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INSTRUMENTS OF DARKNESS

The History of Electronic Warfare 1939–1945

ALFRED PRICE

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The History of Electronic Warfare, 1939–1945

Dr Alfred Price

Frontline Books

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FOR JANE

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Foreword

by
Sir Robert Cockburn, KBE, CB

(Written in 1967)

World War II was dominated by air power, which permeated every phase of the conflict. The aircraft became a major instrument of offence and defence in the air and a vital weapon in support of ground forces, in maritime warfare, in reconnaissance and in transport. This expansion of air power was stimulated by, and became critically dependent on, a series of remarkable developments in the fields of radar and radio communications. Both sides committed large resources to successive systems of early warning and detection, navigation, target identification and weapon guidance. Under the stimulus of war, technology advanced rapidly and each new system provided greater range, greater precision and greater capacity. Yet by modern standards they were still relatively naïve in concept and were soon found to be vulnerable to interference, deception and manipulation. It was a rude shock to designers to discover how quickly performance demonstrated in the laboratory was nullified in operation against a resourceful enemy; and as the war progressed scientists and engineers pitted their wits against one another to preserve their own systems, and to discover and exploit the weaknesses in those of their opponents. It is this story which Alfred Price describes in *Instrument of Darkness.*

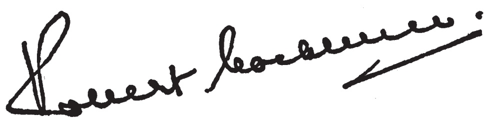
Alfred Price is a serving officer in the Royal Air Force, at present with Bomber Command; and he has been able to recapture the excitement and drama of a struggle in which new techniques and tactics could have such immediate and catastrophic consequences. But he is also an electronics specialist well qualified to deal with the technical aspects of his subject and to appraise the relative importance of the various countermeasures of World War II.

Rarely before or since has it been possible for the scientist in the laboratory to make such a direct impact on military operations. A few black boxes based on a new piece of intelligence, a revealing reconnaissance photograph or observations by a returning bomber crew could within a few weeks or months affect the fate of cities and the lives of hundreds of aircrew. Not all black boxes were equally effective; some were at best of psychological value, some were a temporary nuisance, and some were not only useless but positively dangerous. In the heat and fog of war any opportunity, however slight, must be exploited, but in retrospect it is clear that clever devices and adroit tactics were usually of limited value. Trivial weaknesses in a system were easy to exploit but equally easy to remedy, and over-sophisticated jamming and warning methods were incompatible with the nightly holocaust over German targets. Subtle countermeasures like 'Moonshine' were effective for special operations where surprise could be exploited, and they played an important part in the spoof invasions of the Pas de Calais. But it was straightforward noise jamming and the massive use of 'Window' which was most effective in sustained operations.

Alfred Price has profited by the lapse of twenty years to put his story of World War II into perspective. He has gone to a lot of trouble to present at each stage both the British and the German story, and he shows how closely developments on one side were matched on the other. There was, for example, the extraordinary similarity in the evolution of British 'Window' and German *Düppel*. Nowadays it is accepted that major technical advances will occur almost simultaneously in a number of countries, even in highly classified military projects. In peacetime the time scale of development is long enough that a year either way in producing a new weapon may not seriously affect the issue, but in war six months can make the difference between victory and defeat; and it was by such narrow margins that the outcome of the Radio War was determined.

Both sides entered the war believing that they possessed in radar a unique advantage over the other; and neither foresaw the profound effect that this scientific breakthrough would have on air operations. In 1940 our own radars were in many respects inferior to the *Freya* and the *Würzburg*, and we had no bombing and navigation systems to compare with the *Knickebein* beams and their successors. At the end of the war the Germans were introducing, well ahead of the Allies, a range of guided weapons, including the pilotless aircraft V-1 and the ballistic missile V-2. But the German High Command did not properly appreciate the pace of development or its inevitable impact on operations. For two critical years they failed to maintain the momentum of research in radar, and rapidly lost their initial advantage. By the end of the war British and American equipments were far superior both in performance and in range of application; and the German guided weapons came too late to redress the balance. In particular we were quicker to recognise and exploit the intrinsic vulnerability of radar and radio systems, and the initiative in the jamming war lay firmly in our hands.

The importance of the electronic environment not only to aircraft and guided weapons but to the whole range of military operations is now well understood; and one of the most important criteria of any radar or radio system is the ability to discriminate against unwanted and irrelevant information. Vulnerability can be theoretically specified, and allowed for. Nevertheless, jamming and deception are always possible, with sufficient effort. Ideally an economic balance should be struck between complexity and vulnerability, so that the cost of nullifying a system is comparable to the cost of establishing it. But this condition can seldom be met in practice, and Alfred Price's book is a salutary reminder that the impressive panoply of modern weapons is dependent ultimately on the survival, in war, of their guidance and control systems.



Author's Acknowledgements

First Edition

In writing *Instruments of Darkness* I have been greatly helped and encouraged by the many busy men who have unhesitatingly given me their valuable time: to all of them I tender my grateful thanks. Space does not allow me to mention each one by name, but I am particularly indebted to Sir Robert Cockburn, Professor R. V. Jones, Professor D. A. Jackson, Air Marshal Sir Robert Saundby, Air Vice-Marshal E. B. Addison, Air Commodore Chisholm, Dr B. G. Dickins and Mr J. B. Supper and, in Germany, the S*tudiengruppe der Luftwaffe*, the Telefunken Company and Herr Hans Ring.

I should like to thank Sir Donald MacDougall for allowing me access to Lord Cherwell's papers and Mr. R. Bruce and Mr. C. Moore for allowing me to examine documents under their control. Also I am indebted to Mr. L. A. Jackets and the staff of the Air Historical Branch for much of the material I have used. I must stress, however, that I alone am responsible for the opinions expressed.

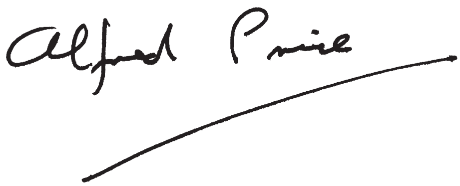
My thanks go to Her Majesty's Stationery Office for permission to quote from *The Strategic Air Offensive Against Germany 1939–1945* by Sir Charles Webster and Noble Frankland. I should also like to thank Messrs. Cassell and Co. for allowing me to quote from Winston Churchill's *The Second World War*; Messrs. Methuen and Co. for permission to quote from *The First and the Last* by Adolf Galland; Group Captain J. R. D. Braham for the use of the passage from his autobiography *Scramble*; and the proprietors of the *Daily Mirror* for permission to reproduce the Buck Ryan cartoon strip.

I should like to record my debt to my wife, who gave valuable support when the going was tough, and my mother, who helped with the German translations.

This Edition

In the thirty-seven years since the initial appearance of this book, important additional material has become available. This completely revised edition takes the story up to the time of the Japanese surrender in August 1945, and details the huge US efforts in this area in both the European and the Pacific theatres of operations. I am grateful to the Association of Old Crows, Washington DC, for permission to use material from Volume 1 of *The History of US Electronic Warfare*, which I wrote to their commission.

On a sad note, I must mention that almost all of the men and women I interviewed for this book are no longer alive. Let these pages serve as a memorial to their achievements.



‘The instruments of darkness tell us truths,
Win us with honest trifles, to betray’s
In deepest consequence.’

Shakespeare, *Macbeth*

Prologue

On the evening of 2 August 1939 the giant airship LZ130 *Graf Zeppelin* lifted off from her base at Frankfurt-am-Main and climbed slowly into the night sky. Leaving the German coast near Cuxhaven, she rumbled out over the North Sea heading for a designated search area off the coast of Great Britain.

The LZ130, last of the long line of rigid airships built in Germany, had been designed to fly on the trans-Atlantic passenger service in conjunction with her sister ship, the LZ129 *Hindenburg*. Before the new airship was completed, however, *Hindenburg* came to a fiery end. With her died the notion of the airship as a passenger-carrying vehicle. For a time, *Graf Zeppelin* had no formally assigned role. Then, in the spring of 1939, she was modified for a quite different task.

If war came, Luftwaffe intelligence officers would need to know the use potential enemies made of the radio spectrum for communications, navigation and even radar systems. Without such knowledge, and the method of operation and location of these systems, countermeasures would be impossible. *Graf Zeppelin*'s luxurious passenger compartments now carried a battery of radio receivers and a team of signals experts to operate them. The airship was the world's first airborne electronic intelligence, or Elint, collector.

From April 1939 the *Graf Zeppelin* flew a series of missions along Germany's eastern and western frontiers, hunting for radio and other signals of interest emanating from neighbouring countries. On 12 July she ventured over the North Sea, and reached a point about a hundred miles off Middlesborough before turning for home.

The mission on 2 August was a more determined attempt to examine the radio spectrum in the skies around Great Britain. For that mission the airship carried a crew of forty-eight, who included a twenty-five-strong team of radio specialists under the command of Dr Ernst Breuning. The airship crossed the North Sea and flew close to the east coast of Scotland, taking care to remain outside territorial waters. She then turned around and flew southeast down the coast to a point abeam Lowestoft, before returning to Germany.

While the Zeppelin was within their cover, Britain's newly erected line of 'Chain Home' radars reported her every move. When she passed Aberdeen an RAF Magister training plane took off to get a closer look at the airship, and for a time flew in formation with her.

Given the amount of British radar activity over the North Sea, it is surprising that the radio operators aboard the Zeppelin failed to identify British radar signals. Interviewed in 1969, Ernst Breuning told the writer that his team had concentrated their search on the radio spectrum above 100 MHz. That was where early German radars operated, and it seemed reasonable to expect that British radars might do the same. In that part of the spectrum the listeners found none of the expected pulsed radar signals. They did, however, hear transmissions from the new VHF radios being developed in Britain for the RAF.

Breuning and his team did make a cursory search in the 20–50 MHz band – which was in fact that part of the spectrum where the early British radars operated. There the listeners found some pulsed signals, but these were discounted. The transmissions sounded just like those picked up during earlier flights, identified as coming from a station in Germany conducting experiments to measure the altitudes of the layers of ionised gas that surround the earth. Missing the British radar signals was an easy enough mistake, given that the German radio operators were learning the rudiments of Elint 'on the job' and their receivers had not been designed for this task.

Graf Zeppelin's marathon flight lasted 48 hours and covered a distance of 2,600 miles. It was the longest she would ever make. Less than a month after she returned from her sortie, on 1 September 1939, Germany invaded Poland. Within a couple of days, Great Britain and France entered the conflict in support of their eastern ally. With a major war on its hands, the Luftwaffe saw no further role for the big airship and she was scrapped.

Graf Zeppelin's unsuccessful missions off the coast of Great Britain are of historical interest only, for they achieved little of military value. Yet the notion of searching the radio spectrum for enemy or potential enemy signals, as a prelude to countering them, was an idea whose time had come. The airship's flights marked the first tentative steps in a completely new form of warfare, one whose significance both sides would quickly learn.

Chapter 1

The Battle of the Beams

> 'During the human struggle between the British and German air forces, between pilot and pilot, between AA batteries and aircraft, between ruthless bombing and the fortitude of the British people, another conflict was going on step by step, month by month. This was a secret war, whose battles were lost or won unknown to the public; and only with difficulty is it comprehended, even now, by those outside the small high scientific circles concerned.'
>
> Winston Churchill, *Their Finest Hour*

The truth about military intelligence work is that much of its success depends on chance, and much upon tenacity. Little of it is glamorous in the way that readers of espionage thrillers would believe. In the case of a secret device to guide bombers to targets, for example, in time of war it is usually only a matter of time before an aircraft carrying it is shot down and falls in hostile territory. Then, a diligent examination of the wreckage should reveal its existence and survivors, perhaps still shaken after narrow escapes, may be induced to talk under interrogation. Aircrew cannot be expected to memorise detailed lists of radio frequencies, callsigns and the geographical positions of beacons. If that information is to be used in the stress of action, it has to be written down and taken on the sortie. Sooner or later, one of those briefing sheets is bound to be captured.

