malta, three of the original four Beaufighter aircraft were written off by crash-landings and taxying accidents. A steady if small stream of A.I. Mark VII-equipped aircraft replacements trickled from the few available in the United Kingdom during the rest of 1942.

Meanwhile, in North Africa the all-important Allied supply lines depended on the unrestricted availability of the ports. After the losses incurred in attempts to bomb Algiers and Bone, German night-bombers used low level approaches and other evasive tactics which could not satisfactorily be dealt with by 1½ metre A.I. A request was made for a supply of centimetric A.I. equipment. In January 1943 Fighter Command still had only five aircraft fitted with A.I. Mark VIIIA sets, but it was hoped that two squadrons would be fitted by the end of the month. The Chief of the Air Staff approved the move of twelve Beaufighters and A.I. Mark VII sets to North Africa, complete with experienced aircrews from Fighter Command and twelve spare A.I. sets with test gear. The aircraft reached North Africa in February and were fitted with the Mark VII sets at Setif during March by a fitting party sent specially for the purpose.[2] No. 600 Squadron received Mark VII equipment first and there was an immediate improvement in its operational success. Eighteen enemy aircraft were destroyed during April compared with five and two in February and March respectively. On the last day of the month one pilot of No. 600 Squadron destroyed five Ju.52 aircraft in one sortie. During April a special flight of No. 153 Squadron was also equipped with A.I. Mark VII and the benefit of the new equipment was soon felt, the squadron claiming thirteen enemy aircraft destroyed during May.

Thus, in the late spring of 1943, each squadron in Malta and North Africa had a few aircraft fitted with A.I. Mark VII, the remainder flying with A.I. Mark IV.[3] It was arranged that three A.I. Mark VII-equipped Beaufighters would be flown out to North Africa as replacements against normal wastages each month as an interim reinforcement programme until A.I. Mark VIII became available. Such a policy could not continue for long; the A.I. Mark VII aircraft could only be provided by drawing on Fighter Command. After two months only, it was therefore decided that A.I. Mark VIIIA should be introduced into the Mediterranean theatre in spite of the competition of Fighter Command requirements at home.[4]

To strengthen the night defence in North Africa still further, No. 219 Squadron was sent out from the United Kingdom, the ground party sailing on 19 May followed by the aircraft which were flown out during the first week in

[1] A.M. File C.S. 17132, Encls. 81A, 82B and 113A.

[2] A.M. File C.S.17913, Encls. 1A, 2B, 3A, 54B and 25B.

[3] A.M. File C.S.18957, Encls. 8A, 88 and 17A. One flight of No. 89 Squadron in Malta and three squadrons, Nos. 153, 255 and 600 Squadrons, in North Africa. One advantage of having the two types of A.I. was that from January 1943 A.I. Mark IV-equipped Beaufighters could be used for night intruder operations over enemy airfields. Centimetre A.I. equipment on the other hand could not be employed in forward areas except at the Air Officer Commanding's discretion in an operation of importance; this security measure continued until 1 May 1944. A.M. File C.S.10987, Encl. 47A.

[4] A.M. File C.S.18667, Encls. 17A, 18A.

June.[1] The fitting of A.I. Mark VIIIA proceeded more slowly than had been hoped, mainly because almost every A.I. equipment arrived with some vital part missing. Notwithstanding these difficulties, a total of about 140 aircraft in Malta and North Africa were equipped in time for the Sicilian campaign, and of these, the aircraft based in Malta alone claimed during the month of July 40 enemy aircraft destroyed and 3 damaged.[2] The use of A.I. Mark VIIIA was discontinued in the United Kingdom, all squadrons converting to Mark VIII for the sake of uniformity.[3] All A.I. Mark VIIIA was concentrated in the Mediterranean area, where seven squadrons were eventually fitted, including some American squadrons of the Mediterranean Allied Coastal Air Force.

Re-orientation of A.I. Policy

The problems of night interception changed continually throughout the course of the war. Although the centimetre sets of the A.I. Mark VIII series overcame the limitations of 1½ metre A.I. equipment by virtue of its freedom from the effects of enemy jamming and by its value in the interception of low-flying raiders, new problems were still arising in 1942 and 1943. The use of Window was under consideration and before allowing it to be used, the Royal Air Force needed radar equipment which would not be seriously affected by the German use of the same jamming device.[4] Tests had been carried out secretly to determine the effect of Window on A.I. Mark VII, and its radial time base presentation was found to be vulnerable to this type of interference; the display did not give a direct presentation of the target position and there was no easy method of distinguishing Window from an aircraft response.[5] It was concluded that a bomber aircraft dropping the necessary quantities of Window would have no difficulty in avoiding interception by an A.I. Mark VII or VIII-equipped fighter and that it was also possible for a few enemy bombers to produce a Window 'lane' in which defensive night fighter opposition to a large bomber force would be negligible. In addition, the type of ground control radar station in operation at that time was also greatly affected, making controlled interception doubly difficult.

Another factor affecting A.I. policy was the German introduction of faster and smaller aircraft of the F.W. 190 or Me. 410 type, capable of taking violent evasive action and possibly fitted with tail warning devices. Attention was drawn to the probable ineffectiveness of the stern chase necessary with A.I. Mark VIII. The likelihood of enemy aircraft being fitted with a tail warning device accentuated the desirability of being able to get initial A.I. contact from port or starboard. This was extremely difficult with A.I. Mark VIII owing to the limited azimuthal coverage. These new factors, together with the basic unchanging requirements of A.I., were taken into account by the Air Interception Committee in its consideration of the detailed operational needs of

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[1] No. 219 Squadron O.R.B., May/June 1943.

[2] A.M. File C.S.18667, Encls. 98A and 104B. History of T.R.E. Post Design Services. 1941–1945. A.H.B. IIE/244.

[3] Later, A.I. Mark VIII was also used in India.

[4] *See* Volume VII, Chapter 9.

[5] T.R.E. Journal, July 1945. A.H.B. IIE/184.

future A.I. equipments in November 1942.[1] It was decided that new A.I. equipment should aim at fulfilling the following requirements :—

(a) All round location in plan, but coverage was not necessarily to be spherical. The wider coverage would simplify ground control and enable effective night fighter patrols to be maintained without assistance from the ground.

(b) Direction finding was to be accurate to within half a degree within 10° of the dead ahead position, with no time lag in the electrical display equipment in order to enable the pilot to fire blind after having closed to minimum range in cloud.

(c) The maximum target range required was of the order of 10 miles ; minimum range was to be not more than 200 feet. These ranges were to be obtainable at all heights between 500 and 50,000 feet. The object of such a low minimum range was to allow a successful interception to be achieved in cloud either by day or night.

(d) Immediate indication was required as to whether the target aircraft was friendly or not.

(e) Automatic following of the selected target was desirable.

In addition, the committee specified other desirable features of A.I. presentation, including an accurately calibrated range meter, visual indications from an A.I. Beam Approach system, and a readable range of 100 miles on an A.I. beacon.

A.I. Mark IX

The new requirements called for important changes in the trend of development because the attainment of the maximum range specified was beyond the capabilities of A.I. Mark VIII, and also because its display was known to be seriously affected by Window interference.[2] There were three possible systems along which development could proceed: firstly, a 10-centimetre system with locked automatic following, the strobe system for lock being set by the observer ;[3] secondly, a 3-centimetre system broadly similar to the 10-centimetre system except for the necessary changes in wavelength ; thirdly, a television or range/azimuth system similar to the American development. It was considered that the first system of 10 centimetres wavelength was the

[1] A.M. File C.S.20351, Encl. 3c, A.I.C. 95, Appendix 'A' (revised), 5 November 1942. The basic requirements have been discussed earlier in this monograph. Summarising, the most important were :—

(i) Best possible maximum and minimum range.
(ii) Best possible coverage in azimuth and elevation.
(iii) As continuous, direct and simple a presentation as possible.
(iv) Freedom from interference.

[2] *Ibid.*, Encl. 3B.

[3] Permission to start work on A.I. lock-follow had been given to T.R.E. by D.C.D. as early as 10 April 1941. The great advantage to be gained by tracking of the target was, of course, directional accuracy sufficient for effective blind firing. Windscreen projection was developed for A.I. Mark V but the accuracy of the radar data was poor.

The A.I.S. (F) system first flew in a Blenheim aircraft at Christchurch towards the end of 1941. The trials were successful and during 1942 considerable work was done to prove the merits of the system for blind firing. (T.R.E. Reports 12/94 and 12/112.) A.H.B. IIE/193/1.

most attractive because it could be used in conjunction with the then-existing 10-centimetre organisation, test gear and experience of the radar personnel in Fighter Command in the maintenance of A.I. Marks VII and VIII. The Telecommunications Research Establishment suggested a specification for A.I. Mark IX operating on a frequency of 3,300 megacycles per second (9·1 centimetres wavelength), and at a meeting called by the Assistant Chief of the Air Staff (Operations) on 10 February 1943 it was agreed to proceed with A.I. Mark IX as a long-term project. It was expected that the new A.I. set would be available for operations in the early summer of 1944.[1]

Several variants of the Mark IX series of equipments were envisaged by T.R.E. based on the 10-centimetre wavelength automatic 'lock follow' system, but efforts were concentrated on producing a basic experimental set which could be fitted into a night fighter aircraft for flight trials.[2] At the same time, some 10-centimetre (S-band) equipment was being modified to operate on a wavelength of 3 centimetres (X-band) for comparative air tests between the two equipments. The development of A.I. Mark IX did not go as well as had been hoped because some of the capacity of the T.R.E. had been absorbed in the task of putting A.I. Mark VIII into operational use in the Service.[3] Nevertheless, work on Mark IX was pursued energetically during the early months of 1943 and an experimental set reached the stage of air tests in a Mosquito night fighter aircraft.

In April, however, the need for a new type of A.I. became far more urgent by reason of a decision made by the Chiefs of Staff that the time had come to use Window in forthcoming bomber operations, which would inevitably precipitate the German use of the same device against British radar.[4] Despite the progress made with A.I. Mark IX it was clear that it could never be produced in quantity in time to be of wide use during the war, and there was no alternative but to adopt an American equipment which was known to be less prone to the effects of Window. As a result, development of A.I. Mark IX was relegated to low priority and the equipment was not ready for operational use before the end of the war.

A.I. Mark X

In December 1942 a prototype model of an American centimetre A.I. set, the SCR. 720B, had been sent to the United Kingdom for Service trials in the Royal Air Force.[5] The equipment was installed in a Wellington aircraft

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[1] A.M. Files C.S.16221, Encl. 13B and C.S.20351, Encl. 11A.

[2] A.I. Mark IX. 200 kw. S-band equipment with automatic lock follow system.
A.I. Mark IXA. Originally this was a 25-kw. S-band equipment (T.R.E. Report 12/138. A.H.B. IIE/193/1), but later the term was used to describe A.I. Mark IX with windscreen projection (T.R.E. Report T.1544. A.H.B. IIE/193/1).
A.I. Mark IXB. As A.I. Mark IX, but with windscreen projection and roll stabilisation of scan.
A.I. Mark IXC. As A.I. Mark IX, but with gyro gunsight and roll stabilisation of scan.
A.I. Mark IXD. As A.I. Mark IXB, but with electrical prediction for blind firing.
T.R.E. Report T.1544. A.H.B. IIE/193/1.

[3] A.M. File C.S.20351, Encl. 3A.

[4] Window was first used by Bomber Command on 24/25 July 1943, during a heavy raid on Hamburg. The Germans first used Window over the United Kingdom on 7 October 1943, having previously used it over Bizerta on 6 September 1943.

[5] A.M. File C.S.19327, Encls. 13A and 16A.

to save the time which would have been required to build a new nose for the Mosquito night fighter. Further trials to determine its effectiveness against Window interference were carried out with great urgency during the first week of February 1943 and the results were favourable.[1] As a result of further trials by the Telecommunications Flying Unit and the Fighter Interception Unit assisted by T.R.E. scientists, immediate recommendations were made for a number of modifications.[2] By April these had been embodied and the set installed in a Mosquito night fighter for further trials. These were highly successful; the main advantages of the modified SCR. 720B, given the Royal Air Force nomenclature A.I. Mark X, over the Mark VIII equipment were better discrimination between aircraft and Window responses owing to the direct nature of the display, better coverage, and increased maximum range. The Director of Radar thought the set 'a grand job' and recommended that a large programme of re-equipment of the night-fighter force with A.I. Mark X should be undertaken at high priority, particularly in view of its effectiveness against Window. Re-equipment was, of course, dependent on American SCR. 720 production and on what part of it could be obtained for the Royal Air Force. Work on A.I. had not been accorded high priority in the United States during 1942 and no deliveries of the SCR. 720 set were likely before July 1943. The Western Electric Company (U.S.A.) forecast small outputs available in May and June, reaching one hundred sets in July and afterwards rising to two hundred per month.

The modified SCR. 720B was approved for introduction into the Royal Air Force; 2,900 sets were ordered, of which 250 were expected by the end of 1943, after which a flow of 120 sets each month was anticipated.[3] The Prime Minister had been given an assurance that after the first one hundred sets had been installed, sixty aircraft equipped with these sets would become available per month. This was a factor of importance in relation to the decision to use Window. He therefore directed that 'the most strenuous efforts must be made to increase the fitting programme and to have the largest possible number of sets in operational use as soon as possible.'[4]

Despite high priority, there were many delays. Most of the modifications of the set for Royal Air Force use as A.I. Mark X were not made on the American production line and had to be done in the United Kingdom.[5] The first forty sets to arrive were modified by the Post Design Services at Defford, and subsequent sets by Metropolitan-Vickers and other firms. Installation began at the Special Installation Unit where the first twelve aircraft, of a programme of ninety Mosquito XVII aircraft, were to be fitted and also some Wellingtons for

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[1] A.M. File C.S.19327, Encl. 8A.

[2] The most important of these were :—
(i) Change of tilt limits of the helical scanner, so that it suited the R.A.F. interception technique.
(ii) Replacement of unsatisfactory R.F. feeder by a flexible one.
(iii) Change of range scales to 3, 5, 10 and 100 miles.
(iv) Change of range marker width.
(v) Design of new visor for the indicator.
(A.M. File C.S.19327, Encl. 48B.)

[3] A.I.C. 136. N.A.D. (43) 2nd Meeting, 24 June 1943.

[4] A.M. File C.S.19327, Encl. 76A. N.A.D. (43) 2nd Meeting, 24 June 1943.

[5] The History of T.R.E. Post Design Services, 1941–45. A.H.B. IIE/244.

aircrew training.[1] The remaining aircraft were to be fitted with A.I. Mark X at No. 218 Maintenance Unit. Shortage of S.C.R. 720 equipments caused some delay, but a much more serious set-back occurred after the first installation was completed, in the shape of interference to the aircraft V.H.F. R.T. system caused by the spark gap modulator of the A.I. set.[2] It proved exceedingly troublesome and many expedients were devised to effect a cure. Eventually after much work interference was reduced, but the re-equipment programme had by that time fallen seriously into arrears.[3] Instead of one hundred aircraft fitted with A.I. Mark X, which the Prime Minister had been assured would be completed by the end of December 1943, the best that could be achieved was five aircraft fully fitted by that time, the first squadron to be completed by the end of January 1944.

Meanwhile, ground servicing personnel were being trained with the new equipment. The first courses were held at the T.R.E. school and later this training was transferred to Technical Training Command. Aircrews in squadrons to be re-equipped were visited by a Fighter Command A.I. Flying Training Section and trained in the operation of the new set. No. 85 Squadron at Hunsdon was fully equipped and No. 25 Squadron at Church Fenton nearly completed by the end of January 1944.[4] A.I. Mark X was first used operationally on the night of 12 January, when one aircraft of No. 85 Squadron was included in the night programme. No. 25 Squadron obtained the first confirmed destruction with A.I. Mark X when one of its pilots shot down two enemy aircraft on the night of 20 February 1944. With only two squadrons operating, the results for A.I. Mark X-equipped night fighters during February were sixty A.I. contacts with enemy aircraft, of which seven were destroyed, one probably destroyed, and five damaged. The high number of lost contacts was attributed largely to the speed of the F.W. 190 aircraft and to vigorous evasive tactics of the German pilots.[5]

Re-equipment of further squadrons proceeded smoothly.[6] For a new equipment, serviceability was satisfactory ; an average of 25–30 flying hours per fault was achieved after the first two weeks. The performance figures were good, maximum ranges of 5½–6 miles and minimum ranges of about 400 feet being obtained as operators became accustomed to the equipment. A large proportion of the recurring faults of A.I. Mark X occurred in the electrically driven scanner, but apart from both electrical and mechanical troubles, the scanners were never satisfactory from the tactical aspect ; the maximum downward

[1] The Special Installation Unit (S.I.U.) grew out of the T.R.E. fitting party formed for the A.I. Mark XII installation programme at Christchurch during the spring of 1942. The installation party moved to the Royal Air Force airfield at Hurn in April 1942.

[2] A.M. File C.S.19327, Encl. 106A.

[3] The following modifications were necessary :—

- (a) The complete screening of certain vital connectors (later, in the main re-equipment programme of Mosquito XXX aircraft, all connectors were fully screened).
- (b) The addition of several special filter chokes to the modulator and R.F. unit of the SCR. 720A.
- (c) The re-positioning of the aircraft V.H.F. aerials.
- (d) A suppression modification to the V.H.F. R.T. equipment.

[4] Nos. 85 and 25 Squadrons O.R.B.s. A.M. File C.S.19490, Encl. 11A.

[5] A.M. File C.S.19490, Encl. 10A.

[6] During March, No. 456 Squadron at Ford and No. 125 at Hurn were completed, and No. 219 Squadron at Woodvale was being fitted.

cover of the scanner was inadequate and several modifications were tried to improve it. The most successful modification, entailing rebalancing of the scanner, was carried out by the firm of Reyrolles on all the scanners arriving in this country. During the summer of 1944 visits were paid to the United States by technicians, and the Royal Air Force point of view was presented to assist in preparing the design of a new scanner with improved coverage and superior serviceability. Sets which embodied the new scanner and other changes were known as S.C.R. 720D or A.I. Mark XA, but only a few arrived in the United Kingdom before the cessation of the Anglo-American Lease-Lend Agreement.

Delays in the A.I. Mark X programme in the latter part of 1943 resulted in additional A.I. Mark VIII fitting work. It had been the Air Staff intention to fit all the new type of Mosquito aircraft (Mark XXX) becoming available in January 1944 with the new A.I. equipment.[1] Because of the uncertainty in the supply of A.I. Mark X at that time, and in order to maintain the flow of aircraft from production, it was decided to fit the first fifty new aircraft with A.I. Mark VIII. This number was increased to one hundred in anticipation of the release of Mark VIII equipment for operating over enemy territory in time for the landing in Normandy. The Mark X would, of course, still be restricted to use over friendly territory.[2]

In view of the motive for introducing A.I. Mark X, to provide better performance against Window, a comparison between A.I. Marks VIII and X in night defence operations is of interest. Despite the technical advantages of A.I. Mark X over Mark VIII which gave better coverage, increased range and discrimination against Window, statistical analysis of G.C.I.-controlled interceptions over this country up till 'D Day,' 6 June 1944, showed very little difference in the operational efficiency of the two types. The density of Window used by the enemy was never sufficiently serious to affect interception to any great extent and it is probable that the new centimetric G.C.I. station control was always sufficiently good to put the night fighter within the maximum A.I. range of both equipments.[3] Reports of interceptions attempted with both installations showed that about 12 per cent. were successful.

A.I. Marks VIII and X in the Landings in Normandy

In the planning for the liberation of North-West Europe, No. 85 Group, Royal Air Force was established for the defence by day and night of the base areas and ports.[4] The night-fighter force in this Group consisted of six squadrons of Mosquito aircraft equipped initially with A.I. Mark VIIIB.[5] The squadrons

[1] A.M. File C.S.19327, Encl. 106A.

[2] A.M. Files C.M.S.50, Encl. 42A and C.S.19327, Encls. 100A and 111A.

[3] T.R.E. Journal July 1945, A.H.B. IIE/184, p. 95.

[4] This planning is given in detail in Volume IV—Chapter 23.

[5] In June 1944 these were Nos. 29, 264, 409, 410, 488 and 604 Squadrons. During August 1944 No. 219 Squadron (Mosquito XXX aircraft fitted with A.I. Mark X) replaced No. 29 Squadron. (No. 85 Group, O.R.B., June/August 1944.) A.I. Mark VIIIB was a modified Mark VIII with which a version of Lucero Mark II was used in place of the 1½ metre interrogator. This was because the interrogator was only capable of working with I.F.F. and A.I.B.A. and was not powerful nor sensitive enough to trigger and receive the T.R.3107 long range 1½ metre homing beacons. (A full account of beacons for A.I. is given in Volume III.) S.H.A.E.F. Air Signal Report on Operation Overlord. A.H.B. IIE/159.

were made as mobile as possible during the pre-D Day period; all radar servicing was carried out from mobile workshops, and the squadrons were constantly moving between many night-fighter airfields in the United Kingdom whilst they remained operating throughout. Squadron personnel rapidly adapted themselves to their more arduous circumstances and A.I. serviceability was maintained under realistic field conditions.[1] During June 1944 no contacts were lost by No. 85 Group night fighters by reason of A.I. technical failures.

Night-fighter aircraft were initially under the control of the G.C.I.s on the Fighter Direction Tenders off-shore on the Normandy coast from 'D Day,' 6 June 1944, until the No. 85 Group base defence sectors were established ashore.[2] Defensive A.I. patrols were flown every night from 'D Day' until the end of June and sixty-two enemy aircraft were claimed as destroyed. This was a satisfactory total against an unexpectedly small enemy night bombing effort.

As the Allied breakout from the Normandy bridgehead progressed, the disorganisation of the *Luftwaffe* increased and the enemy night effort fell off still further. By October, the front was again static in Holland and Belgium and the night activity then was typical of the latter part of 1944. A total of 460 sorties were flown during October by No. 85 Group night fighters, two squadrons of which were operating with A.I. Mark X. In addition, 230 sorties were flown by Fighter Command aircraft under No. 85 Group control. Altogether a total of 206 attempts at interception were made, and in only 77 cases was the target not identified as friendly. 63 per cent. of the G.C.I./A.I. effort was thus expended on friendly aircraft as a result of the low efficiency of the I.F.F. Mark III system in the circumstances prevailing.[3]

The German offensive in the Ardennes in December 1944 was accompanied by a considerable increase in night activity, which was on a higher scale than in any month since August 1944. By that time three squadrons of No. 85 Group aircraft were operating in Mosquito XXX aircraft equipped with A.I. Mark X.[4] All six squadrons took part in night defence operations and 43 combats ensued in which 37 enemy aircraft were destroyed, 26 with A.I. Mark X. The total successes of both Mark VIII and Mark X improved during December; the proportion of interception attempts resulting in enemy aircraft destroyed rose from 11·1 per cent. in November to 18 per cent. in December for A.I. Mark VIII and from 11·5 per cent. in November to 19·5 per cent. in December for A.I. Mark X. A comparison between the two equipments in terms of their ranges at this period shows that Mark X had a maximum range of up to 10 miles with an average range of 4·9 miles, while the comparable ranges for Mark VIII were 8 and 4·16. The superiority of Mark X was reflected in the figures for the conversion of interception attempts to A.I. contacts, being 68 per cent. for Mark X as compared with 52 per cent. for Mark VIII.[5]

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[1] No. 85 Group O.R.B., 2 July 1944.

[2] An account of the control organisation set up is given in Volume IV, Chapter 24.

[3] No. 85 Group O.R.B. Appendices, November 1944. Part II of this volume deals with the difficulties encountered with the I.F.F. Mark III system.

[4] Nos. 219, 410 and 488 Squadrons were fitted with A.I. Mark X, Nos. 264, 409 and 604 Squadrons were still operating with A.I. Mark VIIIB.

[5] No. 85 Group O.R.B., January/February 1945.

During the first months of 1945 the German night effort over the Allied lines became intermittent and then died away. The Second Tactical Air Force night fighter squadrons continued to operate, mostly in support of our bombing activities. They made sorties over enemy territory in search of aircraft taking off and landing, and the role of the mobile night fighter squadrons thus changed from the defensive to the offensive. During the whole period from ' D Day ' to ' VE Day,' 298 enemy aircraft were destroyed at night, 15 probably destroyed, and 44 damaged.[1]

A.I. against Flying Bombs

The complete reliance of the Germans on pilotless ' V ' weapons for attacks on the United Kingdom for six months following ' D Day ' changed the character of defensive night fighting. It was no longer all-important to have accurate airborne radar in night fighters. The emphasis had in fact suddenly shifted from controlled interception, involving careful analysis of position and estimation of vectors, to speed of aircraft and gunnery involving accurate range and prediction only. Mosquito aircraft derived no great advantage from their A.I. equipment against flying bombs and the main harvest was reaped by the faster Tempest aircraft and by the anti-aircraft guns.

A.I. in Bomber Support

Towards the end of 1943 Mosquito aircraft of three squadrons in No. 100 Group had taken part in two types of operations in support of Bomber Command's offensive against Germany. In one, night fighters accompanied our own bomber force and attempted to intercept enemy night fighters coming up to attack at high level ; in the other, German airfields in use for night defence were regularly patrolled by intruder aircraft. During the early months of 1944 these Mosquito night-fighter aircraft were equipped with A.I. Mark IV and Serrate, an equipment with which the first warning was obtained by listening for A.I. transmission from enemy aircraft.[2] Outstanding successes were achieved initially, but gradually the German Air Forces became aware of the use of these radar and radio countermeasures and took steps to counter them by evasive action and by jamming the 1½ metre waveband.

No. 100 Group urgently required centimetric A.I. Two squadrons of Mosquito aircraft fitted with A.I. Mark X were transferred from Air Defence of Great Britain to No. 100 Group early in May 1944 and were very successful for a short time.[3] It was also intended to re-equip the other No. 100 Group squadrons from A.I. Mark IV to Mark X but owing to the large demands on all available Mark X equipment made by squadrons engaged in night air defence the refitting progressed very slowly indeed. The shortage of centimetric equipment in No. 100 Group became crippling when the two squadrons were transferred back to A.D.G.B. in June 1944 to help against the flying bombs.[4]

[1] S.H.A.E.F. Air Signals Report on Operation Overlord. A.H.B. IIE/159.

[2] An account of Serrate operations is given in Volume VII, Chapter 14.

[3] Nos. 85 and 157 Squadrons.

[4] Further details of the use of A.I. by squadrons of No. 100 Group are given in Volume VII, Chapter 14.

A.I. Mark XV[1]

During June, No. 100 Group obtained one set of A.S.H. equipment, a 3-centimetere light-weight A.S.V. of American design (AN/APS. 4) for bomb rack mounting, which was then coming into use in the Fleet Air Arm.[2] After some weeks of work a modified form of A.S.H. was installed in the nose of a Mosquito Mark VI aircraft in such a way that only the antenna unit in its perspex case projected. Flight tests during the last week in August 1944 yielded good results from the radar equipment; average maximum and minimum ranges of 4 miles and 500 feet being obtained. Air Ministry approval was given for installation to begin in a sufficient number of Mosquito Mark VI aircraft to re-equip three squadrons as an interim measure until A.I. Mark X equipment became available to No. 100 Group. The modified A.S.H. equipment was given the R.A.F. nomenclature of A.I. Mark XV. The first few aircraft were completed and in operational use by mid-November. By the end of 1944 thirty-five aircraft were fitted and eventually the three squadrons approved by the Air Staff were completed.[3] Only four months of hostilities against Germany then remained and during this period the German fighters were, in the main, grounded on most nights and the chances of successful interception were very much smaller than earlier in the war. Nevertheless, twelve enemy aircraft were destroyed and several others damaged.

After operational experience with A.I. Mark XV, navigators of No. 100 Group considered the equipment a marked improvement on $1\frac{1}{2}$ metre A.I. Its main assets were the comparative ease of locating and following a target through Window, the clear and distinct picture the single tube presentation gave, making it easy to keep a watchful eye on other radar equipment installed and finally, the excellent search scan which made it a valuable navigational aid in the same manner as H2S, especially in intruder work. In comparison with A.I. Mark X, however, the range was not so good and criticism was levelled at the scanner, indicator and control box. The slower speed of scan and insufficient upward cover were distinct drawbacks, and the smaller cathode ray tube face and its long afterglow often resulted in the tube face being swamped by ground returns during a turn. The smaller size of the control box caused controls to be cramped and difficult to manipulate when wearing flying gloves. Another disadvantage of A.I. Mark XV, inseparable from 3 centimetre wavelength working, was the considerable amount of cloud echo obtained at times, strong enough to make interceptions very difficult.

A.I. at the end of the War

During the last two months of the war the German night effort was so small that some A.I. squadrons were already disbanding. All those remaining were equipped with A.I. Mark X or so equipped after the end of hostilities. A.I. Mark X remained the major A.I. equipment for Royal Air Force use until

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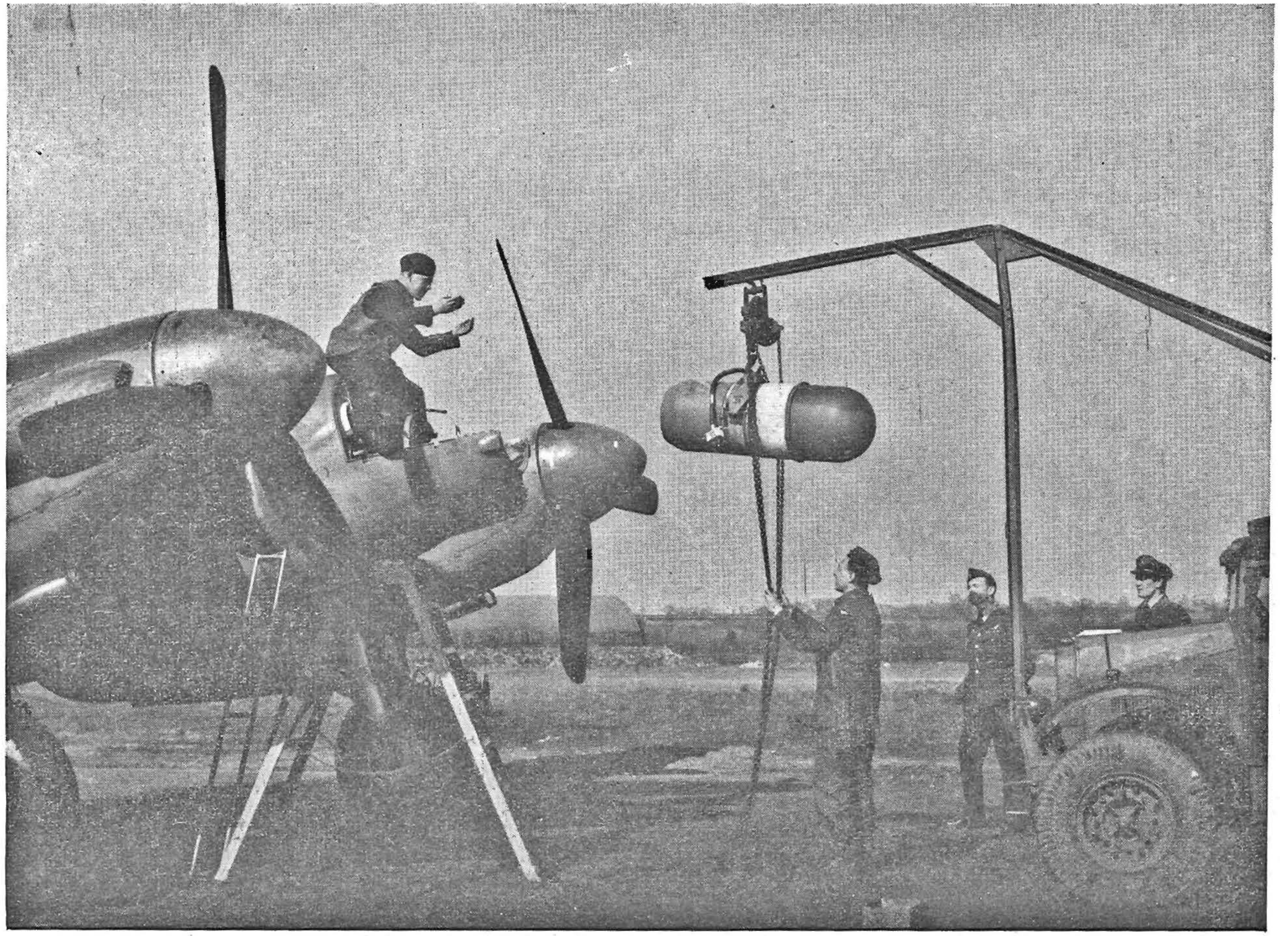
[1] A.I. Marks XI, XII and XIII were 3 centimetre equipments developed for and used by the Fleet Air Arm. A.I. Mark XIV was an American 3 centimetre equipment, AN/APS.6.

[2] History of T.R.E. Post Design Services—1941–1945, Chapter 1.6. A.H.B. IIE/244.

[3] These were Nos. 23 and 515 Squadrons at Little Snoring airfield and No. 141 Squadron at West Raynham. The latter squadron retained the necessary units of A.I. Mark IV in modified form to give backward looking facilities, usually known as Monica Mark VI. An account of Monica is given in Volume III.



A.I. Mark XV (A.S.H.)—Installation in Mosquito F.B. VI a British equipment was produced. Serviceability was very high at the end of the war, averaging more than 100 flying hours per fault and the ranges obtained were sometimes as great as 12 miles.

The change in night fighter tactics from mainly defensive to offensive operations which had been so marked during the last year of the war had clearly indicated the radar requirements. Night-fighter aircraft were required not only to operate under close control from ground radar stations but also to have sufficient airborne radar range for independent search in operations over hostile territory. All-round A.I. cover, and particularly rearward cover, were most important. The latter facility was being provided at the end of the war by fitting a radar tail-warning device in addition to the A.I. equipment.

Part IV

RADAR CONTROL

PART IV

Introduction

Attempts to control aircraft directly from a radar station were made in 1938 and again in 1939 because it was felt that more accurate interception would result if both bomber and fighter could be observed from the same instrument. The characteristics of the first radar stations made them unsuitable, however, for the direct control of interception. They were designed to give maximum early warning range rather than precise positioning, and their display of information in the form of separate readings of range, bearing and height required mathematical calculation before the position in space of even one aircraft could be visualised. Furthermore, they were restricted to seaward looking.

When it became evident in 1940 that airborne radar was incapable of effecting night interception under the existing forms of ground control, a new type of radar station was designed specially for night fighter control. It combined a simplified and continuous display of the relative plan positions of aircraft, with facilities for measuring height which had not previously been available. It was also the first type of station capable of operating inland. Very accurate positioning of aircraft became possible, and night fighters equipped with airborne radar were enabled to inflict heavy losses.

The same type of equipment was modified for use in the control of fighter formations in offensive operations and in conjunction with land forces. Control was usually in the form of general directions to give tactical advantage, as opposed to the precise method necessary for night interception. Fighters were given information by R.T. which enabled them to attack from the most favourable height and direction, and to avoid being taken at a disadvantage themselves. In the North-West Europe campaign the radar equipment initially supplied was more suitable for defensive than for offensive purposes, and the impossibility of laying landlines in quantity under mobile conditions often precluded the integration of the whole air picture. During the final months of the war a highly centralised form of radar station was provided combining facilities of early warning, daylight fighter directing and night interception, with multiple control. It was most effective in the state of air superiority prevailing, but in less fortunate circumstances would offer a tempting target for air attack to an enemy strong enough to attempt it.

CHAPTER 11

EARLY DEVELOPMENT OF RADAR CONTROL

The first attempts were made early in 1938 to integrate the radar reporting chain with the system of fighter control using H.F. D.F. which had been evolved from the Biggin Hill experiments during the preceding year and a half. No immediate success was achieved, chiefly because of the difficulty of correlating the radar plots of the bombers with the position of the fighters as obtained by D.F. fixing. Both systems of aircraft positioning gave rise to their own peculiar errors, which were aggravated by delays in telephoning and in plotting the aircraft positions in the sector operations room. To make matters worse, the radar tracks tended to fade before the bombers reached the coastline where the interceptions were planned to take place. The chance of intercepting before they reached the coast was lessened because D.F. fixing was more inaccurate at longer range. Altogether, the picture on the sector operations room table was neither sufficiently reliable nor up to date.

The 'Lamb' Experiments

To overcome the initial difficulties of interception by Sector Control it was suggested that the interception might more effectively take place some twenty miles out to sea where the radar method of plotting could be used for both bomber and fighter. The latter could then be directed by a controller with a R.T. set at one of the radar stations where he would have all the information immediately available. It was intended that a fast twin-engined fighter would be employed as the intercepting aircraft, and its purpose was not to attack the enemy but to follow him inland, emitting meanwhile a succession of wireless signals which would enable the fighter's position, and therefore that of the hostile aircraft, to be followed overland by direction-finding until a fighter formation could be directed to attack. The twin-engined interceptor was known as the 'Lamb,' because the hostile aircraft was regarded as being 'Mary' of the nursery rhyme, and '. . . everywhere that Mary went the lamb was sure to go . . .'

Lamb experiments were made in April and later in October and November 1938, and were controlled from Bawdsey radar station.[1] The first attempts were made against flying-boats, and although they were intercepted successfully their slow speed made the achievement of little practical value, apart from the experience gained. The controller endeavoured to keep a continuous picture of the relative positions in space of the fighter and bomber by taking separate readings of bearing, height and distance of the aircraft from the radar station. Readings of bearing in particular were rather vague except at close range, and periodically, at certain distances, the indications faded from the cathode ray tube.

Because of these difficulties, attempts to intercept the faster Blenheim aircraft were not wholly successful. Interception was possible but only by plotting the aircraft positions in the Bawdsey filter room and controlling in

[1] A.M. File S.43174/I, Encls. 9A and 22A.

much the same way as that practised on the sector operations table. After several trials the controller reported that little value could be derived from further attempts until improvements to the equipment were made. Better R.T. was required, some form of recognition device was desirable, and the radar stations required 'gap-filling' to prevent periodical fading of aircraft echoes. Further trials were thereupon postponed until these shortcomings could be remedied.[1] The Lamb trials were unfortunately not followed up with great urgency because concurrent improvements in radar reporting and D.F. fixing rendered the Sector Control system workable, and no further radar control experiments were made until after war had been declared.

'All R.D.F.' Interception

Trials in radar control were resumed at Bawdsey on 23 September 1939 in the hope of improving the accuracy of interception of about five miles obtainable by Sector Control. The fighter pilot could usually sight the enemy at this range by day, but preparations for night air defence soon showed that greater precision of interception would be required in darkness. Great hopes had been pinned on the development of A.I., but early trials had shown that the possibility of giving the pilot the radar equivalent of five miles daylight vision was far from attainment. An effort to obtain more accurate interception was therefore made by direct control from the radar station, the controller operating the radar receiver himself, with no plotting of tracks. To make the task easier in the first instance, it was arranged that the target aircraft should fly directly towards the radar station, where the fighter would be already in the air. Experiments continued for three months during the autumn of 1939 and a method of interception control was slowly evolved.

The inaccuracy of radar bearings was overcome to some extent by an ingenious method of deducing a raider's track by assessing the rate of decrease of range. The more slowly the aircraft approached, the more oblique its track was judged to be. The method entailed the doubtful assumption of constant speed and constant course by the raider, but strangely enough it gave a certain measure of successful interception when combined with other information obtained from the radar equipment, and with a high degree of imagination and skill on the part of the controller.[2] Determined efforts were made both on the ground and in the air, but in the end it was found impossible to do away with plotting altogether, and the accuracy of interception achieved was still only about four or five miles.[3]

To find a solution to the night-interception problem became a matter of urgency in November 1939, because the German Air Force began a series of night operations consisting of minelaying in the mouth of the Humber, off Harwich, and in the Thames Estuary, and of early morning reconnaissance flights over south-east England. For lack of a better method, the Bawdsey system of radar control was adopted and a number of controllers were allotted and posted to Bawdsey to be trained. The flight of Blenheim aircraft which had made the experiments was equipped with A.I. Mark II equipment and the interception practice flights gave place to active operations against the enemy.[4]

[1] A.M. File S.43174/I, Encl. 48A.
[2] Interview with Group Captain J. A. Tester.
[3] A.M. File S.43174/I, Encl. 63A.
[4] Fighter Command O.R.B., November 1939.

The airborne radar equipment, however, was not suitable to deal with the nightly minelayers who for the most part flew at low altitude, causing their A.I. indications to be hidden in a mass of sea returns.

C.H.L. Interception

Nor were the radar controllers much better off. The C.H. radar stations of which the chain then consisted had been designed on a ' floodlighting ' principle to give the maximum range of warning at medium and high altitude, and were incapable of tracking low flying aircraft. Low level radar cover was already practicable, for an Army Coast Defence (C.D.) radar set had been designed for shorter wavelengths for surface watching. The shorter wavelength of the C.D. set made possible a ' beamed ' transmission which could be directed closer to the surface of the sea than could the radiation from C.H. stations. There was an immediate demand by the Royal Air Force for a similar equipment for detecting aircraft at low altitude and a programme of building C.H.L. stations was begun. At the same time a C.D. equipment was adapted and set up for air interception experiments at Foreness, where it operated in conjunction with fighters of No. 600 Squadron fitted with A.I.[1]

The controller at Foreness evolved his own interception technique, suitable for use with narrow beam radar equipment. Because of the very narrow area illuminated by the radar beam as it traversed the horizon, it was impossible to keep track simultaneously of both a bomber and a fighter aircraft whose bearings from the station differed considerably. Attempts to take readings on each aircraft alternately failed because the echoes faded periodically when the aircraft entered the blank spaces in the vertical radiation of the radar beam, and could not be recognised again with any certainty. When a hostile aircraft was detected, therefore, the fighter was despatched to fly along the radar beam which was kept trained continuously on the target aircraft. The fighter was ordered to change course by R.T. from time to time to keep it in, or very close to, the radar beam, until it reached the same range from the station as the target aircraft when there was a good chance of interception.[2] Out of seven practice interceptions using this technique made by day in November and December 1939, at heights between 500 and 1,000 feet, three were most successful. The pilots stated that they were ' literally placed in a position to open fire.' Of the four failures, three were due to fading of the radar echoes at the critical moment, and the fourth to a misjudgement by the controller. When used for interception of enemy aircraft, which were less co-operative than friendly aircraft in the matter of keeping a steady course and height, there was difficulty because the C.H.L. station could not register the height of aircraft. Attempts were made to obtain height readings of the appropriate aircraft at the right time from neighbouring C.H. stations, but co-ordination was difficult and this solution to the problem proved unsatisfactory, even when the aircraft were high enough to be within the C.H. field of cover.

One most encouraging quality observed in the C.H.L. station, compared with the C.H., was greater accuracy in reading bearing as well as range, and also clearer definition. Both points gave hope that the beam type of station would,

[1] Fighter Command File S.18588, Encl. 1A.

[2] Interview with Air Cdre. W. P. G. Pretty.

suitably adapted, prove to be an effective interception instrument. There was a strong opinion that two C.H.L. equipments should be sited together, one to track the raider and the other to track the fighter, but the suggestion was overruled largely on the grounds that there was not sufficient equipment available.[1] In any event, the problem of height-finding at C.H.L. stations was still unsolved.

C.H. Sub-controllers

Meanwhile, the controllers who had been trained at Bawdsey were appointed by Headquarters Fighter Command to C.H. stations as sub-controllers, to work under the orders of sector controllers. The sectors were at that time regarded as stretching out to sea to the limit of the range of the radar stations. A procedure was devised in which Fighter Groups were to instruct patrols to leave the ground for certain interceptions ; sector controllers were to direct selected aircraft in the air to the most suitable radar station near the anticipated track of the raid ; the aircraft would then be directed by the sub-controller at the radar station, who was in touch with the sector controller by telephone.[2] The Air Officer Commanding-in-Chief, Fighter Command, was averse from greater decentralisation of control because it might lead to waste of flying if all sectors were empowered to despatch aircraft. The resources in aircraft were certainly scanty.