If the system involves radio beams, those investigating it have another clear advantage: such beams cannot be concealed. One has only to look carefully enough and they will be found. Once the transmissions are found, they can be analysed and their purpose deduced. Thus, a handful of intelligence officers can have a bearing on the conflict that is out of all proportion to their numbers.

This was why, on the night of 21 June 1940, Flight Lieutenant Harold Bufton came to be patrolling in the darkness over East Anglia in a twin-engined Anson aircraft. In the rear cabin his wireless operator, Corporal Dennis Mackey, carefully searched the ether with his radio receiver. Suddenly Mackey found what he was looking for: a series of Morse dots, sixty to the minute, piercingly clear in his headphones. As the Anson continued on its heading, the dots merged into one steady note. A little later, the steady note broke up, not into 'dots' but into Morse 'dashes' at the same steady rate of sixty to the minute. Later in the flight, a second radio beam was located. After he landed at his base at Wyton, Bufton reported:

> 1. There is a narrow beam approximately 400–500 yards wide, passing through a position one mile south of Spalding, having dots to the south and dashes to the north, on a bearing of 104° to 284° True.
> 2. That the carrier frequency on the night of 21st–22nd June was 31.5 mc/s, modulated at 1,150 c/s and similar to Lorenz in characteristics.
> 3. That there is a second beam having similar characteristics but with dots to the north and dashes to the south synchronised with the southern beam, apparently passing through a point near Beeston on a bearing lying between 60° and less than 104°.

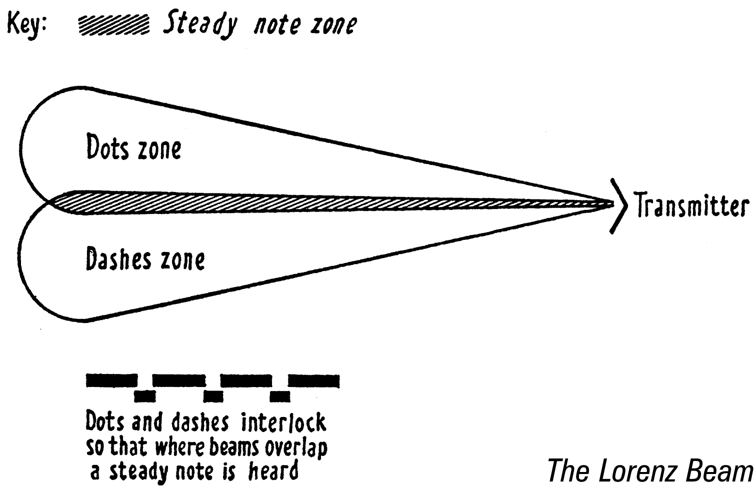
In terms of the effort involved, the flight of the Anson with the two-man crew was far removed from the *Graf Zeppelin*'s abortive Elint collection mission off the coast of Great Britain almost a year earlier. Yet in intelligence collection, success is often unrelated to effort involved.

The Anson had located a couple of radio beams emanating from Germany, which intersected over the important Rolls-Royce aero-engine factory at Derby. It was a highly significant discovery.

* * *

To observe the background of that discovery, we need to look briefly at some scientific developments that had taken place in Germany in the early 1930s. There the Lorenz Company had developed a blind-approach system to help aircraft find airfields in bad weather. The so-called 'Lorenz System' used two adjacent radio beams to mark a path extending up to thirty miles from the airfield. In the left-hand beam Morse dots were transmitted, and in the right-hand beam Morse dashes. The signals interlocked, so that where the two beams overlapped a listener heard a steady note. Aircraft navigated by flying down the steady-note zone until they came to the beams' transmitter.

By the mid-1930s the Lorenz system was in widespread use by civil airlines and some air forces. The Royal Air Force used it, as did the Luftwaffe. In Germany Dr Hans Plendl, a specialist in radio-wave propagation, then adapted the Lorenz system to assist aircraft to attack accurately at night or in bad weather. This system became the *X-Gerät* ('X-device') which employed six Lorenz-type beams. Marking the approach to the target were three such beams, one coarse and two fine, all transmitted on different frequencies and all pointing straight at the target. The other three beams crossed the approach beams at three points leading up to the bomb-release point. The *X-Gerät* radio beams were transmitted on frequencies between 66 and 75 MHz (see map on p. 44).



The Lorenz Beam

A bomber using *X-Gerät* followed the approach beam to the target. When it was 50 km (30 miles) from the bomb-release point, the aircraft flew through the first crossbeam. That served as a warning that it was time to line up accurately in the approach beam. When it was 20 km (12 miles) from the bomb-release point, the aircraft flew through a second crossbeam. As it did so, the navigator pressed a button to start one hand of a special clock, similar to a stopwatch but with two hands that rotated independently. When the bomber was 5 km (3 miles) from the bomb-release point, it passed the third and final crossbeam. When he heard the steady-note signals from that beam, the navigator pressed the button on his special clock a second time. The hand which had been moving stopped, and the other hand started rotating to catch it up. The distance from the second crossbeam to the third crossbeam was three times that from the third crossbeam to the bomb-release point (5 km or 3 miles), so the second hand on the clock travelled three times faster than the first. When the hands coincided, a pair of electrical contacts closed and the bombs were released automatically.

All in all this was a sophisticated system, considering that it had been produced before World War II. The combination of the clock and the beams provided accurate data on the bomber's speed over the ground, one of the most important facts to be known for accurate bombing once an aircraft was routed correctly over the target. The Luftwaffe established a special unit to operate with *X-Gerät*, No. 100 Air Signals Battalion (*Luftnachrichten Abteilung 100*) based at Köthen near Dessau and equipped with Junkers 52s and Heinkel 111s.

Meanwhile Telefunken, a competitor of Lorenz, had produced another blind-bombing system for the Luftwaffe. Called *Knickebein* ('Crooked Leg') this system was much simpler than *X-Gerät* and it employed only two Lorenz beams. One beam marked the approach to the target, the other crossed the first beam at the bomb-release point. The system was less accurate than the *X-Gerät*, but it had two major advantages over it. Firstly, the device used the same frequencies – 30, 31.5 and 33.3 MHz – as the Lorenz airfield-approach receiver fitted as standard in all German twin-engined bombers, so that receiver could pick up the *Knickebein* signals, and there was no need for the bomber to carry specialised equipment. Secondly, crews trained in the use of the Lorenz airfield-approach receiver could fly the *Knickebein* beams without further training. Thus *Knickebein* could be used by the entire Luftwaffe bomber force and not just part of it.

The aerial array necessary at the *Knickebein* ground transmitter was a huge structure, more than 100 feet high and 315 feet wide. The whole thing rested on railway bogies running on a circular track, to allow the beam to be aligned accurately on the distant target. The system's range depended on the altitude of the receiver aircraft: a bomber at 20,000 feet could receive the signals from a transmitter 270 miles away. The steady-note lane was one-third of a degree wide, giving a theoretical accuracy of one mile at a distance of 180 miles.

By the end of 1939, the Luftwaffe had erected three *Knickebein* transmitters to cover potential targets in Great Britain and western Europe. One was at Kleve close to the Dutch frontier, a second was at Stollberg in Schleswig-Holstein, and a third was at Lörrach in the southwest corner of Germany.

Towards the end of 1939, No. 100 Air Signals Battalion was redesignated Kampfgruppe 100 (KGr 100) and now possessed twenty-five He 111s fitted with *X-Gerät*. During the campaigns in Norway and France, however, the unit did not use its night precision-attack capability and operated as a normal day-bombing unit. However, soon after the Allied evacuation from Dunkirk in June 1940, Luftwaffe signals personnel began erecting *Knickebein* and *X-Gerät* transmitters in Holland and northern France as part of the preparations for attacks on Great Britain.

* * *

Until the spring of 1940, the RAF had not considered it likely that German night bombing attacks would prove a serious threat. The general view was that the darkness that hid the bombers from the defences would also hide the targets from the bombers. Dr R. V. Jones, a scientist who a few months earlier had taken up a post at the Directorate of Intelligence at the Air Ministry, had a wide remit. His task was to determine which scientific developments taking place in Germany might affect the air war. He began receiving clues from various sources which suggested that the Luftwaffe possessed, or would soon possess, a radio system to guide bombers to their targets at night or in bad weather.

In March 1940, an He 111 bomber crashed in England. In the wreckage, searchers found a scrap of paper which stated:

> *Navigational aid:* radio beacons working on Beacon Plan A. Additionally from 0600 hours Beacon 'Dunhen'. Light beacon after dark. Radio beacon '*Knickebein*' from 0600 hours on 315°.

At about the same time, a prisoner admitted under interrogation that *Knickebein* was 'something like the *X-Gerät*', about which he assumed his captors already knew. He said that a beam was sent from Germany which was so narrow that it could reach London with divergence of no more than one kilometre (the prisoner had exaggerated the fineness of the beam, though Jones had no way of knowing this).

Two months later, the diary of a German airman was found in the wreckage of another He 111. Under 5 March it carried the significant entry:

> Two-thirds of the *Staffel* on leave. In the afternoon we studied *Knickebein*, collapsible boats, etc.

From these snippets of information Jones deduced that *Knickebein* – and the *X-Gerät* which was 'something like' it – might be some sort of directional radio beam. The bearing of 315 degrees might point from the northwest coast of Germany to Scapa Flow, an area where Luftwaffe bombers had been active. What seemed unbelievable was the prisoner's assertion that a radio beam from Germany to London – a minimum distance of 260 miles – could have a divergence of only one kilometre. In fact the prisoner had exaggerated: the beam's divergence at that distance would have been nearly 1½ miles.

By now the Government Code and Cipher School at Bletchley Park was starting to produce a useful stream of decrypts of German radio signals transmitted in high-level Enigma ciphers. One such signal, picked up on 5 June and decrypted four days later, stated: '*Knickebein* at Kleve is confirmed [or established] at point 53° 21' N, 1° W.'

The signal had come from the Chief Signals Officer of Fliegerkorps IV and it seemed that the position, near Retford in Nottinghamshire, might be the location of an illicit radio beacon. A search of the area produced nothing but, significantly, the signal gave the location of a *Knickebein*. For, apart from being the home of the fourth wife of King Henry VIII, the town of Kleve lay at the part of Germany closest to Great Britain.

The next logical step was to examine the radio equipments carried by the He 111 bomber, since this aircraft was linked with each intelligence report on *Knickebein*. Did it carry any device that could receive beam signals at long range? In October 1939, an He 111 had crash-landed near Edinburgh. At Farnborough, technicians had carefully dissected and analysed each item of the plane's equipment. At the time they noted that the plane's Lorenz blind-approach receiver was far more sensitive than its British counterpart. Might this be the device that picked up the long-range beam signals?

At first sight it might seem a simple matter to find out whether the Luftwaffe possessed a long-range radio-beam system. A few flights by aircraft carrying search receivers would settle the matter. But Jones was young and recently appointed and had no such aircraft under his control. Also, he knew he had to play his cards carefully. Jones saw his position as being analogous to that of a watchdog. He had to bark when he saw danger, but if he barked at the first whiff of trouble and none was subsequently revealed, people would learn to disregard his cries. On the other hand if he barked too late, the Luftwaffe could strike unhindered. There could be no mistaking the gravity of the situation, if the Luftwaffe really did possess an accurate method for attacking targets by night at a time when Britain's air defences were ineffective.

There was one man who could secure for Jones the influential backing he needed, and upon whom he could rely for a sympathetic hearing: his tutor at Oxford before the war, Professor Frederick Lindemann. Frederick Lindemann and Winston Churchill had been close friends since 1919, and when Churchill became prime minister in May 1940 the association continued. For all his superlative qualities as a war leader, Churchill had little grasp of scientific matters and he relied heavily on Lindemann to explain these to him.

Clearly, if Jones could convince Lindemann of the possible danger of the Luftwaffe radio beams, his battle would be half won. On 12 June Lindemann sent for Jones to discuss another matter. At the end of the conversation, Jones steered the discussion round to *Knickebein*. Lindemann was unimpressed, however. He said he could not believe that a long-range beam on a frequency of around 30 MHz – the part of the spectrum covered by the Lorenz blind-approach receiver – would bend to follow the curvature of the earth. At that time such signals were thought to travel almost in a straight line, which limited their effective range to about 180 miles if the receiving aircraft was flying at 20,000 feet. That fell far short of the 260-mile range necessary to reach London from the nearest point in Germany.

On the day after the unsuccessful encounter, Jones returned to Lindemann's office carrying an unpublished paper he had discovered. Its author was Thomas Eckersley, scientific advisor to the Marconi Company and a leading authority on the propagation of radio waves. The paper contained a series of graphs to illustrate the maximum ranges at which radio signals on various frequencies could be received. By taking the extreme end of one of the curves, it looked as if signals on 30 MHz might be picked up by an aircraft flying at 20,000 feet over much of England, provided the transmitter was situated on high ground in Germany. That satisfied Lindemann, who immediately wrote to the Prime Minister:

> There seems to be some reason to suppose that the Luftwaffe have some type of radio device with which they hope to find their targets. Whether this is some form of RDF [radar] . . . or some other invention, it is vital to investigate and especially to seek to discover what the wavelength is. If we knew this, we could devise means to mislead them; if they use it to shadow our ships there are various possible answers . . . If they use a sharp beam this can be made ineffective.
>
> With your approval I will take this up with the Air Ministry and try to stimulate action.

Before passing the note to Sir Archibald Sinclair, his Secretary of State for Air, Mr Churchill jotted a brief comment at the bottom: 'This seems most intriguing and I hope you will have it thoroughly examined.'

Now Jones had the big guns firing for him. Sinclair acted promptly and on the following day, 14 June, he placed Air Marshal Sir Philip Joubert in charge of the investigation. On that very day RAF interrogators were questioning another prisoner, who stated that *Knickebein* was a bombing device involving two intersecting radio beams which could be picked up by the aircraft's Lorenz receiver. He added that bombers had to fly very high to pick up the beam signals at long ranges. For example, to receive the signals over Scapa Flow the aircraft had to be above 20,000 feet. Jones observed that from Scapa Flow to the nearest point in German-controlled territory – in western Norway – was 260 miles. That was exactly the same distance as from London to the nearest point in Germany.

This intelligence was available in time for a meeting Air Marshal Joubert had called for 15 June, attended by Lindemann and Jones. Now there was sufficient evidence to justify bringing more people into the picture, and Joubert summoned a further meeting for the following afternoon. In addition to Jones the attendees included Air Chief Marshal Sir Hugh Dowding, C-in-C Fighter Command, and Air Commodore Charles Nutting, the RAF Director of Signals. Jones recounted the available evidence, and it was decided to fit special radio receivers to aircraft to hunt for the beams. Three Avro Anson general-purpose aircraft would be made available, and work began immediately to fit them with the necessary radio receivers.

Squadron Leader Rowley Scott-Farnie, representing the RAF signals intelligence service at the meeting, opined that the beams would probably be found on a frequency of 30, 31.5 or 33.3 MHz. He said that every Lorenz receiver found in a wrecked Luftwaffe aircraft was tuned to one of those three frequencies.

On the following Tuesday, 18 June, fresh evidence arrived in a miscellany of papers salvaged from a German aircraft shot down in France some weeks earlier. On one of them was written:

Long-range radio beacon = VHF

1. *Knickebein* (near Bredstedt, north-east of Husum)
   54° 39'
   8° 57'
2. *Knickebein* (near Kleve)
   51° 47' 5"
   6° 6'

That served to confirm some of the earlier pieces of information on *Knickebein*. If those were the locations of two *Knickebein* transmitters, that would make sense. Those positions were at points in Germany among the closest to England, but they were well separated to give the greatest possible 'angle of cut' between a pair of beams. Jones noted that Scapa Flow lay on a bearing of 315 degrees from Bredstedt, which explained the earlier reference.

As if more proof were needed, a wrecked Heinkel provided a further clue. The wireless operator's log had been recovered intact and it included a list of known radio beacons. At the head of the list was a jotted entry: '*Knickebein* Kleve 31.5'. Each of the other beacons was followed by a radio frequency, and the RAF listening service confirmed that the list was correct for the night in question. It was therefore reasonable to assume that the *Knickebein* at Kleve had on that night been radiating on 31.5 MHz. That fitted in with Scott-Farnie's prediction.

That evening, 19 June, an Anson took off on the first flight to search for beam transmissions; its receiver developed a fault, however, and the radio operator heard nothing. On the next night, the 20th, another Anson flew a patrol to look for beams but found nothing – the Luftwaffe had stayed at home.

Even as that aircraft was airborne, however, an RAF intelligence officer was literally piecing together another clue. A Luftwaffe wireless operator had baled out of his crippled aircraft over England. Soon after landing the airman, more conscientious than many of his compatriots, realised he still had his notebook. He carefully tore it into more than a thousand pieces, but as he attempted to bury them he was captured and the pieces were recovered. The reward of much hard work was a table of data, which confirmed the positions of the Kleve and Bredstedt transmitters and the operating frequency of the former; it also gave the frequency of the latter as 30 MHz.

Thus, by the morning of 21 June, R. V. Jones had established the positions and frequencies of two of the *Knickebein* transmitters. The findings were timely, for that very morning Churchill decided to summon a top-level meeting at No. 10 Downing Street to discuss the latest intelligence on the German radio beams. Among those present were Sir Archibald Sinclair (Air Minister), Lord Beaverbrook (Minister of Aircraft Production), Professor Lindemann, Sir Cyril Newall (Chief of Air Staff), Sir Hugh Dowding and Sir Henry Tizard (Scientific Advisor to the Air Staff). When Jones arrived, the meeting had already started. He arrived to find a discussion in progress on whether aircraft could in fact be guided by long-range radio beams. Both in rank and age, Jones was by far the most junior person present. He sat there waiting to be asked to speak, and after a few minutes the Prime Minister questioned him on a technical point. That was the excuse Jones had been waiting for and he asked 'Would it help, sir, if I told you the story from the start?' Churchill said it would, and Jones recounted various pieces of evidence supporting the theory that the Luftwaffe possessed a system of radio beams to direct bombers on to targets. That convinced the meeting that here was a matter worthy of further investigation. The axis of the discussion shifted from 'Do the German radio beams exist?' to 'How can we find out more about them?'

That afternoon Air Commodore Nutting summoned Jones and Eckersley to his office, to discuss the technical details of the beam transmissions that might be used by Luftwaffe bombers over England. Then Eckersley dropped his bombshell: despite the series of graphs he had previously drawn, he said he could not agree with the widely held explanation of *Knickebein*. He said he did not believe that radio signals on 30 MHz would bend to follow the curvature of the earth. Jones pressed Eckersley to explain why he had produced the set of graphs upon which he, Jones, had relied so heavily in the Cabinet Room that morning. Eckersley renounced them, saying they applied to a different case when he had tried to stretch his theory. The feelings of Jones can be imagined more readily than described, since he had used Eckersley's graphs to convince Lindemann that a long-range beam following the curvature of the earth was a possibility. Obviously someone was barking up the wrong tree; Jones could only hope it was not himself. (In fact partial bending to conform with the earth's curvature does occur with transmissions on 30 MHz, but its extent was not realised in Britain at the time.)

While Jones pondered on this unexpected development, the hunt for the beam signals continued. That very night, the patrol by Bufton and Mackey picked up the German beam transmissions over the Midlands, as described at the beginning of this chapter. Appropriately, given the seriousness of the new threat, the RAF code-named the beam system 'Headache'.

It fell to Air Commodore O. G. Lywood to initiate counter-measures. Wing Commander Edward Addison, one of Lywood's staff officers, latter recalled:

> One day he [Lywood] called me in and told me that a young fellow from scientific Intelligence called Jones had produced an extraordinary story of the Luftwaffe using a beam over this country to bomb London. It was known as *Knickebein*. He said: 'I can't tell you how he came by this information, but he has. It looks extremely dangerous. What do you think we ought to do?'

Addison suggested the formation of a specialised organisation to counter the German beams. Lywood agreed, and placed Addison in charge. Addison's new unit, No. 80 Wing, was hastily established and set up its headquarters at Garston near Radlett in Hertfordshire.

Thing were now moving ahead rapidly, but one further element of the defences was required. There needed to be an organisation to build the specialised jamming devices to render the German beams unusable. That task fell to Dr Robert Cockburn, a young physicist who had recently joined the Telecommunications Research Establishment (TRE) at Swanage. He and a small team began work to design and build tailor-made jammers to counter *Knickebein*.

The process of building specialised jammers would take time, however, and time was short; an all-out bombing offensive on Great Britain might begin any day. Accordingly, Addison requisitioned several diathermy sets (devices used in hospitals to cauterise wounds) and had these modified into crude spark transmitters to transmit a 'mush' of radio noise on the *Knickebein* frequencies. RAF personnel installed the diathermy jammers in selected police stations, where the duty constable had instructions to switch them on when instructed to do so from No. 80 Wing headquarters.

Addison also secured some RAF Lorenz airfield beam-approach transmitters and modified these to radiate a beam similar to that put out by *Knickebein*. His idea was to produce a fake beam that could be laid across the German beam, in the hope that the German bombers might wander off course without the crews noticing it. Monitoring flights revealed that the deviation produced by the low-powered device was negligible. Nevertheless, in the interests of getting countermeasures up and running as soon as possible, a few of these systems went into service with No. 80 Wing.

An important component of the new wing was the flight of Anson aircraft commanded by Squadron Leader R. Blucke, which now flew patrols each night to determine the directions and crossing points of the German beams. Initially this unit operated under the cover name of the Blind Approach Training and Development Unit (BATDU for short). In September 1940 the unit was renamed the Wireless Intelligence Development Unit (WIDU), but its work continued exactly as before.

Soon after the Anson aircraft had first picked up *Knickebein* signals, the RAF listening service discovered that suitably equipped ground stations could also receive these signals. Several outstations were now set up, which passed information on the beams' frequencies and of their dot or dash transmissions to No. 80 Wing headquarters where they were plotted out on a special map. Those ground stations alone could not provide an exact picture of the German beam patterns. Yet they provided a useful cue for the Ansons to get airborne, and greatly narrowed the search area for their crews to hunt for the beams' steady-note lanes.

To underline the increasing potency of the new threat, during August RAF listening posts picked up signals that were traced to two new *Knickebein* transmitters erected on the north coast of France. One was at Greny near Dieppe, only 120 miles from the centre of London. The other was at Beaumont-Hague near Cherbourg, 150 miles from the capital.