Apart from the difficulty of the interception technique itself, the innovation started with several disadvantages. Sector controllers were generally reluctant to entrust fighter aircraft to the mercies of the recently trained radar sub-controllers for fear that the aircraft would be unnecessarily hazarded. The R.T. equipment to be supplied to radar stations was very scarce, and was slow in arriving. The fact that radar stations, when engaged in interception, ceased to be useful members of the aircraft reporting organisation probably diminished the number of occasions on which they were ordered to take over control. On the whole, the sub-controllers felt that they were not getting their fair share of opportunities. The radar control organisation was continued for some three months until March 1940, but it was ineffective at night against the German minelayers and other aircraft. At Foreness, experiments and attempts at night interception with C.H.L. were continued until August 1940, also without any substantial measure of success.

Need for Special Interception Equipment

Meanwhile, the impulse towards the development of a new radar instrument specially designed for the control of aircraft interception by night had been given by Mr. R. Hanbury Brown, who acted as scientific observer of the early A.I. trials at Northolt.[3] In a report dated 24 November 1939 he drew attention to the short range and limited field of vision of A.I., and to the extremely short time consequently available to the fighter to observe the bomber when the two aircraft were flying on different courses. He estimated that to enable the fighter to keep the bomber in A.I. observation, the fighter must first detect the bomber whilst on a course within 40° of it at the most, and flying in a stern chase position. It was impossible to achieve such accuracy using C.H. station

[1] A.M. file S.43174/I, Encl. 66A.

[2] A.M. File S.3377.

[3] Fighter Command File R.E.S.13.

control because the goniometer bearings were too inaccurate. The plotting method was also ruled out because of the delay in taking and recording separate readings of plots. It was essential for the controller that his aircraft information should be presented continuously, and in such a way that he could estimate the turns the fighter must make at any moment to bring him into a suitable attitude for A.I. detection to start. 'To obtain such a suitable continuous pattern for fighter control,' the report continued, 'the principle of cathode ray direction finding could be employed to give a plan position on the cathode ray tube direct to the controller. The controller could receive plots from the main radar stations and position his fighters in advance, controlling the actual interception by means of this special picture.'

Two days later, on 26 November, Dr. E. G. Bowen forwarded a copy of Mr. Hanbury Brown's report to the Superintendent of the Air Ministry Research Establishment, Dundee, adding suggestions of his own for an improved method of achieving the same form of presentation by using a rotating beam radar system, or radar lighthouse. The rotating goniometer device had in fact previously been suggested by him on 9 October 1935 as a means of presenting range and bearing but had not been adopted because of the difficulty at that time of obtaining sufficient range on the shorter wavelength required. A similar suggestion had been made by Mr. P. E. Pollard on 1 February 1938, followed by the first radar lighthouse proposal on 11 July 1938.[1] Development of higher power on the shorter wavelength had then, as the result of research, become practicable, but again the suggestion could not be pursued for another reason. The improvement and installation of the C.H. chain was then of overriding urgency, and despite the emergence of other and possibly better ways of providing early warning of hostile aircraft, it was considered essential to concentrate all efforts on producing the accepted C.H. equipment in order to have something ready in time for war.

Now, in November 1939, the situation had changed. It was all important to meet the need for control of night interceptions, and Dr. Bowen returned to the charge with his radar lighthouse. 'Isn't it,' he concluded the letter, 'the solution to the interception problem when used in conjunction with R.D.F.1? We have the kind of equipment (C.H.L.) to make it work, and we have the people skilled in using it. Could we get on with this as one of our research items as soon as people are available from the St. Athan (A.I.) fitting programme?'

Need for Inland Reporting

There had been a disturbance of the close practical understanding between Fighter Command and the scientists when the Bawdsey Research Section was moved to Dundee at the outbreak of war, and renamed the Air Ministry Research Establishment. The liaison was re-established in another form by the attachment to Headquarters Fighter Command of three scientists who, though remaining on the staff of the Air Ministry Research Establishment, were stationed at Stanmore and made a close study of all operational aspects of fighter defence. Their initial position was somewhat delicate because they were the first scientific observers to be regularly attached to an operational headquarters and for

[1] Bawdsey Research Station File 4/4/300.

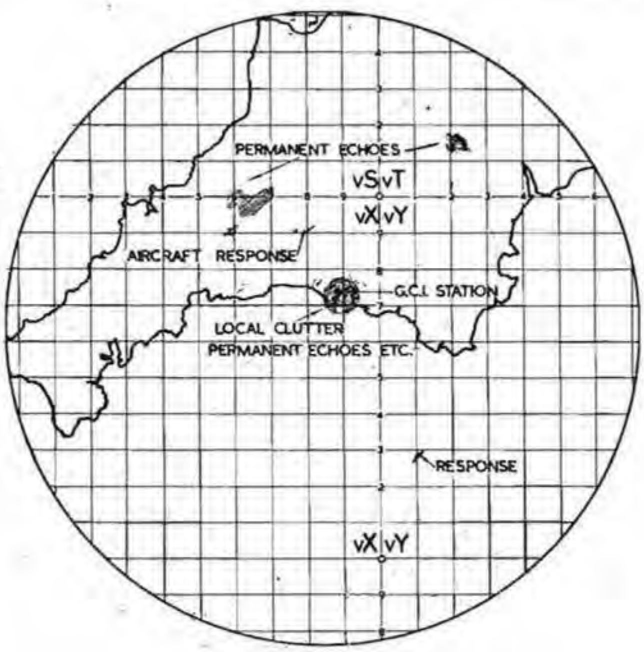
the first six months their watchword was tact. On one occasion at least the question of their retention at the Headquarters was very much in the balance but suffice it to say that they survived this period successfully and became the first of the valuable organisation which was later widely applied under the name of Operational Research Sections.

The Stanmore Research Section gave support to the projected interception equipment from the operational angle when they suggested, early in 1940, the desirability of a separate chain of inland radar equipment whose sole function would be to effect interceptions.[1] The suggestion was taken up by the Air Ministry Research Establishment as a means of locating aircraft inland and thus supplementing the information from the Observer Corps, which was handicapped during bad weather. The preferred technical solution to this problem was to abandon the floodlight principle used in the coastal chain, which was ineffective over land because of 'permanent echoes', and to use a narrow rotating beam to give indications of aircraft displayed in map form on a cathode ray tube.[2]

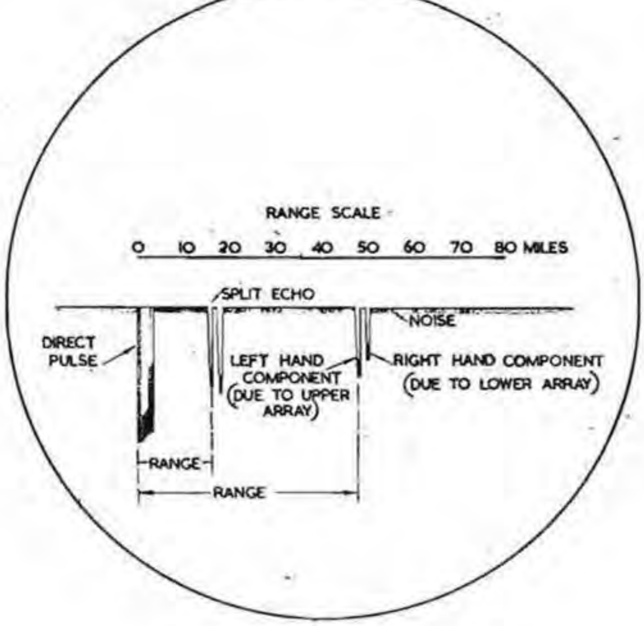
The Director of Communications Development accepted the proposals and agreed to the development of an inland radar reporting system only for operational trials, initial experiments to be on 1½-metres wavelength. Whilst admitting that the cathode ray direction-finding technique should be pursued, however, he denied the need for high priority in the development of a beam system, and recommended consideration of the use of Army G.L. sets at fixed sites in order to send limited intelligence to searchlight control centres and to group filter rooms in the R.D.F. network.[3] But the extreme range of G.L. sets was of the order of only twelve miles, and taking into account the prior claims for guns and searchlights to acquire all information possible during the very brief warning period, and also the inevitable delays in the complex communication network, the suggestion was not promising. It certainly could not help to solve the increasingly urgent problem of interception.[4] The reference to group filter rooms was presumably in connection with a system for improving interception proposed at the Air Ministry during the previous month, which involved filtering on group operations tables. The Air Officer Commanding-in-Chief, Fighter Command successfully resisted the pressure brought to bear on him to adopt this proposal, which he described as fantastic.[5]

Moreover, despite the failure in practice of the C.H. stations as interception controls, the belief that they might be made to perform this function died hard, and a report was called for from the Stanmore Research Section at Headquarters, Fighter Command. The memorandum produced for the Director of Communications Development on 3 June 1940 left no doubt as to their views. It enumerated no less than thirty contributory causes which might result in a failure to intercept using the existing equipment. The need for a more practical outlook was emphasised by the somewhat exasperated statement that the pilot could not see through cloud, nor could he distinguish an aircraft at any distance in excess of a few hundred feet on a dark night. The solution, the memorandum concluded, lay in the use of higher frequencies, shorter pulses, and the perfection of the rapidly rotating radar lighthouse employing a narrow vertical

[1] A.M. File S.43174/I, Encl. 71B.
[2] A.M. File S.47718, Encl. 3B.
[3] A.M. File S.47718, Encl. 7A.
[4] *Ibid.*, Encl. 5A.
[5] A.M. File S.3377, Encl. 3A.



THE P.P.I. TUBE



HEIGHT RANGE TUBE

fan-like beam. An additional advantage of such a system was the possibility of conducting interceptions locally without interfering with the continuous reporting of positions of aircraft to the central filter room.[1]

The Plan Position Indicator

A measure of success in this direction had already been achieved in the laboratories of the Telecommunications Research Establishment at the end of May, when the first Plan Position Indicator cathode ray tube was made to work.[2] Instead of the C.H. station display of a fixed horizontal time base with protruding blips to indicate the distance from the station of the aircraft observed, and separate goniometer readings, the P.P.I. display gave information in two dimensions at a glance. A rotating time base ran from the centre of the tube to the circumference, and moved steadily around the face of the tube like the spoke of a wheel, in synchronism with the rotation of the narrow beam aerial array. Echoes were shown not by blips but by a momentary brightening of a very small section of the trace. The distance of the bright spot from the centre of the tube was proportional to the range of aircraft observed, and the angle subtended between the vertical and time-base at that instant was the bearing of the aircraft from the station.

In order to present a continuous picture to the observer instead of a series of momentary bright spots, the inner surface of the P.P.I. tube was coated with fluorescent and luminescent material to give a persistent after-glow effect to the spots illuminated. The after-glow device was not new, having been developed before the war as part of the anti-jamming equipment of C.H. stations, but for use in interception stations the degree of persistence was made variable. The brilliance of the after-glow was normally adjusted to make the time base scarcely visible, while the bright spots persisted for a period equal to that taken by one revolution of the trace. The result was to show a map of an area of which the station was the centre, with spots of light changing position gradually and constantly over the area in accordance with the movements of the aircraft they represented. More important still, from the point of view of the interception controller, the relative position of any two aircraft within range was clearly and continuously visible.

Such was the new type of radar presentation which was to simplify enormously the task of the radar controller. As yet, however, it was simply a laboratory model under test in artificial conditions. The radar set required to work with it would necessarily be of the C.H.L. type, but much modification was needed. Shorter pulses were required to give the requisite definition to the picture, a turning gear was necessary to enable the aerial array to rotate continuously without breaking electrical contact, and the form of aerial would have to satisfy the extent of cover in range and height to be decided by the Air Staff. A method of filling the ever-troublesome gaps was required if the continuous following required for interception was to be obtained, and also some method of reading the height of aircraft must be evolved. The last problem was still outstanding from C.H.L. development.

[1] A.M. File S.43174/II, Encl. 3B.

[2] Formerly Air Ministry Research Establishment.

Overhead cover presented a new problem because the primary function of C.H.L. stations had been to give low level cover over the sea. To prevent the horizontal beam of the set from being reflected skywards by the ground in front of the station, the practice had been to site the aerial array as high above the ground as possible, for example, on the edge of a cliff or on a high tower. Where this was not possible the beam was tilted slightly above the horizontal to avoid the effects of ground reflections. On 9 June 1940 the Stanmore Research Section reported to the Telecommunications Research Establishment the results obtained by a C.H.L. station which was being used for training purposes in a concave site at Yatesbury, and made recommendations for obtaining overhead cover.[1] 'The plots and tracks of both hostile and friendly aircraft observed at this station', they said, 'are most impressive in their completeness within the interval of range between three and thirty miles from the station. We feel that there is a strong case for trying C.H.L. equipment in flat plain-like country, utilising perhaps lower aerials than normal so that the greater proportion of radiation will be reflected skywards, and concentrating mainly on aircraft above, rather than under, 3,000 feet. Such results were entirely in accord with the calculated expectations of the scientists who had already studied the problem of deriving maximum high cover by the reflection technique.

First G.C.I. Specification

Within the next week, a specification for the Ground Control Interception set, as it became known, was worked out by the Stanmore Research Section in consultation with the Signals Staff of Headquarters, Fighter Command. A close collaboration between scientific and operational staffs was essential in framing the requirement, and this was indeed an outstanding characteristic of the whole of the subsequent development of the G.C.I. station. The specification drawn up had to demand the facilities to satisfy operational needs, but because of the urgency of these, it could not be so exacting as to require prolonged research or development which would delay the engineering design and production of the equipment. A balance between Service requirement and immediate scientific possibility was struck as follows :—

(*a*) Ability to detect and locate aircraft from extremely low to very high angles of elevation, to measure height and respond to I.F.F.

(*b*) Freedom from vertical gaps.

(*c*) Continuous following.

(*d*) Range of at least 50 miles from 5,000 feet upwards.

(*e*) Greater accuracy than C.H. station in all respects.

(*f*) Display giving continuous indication of position, speed and direction of flight of both fighter aircraft and target.

The stipulation for range shown in item (*d*) had originally been from 500 feet upwards, but when it was explained that to provide the deeper field of detection might well mean two more years of research, whereas equipment to satisfy the smaller requirement could be produced in about six months, the Air Officer Commanding-in-Chief agreed to modify the specification accordingly.[2] It was

[1] A.M. File S.47718, Encl. 13B.

[2] It is related that the A.O.C.-in-C., Fighter Command, greatly concerned on one occasion by the protracted period which a scientist stated would be necessary for the development of certain urgently needed equipment, managed to reply, 'You remind me of the hymn—"A thousand ages in Thy sight . . ." '.

presented at the 9th meeting of the Air Interception Committee at the Air Ministry on 18 July 1940 by Wing Commander R. G. Hart of Headquarters, Fighter Command, who took a leading part in steering the opinions of the committee towards acceptance of the G.C.I. station, and bore much of the responsibility for putting the equipment into service.

The technical specification having been framed, there was the question of what form the new G.C.I. station should take. The recent withdrawal from Dunkirk coloured all ideas, and thoughts tended towards mobile or transportable equipment and towards the need for inland looking radar to guard against glider-borne invasion. Wing Commander Hart had in mind a double-decker motor bus fitted with R.T. and radar interception equipment, and his idea received warm support from many menbers of the Air Interception Committee and from the Air Officer Commanding-in-Chief. A station of this kind could be set up quickly in the vicinity of a squadron at any airfield from which it was required to operate. Aerials designed specially for interception would be required. On 15 August 1940 it was reported that the Royal Aircraft Establishment had spent some time in designing a set for fitting to the Army type of rotatable chassis. Work was now going forward on fitting a C.H.L. set into a furniture van which would aet as the station.[1] At the 12th meeting of the Air Interception Committee on 29 August 1940, it was stressed that gap-filling was a requirement for interception. The urgency of providing G.C.I. equipment was clear but no further action could be taken until the two experimental sets being constructed were tested practically.[2] Meanwhile, a further example of satisfactory inland cover was now reported from a C.H.L. set at Swanage, where it had been sited to be near T.R.E. at Worth Matravers, chiefly for experimental use. The site was too low to give good low cover over sea, but it was found to give good overhead cover inland. Here the P.P.I. tube was first fitted to a C.H.L. station and late in August 1940 was working satisfactorily, enabling a controller to visualise the movement of aircraft in plan position without the complication and delay of mathematical calculation.[3] The problems of gap filling and height finding, however, remained to be solved. These were essentially technical problems directly related to the radiation cover. There was also the need to provide means for the continuous rotation of the cumbersome aerial array. This was not a new problem since a comparable type of aerial had already been fitted, early in 1940, with power operated turning gear for a C.H.L. installation on a 200 foot high platform of the C.H. station at Douglas Wood.

Despite these as yet unresolved difficulties the decision was taken at a conference at the Ministry of Aircraft Production on 3 September 1940 to build immediately one mobile and one transportable G.C.I. station for testing in the Shoreham area. From four possible methods of gap filling, that of a tilted array system was accepted for development, but a more immediate solution was the use of aerials at different heights.[4] Two sets of prototype turning gear made by General Electric Company and British Thomson Houston were available for test. The choice of a site of suitable configuration was regarded as most

[1] A.M. File S.3984, Encl. 59A.
[2] *Ibid.*, Encl. 62A.
[3] T.R.E. History of Fighter Direction, A.H.B. IIE/205.
[4] A.M. File S.6462/I, Encl. 3A.

important. The perfect site was a saucer shaped depression about a mile-and-a-half in diameter wholly surrounded by low hills to cut off permanent echoes. R.T. apparatus was required at the station for communication with aircraft and operations room space was necessary. Work proceeded at high pressure in the foreknowledge that the Battle of Britain then being fought out would almost certainly be followed by heavy night bomber attacks on the United Kingdom.

Trials with G.M. and C.H. Stations

The G.C.I. station was not without competitors in the autumn of 1940 in the function of overland looking and interception control. Four sites were chosen for G.M.2 mobile stations of the floodlighting type, and installations were set up at Mariners Hill, in Kent, and at Sidmouth. Little value was gained from these stations, largely because of permanent echoes, but the observations made revealed that plots received through the C.H. and filter room system were usually two or three minutes old when they arrived, thus emphasising the value of direct radar control. The G.M.2 stations were withdrawn about the beginning of September and handed over to the Army. The Telecommunications Research Establishment expressed its dismay that so little use had been made of equipment the modification of which during the previous June and July had almost incapacitated their workshops for other purposes. It appears that two technically incompatible kinds of performance had been expected from the stations.

The hope of using C.H. stations for interception control was still not entirely dead and Mr. A. F. Wilkins of the Telecommunications Research Establishment spent several weeks in September and October at Pevensey station endeavouring to perfect a system of night fighter control. Ten A.I. contacts resulted from sixty-nine attempts but no aircraft was shot down. The lack of speed of the Blenheim aircraft and poor efficiency of A.I. were held responsible for failure, although Beaufighters fitted with A.I. Mark IV were also used.[1]

On the last day of October 1940 Mr. I. H. Cole of the Stanmore Research Section took over the experiments at Pevensey C.H. Station. Rapid working protractors and curves had been prepared to speed up the controller's calculations and to compensate for time-lags, wind velocity, and speed of aircraft. Briefly, the method planned was to patrol the fighter aircraft on one side of the main stream of incoming bombers, and to manœuvre it on to a course which kept the distance between fighter aircraft and bomber constant and brought the fighter across the bomber's track a short distance behind it. The A.I. was to be left switched on all the time, and when the fighter was brought within A.I. range of the target the air radio operator would assume control and complete the interception. The method was analogous to the common bearing method used with C.H.L. interception, and was performed directly from the cathode ray tube with practically no plotting of the fighter aircraft. Despite these new efforts, results were still disappointing, but valuable experience in the practical difficulties of radar control were obtained and some of the aids were adapted later for use at G.C.I. stations.

[1] A.M. File S.43174/II, Encl. 6A.

Trials with G.L. and S.L.C. Sets

Another method of controlled night fighter interception was attempted in the autumn of 1940 when about ten Army G.L. sets were installed at searchlight posts in the Kenley sector, chosen because it lay on the usual track of German bombers to London. To overcome the lack of precise inland reporting, the G.L. sets reported aircraft positions at half-minute intervals to the sector operations room where night fighter plots taken by D.F. fixing were available. The experiment promised success for three reasons: the height of the enemy could be given with fair accuracy by the G.L. set, the tracking of the bomber would be more exact than hitherto, and the pilot would be aided by the single beam of the master searchlight pointing directly at the target aircraft. Several A.I. contacts were obtained using this method but the limitations in range and field of vision of the A.I. equipment made it impossible for the fighter to follow up the contacts unless he obtained them from astern of the bomber and was flying on approximately the same course. The combination of the G.L. and D.F. fixing and reporting systems did not give the relative positions of fighter and bomber accurately enough at close quarters for such a precise degree of interception. As for the searchlights, night fighter pilots could not see the beam above 10,000 feet even in clear weather, and cloud or mist frequently obscured it at lower heights. A similar experiment using S.L.C. (Searchlight Control) radar equipment was also tried, but the range of the set was even less than that of the G.L., and although it gave better searchlight operation it did not measure height, neither could a plan position be obtained from a single instrument.[1] One result of these experiments, however, was to draw attention to the need for more and better qualified technicians at radar stations and recruits were drawn from the British Broadcasting Corporation, the General Post Office and the radio industry.

To enquire into the causes of weakness of night air defence, a committee was formed under the chairmanship of Marshal of the Royal Air Force Sir John Salmond in September 1940. The committee examined the whole field of night defence and produced valuable recommendations regarding the installation of homing and navigation aids for night fighters, and the selection and training of night fighter pilots, all of which eventually improved the efficiency of operation of the night defence. The importance of technical equipment and a specialised technique for night interception were emphasised, but a solution to the immediate problem of putting the night fighter on to the tail of the bomber still remained to be found.

The Experimental G.C.I.

Meanwhile the efforts of the ground radar development teams of the Telecommunications Research and Royal Aircraft Establishments were bearing fruit. Within the short space of a month the first experimental G.C.I. equipment had been produced. A modified C.H.L. aerial array, ten feet high by twenty-eight feet wide, had been mounted on a turntable and fitted on a four-wheel trailer. A suitable site was chosen at Durrington, near Shoreham, and on 16 October 1940 the aerial vehicle and radar equipment were tested there. On 18 October the first aircraft was detected and on 19 October the first special test flights were made by aircraft of the Fighter Interception Unit, Tangmere.[2]

[1] A.H.B. Narrative, A.D.G.B., Volume III. The G.L. and S.L.C. equipments were known for security reasons as George and Elsie respectively. [2] A.H.B. IIE/205.

There was no time to lose, for the Battle of Britain was now virtually over as a daylight operation, and the shortening days were a constant reminder of the impending night offensive.

The experimental G.C.I. station was subjected to an exhaustive series of tests and calibration flights to determine its coverage and shortcomings. There was no lack of criticism. The Officer Commanding the Fighter Interception Unit who flew in the trials, told the Interception Committee that the vertical coverage was full of gaps, the height indications were not accurate and the station was incapable of all-round looking.[1] He was not without some justification. The height of the aerial array from the ground had been reduced from 25 feet normal with C.H.L. aerials to a height of only 10 feet so that more radiation would be reflected from the ground and that better overhead cover would be given. Good cover resulted extending at 20,000 feet from five to forty-five miles in all directions from the station but unfortunately there was a bad gap between twelve and fifteen miles, just where a continuous track was most necessary for interception.[2] This actually confirmed the radiation pattern anticipated by the scientific staff who, appreciating the extreme urgency, had seen the need to accelerate the practical engineering of the station by all possible means, leaving refinements to be applied later. A gap-filling technique was devised by dividing the transmitter aerial into two sections and transmitting sections alternately ' in phase ' and then ' out of phase,' and by this means the required coverage was obtained. The echo segment on the display was found to be too wide, extending over an apparent distance of three miles. Clear definition and high resolving power in the P.P.I. tube were of the greatest importance for interception and efforts were therefore made to reduce the pulse width and to improve the focus thereby reducing the size of the echo and increasing its intensity or brilliance. Meanwhile the height finding problem on $1\frac{1}{2}$ metres wavelength had been solved by employing a technique somewhat similar to that used for gap-filling by utilising the division of the aerial array. This new height finding system proved to be, after the P.P.I., the second important scientific advance which made G.C.I. possible.

Decision to Manufacture

During November anxiety regarding night interception was rising fast. The fourth successive version of the airborne interception equipment, A.I. Mark IV, was already in use but the night fighters were still unable to inflict any serious damage on the German bombers which continued their raids with impunity. London had been bombed every night except seven between 7 September and 7 November 1940, with an estimated average of 166 bombers each night. Provincial towns and cities were also heavily attacked as, for example, Coventry on the night of 14 November when a force of over 400 enemy bombers did great damage and suffered no loss. So serious was the outlook that during the next few days the decision was taken to manufacture, by hand, six G.C.I. stations of the Durrington pattern. The decision was something of a gamble. Successful trials had not yet taken place. The stations were to have the 10 feet aerial

[1] A.M. File S.3984, Encl. 66A.

[2] A.M. File S.6462/I, Encl. 59B. Appendix No. 14 gives the performance of the divided 10-foot aerial at Durrington, together with the vertical polar diagram.

which, in the absence of power-turning gear, was to be rotated by hand. Only three P.P.I. tubes could be provided and the supply of R.T. apparatus was problematical. The target date fixed was Christmas, at first sight an impossible task because the sets could only be made manually and much of the work demanded purely scientific handling.

Modification and testing of the experimental G.C.I. went on at high pressure, and work was continued at Durrington at all hours of the day and night by a small but willing team of scientists and service personnel who walked many miles, often in pouring rain, between their billets and the site. On one noteworthy occasion a certain scientist arrived with scarcely anything undamped save his enthusiasm. He removed many wet garments including his trousers and hung them to dry on the transmitter while he continued his work and it was thus that he was discovered by a rather embarrassed senior officer who had arrived unexpectedly, in full rig, to view the station.[1]

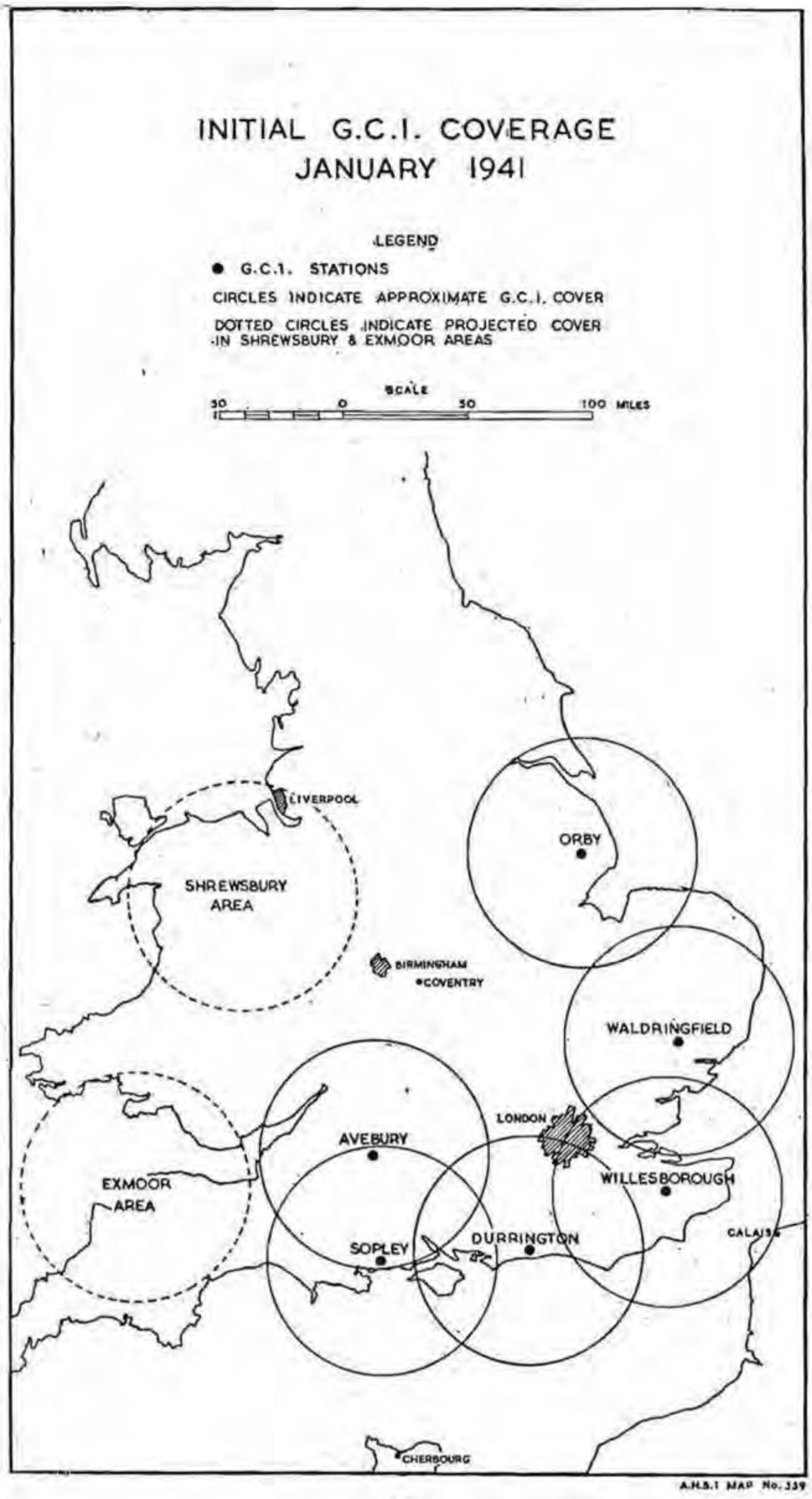
As soon as the experimental set was ready, operational trials began and between 29 November and 3 December 1940 thirty-six practice interceptions were made. It was still not clear how the controller was to combine the plotting-map information provided by the C.H. chain with the small, continuously moving indications on the P.P.I. tube. Six different methods were attempted, based on the experience which had been gained in the past year by Wing Commander Pretty, Mr. Cole and other pioneer radar controllers with C.H. and C.H.L. sets. Attempts to use both map and tube simultaneously failed because of difficulty in reconciling the difference in scale. At the first glance, most controllers were convinced that they could work directly from the P.P.I. tube, but experience showed that this would be too difficult until one of larger scale was provided. The method finally adopted consisted of using the map for the early stage of the fighter's approach, and of controlling the final convergence from the P.P.I. tube in a pure curve of pursuit. A small circular protractor was held in front of the tube, centred on the fighter, and the vectors given from time to time were the actual angle between bomber and fighter echoes. No allowance for wind was necessary. A serious setback occurred when it was found that many indications faded from the tube when heights were being taken ; for the time being heights had to be disregarded until a technical remedy was found. Generally, however, the trials were very successful ; a report by Squadron Leader B. Drewe who was at Durrington stated that accurate interceptions resulted from nine out of every ten attempts.[2] Another report by the Fighter Interception Unit which provided the aircraft and pilots for the experiments confirmed that interception could be controlled either from the G.C.I. or from the sector operations room using G.C.I. plots, but the final note that the controller's task would be simplified when all fighters were equipped with an I.F.F. set to respond to G.C.I. equipment, gave an indication of the difficulties still to be overcome.

Siting and Manning

The siting plan for the first batch of six mobile G.C.I.s was to give continuous or overlapping cover over the south and east of England but the choice was complicated by the need for stations to be fairly near the different sector operations rooms with which they were to work, with an overriding consideration for

[1] A.H.B. IIE/205.

[2] A.M. File S.6462/I, Encl. 60A.


INITIAL G.C.I. COVERAGE
JANUARY 1941
LEGEND
G.C.I. STATIONS
CIRCLES INDICATE APPROXIMATE G.C.I. COVER
DOTTED CIRCLES INDICATE PROJECTED COVER IN SHREWSBURY & EXMOOR AREAS
SCALE
50
0
50
100 MILES
LIVERPOOL
SHREWSBURY AREA
BIRMINGHAM
COVENTRY
ORBY
WALDRINGFIELD
LONDON
AVEBURY
WILLESBOROUGH
EXMOOR AREA
SOPLEY
DURRINGTON
CALAIS
CHERBOURG
A.H.B.1 MAP No. 339

favourable land configuration surrounding the station. The ideal saucer shaped site proved hard to find in many localities. The sites chosen were as follows :—

Priority	*Location*	*C.H. Stations to which connected*	*Fighter Sectors to which connected*
1	Sopley	Worth Matravers	Middle Wallop.
2	Durrington	Poling	Tangmere and Kenley.
3	Avebury	Worth Matravers	Colerne and Middle Wallop.
4	Willesborough	Rye	Biggin Hill and Kenley.
5	Waldringfield	West Beckham	Wittering and Duxford.
6	Orby	Stenigot	Digby and Wittering.

As shown in the table, most G.C.I.s were connected with more than one sector station to give flexibility of organisation in accordance with weather conditions and serviceability of airfields and aircraft. This degree of flexibility was particularly necessary because, despite the mounting of the equipment in vehicles, it still could not come into operation without delay on any new site. The technical performance of the station varied with each site and the calibration required before it could work effectively took anything up to seven days.[1] A G.C.I. could not, therefore, be moved from place to place to counter the varying tactics of the enemy, nor could it quickly replace, for example, another station which had been damaged by bombing.

In the matter of manning the G.C.I. stations, Headquarters Fighter Command had taken the initiative as early as September 1940 in asking for a special C.H.L. maintenance and operating crew to be sent to Worth Matravers to learn the technical details of the experimental G.C.I. and how to handle the apparatus. By the beginning of December the G.C.I. personnel establishment had been decided, and operators of the Women's Auxiliary Air Force were included. No women had previously been trained on the similar C.H.L. equipment, and a special course at the Telecommunications Research Establishment was necessary. A noteworthy item in the first establishment was two aircraftmen whose duty it was to take solitary turns at the handwheel in the aerial array cabin, rotating not only the aerial but the cabin and themselves as well. This dreary but essential occupation did not disappear until power turning machinery became available.[2]

Manufacture of the first six mobile G.C.I. stations went on throughout December at the Royal Aircraft and Telecommunications Research Establishments. All available outside help was sought and the staff worked night and day, taking a few hours for sleep when they could. The value of their effort

[1] A.M. File S.3984, Encls. 50A and 54A.

[2] The first technical establishment for one watch, in charge of a Senior N.C.O., Radio Operator or Mechanic was :—

3 A.C.s.	Radio Operator.
1 Cpl., 1 A.C.W.	Radio Operator (W.A.A.F.).
1 A.C.	Radio Mechanic.
2 A.C.s.	Aircrafthand.

A.M. File S.6462/I, Encl. 55A.

may be judged in comparison with the slow rate of bulk production of G.C.I. stations during the following year. The first of the six mobile sets was completed on Christmas Day, 1940, which was the apparently unattainable target date, and the other five were ready at intervals during the next fortnight. The first was sited and manned at Sopley by 1 January 1941. Four more were sited at Avebury, Willesborough, Waldringfield Heath and Orby by the middle of the month and by the end of January they had all been handed over to the Royal Air Force.[1] The experimental station remained at Durrington and became operationally active, leaving a sixth station at the disposal of Headquarters Fighter Command. Sector controllers at the respective sectors were instructed in radar control and took charge of the G.C.I. stations in turn.

[1] Fighter Command O.R.B.

CHAPTER 12

EARLY AND INTERMEDIATE G.C.I. STATIONS

The installation of the first six mobile G.C.I. stations marked the beginning of a new effort by Fighter Command to master the difficulties of night interception. After the disappointments of the previous year there was now much hope that the ability of the ground control to position the fighter close to the tail of the bomber would result in more effective use of A.I. The method of G.C.I. control worked out by trial and error in early December 1940, consisting of giving the first bold vectors towards the bomber by reference to the plotting map and the subsequent finer corrections from the P.P.I. tube, was confirmed in many later practices as being sound and effective.

Organisation and Training

The G.C.I. stations were organised as part of their respective sectors. The sector controller was in touch with the night fighter on one V.H.F. R.T. channel, and since he received long distance plots on a prospective target before the G.C.I., he sent the fighter to a suitable position where it was taken over on another R.T. channel by the G.C.I. controller. The G.C.I. controller checked with the C.H. station whether the target showed I.F.F. and at what height it was flying. During the interception, plots on fighter and enemy continued to be told to the sector operations room. As soon as the first fighter had been handed over to the G.C.I. another was put into position by the sector controller.[1]

The selection and training of G.C.I. controllers was of first importance and a matter of urgency. They were chosen from amongst sector controllers who already had considerable experience in directing aircraft by radio telephony. This practical course of action was put forward on 19 December 1940 when the establishment of two additional officers for duty at each G.C.I. station was recommended. Even the scientists who devised the methods of interception were prone to make ordinary elementary mistakes in controlling when they attempted to put their own excellent systems into practice and, on these grounds, previous sector controlling experience was held to be essential.[2] At the same time the term 'sub-controller,' by which officers who had in the past conducted interceptions at forward radar stations were known, was discontinued because interception control was no longer considered as a subordinate task, but rather as one to be undertaken by all sector controllers in their turn. By 15 January 1941 controller instructors were teaching the G.C.I. technique to sector controllers at Middle Wallop, Biggin Hill and Debden, the instruction consisting of watching two or three interceptions being performed and then doing a minimum of six daylight interceptions themselves under supervision. It was impossible to train all the sector controllers at a single station, and so it was done by using all operational G.C.I. stations as they became available, and the aircraft in their respective sectors.[3]

[1] A.M. Joubert's Folder on G.C.I. A.H.B. IIE/207, Encl. 19A.
[2] A.H.B. IIE/207, Encl. 14A.
[3] *Ibid.*, Encl. 17A.

The technique was not allowed to become a hard and fast method. 'Continuous development work on G.C.I. control,' wrote the Air Officer Commanding-in-Chief, Fighter Command, 'is undoubtedly desirable in exactly the same way as continuous work is necessary on the home chain of radar stations.' Arrangements were made for analysis by the Stanmore Research Section of operational results obtained with G.C.I. stations in order that operational weaknesses could be investigated and rectified.

G.C.I. Operations

The effort to assimilate and master the G.C.I. technique was by no means confined to controllers. The pilots and radar operators who by their flying provided the interception practice for the ground staff, were themselves striving to become expert not only in using G.C.I. control to the best tactical advantage, but also in perfecting their use of A.I. for the final approach to within visual range of the target. Disregarding inconvenience and discomfort, the aircrews persisted in the face of very bad weather during the first two months of 1941 to master the flying technique of the new method of night interception. German night activity was much reduced by adverse weather during the same period. The number of A.I. contacts increased in January, but only one bomber was destroyed and one damaged by fighters under G.C.I. control.[1] One more was shot down in February with the aid of Durrington G.C.I.[2] These successes were gained by pilots who were the pioneers in A.I. tactics. Widespread proficiency could not come overnight. In March, when the weather improved, greater numbers of German aircraft than ever before were available for operations, but the experience and confidence of the defence had made great strides.[3] During three nights of intensive raiding between 12 and 14 March, fifteen German bombers were claimed as shot down, with four probably destroyed and three damaged. There was an absence of large scale attacks during the remainder of that month. During April and May the German night bomber losses continued to mount, reaching 48 and 96 respectively in these two months.[4]

Only five night-fighter squadrons were equipped with A.I. even as late as 9 May 1941 and to meet the deficiency in defence against overwhelming numbers of German bombers, eight squadrons of single-engined fighters were also employed. The pilots received some G.C.I. assistance to direct them towards the main stream of enemy aircraft but continued their search by visual observation only. The 'catseye' fighters, as they were called, achieved remarkable successes on moonlight nights in areas of highly concentrated enemy activity, such as occurred over London on the night of 11 May. On the other hand, only

[1] Fighter Command O.R.B.

[2] A.M. File S.6848, Encl. 33A.

[3] A.D.I.(K) Report No. 12 (1946). A.H.B. II G/29.

[4] A.H.B. Narrative A.D.G.B., Volume III.

		Estimated Enemy Sorties	*Claimed as Destroyed*
1940	September	6,135	4
	October	5,845	3
	November	5,495	2
	December	3,585	4
1941	January	1,965	3
	February	1,225	4
	March	3,510	22
	April	4,835	48½
	May	4,055	96

the A.I. night fighter, directed by G.C.I., had a reasonable chance of intercepting isolated raiders in anything but the brightest moonlight. 'Both types are effective in conditions suitable to them. Their roles are complementary, not competitive,' wrote the Commander-in-Chief, Fighter Command.

The value of the combination of A.I. and G.C.I. was quickly assessed by the Commander-in-Chief, who reported: 'The major successes of the early spring of 1941 are attributable to the effective use of A.I. which has been greatly assisted by the accurate positioning now possible with the G.C.I. apparatus.' He considered that the G.C.I. mobile stations had come into most effective operation.[1] Including the contribution by anti-aircraft guns and balloon barrages, the total enemy losses rose from ½ per cent. to 7 per cent. between December 1940 and May 1941.

Teething troubles

Concurrently with the operational successes came an increasing flood of activity in connection with G.C.I. Technical development of equipment went on simultaneously with the organisation of training the crews and maintenance of the equipment. Demands for immediate extension of G.C.I. cover and greater production competed with the urgent need to improve the existing equipment. The changing tactics adopted by German bombers to circumvent the new-found effectiveness of the night defence made constant resiting of G.C.I. stations necessary with all the complication of recalibration, fresh communications and new liaison with different fighter sectors. The struggle to establish what was virtually a new radar chain in 1941 was comparable with the efforts made in the previous year with the coastal C.H. and C.H.L. stations, but whereas the Home Chain had a considerable period for preparation, the G.C.I.s were engaged in the night battle the instant they were produced. On the other hand operational understanding and knowledge of radar weapons was wider and technical resources had increased, although the latter were fully absorbed by the ever increasing demands on them brought by A.I., A.S.V., the development of centimetre technique and the growing requirements of the other Services.

Teething troubles were inevitable. On 26 February Beaufighter pilots at Middle Wallop complained that Sopley G.C.I. was bringing them into sight of the enemy much too high. This fault may well have been a legacy from day fighting control methods in which height was an advantage. But to be seen

[1] Stanmore Research Section File S.R.S.9/2/1, Encl. 113A. During the period 2 March–11 May, 61 enemy aircraft were destroyed by night fighters under G.C.I. control out of a total of 140. Station performances were as follows:—

G.C.I Station	*Enemy Aircraft Destroyed*	
Sopley	27	
Durrington	12	(Station U/S for the better part of one moon period.)
Waldingfield	7	
Orby	7	
Langtoft	3	
Exminster	3	
Willesborough	1	
Wartling	1	

by the enemy bomber silhouetted against the night sky during a controlled approach was a grave disadvantage to the night fighter, and to approach out of the comparative darkness below became the rule.[1]

Liaison between G.C.I. station and sector operations room brought its difficulties when the first attempt to transfer additional fighters from the sector pool to G.C.I. control during operations in March led to confusion. Confidence in G.C.I. was already established, however, and the Officer Commanding No. 604 Squadron affirmed at the investigation of the incident that even in such circumstances there was more to be gained by pilots sticking to directions given, than by attempting to search independently by A.I. alone.[2]

Identification was a constant difficulty. Only the special form of I.F.F. carried by night fighters, the Mark IIG, was visible at G.C.I. stations; for identification of day fighters, bombers and coastal aircraft, assistance was required from the nearest C.H. station or the sector operations room. There was always a risk of confusing different raids during periods of congestion, which was accentuated by the time lag in plotting on the sector operations table, where occasionally the aircraft in doubt did not appear at all. Sometimes a friendly aircraft did not show I.F.F. because of unserviceability or by omission to switch on, and the C.H. station was powerless to help. In such cases the interception of an unidentified aircraft might be attempted, the pilot being told to investigate with caution, but such expedients gave rise to waste of effort and additional hazards to both the fighter and a possible friendly target.[3]

Communications and Liaison

Installation of direct telephone lines facilitated close liaison between G.C.I. stations and the nearest C.H. stations, and with the one or two sector operations rooms with which they were associated. By this means C.H. stations provided the G.C.I. with long range plots, height readings and information whether I.F.F. was being shown by aircraft in a suitable position for interception. The links with sector stations allowed aircraft plots to be told to the sector operations room by a separate observer at the P.P.I. tube, and the G.C.I. station was thus used as part of the reporting system, in addition to its interception function, even while fighters were being controlled.[4]

When first installed the G.C.I. stations were considered as interception controls during the hours of darkness only, but by April 1941 their value for both interception and reporting during daylight also had been recognised, especially during bad visibility. Two more requirements arose therefrom,

[1] A.M. File S.6462/II, Encl. 37A. [2] A.M. File S.3984, Encl. 77A.

[3] A.M. File S.6462/II, Encls. 33A and 36B.

[4] *Ibid.*, Encl. 46A. The line from the G.C.I. station to the Sector terminated on the station switchboard, and during operational periods was plugged through to the following Sector Operations Room terminals:—

(a) G.C.I. Liaison, on the Dais or Deputy Controller's level, to be within easy speaking distance of the Controller.

(b) On the floor, for a plotter to plot bomber and fighter plots for display so that Operations Room Staff would know the position of the G.C.I.'s aircraft.

(c) In the Army Room or near the Army board, where such existed, to enable bomber and fighter plots to be correlated with G.L. plots so that G.L. heights could be obtained on the correct track.

additional maintenance crews and controllers, and the fitting of I.F.F. Mark IIG in the day fighter squadrons, numbering sixty-six in all with twenty-four aircraft each. The sets were ordered but fitting was impossible until they were manufactured. It was also impossible to find sufficient controllers immediately without drawing on experienced flying personnel, although thirty-one had been trained by the end of March. Until both these deficiencies could be made good, effective use of G.C.I. could not be made by day.

Unlike the coastal chain of radar stations, which remained in No. 60 (Signals) Group, the G.C.I.s were absorbed operationally and administratively into the organisation of the sector to which they were allotted. No. 60 Group retained responsibility for the installation and maintenance of G.C.I. equipment and the officer commanding the nearest regional signals wing was responsible for its technical efficiency. To carry out this division of duties, radar mechanics were provided by No. 60 Group, while radar operators chosen from among Clerks (Special Duties) were provided by Fighter Command, by whom they were trained in G.C.I. work.[1] Direct liaison between controllers and night-fighter airfields was encouraged and coupled with interchange of experience between night fighter squadrons it was found to be one of the best means of improving the night interception organisation.[2]

Provision of Extended G.C.I. Cover

Meanwhile, from the beginning of the year, plans were being made to reinforce the first six mobile stations and to satisfy the increasing demands for the new equipment. At a meeting at the Air Ministry on 15 January 1941 it was decided that forty-seven G.C.I. stations were to be supplied by June of that year. They were of three types :—[3]

(a) *Fully mobile.*—This type was to be fully mobile and capable of being erected and dismantled in twelve hours. All the equipment was to be on wheels including a simple form of gantry and aerial system. The setting up was to be independent of Works Services and the crew of the station were to be capable of both erecting and operating the equipment.

(b) *Transportable.*—Twelve sets of this type were being made by the Royal Aircraft Establishment at Farnborough. The type utilised six prime movers and six trailers. The equipment was mobile to the extent that it could be brought to site on wheels, but the gantries and aerial systems were taken off the vehicle and erected on the ground. The erection of the gantries was a fairly lengthy process and, in practice, took ten men three days to complete. The manufacture of these sets was to be discontinued as soon as the twelve already on order were completed.

(c) *Fixed.*—This type of equipment was to be housed on the ground in huts provided by Works Services. The G.C.I. station was similar in style to a standard C.H.L. station, except for the choice of site.

[1] A.M. File S.6462/II, Encl. 76A.

[2] A.M. File S.6848, Encl. 50A.

[3] A.M. File S.6462/I, Encl. 113A. Fixed G.C.I. stations were to be termed A.M.E.S. Type 7. Mobile, Transportable and later Intermediate G.C.I. stations were to be termed A.M.E.S. Type 8. (A.M. file S.6462/II, Encl. 54A.)

The general distribution foreseen for the forty-seven projected G.C.I. stations was as follows :—

Locality	*Fully Mobile*	*Trans-portable*	*Fixed*	*Total*
Eire (if required)[1]	6			6
United Kingdom		12	11	23
Middle East	7			7
Far East	5			5
Gibraltar			2	2
Expeditionary Forces	4			4
Total	22	12	13	47

One weakness of this manufacture and allocation schedule was the omission of requirements for training and further development. At the instigation of the Stanmore Research Section the Telecommunications Research Establishment asked in February 1941 that a G.C.I. receiver be allocated to them for use in designing a suitable training attachment.[2] At the same time the Royal Aircraft Establishment asked for a complete equipment to enable them to construct a prototype of a fully mobile station. Such requests could only be met from the twelve transportable equipments promised from production by April 1941, all of which were urgently needed for operational use, but it was realised that to refuse them would be detrimental to long term progress.

Another meeting was held to discuss design and production on 24 January 1941, when the difficult problems surrounding G.C.I. manufacture were made clearer. Conscious of operational urgency, Headquarters Fighter Command pressed for the immediate production of mobile units regardless of sacrifice of performance. Dr. D. Taylor, of the Telecommunications Research Establishment, explained that the original six mobile equipments were built as an emergency measure only. In that form the equipment was subject to many limitations, especially in height finding which was essential for night interception. The equipment proposed involved certain new techniques not yet fully tested. Nevertheless, immediate production was decided upon, with the optimistic proviso that improvements were to be incorporated as soon as possible. The insistence of one representative on the need for the equipment to be mobile called forth a categorical reminder by the No. 60 Group representative that the week necessary for installation, calibration and telephone connections would preclude any true measure of mobility.[3] A production target of ninety mobile and sixty fixed stations was set, of which thirty were required before June.

In the meantime, as Dr. Taylor had foreseen, experimental modifications made to the mobile G.C.I. station at Sopley had resulted in greatly improved performance in many respects. Instead of the original very rough system of

[1] In anticipation of a possible German landing in that country.

[2] A.M. File S.6462/I, Encl. 113A.

[3] A.M. File S.6462/II, Encl. 36A.

height finding it was now possible to obtain fairly accurate heights, and also to read the relative heights between bomber and fighter without interfering with the continuous progress of interceptions. The operation of the first mobile stations was confined to sweeping backwards and forwards over a small arc which limited the possibility of interception to one bomber at a time. Continuous rotation of the aerials at either three or six revolutions per minute to facilitate multiple interceptions had now become possible, and the necessary mechanism was being included in the first of the transportable stations, shortly to be opened on 7 April at Langtoft. The combination of immediate production and continuing development had rendered the original design of the transportable stations partially out of date before the first one had been completed.[1] Other modifications to be embodied involved the removal of the horizontal split in the aerials, provision of strained feeders, clearing up of the receiver time-base and the removal of the range rack. The addition of an aerial at 35 feet above the ground was required to give wider cover at lower altitudes. The original sets could not keep aircraft in view long enough to control an interception, if they were flying below 10,000 feet.

The simultaneous demands for production and improvement threw a great strain on the organisations responsible for them. Defects in the construction of the rotating aerial systems, possibly aggravated by unskilled handling and over-intensive testing, were reported in April 1940.[2] At first the breakages were merely repaired on the spot, as they occurred, by a working party of No. 2 Installation Unit. No attempt to investigate the true cause of failure was made until the Avebury G.C.I. station was 'placed unserviceable' on 5 May. In the meantime four more stations had been completed, all containing the same faults. The equipment was reported to be too weak in some vital parts and needlessly strong in others, incorporating features incompatible with good engineering practice.

By 16 May 1941 only eight complete sets, five transportable and three mobile, had been produced in addition to the original six mobile G.C.I.s, all of which were now modified to the Sopley standard and operating with success. In an effort to speed up the rate of production an appeal was made to the Army for C.D./C.H.L. transmitters and fourteen were promised.[3] A programme for production of receivers for mobile equipments was planned to start about the middle of June, and of transmitters about the beginning of July. There was much ground to be made up, therefore, in the manufacture of G.C.I. equipment. The total number of sets required was still stated to be one hundred and fifty. Two months later, on 17 July 1941, only seventeen G.C.I.s were operational and the estimated total required at home and abroad had risen as high as one hundred and seventy-eight.[4] Production was expected to rise to ten per month from the end of August.

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[1] A.M. File S.6462/II, Encl. 65A.

[2] Fighter Command O.R.B.

[3] In return the Royal Air Force gave up one complete mobile G.C.I. set to the Army Defence Research and Development Establishment for experimental purposes in connection with Anti-Aircraft Command. It was erected in Hyde Park with a remote P.P.I. installed in the Brompton Road, S.W.3. A.M. File S.6462/II, Encl. 186A.

[4] A.M. File S.6462/II, Encl. 184A.

Re-siting Problems

The shortage of G.C.I. equipment during the first six months of 1941 was reflected in the expedients which Headquarters Fighter Command were driven to adopt in their efforts to make the best use of the available sets. By the end of March thirteen sites had been selected for the twelve transportable stations then confidently expected and the remaining single mobile G.C.I.[1] The siting plan was soon in need of modification. It had been drawn up to cover appropriate localities in relation to the trend of night bombing at the time, but the German tactics changed quickly in March and early April, as a result of the new-found effectiveness of the night defence. Instead of flying straight to the target with the help of radio beams, the raiders began to skirt the defence along the coast and then cut sharply inland. Several moves of G.C.I. stations became imperative, as for example that of the station at Dirleton in East Lothian to Anglesea. The need for G.C.I. cover to be continuous and overlapping in all directions also became evident from combat reports of night fighter pilots. A series of turns to evade the night fighter soon brought an enemy bomber out of the range of a single G.C.I., and the night fighter was powerless to pick up the target again by use of A.I. alone. Increased enemy attention to coastal targets also had to be considered and a radical change in the siting plan was adopted in April. The four transportable stations which were complete or nearing completion, Langtoft (near Peterborough), Hack Green (near Market Drayton), Comberton (near Birmingham) and Avebury (near Marlborough) were to remain in position but the rest of the sets were to be erected on coastal sites where their ability to see low-flying aircraft could be utilised against

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[1]

R.A.F. Group	*Fighter Sector*	*Associated G.C.I.*	*Telephone Communications*	*Target Opening Date*
12	Wittering	Langtoft	Wittering Ops Room	April 1941
13	Ayr	St. Quivox	Ayr Ops Room North Cairn C.H. Kilmalcolm C.H.	April 1941
9	Ternhill	Hack Green	Ternhill Ops Room Speke Ops Room	April 1941
9	Baginton	Comberton	Baginton Ops Room Ternhill Ops Room	April 1941
10	Filton	Avebury	Filton Ops Room Middle Wallop Ops Room	April 1941
10	Pembrey	Wrafton	Pembrey Ops Room St. Eval Ops Room West Prawle C.H. Northam C.H.	May 1941
12	Church Fenton	Hampton Hill	Church Fenton Ops Room Catterick Ops Room Staxton Wold C.H.	May 1941
13	Drem	Dirleton	Drem Ops Room Drone Hill C.H.	May 1941
11	North Weald	Boarscroft	Northweald Ops Room	May 1941
11	Kenley	Wartling	Kenley Ops Room Pevensey C.H.	May 1941
9	Rhosneigr	Trewan Sands	Rhosneigr Ops Room Nevin C.H.	May 1941
13	Ouston	Dinnington	Ouston Ops Room Ottercops Moss C.H.	May 1941
14	Kirkwall	Northtown	Kirkwall Ops Room Netherbutton C.H.	May 1941

mine-laying and cloud flying raiders in daylight.[1] The mobile G.C.I. stations at Durrington, Sopley, Exminster, Waldringfield and Willesborough were to be replaced by transportable stations, and the mobile radar equipments thus released were to be placed at Coltishall, Boarscroft, Wrafton, Basingstoke and Hampton Hill. Apart from Foulness and Wartling, which were to have transportable stations, the remaining sites on the priority list were to be provided with mobile sets.

It was scarcely to be expected that the sudden changes of site, made as they were for reasons of tactical necessity, could be accomplished entirely without demur from the technical and scientific staffs responsible for the arduous tasks involved in setting up and calibrating the apparatus. Changes in the plans for the extensive requirements for telephone and teleprinter communications often involved considerable dissipation of the limited technical resources and materials of the General Post Office Telecommunications War Group. The Controller of Telecommunications at the Air Ministry cited the G.C.I. station at St. Quivox, Ayrshire, which, having been rushed into position at a time when severe raids were occurring on Glasgow and having been carefully set up and calibrated a few days before full moon, was at once ordered to be dismantled and transferred to Acklington in circumstances in which it was impossible to secure its effective operation again in less than ten days. He added that it might be as well if the term 'Mobile G.C.I.' were discontinued since it tended to give an incorrect idea of its true degree of mobility.[2]

In May 1941 the disposition of G.C.I. stations for the protection of London was given special consideration as a result of representations by the Air Ministry for increased cover. Examination of the problem by Headquarters, Fighter Command, made clear two limitations in the value of G.C.I. in the circumstances prevailing. Firstly the balloon barrage would obstruct the use of G.C.I. by reason of the multiplicity of permanent echoes, and secondly the flying to and fro by enemy aircraft over the target area would preclude any great chance of successful interception. It was considered that cover in the area where aircraft flew on straight lines of approach would be far more favourable for interception, and additional cover for the London area was therefore not allowed.[3]

Greater Demands for G.C.I. Equipment

The acute shortage of G.C.I. stations during the early part of 1941 was accentuated by demands from many sources for the complete equipment or its component parts. The Germans held the initiative and extended their attacks on west coast ports to targets in Northern Ireland and to merchant

[1] The priority list of sites then stood as follows :—

1. Weston-super-Mare (later changed to Acklington).
2. Foulness (later changed to St. Davids)
3. Coltishall (later changed to Land's End)
4. Startpoint
5. Boarscroft
6. Wrafton
7. Basingstoke
8. Hampton Hill
9. Nuneaton
10. Dinnington
11. Northtown
12. Trewan Sands
13. Middlesbrough
14. Calshot

A.M. File S.6462/II, Encl. 112A.

[2] *Ibid.*, Encl. 132B. [3] *Ibid.*

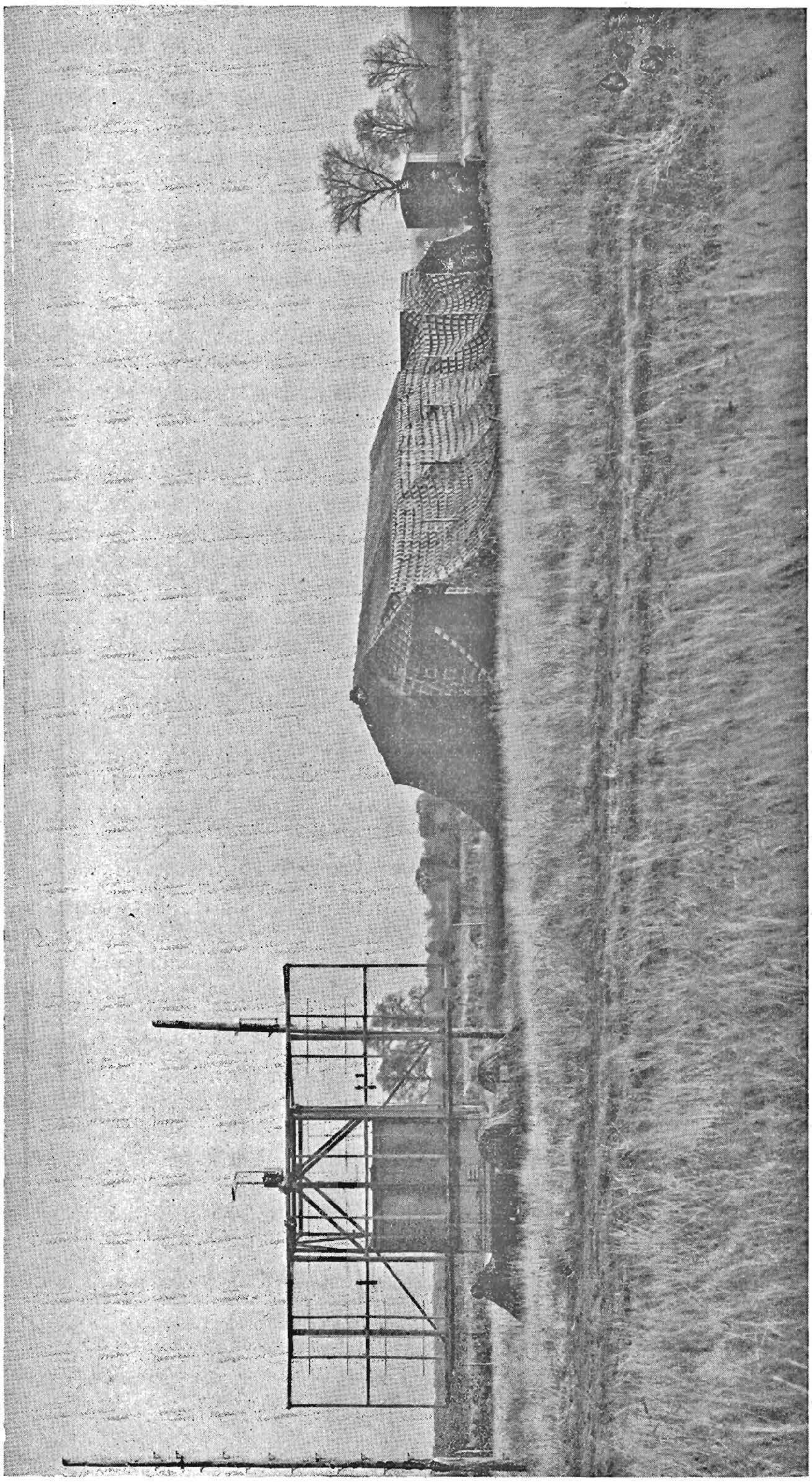
shipping in the Western Approaches. The Avebury G.C.I. was moved to Exeter where it would cover the route taken by enemy aircraft crossing the coast at Lyme Bay and flying north over Somerset to the Irish Sea. Once over the sea the Germans usually flew below 1,000 feet, and C.H.L. stations with P.P.I. tubes were demanded for the south-western coastal area. A site in the Scillies was considered but installation was deferred until August because of the vulnerability to capture of secret equipment placed on these islands.[1] Four mobile G.C.I. convoys were installed to cover the approaches to Belfast and Londonderry despite the difficulty of finding technically suitable sites in Northern Ireland.[2]

The high priority given to the Battle of the Atlantic in March 1941 by the Prime Minister resulted in a concentration of effort on the installation of C.H.L. and G.C.I. stations, both shore-based and ship-borne, for the purpose of giving radar warning and fighter control by day and night over shipping convoys approaching and leaving the western ports of the United Kingdom. Such effort could only be made at some expense to the existing task of providing G.C.I. cover for defence against German night bombers.[3] The installation of G.C.I. equipment in ships to give fighter control at sea was first suggested in March 1941 and the need for six sets was mentioned. A small sub-committee was convened under the Director of Radar on 11 March to examine the peculiarities of the requirement.[4] Development work on this project went forward steadily throughout the next two years and progress was reported regularly to the Air Interception Committee. The Admiralty had a requirement for day fighter control at sea which was linked with that of Fighter Command for night interception at sea by shore-based fighters beyond the range of coastal G.C.I. stations. Catapult armed merchant vessels and cruisers were fitted with G.C.I. and Naval radar equipment. A result of this development work was the fighter director ship used in landing operations much later in the war. On 19 April 1941 a proposal was made by Coastal Command Operational Research Section to install a G.C.I. in a Liberator aircraft for fighter control at sea. The project was not taken up at the time chiefly because of the shortage of G.C.I. equipment and Liberators and was still an outstanding item at the end of the war, although the greater resources of the United States enabled the Americans by that time to produce the Airborne Early Warning Radar (A.E.W.) equipment.[5]

Further demands for G.C.I. equipment arose in April 1941 for the defence of vital supply areas in the Egyptian Delta and Suez Canal zones. It was calculated that it might be possible to send three sets to the Middle East by 21 June 1941 but this was not in fact achieved until two months later, despite a comment from the Prime Minister on the tardiness of distribution.[6] The

[1] A.M. File S.6462/II, Encl. 26A.
[2] A.M. File S.6462/III, Encl. 179A.
[3] Fighter Command File S.24425, Encl. 27A.
[4] A.I.C. 39.
[5] A.I.C. 193, 21 June 1945.
[6] A.M. File C.S.10234, Encl. 7A, App. B.

	Totals Distributed	
Date	*Home Transportable and Mobile G.C.I. Stations*	*Overseas Mobile G.C.I. Stations*
By 1 August 1941	21	nil
By 1 September 1941	25	4
By 1 October 1941	29	9
By 1 November 1941	33	14
By 1 December 1941	37	19
By 1 January 1942	41	24



G.C.I. Intermediate Mobile (Type 8)

need to despatch G.C.I. stations overseas resulted in arrangements to have a self-destructive mechanism incorporated in these sets in order that the risk of capture of an intact equipment should be minimised. To facilitate the operation of mobile G.C.I. sets in overseas theatres, the Telecommunications Research Establishment compiled complete instructions on the G.C.I. system, including all aspects of siting, the latest theory of defraction over hill tops, and data on the probable effect of permanent echoes at various distances.[1]

A further call for G.C.I. equipment came as a result of enquiries from United States Army Air Force observers about British interception methods.[2] The radar controlled interception technique had been changing and progressing so rapidly that it was very difficult to bring out a full and satisfactory specification which would not be out of date before it was issued. A complete mobile G.C.I. set was therefore allocated to the United States on 23 June 1941, to be sent out in the first week of July.[3] This formed the basis on which the Americans began mass-production of G.C.I. equipment.

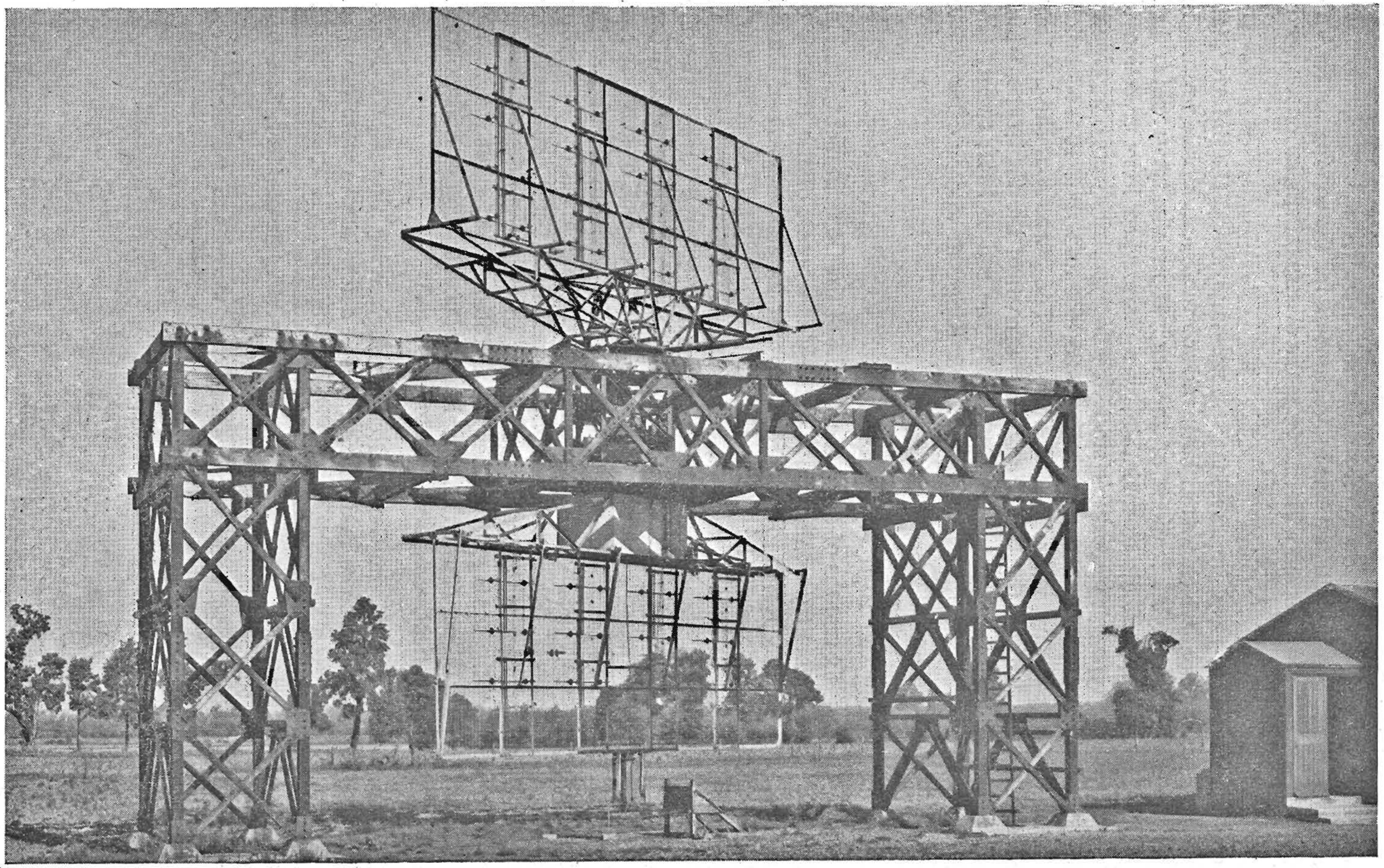
Short Term Improvement Programme

In July 1941 it became apparent that a clear cut policy towards the production of G.C.I. equipment was essential. The rate of production showed no sign of catching up with the steadily increasing demand for more and more equipment. The stations being made still fell far short of the facilities and performance held to be desirable, but the piecemeal incorporation of improvement after improvement both during and after manufacture absorbed the attention of a large technical staff, while full scale effort was frustrated by the lack of a definitely fixed design of equipment on which production could be standardised. The need for stabilising the position was emphasised by the Air Officer Commanding No. 60 Group, who urged that the immediate requirement should be met with equipment of only the simplest and well-proved design and that perfection should be left to the future. He added that all siting and other work in preparation for such sets should be 'driven ahead now to ensure that more Huns can be shot down before Christmas'.[4]

A survey of future research and development for G.C.I. equipment had already been made by Dr. Taylor, who explained to a meeting at Headquarters Fighter Command on 17 June 1941 the implications of providing the type of equipment which was being asked for. Even assuming that existing problems were solved, including power drive, continuous rotation at six turns per minute and common transmitter and receiver aerials, at least six more months of development work would be required before the means for multiple controlling, more reliable height-finding, and ability to discriminate between activity at different levels, could be found. In its simplest form, and introducing a minimum of additional components, the development scheme to evolve the interception facilities desired was necessarily of a long-term character. Hopes of obtaining the G.C.I. in its final form were therefore deferred until a later date.[5]

The Air Ministry issued on 29 July 1941 a short-term improvement programme which aimed at making the best use in the meantime of known

[1] A.M. File S.6462/II, Encl. 169A. *See also* Volume IV, Chapter 12.
[2] Minutes of 30th Meeting of Air Interception Committee.
[5] A.M. File S.6462/II, Encl. 159.
[4] Fighter Command File S.24425, Encl. 32A.
[3] A.M. File S.6462/II, Encl. 147A.



G.C.I. Intermediate Transportable Aerial System (Type 8) equipment and operating it with the highest degree of efficiency. In addition to existing improvements, all stations were to be converted to common aerial working, gantries were to be used only at transportable stations and at certain sites for use against German low flying minelaying aircraft, and hutted accommodation was to be set up at all stations in preparation for the coming winter.[1] All future sites were to be selected with an eye to the eventual installation alongside of a G.C.I. of the 'final' type.

Out of the short-term improvement programme arose the intermediate type of G.C.I. station, which was in both transportable and mobile form. In October 1941 eight G.C.I. stations of the original mobile type, which had become increasingly difficult to maintain, were earmarked for conversion to the intermediate type; transportable stations whose gantries were dangerously weak were given strengthened gantries and 35 foot and split 10 foot aerials to improve low coverage where most required. The purpose of the intermediate stations was to fill the breach until the arrival of the final type, which it was hoped would appear early in 1942.[2] By the end of 1941, twenty-nine G.C.I. stations were operating in the United Kingdom and five more had been sited.[3]

German Minelaying and High Flying Activity

During the last six months of 1941, the weight of the German night bombing effort against this country diminished materially as a result of the transfer of the bulk of the enemy forces to their eastern front for the invasion of Russia which began on 22 June 1941.[4] Only during June, July and October was a substantial number of attacks made on targets which involved flying inland in circumstances favourable to interception.[5] The Germans turned steadily towards a more economical use of their limited forces in the west and concentrated on coastal targets and minelaying in which the risk of loss was less. The chance of interception was minimised when the Germans flew below the height of G.C.I. cover and followed erratic courses. An analysis by the Fighter Command Operational Research Section showed that G.C.I. stations were concerned in 50 per cent of the total casualties of the enemy, and in 46 per cent of raiders destroyed. During September and October these figures rose as high as 72 per cent and 63 per cent, when the lower concentration of raids enabled G.C.I. to be more effective against isolated raiders.[6]

In the autumn of 1941 the Germans used a high flying aircraft, the Folke-Wulf 190, for reconnaissance raids during which a few bombs were dropped. Such raids demanded a special technique of interception. It appeared that a

[1] A.M. File S.6462/III, Encl. 13A.

[2] A.M. File C.S.11397, Encl. 4A.

[3] Appendix No. 15 gives a list of the stations.

[4] The decline of effort, and of fighter successes claimed, are shown in the following table:—

Month	*Enemy Sorties*	*Claimed Destroyed by Fighters*
June	3,525	27
July	2,417	26
August	1,796	3
September	1,386	8
October	1,413	11
November	1,165	7
December	794	3

[5] A.H.B. Narrative A.D.G.B., Volume III.

[6] A.I.C. 82.

DIAGRAM 21

Facing Page No.

control area far wider than that of the sectors was necessary, and secondly, that G.C.I. equipment would provide the most efficient tracking unit for the purpose, despite the fact that this type of station was not then part of the normal reporting system. An 'Area Control' system was evolved by the Operational Research Section in conjunction with Headquarters, Fighter Command operations staff. G.C.I. stations were linked to a special plotting room either at a group headquarters or a selected central point in which all the available information was displayed, and fighter controlling was carried out from there. This system was in existence by the end of 1941 but the procedure was as yet primitive. To develop it, exercises known as 'Quarries' were flown by Fortress aircraft, and interceptions were practised. The limitations imposed by the range of the early warning system and the rate of climb of fighter aircraft made defence against these high flying raids difficult in the extreme, and firmly established the necessity for the final fixed G.C.I. station, with its increased range.[1]

Use of C.H.L. Stations for Interception

Towards the end of 1941 the German low level minelaying and coastal attacks were the greatest cause of anxiety to Fighter Command. The inability of the Intermediate G.C.I. stations to effect interception below 5,000 feet and out to sea resulted in the increasing use of C.H.L. stations for interception control. In July 1941 Foreness C.H.L. station was fitted with a P.P.I. tube and used for fighter control.[2] A technique of close control of night fighters equipped with A.I. Mark IV had been developed there, and two enemy aircraft were destroyed during the month. In the following month Happisburgh C.H.L. Station, also equipped with P.P.I., made one successful interception. Headquarters Fighter Command intended to use this type of station in collaboration with a G.C.I. set in the early stages of an interception while the hostile aircraft was beyond G.C.I. range,[3] and on 25 October 1941, instructions were issued to Fighter Groups that at certain times during the night or day, C.H.L. and C.H.B. stations were to abandon their raid reporting duties and be used for fighter control.[4] By November five C.H.L. stations were equipped for this type of work, although lack of height finding equipment was still a severe limitation.[5] Further interception experiments under Fighter Command Operational Research Section supervision were carried out by No. 29 Squadron at Coltishall under C.H.L. control, and a method of interception out to sea was evolved by January, 1942. On the night of 14 January two A.I.-equipped Beaufighters each shot down a Dornier 217 aircraft on minelaying sorties in the environs of the Thames Estuary. The C.H.L. station at Foreness was the ground control in both cases.[6]

[1] A.I.C. 116.

[2] Fighter Command O.R.B. July 1941 and September 1941, Appendix 'O.'

[3] A.M. File C.S.12638, Encl. 3A.

[4] No. 60 Group File 60G/60/4/Ops, Encl. 12A.

[5] These five stations were :—
Bawdsey, Pen Olver (Cornwall) and Kete (South Wales) each working with a neighbouring G.C.I. station and supplementing its information; Foreness and Happisburgh working quite independently.

[6] Fighter Command O.R.S., Report No. 307. A.H.B. II/39/2. A.M. File S.6848, Encls. 83A and 82A. Appendix Part I, Serial Nos. 12 and 13.

In April 1942 the number of C.H.L. stations to be used for aircraft interception purposes was further increased.[1] This measure proved not altogether satisfactory because the interception duties of C.H.L. stations entailed the sacrifice of continuous raid reporting. The complication was all the more embarrassing because, by an agreement made during the invasion threat of the previous year, the stations were also responsible to the Royal Navy and the Army for providing information of coastal shipping.[2] Upon the Group Commander of the stations concerned lay the responsibility for deciding whether he could afford to sacrifice raid reporting to obtain interception control whenever the need arose. The implications of using coast watching stations for controlling purposes had recently been made evident during a raid by six German bombers on Aberdeen, on which very scanty information had been given by the neighbouring C.H.L. station at Cocklaw because it was busy keeping track of a defensive fighter aircraft. One solution to the problem was the installation of a second equipment to be used entirely for aircraft reporting, but the supply of new sets was constantly being diverted to overseas theatres and very few were available for use at home.

In August 1942 an examination of the value of C.H.L. stations for interception showed that they had been responsible for only three night combats below 5,000 feet, which scarcely justified the effort entailed by their use. The provision of controllers and operating crews was becoming more difficult. Landline resources, too, were severely strained. The installation and maintenance of the C.H.L. stations used solely for interception purposes made an additional call on the efforts of No. 60 Group which already had to face a heavy task in improving the existing radar chain and installing the final G.C.I. stations. Finally, there was the interruption of the normal reporting function of the C.H.L. stations to be taken into account. The Air Officer Commanding-in-Chief, Fighter Command, therefore reduced the number of C.H.L. stations to be used for controlled interception from nineteen to nine.[3] Two of these, Happisburgh and Foreness, were taken over as G.C.I. stations ; the remainder continuing to be the responsibility of No. 60 Group, but available on demand for controlled interception.[4]

[1] A.M. File C.S.12638, Encl. 22A. The C.H.L. stations were :—

Stations already in use for interception		*Stations to be used for interception*	
Foreness	Cocklaw	Walton	Bolt Tail
Swingate	Kete	Dunwich	Worth Matravers
Happisburgh	Marks Castle	Goldsborough	The Needles
Easington	Pen Olver	Cresswell	Bembridge
		South Stack	Beachy Head
		Kingswear	

[2] The triple Service responsibilities of C.H.L. Stations in a reporting capacity are explained in Volume IV, Chapter 15.

[3] The C.H.L. stations to be used for interception purposes were :—

No. 10 Group	No. 12 Group
Kete	Happisburgh
Kingswear	Easington
No. 11 Group	No. 13 Group
Foreness	Goldsborough
Beachy Head	No. 14 Group
Swingate	Cocklaw

[4] Although direct control from radar stations did not provide a solution to the problem of the wave-hopping raider, the matter was not abandoned entirely. Every effort was made to improve the raid reporting/operations room control system. This has been described fully in Volume IV. (Fighter Command Operations Research Section File, O.R.S./9/1/1005.)

G.C.I. Operations

From October 1941 to March 1942 there had been comparatively little enemy air activity over Britain, the Germans having limited their operations to anti-shipping raids and mine-laying off the coast, with here and there a low level raid on some east coast targets.[1] During the early part of 1942 one of the main obstacles to the achievement of successful combats was the lack of an efficient identification system.[2] The following combat report from the Fighter Command Interception Summary of March 1942, typical of this phase, illustrates the circumstances to which this might lead :—

> 'While under G.C.I. control three contacts were obtained and one visual without information from the ground. Two of the contacts showed I.F.F. and the visual was a friendly bomber. The third contact was well below and just inside maximum range. Correction given hard to port and down 3,000 feet. Before instructions could be followed, contact lost hard to port and still inside maximum range. Ground had no help to offer.'

It looked as though the G.C.I. controller were to blame. When the report was investigated it was found that the night fighter's I.F.F. set had not been working, and in consequence the controller had no idea which of the many 'blips' on his tube represented the aircraft he was trying to vector. The result was misunderstanding and very probably irritation on the part of the pilot. Pilots were strongly advised, when such incidents occurred, immediately on landing to find out the cause of the apparent inefficiency of the ground control. By so doing they learned of the difficulties which controllers had to face, and controllers in their turn would understand the irritation which pilots felt when they thought they were not receiving proper attention from the man on the ground.

Another important factor was close co-operation between sector controller and G.C.I. controller.[3] A good G.C.I. controller could conduct quick interceptions provided he was 'supplied' with fighter aircraft correctly positioned for him by sector Control. This was shown by the excellent results obtained by a controller at Exminster G.C.I. station on the night of 4/5 May 1942 during an attack on Exeter. Three Beaufighters of No. 307 Squadron were in the air, and with these three aircraft the controller made twelve attempts to intercept enemy aircraft. Twelve A.I. contacts were obtained, resulting in six visual sightings and four enemy aircraft destroyed. The first successful interception took 15 minutes from start to close, the second $4\frac{1}{2}$ minutes, the third $2\frac{3}{4}$ minutes and the fourth $5\frac{1}{2}$ minutes ; an average of 7 minutes per interception. The attack of Exeter was one of the series of 'Baedeker raids' against English cathedral cities which occurred between April and July 1942. The Germans lost heavily and the series of raids was perforce brought to a close. No further raids by heavy bombers were experienced until 1944.[4]

G.C.I. Controlling

During the whole of 1941 and 1942 the steadily increasing number of G.C.I. stations both in the United Kingdom and overseas caused a persistent shortage of qualified controllers. During 1942 alone, forty-eight officers were posted

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[1] Fighter Command, O.R.B., September 1945, Appendix P.

[2] A.M. File S.6848, Encl. 85A.

[3] *Ibid.*, Encl. 86A.

[4] A.H.B. Monograph *The Rise and Fall of the German Air Force*. A.M.P. 248.

from Fighter Command, and thirty-six of them were for special operations for which experienced men were required. The training programme did not overtake the growing demand until the middle of 1943, by which time eight schools were open at certain G.C.I. stations and a preliminary course was running at the Controllers Training Unit in Fighter Command.[1] Schools were also set up for training G.C.I. crews, and special attention was paid to methods of finding height which were different in the mobile and in the later 'final' equipment. The technique of controlling developed into three principal methods, used according to the type of aircraft, the mark of A.I., or other circumstances.[2]

R.T. procedure used by G.C.I. controllers was more informal and individual than the standardised pattern used in sector operations rooms. The manner and atmosphere was that of a close and confident liaison between the pilot and the controller, as if the latter were actually projected into the aircraft and sitting just behind the pilot's shoulder. A typical G.C.I. interception would usually begin something like this :—[3]

Fighter : Hullo, Seecut, Seecut. This is Cantab two-nine. Over.
G.C.I. : Hullo, Cantab two-nine. This is Seecut. Port two-four-zero, angels eleven.
Fighter : Two-nine two-four-zero, angels eleven.

The controller has already established the identity of both fighter aircraft and enemy from his P.P.I. tube. Having put his fighter in the right direction he then proceeds to tell him as much as possible about the enemy aircraft.

G.C.I. : Hullo, two-nine, I have a bandit for you. He is about twenty miles away, flying west.
Fighter : Understand bandit.
G.C.I. : Bandit's angels are about ten. He is south-east of you now. I will try and bring you in from the south.
Fighter : Roger.
G.C.I. : Bandit's course is about three-two-zero.
Fighter : Understand bandit's course is about three-two-zero.
G.C.I. : I will let you have his speed as soon as possible.
Fighter : Roger.

After further similar instructions the controller brings his fighter aircraft within A.I. range of the bandit.

G.C.I. : Bandit's range two miles.
Fighter : Roger.
G.C.I. : Port, three-zero-zero.
Fighter : Three-zero-zero.
G.C.I. : One and a half miles dead ahead.
Fighter : Contact. (Radar response observed by pilot.)
G.C.I. : Judy. (Controller hands over interception to pilot.)

[1] Progress Report by A.O.C.-in-C., Fighter Command, on the development and results obtained in night interception for the period up to 16 September 1943. N.A.D. (43) 9, 16 September 1943.

[2] These were :—

(a) The Curve of Pursuit Method.
(b) The Cole Mark IX Protractor Method.
(c) The point 'D' Method.

Elementary principles of G.C.I. control, H.Q.F.C., A.H.B. IIE/213.

[3] In this outline of the R.T. control used, 'Seecut' is the G.C.I. station call-sign, 'Cantab 29' is the aircraft call-sign. 'Angels' was the R.T. code word for aircraft height in thousands of feet. 'Bandit' meant enemy.

Disadvantages of R.T.

This highly convenient method of control by direct speech unfortunately suffered from several serious disadvantages. It was not a secure system since it offered a radio broadcast commentary on air operations and it was vulnerable to interference. Before the end of 1941 a Spitfire fitted with V.H.F. homing apparatus could home to R.T. transmissions from other aircraft and ground stations from ranges up to 100 miles.[1] As soon as the enemy had similar equipment there was thus an increased element of risk to talkative pilots. The main weakness of radio telephony, however, was that it provided the enemy with valuable intelligence. The interception of R.T. revealed :—

(*a*) The fact that aircraft were operating.

(*b*) The nature and intention of the air activity.

(*c*) The position, course and speed of aircraft.

(*d*) The position of the R.T. ground stations.

(*e*) Information of technical developments, frequencies used and the organisation of fighter control.

(*f*) The tactical methods and the interception technique.

(*g*) Warning of impending attack.

(*h*) Information for building up the Order of Battle, the numbers and location of aircraft and the movements of squadrons.

The Allies and the Germans were well aware of the dangers and shortcomings of radio communications and both sides adopted measures to exploit the defects of the system and to minimise the risks. The chattering pilot or radio operator was a very real menace since he laid himself open to attack and unwittingly gave information to the enemy. General Martini, the Luftwaffe Director General of Signals has stated that his staff often repeated a catch-phrase : 'aller funkverkehr ist landersverrat' . . . 'all radio traffic is treasonable'.[2] The Germans established an R.T. interception service to make immediate tactical use of our fighter R.T. transmissions. When the usual R.T. chatter of our A.I. night fighters and controllers indicated readiness to attack a German aircraft, the latter would be warned by a simple code signal to take violent evasive action.[3] This was evidently the cause of many disappearing A.I. contacts experienced by our night fighters. The Royal Air Force likewise made good use of the normal and indiscreet communications of the Luftwaffe. One example will suffice. No. 382 Wireless Unit of 83 Group 2nd T.A.F. was credited with the provision of information from enemy R.T. leading directly to the destruction of 95 enemy aircraft during the eight weeks from D Day.[4] It is therefore obvious that only the most prudent and guarded use of radio and radar facilities can prevent their being of great assistance to the enemy.