While Addison requisitioned equipment for his makeshift jamming organisation to begin operating, there was another commodity he urgently needed: capable personnel. With the highly technical war that was now in the offing, he had no use for other units' misfits and throw-outs. He needed the best material available. Fortunately, interest in the wing's well-being extended from the prime minister down, and Addison had free reign to choose people for his unit. A particularly useful source of recruits was the community of peacetime amateur radio enthusiasts.

* * *

At the same time as the wing began its improvised countermeasures to *Knickebein*, it took control of another jamming commitment that had been initiated some months earlier. Luftwaffe aircraft made considerable use of radio beacons set up in friendly territory, to assist navigation. Each German radio beacon transmitted its identification letters in Morse code, then a 50-second tone to allow aircraft radio operators to take bearings on the beacon. At that time in Britain there were fears that German agents might plant radio beacons near targets, to guide in their bombers. To counter the beacons, Post Office engineers had devised a clever device known as the Masking Beacon, or 'Meacon'.

The device comprised a receiver and a transmitter located about 12 miles apart. The receiver was linked to a directional aerial, aligned on the German beacon it was to counter. The receiver picked up the German beacon's emissions, amplified them and fed them by landline to the 'Meacon' transmitter. The transmitter then radiated an exact replica of the German beacon signal, with the same Morse identification letters and 50-second tone, exactly in step with the German signals. But the 'Meacon' transmitter was, of course, in a quite different position.

Professor Lindemann explained the operation of the Meacons in a paper he wrote for the Prime Minister early in August. The Luftwaffe, he said, had nearly eighty radio beacons in Germany, Norway and northern France, operating on the medium and long wave bands. Not more than twelve of these beacons were in use at any one time, the remainder being held in reserve. Different groups were used on different days.

Lindemann continued:

> There are two ways of dealing with such beacons. The first is to jam them, i.e. to make so much disturbance in the ether that their signals cannot be received. If one compares them with lighthouses, it is like turning on the sunlight so that they would become invisible. This method is difficult because they operate on so many different wavelengths that we must produce very strong signals in each band to cover the lot… Further, each lighthouse has its own colour (wavelength) which has to be outmatched, so that the general glare must be produced over the whole spectrum, ranging from 30 metres to 1,800 metres. In order to cover this range eight very powerful stations would be required, but this leads us to another difficulty. If we had eight such stations, the Luftwaffe would soon get to know where they were and could use them as lighthouses to guide them to their targets. It is much easier to fly towards a beacon than to navigate away from it on back bearings.
>
> In order to prevent this it would be essential to link our jamming stations in groups of three, making each group of three flash simultaneously. If this is done (though there is no exact optic analogy), the radio receiver cannot tell from whence the beam comes, so these could not be used as homing stations. On the other hand, this would imply the use of 3 x 8, i.e. 24 powerful stations, which would mean that all our home wireless had to be sacrificed for this purpose. By giving up the BBC and all other transmitters, this arrangement could possibly be made in four to six weeks. Even then we should have difficulty if the Luftwaffe chose to use, instead of their normal beacons, the super high-power stations normally used for wireless purposes in France and Holland.
>
> This brings us to the second method, called ‘Masking’. For this purpose, we require a number of small stations in England which

> pick up and repeat the German signals exactly in phase. If this is done, the wireless operator in the German machine cannot distinguish between the signals from his beacon and the echo signal from our station, and his direction finding is completely set to nought. Since these echo stations are in exact phase with the ground stations it is impossible to home on them, so that they cannot be used as a navigational aid by the enemy as a German station could. They are admittedly slightly more complicated to set up, but we have already six in action and a further nine will be operating within a week. Providing the Luftwaffe do not use more than twelve stations at a time we can mask them completely with these fifteen stations so this method of navigating will be nullified. All masking beacons are being provided as rapidly as possible and it is hoped in a few weeks to be able to cope with any possible German orchestra of beacons. Obviously, if we had eighty, we could deal with them if they turned on all their eighty beacons. On the other hand it is unlikely that they will use too many at a time as it would certainly confuse their own pilots very much. Thirty stations would probably suffice for anything the Luftwaffe are likely to do.

* * *

By 18 August 1940, No. 80 Wing had nine 'Meacon' stations in operation. Two days later, the strange assortment of hastily erected 'Headache' stations – modified diathermy sets and Lorenz transmitters – was ready to begin radiating on the *Knickebein* frequencies. It was a close-run thing for, on 28 August, a force of 160 bombers delivered the first heavy night attack on a British city, Liverpool. The bombers returned to the port in similar strength on each of the following three nights. The expected night onslaught had opened.

On 7 September, the bombers shifted their night attacks to London. From then until 13 November an average of 160 aircraft raided the capital each night, except for one occasion when bad weather prevented operations. This assault coincided with the deployment of the first of the jammers which Robert Cockburn and his team had designed to counter *Knickebein*. The RAF code-name for the German beam system was 'Headache', so the code-name for the antidote system – the jammer – was 'Aspirin'. The latter transmitted Morse dashes on the beam frequencies. Those dashes were not synchronised with the beam signals, rather they were superimposed on them. The intention was that when a bomber pilot heard the Morse dashes, he would turn in the required direction. But when he reached what should have been the central steady-note lane he continued to hear dashes and so tended to overshoot. When in the 'dot zone', he heard a mixture of dots and dashes which did not resolve themselves into a clear note.

The 'Aspirins' were prescribed for the more important sites, where they replaced the less efficient modified diathermy sets and Lorenz transmitters. Both of the older types of equipment were then moved to new sites, to increase the area where jamming cover was available.

Throughout this period there was discussion as to whether it might be possible to design a countermeasures system to 'bend' the German beams, to push the bombers off course without their crews realising it was happening. Technically speaking, such a device was feasible. Such an elegant countermeasure would have taken time to design and build, however, and Addison had to meet a major threat to Britain's cities; he did not have time to develop subtle approaches to the problem. In the event there was never any deliberate bending of the German beams, though it is widely believed that this was the case. Possibly the story began as a 'plant' by British intelligence, to weaken Luftwaffe confidence in *Knickebein*. As Addison told this writer:

> Whenever anything unusual happened, people thought it was us. At the time we worked in such secrecy that when these funny ideas got around we had no means of correcting them – even had we wanted to. On one occasion a German aircraft unloaded its bombs in the castle grounds at Windsor. The next morning, the Comptroller of the King's Household rang me; he was very cross, and wanted to know why we had bent the beams over Windsor – His Majesty might have been killed. It was the usual case of a lost German getting rid of his bombs – and we got the credit or the blame, depending on where they fell.

Dr Robert Cockburn voiced similar views during an interview with this writer. He commented:

> The myth has been established that we bent the beams. In fact we didn't. I did rig up a system using a receiver at Worth Travers, near Swanage, and a transmitter at Beacon Hill, near Salisbury. I was going to pick up the modulation of the *Knickebein*, retransmit it, and thus push the beam over. In other words, my transmitter would have produced a beam similar to the German ground station but pointing to where I wanted it to. It was all very nice, but it didn't happen. By the time the system was ready, the other jamming methods were in full swing and we could not spare the time or the effort to bring out a new system to supplement the old. So the deliberate bending of the German beams, which I had worked out, never happened.

When No. 80 Wing took over the Beacon Hill jamming station the unit used it to transmit unsynchronised Morse dashes, just like the other 'Aspirins'.

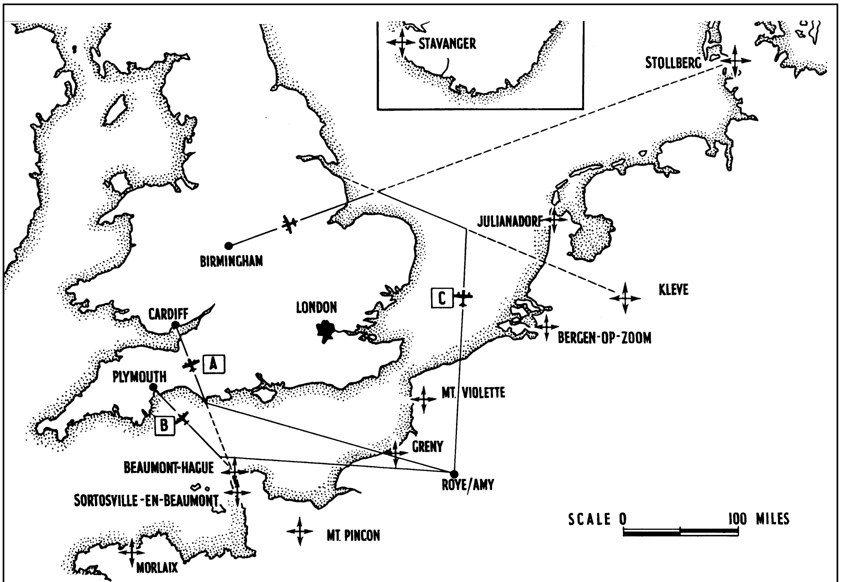
In October 1940, Edward Addison was promoted to group captain. No. 80 Wing now comprised twenty officers and 200 men and women, and operated fifteen 'Aspirin' sites to jam the *Knickebein* beams. How effective was this effort?

The British 'official line', published in several books including the earlier editions of this one, was that the jamming was so effective in disrupting the *Knickebein* beams that the system fell soon out of use. The truth of the matter is rather different, though the outcome was the same.

The *Knickebein* transmitter at Greny, 120 miles from London, often provided the main beam to the British capital. The Beaumont-Hague transmitter, 150 miles from the capital, was well placed to provide the necessary crossbeam. If those two transmitters trained their beams on London they could mark out a diamond-shaped patch of sky with sides measuring about 900 yards and 1,600 yards. The threat of over a hundred German night raiders delivering bombs to that degree of accuracy was a fearful prospect, but it never happened.

Luftwaffe bomber crewmen who flew over Britain at that time have told the writer that usually they could easily hear the beam signals through the early jamming. Yet, even if it was not fully effective, the presence of the jamming was unsettling to the attackers because it indicated that the defenders were aware of the beams' existence and probably knew their location. One Luftwaffe bomber pilot told this writer:

> At first we were very excited about *Knickebein*, a fine new method of navigation and a big help to find our targets. But after we had used it on operations once or twice, we realised that the British were interfering with it. Initially the jamming was weak and it hardly concealed the beam signals at all. But that fact that our enemy obviously knew that the beams existed and that they were pointing towards the target for the night, was very disconcerting. For all we knew, night-fighters might be concentrating all the way along the beam to the target. More and more crews used the *Knickebein* beams only for range, and kept out of them on the run up to the target.



Knickebein Beam Stations

The eleven beam stations used during the attacks on Britain are shown. The map also shows attacks made by a Ju 88 pilot with III/KG 1, flying from Roye/Amy. A: raids on Cardiff on the nights of 1 and 3 March 1941, picking up the Beaumont-Hague beam at the coast and flying from there straight to the target. B: Plymouth 21, 28 and 29 April, again using Beaumont-Hague. C: Birmingham 16 May; this time he flew north to pick up the Kleve beam then northwest to find the Stollberg beam and the route to the target. During March and April the bombers often used the same route for repeat attacks. By May it was considered prudent to make a wide detour to avoid the defences in southeast England.

Other German aircrew echoed those sentiments, which became progressively stronger as the jamming became more powerful and the night defences became more effective.

The primary effect of the jamming had therefore been its effect on the morale of the bomber crews, rather than the disruption it caused to the *Knickebein* signals. Yet the 'bottom line' of the makeshift efforts of No. 80 Wing and Dr Cockburn's team was that they had successfully neutralised the German beam system. That gave a considerable boost to their prestige both in the RAF and in the corridors of power at Whitehall. It was also a triumph for Dr R. V. Jones and the cause of scientific intelligence; the next time the watchdog started to bark, people would listen. That would soon happen, for the Luftwaffe still had its other beam system.

* * *

On 13 August 1940 the Luftwaffe began its large-scale aerial bombardment of targets in Great Britain. On that day the first of the hard-fought daylight battles took place over southern England. After darkness fell, twenty-one He 111 bombers attacked the Nuffield factory at Castle Bromwich producing Spitfire fighters, and the nearby Dunlop tyre factory in Birmingham. The unusual feature of this attack was the inordinately high degree of concentration for a night raid – eleven bombs hit the sprawling collection of factory buildings at Castle Bromwich. The aircraft involved belonged to the special beam-flying unit Kampfgruppe 100, and carried the complex *X-Gerät* beam system.

After its impressive start, KGr 100 delivered night attacks on several other small targets. The high degree of bombing accuracy achieved during the initial attack was not repeated often, however, and usually the attacks were not so effective.

Halfway through August, the RAF monitoring service picked up unexplained signals on 74 MHz which appeared to originate from a point on the French coast. Jones code-named the new system 'Ruffian'. By the end of the month the monitors had noted signals on nearby frequencies, and ground direction finders pinpointed their sources to the Calais and Cherbourg areas. The signals differed from those of *Knickebein* in their frequency and the keying rate, but they were sufficiently similar to identify them as an aid to navigation. During the following month Jones added further items to his file on 'Ruffian' and after his success with *Knickebein*, his new fears found ready ears. At the end of the third week in September his report, passed via Professor Lindemann, reached the prime minister's desk:

> It appears that the Luftwaffe are making great efforts to improve the accuracy of their night bombing. A number of new beams on a shorter wavelength than before have appeared. . . One *Kampfgeschwader*, KG 100 consisting of about forty machines [*sic* – in fact it was a *Kampfgruppe*, though the unit's strength was given correctly], has been equipped with special new apparatus to exploit these beams with which apparently accuracies of the order of 20 yards are expected.
>
> With the technique they seem to be developing such a result does not seem impossible. We know the exact location of the sources of the beams in question. The parent beam is on the very tip of the Cherbourg peninsula; the crossbeams are in the Calais region. They will probably not reach much beyond London. Apart from attacks on the machines using the beams, our possible lines of defence would be:
>
> 1. to try to destroy the specially fitted KG 100 machines which are stationed at Vannes; home station Lüneburg and reserve station at Köthen;
> 2. to try to destroy the beam stations
> (a) by bombing, which would be very difficult since they are almost invisible targets
> (b) by a special [i.e. commando] operation;
> 3. to employ radio-countermeasures.

Early on in the investigation, RAF intelligence identified the distinctive footprint of the new series of attacks: great accuracy along a line running from Cherbourg, with a somewhat lower accuracy in range. The heaviest bombs used were 550-pounders.

From the early summer of 1940 Luftwaffe signals personnel had worked hard to establish landline connections between each of the major bases and airfields in France, and that service's main communications network in Germany. Starting in eastern France, they gradually worked their way westwards. As each airfield came on line it ceased using wireless for ground-to-ground communications, a move which deprived the cipher crackers at

Bletchley Park of the opportunity to read their traffic. As luck would have it, however, KGr 100's base at Vannes lay in the extreme west and so was one of the last to be connected to the network.

Thus, from the autumn of 1940 until well into 1941, Bletchley Park was able to deliver to Jones's office a steady stream of decrypted signals on KGr 100's activities. On occasions the intercepted signals listed the beam frequencies and alignments for a night's attack. Yet, at that stage of the war, the painstaking task of decryption often took several days. Although the raids were therefore over long before Jones read the signals, the information they contained was invaluable to build up a general picture of how the system worked. He noted that the beams were aligned to within five seconds of arc, which implied a maximum accuracy of the order of twelve feet at a distance of 100 miles from the beam transmitter. From this, Jones estimated accuracy of the new system to be 'of the order of twenty yards'. In fact his report exaggerated the accuracy of the system by a factor of about six, but even so it represented a potent threat.

To counter the X-beams Dr Cockburn and his team hastily modified the transmitter from an Army gunlaying radar to jam the beam frequencies, and code-named the device 'Bromide'. When the prototype appeared to work satisfactorily, Cockburn's section began a crash programme to build sufficient 'Bromides' to provide cover for potential targets. The immediate plan was to install these jammers at ground stations between Cherbourg – the source of the approach beams – and the Midland towns, Manchester and London.

By the end of September KGr 100 had taken part in more than thirty attacks, more than half of which were on London. For the rest of the attacks the unit usually visited targets alone, attempting precision attacks using the beams.

Early in October, RAF intelligence noted that KGr 100 had started dropping 1-kg stick-shaped incendiary bombs during some of its attacks. On the face of it that was a strange development; these small weapons scattered over a large area and could not be aimed accurately, which seemed to nullify the major advantage of the X-beam system. There seemed only one reasonable explanation for the change: KGr 100 was practising to lead the rest of the Luftwaffe bomber force to its targets.

Apprised of the new information, Lindemann advised Mr Churchill on 24 October:

> There is some reason to believe that the method adopted is to send a few KG 100 aircraft fitted with special devices to assist in blind bombing on these expeditions, in order to start fires on the target which any subsequent machines without special apparatus can use.

The note accurately predicted the course the Luftwaffe would adopt a few weeks later.

In the meantime, fate played into the hands of British intelligence in one of the more inept episodes of the secret war. Early on the morning of 6 November, a raiding Heinkel bomber suffered a compass failure over England. After tuning their radio compass to the beacon at Saint-Malo in Brittany, the crew turned for home. When the radio compass indicated that the aircraft had passed over the beacon, the aircraft descended but as it broke the cloud the pilot saw he was still over the sea. This had to be the Bay of Biscay, so he reversed his course and headed back to the beacon. By now his fuel was almost exhausted and, when a coastline came into view, he decided to set the bomber down on the beach. The pilot misjudged his approach, however, and in the resultant crash one crewman was killed and two were injured.

The survivors scrambled up the shingle beach where, to their great surprise, they were immediately surrounded by soldiers in khaki uniforms. The beacon in which the airmen had misplaced their trust had been covered by a No. 80 Wing 'Meacon' transmitter at Templecombe in Somerset. What the crew had thought to be the southwest coast of Brittany, was in fact the beach at West Bay near Bridport. Some soldiers waded out to the wreckage and secured a rope round it, and all would have been well had a Royal Navy vessel not arrived. The ship's captain pointed out that, since the bomber was in the sea, its salvage was technically a Navy matter. After some wrangling, the Army grudgingly agreed. The sailors took the line aboard their ship and solemnly towed the aircraft out into deeper water, preparatory to lifting it out. Unfortunately, in the course of that operation, the rope snapped and the Heinkel sank to the bottom. Dawn broke to reveal the upper part of the wrecked bomber protruding from the waves, looking rather like a stranded whale. As the tide receded, the plane's markings gradually came into view; painted on the rear fuselage in characters nearly four feet high were the identfication markings 6N+BH. And 6N was the unit code for KGr 100.

Professor Lindemann was understandably bitter when he learned what had happened. A week later, he wrote to the prime minister:

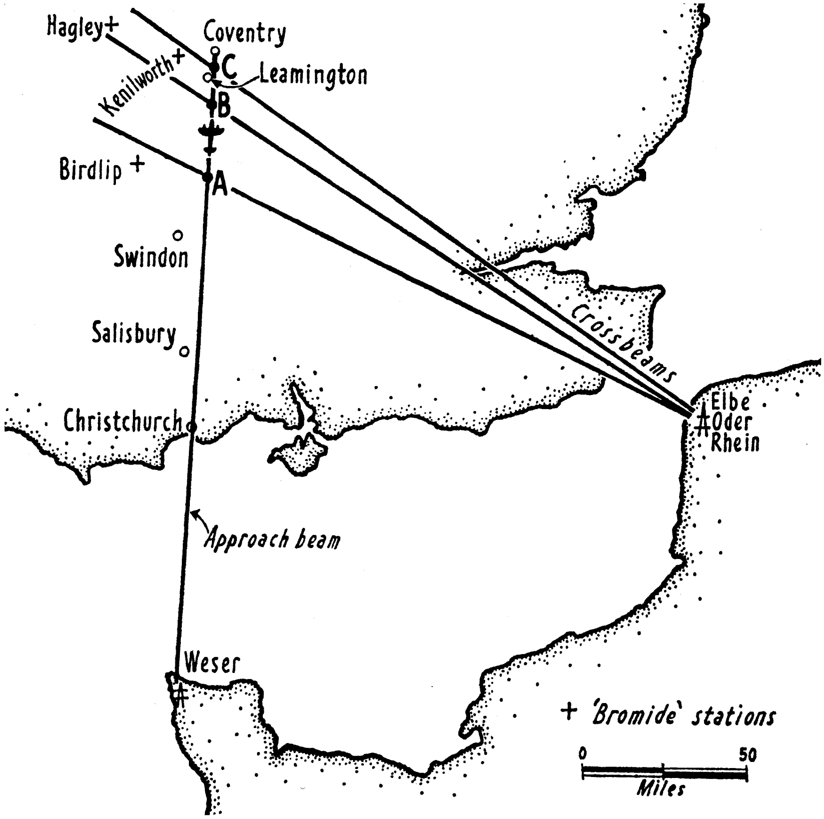
> The KG 100 squadron is the only one known to be fitted with the special apparatus with which the Luftwaffe hope to do accurate night bombing using their very fine beams. As it is important to discover as much as possible about this apparatus and its mode of working, it is a very great pity that inter-Service squabbles resulted in the loss of this machine, which is the first of its kind to come within our grasp.

All was not lost, however. RAF technicians removed the invaluable X-beam receivers from the waterlogged hulk and, looking somewhat the worse for their immersion, they went to Farnborough for examination. Any last doubts regarding the advanced nature of German radio-beam technique were dispelled by the dates on some of the receivers' inspection-stamps. They went back to 1938.

In the second week of November, the Luftwaffe shifted the burden of its attack from London to the Midlands cities. In the first of these attacks KGr 100 was to lead the bomber force to its target, Coventry. On the afternoon of 14 November the Boulogne headquarters of 6th Air Signals Company – the unit which operated the X-beam transmitters – received its orders on beam alignments from KGr 100's headquarters at Vannes. It relayed these instructions to transmitters *Elbe*, *Oder* and *Rhein* nearby, and to *Weser*, the 'approach-beam' transmitter, on the Cherbourg peninsula. The approach-beam crossed the English coast near Christchurch, ran to the east of Salisbury and Swindon, and passed over Leamington and Coventry. Shortly before the target city the three 'crossbeams' intersected it.

That night KGr 100 sent thirteen He 111s to mark Coventry. Soon after 1900 hours, the leading aircraft crossed the Thames. Six minutes later it flew through the first of the crossbeams, and moved into the centre of the main approach beam aligned on the city.

On that night, only four 'Bromide' transmitters were available to counter the X-beams. One of these, at Kenilworth, lay almost directly beneath the bombers' run in. Yet the jammers caused the raiders little trouble; the system had been conceived in haste at a time when too little had been known about *X-Gerät*. Consequently, although the jammers probably emitted on the correct frequency, the radiated note was modulated at 1,500 cycles instead of 2,000 cycles. The difference – between a whistle and a shriek – is just perceptible to the human ear; but the filter circuits in the German receivers were sensitive enough to pick the beam signals out of the jamming with ease.