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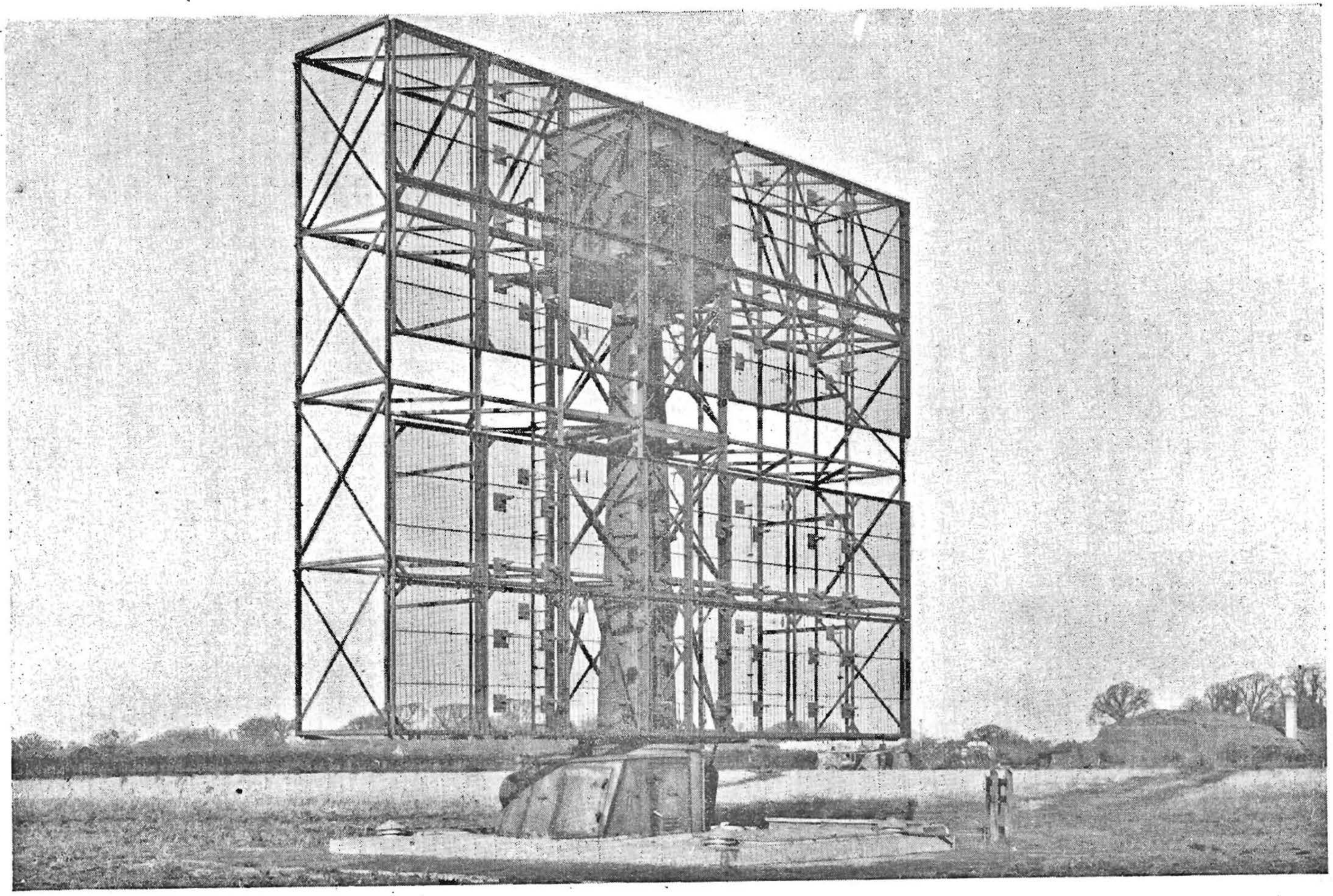
[1] A.I.C.83. 31 Dec. 1941.

[2] *See* Volume VII Radio Counter-Measures. Chapter 14.

[3] Interrogation of German W/T operator shot down 7/8 July, 1942. No. 8 S.O.R. File M.S./5661/8 S.O.R. A.H.B.II/J5/88/27.

[4] A.E.A.F. File T.S./16514/Int.



G.C.I. Fixed Station Rotating Aerial (Type 7)

CHAPTER 13

RADAR CONTROL IN DEFENCE

By the middle of 1941 sufficient experience had been gained with the first mobile G.C.I. stations to form an idea of the ultimate operational requirements for night interception. Whilst the intermediate stations were being installed, the building of a chain of 'final' fixed G.C.I. stations was begun. This was to be the basis of a night air defence system capable of dealing with concentrated bombing attacks such as those experienced in the previous year. At a meeting at Headquarters, Fighter Command, on 17 June 1941, Dr. Taylor put forward proposals for multiple controlling, more reliable height finding, and ability to discriminate between different levels of activity.[1] Despite every effort to depart as little as possible from the original design, it was inevitable that some development would be required. A modest estimate of six months was made.

Development of A.M.E.S. Type 7

The chief operational disadvantage of the mobile and transportable stations was their inability to deal with more than one interception at a time. It was feared that intensive bombing by large numbers of aircraft might well result in the percentage of losses being too small to act as an effective deterrent. Multiple controlling was therefore an important requirement for the A.M.E.S. Type 7, as the 'final' fixed G.C.I. was called, and a display arrangement was needed to allow one controller to supervise the work of two deputy controllers, each performing separate interceptions.[2] The Type 7 was also required to give the senior controller a reliable picture of the general trend of hostile activity, and in particular heavy activity which would demand reinforcements of night fighter aircraft from the sector. In addition to its primary function of interception the new G.C.I. station was to act as part of the radar reporting system, supplementing with greater accuracy the Royal Observer Corps information of high flying enemy aircraft overland, especially at night. It was to have gap filling and improved range at low angles. Accurate height finding at long range and at low angles of elevation was also required.[3]

On 8 September 1941, the Air Officer Commanding-in-Chief, Fighter Command, stated his requirement for twenty-one fixed G.C.I. stations.[4] On 4 November 1941, he stated that it was essential for twelve stations to be operational by April 1942, and the balance by June 1942. This target date proved unattainable. A great research and production effort was necessary to put such equipment into service, and it is doubtful whether it could have been done by the date mentioned even had the full and undivided resources of the Telecommunications Research Establishment been available. Conversion of the existing G.C.I. chain

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[1] A.M. File S.6462/11, Encl. 147A.

[2] A.M. File S.43174/II, Encl. 75A.

[3] A.M. File C.S.11186, Encl. 1A. *See* Appendix No. 16 for Operational Requirement in full.

[4] *Ibid.*, Encl. 18A.

to the intermediate stage was, however, already a large task. More important still, the decline of the German bomber effort against the United Kingdom during the second half of 1941 served to reduce the urgency for stronger night defence, and greater priority was given to radar equipment for offensive use.

On 2 April 1942, the Vice-Chief of the Air Staff adjusted the requirement to thirteen stations by November 1942. The Director of Radar examined the position and reported that research work was not yet complete on the experimental station at Durrington. For this reason, development work on the production model of the equipment had been delayed and manufacture, naturally, was at a standstill. Six weeks later, on 27 May, the Director of Radar indicated that only seven fixed stations could be completed by the end of 1942. The Air Officer Commanding-in-Chief, Fighter Command, registered his dismay at this evidence of further tardiness in a programme which had been agreed to as vital for the defence of the country.[1] At a special meeting of the Chain Executive Committee held on 8 June 1942, a new programme for providing thirty fixed G.C.I. stations in addition to Durrington and Sopley was prepared.[2]

Delays in Production

The prototype fixed station at Durrington was used operationally for the first time on the night of 9/10 June 1942. On the following night enemy minelayers were in action off the Isle of Wight, and one was shot down by an aircraft of No. 219 Squadron under control of the new equipment. As a result of preliminary training, the crew and their improved apparatus worked smoothly from the start, but experiments with the method of displaying aircraft tracks on the map tables were still going on. It was satisfactory as long as the density of the raids was low, but the small P.P.I. tube, at which only one person could work, was the limiting factor. On 17 July 1942 the Director of Radar again revised his estimate of the fixed G.C.I. programme to six stations operational by the end of 1942, and a few weeks later, on 5 August, the Ministry of Aircraft Production confirmed this number, and stated that the remaining twenty-six stations were expected to be in operation by the end of June 1943. Two months later, however, the Ministry forecast that only three stations would be working

[1] A.M. File C.S.11186, Encl. 94A.

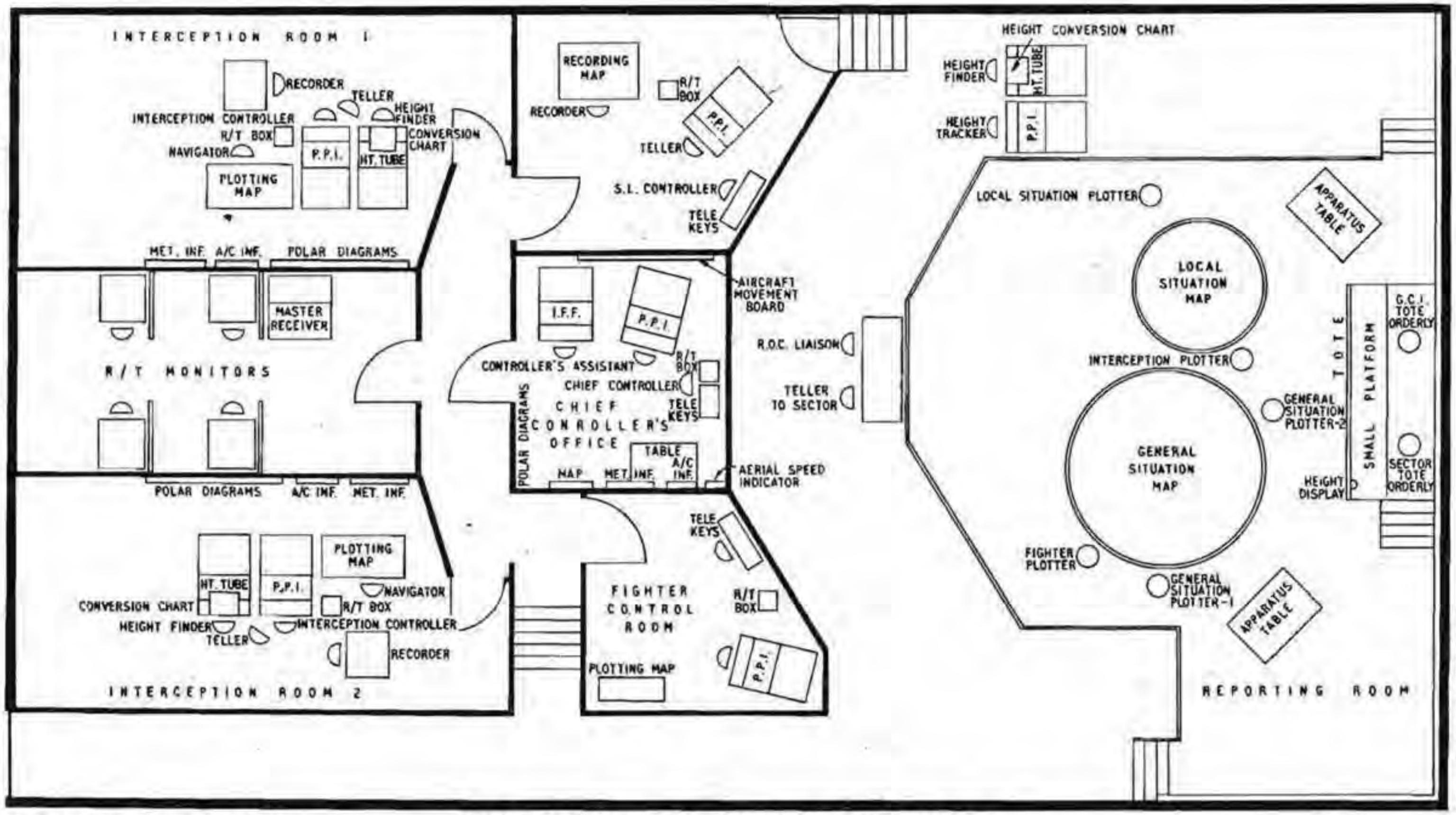
[2] The programme for the thirty final G.C.I. stations consisted of the following stations :—

Station	*Proposed Date*	*Station*	*Proposed Date*
Trimley Heath	21.11.42	Northstead	22.5.43
Neatishead	19.12.42	Hack Green	29.5.43
Ripperston	16.1.43	Longload	5.6.43
Patrington	23.1.43	Cricklade	12.6.43
Exminster	13.2.43	Dirleton	19.6.43
Trewan Sands	20.2.43	East Hill	19.6.43
Orby	6.3.43	St. Annes	26.6.43
Treleaver	27.3.43	Fullarton	26.6.43
Langtoft	3.4.43	Russland	3.7.43
Wrafton	10.4.43	Ballywoodan	10.7.43
Comberton	17.4.43	Ballinderry	17.7.43
Sandwich	24.4.43	Staythorpe	17.7.43
Hope Cove	1.5.43	Roecliffe	24.7.43
Seaton Snook	8.5.43	Dunragit	24.7.43
Wartling	15.5.43	King Garth	24.7.43

A.M. File C.S.17047, Encl. 7B

Facing Page No.

DIAGRAM 23



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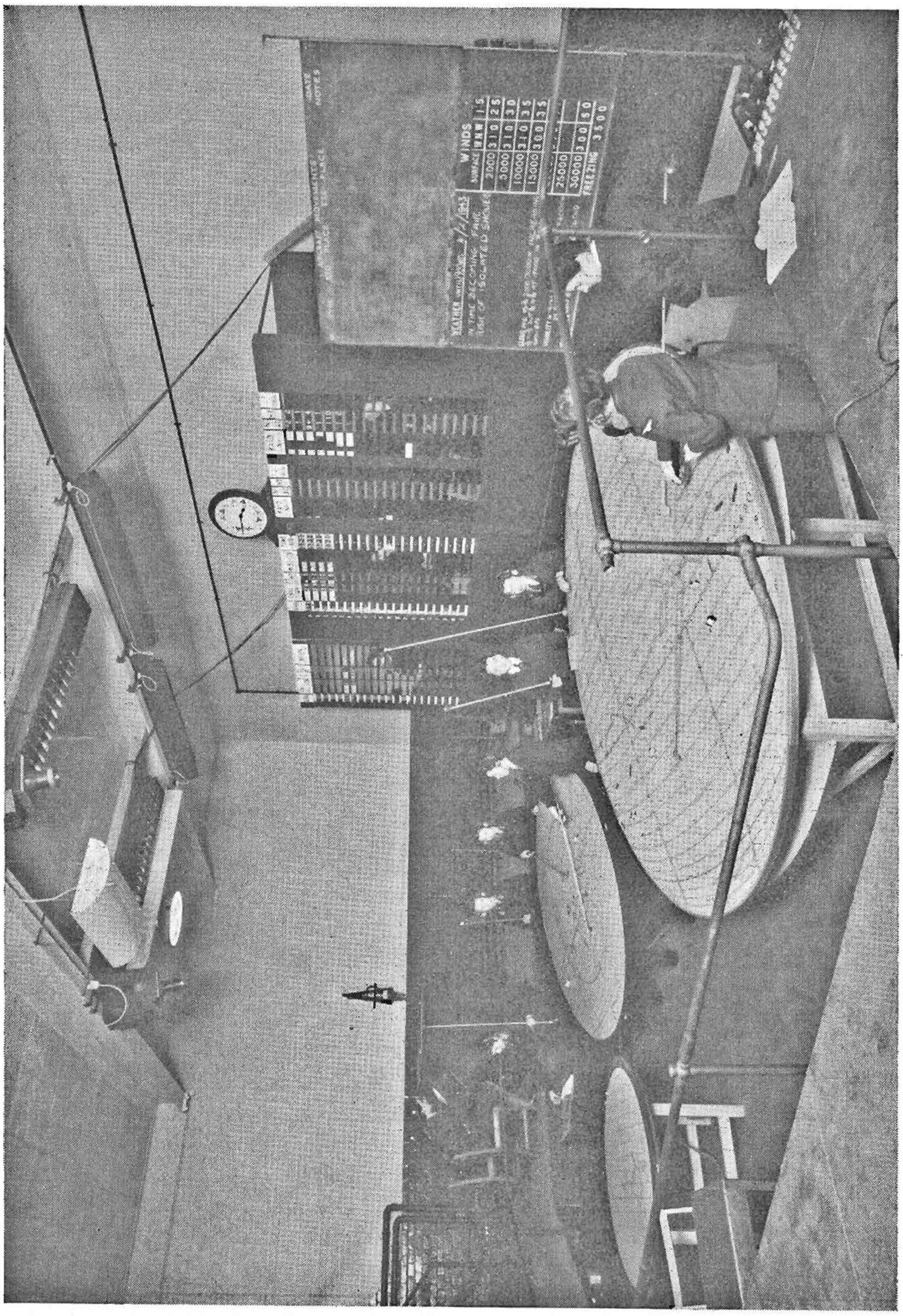
A.M.E.S. TYPE 7 - FINAL G.C.I. LAYOUT OF OPERATIONS ROOM



G.C.I. Reporting Room

(C36397) I

by the end of 1942, and that the thirty-station programme would not be completed until the end of September 1943. The rate of progress now began to bear little relation to the target dates, and the Director of Radar called upon all authorities concerned to try to stick more closely to the programme.[1]

At the 26th Meeting of the R.D.F. Chain Executive Committee C.H.L./G.C.I. Working Sub-committee on 26 October 1942, some of the reasons for the protracted delay were explained. The design of the Mark VI receiver had given much trouble, and the final pattern was not approved until September 1942. Certain essential components of the G.C.I. equipment had been diverted to undertakings of higher priority. Further delay had occurred because the design of both technical and operational details was still going on at the prototype station at Durrington. The attempt to manufacture a number of stations according to a prototype which was still not in definite and final form was resulting in great waste of effort, and successive modifications were being introduced during the process of manufacture. There was no time to prepare specifications to enable engineers to repeat the improvements at other stations, and no instructions existed for the guidance of R.A.F. maintenance personnel at completed stations. 'Modifications being asked for,' wrote the Director of Radar, 'involve alterations to height signalling equipment which the contractors cannot apply in less than six or nine months. All this emphasises the need for stabilising the design now, if progress and reliable maintenance in service are to be achieved. There is a real danger of indefinite delay if this process is continued.' Building and construction work was hastened at most of the projected stations, but when the whole scope of production had been examined in detail, it was reluctantly agreed that only two fixed G.C.I. stations could possibly come into operation by the end of 1942 in addition to those at Durrington and Sopley.[2]

Reduction of Priority

By the end of 1942 it had become clear that the full fixed G.C.I. programme was beyond the resources which could be devoted to it. 'The original programme,' stated the Air Officer Commanding-in-Chief on 19 December 1942, 'which had called for the provision of thirty-one fixed G.C.I. stations was conceived during a period of intense enemy activity. The situation had now changed and it appeared unlikely that the enemy would deliver large scale night attacks on this country for some time to come. Owing to the acute shortage of manpower, and the need for men in other branches of the Services, as well as in the factories, a datum line must be fixed as the safe low limit on which the United Kingdom's night defences can operate. It is therefore necessary to decide on our minimum requirements both in equipment and personnel and to ask for this and no more.'[3] At the meeting which followed, it was decided to curtail the construction and installation of 'Happidromes,' as the fixed G.C.I. stations came to be nicknamed, and the total of thirty-one was

[1] A.M. File C.S.17047, Encls. 10A, 16B and 18A.

[2] *Ibid.*, Encls. 20A, 22A, 26A and 28A.

[3] *Ibid.*, Encl. 31A. The A.O.C.-in-C. Fighter Command was then Air Marshal T. L. Leigh-Mallory.

reduced to twenty-one.[1] A reduction was also made in the total number of all types of G.C.I. stations in operation. Five of the thirty-nine G.C.I. stations then operational were to be put on a care and maintenance basis or removed completely.[2] Of the remaining thirty-four G.C.I. stations, twenty-one were to be Happidromes, and thirteen were to be either intermediate or mobile. No new intermediate stations were to be built, but those on which work had been started were to be completed.

Consôles Types 8 and 9

The display equipment for the G.C.I. Type 7 was an even later starter than the main equipment. It did not, in anything approaching its final form, start at all. This was particularly disappointing because the simultaneous control of four aircraft was an essential part of the plan for the Type 7 station. In July 1941 the operational requirement for an improved type of control console had been proposed as follows :—[3]

(*a*) A means should be provided by which one controller could carry out two interceptions simultaneously.

(*b*) This could best be achieved by providing means by which the fighter and bomber signal in respect of each interception should be selected from the remaining echoes and displayed as points of lights upon maps (one for each interception). The points of light in moving would leave their tracks behind them on the maps and the successive positions of these points of light should be left as a permanent record on the map, *i.e.*, the track of the aircraft should be displayed by illumination.

(*c*) In addition to the track display for each interception there should be provided a course display on which the speed and direction of the wind should be added to the tracks to give the course. On this presentation the point of light representing the target aircraft should have displayed around it the projection of a protractor, the controller being given a simple control for orientating the protractor in accordance with changes of course by the target aircraft.

(*d*) A normal P.P.I. display should be visible to the controller.

The original conception of the complete display equipment was two such consoles, operated by deputy controllers and driven from the principal P.P.I., where an automatic height strobing unit would give the necessary height discrimination. On 27 April 1942 contract action was taken for the supply of sixty consoles Type 8 to be installed at the thirty fixed G.C.I. stations.[4] A P.P.I. unit which was generally understood to be the ' first half ' of the console Type 8 was installed at Durrington and used for single interceptions only. The results obtained were promising to the extent that the task of controlling was facilitated, permitting a less experienced or less highly trained person to direct

[1] The Happidromes to be cancelled were Ballinderry, East Hill, Staythorpe, Roecliffe, Russland, Dunragit, Fullarton, Longload, St. Annes, and Cricklade. A.M. File C.S.11186, Encl. 110A.

[2] The stations to be reduced to care and maintenance were Ballydonaghy, Lisnaskea, Dunragit, King Garth and Foulness. A.M. File C.S.17047, Encl. 31A.

[3] A.M. File C.S.14108, Encl. 20A.

[4] *Ibid.*, Encl. 9A.

interceptions successfully. The intention of console Type 8 development was an increase of the capacity of the system and a reduction in the amount of skill required for controlling. However, although the technique required less skill on the part of the controller himself, it imposed increased responsibility on the two airmen who, in order to provide the controller with his information, maintained markers on the fighter and target for each interception. This proved to be a great handicap when activity was intense, especially when Window was used by the enemy. In such circumstances the senior controller would undoubtedly wish to observe the radar display himself.

Further trials were made in March 1943, although the automatic height strobing unit had still not been installed. Two simultaneous interceptions were practised successfully by day, but no attempt was made by night because of the shortage of aircraft. The Air Officer Commanding-in-Chief, Fighter Command observed that the number of staff employed for a double interception was actually one less than that employed for a single interception using the normal apparatus. Bearing in mind the need for the strictest economy, he reduced the number of fixed stations at which two consoles Type 8 were to be installed to eight.[1]

Meanwhile, the extreme difficulties, both mechanical and optical, of designing the complete console Type 8 had become clear to the Ministry of Aircraft Production, and on 5 January 1943 the Director of Radio Production expressed the hope that Headquarters, Fighter Command, would cancel all provisioning.[2] On 4 September 1943 the Director of Communications Development admitted that the design of the console Type 8, and of the height strobe in particular was not complete. He recalled that it was now two years since the requirement was formulated and that completion of production was still a long way off. Much effort was required for the project, and in the meantime the use of Window against the G.C.I. Type 7 might well render the effort nugatory. The drive to install a centimetre wavelength G.C.I. equipment for use against Window had already begun. In the circumstances it was therefore decided to abandon the development of the console Type 8 which was in a far from finished state. Not only was the height strobe lacking, but the two subsidiary P.P.I. tubes, to be known as consoles Type 9, were still unfinished. All that had in fact been achieved was the production of twelve optical units Type 1, a form of improved P.P.I.[3]

By January 1943 three fixed G.C.I. stations were complete at Durrington, Sopley and Neatishead.[4] Their high coverage, over 10,000 feet, was by far the best of any G.C.I. equipment during the war, but cover below 5,000 feet was still not satisfactory. The stations had the same characteristics as the mobile G.C.I. stations in their dependence on site and vulnerability to jamming. It was not possible to assess their performance in high raid densities for which they were originally designed because mass raids never occurred after the stations were completed. By October 1943 twenty of the twenty-one fixed

[1] A.M. File C.S.14108, Encl. 41A.

[2] A.M. File C.S.17047, Encl. 40B.

[3] A.M. File C.S.14108, Encls. 75A and 85A.

[4] Appendix No. 17 gives the revised G.C.I. station programme.

G.C.I. Interception Cabin

G.C.I. stations were completed.[1] Generally they controlled at night, but if the weather was bad or the visibility poor they took over daytime control from sector operations rooms.

Searchlight and Fighter Pool Control

The improved controlling facilities available in the A.M.E.S. Type 7 made possible a closer co-ordination between different sections of the night air defence organisation.[2] Previously, it had been necessary for the sector operations room to control the pool of airborne fighter aircraft available for G.C.I. operations, and also searchlight-aided interceptions. Difficulties had arisen when transferring night fighters from one role to another and in co-ordinating the effort between them. Trials with the Type 7 showed the possibility of centralising the control of all these activities at the G.C.I. station, resulting in ability to engage a greater number of targets simultaneously.[3] Additional communications were required, but by September 1943 seven Type 7 stations were using the centralised system. The Air Officer Commanding-in-Chief, Fighter Command, reported favourably on the value of the system in March 1944.[4] Of the twenty-one Type 7 stations, twelve were by then provided with facilities for both fighter and searchlight control.[5]

Reserve G.C.I. Stations

During the installation of the Type 7 stations the need was felt to provide a reserve of interception controls against the possibility of serious damage to G.C.I. stations by bombing. In October 1942 a fresh attempt was made to use C.H. stations for interception, but trials at Pevensey confirmed their unsuitability in this role.[6] It was then decided to make use of the mobile G.C.I. stations rendered redundant by the installation of the intermediate and final

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[1] R.D.F. Equipment (Ground) Policy Memorandum, October 1943. A.H.B. II/69/93. A report on the Operations Rooms of the Fixed G.C.I. stations is given at Appendix No. 18.

[2] Searchlight-aided interceptions were carried out by night fighter aircraft equipped with A.I. The pilot orbited a beacon until the code word 'Trade' from the controller indicated that enemy raiders had entered the searchlight belt. The searchlights used a radar searching device and illuminated the enemy aircraft by a cone of beams. On sighting one of these cones the pilot would make for it, reporting his movement to the controller by the word 'Gauntlet". Having received permission to carry on from the controller, if no other aircraft was in the vicinity, the pilot carried out the search and subsequent interception by the aid of his A.I. alone. Fighter Command Ops. Instr. No. 35/43. A.H.B. IIH1/64B.

[3] Progress Report by the A.O.C.-in-C., Fighter Command, on the development and results obtained in night interception for the period 1 December 1942–28 February 1943. N.A.D. (43)1, 12 March 1943.

[4] Air Marshal Sir Roderic Hill.

[5] N.A.D.(44) 2nd Meeting, 2 March 1944. An analysis of the results over three months showed the following figures :—

Method Used	*No. of attempted Interceptions*	*No. of Enemy Aircraft Destroyed*
G.C.I. Stations	481	36
Searchlights	254	14
G.C.I. and Searchlights	105	5

Stations to be fitted with searchlight as well as fighter control facilities were Patrington, Orby, Neatishead, Trimley Heath, Wartling, Langtoft, Durrington, Sopley, Exminster, Comberton, Hack Green and Ballywoodan. A.M. File C.S.17047, Encl. 90A.

[6] Fighter Command File S. 19812, Encl. 11A.

A.M.E.S. Type 11 Aerial Vehicle

types. Out of a total of twenty-three available by May 1942 ten were retained in reserve by Fighter Command, and thirteen were handed over to Anti-Aircraft Command. Others were transferred to the Royal Navy towards the end of 1943. Another radar set used as a reserve was the A.M.E.S. Type 19, working on 250–300 megacycles per second, which it was thought would be useful if German jamming on 209 megacycles per second persisted.[1] The plan was proposed in January 1942 but the falling off in priority resulted in only three stations being complete by 26 March 1944.[2] These were allotted to Sandwich, Trimley Heath and Wartling, but by this time the chief jamming threat was from Window, and the Type 19 equipment was converted for use in the manufacture of centimetre wavelength equipment.

A.M.E.S. Type 11

Fear of enemy jamming in the 1½ metre band where all G.C.I. equipment was concentrated led to the introduction of the Type 11 working on a wavelength of 50 centimetres, because the fact that the Germans were also operating radar equipment on that wavelength was considered to make the chance of jamming remote.[3] Research on decimetre radar was sufficiently advanced to be applied to ground control equipment by the end of 1941, and in January 1942 six Type 11 stations were ordered urgently. To facilitate the avoidance of jamming the set was vertically polarised. It gave plan position indications up to 60 miles radius, but height finding facilities were not available.[4] A few models of a 50 centimetre set for height finding were therefore especially constructed as an interim measure. These were known as the Decimetre Height or D.M.H. equipment and operated in the same wave band as the Type 11. The new height finding equipment, the D.M.H. Mark II, employing horizontal polarisation, was tunable between the wider limits of 500 and 600 megacycles per second.

On 29 April 1942 three mobile Type 11 sets were installed at the C.H.L. stations at Swingate (Dover), Foreness and Beachy Head. It was intended to instal Type 11 sets at all C.H.L. stations from the Needles in the west to Bawdsey in the east, and by December 1942 three more equipments were established at Fairlight, Ventnor and Truleigh Hill C.H.L. stations. A rigid restriction of transmission was enforced to prevent the Germans discovering their existence.[5] In October 1943 the siting plan was changed to meet the Window jamming threat, the intention then being to place Type 11 sets alongside the G.C.I. stations, beginning with Durrington, Wartling, Blackgang, Trimley Heath, Sandwich and Sopley.[6] Another set was placed at Dimlington in the hope of intercepting minelaying aircraft off the Humber and of detecting low-flying intruders.[7]

The performance of the Type 11 was generally disappointing. There was one large gap in particular which could not be filled by any form of beam tilting and it had to be overcome by the less scientific method of lowering the aerial twenty inches by digging it into a trench.[8] The equipment required very careful handling and could easily be incorrectly set up. It subsequently came to

[1] A.M. File C.S. 13559, Encl. 1A.
[2] A.M. File C.S. 14192, Encl. 111A.
[3] I.C. 57. A.M. File C.S. 16651, Encl. 2A.
[4] A.M. File C.S. 16651, Encl. 3A.
[5] A.M. File C.S. 14132, Encl. 51A.
[6] A.M. File C.S. 17651, Encl. 25A.
[7] Fighter Command O.R.S. File 4/1/20, Encl. 9A.
[8] For siting brief of Type 11 and D.M.H. stations *see* Appendix No. 19.

light that the mean height above ground for which the aerial had been designed was not observed by the engineers when the aerial was erected on its allotted vehicle. Whatever the practical reasons may have been for this departure from design, it demonstrates the importance of continuous close liaison between scientists, engineers and operating staff. In general, the Type 11 did not have the opportunity to distinguish itself in fighter interception, aircraft reporting, or in its main role as an anti-jamming set. During the latter stages of the war, however, the set was included with various combinations of radar equipments as a standby. The development and production of the Type 11 later proved to be of enormous value when it became necessary at short notice to meet the specification requirements for radar Types 16 and 24.

German use of Window

The enemy first used metallised strips dropped from aircraft to jam radar stations in the United Kingdom on the night of 7/8 October 1943. The device was already known in the Royal Air Force as Window and was called *Duppel* by the Germans. Neatishead Fixed G.C.I. and Happisburgh C.H.L. station, both being used for radar control, were affected. The following extracts from a report give the impressions at the time of the observers at these stations.[1]

'At Neatishead at 2028 hours, indications were observed on the P.P.I. tube of aircraft travelling west corresponding to filter room tracks of some friendly bombers. At 2036 hours the number of echoes increased rapidly and by 2050 hours a considerable area of the tube was blanked out. Accurate control of fighter aircraft became practically impossible, I.F.F. could not be seen, and the height/range tubes were swamped. It was not observed for some time that the mass of echoes was stationary. At Happisburgh C.H.L. station too, an area raid of some 80 aircraft was seen on the tube, covering about 150 square miles and travelling at a speed of 180 miles per hour on course 280°. Individual aircraft were noticed at the southern leading edge of the area raid, at about five miles south of the main mass and travelling on a course of 340°. At approximately 2043 hours the raid had increased to about 200 echoes and split into two main parts, a northerly and southerly mass with a gap of six miles between them. Fighter aircraft were difficult to control because their I.F.F. was not visible through the interference on the cathode ray tube. One contact and a visual on a Stirling aircraft was obtained at 2059 by a night-fighter pilot who reported six A.I. contacts in all, only two of which did not fade. At 2125 hours it was realised that the mass was no longer moving, the echoes on the height/range tube were beating, and that while many echoes appeared to pass directly overhead, no sound was audible.'[2]

Some confusion occurred as a result of the first use of Window by the Germans and an exaggerated picture was shown in some operations rooms. Later raids caused less confusion and information was adequately filtered. On the night 15/16 November, when Window was first used in the Plymouth area, there was no exaggerated picture of the raid and the interference was easily recognised by the G.C.I. stations in the area affected.[3] The enemy used Window on three occasions during December 1943 but the quantity was insufficient to have any

[1] No. 8 S.O.R. File, M.S./5661/8 S.O.R. A.H.B. II J5/88/27.

[2] 'Beating' or 'flutter' were terms used to describe the rapid movement of echoes when in close proximity to one another. They were characteristic of Window effect.

[3] Annex to Minutes of 4th Meeting of reconstituted Air Interception Committee.

appreciable effect on $1\frac{1}{2}$ metre G.C.I. stations.[1] The Type 11 stations had been provided against just such a contingency but they were seriously affected by the German Window, which was dropped in 80 centimetre lengths.

An investigation of the effects experienced from Window dropping was made and instructions were issued to assist operators and controllers to continue to work through the interference. The chief points mentioned were as follows. It was considered impracticable to drop metallised strips of sufficient length to respond to the wavelength of C.H. stations, which would therefore be immune from their effects and would continue to give accurate numbers and heights to $1\frac{1}{2}$ metre and 50 centimetre stations in affected areas. A single aircraft dropping Window would be readily detected by the trail of stationary echoes which would break away and separate from the aircraft echo. Window dropped by a large number of aircraft together was more difficult to detect, but it could be recognised by the rapid ' beating ' on the range tube which was characteristic of the interference. Lack of movement, other than drifting with the wind, was another sign of Window. When a large area was being infected the most profitable plan was to try to shoot down the aircraft in the leading edge of the area provided that this was moving at flying speed, and to keep a sharp watch for stragglers and single aircraft which offered an easier target. The best method for a fighter to approach a Window area was from the windward side and from above, where the density was least. Once in the area the fighter should travel in the same direction as the enemy. The fighter should then ignore head-on contacts quickly approaching and concentrate on contacts which appeared almost stationary relative to his own movement.

In general, the use of Window by the Germans in the autumn of 1943 was not seriously detrimental to the defence because it was not dropped in sufficient quantity, nor had the dropping technique been properly developed. Furthermore, although German night activity showed some increase during October and early November 1943, 345 aircraft crossing the coast during 31 nights mainly to attack London, this could not be considered as a large scale exploitation of the new jamming technique. The destruction of 22 enemy aircraft was claimed by the G.C.I./A.I. organisation during this period, and of ten during November and December. Intruders had also been active previously in September. Seven of the 103 which made landfall were destroyed, but they succeeded in shooting down three British bombers and damaging four.[2]

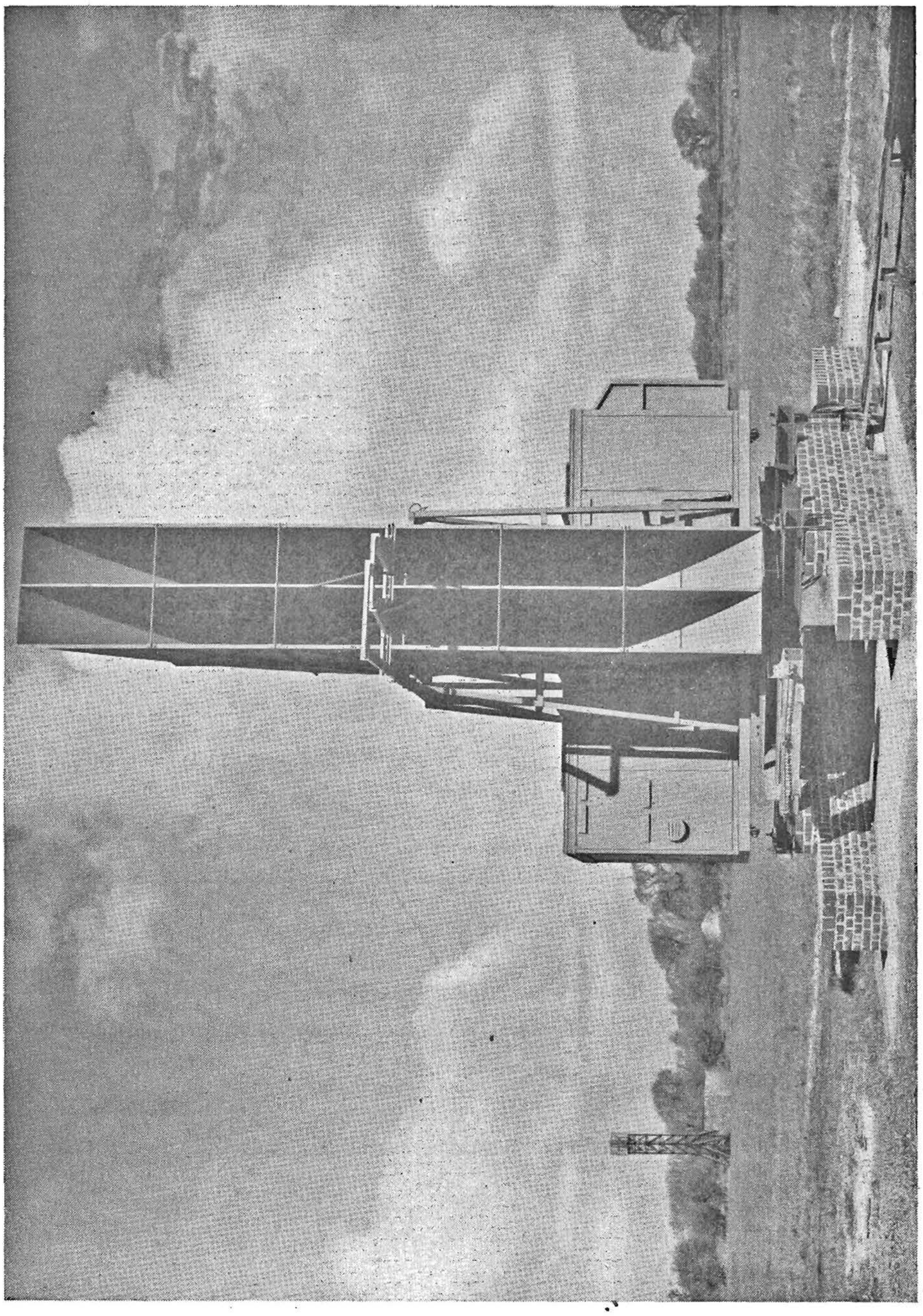
Centimetre G.C.I.

The German use of Window was, of course, a reaction to the use of Window by Bomber Command which began on 24 July 1943. The possibility of retaliation by the enemy had been carefully considered beforehand, and new radar sets on which the effect of Window was calculated to be small were already in production.[3] These were the A.M.E.S. Types 13 and 14 ground equipments and the airborne A.I. Mark X, all working on centimetre wavelengths. The sharp focusing of the beam of radiation which was possible with shorter wavelengths enabled these sets to concentrate with high discrimination on small segments of the sky, unhindered by interference being produced from other directions.

[1] Annex to Minutes of 5th Meeting of reconstituted Air Interception Committee.

[2] Annex to Minutes of 4th Meeting of reconstituted Air Interception Committee.

[3] N.A.D.(44) 1st Meeting, 24 February 1944.



A.M.E.S. Type 13

Development of the first A.M.E.S. Type 13 began in September 1942 as a mobile height-measuring instrument but it was not produced in quantity. An improved Mark II version known as the Centimetre Height or C.M.H. set was put into production in March 1943. It was one of the first equipments to use a fan shaped beam, 7½° wide in the horizontal plane and only 1½° in the vertical, produced by a reflector formed by a thin vertical slice of a parabolic mirror with sides of plane sheet metal, into which the radiation was fed through a horn-shaped wave guide. From its shape it was known as a cheese aerial. By rocking the beam up and down, great accuracy and discrimination in height finding was possible down to ½° elevation. This was the first set to give direct reading of height, and the value of the display, like that of the Plan Position Indicator, lay in cutting out the need for mathematical calculation when taking readings.[1]

The need for similar performance in reading plan position led to the development of the Type 14, in which a cheese aerial was also employed. The Type 14 aerial rotated in the horizontal position, and radiated a narrow vertical beam which swept through 360° in azimuth. A Type 13 and Type 14 together constituted an A.M.E.S Type 21. Production of the Type 21 started in June 1943 and the first set was completed by Christmas, by which time the Air Officer Commanding-in-Chief, Fighter Command, was anxious to see the anti-Window equipment in operation.[2]

The first Type 14 set was working at Sandwich by 18 January 1944 and the first Type 13 Mark II shortly afterwards. The second installation was placed at Wartling and by June 1944 most of the important fixed G.C.I. stations were equipped with Type 21 sets. It was found that the proportion of attempted interceptions resulting in enemy aircraft destroyed, or probably destroyed, during heavy Window activity was significantly higher when the Type 21 equipment was brought into use.[3] The greater success was apparent at all stages of interception, indicating that not only was it easier for the controller to vector the fighter aircraft into a position where A.I. contact could be made but also that these contacts were more easily brought to the visual stage.

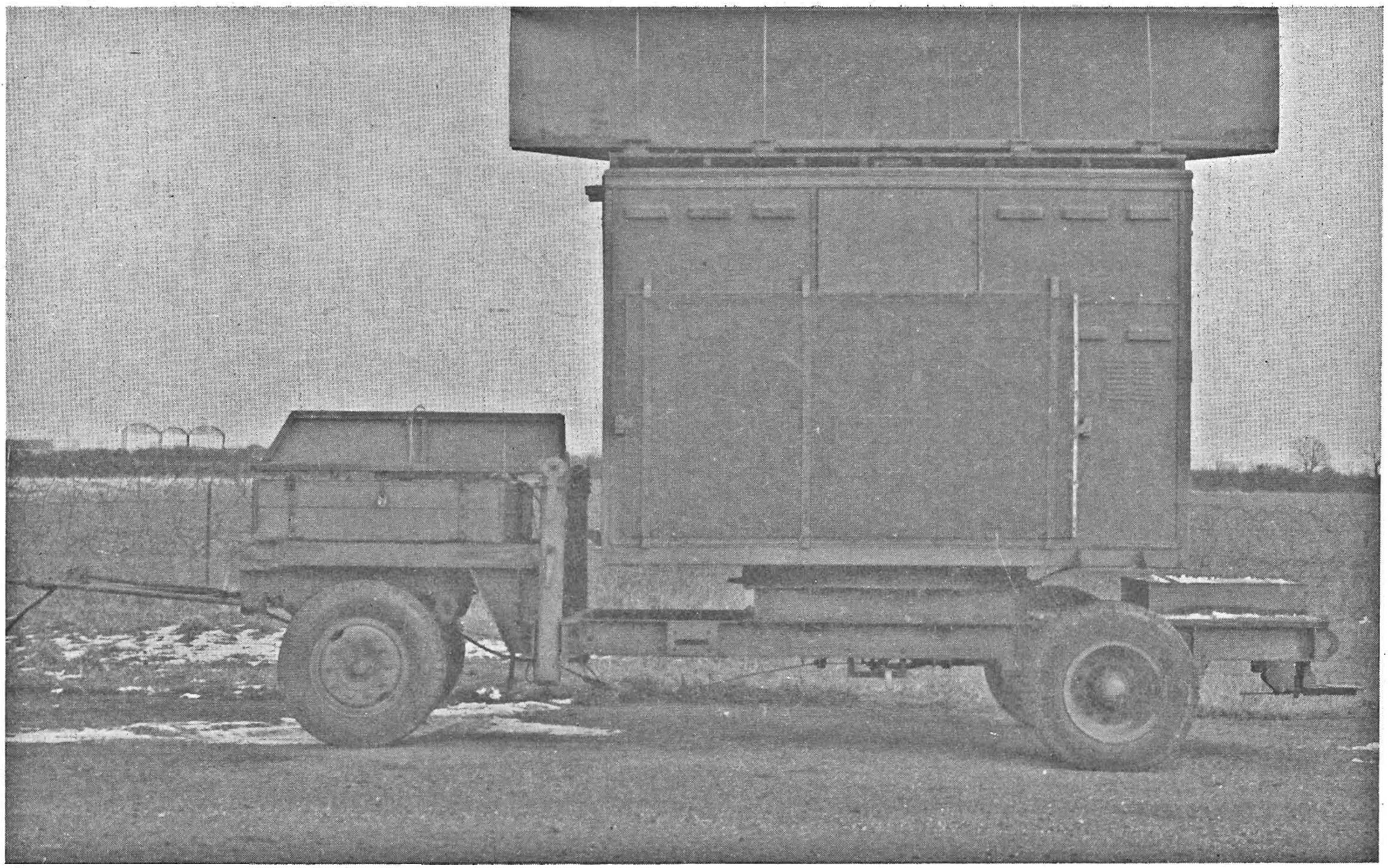
[1] A.M. File C.S. 15104/II, Encl. 1A.