Layout of the X-Beams over Coventry, Night of 14 November 1940

The leading Heinkel continued on its northerly course undisturbed and at 1906 hours, three miles south of Leamington, it flew through the second crossbeam. The observer started the automatic bomb-release clock and two and a half minutes later, about a mile east of Bagington, the aircraft flew through the third and final crossbeam. The second pointer on the clock began moving rapidly to catch up with the first. Fifty seconds later the two pointers overlapped, the pair of electrical contacts closed and the bombs were released. The time was 1920 hours.

During the next 45 minutes, the twelve remaining Heinkels from KGr 100 dropped their bombs on the city, starting some fires. By then the first of the main force of bombers had arrived, and in the hours to follow their loads reinforced the destruction already caused. Yet, even without the assistance of KGr 100, it is likely that the main force of bombers would have found the target with little difficulty. It was a bright moonlight night, with clear skies. Feldwebel Günther Unger of Kampfgeschwader 76 (KG 76), piloting a Dornier 17, attacked later that night. He recalled:

> While we were still over the Channel on the way in we caught sight of a small pinpoint of white light in front of us, looking rather like a hand torch seen from two hundred yards. My crew and I speculated as to what it might be – some form of beacon to guide British night-fighters, perhaps. As we drew closer to our target the light gradually became larger until suddenly it dawned on us: we were looking at the burning city of Coventry.

One stream of bombers came in over the Wash, another over the Isle of Wight and a third over Brighton. Altogether 449 bombers hit Coventry during the ten hours of the attack. Between them they dropped 56 tons of incendiaries, 394 tons of high-explosive bombs and 127 parachute mines. The city was hit heavily and several factories were forced to cease production, albeit temporarily. Nearly 400 people were killed and a further 800 were seriously injured.

The attackers had the rare benefit of a combination of perfectly clear skies, a full moon, a combustible target (there were many old timbered buildings), and weak anti-aircraft defences. Although the *X-Gerät* beams played a part in the raid's success, this should not be exaggerated. Crews in the follow-up bomber units, including Günther Unger, have said the night was so bright that they would have found the city even without the assistance of marking by KGr 100.

Meanwhile, examination of the captured *X-Gerät* receiver had revealed the weakness of the 'Bromide' jammer, and within a few days of the attack they had all been modified to transmit the correct jamming note. With modified 'Bromides' emerging from Cockburn's workshop at an encouraging rate, it seemed that a much more effective No. 80 Wing was ready to counter KGr 100's next major pathfinder marking effort.

Birmingham came under attack on the night of 19 November (by thirteen bombers from KGr 100 and 344 aircraft in the follow-up force), on the 20th (eleven and 105) and the 22nd (nine and 195). Yet that city suffered nothing like the concentrated damage inflicted on its neighbour. Nor, during the months to follow, would any other British city.

At the time British intelligence attributed the sudden deterioration in the effectiveness of KGr 100-led attacks to the improvements made to the 'Bromide' jammer. With the benefit of hindsight, however, it is possible to offer a quite different explanation for the failure to repeat the destruction inflicted on Coventry. The steady improvement in Britain's night air defences during the winter of 1940 forced the Luftwaffe to cease large-scale attacks when there was a full moon. Also, during that period, the raiders had to contend with frequent spells of bad weather. So, when Kampfgruppe 100 led attacks on nights when there was little or no moon and poor weather, against targets that were better defended than Coventry and less combustible, it is not surprising that the results were less impressive. Although other cities suffered damage comparable with that suffered by Coventry in relation to their size – notably Liverpool and Plymouth – in their case it was the cumulative effect of several attacks and not just one.

Even when *X-Gerät* worked perfectly, the weak system of target marking usually mitigated against an effective attack. The Luftwaffe was evolving its technique from scratch, and it still had a lot to learn. For one thing, it employed far too few pathfinder aircraft. Sending ten or a dozen bombers mark the target, for a follow-up attack that might last six hours or more, was not enough. Moreover, the 1-kg 'stick' incendiary bomb dropped by KGr 100 to start fires had poor ballistics and was a relatively inaccurate weapon. Even if the initial fires were accurately laid, the pathfinder marking rapidly became diluted as bombers in the follow-up force dropped much greater numbers of incendiary bombs with varying degrees of accuracy. Since the bombers all carried more or less the same types of high explosive and incendiary bombs, it was impossible to tell which fires had been started by pathfinders and which by the follow-up bombers. If there was cloud cover, the follow-up bombers often failed to find their target even if the initial marking had been accurate. In a later chapter we shall observe how the RAF applied the lessons it learned from the Luftwaffe attacks in 1940 and 1941.

In the autumn of 1940, No. 80 Wing took control of a special unit to counter the Luftwaffe pathfinder tactics. If the follow-up raiders aimed their bombs at fires on the ground, why not light fires in the countryside for them to bomb? The job of establishing the necessary decoy fires – known as 'Starfish' – fell to a section headed by Colonel J. Turner, one-time head of the RAF Works Department. Since the decoys needed to look plausibly like cities under attack, timing was critical. The fires had to be well alight in time to catch the follow-up attackers, and ideally the bombers should need to fly over a decoy to reach the real target. That called for careful control and good communications. The 'Starfish' operation was an integral part of No. 80 Wing's activities, directed from its headquarters. By the end of November twenty-seven decoy sites were ready for action.

The first two 'Starfish' were ignited on the night of 2 December 1940, just over two weeks after the Coventry attack, during a raid on Bristol. In the course of that action the sites collected sixty-six high-explosive bombs. From then on, the 'Starfish' were a regular feature of Britain's passive defences. If the local fire and civil defence services were able to extinguish the pathfinders' fires promptly, decoy fires often drew away a large proportion of the bombs intended for city targets.

By February 1941, No. 80 Wing had sufficient 'Bromide' transmitters to jam all of the approach and crossbeam frequencies. That brought about a significant improvement in jamming effectiveness, and a resultant deterioration in the performance of *X-Gerät*. Now, when KGr 100 delivered an attack on its own, the unit's 'bomb signature' often showed that a large proportion of its bombs had fallen outside the target area.

* * *

In November 1940 the RAF monitoring service noticed more unusual signals on frequencies in the 42–48 MHz band, and R. V. Jones allocated these the code-name 'Benito'. The new system, called *Y-Gerät* by the Germans, was another brainchild of Dr Hans Plendl. This employed a single beam made up of 180 directional signals per minute, which was aligned on the target. That was too fast for human interpretation, and the aircraft carried an electronic analyser to determine its position relative to the beam.

To measure the aircraft's range from the ground station, the ground station transmitted additional signals which the aircraft picked up and re-radiated on a different frequency. The ground station then measured the range using normal radar methods. When the aircraft arrived at the pre-computed bomb-release point, the ground station transmitted the bomb-release signal. Since it used only one ground station, *Y-Gerät* was more flexible than either of the predecessor systems. It was more accurate than *X-Gerät*, though it was also a great deal more complex.

General Wolfgang Martini, head of the Luftwaffe signals service, later recounted how he tried to explain the operation of *Y-Gerät* to Hermann Göring. The Reichsmarschall listened for about two hours, then asked a few questions which showed he was none the wiser. Göring, a World War I fighter ace, had little time for such things. He thought wars should be fought by brave men with guns, not like this. He is said to have commented on another occasion, 'Radio aids contain boxes with coils, and I don't like boxes with coils.' It is hard not to feel for him.

After a false start in the summer of 1940, Plendl's new system resumed operations at the end of the year. The *Y-Gerät* was fitted to the He 111 bombers of III Gruppe of KG 26 (III/KG 26) based at Poix near Amiens, and beam transmitters were situated at Poix, Cherbourg and Cassel in France.

When he examined the *Y-Gerät* signals, Dr Cockburn noted that there were separate transmissions to fix the aircraft's bearing and range from the ground beacon. To counter the system, therefore, he worked out a separate jamming method for each. At the time it was discovered the new beam system was still at the working-up stage, so Cockburn was under no great pressure to rush his jammers into operation. He even had time to introduce subtlety into his countermeasures.

The prototype of Dr Cockburn's new jammer for *Y-Gerät* – code-named 'Domino' – employed a receiver at Highgate and the BBC's dormant television transmitter at Alexandra Palace north of London. The receiver picked up the ranging signal from the bomber's transmitter and passed it to Alexandra Palace, where the powerful equipment there returned the 'echo' to the German ground station to produce an erroneous range indication.

The first 'Domino' went on the air in February 1941, soon followed by another at Beacon Hill near Salisbury. It soon became obvious that the 'Domino' transmitters were causing embarrassment to bomber crews relying on the *Y-Gerät*. On 9 March, the Y-beam signals changed frequency in the middle of an operation in an attempt – unsuccessful – to shrug off the jamming. Two nights later a small force of bombers attacked the Beacon Hill jammer, and one scored a near miss which put the station out of action for a few days. On the following night that jammer was still off the air, when III/KG 26 operated once more. The Alexandra Palace jammer covered the transmitter at Cassel, and none of those crews received the bomb release signal. There was no 'Domino' cover for the Beaumont-Hague transmitter, however, and crews using that ground station made accurate attacks. On the next night the Beacon Hill station was back on the air, and full jamming cover returned. Of eighty-nine *Y-Gerät* sorties flown over England during the first two weeks of March 1941, only eighteen aircraft received the bomb-release instruction.

On the night of 3 May 1941, during an attack on Liverpool and Birkenhead, the Y-beam unit lost three Heinkels shot down. In each case the *Y-Gerät* equipment was removed from the wreckage and sent to Farnborough for examination. This revealed that between each pair of direction signals there was a short gap, which locked the electronic bearing-analyser to the beam. Later Dr Cockburn commented:

> Unlocking the Y-beam was a piece of cake: they had fallen into the trap of making things automatic, and when you make things automatic they are more vulnerable. All one had to do was radiate a continuous note on the beam's frequency. This filled in the gap between the signals, unlocked the beam analyser and sent the whole thing haywire.

Dr Cockburn's new jammer, code-named 'Benjamin', first went on the air on 27 May 1941.

By then, however, a major development in the German war strategy had brought about a profound change in the air war over Great Britain. During May 1941 the bulk of the Luftwaffe bomber force moved to bases in eastern Europe, in preparation for the long-planned attack on the Soviet Union. On 21 June the offensive began, and the intensity of the night Blitz suddenly gave way to the boredom of waiting for an enemy who rarely came.

An air of almost unreal calm descended on Great Britain, but Group Captain Addison could not rely on the respite lasting for long. If German forces achieved a rapid victory in the east, the Luftwaffe would resume its onslaught on Great Britain. During the summer and autumn of 1941 No. 80 Wing continued its build-up, and replaced the last of the makeshift jammers with purpose-built systems. By September the unit had a strength of some 2,000 men and women of all ranks. It operated eighty-five ground stations scattered throughout the British Isles, and controlled more than 150 'Starfish' decoys.

* * *

So ended the first-ever electronic warfare action. *Knickebein* had surrendered almost without a fight. *X-Gerät* proved more difficult to jam, but in the time available its capabilities were not exploited sufficiently to provide effective target-marking for Luftwaffe bombers. *Y-Gerät* played only a minor role, its effectiveness much reduced by jamming, before the bombing campaign ended.