[2] A.M. File C.S. 19327, Encls. 101A and 115A.

[3] The following table summarises all attempts during the period January 21/22–March 31/1 1944 in which controllers reported use of Type 21 equipment either alone or in conjunction with Type 7 sets.

Station	Type of Equip-ment	Attempts	A.I. Detec-tions	Visuals	Combats	Des-troyed	Prob-ables	Damaged
Sandwich	21	29	16	7	5	3	1	1
Wartling	21	4	3	2	2	2	0	0
Trimley ..	21	10	7	2	2	2	0	0
Neatishead	21	5	5	5	4	4	0	0
Hope Cove	21	3	3	1	0	0	0	0
Sandwich	11	1	1	0	0	0	0	0
Trimley ..	11	1	0	0	0	0	0	0
Durrington	20	17	7	3	2	2	0	0

(O.R.S. Report No. 59. A.H.B. IIM/A2/5B, Appendix O.)



A.M.E.S. Type 14 Mark II T Aerial Vehicle

The Type 21 equipments, however, were not entirely immune to interference by Window. One disadvantage of the Type 14 which soon became apparent was that the extent of its operational performance was somewhat limited since it did not provide such effective high cover, above 10,000 feet, as the Type 7. When Type 21 was employed with tactical air forces in mobile warfare this was not a serious disadvantage, since it was completely overcome by the use of Type 15 which not only gave the high cover required but also provided means for another simultaneous controlled interception and served as a standby.

The Little Blitz

Between January and June 1944 the Germans increased their night bombing against the United Kingdom to an intensity which was known as the Little Blitz. On 28/29 January the attack was estimated to be the heaviest since May 1941 and the accompanying Window had a serious effect on all G.C.I. equipments except C.M.H. sets. Fourteen enemy aircraft were destroyed by fighters under G.C.I. control during that month.[1] Over the whole period 144 enemy aircraft were destroyed, 21 probably destroyed and 30 damaged. For 20 combats there was no claim. On the average one claim was made for every eleven night-fighter sorties. The total number of German sorties was estimated at 4,500. By March the centimetre G.C.I. stations had come into successful operation but the effectiveness of the defence was lessened by the effect of German Window on 1½ metre G.C.I. stations and also by the use of a rearward looking radar warning device called *Neptun* carried by German bombers.[2] During the final six weeks of preparation for the landings in Normandy, the Germans employed 377 aircraft on spasmodic night raids over England. Twenty-two enemy aircraft were destroyed, six probably destroyed and five damaged. Little further German piloted air activity against the United Kingdom took place from that time up to the end of the war in Europe.

Ground-Launched Flying Bombs

New methods of fighter control were called for to meet the attacks on the London area by flying bombs launched from the Pas de Calais. 8,095 flying bombs were plotted during the whole period from 13 June to 6 September 1944, and out of a total of 3,752 destroyed, 1,904 were attributable to fighters and about 1,570 to gunfire.[3]

Two systems of fighter control were used, 'close' and 'running commentary'. The former system was employed for aircraft patrolling over the Channel, control being exercised at first from three coastal radar stations, the Type 16 being the most valuable for this purpose.[4] The 'running commentary' method was chiefly used for controlling fighter aircraft overland, and controllers were located at two Royal Observer Corps centres at Maidstone and Horsham, and at two radar stations. These controllers did not give vectors to the pilot, but transmitted simply the position and course of flying bombs, leaving the pilots to choose the best course for effecting an interception. A disadvantage of the

[1] Annex to Minutes of 8th Meeting of the reconstituted Air Interception Committee.

[2] *See* Volume VII, p. 53.

[3] A.D.G.B. Report, 13 September 1944, A.H.B. II/69/46.

[4] The development of the Type 16 station is described in Chapter 14.

running commentary method was the possibility of more than one fighter aircraft chasing the same flying bomb, thus wasting effort while other bombs slipped through. But the method was, on the whole, successful overland, where fighter aircraft were also helped by marker gunfire, by rockets fired by the Royal Observer Corps posts and Wireless Observer Units, and at night by searchlight beams. The accurate form of radar control developed for use against piloted bomber aircraft was unnecessary against flying bombs because their jet flame was clearly visible and their trajectory constant.

The pick-up range of the coastal radar stations was found inadequate, and the presence of friendly aircraft over France and the English Channel often made it difficult for radar operators to recognise the 'echo' of a flying bomb in time for an interception to be made. It became essential that the low-cover for interception purposes should be improved. The Americans had a most appropriate equipment in the Microwave Early Warning Set or M.E.W., which had recently taken part in trials at Start Point, Devon. Its long range, high discrimination and multi-control facilities were very suitable for both early warning and fighter direction against flying bombs, and the Americans agreed to lend it for that purpose until a similar equipment could be constructed in England. It operated with great success at Fairlight from 29 June 1944, one hundred and forty-two flying bombs being destroyed by aircraft under its direction. It was handed back to the United States Army Air Force for use on the Continent at the end of August 1944.[1]

A Type 26 set on similar lines to those of the M.E.W. was constructed at the Telecommunications Research Establishment. Like the M.E.W. it made use of the S-band to provide long range low angle cover and it combined facilities for early warning and for control of interception. The transmitter and aerial head were adapted from the American M.E.W. equipment, and the A.M.E.S. Type 24, a long range centimetre height finding equipment, was used in conjunction to give heights. The operations room contained five controller's positions. After 5 September 1944, the launching of flying bombs from the Pas de Calais ceased when the launching area was over-run by the Allied armies.

Air-Launched Flying Bombs

The loss of the Pas de Calais forced the German to rely on the air launching method for delivering flying bombs, which was continued over the North Sea by Heinkel 111 aircraft. Between 12/13 September 1944 and 13/14 January 1945, the period of air-launching, 881 flying bombs were plotted. 317 bombs were destroyed by gunfire and 70 by night fighter aircraft; 26 Heinkel 111 aircraft were also destroyed by night fighters.[2] To improve the fighter controlling facilities, the A.M.E.S. Type 26 and a Type 24 were moved from Fairlight to Greyfriars, near Dunwich, and became operational on 29 November 1944. This co-ordinated the effort for interception, over the sea, assisted by C.H.L. stations at Happisburgh, Hopton and Bawdsey. The Heinkels avoided operating in the moon periods, and evaded radar detection as far as possible

[1] Details of the origin of the M.E.W. equipment are given in Appendix No. 20. Further information is to be found in Volume IV, Chapter 25.

[2] Minutes of the Air Interception Committee.

by flying low, climbing to a few thousand feet for a brief period only to release their projectiles. Ship-borne control was attempted with H.M.S. *Caicos* but the positioning of the ship was restricted by minefields.

There was a need for a form of air-controlled interception, first contemplated in the spring of 1941 but abandoned in the following year. Trials were made in February 1945 with A.S.V. Mark VI installed in a Wellington aircraft, but results were disappointing, the maximum range averaging 14 miles and sea returns extending to seven miles radius when flying as low as 500 feet. Further trials were recommended with A.S.V. Mark X (AN/APS 15) in a Liberator aircraft, A.S.V. Mark XVII in a Warwick and H2S Mark IV modified to the extent of a 200 kw. transmitter and a six-foot aerial array. The trials were begun at the Central Fighter Establishment, but there was no time to complete them before the end of the war.

The most desirable set for air controlled interception appeared, however, to be the American Airborne Early Warning (A.E.W.) embodying a 1-megawatt transmitter and an 8 feet by 3 feet scanner, which was designed to detect a low flying aircraft of torpedo bomber size at 50–60 miles and a destroyer at 200 miles. The special feature of the equipment was the relay radar which enabled the information picked up by the A.E.W. aircraft to be relayed to a base or aircraft carrier some 40 miles away, thus allowing remote control. Interrogation of I.F.F. was designed to be made either from the aircraft or by radio control from base. The total weight of the airborne equipment was 2,300 lb. This set was unfortunately not available in time.

CHAPTER 14

RADAR CONTROL IN OFFENSIVE OPERATIONS

Early in 1941 Fighter Command began a series of offensive operations over enemy occupied Europe with the intention of bringing the German fighters to battle. For some time the tactical advantage lay with the enemy. For example, during the first part of the sortie our main formations usually found few German fighters in the air, but by the time they were running short of petrol and oxygen and were in no position to fight a major battle, the enemy would suddenly appear in strength.[1] 'Our idea,' commented the Air Officer Commanding-in-Chief, Fighter Command, 'was to go over to the other side and leap on the enemy in superior numbers from a great height, instead of which it looks as though we ourselves are being leapt on.' The German fighters had the benefit of early warning from their radar stations and observer posts, while the Royal Air Force squadrons were for the most part beyond effective fighter control. A study was therefore made by Headquarters Fighter Command of the possibility of using for offensive sweeps the type of information derived from filter rooms, but this proved generally to be too slow and not accurate enough for the purpose. Nor was the range of the radar stations adequate.

In the autumn of 1941, the Air Officer Commanding-in-Chief Fighter Command visited the Telecommunications Research Establishment personally and discussed the difficulties encountered in employing fighter sweeps over the Pas de Calais. In May 1942 he stressed the need for taking 'advantage of the opportunities in which our aircraft are in a superior tactical position to the enemy and, . . . for the Operations Control Staff to know with accuracy the dispositions of the opposing forces.' One of the measures he recommended was the 'provision of special ground radar equipment to track aircraft over as much as possible of the operating area so as to permit our aircraft being placed in a tactical position superior to that of the enemy.' The close control of fighter aircraft over enemy occupied territory was not immediately envisaged, but it was hoped to examine and develop the possibilities of doing so.

Fighter Directing Stations

The basic requirements of the type of radar station required were that it should give plan position and height finding of aircraft at and above 10,000 feet at distances at least 90 miles from the coast of England, with permissible errors in plan and height of 2 miles in plan and 1,000 feet in height. The tracking of six separate formations simultaneously was also required, their alterations in plan position and height to be rapidly followed. To this end a modified Type 8 G.C.I. set without height console was erected at Appledore in Kent by the Telecommunications Research Establishment.[2] By June 1942 the station was working. It was a gap filled station giving a range of 115 miles and could detect a single aircraft anywhere between Le Havre and the Dutch Islands.

[1] A.H.B. Narrative—A.D.G.B. Volume IV.

[2] A.M. File S.5249, Encl. 5A.

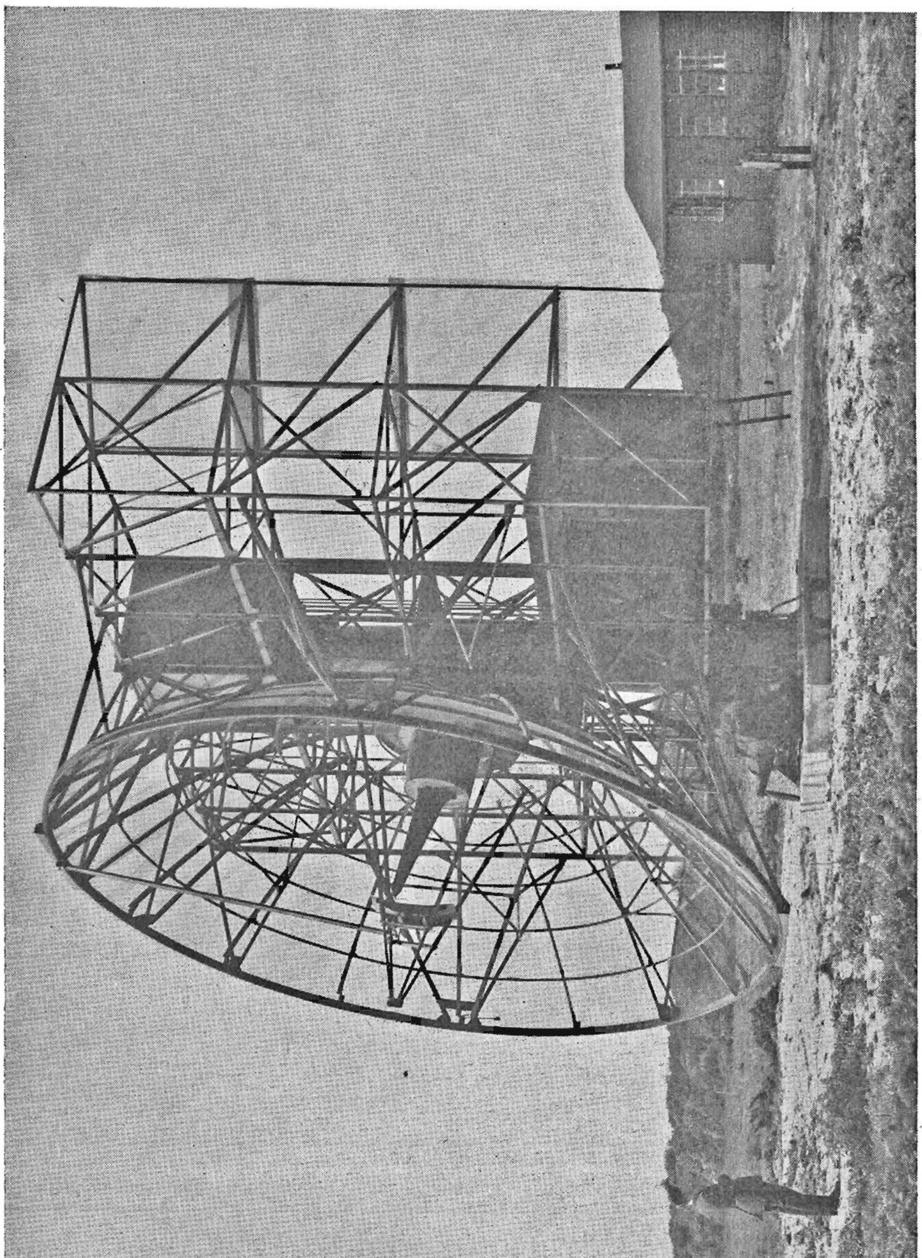
The possibilities of such a range of cover were seen to be enormous. If a single station could provide all the information over an area for which formerly several C.H.L. and C.H. stations were required, a great reduction would be achieved in the delays and ambiguities which occurred in filtering and plotting. As a result, not only could fighters be warned of the presence of enemy aircraft, but they could also be given instructions as to the best way of taking the tactical offensive against them. At first, through lack of height information, Appledore was used simply for plotting to No. 11 Group operations room by a new simplified and rapid technique, movement of offensive sweeps being displayed on a special plotting table. By October 1942, height finding equipment and an operations room had been provided at the station, a G.C.I. controller was posted in to take charge of fighter directing, and about the end of the year direct radar control of offensive operations was carried out.[1] Much of the undisputed success of the station was due to a close collaboration between the fighter pilots and the radar personnel of the G.C.I. station. Spitfire pilots spent their off-duty periods at the set watching the progress of fighter sweeps by other squadrons, and hearing the controller give warning of the approach of enemy aircraft and advice as to the best position for counter-attack. When they in their turn operated over enemy occupied France they knew that the radar at Appledore was on watch, and that should a German force be airborne, they would be given every assistance to out-manœuvre it. The result was, in the words of one Spitfire Wing Commander, to 'put their tails right up in the air.' It took the Germans some time to discover the reason for the upward trend in their defensive fighter losses. When they realised the cause, they sought radio means to neutralise it, and jammed Appledore continuously. Fortunately, anti-jamming modifications had been applied and the station continued to operate, though with reduced effectiveness, until December 1943.

Meanwhile, in December 1942, Headquarters Fighter Command lost no time in asking for four more fighter directing stations.[2] The original set at Appledore was not copied because it had several inherent faults, especially in its vulnerability to jamming. The specification for the new equipment included improved coverage in azimuth, range and ceiling height, early warning up to 200 miles, good comparative height measurement, high discrimination and adequate anti-jamming components. Two proposals were offered: one on 50 centimetres wavelength which could be produced fairly quickly and which later became the A.M.E.S. Type 16, and the other a long term project from which eventually came the A.M.E.S. Type 26. The Type 16 gave ranges of up to 200 miles on a Fighter Wing and the same aerial provided both plan position and height information. The aerial system had a paraboloid reflector 30 feet in diameter which concentrated the transmission in a pencil beam. The beam scanned both vertically and horizontally, the former by the movement of a dipole up and down in the focal plane some ten times a second and the latter by rotating the complete aerial system. By May 1943 the first Type 16 was erected at Greyfriars, close to the Dunwich C.H.L. site.[3] This set had been designed to provide longer range and lower

[1] The height-finding equipment was known as the Variable Elevation Beam or V.E.B., which comprised a 7-bay vertical aerial array some 75 feet high mounted on 110-foot masts, and gave ranges up to 100 miles on a Fighter Wing.

[2] A.M. File C.S.17935, Encl. 5A.

[3] *Ibid.*, Encl. 65A.



A.M.E.S. Type 16

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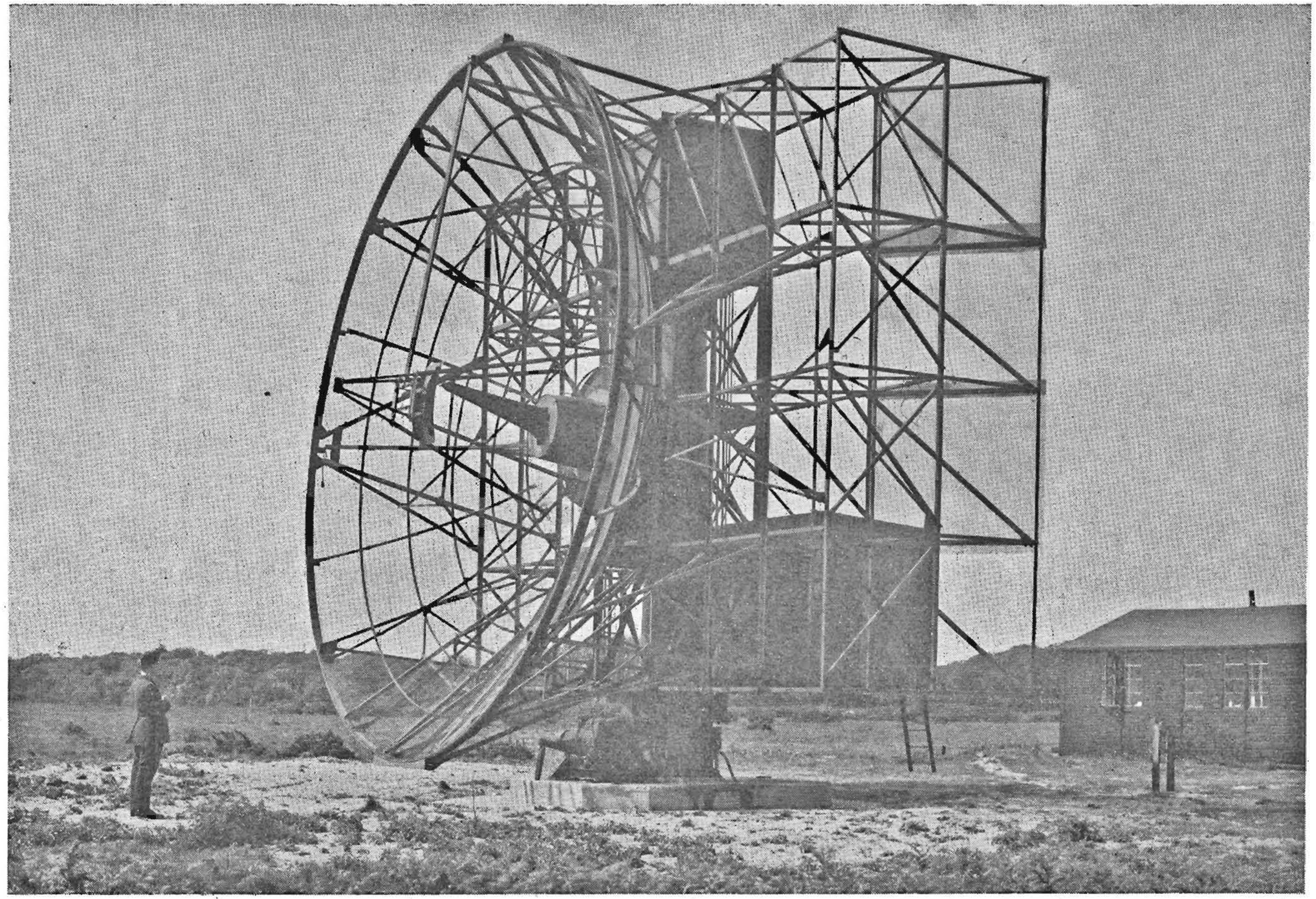


A.M.E.S. Type 16

coverage than the Appledore experimental station. Three further stations were operating at Hythe, Ventnor and Beachy Head at the end of the summer of 1943 and each sector of No. 11 Group had its own radar fighter directing station which controlled various forms of offensive tactics.[1] This development in fighter directing, both from Appledore and from the Type 16 stations, provides a classic example of an invaluable technique resulting from the closest possible collaboration of the scientists, pilots and the controllers.

Despite the generous range of the Type 16 for detection purposes, it was inaccurate for height finding below a certain limit which reached 20,000 feet at 70 miles range and 30,000 feet at 100 miles. Consequently, at the longer ranges normally used for fighter directing, no information in regard to height could be given.[2] To meet this important deficiency the Type 24 station was developed, working on a wavelength of ten centimetres and having a three-section vertical cheese aerial with an aperture 30 feet high and rather less than 6 feet across. It gave effective height finding down to 11,000 feet at 100 miles range and could register on a squadron of Spitfires at 135 miles. The latter range was rather less than the requirement of 150 miles, but this was unattainable until the higher powered 2 megawatt transmitter then under development was produced. A greater range was obtainable for detection using the earth or sea reflected ray, but this was of no use for height finding. The Type 24 came into operation in March 1944.[3] Royal Air Force fighter wings were thus provided with an immense tactical advantage over the enemy and gradually the German zone of operations was forced back into France. During the winter of 1943/1944 the Type 24 stations were used to protect fighter aircraft bombing the V-weapon sites on the Continent, and they also played their part in the directing of fighters against the flying bombs.[4]

Fighter Control in the Mediterranean Theatre

Tactical use of radar information was made similarly in the Mediterranean theatre, but under different conditions. Geographical and meteorological peculiarities were partly responsible for hastening the introduction of radar control. During the winter of 1941/1942, Cyrenaica was held by Allied forces against the Germans at Agheila south of the Gulf of Sidra. The cloud prevalent over the more broken country of Cyrenaica was used as cover with great skill and success by the German pilots when making bombing raids on Allied forces and it was realised that the raiders could only be intercepted successfully if they were attacked in the clear sky to the west of the clouded area and forward of the Allied lines.

This called for a forward system of early warning. Our fighters could not reach an advantageous position with the aid of the aircraft reporting system then in use. This consisted of wireless links with the associated delays

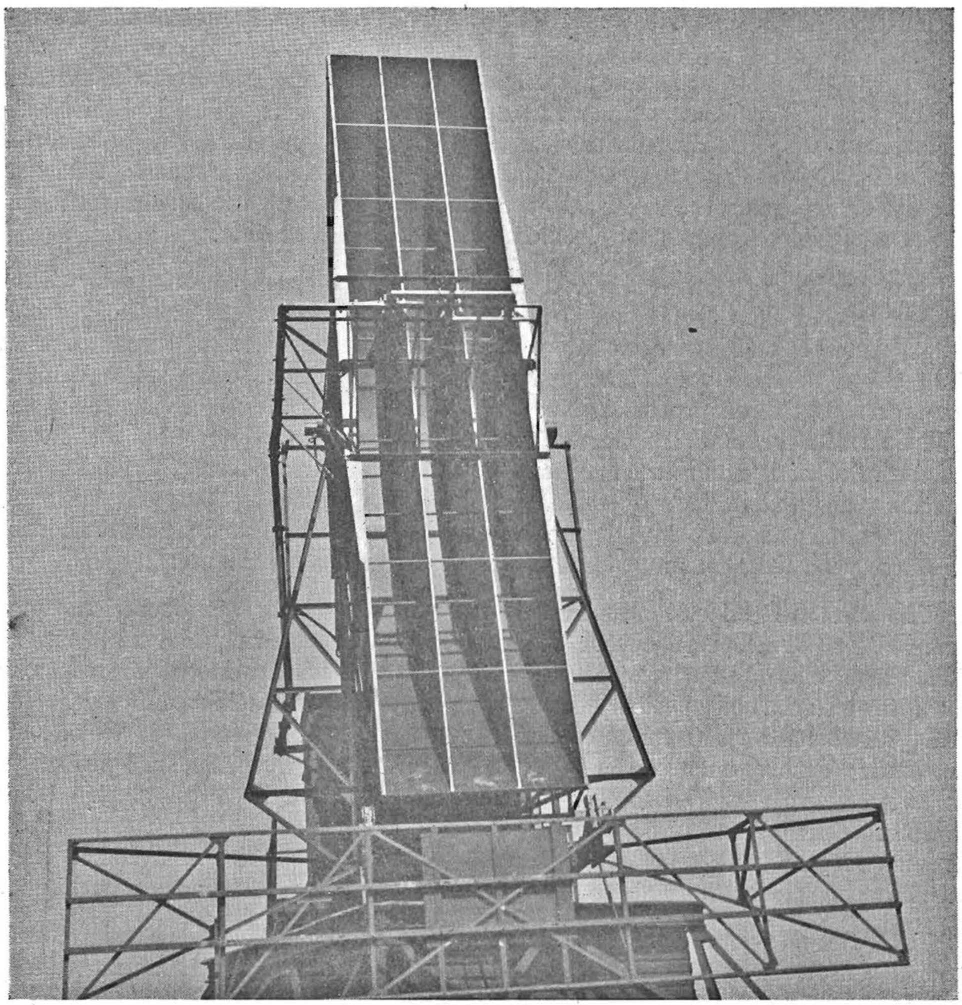
[1] The forms of attack were :—

Rhubarbs	Fighter attacks on enemy installations.
Roadsteads	Destruction of enemy shipping.
Rodeos	Free lance fighter sweeps to destroy airborne enemy aircraft.
Ramrods	Fighter defence of bomber formations.
Circuses	Combined ramrod and rodeo operations.

[2] The Harley Narrative, A.H.B. IIE/90.

[3] A.M. File C.S.17935, Encl. 73A.

[4] The T.R.E. History of Fighter Direction, A.H.B. IIE/205.



A.M.E.S. Type 24 Aerial

of coding, decoding, and plotting, between the mobile radar units and the mobile wing operations room. In addition, the mobility of the radar equipment was limited by the time required to erect and dismantle. It could not be exposed to the risk of capture entailed by setting it up close to the sometimes rapidly fluctuating front line, and forward radar cover was therefore not available. To provide forward cover, one of the few available C.O.L. stations (the overseas version of the C.H.L.) was specially modified for the purpose. To guard against the capture of this secret equipment in the ebb and flow of desert warfare, the station was turned into a fully mobile and desert-worthy unit by an increase in the number of prime mover vehicles, all equipment being fitted in such a way that the unit could come into operation within a matter of minutes after arrival at a site, and move off again if required at short notice. With the addition of camouflage, Bofors guns, and light anti-aircraft weapons, the unit was equipped to operate in foremost positions. Delays in reporting the radar information were to be cut out by controlling a force of fighters from a position alongside the C.O.L. station.

Scarcely had the station arrived at the forward site of Belandeh from where it could cover the German lines when the advance of the enemy on 21 January 1942 caused it to be withdrawn. But by that time the idea of direct control had taken root. From its next site near Gazala, only twelve miles behind the foremost Allied positions, No. 510 C.O.L. gave good radar cover across the Gulf of Bomba to the German airfields of Derna and Martuba, and news of the take-off and movement of enemy aircraft was immediately made known in the wing advanced operations room from which fighter control was exercised. From that time there was no difficulty in bringing the fighters into contact with German aircraft at the most advantageous moment.

The increased effectiveness and economy in several fighter operations was the subject of a special report by the Officer Commanding No. 258 Wing.[1] The most striking success was on 14 February 1942 when a model interception of a large formation of enemy fighters and bombers was achieved by eighteen Kittyhawk fighters, the first attack being made entirely unperceived out of the sun. Twenty enemy aircraft were claimed as destroyed, and two probably destroyed and ten damaged. The Kittyhawks incurred no loss.[2] The encounter had great moral effect, because the German Messerschmitt 109F fighter aircraft was superior in general performance to the Kittyhawk, and at that time the enemy fighter force was by no means inferior in total numbers.

That the new-found ability to intercept and superiority of tactical control was a source of concern to the Germans became evident from their immediate adoption of widely circuitous tactics; but their attempts to surprise by approaching from out to sea, and from other unusual angles, mostly failed

[1] Interceptions by fighter sweeps from Maddalena, Cyrenaica, during a typical nine day period in December 1941.

No. of Sorties	*No. of Interceptions*	*Enemy Casualties Claimed*
898	9	100 (includes 36 destroyed).
Interceptions by C.O.L., 8–16 February 1942		
193	8	48 (includes 26 destroyed).

[2] A.H.B. Narrative—Middle East Campaign, Volume III.

because their initial direction of departure had been noted. They then attacked the R.T. control station, having located it by direction finding, but the bombs fell harmlessly on decoy tents. Curiously, and fortunately, no attack was made on the C.O.L. station despite its meagre camouflage.[1]

The adoption of the C.O.L. for day fighter control in the Western Desert was the first recorded example of the use of radar for tactical control by day. It was all the more noteworthy by reason of the technical shortcomings of the apparatus available, all of which were overcome by skilful improvisation. There was no means of identification at the C.O.L. station but this was minimised by careful study of friendly aircraft movements, and by the reliable reports from wireless observer posts. Accurate height finding was impossible but this disadvantage was to some extent overcome by improvised methods. The degree of accuracy required was not, of course, as close as for night interception.

Forward Fighter Control

The system of direct radar control as used in the Western Desert greatly impressed many senior officers who saw it in action. It was used thereafter, as circumstances permitted, throughout the Mediterranean theatre. From this point onwards the story of fighter direction in that theatre becomes inextricably bound up with that of radar in the early warning role, which has already been related.[2] The same system appeared in the Italian campaign under the name of Forward Fighter Control. The radar station used was the G.C.I./C.O.L., Nos. 15052, 8033 and later 886 being modified to form Forward Fighter Control Units, but modifications were made in such a way as not to affect their normal function. Landline or wireless communications were provided to satellite radar stations for the exchange of aircraft information, and to the main Mobile Operations Room Unit (M.O.R.U.) and fighter airfields. Four V.H.F. R.T. channels supplied communication to fighter aircraft. Information received was plotted on a small filter table some four feet square which was also used as a 'General Situation Board.' Chinagraph pencil was at first used for plotting, but was later abandoned in favour of plotting counters. The controller sitting in the P.P.I. compartment had a clear view of the filter table.

The Forward Fighter Control Unit was most versatile in operation. It could be used either for fighter directing by day or for the more precise interception control by night, according to the type of cover resulting from the characteristics of the site. It could also be used as a C.O.L. station for aircraft reporting, or as a Master Control station to provide filtered tracks by combining its own information with that from other radar stations and wireless observer posts. The F.F.C.U. generally performed the last mentioned function, which was similar to that of the M.O.R.U., when the latter unit was on the move or temporarily out of action for some other reason. During an advance, the site of the F.F.C.U. was usually chosen with an eye to it being taken over by the M.O.R.U. after the fighter control had moved forward.[3]

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[1] Interview with Group Captain J. A. Tester, who was Chief Radio Officer at the time.

[2] Volume IV—Radar in Raid Reporting. Chapter 21.

[3] Desert Air Force, O.R.B., Appendices, A.H.B. IIM/A.48/1c.

Fighter Control Equipment Afloat

The first use of seaborne G.C.I. stations in offensive operations was made during the Allied landing in Sicily in July 1943. Two of the three G.C.I. stations installed in tank landing craft (LCT) were originally intended to be landed to operate ashore on 'D Day' but when congestion prevented their landing punctually they operated afloat, controlling successful night interceptions. Their performance afloat was so effective that ship-borne G.C.I.s were thenceforward considered an essential factor in major landing operations. In preparation for the landing in Normandy more comprehensive control arrangements were made. Three fighter directing tenders were provided, consisting of the larger tank landing ships (LST) carrying an A.M.E.S. Type 15 as the main G.C.I. equipment and an A.M.E.S. Type 11 as a reserve.[1]

Fighter Control in the North-West European Campaign

Two types of radar control were practised in the North-West European campaign. No. 85 (Base Defence) Group was responsible for the protection of beaches and dumping grounds in the early stages, and later of ports and other important centres on the lines of communication. No. 85 Group was, however, the only group which had concerned itself with night fighting and its activities in this role extended to the most forward areas. Day fighter control in the battle areas was the prerogative of the fighter director posts of Nos. 83 and 84 (Tactical) Groups. The exercise of control in the forward areas was hampered by the shortage of telephone lines which prevented the continuous reporting of air information from widely separated radar stations during mobile warfare. It was not until the Type 70 radar station provided a complete and continuous picture at the group control centres that a greater measure of day fighter control was possible.

Night Fighter Control

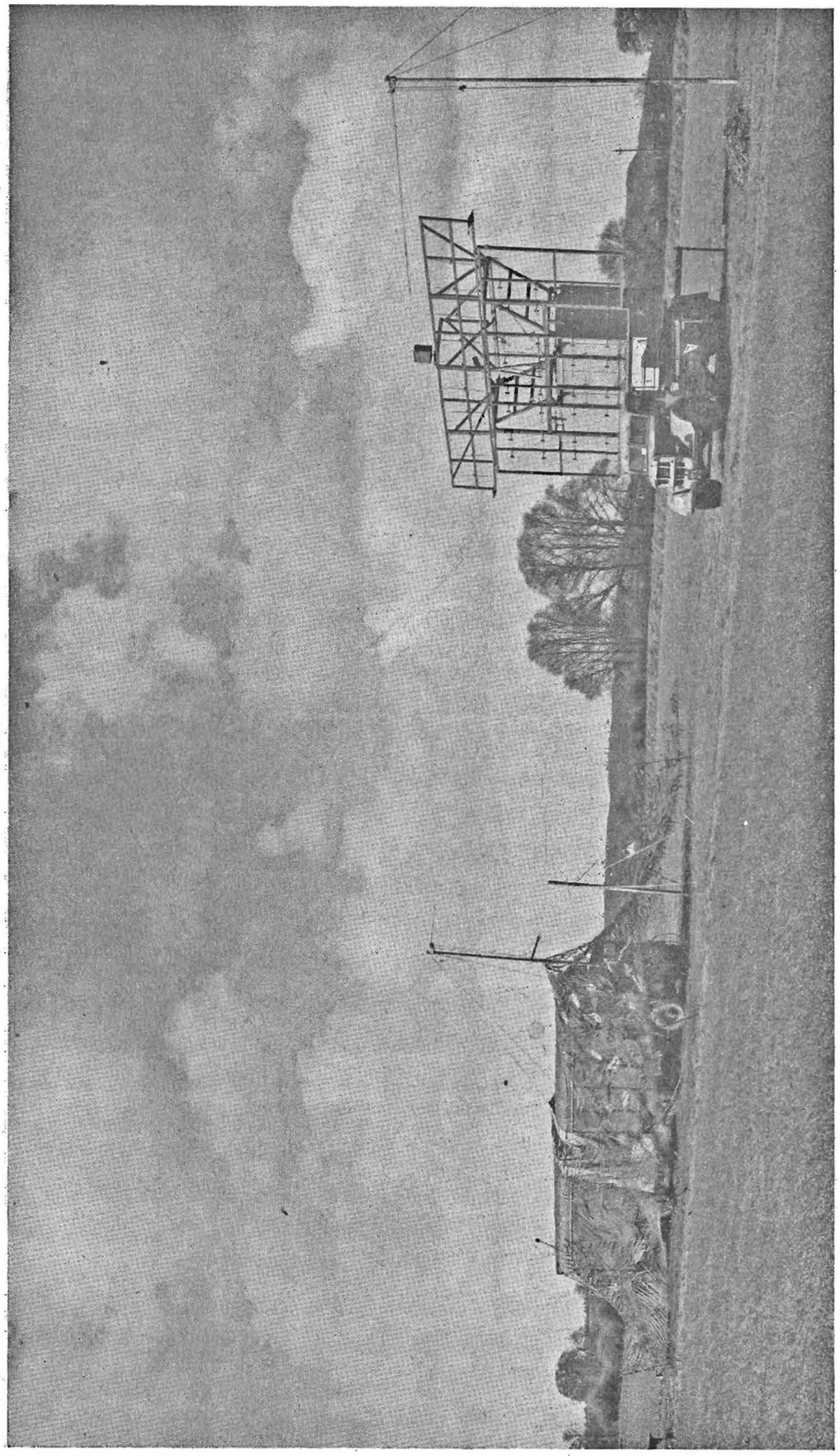
For the defence of beaches, base areas and ports, mobile radar convoys Type 25 were provided. They comprised one A.M.E.S. Type 15 Mark II ($1\frac{1}{2}$ metre) one Type 11 (50 centimetre) and one each of Types 13 and 14 (10 centimetre) equipments. Three simultaneous interceptions could thus be controlled, and the diversity of waveband gave a safeguard against electronic jamming.[2] The Type 15 was a mobile station on the lines of the original mobile G.C.I. equipment Type 8E which formed the basis for design. It worked on 209 megacycles per second like its predecessor but incorporated greatly improved power-turned aerials and other developments.[3] Up to the end of the war it gave better all-round cover against high flying aircraft than any other single equipment and was the most popular with controllers because of its simplicity of operation.

For the first two months after the landing, all six night fighter squadrons of No. 85 Group operated across the Channel from airfields in England. They began to move to continental airfields at the end of July 1944. During the first five months they were assisted by squadrons of the Air Defence of Great

[1] A more comprehensive account is given in Volume IV, Chapters 20 to 25, and Appendix 30.

[2] S.H.A.E.F. Air Signals Report on 'Overlord', A.H.B. IIE/159.

[3] A.M. File C.S.20672/II, Encl. 127A.



A.M.E.S. Type 15

Britain Command, especially during June, July and August, after which the need diminished.[1] Enemy minelaying and anti-shipping attacks took place off the bridgehead area and the front line positions were also bombed almost every night for the first two months. During August the attacks were switched to troop concentrations and other front line targets, and in September the whole scale of enemy night attacks fell off considerably and remained low until the time of the Ardennes offensive in December. A summary of German aircraft destroyed by night in North-West Europe during the first four months is given below.[2]

From June to September no detailed reports were made on operations by controllers of the various G.C.I. stations. The summary below of station claims is as complete as records allow but there was a small number of combats for which the controlling station is unknown.[3] In addition, during the first month after 'D Day,' fighters under fighter directing tender (waterborne G.C.I.) control claimed twenty-three aircraft destroyed and five damaged. Fighters under A.D.G.B. control claimed twenty-four destroyed, two probably destroyed and one damaged. The remaining claims of twenty-six destroyed, three probably destroyed, and three damaged were by fighter aircraft operating unaided by control, or operating under unknown control.

During the first three months of the campaign, that is the bridgehead and break-through phases, the Base Defence area was divided into two Sectors, No. 21 covering the Cherbourg peninsular and operating temporarily with the United States Army, and No. 24 covering the British Army Group area. When the battle moved into Belgium and Holland in September 1944, No. 24 Sector sent a detachment forward to set up a skeleton organisation for the

[1] Summary of Defensive Fighter Sorties.

Month (1944)	*85 Group*	*A.D.G.B.*
June	599	889
July	818	476
August	360	556
September ..	447	73

[2] Summary of German aircraft destroyed by night in North-West Europe.

Month (1944)	*Destroyed*	*Probably*	*Damaged*
June 6–30	56 (85)	3 (5)	12 (12)
July	37 (46)	2 (2)	3 (5)
August	62½ (67½)	4 (4)	8 (9)
September	8 (8)	—	—

(*a*) Plain figures were inflicted by No. 85 Group aircraft. Bracketed figures include casualties inflicted by A.D.G.B. aircraft.

(*b*) Fighters of 85 Group on intruder operations claimed 17 destroyed, 3 probably destroyed and 9 damaged during the period.

(*c*) The increased figures for August were probably due to introduction of more G.C.I.s.

2nd T.A.F. O.R.S. Report No. 21, Appendix 21. A.H.B. IIF/101/1.

[3] Claims by night-fighter aircraft controlled by No. 85 Group radar stations.

June–September, 1944

Station	*Destroyed*	*Probably*	*Damaged*
15072	3	—	—
15081	24	1	3
15082	43	1	5
15121	13	1	3
15083	44	4	8
15119	3	—	—
15120	2	—	—
15122	1	—	—

protection of Antwerp and Brussels, until No. 25 Sector, which had just been organised in the Brest area, moved complete to the Low Countries and took over from it. Between September and January 1945, No. 24 Sector covered the British zone in France north-east of the Seine and No. 25 Sector covered occupied Belgium and Holland. No. 21 Sector returned to the United Kingdom in September. In January 1945 the new Base Defence area was defined, control being vested in No. 25 Sector until March, when it was taken over by No. 85 Group Headquarters, who had recently set up a static group operations room at Ghent.

From October 1944 to March 1945 the major part of the German effort consisted of fighter and fighter-bomber operations over the tactical areas. During the Ardennes offensive in December the scale of operations was intensified to twice that of any other time. On five nights during that period minelaying and anti-shipping activities took place in the area of the Scheldt estuary. The low height at which these operations were carried out made radar tracking difficult and only one minelaying aircraft was destroyed by night fighters. A summary of interceptions controlled by G.C.I. stations for the six months period is given below.[1]

During the German attack in December, air activity was heaviest in the United States sector, and No. 85 Group night fighters flew reinforcement patrols under the control of an American M.E.W. In these operations two enemy aircraft were destroyed and one damaged. No. 85 Group aircraft were controlled by No. 83 Group Control Centre and destroyed three aircraft on the night of 25/26 March. The only G.C.I. to follow the rapid Allied advance in April and May 1945 was No. 15121 G.C.I., which moved forward to the vicinity

[1] Summary of Interception Operations by No. 85 Group Radar Stations, October 1944–March 1945. A.H.B. IIF/101/1. Report No. 18.

Interceptions on Hostile and Unidentified Aircraft

Station	*Procedure*	*Total Attempts*	*Attempts*	*A.I. Detections*	*Visuals*	*Combats*	*Destructions*	*Probables*	*Damaged*	*No Claim*
15081	Close Control	37	6	3	1	1	—	1	—	—
15083	Close Control	58	41	33	16	11	10	—	1	—
	Free lance	2+	2+	2	1	—	—	—	—	—
15092	Close Control	101	61	26	6	—	—	—	—	—
15093	Close Control	16	8	2	2	1	1	—	—	—
15119	Close Control	477	211	129	63	51	47	1	2	1
	Free lance	12+	12+	12	8	8	6	—	2	—
15120	Close Control	356	148	95	29	18	13	—	4	1
	Free lance	8+	8+	8	4	2	2	—	—	—
15121	Close Control	1	—	—	—	—	—	—	—	—
15122	Close Control	105	34	18	3	3	3	—	—	—
	Free lance	2+	2+	2	—	—	—	—	—	—
15128	Close Control	4	1	1	1	1	1	—	—	—
15130	Close Control	10	2	2	1	—	—	—	—	—
6090	Close Control	43	29	20	9	6	6	—	—	—
	Free lance	3+	3+	3	3	2	2	—	—	—
6342	Close Control	20	7	4	—	—	—	—	—	—
Type 63	Close Control	2	—	—	—	—	—	—	—	—
	Total	1,257+	575+	360	147	104	91	2	9	2

of Standhal and was able to cover the Berlin area while the air evacuation of important Germans was proceeding. This station controlled 25 out of the 29 combats during the last period. Twenty-five enemy aircraft were destroyed, one probably and two damaged.

The frequent rapid movement of fronts during the campaign emphasised the advantages to be gained from a highly mobile form of light G.C.I. set. Light Warning Sets were used for this purpose, despite their limitations, and five enemy aircraft were destroyed by night fighters under the control of one of these sets during October 1944. The Light Warning Sets were sent ahead as a tentacle of the main G.C.I. to extend the area in which controlled interception was possible. The designing of a special set to perform this function, but with a greater range of cover, was recommended.[1]

In anticipation of a lack of low radar cover, both for detection and interception, occasioned by the lack of good sites along the low lying coast of the Low Countries, efforts to evolve equipment which could easily be manhandled to the top of high buildings were made in the Normandy bridgehead. Experiments with an A.I. Mark X equipment, suitably modified, were successful, and in the autumn of 1944, Headquarters No. 85 Group installed the set on the top of the Casino at Blankenberghe, 125 feet above sea-level, where the high site would give lower cover.[2] When Walcheren Island was taken, the set was further modified and was moved to the top of the 200-feet tower of the West Kappelle lighthouse, where by the end of the year it was operated as a subsidiary of a G.C.I. at Blankenberghe, with which communication was made by V.H.F. R/T. The expedient was successful, but emphasised the need for development of a standard lightweight equipment, easily hand-portable, which could be installed quickly in water towers and similar high buildings.[3]

A set which gave disappointing performance in the G.C.I. role was the A.M.E.S. Type 14, which, despite the quantity of Window detected (mostly friendly) was comparatively little used. One of the reasons for lack of confidence in the set appears to have been a ' beating ' effect produced by single aircraft.[4] This occurred when the aircraft, flying at low angles of elevation to the station, moved through the irregular radiation field and thus gave radar reflections of varying intensity.

The greatest weakness of the G.C.I. system was lack of reliable identification devices. At least 54 per cent of interception effort was wasted in chasing friendly aircraft. Identification at G.C.I. stations was made largely by controllers using track behaviour. Friendly movement notifications enabled half the total number of tracks to be identified at sector operations rooms, but this was insufficient. Between October 1944 and March 1945, 60 per cent of the attempts at interception which did not result in combats were abandoned because the target was identified as friendly, and 64 per cent of these attempts were taken to the visual stage before being abandoned. The proportion of identifica-

[1] 2nd T.A.F./O.R.S. Report No. 6, A.H.B. IIF/101/1.

[2] 2nd T.A.F./O.R.S. Report No. 4, A.H.B. IIF/101/1.

[3] *See also* Volume IV, Chapter 25.

[4] 2nd T.A.F./O.R.S. Report No. 16, A.H.B. IIF/101/1.

tions left to the pilot to make visually were reasonably consistent during the period, and there was nothing to suggest that other means of identification were improving.[1]

Some idea of the general effectiveness of the night defence system in north-west Europe can be gained from the following figures. Between 5/6 June 1944 and 5 May 1945 probably about 5,000/6,500 enemy aircraft operated in No. 85 Group operational areas, and of these 313 were destroyed or probably destroyed by the Group's night fighters, and 49 by night fighters of Fighter Command.

Fighter Control in the Tactical Area

The aircraft warning and fighter control radar organisation for the whole of the Allied Expeditionary Air Force had been planned on defensive lines to deal with a strong enemy air force. The tactical Groups Nos. 83 and 84 had each been equipped with four A.M.E.S. Type 25 convoys, similar to those of the Base Defence Group, which were to act as radar equipment for the Fighter Director Posts.[2] Their purposes were threefold. They were intended to direct fighters to intercept enemy aircraft, and at the same time to present a general continuous air situation picture. This would have many uses including those of enabling sorties to be routed clear of opposition and of warning them of the approach of enemy fighters. They were also to assist aircraft to navigate to ground targets.

The first two of these aims pre-supposed an active hostile air force, operating in some strength. The fact that such an air force was not encountered does not mean that the equipment should not have been supplied, but the result was that full operational value was not extracted from them. The third purpose, navigation to ground targets, was rarely used because it was generally agreed that it was not worth putting pilots under radar control for the sake of the few occasions when placing them within a mile or two of their targets would have helped them.

The radar control equipment provided had been designed primarily for defensive purposes and its range was too short, particularly at low altitude, to enable it to be very effective when used for offensive operations over the enemy lines. The limitation in range was aggravated by the constant receding of the operational zone from the area of radar cover. The stations themselves proved extremely mobile, but repeated movement made the provision of adequate telephone lines to the group control centre an impossibility, with the result that a continuous centralised picture of air activity was frequently not available there.[3]

Radar information was nevertheless of value in offensive operations, particularly in conjunction with other sources of information available at the F.D.P., such as Movement Liaison, D.F. fixing, and interception of enemy R.T.

[1]

October	November	December	January	February	March
65 per cent	54 per cent	63 per cent	70 per cent	70 per cent	61 per cent

2nd T.A.F./O.R.S. Report No. 21, A.H.B. IIF/101/1.

[2] The Americans were provided with a number of Type 25 convoys on reverse lease-lend in order to standardize radar equipment in the bridgehead and special training was given to the American crews by Telecommunications Research Establishment staff.

[3] S.H.A.E.F. Air Signals Report on 'Overlord'. A.H.B. IIE/159.

How the information was used in air fighting is shown by the following extract from No. 6 F.D.P. operational reports referring to fighter sweeps by No. 331 (Norway) Squadron in the Enschede–Rheine area on 29 December 1944.

Operation No. 4

10.10 Leader contacted.

10.15 Warned of bogies[1] approaching Rheine from north (intercept).

10.46 Told bogies were most likely bandits[2] and would probably be low down.

10.52 Bandits now in Rheine area.

10.55 Bandits 10 miles north-east of Rheine (intercept).

11.00 R.T. became very faint; squadron had obviously gone down and appeared to have sighted enemy aircraft.

11.08 Yellow 2 baled out on bearing of 015° True from station. Leader asked to detail someone to orbit and fix, but replied he had no time.

11.15 Leader reported a claim of four destroyed.

Operation No. 5

14.44 Leader warned of enemy aircraft in Enschede and Rheine area.

14.45 Warned of gaggle of aircraft at 11 o'clock, 8 miles away at 13,000 feet (radar).

14.47 Warned that this gaggle was formating on Leader at 6 o'clock (radar).

14.50 to 15.00 He thought they were friendly, but after an orbit to port, he saw they were bandits and quite a dogfight ensued.

15.14 331 Squadron aircraft returning to base.

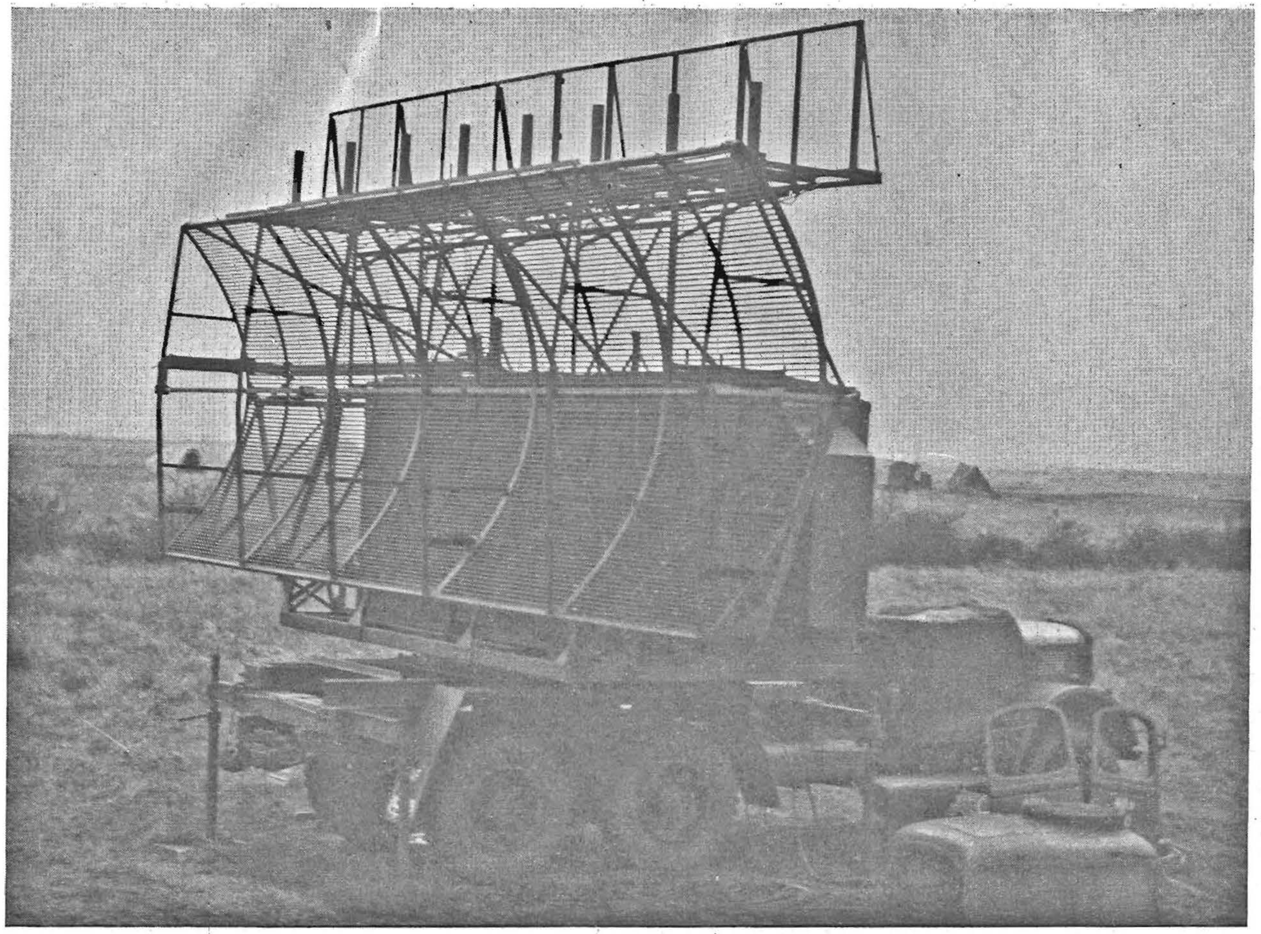
The squadron claimed 12 Messerschmitt 109's destroyed and two damaged. All their aircraft landed at base at 1500 hours.[3]

Between 3 December 1944 and 14 January 1945, a period chosen as being reasonably representative of the use of radar in No. 84 Group, the occasions on which warnings were given to aircraft by No. 6 F.D.P. are summarised as follows :—

Warned on intercept information		33
Warned on radar information :—		
Confirmed hostile	5	
Confirmed friendly	7	
Not confirmed	17	
	—	29
Operations not warned		137
		—
Total operations controlled		199

In order to obtain an opinion from the flying angle on the usefulness of ground radar, three wing, six squadron and two flight leaders, all from the five wings

[1] Unidentified aircraft. [2] Enemy aircraft. [3] No. 331 Squadron O.R.B.



A.M.E.S. Type 70, Low Looking Aerial

of No. 84 Group, were asked by the Operational Research Section for their views, which were consolidated as follows :—

(*a*) In general, wings and squadrons do not make great use of radar, but all leaders agree that the knowledge that some ground radar station is watching for any enemy aircraft coming near them is a great advantage.

(*b*) On fighter sweeps radar is used as the main indication of where to find enemy aircraft.

(*c*) Some leaders have occasionally used radar to vector them towards their targets. Others like the idea of doing this under certain circumstances but have never done it. A small minority are not in favour of the idea, and would prefer to navigate themselves on every occasion.

(*d*) Most leaders have occasionally obtained homings from F.D.P.s, but these have almost always been by D.F. and not by radar. Practically all homings are asked for from the airfield flying control, and these homings are universally praised.[1]

Although the Type 25 convoys were somewhat inappropriate for work in an offensive campaign, their information helped in the interception of hostile aircraft, and fighter sweeps relied on it to a substantial extent. Radar also acted as a deterrent against medium height air activity by the enemy. It helped to clarify the air situation, although the problem of conveying instantaneously a co-ordinated picture proved more intractable than the corresponding problem in the United Kingdom. It was stated that service of assistance to navigation of aircraft to ground targets was not required. Instead there was a requirement for blind bombing in cloudy weather with an accuracy comparable to that of visual bombing. This was to be provided in a later stage of the campaign in the form of the mobile radar control post.[2]

The gravest weakness of the Type 25 convoy equipment was the lack of a means of reliable identification. Criticism of the I.F.F. system, which appeared at its worst in the prevailing condition of air superiority, included the following comment : 'To produce further Marks, even twice or three times as useful as the present, seems quite vain ; and the time spent on their production could better be devoted to leisure, and the components to its entertainment.'

A.M.E.S. Type 70

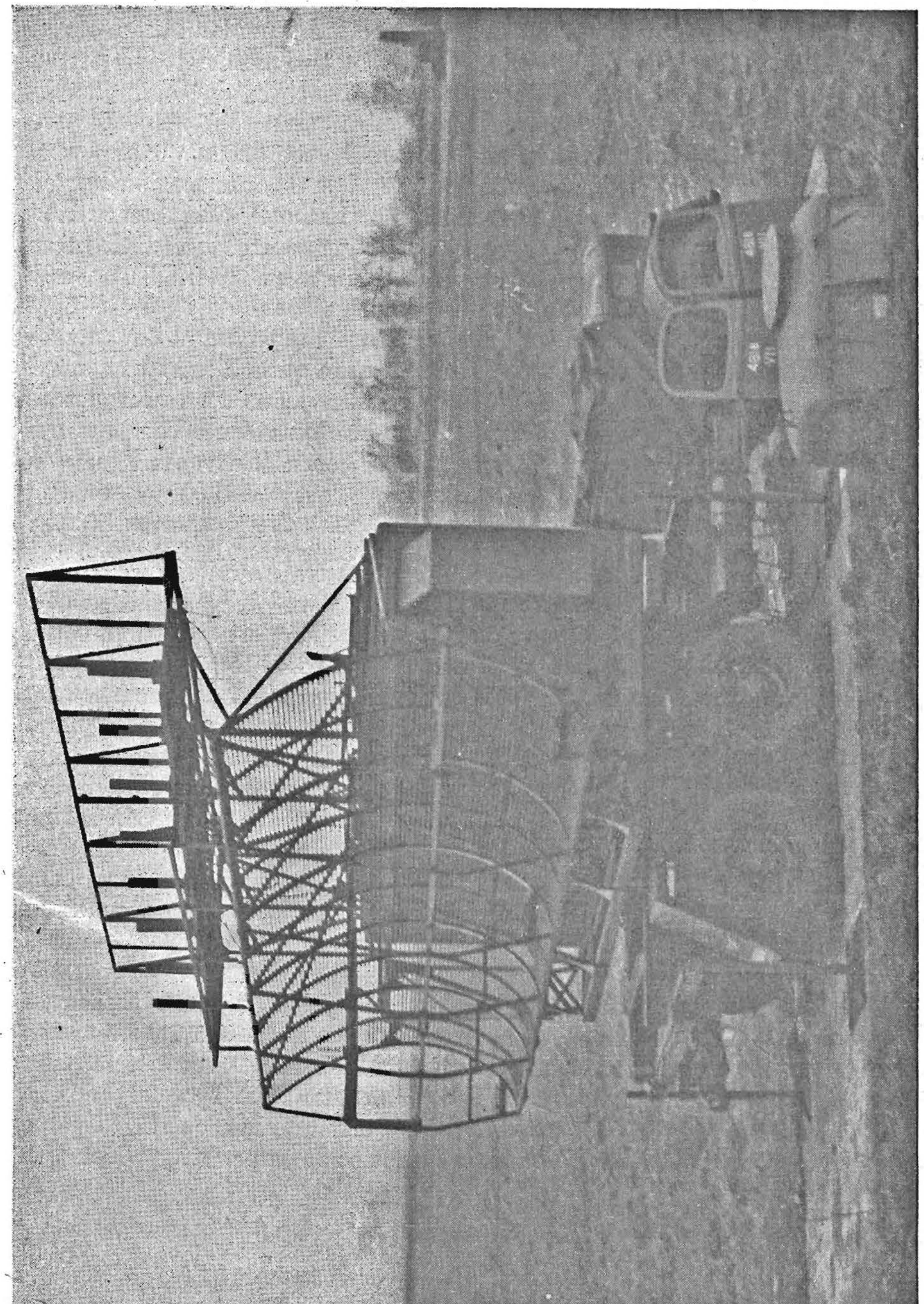
Influenced by the success being obtained by the American Microwave Early Warning set, Headquarters 2nd Tactical Air Force voiced on 22 September 1944 an urgent operational need for a long range radar to provide low cover and multi-control facilities, with a high degree of mobility.[3] The first A.M.E.S. Type 70 was built by the Telecommunications Research Establishment in thirteen weeks. It was sited near Erp, in Holland, in early February 1945, and remained with No. 83 Group Control Centre until the end of hostilities on 5 May. A second Type 70 was built for No. 84 Group, but was not in operation until after the end of the war.

The Type 70 was the most complex mobile ground radar developed during the war, comprising a technical convoy of thirty vehicles, ranging from aerial cabins and controllers' rooms to power supply vehicles and a telephone exchange,

[1] 2nd T.A.F./O.R.S. Report No. 17, A.H.B. IIF/101/1.

[2] *See* Volume IV, Chapter 25, p. 451.

[3] S.H.A.E.F. Air Signals Report on 'Overlord', A.H.B. IIE/159.



A.M.E.S. Type 70, High Looking Aerial

associated with mobile living accommodation and domestic appliances for the crews. The plan position aerials were of new design, consisting of a centimetre reflector of tubular shape, specially devised to minimise weight and wind pressure without reducing the range of the equipment. One plan position aerial was used to provide cover at low heights and a second to provide the high cover. Accurate height finding information was produced by two mobile and improved A.M.E.S. Type 13 cheese aerials. The operations room was the main characteristic of this station. Inside a large tent were housed four vehicles (two controllers cabins, a planning cabin, and an intelligence officer's cabin) with perspex windows which allowed the occupants to view the information carried by plotting screens and 'tote' boards also standing in the tent.[1] Greatly increased range, especially at low altitude, was provided. Five controlling P.P.I. tubes were available, facilitating the close control of eight missions simultaneously by four deputy controllers, the fifth tube being normally reserved for the chief controller and emergency situations. In addition to the technical advantages of the Type 70, the identifying of the radar station with the group control centre overcame the difficulties in mobile warfare of transferring the air picture seen by several dispersed radars to the operational headquarters. This information, together with that from Army Liaison, Intelligence, intercepts, squadron availability states, and latest reports from aircrews, enabled the group control centre to plan and conduct day to day operations with the greatest efficiency.

The value of the ability to maintain an accurate track of a mission, and so to pass useful information to the aircraft at the right moment, was realised in a variety of ways. Offensive aircraft operating on close support operations could be prevented from mistaking the target, a condition which became important when ground forces were moving or when a bomb-line was badly marked by natural features. The accuracy of the Type 70 was not such as to allow blind bombing, but it was possible to position aircraft to within approximately one mile of their target. This facility acquired a new value with the availability of the mobile radar control post, to which it was possible to maintain a high rate of feed. Time could be saved by air briefing and diversion to new targets, though this practice was less used by the Royal Air Force than by the Americans as a consequence of the longer duration of their aircraft. Under medium cloud conditions, aircraft could be taken out above cloud and dropped through at a pre-arranged recognisable point. Information of the whereabouts of hostile aircraft could be of great value. Not all missions required the assistance described above; the advantage of close control could be lost by failure to reserve the controller's time for those sorties which most required his aid. Despite the indisputable technical excellence of the A.M.E.S. Type 70, and the operational success by both day and night of aircraft under its control, its value should be assessed in relation to the high degree of air superiority which was enjoyed at the time.

[1] The T.R.E. History of Interception, A.H.B. IIE/205. A more detailed description of the Type 70 A.M.E.S. is given in Volume IV, Chapter 25 and Appendices No. 47, 48 and 49.

APPENDIX No. 1

MINUTE BY DIRECTOR OF SCIENTIFIC RESEARCH TO SECRETARY OF STATE, 12 NOVEMBER 1934

A.M.S.R.

C.A.S.

S. of S.

When one looks back on the stupendous technical advances of the last fifty years one cannot but wonder what equally striking advances can possibly lie ahead of us in the next equal period of years. Apart from television and the use of new ways of deriving our food from the soil, it is difficult to forecast what important discovery the future may have in store, but I feel confident that one of the coming things will be the transmission by radiation of large amounts of electric energy along clearly directed channels. If this is correct the use of such transmissions for purposes of war is inevitable, and welcome in that it offers the prospect of defence methods at last overtaking those of attack.

The defence of a great city against hostile aircraft, carrying bombs or gas, has now become increasingly difficult on account of higher speed, higher ceilings, less noisy airscrews and engines, and the ability to fly with an automatic pilot in clouds and fog. We need, therefore, to intensify our research for defence measures and no avenue, however seemingly fantastic, must be left unexplored. The idea of a ray of energy to put the engine ignition out of regular action has often been proposed, but it suffers from the vital defect that it is easy to screen the ignition leads and plugs. The further idea of detonating bombs by such energy is probably impracticable because the actual bomb case may be expected to afford an efficient screen against radiation (though the idea will not be lost sight of).

There remains to consider the effect of this radiation on the human body (and perhaps on metal fuselage and wings). I therefore sought the opportunity of a discussion on the physiological aspect of this matter with Professor A. V. Hill, F.R.S., the Professor of Biology at University College, London, and an able worker on artillery problems during the War. The result of our talk will be found in enclosure 1A (not reproduced). Certain possibilities are there revealed—for the future if not for the present moment—and these I think need careful watching.

Scientific surveys of what is possible in this, and other, means of defence at present untried are best made in association with two or three scientific men specially collected for the purpose: their findings may sometimes prove visionary, but one cannot afford to ignore even the remotest chance of success: and at the worst a report that at the moment ' defence was hopeless ' would enable the Government to realise the situation and know that so far retaliation was the sole remedy—if such it can be called. I would submit, therefore, that the formation of such a body be now considered.

I submit for consideration that of such a Committee an excellent Chairman might be found in Mr. Tizard, the present Chairman of our Aeronautical Research Committee and a former R.F.C. pilot. The other members should, I suggest, be the Professor A. V. Hill, F.R.S., already mentioned, and Professor Blackett, F.R.S., who was a Naval Officer before and during the War, and has since proved himself by his work at Cambridge as one of the best of the younger scientific leaders of the day. The terms of reference which should, I submit, be sufficiently wide to cover all possible developments, might be: ' 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 should be at liberty to consult other experts (for example in radio technology) when they deem this to be necessary.

There is much to say in favour of such a body acting not merely under the Air Ministry but as part of the machinery of the Committee of Imperial Defence, seeing that the Admiralty and War Office are each concerned in anti-aircraft work, and that the existing knowledge of that Committee and its Secretariat might save the new proposed Committee from working on schemes whose merits had been investigated already.

In either case D.S.R., Air Ministry would need to serve on the Committee and see that its findings were brought to the knowledge of the Air Council.

(Signed) H. E. WIMPERIS,
D.S.R.

12.11.1934.

APPENDIX No. 2

FIGHTER CONTROL R.T. CODE

Code Word	*Meaning*
Scramble ..	.. Take off, set course . . . . climbing at 140 m.p.h.
Angels ..	.. Climb to . . . . feet. (Pilot will automatically fly level when he reaches this height.)
Vector ..	.. Alter course to . . . . (Either climbing or in level flight.)
Buster ..	.. Increase speed to 170 m.p.h.
Gate ..	.. Increase speed to 200 m.p.h. for 5 minutes only. (Pilot and plotters to remember to revert to 170 m.p.h. after 5 minutes.)
Orbit ..	.. Circle.
Bandit ..	.. Look out for . . . . enemy . . . . miles in a given direction.
Tally Ho ..	.. Enemy sighted.
Pancake ..	.. Return to aerodrome and land.

A.M. File S.38638, Encl. 112A, October 1937.

APPENDIX No. 3

TABLES FROM PAPER ON INTERCEPTION WITH R.D.F. LOCATION

TABLE I

Height (Feet).	Time after 'Sector Warning' (Mins.) Distance of Aerodrome from Coast.		
	60 Miles.	40 Miles.	30 Miles.
5,000	20 mins.	16 mins.	13 mins.
10,000	20 mins.	16 mins.	14 mins.
20,000	22 mins.	18 mins.	15 mins.
30,000	25 mins.	24 mins.	24 mins.

TABLE II

Distance of Aerodrome from Coast.	Height of Raid (Feet).	Minimum Distance from Coast for		
		'Sector Warning.'	Approx. Height measured.	Positions every 1–2 mins. Height every 3–4 mins.
60 miles	5,000	80 miles	60 miles	60–30 miles*
	10,000	80 miles	60 miles	60–30 miles*
	20,000	90 miles	70 miles	70–30 miles*
	30,000	100 miles	80 miles	80–30 miles*
40 miles	5,000	65 miles	45 miles	50–30 miles*
	10,000	65 miles	45 miles	50–30 miles*
	20,000	75 miles	55 miles	60–30 miles*
	30,000	95 miles	75 miles	80–30 miles
30 miles	5,000	55 miles	35 miles	40–30 miles*
	10,000	55 miles	35 miles	40–30 miles*
	20,000	60 miles	40 miles	40–30 miles*
	30,000	95 miles	75 miles	80–30 miles*

* Within 30 miles of the coast, positions are required once per minute and height measurements every 2 minutes.

TABLE III

Height of Raid.	Distance from Coast of ' Sector Warning ' when Distance of Aerodrome from Coast is			Normal maximum Range of Detection of an existing Station.
	60 Miles.	40 Miles.	30 Miles.	
5,000 ft.	80	65	55	70 miles
10,000 ft.	80	65	55	100 miles
20,000 ft.	90	75	60	140 miles*
30,000 ft.	100	95	95	170 miles*

* Estimated as proportional to height.

TABLE IV

Height of Raid.	Normal Range of Detection.	Range of ' Sector Warning.'	Distance of Aerodrome from Coast 60 Miles	40 Miles	At Coast
			Position of Interception in Relation to Coast.		
5,000 ft.	70 miles	58 miles	– 10 miles*	At coast	15 miles
10,000 ft.	100 miles	88 miles	At coast	10 miles	30 miles
20,000 ft.	140 miles	128 miles	20 miles	30 miles	50 miles

* Inland.

TABLE V

Height of Raid (Feet).	Range of ' Sector Warning ' (Miles) Distance of Fighter Aerodrome from Coast.		
	60 Miles.	30 Miles.	At Coast.
5,000	90	65	45
10,000	95	65	55
20,000	100	75	70
30,000	110	100	100

APPENDIX No. 4

FORMULA FOR DETERMINING THE POSITION OF INTERCEPTION

In determining the requirements of radar for interception purposes, the climbing speed of the fighters has been chosen so that while the height of the raid is attained in sufficient time, the fighters will also have progressed as far from the aerodrome as possible. Actually for the distances under consideration it makes little difference to the position of interception, if the fighters climb at the maximum rate of climb and on attaining the required height fly at their normal cruising speed, or alternatively climb at a greater speed with a correspondingly lower rate of climb.

For raids at altitudes up to 20,000 ft. the position of interception is given by the following formula :—

$$X = \frac{SV}{60(S+V)}\left(\frac{60R}{V} - \frac{H}{h}\,\frac{(S-C)}{S} - \frac{60D}{S} - t\right)$$

$$\text{Provided } D + R = \text{or} > \frac{HC}{60h} + \frac{V}{60}\left(\frac{H}{h} + t\right)$$

Where

S = cruising speed of fighters (m.p.h.).
C = average climbing speed of fighters (m.p.h.).
h = average rate of climb of fighters (ft./min.).
D = distance of aerodrome from coast (miles).
R = range of ' Sector Warning ' from coast (miles).
H = height of raid (ft.).
V = speed of raiders (m.p.h.).
t = time (in minutes) from ' Sector Warning ' to ' take off ' of fighters + time lag.
X = position of interception in relation to coast (miles) (X is positive when interception is made out to sea).

Present day performance of fighter taken as :—

$S = 270$ m.p.h., $C = 180$ m.p.h., $h = 2{,}000$ ft./min.

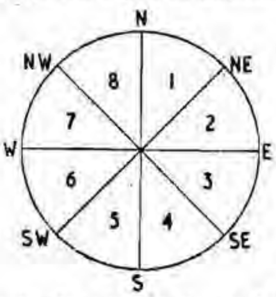
APPENDIX No. 5

WIRELESS OBSERVER UNITS

Wireless Observer Units provided air intelligence in areas where landline communications were not available or were considered unsuitable, and in overseas theatres of war carried out the duties normally performed in the United Kingdom by detached posts of the Royal Observer Corps. The unit, when deployed for operations, usually consisted of a Unit Headquarters, two Advanced Section Headquarters, and about 30 Advanced Observer Posts.

The Unit Headquarters was, whenever possible, sited at or within easy reach of an operational station, or the sector or group headquarters to which the unit was operationally responsible, and from whom it received information and instructions. The functions of the section headquarters were largely those of supervision, and it was consequently normally sited as near as possible to the centre of the posts for which it was responsible. Each advanced post was, as far as possible, completely self-contained and fully mobile. The signals organisation consisted of a point-to-point W/T system with ground observers linked to the A.O.P. W/T station by field telephone. At Unit Headquarters a W/T Control Station, working on two frequencies, was established for reception of plots, control of W/T traffic, and transmission of time signals and frequency checks.

The ground observer attempted to observe and report accurately the movements of all aircraft, friendly, hostile or unidentified, which came within his field of vision. In the United Kingdom the grid system of plotting was usually employed, but overseas the following method was found very satisfactory. The area surrounding the O.P. was divided into eight sectors with the O.P. as the centre, and each sector given an appropriate figure in addition to compass points thus :—



The dividing lines were visualised as continuing indefinitely into distance, and it was thus possible to classify immediately an aircraft passing within range as being one or another of the eight sectors, and the appropriate figure given to the plot. Each plot consisted of two groups of five symbols which conveyed the following information :—

(*a*) Number of aircraft in plot.
(*b*) Identification.
(*c*) Height.
(*d*) Direction.
(*e*) Post (Each A.O.P. was numbered 1–30).
(*f*) Sector in which aircraft observed.
(*g*) Distance of aircraft from post.

Method of Coding Aircraft Plots

First Group.	1st figure indicated number of aircraft.	1 = 1 aircraft. 2 = 2 ,, 3 = 3 ,, 4 = 4 ,, 5 = 5–6 ,, 6 = 7–12 ,, 7 = 12–20 ,, 8 = 21–50 ,, 9 = over 50 ,,
First Group.	2nd figure identified aircraft.	1 = Hostile. 2 = Unidentified. 3 = Sound plot. 4 = Friendly fighter. 5 = Friendly coastal. 6 = Friendly bomber. 7 = Training. 8 = Naval or Army Co-operation. 9 = Communication or Civil. 0 = British or Neutral not identified by type.
First Group.	3rd and 4th figures.	Height in thousands of feet.
First Group.	5th figure gave direction.	1 = North-East. 2 = East. 3 = South-East. 4 = South. 5 = South-West. 6 = West. 7 = North-West. 8 = North. 9 = Aircraft landed. 0 = Aircraft circling.
Second Group.	1st and 2nd figures	= Post number.
	3rd figure	= Sector figure.
	4th and 5th figures	= Distance in miles.

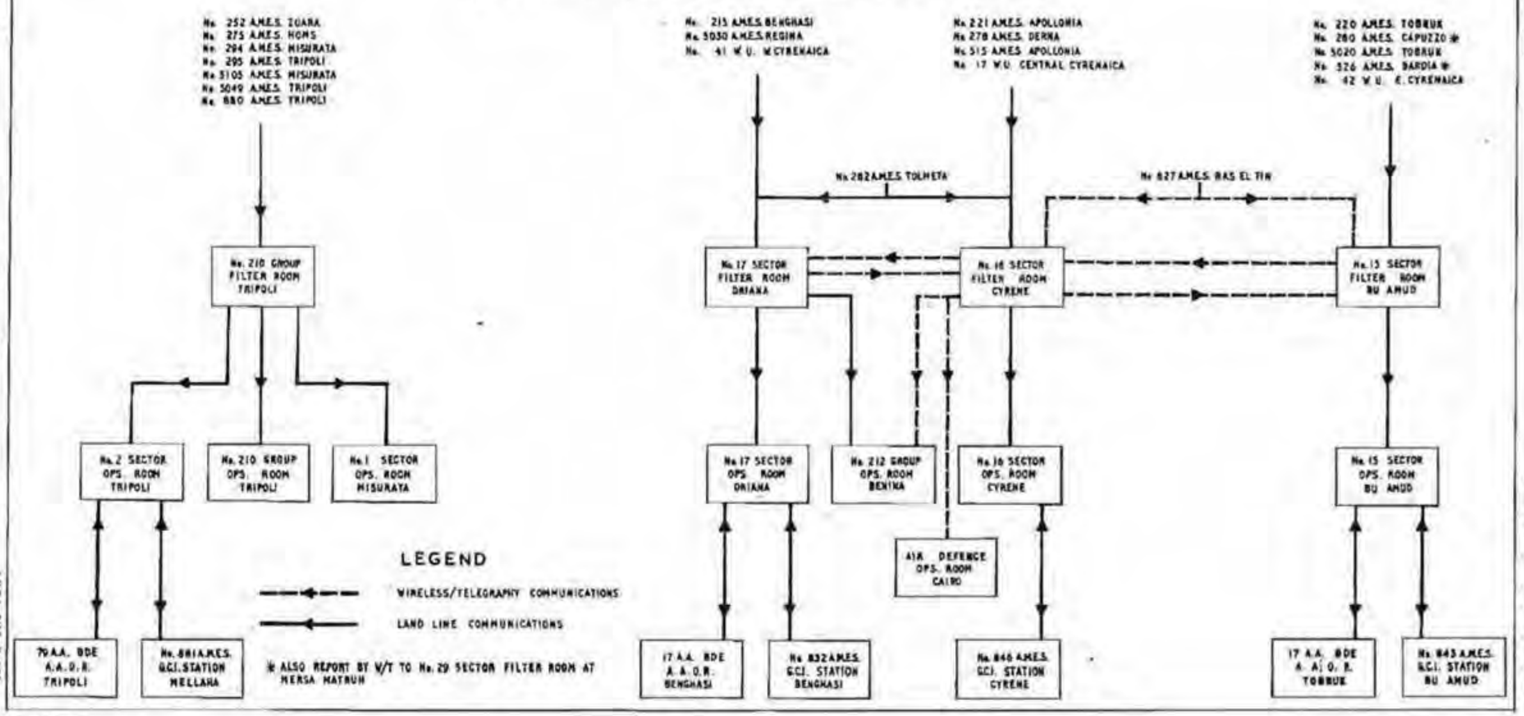
Facing Page No.

APPENDIX 6

AIR DEFENCE OF LIBYA

AIR REPORTING ORGANISATION 22 AUGUST 1943

AIR MINISTRY EXPERIMENTAL STATIONS AND WIRELESS UNITS



A.H.B.1 DIAG. No 829

C.B.H.21577

To provide the controller with adequate tracking information and to ensure that identification of tracks which crossed did not change at the cross-over, plots were passed at one-minute intervals. It was essential that wireless operators logged all plots emanating from other posts to provide lateral communication between observers and to ensure continuity especially when visibility was bad and when the unit was deployed in hilly or mountainous country. Observers were, however, warned against accepting the opinion of others on such matters as the height of an aircraft, since it could change very rapidly, and were encouraged to make their own estimations at all times. The code figure which was provided in the identification section for a sound plot was used in periods of bad visibility or at night when identification was impracticable since aircraft could only be heard and not seen.

APPENDIX No. 7

SIGNALS DIRECTIF FOR THE AIR DEFENCE OF TRIPOLITANIA, JANUARY 1943

Appendix A.	Schedule of W/T Channels and Priority of Opening.
Appendix B.	Diagrams of W/T Channels. (Not included.)
Appendix C.	Schedule of Land Lines.
Appendix D.	Instructions for Track Broadcasting.

This directif supersedes Air Headquarters, Egypt, Signals Instructions No. 25 which is to be destroyed.

2. Nos. 1 and 2 Sectors are forming under No. 243 Wing. The Wing will be transferred from W-D Command to this Command at a time to be decided by A.O.C. W-D.

3. No. 1 Sector will be sited near Misurata, and No. 2 Sector with the Wing Headquarters, near Tripoli.

4. No. 8 Signals Centre will be in the Tripoli vicinity.

5. All Signals facilities will originally be supplied by Mobile Signals Units. The Units are self-administering. They are being made available by A.O.C. W-D and details of their scope are not yet decided.

6. Until a considerable degree of stability has been obtained it will probably not be possible to implement the whole of this plan. The order of priority in which the various W/T channels are to be opened is indicated.

Intention

7. To organise and provide communications which will be adequate for Defence purposes.

Siting of Units

8. No. 243 Wing, No. 2 Sector, and No. 8 Signals Centre are to be so sited that one common Signals Station can serve all of them. Channels shown as terminating in any of these will all in fact terminate in the same place.

Scale of Provision

9. Provision of equipment and men will ultimately allow for the following W/T Channels :—

(*a*) Headquarters No. 243 Wing to Air Headquarters, Egypt. A channel for aircraft movement and intelligence messages. It may also be used for the passage of priority traffic when the Signals Centre Channel is at capacity.

(*b*) No. 8 Signals Centre to T.M.E. All ordinary traffic for A.H.Q. Egypt and for units not working direct should be passed on this channel.

(*c*) No. 8 Signals Centre to No. 6 Signals Centre (No. 212 Group). Primarily for Met. and Movements.

(*d*) No. 8 Signals Centre to No. 1 Sector Administrative traffic.

(*e*) No. 243 Wing to No. 2 Sector. This channel is intended primarily for Wing Operational traffic and Meteorological messages.

(*f*) No. 1 Sector to No. 2 Sector. A duplex channel,—that is, two single-way channels which can be worked simultaneously. The *transmitting* operator on this channel will be connected by telephone to the *filter teller*. He will broadcast spoken plots, as detailed by the instructions given in Appendix D. The *receiving operator* will be connected by telephone to an operations room *plotter*, and will speak plots broadcast by the other sector as he receives them. This channel will also be used for passing aircraft movement messages and for Sector liaison. All messages, except plots, are to be written by the originator in the appropriate code, and passed by hand into the W/T office, except that where they are very short they may be spoken (in code) by the teller direct to the operator. Great care must be taken to ensure that this channel does not become clogged by simultaneously passing written and spoken messages. It is *essential* too, that when messages are spoken to the operator, they be spoken exactly as they are to be transmitted. That is in code and with address, serial number and ending. The traffic supervisor is to ensure that only messages originating in the operations room in operational codes are passed on this channel, when other channels are open. Inter-Sector Cypher messages must be passed on one of the other channels.

(*g*) Each Sector will have one channel to its R.D.F. stations, on which the plotting code will be used. Administrative traffic will also be passed where the R.D.F. stations are too far for D.R. to suffice, the ' T ' code in transposition being employed instead of cypher.

(*h*) Each Sector will maintain one channel to its fighter squadron's Operational offices ; lines will no doubt be available from the beginning, but an emergency W/T link must be maintained.

(*i*) Each Sector will keep a channel for working with ships. Instructions for the use of this channel are given in M.C.A.O.s.

(*j*) No. 2 Sector will keep an emergency channel with its fixer stations.

Codes

10. Codes for use on all these channels are supplied with these instructions.

R/T

11. Equipment and men will be provided for two V.H.F. R/T channels at each Sector, for 3 H.F. D/F stations in No. 2 Sector, and for a V.H.F. D/F in No. 1 Sector.

12. Aircraft escorting convoys are to work on channel C, but on all other occasions are to work on the Sector frequencies.

13. R/T failures, whether partial or complete, are to be reported to this Headquarters without delay. Information is to include the time, nature of flight, cause and remedy.

R.D.F.

14. The following R.D.F. stations will be installed initially under Headquarters Royal Air Force, Middle East, arrangements :—

Tripoli	M.R.U.	No. 274
	C.O.L.	No. 888
	G.C.I.	No. 881
Misurata	M.R.U.	No. 294
	C.O.L.	No. 880
Home	C.O.L.	(Provision not decided).

Landlines

15. Landlines will be arranged by No. 4 A.F. Sigs. (N.S.Y.). A schedule is attached as Appendix C. No. 243 Wing is responsible for originating suggestions for the development of line communications in Tripolitania.

Z Broadcast

16. Z Broadcast messages are to be taken by No. 8 Signals Centre and No. 1 Sector, and passed by D.R. to local units, as applicable.

Progress Reports

17. Progress reports are to be submitted to this Headquarters by each Signals Station. They are to be made weekly, for the first few weeks, and will subsequently be required monthly until this plan is completed. Reports are to be made on the following subjects :—

(*a*) Land Lines, including operations rooms internal work.

(*b*) Line Plans.

(*c*) W/T Channels and equipment in use.

(*d*) Cypher traffic levels.

(*e*) Causes of Signals delay.

(*f*) Strength (to include cypher officers and sergeants).

(*g*) Equipment spare or being erected.

(*h*) Equipment urgently required.

(*i*) Power supplies.

(*j*) Arrangements with other formations or Services.

(*k*) D/R Services.

(*l*) R.D.F.

(*m*) Failures.

(*n*) Matters of general interest which have impeded or assisted progress.

Transition to Static State

18. The transition from mobile to static working should be achieved as quickly as possible. Adequate static equipment will be provided as soon as stations are ready to receive it. The transition from mobile to static working is not to be delayed for lack of permanent plans or facilities. Where permanency cannot be achieved interim expedients are to be adopted.

Supply of Equipment

19. Supply of equipment will be arranged by this Headquarters up to the scale (with spares) given in para. 9. Minor items are to be demanded on local A.S.P.s. Where they are unable to meet urgent demands at once, reference should be made to this Headquarters, the demand voucher number, date, and unit demanded on being quoted. It is imperative to avoid duplication in urgent supplying.

(Signed) Q. W. ROSS, Wg. Cdr.
For Air Vice-Marshal, Air Officer Commanding,
Royal Air Force, Egypt.

Air H.Q. Egypt Signals Instruction No. 26, 17 January 1943.