We now know that the jamming of *Knickebein* and *X-Gerät* was less disruptive than had been thought at the time. Yet, although the initial jamming of *Knickebein* was insufficiently powerful to conceal the beam signals, it dissuaded Luftwaffe crews from using their beams when flying over England.

Although the Luftwaffe reaction to the various countermeasures had been slow in coming, it would unwise to conclude that Luftwaffe technicians could not have modified their radio aids to operate more effectively in the face of the jamming. In fact, before they could do so, the night bombing offensive against Britain had come to a halt. As we shall see, the Luftwaffe could do much better than this.

Chapter 2

The Instruments

> 'I have done my best during the past few years to make our air force the largest and most powerful in the world. The creation of the Greater German Reich has been made possible largely by the strength and constant readiness of the air force. Born of the spirit of the German airmen in the First World War, inspired by its faith in our Führer and Commander-in-Chief – thus stands the German Luftwaffe today, ready to carry out every command of the Führer with lightning speed and undreamed-of might.'
>
> Order of the Day from Hermann Göring
> to the Luftwaffe, August 1939

Radar, like many major inventions in the twentieth century, did not result from a sudden and inspired line of thought pushed to the point of fulfilment by a single inventor. As with many innovations, the basic idea preceded the invention by several decades. Only when each of the major components had been developed, could its realisation become practicable. Again, as with many other inventions, once the background work was complete, development of the device proceeded independently in several nations simultaneously.

In the case of radar, by the early 1930s the major components necessary to assemble such a system already existed. These were: a high powered pulsed transmitter; a very sensitive receiver; a device for measuring small time differences very accurately (the cathode-ray tube); and a highly directional aerial system. During that decade scientists working independently in Great Britain, the USA, France, Germany, the Netherlands, Japan and the Soviet Union all produced working radars. Each nation claimed the device as its own, and in each the fighting services believed that it offered them a unique advantage. Since they would be the target systems in the next phase of the electronic warfare battle, however, the account that follows will concentrate on radar developments in Germany.

* * *

When World War II began in September 1939 the German armed forces had two separate types of radar in service and a third was at the advanced testing stage. For early warning against air attack the Gema Company had produced the *Freya* radar operating on frequencies around 120 MHz, initially with a maximum range of about seventy-five miles. Gema also produced the *Seetakt* radar operating on 370 MHz, for installation in warships and at shore batteries. This radar provided surface-search and also accurate range information to assist naval gunnery.

Late in the 1930s the rival Telefunken Company also entered the field of radar, and its *Würzburg* equipment was the impressive result. When the war began this equipment was still in the trials stage. The small, highly mobile set operated on what was then the extremely high frequency of 560 MHz, and could plot the position of aircraft to within fine limits at ranges up to twenty-five miles. The *Würzburg* was the first radar in the world with the precision to allow anti-aircraft gunners to engage targets accurately at night or through cloud. Also at this time, Telefunken had commenced testing a small airborne radar.

How well did the German radars compare with their British equivalents at the outbreak of World War II? The *Freya*, the only German early-warning equipment, had a maximum range of seventy-five miles, its rotating aerial array gave it full 360-degree cover and its wheeled carriage allowed a high degree of mobility. Yet, it could not measure the altitude of approaching aircraft. Its nearest British equivalent, the 'Chain Home' operating on the far lower frequencies between 20 and 52 MHz, had a maximum range of 120 miles and could determine the altitude of approaching planes. But the 'Chain Home' stations gazed out to sea with a fixed 120-degree angle of look, and for technical reasons the radar could not give reliable plots on aircraft flying over land. Moreover, the four 300-foot high towers – each twice the height of Nelson's column – supporting each station's transmitter aerials precluded mobility.

It was not in its radar hardware that the RAF had established a lead, but rather in the way in which the information was exploited. Only in Fighter Command could reliable and up-to-date information based on radar plots be passed to fighter pilots by radio. By September 1939 the RAF had nineteen 'Chain Home' radars operational, covering the approaches to the east coasts of England

and Scotland. Its system of fighter control had been developed and tested during scores of exercises. The Luftwaffe had made no attempt to perfect such a system of its own before the war. Since it had little to fear from hostile bombers, that service had logically concentrated its energies on offensive developments – like the radio beams.

The *Seetakt* and *Würzburg* precision radars were the most advanced equipments in the world in their respective categories. When war broke out, the Royal Navy had no equivalent of the *Seetakt* for its ships nor would it have one for another two years, and the *Würzburg* was considerably in advance of its nearest British equivalent in both range and plotting accuracy. But Britain had established a lead in the development of radar sets small enough to be carried in aircraft; there were two types on the point of entering service, one for coastal patrol aircraft and one for night-fighters.

* * *

In the autumn of 1939 the Luftwaffe had eight *Freya* stations operating on the chain of islands along the northwest coast of Germany: two on Heligoland, two on Sylt, two on Wangerooge, one on Borkum and one on Norderney.

At that time the RAF was prohibited from attacking targets on the German mainland, because this would endanger civilian lives. It therefore sent bombers in probing attacks, to feel out the defences with attacks on German warships in the Heligoland Bight. The first three daylight bombing attacks were inconclusive. Then, on 18 December 1939, twenty-four Wellingtons of Nos. 9, 37 and 149 Squadrons set out from their bases in East Anglia to patrol the Schilling Roads, Wilhelmshaven and the Jade Roads. Two of the Wellingtons turned back early with technical problems, the rest continued with the mission.

Just after midday, a *Freya* radar on the pre-war holiday island of Wangerooge picked up the approaching Wellingtons at a range of seventy miles. The operator reported the formation to the nearby fighter station at Jever and, after a delay, the defending fighters, sixteen Messerschmitt Bf 110s and thirty-four Messerschmitt Bf 109s, took off to engage. By then, having found no warships at sea, the bombers had turned around and were heading for home. It was a clear winter's day and the fighter pilots could see the RAF formation from several miles away. They quickly caught up with the raiders and, in the heated engagement that followed, bomber after bomber went down. Of the twenty-two bombers involved in the action, only ten regained friendly territory.

So the RAF had learned the hard way, as the Luftwaffe was to learn during the Battle of Britain and the US Army Air Force would learn in 1943, that formations of bombers operating over enemy territory by day without fighter escort risked heavy losses. The lesson was clear, and throughout most of the conflict that followed RAF Bomber Command sought to avoid the German defences by delivering attacks under cover of darkness.

On 14 May 1940, following the destructive Luftwaffe attack on the city of Rotterdam, Prime Minister Winston Churchill lifted the ban on air attacks on the German mainland. By 4 June, RAF bombers had flown some 1,700 night sorties over Germany at a cost of thirty-nine aircraft, most of them lost in accidents. Compared with what Bomber Command would achieve later in the war, those early operations were no more than gestures of defiance. Yet they caused a degree of consternation in Germany. Had not Hermann Göring declared that the Ruhr industrial area would not be exposed to a single bomb from an enemy aircraft?

After inspecting the AA gun defences in the Essen area in August 1939, Göring's imagination had been captivated by the *Würzburg* radar. Here was a device to enable the gunners to engage enemy planes even through the thickest cloud or at night. It was the success of the early *Würzburg* trials that had inspired him to make his much-quoted declaration regarding the invulnerability of the Ruhr. Yet the introduction of *Würzburg* into service took somewhat longer than anticipated, and the first sets did not become operational until the summer of 1940. Lacking radar, the gunners sought out the night raiders using searchlights and largely ineffective sound locators, with poor results.

Göring was not at all satisfied by this – while his reputation had suffered, the raiders had not. Since the AA guns alone could not inflict losses sufficient to deter the night raiders, he decided to form a specialised night-fighter force. Up to that time a few intrepid pilots had flown night patrols in single-seat Bf 109 fighters, and on occasions they had shot down raiding bombers. Yet, lacking any formal system of ground control, an interception at night remained a matter of chance.

In July 1940 Göring summoned Oberst Josef Kammhuber to his headquarters, and ordered him to set up a specialist night-fighter unit and a ground-control system to support it. Kammhuber was forty-three when he took on his new appointment. In his previous posts he had demonstrated that he was a methodical worker, displaying great drive tempered by sound judgement. He was to use these qualities to the full in his new post.

Kammhuber worked fast. By mid-August 1940 the first specialised night-fighter unit, Nachtjagdgeschwader 1 (NJG 1), had a strength of seventy Bf 110s, seventeen Ju 88s and ten Do 17s. None of these planes carried radar or other specific equipment for their new role, however. Backing these fighters, on the ground, was a regiment of searchlights and a few *Freya* early-warning radar sets. Kammhuber was promoted to Generalmajor and established his headquarters in a seventeenth-century castle at Zeist near Utrecht. The night-fighter organisation was subordinated to Generaloberst Hubert Weise, responsible for overall command of the air defence of the Reich.

During the summer and autumn of 1940, radar-directed night-fighting was in its infancy. Usually fighters were scrambled when early-warning radar stations on the coast reported approaching raiders. After take-off the night-fighters flew to assigned radio beacons, which they orbited until searchlights nearby illuminated an enemy bomber. Then, with his target in sight, the night-fighter pilot closed in for the kill. Known as 'illuminated night-fighting' (*Helle Nachtjagd*), this system achieved some success.

The early engagements revealed an important weakness in the system, however. The searchlights were positioned around the bombers' potential targets, as were the AA guns. There was no effective system of identification, with the result that night-fighters often came under fire from the ground. Quite apart from the loss of men killed or wounded, and in aircraft destroyed or damaged, that made the system manifestly inefficient. The gunners were shooting at fighters, and the fighter pilots had to manoeuvre to avoid the shells, at a time when both should have been engaging enemy bombers.

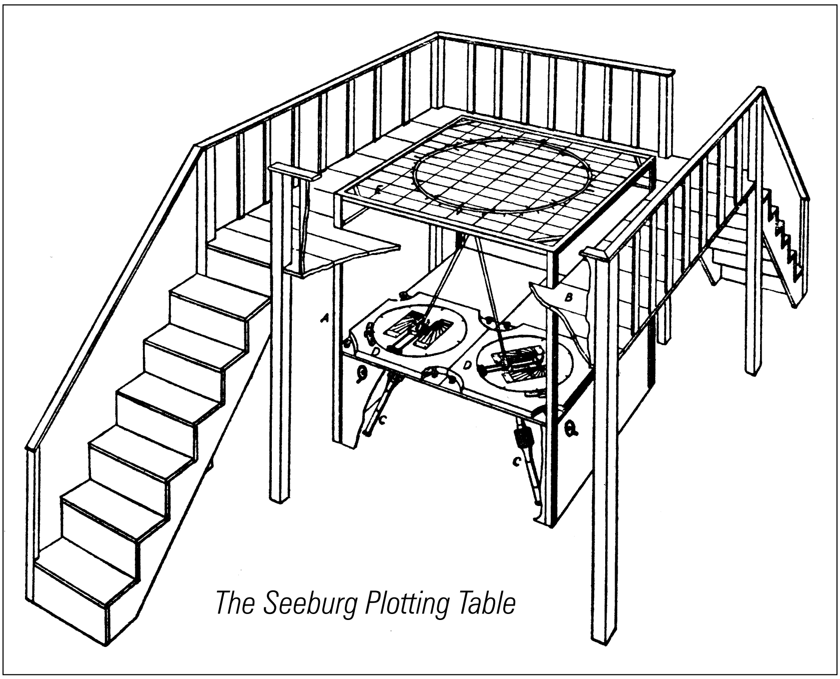
To prevent such 'friendly fire' incidents, Kammhuber saw that it was important to designate separate engagement zones for AA guns and night-fighters. He therefore moved his searchlight batteries into the countryside, well clear of the AA gun defences, to form a defensive belt that ran parallel to the coast from Schleswig-Holstein to Liège in Belgium. Raiding aircraft would have to pass through that belt, to reach their targets in Germany. Kammhuber subdivided his searchlight belt into a series of 'boxes' about twenty miles wide, each with a radio beacon where a night-fighter would orbit while waiting for the enemy raiders to appear.