APPENDIX 'A'

Channel.	*Stations.*	*Frequency.*	*Detail.*	*Priority.*
(*a*) 2	A.H.Q., Egypt No. 243 Wing	10,330 5,310	Aircraft Movements, Intelligence.	1
(*b*) 2	T.M.E. No. 8 Signals Centre		Temporarily joining S.C.6	1
(*c*) 2 (S.C.7)	Nos. 8, 7, 6 Signals Centre (Common Channel)	4,250	Administration	1
(*d*) 2	No. 8 Signals Centre No. 1 Sector	3,890	Administration	3
(*e*) 2	No. 243 Wing No. 1 Sector	3,840	Intelligence and Met.	4
(*f*) 2	No. 1 Sector No. 2 Sector	R 3,960 T 4,077 R 4,077 T 3,960	Duplex Channel Liaison	1
(*g*) 2	No. 1 Sector R.D.F. Stations	380 or 3,120	Plotting Channel	1
(*g*) 3	No. 2 Sector R.D.F. Stations	230 or 3,150	Plotting Channel	1
(*h*) 2	No. 1 Sector Fighter L.G.s	3,230	Movements Stand-Bi	2
(*h*) 3	No. 2 Sector Fighter L.G.s	3,350	Movements Stand-Bi	2
(*i*) 2	No. 1 and No. 2 Sectors Ships	4,350	General R/T Channel To Ships	6
(*j*) 2	No. 2 Sector V.H.F. D/F Stations	3,120	Plotting Channel	5
S.C.1–	No. 6 Signals Centre	10,640, 10,020 7,760, 7,060 5,820, 5,710 4,840, 4,400	Auto Hi-Speed Channel	For information
S.C.6–	No. 6 Signals Centre T.M.E.	10,160, 7,740	Stand-Bi to S.C.10	For information

APPENDIX 'C'

SCHEDULE OF LINES

1.	Tripoli ..	No. 243 Wing H.Q. ..	Benghazi ..	No. 212 Group H.Q. ..	Liaison ..	Speech ..	Priority 3
2.	Tripoli ..	No. 243 Wing H.Q. ..	Cairo ..	A.H.Q., Egypt	Admin./Ops. ..	Teleprinter ..	Priority 3
3.	Tripoli ..	No. 243 Wing H.Q. ..	Misurata ..	No. 1 Sector	Order	Speech ..	Priority 2
4.	Tripoli ..	No. 243 Wing H.Q. ..	Misurata ..	No. 1 Sector	Information ..	Speech ..	Priority 2
5.	Tripoli ..	No. 243 Wing H.Q. ..	Misurata ..	No. 1 Sector	Admin./Ops. ..	Teleprinter ..	Priority 1
6.	Tripoli ..	No. 243 Wing H.Q. ..	Tripoli ..	Main exc.	Speech		Priority 1
7.	Tripoli ..	No. 243 Wing H.Q. ..	Tripoli ..	Main exc.	Speech		Priority 2
8.	Tripoli ..	No. 243 Wing H.Q. ..	Tripoli ..	Balloon Squadron ..	Speech		Priority 1
9.	Tripoli ..	No. 243 Wing H.Q. ..	Tripoli ..	Navy House	Speech		Priority 1
10.							
11.							
12.							
13.	Tripoli ..	No. 2 Sector H.Q. ..	Tripoli ..	Fighter L.G.	Order	Speech ..	Priority 1
14.	Tripoli ..	No. 2 Sector H.Q. ..	Tripoli ..	Fighter L.G.	Admin.	Telegraph ..	Priority 1
15.	Tripoli ..	No. 2 Sector H.Q. ..	Tripoli ..	No. 274 R.D.F. Station ..	Plotting ..	Speech ..	Priority 1
16.	Tripoli ..	No. 2 Sector H.Q. ..	Tripoli ..	No. 888 R.D.F. Station ..	Plotting ..	Speech ..	Priority 2
17.	Tripoli ..	No. 2 Sector H.Q. ..	Tripoli ..	No. 881 R.D.F. Station ..	Plotting ..	Speech ..	Priority 1
18.~	Tripoli ..	No. 2 Sector H.Q. ..	Tripoli ..	No. 881 R.D.F. Station ..	Liaison	Speech ..	Priority 2
19.	Tripoli ..	No. 2 Sector H.Q. ..	Tripoli ..	Bomber L.G. Station ..	Movements ..	Speech ..	Priority 2
20.	Tripoli ..	No. 2 Sector H.Q. ..	Tripoli ..	A D/F Station	Plotting ..	Speech ..	Priority 2
21.	Tripoli ..	No. 2 Sector H.Q. ..	Tripoli ..	B D/F Station	Plotting ..	Speech ..	Priority 2
22.	Tripoli ..	No. 2 Sector H.Q. ..	..	B D/F Station	Plotting ..	Speech ..	Priority 2
23.	Tripoli ..	No. 2 Sector H.Q. ..	Misurata ..	No. 1 Sector	Liaison	Speech ..	Priority 1
24.	Tripoli ..	No. 2 Sector H.Q. ..	Misurata ..	No. 1 Sector	Plotting ..	Speech ..	Priority 2
25.	Tripoli ..	No. 2 Sector H.Q. ..	Misurata ..	No. 1 Sector	Plotting ..	Speech ..	Priority 2
26.	Tripoli ..	No. 2 Sector H.Q. ..	Homs ..	No. R.D.F. Station ..	Plotting ..	Speech ..	
27.	Tripoli ..	No. 888 R.D.F. Station	Tripoli ..	No. 274 R.D.F. Station ..	Liaison	Speech ..	Priority 1
28.	Tripoli ..	No. 881 R.D.F. Station	Misurata ..	No. 274 R.D.F. Station ..	Liaison	Speech ..	Priority 2
29.	Misurata ..	No. 2 Sector	Misurata ..	No. 294 R.D.F. Station ..	Plotting	Speech ..	Priority 1
30.	Misurata ..	No. 2 Sector	Misurata ..	No. 880 R.D.F. Station ..	Plotting ..	Speech ..	Priority 2
31.	Misurata ..	No. 2 Sector	Misurata ..	Fighter L.G.	Orders	Speech ..	Priority 1
32.	Misurata ..	No. 2 Sector	Misurata ..	Fighter L.G.	Admin.	Telegraph ..	Priority 1
33.	Misurata ..	No. 2 Sector	Misurata ..	V.H.F. D/F Station ..	Plotting ..	Speech ..	Priority 2
34.	Misurata ..	No. 2 Sector	Misurata ..	Bomber L.G.	Movements ..	Speech ..	Priority 2
35.	Misurata ..	No. 880 R.D.F. Station	Misurata ..	No. 294 R.D.F. Station ..	Liaison	Speech ..	Priority 1

APPENDIX 'D'

TRACK BROADCASTS BETWEEN WINGS

The shortage of Land Lines necessitates the use of W/T for passing tracks between certain Wing Filter Rooms.

Types of Tracks and When Passed

2. Filtered tracks of Hostile, 'Unidentified' and certain 'Friendly' aircraft will be broadcast on Track Broadcast Channel when they appear to be passing into another Filter Area.

Procedure to be Employed

3. The procedure detailed below is to be used for the passing of Tracks in the Eastern Mediterranean.

4. Information passed on the Track Broadcast Channel is divided into sections. 'Hostile and Unidentified Aircraft,' 'Friendly Aircraft by day and at night when Night Fighters are NOT operating,' 'Friendly Aircraft at Night when Night Fighters ARE operating.'

Hostile and Unidentified Aircraft

5. Tracks of all Hostile and Unidentified Aircraft will be plotted in full and continuously until the Filter Officer is certain that further information is necessary.

6. 'Friendly Aircraft by day and at night when Night Fighters are NOT operating.'

If showing I.F.F. and conforming to (*a*), not to be passed.

NOT showing I.F.F. and conforming to (*a*), not to be passed.

If showing I.F.F. and NOT conforming to (*a*), pass 2 plots.

Not showing I.F.F. and NOT conforming to (*a*), pass 2 plots.

(*a*) S.D. 158 (Part 1) and H.Q. R.A.F. M.E. S.44115/Ops. dated October 1941 (Routeing, Recognition and Identification of Aircraft in the Middle East).

7. 'Friendly Aircraft at night when Night Fighters ARE operating.'

If showing I.F.F. and conforming to (*a*) above, pass 2 plots.

NOT showing I.F.F. and conforming to (*a*), to be passed in full.

If showing I.F.F. but NOT conforming to (*a*) (until acknowledged).

NOT showing I.F.F. and NOT conforming to (*a*) (*see* para. 11).

Dark Raids

8. When a Hostile has been classified as a 'Dark Raid' the receiving Filter Room will be notified on the Liaison Channel. The raid will continue to be broadcast as Hostile until the interception is broken off or the enemy destroyed. Each track will then be broadcast according to its known identification.

Handing Over and Acknowledging of the Tracks

9. All tracks will be acknowledged by the Filter Room taking over by a re-broadcast of the Track. In the case of Friendly aircraft the Filter Room handing over will cease to pass plots. In the case of hostile or unidentified aircraft the Filter Officer will continue to pass plots if he considers they will be of use to the receiving area.

Change of Raid Indicators

10. On an unidentified aircraft being identified the indicator will be changed. This change will be acknowledged by a re-broadcast of tracks from the receiving Filter Room. Plots will continue to be passed according to the new indication given.

Corrections to Track Numbers

11. Corrections to Track numbers will be acknowledged by a re-broadcast.

Code to be Used

12. The Code shown in the supplement to this Appendix will be used for passing plots.

Responsibility of Filter Officer

13. The Filter Officer will be responsible for ensuring that the information is transmitted correctly.

14. Normal aircraft movements information is to be passed on the Liaison Channel unless the Track Channel is not in use for Broadcasting.

Security Precautions to be Observed

15. No amplifying groups or deviations from the approved code are to be passed. Great care must be exercised to ensure that the minimum amount of information concerning the movements of Friendly aircraft is transmitted.

SUPPLEMENT TO APPENDIX 'D'

Code to be Employed

1. Information will be passed by W/T in the following Code :—

1st Group.—Track Number and Identity.

2nd Group.—Type of Aircraft and Identification.

3rd Group.—Direction of Flights in Code.

4th Group.—Square and Grid reference.

5th Group.—Number of Aircraft.

6th Group.—Height in thousands of feet.

Passing of Plots

2. Plots will be passed in the following order :—

In the first plot passed all the Groups of the code will be employed.

e.g. H38 — QB — R — PW4630 — 01 — A15
Hostile Track 38 — 2-Engined Bomber — Flying East — At PW 4630 — 1 Aircraft — 15000 Feet.

Successive plots will normally be formed on the First and Fourth Groups unless any change occurs in the others when they will be included as required :—

e.g. H38 — PW4932
H38 — PW5234 — A10
H38 — PW5030.

Track Numbers and Corrections

3. Filter Rooms will allot Track numbers from blocks indicated in H.Q. R.A.F. M.E. Signals Instruction No. 84 dated 2nd June 1942.

4. The Serial number allotted will remain with the track throughout its life. Corrections on track numbers will be indicated by the use of the Code Group TC (Track Correction). The Filter Room wishing to correct track numbers will broadcast :—

TC — Original Track Number — New Track Number

e.g. TC — H38 — H37.

Further Information and Interrogation

5. When further information is required to be passed or any Broadcast is queried by the receiving station the following permitted vocabulary will be employed :—

A—Height.	Q—South
C—Affirmative, Correct	R—East
F—Friendly	S—West
H—Hostile	T—Track
J—Faded	V—Shipping Plot, Vessel
K—Class of (Plot Height)	W—Number of Aircraft
M—Negative	Y—Showing I.F.F.
O—Orbiting	Z—Showing Broad I.F.F.
P—North	INT—Interrogative
HF—Dark Raid (to be passed on Liaison channel only)	TC—Track Correction
	CN—Naval Aircraft
FB—Four-Engined Bomber	CR—Coastal Aircraft
TB—Three-Engined Bomber	CC—Civil Aircraft
QB—Two-Engined Bomber	CS—Seaplane
BB—Bomber	CU—Fighter

6. When a Filter Room desires to query a plot passed to it, the interrogative Group and Track number will always be employed :—

Examples

Station A transmits—H38 INT TC H37 (should Track 38 be 37).

Station B replies—C—TC—H38—H37 (Yes. Correct track 38 to read 37).

Station A transmits—X21—INT—WC (Query Number of Aircraft Track 21).

Station B replies—X21—W—C—02 (Number of Aircraft Track X21 is 2).

APPENDIX No. 8

EXTRACT FROM A LETTER FROM AN R.A.F. OFFICER IN CHARGE OF A ROAD CONVOY DELIVERING V.H.F. TWIN-CHANNEL RADIO EQUIPMENT TO SECTOR OPERATIONS ROOM VIZAGAPATAM FROM HEADQUARTERS No. 225 GROUP BANGALORE

15th October

Left Bangalore 1810 hours. At 54th milestone prime mover failed and refused to start. 1045 M.T.M. working on engine until 0500/16 without result.

16th October

0700. Resumed work on engine—carburettor stripped down—auto vac stripped down and main petrol tank drained. Water everywhere. Engine started 1030 hrs. During this halt I tapped in on a telephone line by the road, only to find out from village 15 miles distant that the line back to Chic Ballapur was down, hence could not get through to Bangalore. Everything went well as far as Gooty. Here the road (as per Movement Control) passed beneath a bridge 10 feet high, hence detour via Pyaali was made. The road between Pyaali and Jannagiri deteriorated until we did not know which was road and which paddy. Finally I halted the vehicle on a bund with 40 foot drop on either side and which was partially washed away by floods, deeming it much too dangerous for night driving.

17th October

Engine had once again to be stripped down before she would start and we moved off about 1030. Jannagiri presented difficulties re a bridge definitely unsuited for 8-ton vehicles. We crossed this with tongues in cheek and proceeded as far as Patkikandi where I despatched first wire. Passing through to Aspei a flooded ford necessitated a further detour via Devanakonda and back to Aspei. We arrived at Adoni 1730 hrs. and started refuelling. Road from there to Tungabhadra Bridge was of the 5 m.p.h. variety, every mile of it containing some ford which required one man to wade through and test the bottom and depth. I personally waded through three. We arrived at bridge at 2359 and after an hour's delay awaiting special sanction to cross by night we passed over bridge at 0110/18.

18th October

Five miles later road gave way under offside wheels and stuck. By uncoupling the trailer and digging away most of the mud, prime mover was cleared within 30 minutes and contingent proceeded as far as next tributary of Tungabhadra, where a ford of 120 yards width proved on test to be at least 2 feet 9 inches to 3 feet deep 20 yards from edge. Stopped here at 0300 hours awaiting daylight before making attempt to cross. Dressed in bathing costume I preceded the vehicles at 0800 hours. By this time water had fallen 9 inches and vehicles slowly crossed to far side. Proceeded a further 4 miles and at 0900 approx. arrived at second large ford. Here bullocks were walking through and driver judged water shallow and proceeded without further test. Left-hand side of road, however, gave way under weight of vehicle and dropped into 3 feet of water, vehicle tipping up at an angle of some 70 degrees. Engine failed and vehicle was irretrievably stuck.

Bunyan, White and I walked 2 miles to nearest village where we managed to borrow a bicycle on which I proceeded to Raichur—12 miles distant, arriving there on my knees. A quick lunch at Railway Station and then contacted the D.S.P. who from that point onward did everything in his power to put us right. By evening he had some 100 men available with ropes and we proceeded to scene of disaster. The trailer was pulled out reasonably easily, but the transmitting vehicle refused to move. Party worked on until 2230 by light of petrol-mex lamps but made no impression. D.S.P. sent off telegram for me that evening.

19th October

S.I.P. arrived early with his men. Aerial stay wires were passed round vehicle and tightened by pulley tackle and anchored on ground 30 yards away to prevent subsidence. Vehicle had slipped further during the night and was over at an angle of 60 degrees. All moveable gear was shifted from transmitting vehicle and I was just going to remove Transmitters—a dangerous proposition at that angle—when the S.I.P. asked permission to make third desperate attempt to move her. The steel wires on side released more men to pull from behind. For 10 minutes they pulled and strained—then something moved. This put them into a frenzy of delight and their successive efforts were terrific. I was at the wheel when, with a jar, she moved back. Stay wires were then removed as fear of capsizing was smaller and with a final effort, amidst terrific cheering, vehicle moved back up the slope onto the road.

Work started immediately stripping down magneto and cleaning out carburettor. In reassembling the rotor arm was damaged but this, as was later proved, was a small matter. The insulation of coil and condenser was nil. Water had gone down so vehicle was manhandled over stream before night fall.

20th October

Three of the party, including myself, set off at 1000 hours by tonga for Raichur, with damaged magneto to attempt repair. Tonga pony refused to take us more than 3 miles so other two had to walk and bullock cart the other 9 miles. Arriving at Raichur I went straight to D.S.P., borrowed his car and, with the S.I.P. went to workshop with mag. and put repair work in hand. Condenser showed only 70,000 ohms in megger and that of coil was negligible. Mag. was therefore left with mechanic who cooked it overnight over a small electric fire. Party returned to vehicle 1900 hours by D.S.P.s car. I allotted petrol to various vehicles involved in salvage work.

21st October

S.I.P. and mechanic arrived 1030 from Raichur with mag., which was now giving a ⅜-inch spark—still no joy even after autovac, carburettor and plugs had been cleaned a second time. Then found water had penetrated into the sump, so this was drained off, fresh oil put in—still no joy. Mag. was shifted again, heated once more over a wood fire and replaced. This time vehicle fired after a quarter mile run powered by local villagers and police. She was missing badly but we did not dare to stop her to adjust timing. Hopes were again thwarted for as soon as load was applied, engine again failed and mag. was again found to be faulty. Mag. was taken back into Raichur for re-cook and mechanic promised to bring out another mag. to get us into Raichur.

22nd October

Mechanic and S.I.P. arrived 1500 hours with mag.—fitted and engine started again by pushing. Everything set, we moved off towards Raichur—steam issuing from every conceivable bearing. We had only gone 2 miles when Jeep from Bangalore overtook us. The scene of rejoicing was too much for the Crossley, the engine of which failed once again. Spare mag. from Jeep then installed and contingent arrived in Raichur 1930 hrs. We parked at Station and had the first decent meal for quite a while.

23rd October

Transmitting vehicle taken along to the workshop and regreased by M.T.M. and mechanic. Mag. timing properly adjusted and vehicle properly serviceable for the first time at 1200 hrs. News had come through from overseer of Kistna Bridge that an archway built for the opening ceremony by H.E.H. The Nizam was only 10 feet high. Jeep was sent to investigate and, too true, hopes of moving off were once again dashed. Railway immediately approached and requested to get B.F.R.s and necessary permission to carry vehicle and trailer by rail to first station over the Kistna. Sholapur replied N/A, so wire sent to Bombay to forward necessary trucks.

24th October

Still awaiting news of B.F.R.s. Comfortably installed in Travellers Bungalow, but lads will become barbaric if it is impossible to move shortly. Considering the amount of work which has been done by the local Police, I should like the C.S.O. to write letters of appreciation to the following people and their respective staffs :—

1. D.S.P., Raichur.
2. Sub-Inspector Police, Raichur. Mr. B. Billimoria, Yergere, Riachur.
3. Sub-Inspector Police, Raichur. Mr. Mainahuddin.

The health of the lads has been good. Thomas has a septic leg but is having it dressed at the Raichur hospital. Should it become worse I shall send him back to Bangalore. We have rations sufficient for 5–6 days. If more required shall wire Secunderabad. Re telephone communications, no such thing exists here. Railway have control lines to Madras and Guntakel but cannot be plugged through to Bangalore. P. & T. have telegraph routes but no through speech circuits. If B.F.R.s are necessary to cross the Godaveri Bridge will you arrange for them to be available. I shall wait in Secunderabad until I have cast iron gen re the remainder of road, *i.e.*, if I ever get to Secunderabad !

Regretting that I have fallen down on the job.

BRITISH AND AMERICAN VERSIONS OF I.F.F. MARKS III, IIIG and IIIG(R)

Britain and America collaborated in the development of I.F.F. Marks III, IIIG and IIIG(R) and each country produced versions of all three. The aim was to obtain a universal system such that aircraft and ships of either country could identify themselves to the other country's ground stations and ships, and so that airborne I.F.F. sets produced in either country were interchangeable. Some equipments worked on 24-volt power supplies and some on 12 volts so that two versions of each set were required. The British versions were given different R numbers.

List of I.F.F. Mark III Transponders

British or U.S.	Mark	Type No.	Description.
British	III	ARI.5025 comprising R 3067 (12v) or R 3090 (24v).	I.F.F. Mk. III used by British Aircraft.
American	III III	ABK SCR 595	12 or 24-volt equipment used by U.S. Navy, Mk. III facilities only. 12 or 24-volt equipments used by U.S. Army. Similar to ABK in all respects.
American	IIIGO	SCR 695	12 or 24-volt equipments used by U.S. Army. Mk. III and IIIG facilities but no Rooster.
American-British	IIIG	R 3598	American SCR 695 modified for Rooster operation, to fit into British aircraft.
British	IIIG(R)	ARI.5731 comprising R 3120 (12v) or R 3121 (24v)	Standard British equipment giving full Mk. IIIGR facilities.
American	IIIG(R)	AN/APX 1	Standard U.S. Army and Navy Mk. IIIG(R) equipment. 12 and 24-volt versions available.
American	IIIG(R)	AN/APX 2	AN/APX 1 together with interrogator which will interrogate beacons and other I.F.F. 12 and 24-volt versions available.
American	IIIG(R)	AN/APX 8	AN/APX 2 with directional aerials for interrogator to give homing facilities.

APPENDIX No. 10

RESTRICTION OF USE OF I.F.F. MARK III

APPENDIX 'A' TO S.H.A.E.F. OP. MEMO. No. 19

SECOND EDITION, DATED 15th APRIL 1945

1. Area

The rules contained in this Appendix apply only to those areas shown below within the zone of the A.E.F.

(*a*) *Northern Boundary*
Latitude 54° North.

(*b*) *Southern Boundary*
(1) 43° North for the area WEST of longitude 7° East.
(2) 46° North for the area EAST of longitude 7° East.

(*c*) *Western Boundary*
WEST Coast of WALES and ENGLAND to LANDS END, thence to USHANT, then Southwards along the Western border of FRANCE.

2. Codes

(*a*) The 'Narrow' pulse (Code 1) of the I.F.F. set will be used on all occasions, except :—

(1) The 'Distress' Code will be used for the purpose of indicating distress, or by aircraft which have located survivors in the sea and remain orbiting them to assist in their rescue. For the latter purpose its use is limited to one aircraft at a time for each incident.

(2) Code 4 will be used by ships and aircraft fitted with I.F.F. Mk. III or variants of Mk. III and engaged in shadowing enemy surface vessels or enemy submarines on the surface while in contact.

(3) Code 6 will be used by all land-based operational fighter aircraft fitted with I.F.F. Mark III or variants of Mk. III.

(*b*) Application for use of the codes will be made to Supreme Headquarters, A.E.F.

3. Transponders

(*a*) *By aircraft*

All aircraft of the A.E.F. will be fitted for and carry I.F.F. Mk. III or IIIG transponders except, at the discretion of Tactical Air Force Commanders, certain training and liaison type aircraft and P.51 series aircraft when fitted with long range fuel tanks. Transponders will be used by all other aircraft by day and by night in accordance with paragraph 2 above with the following exceptions :—

(1) Aircraft, whose operations are confined to the area of the English Channel between lines drawn from LANDS END to USHANT and from the edge of the port defended area of CALAIS to FOLKESTONE excluding the limits of port defended areas within these two boundaries, need not use their transponders if otherwise ordered by the air command concerned.

(2) Outward bound aircraft proceeding to enemy territory need not use I.F.F. unless specifically requested by ground control. On the return flight transponders will be switched on when within 75 miles of Allied held territory on the Continent.

(3) When formations of three or more aircraft are flying, only two aircraft in each formation will switch on their transponders. For this purpose a formation will be understood to consist of all aircraft taking off from any one airfield for the same mission.

(4) *Bomber Command R.A.F.*—Outward bound aircraft of Bomber Command and their fighter escort proceeding to enemy held territory will not switch on their transponders. On the return flight the following aircraft will switch on their transponders provided they are within 50 miles of Allied held territory :—

Stragglers (defined as those aircraft that are lost or whose flight varies by 30 minutes from the flight plan).
Early returning aircraft.

Aircraft in distress.
Aircraft operating singly.
Aircraft engaged by friendly anti-aircraft fire or searchlights.

(*b*) *By Ships*

Transponders will be used by ships only :—

(1) When shadowing or engaging the enemy.

(2) To " Home ' aircraft in exceptional cases.

(3) When surface visibility is less than 10 miles, by ships operating singly and by I.F.F. guard ships proceeding in convoy, at a scale not exceeding one I.F.F. guard per 30 ships.

(4) When in distress.

4. Interrogators

(*a*) Interrogators will only be operated for the briefest possible periods.

(*b*) The use of interrogators not fitted with switches is prohibited.

(*c*) Commanders of Group/Tactical Air Commands on the Continent may designate not more than one ground radar station as I.F.F. Interrogator guard station. This station will interrogate continuously subject to the following restrictions :—

(1) Only stations with beamed type interrogator antennae (BSRU scheme or equivalent) will be designated as I.F.F. interrogator stations.

(2) Frequencies for these stations will be sub-allotted to the Groups/Tactical Air Commands concerned by Air Staff, S.H.A.E.F., to avoid mutual interference.

APPENDIX No. 11

I.F.F. MARK V—EXTRACT FROM COMBINED COMMUNICATIONS BOARD REPORT—30 NOVEMBER 1944

(*a*) General

I.F.F. Mark V, or the United Nations Beaconry, is being developed in America. It differs considerably from previous systems, and incorporates the functions of both I.F.F. and homing beacons. It will be used by British and American forces, and will replace the present I.F.F. and homing beacon systems.

Mark V I.F.F./UNB will operate on a frequency band of 950 to 1,150 Mcs, and will employ pulsed interrogation and response on any two of twelve spot frequencies in this band. It will provide the following facilities :—

(i) I.F.F. identification of aircraft and ships from aircraft, ships and ground radar stations.

(ii) Identification, together with azimuth and range, of ground, shipborne, and airborne beacons, from aircraft and ships.

(iii) Other miscellaneous functions which can be added by later adaption of the existing I.F.F./UNB units, and which include blind approach (BABS), bombing aids (Oboe), navigation, and certain forms of communications.

The system envisaged differs considerably in detail from the scheme as it was planned in the early days of development. In order to bring forward the date of introduction into the service, it has been necessary to reduce the technical complexity of the various units, and this could only be achieved by sacrificing certain security measures which were originally to be incorporated. The following account gives a brief outline of the system as it is envisaged.

(*b*) Lists of Units

The Mark V scheme employs a number of radar interrogators and transponders, of which the following list includes the most important. All use vertical polarisation. In addition to those mentioned here there will be various display units, connectors, and special units which have not been fully developed as yet, but which may be required for particular applications.

Radar Equipments included in the Mark V I.F.F. UNB Scheme

Equipment. (U.S. references.)	Purpose.	Tx peak power.	Rx sensitivity.	Weight.	Remarks.
AN/APX-6	Airborne transponder for I.F.F. and Rooster.	500 W.	100 micro v.	30 lb.	Fits into Mark III transponder shock mount Omni directional aerial.
AN/CPX-3	High-power surface interrogator-responsor.	8 kW.	10 micro v.	400 lb.	Will use one of several forms of directional antenna.
AN/APX-7	Airborne interrogator-responder for all I.F.F. and Beacons.	2 kW.	?	IR unit alone.	Carries semi-directional antenna, acting as a common T and R aerial and also separate T and R aerial, the latter of which can be lobed switched to give the usual directional facilities. This directional R aerial fits into an 8-in. egg, which permits it to be rotated to take bearings off the line of flight.
AN/SPX-1	High-powered shipboard I.F.F. transponder.	8 kW.	10 micro v.	400 lb.	This will be the AN/CPX-3 converted into a transponder.
AN/CPX-4	Medium power surface interrogator responsor.	2 kW.	?	IR unit alone about 45 lb.	Modified form of the AN/APX-7 for surface use.
AN/SPX-2	Medium power shipboard I.F.F. transponder.	2 kW.	?	IR unit alone about 45 lb.	This will be the AN/CPX-4 modified for use as a transponder.
AN/CPN-8	Paratroop beacon	?	?	25 lb. including aerials and power supplies.	This is a light weight beacon. Its reply can be coded or hand keyed.

Equipment. (U.S. references.)	Purpose.	Tx peak power.	Rx sensitivity.	Weight.	Remarks.
AN/UPN-5	High power surface beacon.	8 kW.	10 micro v.	400 lb.	This is a converted AN/CPX-3. It differs from the AN/SPX-1 in its coding and decoding mechanism.
AN/TPN-4	Medium power surface beacon.	2 kW.	?	IR unit alone about 45 lb.	This will be the AN/CPN-4 converted for use as a transponder. It differs from the AN/SPX-2 in its coding and decoding mechanism.

(c) Test Sets

The following test equipment is also included :—

AN/UPM-4

This is a transportable equipment which will be capable of making all the measurements required for servicing and testing any of the Mk. V I.F.F./UNB units.

AN/UPM-5

The AN/UPM-5 is a depôt equipment which includes the transportable set and also certain standards required for checking its calibration.

AN/UPN-6

This is a light portable equipment which can be carried by one person. It is limited in its scope and will check only the following operations :—

(*a*) Frequency of the transmitter and receiver.

(*b*) Coding of the interrogator-responsor and of the transponder-transmitter.

(*c*) Decoding in the transponder receiver.

(*d*) Receiver sensitivity.

(*e*) Transmitter power output.

(d) Maximum Range

The range of the system will depend upon the particular equipments involved. The following table gives an approximate estimate of the ranges to be expected.

Interrogator and Transponder Involved.	*Estimated Range (Statute Miles)*
(1) *AN/CPX-3 to AN/APX-6*	
(*a*) With overall antenna gain of 15 db.	
Aircraft at 1,000 ft.	40
Aircraft at 10,000 ft.	120
Aircraft at 20,000 ft.	170
(*b*) With overall antenna gain of 5 db.	
Aircraft at 1,000 ft.	30
Aircraft at 20,000 ft.	100

Interrogator and Transponder Involved.	*Estimated Range (Statute Miles)*
(2) *AN/CPX–3 to AN/SPX–1* With antenna heights of 100 ft. and overall antenna gain of 11 db.	35
(3) *AN/APX–7 to AN/SPX–1* (Calculated free space range)	100
(4) *AN/APX–7 to AN/UPN–5* (Calculated free space range)	140
(5) *AN/APX–7 to AN/APX–6*	40 to 80
(6) *AN/APX–7 to AN/QPN–8*	30 to 40
(7) *AN/CPX–3 to AN/SPX–2* With overall antenna gain of 11 db, and I–R antenna at 100 ft. and transponder antenna at 50 ft.	25
(8) *AN/CPX–4 to AN/APX–6* With overall antenna gain of 5 db, and aircraft at 10,000 ft.	90
(9) *AN/APX–7 to AN/TPN–4* (Provided that aircraft is above horizon)	90

(*e*) Coding

The Mark V I.F.F./UNB provides the following coding facilities :—

(i) Variation of Interrogation Frequency.

(ii) Interrogation signal modulation (*i.e.* double-pulsed interrogation).

(iii) Variation of Response Frequency.

(iv) Response signal modulation (*i.e.* coding of response in a way similar to that used in the Mark IIIQ).

These variables are used to provide functional and security coding. The following account gives a brief description of the use of each of the four characteristics in the system as it is visualised at the present time.

(i) Interrogation can occur at any one of twelve channels which are spaced about 17 Mc/s apart. These channels can be divided between I.F.F. and UNB as required. It is expected that beacon interrogation may require the use of several channels at any one time, but that I.F.F. may require either only one channel, or, at the most two, one for interrogation of aircraft and the other for interrogation of surface vessels. There will be no provision for remote control of the frequency in the early interrogators and responsors, but all are being designed for the optional addition at a later date of a remote control mechanism which will permit clock settings to any of the twelve interrogation frequencies.

(ii) The system will employ double-pulsed interrogation. The pulses will each be one microsecond wide, and their leading edges will be separated by a time interval of either 3, 5, or 8 microseconds. The transponders are provided with decoding units which can be set up to give response on any one of these codes. The three codes will normally be used for the following purposes :—

I.F.F. The 3 microsecond interval can be used for normal I.F.F. working.

P.I. Personal identity is often required by a fighter direction station. This can be obtained by requesting the pilot to turn on his P.I., in which case he switches his transponder over to the 5 microsecond code. If the interrogator is also switched over to this interval, it will receive replies only from this particular aircraft, as all other airborne transponders will, normally, be using the 3 microseconds code.

F.L.I. In a large formation of aircraft the I.F.F. clutter renders the reading of the reply code impossible. In this case it is possible to ask the formation leader to switch over to Flight Leader Identity, which uses the 8 microsecond interval. When the interrogator is also switched to this code it will receive only replies from the one aircraft.

These codes are available as follows :—

High Power Surface Interrogators can use I.F.F. and *either* P.I. or F.L.I. simultaneously.

Medium Power Surface Interrogators can use any *one* of the three codes at a given time.

Airborne Interrogator Responsors can use any *one* of the three codes at a time. The pilot can select the one required.

Airborne and Surface I.F.F. Transponders can be set up to respond to the I.F.F. code alone, I.F.F. and *either* P.I or F.L.I. simultaneously, or all three simultaneously.

Beacons will be able to decode any of the interrogation codes, one at a time.

(iii) The response frequency can be varied in the same way as the interrogation frequencies, the transponders being capable of replying on any one of the same twelve channels. The response channel will usually be different from the interrogation channel. Although there will be no provision for remote selection of the response frequency in the first place, interrogators and transponders are being designed with a view to their use with remote selectors at a later date, as in the case of the interrogation frequency.

The reply signal can be modulated to give a considerable measure of coding. The I.F.F. response will consist of a single pulse, one microsecond wide, transmitted for each double pulse interrogation signal. The width of this pulse can be increased to 2½ microseconds when desired, and coding is achieved by a similar method to that employed in the Mark IIIQ system. For a short period of time the transponder gives a succession of either wide or narrow responses ; it is then switched off for a brief interval, after which it comes into operation again for the same length of time as before. Its response then appears as a succession of short 'flashes,' each lasting for the same length of time. Each 'flash' may consist of a succession of narrow pulses or a succession of wide pulses. The response code consists of two or three morse letters transmitted in this way, and is repeated indefinitely as long as interrogation continues.

For aircraft the normal reply will consist of a two-letter code, providing 80 possible combinations, followed by two blank periods each of which lasts for about the same time as a letter. A third letter can be introduced in place of one of these blanks if desired. These two possible conditions are therefore :—

First condition—1st Letter 2nd Letter Blank Blank 1st Letter—and so on.

Second condition—1st Letter 2nd Letter 3rd Letter Blank 1st Letter—and so on.

This code is known as the *slow reply code*, in contrast to another type of code, the fast code, which the original Mark V System incorporated in addition, but which has been abandoned in the present set.

The distress signal for aircraft will be brought into operation by a pilot control. On depressing this emergency control the response to any of the three interrogation codes will consist of a characteristic signal, composed of four one-microsecond pulses spaced eight microseconds apart.

Ship I.F.F. transponders will radiate a multi-letter code group by variation of pulse width in the same way as that described for aircraft. The coding of these equipments will be more flexible than that of the airborne sets, however, and will only be limited by the possible arrangements of 150 elements.

Surface beacon transponders also use pulse width coding, and give a two-letter group on reply to interrogation. This time, however, the pulse width is two microseconds or nine microseconds.

The aerial systems of ground interrogators will usually be highly-directional, and will sweep continuously to cover all azimuth bearings. They may be mounted on either the same turntable as the aerials of their parent radars or separately on their own turntable.

Airborne interrogators will be fitted with two aerial systems. One will be a simple omnidirectional antenna, while the other will be a lobe switch type which will be used in an eight inch ' egg ' which permits the mechanism to be rotated to take bearings off the line of flight. The former aerial will normally be used for transmission, while the latter will, of course, feed into the receiver to give indication on an L type display in the usual way. If no directional facilities are required, however, it will be possible to use the single aerial for common T and R working.

All I.F.F. and beacon transponders will normally have simple omnidirectional aerials, so that they are able to respond to interrogation from any direction.

A.M. File C.S. 23952/I Encl. 18A.

APPENDIX No. 12

BRIEF DESCRIPTION OF A.I. MARK IV INSTALLATION IN A BEAUFIGHTER AIRCRAFT

Aerials

(i) A transmitting aerial was fixed to the nose of the aircraft (Fig. 1) so that radiation was sent out mainly in the forward direction as shown in figure 4. The transmitter field extended to either side, and above and below the aircraft, but there was very little radiation in a backward direction.

(ii) The azimuth receiving aerials were mounted on the leading edges of the wings (Fig. 2). These aerials were directional. The port aerial favoured the reception of signals originating from targets to the left of the line of flight, while the starboard aerial favoured those coming from the right of the line of flight (Fig. 5). This was brought about by the screening action of the body of the aircraft, and by fitting the aerials with directors to increase their natural directional properties.

(iii) The elevation receiving aerials, which were also directional, were placed above and below the starboard wing and had reflectors fitted behind them (Fig. 3). The metal wing acted as a screen so that the upper aerial could best receive signals from above the fighter and the lower one could best receive those coming in from below (Fig. 6). It will be realised that the direction finding properties of the equipment were derived from the receiving aerials only.

Presentation of Information

The Radio Operator was provided with two cathode ray tubes displaying the receiver output. The elevation tube (on the left) had a horizontal trace beginning at the left-hand side of the tube. The right-hand tube was for azimuth and the vertical trace started at the bottom. Typical indications are shown in Figure 7 for a target at two miles from the fighter, above and to the starboard. The operator could tell that the target aircraft was above by comparing the size of the blips above and below the horizontal trace. Similarly the greater amplitude of the echo on the right of the azimuth trace indicated that the target aircraft was to the starboard. When the blips on each tube were equal on each side of the trace the enemy aircraft was dead ahead of the fighter, and its range could be read off on a calibrated scale. In carrying out an interception it was not necessary for the operator to make an accurate estimation of the angular position of the target. Instead he instructed the pilot to turn until the azimuth signals were equal and then the elevation signals were equalised by climbing or diving as the case might be.

Maximum Range

In addition to echoes from aircraft within range, a large echo was produced by ground reflection (Fig. 7). This was called 'ground return' and appeared on the tube as an extensive echo rather like a Christmas tree in shape. The extent of the ground return always corresponded to the height of the aircraft above the land over which it was flying. Unfortunately the ground return was very strong compared with aircraft echoes and consequently there was no chance of detecting aircraft at ranges greater than the height of the night fighter. Above 18,000 feet the maximum range of the equipment was of the order of 3½ miles, but below that height the maximum range was limited to the height of the fighter. Sea returns were somewhat less strong than ground returns and therefore, under favourable circumstances, targets at ranges greater than the height might be detected.

A.I. MARK IV

AERIAL SYSTEMS

TRANSMITTING AERIAL

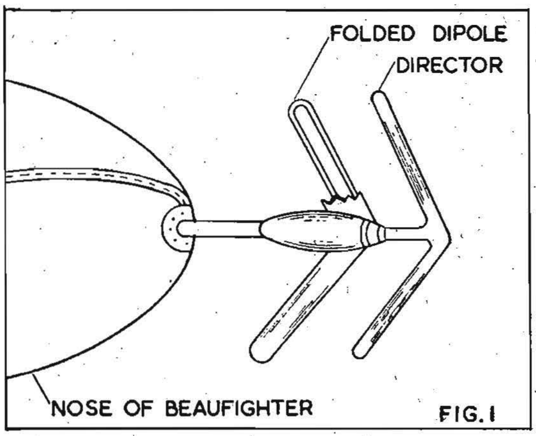


FIG. 1

RECEIVING AERIALS

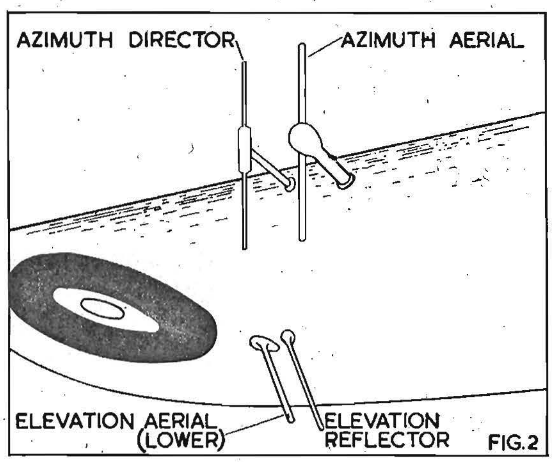


FIG. 2

STARBOARD AZIMUTH AERIAL & LOWER ELEVATION AERIAL IN BEAUFIGHTER AIRCRAFT.

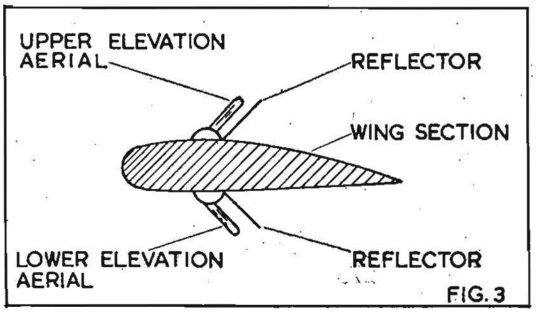


FIG. 3

WING SECTION ILLUSTRATING POSITION OF ELEVATION AERIALS IN BEAUFIGHTER AIRCRAFT

A.I. MARK IV

TYPICAL AERIAL POLAR DIAGRAMS

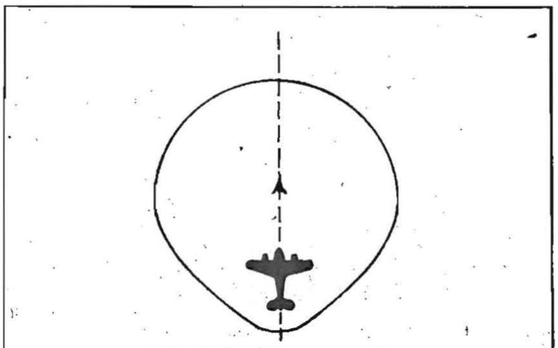


FIG. 4 TRANSMITTER AERIAL

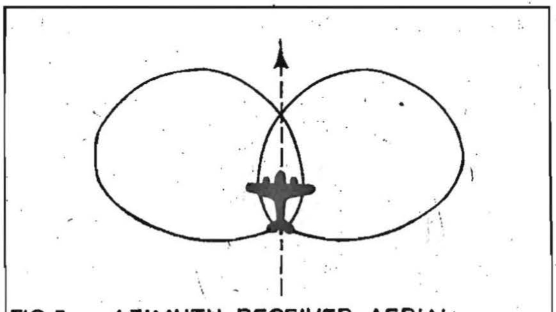


FIG. 5 AZIMUTH RECEIVER AERIAL

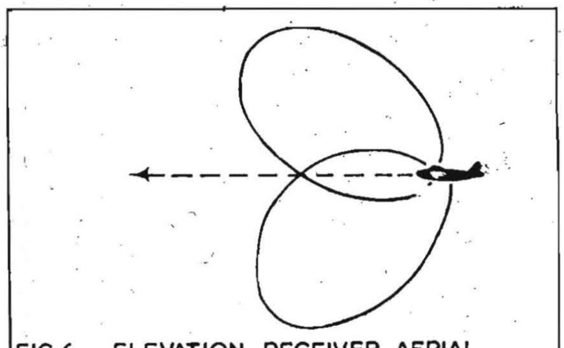
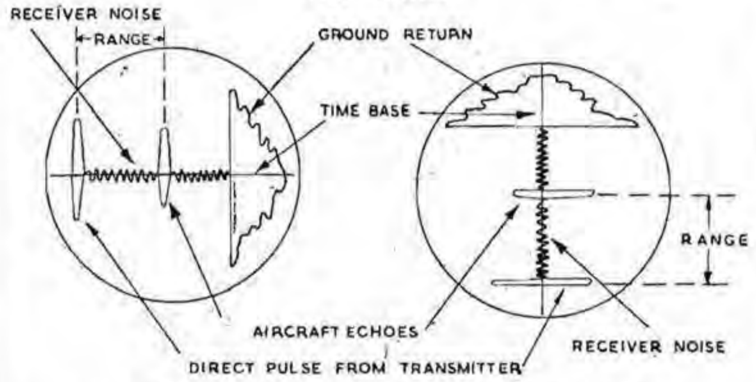


FIG. 6 ELEVATION RECEIVER AERIAL

A.I. MARK IV

TYPICAL INDICATIONS OF TARGET AIRCRAFT ON CATHODE RAY TUBES



ELEVATION TUBE | AZIMUTH TUBE

FIG. 7

INDICATION OF FRIENDLY AIRCRAFT ON A.I. CATHODE RAY TUBE

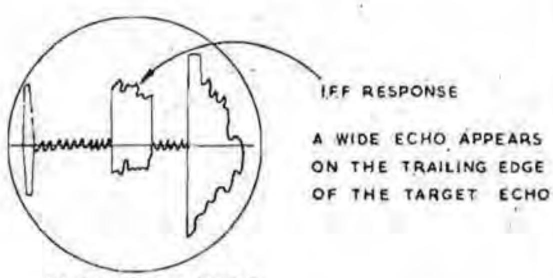
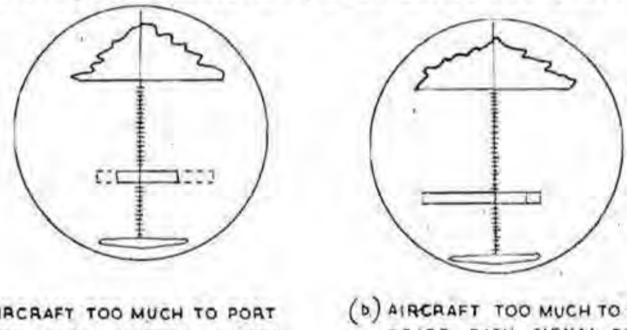


FIG. 8 ELEVATION TUBE

INDICATIONS FROM BLIND APPROACH BEACON IN AZIMUTH TUBE



(a) AIRCRAFT TOO MUCH TO PORT DOT SIGNAL. SIGNAL JUMPS OUT TO GREATER AMPLITITUDE FOR 0·2 SECONDS EVERY 1·2 SECONDS

(b) AIRCRAFT TOO MUCH TO STARBOARD DASH SIGNAL. SIGNAL DIMINISHES IN AMPLITUDE FOR 0·2 SECONDS EVERY 1·2 SECONDS

FIG. 9

APPENDIX No. 13

ANALYSIS OF RESULTS CLAIMED BY DEFENSIVE NIGHT FIGHTERS AGAINST THE GERMAN NIGHT OFFENSIVE NOVEMBER 1940 TO DECEMBER 1941

Month	Number of Enemy Aircraft claimed as Destroyed by				
	Fighters with A.I.		Fighters without A.I.	No. 93 Squadron	All Categories
	By A.I. means	By visual means			
1940					
November	1	1	—	—	2
December	—	1	2	1	4
1941					
January	—	—	3	—	3
February	2	—	2	—	4
March	11	4	7	—	22
April	27	—	20½	1	48½
May	34	3	59	—	96
June	19	2	6	—	27
July	20	—	6	—	26
August	3	—	—	—	3
September	7	—	1	—	8
October	8	1	2	—	11
November	7	—	—	—	7
December	3	—	—	—	3
Totals ..	142	12	108½	2	264½

REPORT 590

T.R.E. REPORT ON THE PERFORMANCE OF THE DIVIDED 10-FT. AERIAL AT DURRINGTON, NOVEMBER 1940

1. General

The station at Durrington consists of standard CHL equipment, with modifications which were necessary to make the station transportable and permit height estimations to be made.

The arrays are mounted on trailers of the GL receiver type. Wire netting reflectors are used and the dipoles are spaced approximately one-eighth of a wavelength in front of them. The mean height of the arrays above ground is 10 feet approximately. VT98 valves are used in the transmitter.

The receiving array is divided into two halves. The top half is at a mean height of 12½ feet and the bottom half at 7½ feet. Separate connections are made to these two halves, so that switching can be effected from one half to the other. For height finding the amplitudes of the signals received on the two halves are compared. The two halves can also be connected simultaneously to the receiver so that the aerial behaves like a standard array at a mean height of 10 feet.

2. Performance of the 10-ft. Aerial

The vertical polar diagram for an aerial 10 feet high and wavelength 1½ metres should have its lowest maximum at angle of elevation 7 degrees, and the first gap should be at 14 degrees. Figure 1 shows the theoretical position of the first two lobes, together with the results of test flights. The tests were made with a Hurricane aircraft, except in one case, where a Blenheim was used. It has been found that the station has a greater range for the larger machines.

For azimuth determination the split beam technique is used. The accuracy of range and azimuth determination is exactly the same as in a standard CHL station (*i.e.* absolute range to within ¼ mile and azimuth to within at least ½°).

3. Inland Following

The site at Durrington is about 2 miles south of a range of hills. These screen objects further inland from radiation from the transmitter so that troublesome permanent echoes are avoided. The site is very suitable in this respect and there are no permanent echoes beyond about 5 miles. The hills do not screen aircraft at angles of elevation of about three degrees and the station works normally at angles above this. Operationally the station performs remarkably well on high-flying aircraft and inland tracking has been at least as successful as the tracking out to sea.

4. Height-Finding Technique

The method of height finding used is the same as that at East Seaton, and was described in detail in Report No. 141, reference A.M.R.E. 4/4/142, dated 19 June 1940.

A three-position switch is provided at Durrington. In position 1 of this switch each echo on the azimuth tube is doubled, and the azimuth is varied until the two components are equal. This is the ordinary split beam direction-finding technique.

For height finding the switch is first set to position 2. Each echo is then trebled, and the azimuth is kept adjusted so that the two outside components are equal. The observer notes whether the middle component is greater or smaller than the outside two. This determines which part of the calibration chart he will use. The switch is then set to position 3, and a calibrated dial is turned until all three components of the echo are equal. The dial is then read, and the reading is converted to height in feet from the calibration chart.

5. Range of Height Estimation

It should be possible to estimate height for aircraft at angles of elevation between about 3 degrees and 20 degrees. If it is known that an aircraft is below 20 degrees, its angle of elevation can be estimated without ambiguity with an accuracy of about ± 1 degree. This corresponds to ± 2,000 feet at range 20 miles. Aircraft are nearly always first observed when they are so far from the station that the angle of elevation is less than 20 degrees, so that trouble from ambiguities on higher angles does not arise. The above results were predicted from theory. The consistency of the results of several calibration test flights has shown that the above degree of accuracy, ± 1 degree, has been achieved at Durrington.

6. Site Requirements for G.C.I.

For proper functioning of the height-finding method it is essential that the ground near the station shall be level to within about ± 6 feet up to ½ mile from the station, and to within about ± 20 feet up to 1 mile. Isolated objects such as trees are not objectionable provided that they are not too numerous. It is also desirable that use should be made of hills where possible, to screen ground objects from radiation when they are likely to give troublesome permanent echoes.

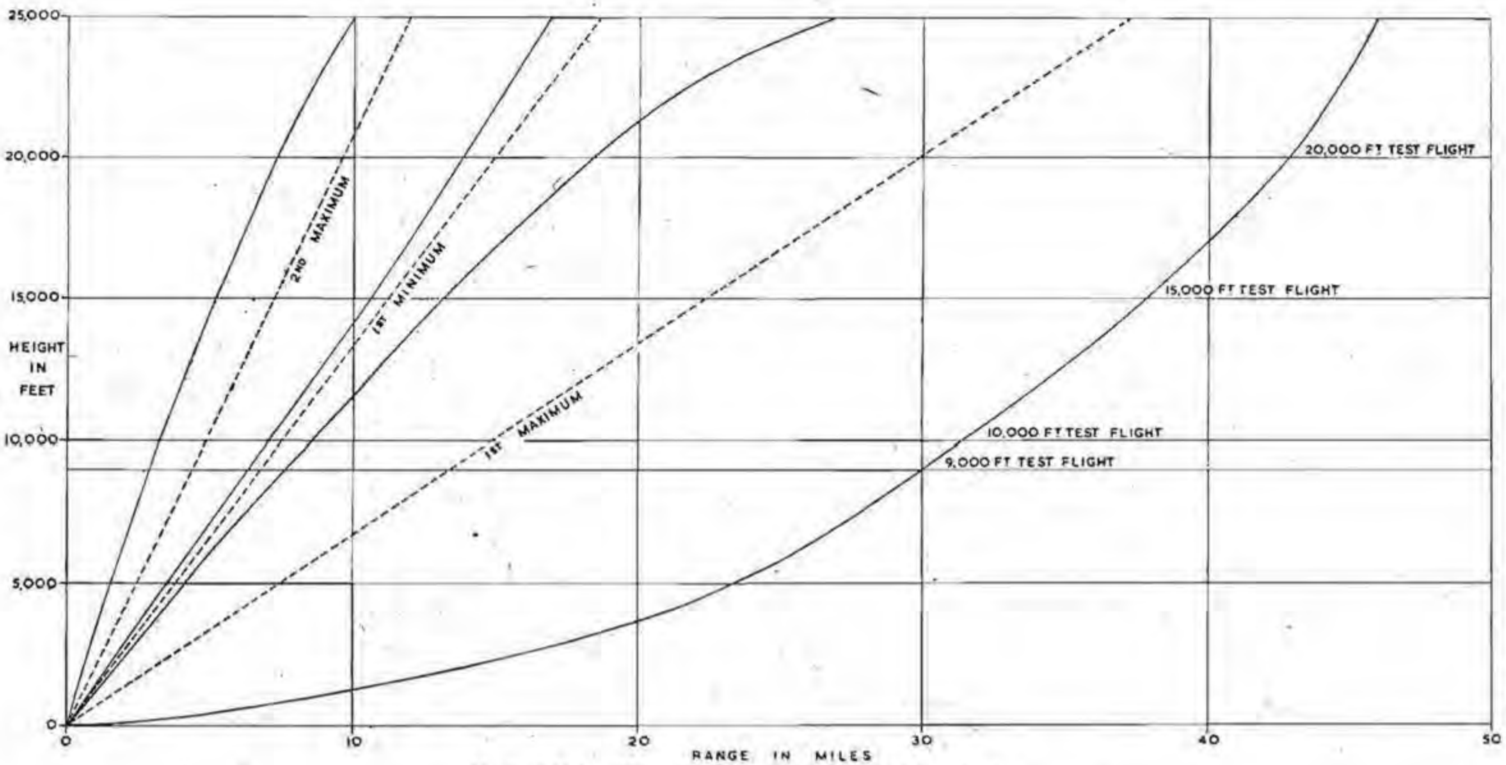
These conditions are fairly well fulfilled at Durrington, but it is clear that the number of such sites in this country is limited. It must be emphasised that the selection of GCI sites is far more difficult than the selection of ordinary CHL sites, and a list of areas where GCI stations are required should be supplied as early as possible.

It should be realised that the above figures apply to the divided 10-ft. aerial, and that the site requirement is more stringent for the 10 and 35-ft. aerial systems envisaged for the final GCI type station.

T.R.E. 4/4/941.

DT/NC/590. 29 *November* 1940.

A.M. File S.6462/I Encl. 59B.



Vertical Polar Diagram of Ten Foot Aerial at Durrington.

APPENDIX No. 15

G.C.I. PROGRAMME (UP TO NOVEMBER 1941)

The following is a list of all G.C.I. stations existing and projected, with the relevant suffix against their names :—

01G	Durrington	M to be I.M. & F.
02G	Sopley	M to be I.M. & F.
03G	Exminster	M to be I.M. & F.
04G	Willesboro.	M to be I.M. & F.
05G	*Waldringfield	M to be I.T. & F.
06G	Orby	M to be I.T. & F.
07G	Sturminster Marshal	M
08G	Langtoft	T to be I.T. & F.
09G	†Hampton Hill	T to be I.T. & F.
10G	Hack Green	T to be I.T. & F.
11G	Comberton	T to be I.T. & F.
13G	Wrafton	T to be I.T. & F.
15G	‡St. Quivox	M to be I.M. & F.
16G	Dirleton	M to be I.M. & F.
17G	Northtown	to be M
18G	Boarscroft	to be M
19G	Trewan Sands	M to be I.T. & F.
20G	Wartling	M to be I.M. & F.
21G	Neatis Head	M to be I.T. & F.
22G	Northstead	M to be I.M. & F.
23G	Huntspill	M to be I.M. & F.
24G	Treleaver	M to be I.T. & F.
25G	Ripperston	M to be I.M. & F.
26G	Bishops Road	M
27G	Ballinderry	M
28G	Lisnaskea	M
29G	Ballywooden	M
30G	Foulness	to be I.T. & F.
31G	Cricklade	M to be I.M. & F.
32G	Newford	M
33G	Seaton Snook	M to be I.M. & F.
34G	Dunragit	to be M
35G	Salcombe	M
36G	St. Annes	to be M

In addition to these, Yatesbury and Cranwell are each to have an I.T. and Cranwell has also got a mobile G.C.I. convoy.

N.B.—* will be called Trimley Heath for I.T. & F.
† will be called Patrington Heath for I.T. & F.
‡ will be called Fullarton Heath for I.M. & F.

Key

G.C.I. Mobile	M.
G.C.I. Transportable	T.
G.C.I. Intermediate mobile	I.M.
G.C.I. Intermediate transportable	I.T.
G.C.I. Final	F.

APPENDIX No. 16

D.C.D.

MINUTE FROM D.D. OF R. TO D.C.D. ON G.C.I. OPERATIONAL REQUIREMENT, 25 AUGUST 1941

Your minute of 20 June has set out the operational requirements for the final fixed type of G.C.I., which has since become known as the 1942 or Merz & McLellan type. The situation has been in a state of flux for some time, and has formed the subject of many discussions both at Meetings and with members of your Staff.

2. Electrically, the type now generally agreed upon is that known as Scheme D, and it is now taken for granted that common aerial operation is a feasible proposition.

3. Operationally, it is now possible to crystallize our ideas along the lines which you have suggested, which are re-stated below with such small amendments as have developed in the meantime.

1. Coverage

(*a*) 360° in Azimuth without obstruction.

(*b*) Gapless in Zenith up to great heights and as low as possible without incurring difficulties from permanent echoes, *i.e.* 1°–40° for practical purposes.

2. Range

(*a*) P.P.I. to operate on two ranges (*e.g.* 45 miles and 90 miles) selectable by switch. The longer range to be used for the general situation and the shorter one for interception.

(*b*) Grid, on the shorter range, will be sufficient.

3. Height

(*a*) To be readable to all Azimuths and Zeniths at any of the speeds of rotation in para. 2 within desired limits.

(*b*) $\pm \frac{1}{4}°$ ($\pm$ 570 ft. at 25 miles).

4. Traffic

(*a*) Ability either to isolate high and low angle responses on separate presentations, or to present both simultaneously on one presentation for the purpose of searching. Height reading will be automatically restricted to the solid angle being scanned.

(*b*) With continuous rotation plan positions can be read continuously from P.P.I., but heights can only be read once per revolution. The maximum rate of all plotting, position and height, will be, therefore, six plots per minute.

(*c*) Twenty-four hour operation is essential subject to the normal maintenance.

5. Identification

(*a*) Identification of controlled fighter to appear on its echo without stopping rotation of aerials.

(*b*) Identification of other friendly aircraft can be on another presentation.

(*c*) The technical system for identification of the controlled fighters will be special, perhaps based on the proposed Mark III G. Technical system for identification of other friendly aircraft will be Mark III.

6. Turning Gear

Continuous rotation with speed continuously variable from zero to 6 revs. per minute. Inching is not required, but facilities for stationary tuning on a P.E. is needed.

7. Operational Layout

(*a*) Presentation of the general situation obtained from the Sector.

(*b*) Advance warnings of positions, tracks and heights of aircraft from two neighbouring R.D.F. Stations (C.H., C.H.L. or G.C.I.).

(*c*) Simultaneous control of, at the most, four fighters.

(*d*) Provision of maximum of two controllers and one supervisor.

(*e*) A station will, when required, perform a normal reporting function. This must not hinder its controlling activity.

(Signed) R. G. Hart.

Group Captain
D.D. of R.

25 *August* 1941.

APPENDIX No. 17

G.C.I. STATIONS—REVISED PROGRAMME, 28 JANUARY 1943

Following a review of the G.C.I. programme held in the light of the enemy activity at that time, it was decided that reductions were to be made in order to achieve economies in man-power and equipment.

The following table covers the complete chain of G.C.I. stations and shows the type of equipment to be installed on each station :—

Station.	*Present Equipment.*	*Future Equipment.*	*Remarks.*
Durrington	Final	Final	Operational
Sopley	Final	Final	Operational
Trimley Heath	Final	Final	Operational
Neatishead	Final	Final	Operational
Sandwich	Transportable	Final	Target Date April 1943
Wartling	Intermediate Mobile	Final	Target Date April 1943
Exminster	Mobile	Final	Target Date End January 1943
Hope Cove	Mobile	Final	Target Date May 1943
Treleaver	Intermediate Transportable	Final	Target Date Mid February 1943
Ripperston	Intermediate Mobile	Final	Target Date April 1943
Patrington	Intermediate Transportable	Final	Target Date End February 1943
Trewan Sands	Intermediate Transportable	Final	Target Date Mid March 1943
Orby	Intermediate Transportable	Final	Target Date End February 1943
Langtoft	Intermediate Transportable	Final	Target Date May 1943
Wrafton	Intermediate Transportable	Final	Target Date May 1943

Station.	*Present Equipment.*	*Future Equipment.*	*Remarks*
Comberton	Intermediate Transportable	Final	Target Date End May 1943
Seaton Snook	Intermediate Mobile	Final	Target Date June (early) 1943
North Stead	Intermediate Mobile	Final	Target Date Mid June 1943
Hack Green	Intermediate Transportable	Final	Target Date Mid June 1943
Dirleton	Intermediate Mobile	Final	Target Date Mid July 1943
Ballywoodan	Intermediate Transportable	Final	Target Date Mid August 1943
Long Load	Intermediate Mobile	Intermediate Mobile	Operational
Cricklade	Intermediate Mobile	Intermediate Mobile	Operational
East Hill	Intermediate Mobile	Intermediate Mobile	Operational
St. Annes	Intermediate Mobile	Intermediate Mobile	Operational
Fullarton	Intermediate Mobile	Intermediate Mobile	Operational
Russland	Mobile	Mobile	Operational
Ballinderry	Intermediate Transportable	Intermediate Transportable	Operational
Staythorpe	Mobile	Mobile	Operational
Roecliffe	Mobile	Mobile	Operational
Dunragit	Mobile	Mobile	C. & M. basis
King Garth	Mobile	Mobile	C. & M. basis
Aberleri	Mobile	Mobile	Operational
Newford	Intermediate Transportable	Intermediate Transportable	Operational
Willesborough	Intermediate Mobile	Intermediate Mobile	C. & M. basis on Sandwich becoming operational
Blackgang	Mobile	Intermediate Mobile	Target Date May 1943
Ballydonaghy	Mobile	Mobile	C. & M. basis
Lisnaskea	Intermediate Mobile	Intermediate Mobile	C. & M. basis when technical installation is completed
Foulness	Intermediate Transportable	Intermediate Transportable	C. & M. basis on Sandwich becoming operational
Coleraine	(Site relinquished and station abandoned.)		
Happisburgh I	C.H.L. used for G.C.I. purposes		Operational
Foreness	C.H.L. used for G.C.I. purposes		Target Date February

The reserve sites at Blankets Farm, Doctors Corner and Knights Farm will continue to be held under requisition for use in the event of Stations becoming unserviceable owing to enemy action.

APPENDIX No. 18

O.R.S., FIGHTER COMMAND, REPORT ON FIXED G.C.I. OPERATIONS ROOMS, 16 JUNE 1941

I.—Introductory

This report envisages the operational functions and ideal layout which should be developed for use within the standard hut designed to house C.H.L., C.H.B. and fixed G.C.I.

The technical requirements, communication facilities and personnel required to man the operations room are also broadly discussed.

It is pointed out that the precise and final form of the operations room layout must necessarily be subject to experimental trials, and the recommendations contained in this report have been made with this in mind.

1.1. Operational Aims

The fixed G.C.I. station will be an operational unit designed to—

(*a*) Carry out precision interceptions simultaneously on more than one raid.

(*b*) Afford facilities by which the controller may know the position and strength of his fighter forces and that of enemy aircraft approaching the operational area of his station.

(*c*) Permit the controller to supervise interceptions being carried out by two deputy controllers.

(*d*) Provide the controller with a reliable picture of the trend of enemy activity, particularly that which is likely to demand more reinforcements from sector.

(*e*) Act as a reporting system to sector, supplementing, in particular, the Royal Observer Corps information which may be incomplete in respect of high flying aircraft, especially at night.

It will be seen that the station will be operating in very close liaison with its parent sector (which has to provide the fighter aircraft) and with an appropriate part of the Fighter Command reporting system by which raids may be identified and numbered. The choice of the place for identification forms the subject of a separate discussion, and it will simply be referred to in this report as the 'identification centre'.

1.2. Technical Requirements

The station operations room has been planned on the assumptions that it is possible to have :—

(*a*) Multiple display.

(*b*) Continuous rotation.

(*c*) Vertical axis P.P.I.s.

(*d*) Adequate operational range at low angles.

(*e*) Gap-filling and height finding, the latter, in particular, being reasonably accurate at low angles of elevation and long range.

In addition, two V.H.F. channels, three lines to sector and two to the identification centre will be required.

II.—Operations

1. Operational Functions

In order to operate effectively the following provisions are needed :—

1.1. Facilities for the deputy controllers to perform interceptions.

1.2. A display to the controller of (i) incoming enemy tracks (both outside the area of the station and within it) ; (ii) the general nature of the attacking force (*e.g.* height, speed, probable objective). This information will be obtained from sector.

1.3. Up-to-date information (in the form of map tracks) as to the state and position of the fighters at the disposal of the controller. In addition, tracks of other friendly aircraft, likely to come within the interception area, must be shown.

1.4. Precise tracks (including heights) of raids being actually intercepted by the deputy controllers, and, with them, the tracks of the fighters with which these deputy controllers are doing their interceptions. This display must be arranged to allow both scrutiny by the deputy controller, and general supervision by the controller.

1.5. The tracks of fighters actually engaged in interceptions to be reproduced at Sector.

1.6. The plots provided by one of the P.P.I.s to be formed into tracks (at a separate console), identified and designated (as far as possible), and passed direct to sector in order that the latter may have as complete and accurate a picture as possible of the trend of all aircraft seen by the G.C.I. within its reporting area.

1.7. Facilities for a close and continuous liaison between the G.C.I. and Sector must be provided.

2. Essential Features of Layout

The operations room will be required to incorporate the following features :—

2.1. A controller's dais. This will have mounted on it the controller's console in approximately the centre of the room. From this position, the controller must also be able to command a view of the two deputy controllers and their plotting maps and the general situation map.

2.2. Two deputy controllers' consoles, on floor level on either side of the controller's dais.

2.3. A general situation map, on the wall opposite the controllers.

2.4. A reporting room, cut off by sound-proof and transparent walls from the remainder of the operations room.

2.5. A P.B.X. in a suitable position for providing communication facilities.

The layout is described in detail in Section III of this report.

3. Personnel required

The G.C.I. operations room will require the following personnel when in full operation :—

3.1. Controller (C) (Officer) and two deputy controller (D.C.1, D.C.2) (N.C.O.s —Sergeants).

3.2. Three P.P.I. observers (O_1 O_2 O_3).

3.3. Three or four height operators (H_1 H_2 H_3 and H_4).

3.4. Two plotters for deputy controller (P_1 P_2).

3.5. An interception plotter (IP) to plot tracks of fighters actually engaged on interceptions.

3.6. A sector plotter (SP) to plot tracks of enemy raids obtained from sector.

3.7. A tracker (TR) to observe plots and make tracks on the reporting P.P.I.

3.8. A reporting teller (RT) to tell tracks from the reporting P.P.I. to sector, and identification centre.

3.9. A reporting liaison (RL) responsible for identification and designation of tracks told outwards from the reporting room (N.C.O.).

3.10. A sector liaison (SL) on the right of the controller, responsible for handing to the controller incoming information from sector concerning fighters, other friendly aircraft, etc. (N.C.O. in charge of watch.)

3.11. A telephone operator (TO) at the P.B.X.

3.12. A record (REC).

The total crew of 19 or 20 thus consists of an officer, 2 sergeants or flight sergeants, 2 other N.C.O.s, and 14 or 15 other ranks.

4. Operational Procedure

The operational procedure is briefly as follows :—

4.1. Controller

The Controller will be responsible for :—

(a) Maintaining contact with sector in order to keep himself informed as to the position, strength and state of his fighter forces.

(b) Allocating raids for each deputy controller to intercept.

(c) Instructing sector controllers to take fighters to positions from which the deputy controllers can complete the interceptions.

(d) Keeping a check on the raids being reported from the reporting room of the G.C.I. to the identification centre and to sector.

He is not responsible for getting fighters off the ground and landing them.

4.2. Deputy Controllers

The deputy controllers will carry out interceptions as detailed by the controller. They will not need to concern themselves with the general situation or preliminary positioning of the fighters.

If the intensity of activity is not sufficient to justify the use of two deputy controllers, only one of them (and his crew) will be on duty. If there is very little activity, only the controller will operate.

4.3. Plotting

There are the following maps :—

(a) The General Situation map (GSM) on the wall, in view of everyone.

(b) The deputy controllers' plotting tables (PT_1 and PT_2).

(c) The controller's plotting table (PT_3).

(d) The reporting plotting table PT_4).

(e) The recorder's map.

4.3.1. The *general situation* map (GSM) will be manned by the sector plotter (SP), who will receive plots from sector.

The information plotted will be the trend of incoming enemy activity within, or which is likely to come within, the operational area of the station. The object of this will be to enable the G.C.I. controller to get a general idea of the activity he may expect in his area. This information will be plotted either in the form of individual tracks (microscopic plotting), depending on the density and amount of activity.

4.3.2. The controller's map (PT_3) will be manned, on the south side, by the sector liaison (SL) and on the north side by the interception plotter (IP).

(a) The information plotted by the interception plotter will be the tracks of the fighters actually being controlled by the two deputy controllers.

(b) The sector liaison besides taking incoming messages from sector on the liaison line and generally assisting the controller in his liaison with sector, will plot the friendly fighters available for the G.C.I. and any friendly aircraft likely to be of interest to the controller.

Apart from the work of the controllers, that of the Sector Liaison will, broadly speaking, be the most responsible and difficult job in the operations room. It is therefore suggested that either the N.C.O. in charge of the watch or some other sufficiently experienced and intelligent N.C.O. be used in this work.

4.3.3. *The deputy controllers' maps* (PT_1 and PT_2) will each show two tracks, that of the enemy aircraft being intercepted and that of the fighter being used for the interception. The plots will be read from the P.P.s by the observers (O_1 and O_2), plotted by the plotters P_1 and P_2 and passed in parallel to the interception plotter (IP). He will have monitoring facilities on the two observers at consoles 1 and 2 (O_1 and O_2) which will enable the interception plotters to plot tracks both from PT_1 and PT_2.

4.3.4. The *reporting P.P.I.* (P.P.I.4) will be manned by a tracker (TR) on the north side and a reporting teller (RT) on the south side.

The *tracker* will be responsible for marking individual plots on the P.P.I. (so that tracks are formed), as well as adjusting the P.P.I. controls. He will be told the raid number of the tracks by the Reporting Liaison (*see* para. 4.3.5. below) and will number these tracks accordingly.

The *reporting teller* will tell all tracks to Sector and Identification Centre thereby supplementing the normal sources of information that Sectors have. He will include in these tracks those of the two fighter aircraft actually carrying out interceptions (which will, however, need to be noted as being so engaged).

4.3.5. The *reporting plotting table* (PT_4) will be used by the reporting liaison (RL) for his work in establishing identity of the tracks being told outwards from the reporting P.P.I. (P.P.I.4). To enable him to do this, he will have a liaison line to the identification centre (distinct from the reporting plotting line to the identification centre and sector in parallel).

He must also be able to monitor onto the interception P.P.I. observers' circuits (O_1 O_2), so that, if at any time he or the reporting teller are not certain as to which echoes correspond to the intercepting fighters, he will be able to listen into the plots being told by the P.P.I. observers 1 and 2.

4.3.6. The Recorder will keep a log of the activity of the station in the form of interception tracks which will be plotted on the *Recorder's map*. The recorder will obtain this information by listening to plots passed by the deputy controllers' observers (O_1 and O_2).

4.3.7. *Height operators*.

4.3.7.1. Interception height operators (H_1 and H_2) are to concentrate on getting accurate heights on the enemy aircraft being intercepted by their respective deputy controllers.

4.3.7.2. Reporting height operator (H_4) will obtain heights on all tracks being reported by the reporting teller.

4.3.7.3. The controller's height operator (H_3) may not be essential but he could take heights on any aircraft in which the controller is interested, if the latter required it. In any case, equipment for height finding (HR3) must be provided at controller's console for the case when there is only one controller operating.

III.—Details of Layout and Facilities

1. Technical Facilities Required

It has been stated in Part I of this report that certain technical facilities are assumed to be available. These will now be discussed in more detail.

1.1. Vertical Axis P.P.I.s

The need for placing the axis of the P.P.I.s vertical is due to the fact that at least two people have to read it, and as far as possible they should be placed so that each can get a good view of the P.P.I. from a comfortable position.

1.1.1. The P.P.I.s should be illuminated (possibly from behind) so that the grid and map on them are easily seen. This illumination should also aid the controller in using any protractors which have to be placed on the P.P.I.

1.1.2. If there are found to be technical difficulties in placing P.P.I.s on an exactly vertical axis, a setting with the axis not more than 15° from the vertical would be almost as good (*see* paras. 2.1 and 2.1.1).

1.1.3. With the separation of the P.P.I. from the rack which normally carries it, it is desirable that the remainder of the gear at present found in the P.P.I. rack be placed either :—

(i) in the height rack

or (ii) on an extension above the height rack (*but see* para. 2.2.1.1)

or (iii) under the plotting table. If this method is used, it will be necessary to leave room under the table for the knees and legs of the plotter.

1.2. Multiple Display

The object of multiple display is :—

(i) to provide plan position (and height) display to two deputy controllers simultaneously ;

(ii) to provide a P.P.I. for the controller, enabling him to supervise the work of the two deputy controllers ;

(iii) to provide plots for outward telling from the station.

1.3. Control of Gap-filling and Height Switches

1.3.1. The operational ideal is provision of gap filling continuously (requiring no operation of switches), and independent and simultaneous height finding (and phase check) switching at each console.

1.4. Continuous Rotation

Continuous rotation at approximately 6 r.p.m. (with effective afterglow) is essential in order that :—

(*a*) More than one interception may be carried out at a time.

(*b*) The controller may have reliable picture of the general trend of enemy activity.

1.5. Low Angle Coverage and Long Range

It is agreeed that while mobile G.C.I.s with 10-ft. aerials are very suitable for high flying aircraft, they are limited in scope, owing to the absence of low coverage (*i.e.* below 10,000 feet) at anything more than short ranges (*i.e.* about 25 miles).

The addition, therefore, of a higher aerial (*e.g.* the 35-ft. on the transportable) or the substitution of some 'compromise aerial' giving lower coverage than the 10-ft. above, is an essential operational requirement.

1.5.1. It has, however, to be borne in mind that an alternative rather than simultaneous coverage of low flying aircraft is needed so that P.P.I. clutter and identification problems are not rendered too acute by the presentation on the P.P.I. of both high and low flying aircraft at the same time.

1.6. Height Finding

The aerials used should give accurate heights (*i.e.* approximately $\pm 1{,}000$ ft.) at all angles between about $2\frac{1}{2}°$ and 20° to 25°.

2. Layout

The layout of the fixed G.C.I. is based on the use of a number of P.P.I.s, units, or consoles. One of these is briefly described first.

2.1. The *plan-position height console* contains a P.P.I. (on a vertical, or nearly vertical axis), a height rack and tube, and a plotting table.

The following further points should be noted :—

2.1.1. The P.P.I. may be tilted not more than 15° from the vertical (towards the controller), without appreciably interfering with the view of the observer.

2.1.2. The P.P.I. should be mounted on a pedestal with the minimum projection beyond the edge of the P.P.I. This will enable the controller to sit in a comfortable position close to the bowl, viewing the surface perpendicularly.

2.1.3. The P.P.I. and plotting table should be about 2 ft. 3 in. above floor level.

2.1.4. The height display panel should be between the plotting table and the P.P.I.

2.2. Plan of the Layout

2.2.1. *The controller's dais* on which is placed :—

(*a*) the controller's console (No. 3), is raised 1 ft. 6 in. above the general level of the floor ;

(*b*) the recorder's table, containing the P.B.X.

2.2.1.1. It will be necessary to arrange for the controller's height rack (HR3) to stand on the floor, and to have its cathode ray tube at the top of the rack. By this means, the controller's views of the general situation map will not be obstructed by the height rack.

Servicing of this height rack is made possible by having part of the dais floor movable.

2.2.2. *The deputy controllers' consoles* are at floor level and in line on either side of the controller's console. The right-hand deputy controller (DC1) has his height rack to the right of the P.P.I. so that he may see the general situation map.

2.2.3. *General Situation Map.*—An approximate scale of $\frac{1}{3}$ in. to the mile and a map measuring 6 feet square are suggested. This will give a display up to 108 miles from the station.

The lower edge of the map should be about 3 ft. 6 in. above floor level, and the plotter's dais should be 2 ft. 0 in. above the floor level.

3. Telephone Facilities

The following broad requirements are envisaged :—

3.1. For Operations Crew

3.1.1. *Controller.*—Two-way speech with :—

(*a*) Deputy Controller 1.

(*b*) Deputy Controller 2.

(*c*) Sector plotter (by monitoring on to line B—*see* para. 3.1.4).

(*d*) Reporting Liaison.

(*e*) Sector—*Line A*.

(*f*) R/T operator (thence to aircraft).

(*g*) P.B.X.

3.1.2. Deputy Controllers. Each deputy controller has two-way speech with :—

(*a*) Controller.

(*b*) R/T operator (thence to aircraft).

(*c*) P.B.X.

3.1.3. *P.P.I. observers at Consoles* 1 *and* 2 (O_1 and O_2).—Each has two-way speech with the Interception Plotter (I.P.). The Interception Plotter will have monitoring facilities enabling him to listen either to O_1 or O_2.

3.1.4. *P.P.I. observer at Console* 3 (O_3.)—Two-way speech with the Reporting Liaison for use when only one controller is in operation.

3.1.5. *Sector Plotter.*—Two-way speech with sector (*Line B*).

3.1.6. *Sector Liaison.*—Facilities for sharing a line to Sector (*Line A*) with the controller.

3.1.7. *Reporting Teller.*—Two-way speech with the G.C.I. plotter at Sector (*Line C*).

The reporting teller's telephone is also connected in parallel to the plotting line (*Line D*) to the identification centre.

3.1.8. *Reporting Liaison.*

(*a*) Two-way speech with the G.C.I. liaison at the identification centre (*Line E*).

(*b*) Monitoring facilities on the interception plotter's line (*see* para. 3.1.3), and the P.P.I. observer 3 (O_3).

(*c*) Facilities for replying to the controller when called by him (*see* para. 3.1.1 (*d*)).

(*d*) Monitoring facilities on the Reporting Tellers' line (*Line C*); this should not interrupt the speech on Line D.

3.1.9. *Recorder.*—The recorder will have monitoring facilities on the interception plotter's line (*see* para. 3.1.3).

3.1.10. *Telephone operator.*

(*a*) Head and breast set to P.B.X.

(*b*) Hand microphone-telephone on table for general use.

N.B.—Administrative lines will be brought to a separate exchange, outside the operations room.

3.2. Traffic Carried by External Lines

A summary of the external line facilities required in para. 3.1 is set out as follows :—

3.2.1. *To Sector.*

LINE A—(Sector Liaison Line)—

(*a*) G.C.I. Controller's liaison with Sector Controller (two-way traffic).

(*b*) Sector liaison's conversation with G.C.I. Liaison at Sector (two-way traffic).

LINE B—(Sector Plotting line)—

General trend of enemy activity, including heights of raids (told by G.C.I. teller at Sector to the Sector Plotter at the G.C.I. station).

LINE C—(Reporting plotting line)—

(*a*) Tracks of raids shown on P.P.I.4.

(*b*) The tracks on intercepting fighters.

(*a*) and (*b*) told by the Reporting teller at G.C.I. stations to the G.C.I. plotter at Sector.

N.B.—The information passed over line B is not the same as that passed over line C, since the former contains all relevant tracks observed by O.C., R.D.F. and G.C.I.

3.2.2. *To Identification Centre.*

LINE D—Tracks of raids shown on P.P.I.4 (told by the Reporting Teller at G.C.I. to the G.C.I. plotter at the identification centre).

This plotter will hear the same information as the G.C.I. plotter at Sector.

LINE E—(Identification Line)—

Liaison between G.C.I. reporting room and the identification centre, in order to identify and designate tracks seen on P.P.I.4.

3.3. Operations during Gas Attack

The obvious ideal protection is to make the whole building gas-proof.

If this is not possible certain additional facilities will be required. These are not discussed here.

4. The problems of lighting, heating and ventilation are not considered in this report.

A.M. File S.43174/I Encl. 75A.

APPENDIX No. 19

SITING BRIEF FOR D.M.H. AND TYPE 11 EQUIPMENTS AT FIXED G.C.I. STATIONS (COMPILED BY T.R.E. 29 NOVEMBER 1942)

The Type 11 equipment consists of a 50 cm. equipment designed to give plan position only. The horizontal beam width at half amplitude is 4½° and the vertical cover is independent of ground reflections except at low angles of elevation. The D.M.H. equipment also operates on 50 cm. and is designed to give height finding and to be used in conjunction with the Type 11 equipment. The horizontal beam width at half amplitude is about 11° and the vertical beam width about 3½°. The array consists of a paraboloid 30 ft. high and 12 ft. wide above ground. The Type 11 equipment is mounted on a trailer, but the D.M.H. Mk. I equipment will be fixed.

It is required that sites should be found on Fixed G.C.I. stations for both these 50 cm. equipments and also for the 260–300 Mc/s G.C.I. Stand-by. The siting requirements for the Stand-by and Type 11 equipments are similar and since both equipments are mobile it has been agreed that they should both use the same site provided that whichever equipment is not in use is kept at least 700 ft. away.

Since the D.M.H. is fixed, it must be placed at sufficient distance from both the Fixed G.C.I. array and the Stand-by or Type 11 array to prevent any mutual screening effects.

The limiting distances of all these equipments are shown in the table below.

	Minimum	*Maximum*
D.M.H. to Fixed or Stand-by G.C.I. Array	800 ft.	
D.M.H. to Happidrome	500 ft.	800 ft.
D.M.H. to Type 11	700 ft.	
Type 11 to Fixed G.C.I. Array	700 ft.	
Type 11 to Happidrome	650 ft.	800 ft.

The maximum figures are fixed by the maximum allowable lengths of cable runs.

The other factors which must be considered are the flatness of the site and the size of obstacles such as trees, wire fences, telephone wires, etc., in the vicinity of the site.

With regard to D.M.H. the essential criterion is that the tops of obstacles which subtend more than 2° in azimuth at the D.M.H. array should not be at an elevation of more than 1½° from the bottom of the array, which is 10 ft. above ground. Thus the normal defence wire, which is about 6 ft. high will not affect the D.M.H. unless the ground on which it is situated is very much above the D.M.H. site. Trees have a greater screening effect at 50 cm. than at 150 cm. and if possible the site should be chosen so that trees conform to the above requirements.

The requirements for Type 11 are rather more difficult to define exactly because ground reflections are involved at low angles of elevation and as yet no complete tests have been done with the equipment on a ground level site. At distances greater than 500 ft. the limiting factor is that the tops of obstacles which subtend more than 1° in azimuth should not be at more than 1½° in elevation from the bottom of the array, which is 4 ft. above ground. At smaller distances the effect of obstacles on ground reflections is more important. Calculations indicate that a 6 ft. wire fence should not be less than 300 ft. away and this figure should be aimed at wherever possible. However, a figure of 240 ft. has already been laid down for the Stand-by G.C.I. and in cases where the Stand-by site has already been chosen and cannot be altered, the same site will have to be used for the Type 11 and some decrease in the performance at angles below 2° may be expected. The requirements for Type 11 in regard to flatness of site are not so stringent as those for the Stand-by so that in general the Stand-by site should be satisfactory for Type 11 in this respect. For Type 11 alone the land should not have an average slope up of more than ½° nor an average down of more than 1°, though small irregularities may exceed these limits.

A.M. File, C.S. 17651, Encl. 1A.

APPENDIX No. 20

ORIGIN OF THE AN/CPS—1A (M.E.W.)

EXTRACT FROM S.H.A.E.F. AIR SIGNAL REPORT ON OPERATION OVERLORD

The introduction of six laboratory pre-production AN/CPS–1As into the European Theatre has had a great effect on the system of ground control for aircraft. It was originally designed to be a microwave early warning set (from which it derives the common name M.E.W.). But before the first production set came off the assembly line the laboratory models became engaged in an important role in an offensive which required little warning of enemy aircraft. It was soon apparent that it would need certain modifications to enable a number of groups to be controlled simultaneously and at the same time keep up with the rapid movement of advancing Armies.

It was necessary to :

(*a*) Provide more facilities for control in the way of communications, off-centre P.P.I.s, plotting screens, data boards, housing, etc.

(*b*) Provide a suitable height finder.

(*c*) Mobilise to a degree consistent with the mobility of the Ground Forces.

As a result of the experience gained in mobilisation and operation of the first three sets a committee of two U.S. and two R.A.F. officers was sent to Headquarters Army Air Forces in Washington in December, 1944, for the purpose of personally pressing the urgency for more M.E.W.s and to obtain modifications in the production models which were supposed to be soon coming off the production line. Plans were already underway to have the Radiation Laboratories at M.I.T. contract for and assemble four additional pre-production sets to fill the urgent demand from USSTAF to be allocated to :

Set No. 6 for XXIX TAC.

Set No. 66 for XII TAC.

Set No. 67 for First TACAF (for the First French Air Corps).

Set No. 68 for Eighth Air Force.

Two of the first few production sets were scheduled for the R.A.F. but the priority on the remainder of the production was for the Pacific Theatre and not the European. It was agreed that the four hand-made sets would be assembled as nearly as possible to conform with ETO requirements for mobility and layout, but it was too late for changes in the production sets to be made. These four sets were to be made mobile and supplied with Jamesway shelters, RC–127 IFF equipment, and AN/TTQ–1 Operations Center equipment.

Six production AN/CPS–1 would be allocated to USSTAF and mobilised, involving a six weeks' delay in delivery. A modification centre was to be set up to accomplish this and the remainder of the work of the committee was with the Army Air Forces Board to settle on the operations room layout, additional modification kits, and the degree of mobility. The delivery of these equipments and No. 68 pre-production model was cancelled on cessation of hostilities.

The second pre-production model made by the Radiation Laboratories was brought over to England and set up at Start Point, Devon, to be used as a fighter direction station prior to and during the invasion. Work began on assembling the equipment in the middle of January, 1944, and the station was technically ready for operations in the latter part of February, but did not officially start working until 1st April. From this location the M.E.W. had excellent coverage over the invasion area and a complete series of still photographs were made showing troop carrier, bomber, and fighter operations on D-day. The primary mission of the station was controlling aircraft and the secondary duty was reporting in to 10 Group as part of the radar chain of Air Defence of Great Britain.

Work had been progressing on mobilising the equipment while it was still in operation at Fairlight. Vehicles had been provided for mounting the indicators and the antenna. Telephone facilities were installed to provide all the internal communications for the equipment. An A.M.E.S. Type 13 was added to provide height reading. It was then moved to the continent and was in operation with the XIXth Tactical Air Command Control Centre near Vigneulles by the latter part of September. From 22nd September to 31st October, a total of 261 missions, including patrols, night fighters and photo reconnaissance, had been run. At the beginning of the German offensive in the middle of December the M.E.W. was sited east of Nancy at Morhange. With the shift of the Third Army to the North it moved to a new site near Longwy to get the necessary cover over the bulge in the front line. This site was occupied on 4th January and proved to have the least objectionable permanent echo pattern the best low cover over both air bases and target area of any site occupied. After the next move the Third Army swept across Germany and the mobility of the M.E.W. and the associated communication net was stretched to the utmost. At times, operations were carried on by radio and situation reports were dropped by plane. During this push the M.E.W. moved an average of 100 miles each week.