Having formed his defensive line, Kammhuber set about improving its effectiveness. He saw that any system that relied on searchlights was a slave to the weather. The answer was to use a precision radar on the ground to direct a night-fighter into an attacking position behind an enemy bomber. The *Freya* was too imprecise for that task, for the 'blips' from the night-fighter and the bomber usually merged on the radar screen long before the night-fighter pilot had his quarry in visual range. The *Würzburg* flak-control radar, with its very much higher frequency and superior resolving power, offered a much better prospect. By the end of 1940, production of this radar was getting into its stride and Kammhuber secured a few to direct experimental night interceptions.

The initial trials with *Würzburg* demonstrated the advantages of using radar to direct night-fighters, and Kammhuber requested more sets to equip his defensive line. This now comprised a series of contiguous boxes, forming a barrier which raiding bombers had to cross to reach their targets and again on their return flights. Each night-fighter box was equipped with a *Freya* and two *Würzburg* radars, a radio beacon and a ground-control station. The *Freya* directed one short-range narrow-beam *Würzburg* to track the night-fighter, while the other tracked the incoming bomber.

The *Würzburg* equipment been designed to direct AA guns and its form of presentation – giving raw range, bearing and elevation information – made it impossible to direct night-fighters from the radar screen. To convert the *Würzburg* information into a form in which it could be used by the fighter controller, the Luftwaffe developed the so-called '*Seeburg* table'. Located in the headquarters building of each ground-control station, the device looked like a large dais with two flights of steps leading up to a 'table' at the centre. The 'tabletop' consisted of a horizontal frosted glass screen, bearing an outline map of the area and the Luftwaffe fighter grid.

Directly beneath this glass screen sat two operators for the light-projectors. Each received telephoned plots on the aircraft he or she was tracking, from the appropriate *Würzburg*. One operator projected onto the screen above a red light to indicate the bomber's position, the other projected a blue spot to indicate the fighter's position. As the coloured spots of light moved across the frosted glass screen, plotters at the top of the 'dais' marked the planes' respective tracks using a coloured wax crayon. The fighter controller stood over the frosted glass screen, passing radio directions to the fighter pilot to bring him into a position to engage the bomber. The '*Seeburg* table' became a standard item of equipment at each fighter-control station. This method of close controlled night interceptions was code-named *Himmelbett*.



The Seeburg Plotting Table

Initially Kammhuber positioned his *Würzburg* radars immediately in front of the searchlight belt. That allowed night-fighter pilots to attempt a radar-controlled interception first. If that failed, they could then resort to the tried and tested 'illuminated night-fighting' tactics. The radars thus increased the effective 'depth' of the searchlight belt, allowing Kammhuber to redeploy searchlights to extend the line from eastern France to the middle of Denmark.

Yet, although the *Würzburg* radar gave a useful improvement in the effectiveness of the defensive line, it soon became clear that the device's range performance fell short of what was needed. All too often, Allied bombers emerged from the line and passed out of *Würzburg* range before the night-fighter could make a successful interception.

After prompting from Kammhuber, Telefunken modified the *Würzburg* to overcome this deficiency. In the spring of 1941, the company produced a variant of the radar with the diameter of the reflector-dish increased from ten feet to twenty-five feet. That narrowed the width of the radar beam, and enabled the equipment to track aircraft up to forty miles away. The new Telefunken radar was called the Giant *Würzburg* (*Würzburg Riese*). Apart from its larger reflector and static mounting, electronically it was little different from the smaller version. During the second half of 1941, the first Giant *Würzburg* radars entered service to replace the standard sets used for night-fighter control.

Following a reorganisation of the night air defences early in 1942, it was decided that, with this influx of new electronic equipment, Kammhuber no longer needed the searchlights in his defensive line. At the time he contested the decision, though later he would admit it was for the best. It forced night-fighter crews to trust their ground controllers to guide them to their targets and, when the crews became accustomed to it the system was more effective than 'illuminated night-fighting' could ever have been.

During the spring of 1942, Kammhuber's line was strengthened by the introduction of three new radar devices. The formula of using a larger aerial reflector to narrow the radar beam and increase range, which had worked so well in the case of *Würzburg*, also succeeded with *Freya*. The result was the *Mammut* ('Mammoth') built by the I. G. Farben company. This was essentially a *Freya* with a greatly enlarged reflector ninety feet wide and thirty-five feet high – about the size of a tennis court on its side. The structure was fixed on supporting pylons, and determined the azimuth of aircraft by 'swinging' the beam electronically through a limited arc of 100 degrees. The enlarged reflector squashed the radar beam into a narrow pencil, which reached out to aircraft up to 185 miles away.

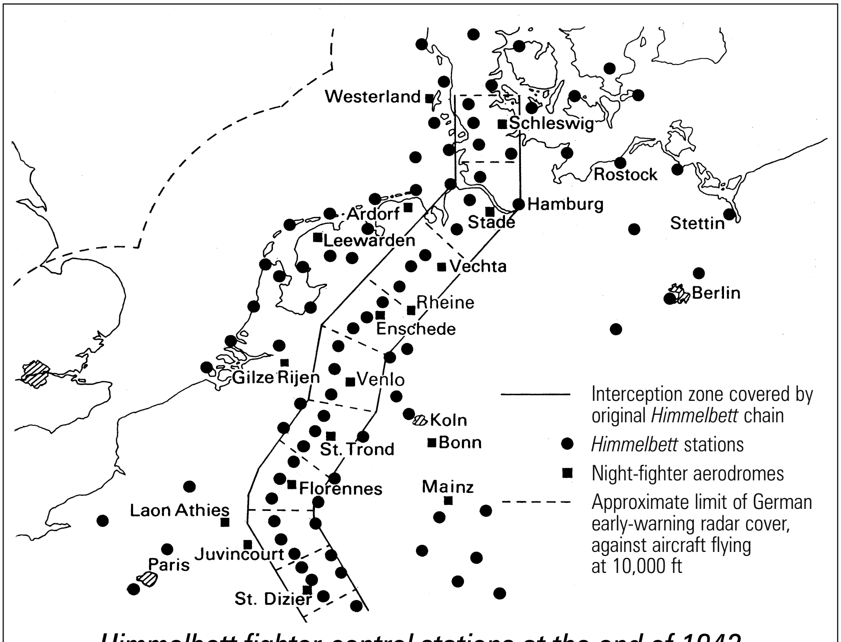
Like its smaller predecessor, *Mammut* could not measure altitude. The second new radar, the *Wassermann*, built by the Gema company, gave accurate height, range and bearing readings on aircraft up to 175 miles away. This set employed a reflector 130 feet high and 20 feet wide, mounted on a rotating tower. *Wassermann* was the finest early-warning radar to be produced by either side during World War II. The Luftwaffe installed *Mammut* and *Wassermann* sets along the coast of occupied Europe, to extend the range of its early-warning cover.

Those two new sets were both early-warning systems. The third new radar was of an entirely different character: the *Lichtenstein* lightweight airborne radar, designed for installation in night-fighters. Another Telefunken product, the *Lichtenstein* operated on frequencies in the 490 MHz band. It had a maximum range of two miles and a minimum range of about 200 yards. That minimum range figure was an important parameter in a night-fighter radar. While the radar transmitted each high powered pulse, the sensitive receiver had to be 'switched off' or it would suffer severe damage. That meant the receiver could not pick up echoes from the nearest targets. That dead distance, between the fighter and the closest target that could be seen on radar, was proportional to the length of the transmitted pulse. In fact, the 200-yard minimum range was low for a first-generation airborne radar.

The new airborne radar went into production and the first four night-fighters fitted with *Lichtenstein* arrived at the operational airfield at Leeuwarden in the Netherlands in February 1942. In service, the shortcomings of the device became clear. The entanglement of aerials and reflectors on the aircraft's nose increased the drag, impaired handling and reduced the top speed of the Ju 88, for example, by 6 mph. Initially, pilots were unwilling to accept those penalties for the privilege of carrying a radar of uncertain reliability. Paradoxically, the main reason for their conservative attitude was the high quality of the ground control using the Giant *Würzburg*, which usually placed the fighter within visual range of its target.

Hauptmann Ludwig Becker and his crew persevered with the *Lichtenstein* equipment, however. They found that when the set could be coaxed into working properly – and it had its share of teething troubles – it offered considerable advantages, particularly when engaging the British bombers on moonless nights. As Becker's score of kills accordingly mounted, other crews began to accept the device.

By March 1942, the German defences were destroying an average of four bombers out of every hundred attacking Germany by night. Of these the fighter defences were responsible for about two-thirds, while AA guns accounted for most of the remainder. By now there were four *Geschwader* of night-fighters with 265 aircraft, of which 140 might be available on any one night. The force continued its expansion. During April it accepted thirty-three Bf 110s, twenty Ju 88s and thirty Do 217s. Telefunken had already manufactured 275 *Lichtenstein* radars, and production was running at about sixty sets per month.



Himmelbett fighter-control stations at the end of 1942

On the ground-radar side as well, there was a steady strengthening of Kammhuber's line. To equip the whole of the defensive line as it then stood, he needed 185 Giant *Würzburg* sets. By the end of March 1942, Telefunken had delivered about half that number, and the rest were following at the rate of about 30 per month.

Although the defences were taking a steadily mounting toll of the British night raiders, Kammhuber's system of fighter control had an obvious Achilles' heel. For its success it depended on the *Lichtenstein*, *Freya*, *Mammut*, *Wassermann* and Giant *Würzburg* radars, and on effective communications between the fighter pilots and their ground controllers. In some degree, all these systems were vulnerable to interference. In the next chapter we shall observe how the British intelligence service stripped away the veil of secrecy surrounding that organisation.

Chapter 3

Discovery

> 'The relief offensive for which Britain's badly harassed Allies have been begging for such a long time has confined itself to the landing of a few parachutists on the coast of northern France. The parachutists were soon forced to make a glorious retreat across the ocean, without having achieved any useful purpose.'
>
> German News Broadcast, 28 February 1942

Throughout 1941 and 1942, RAF Bomber Command was losing a steadily increasing proportion of the planes dispatched against targets in Germany. Yet, until there was detailed knowledge on how the air defences operated, it was impossible to devise appropriate countermeasures. The intelligence sources that had been so useful during the 'Battle of the Beams' – the crashed German aircraft, captured aircrew and the analysis of the beams themselves – were now denied, for the RAF bombers were destroyed over enemy territory. Moreover, because the more sensitive items of information concerning the air defence system were usually communicated via landlines, there was little radio traffic on this subject for Bletchley Park to decipher. In consequence, it took many months of hard work to expose the workings of the system Josef Kammhuber had created.

In the absence of firm evidence before the war, British scientists had regarded with scepticism the possibility that their German counterparts might also be working on radar, though there was little doubt that they could build such systems once they had the basic idea, since they were known to be advanced in high-frequency radio techniques. In mounting the listening operation with the *Graf Zeppelin*, the Luftwaffe had concentrated its search for signals on the frequencies used by its radar systems; now British intelligence was taking much the same approach, with a similar lack of success.

The first clue that the Germans were working on radar came from the so-called Oslo Report, received via the British Embassy in Oslo in November 1939. Probably sent by a disaffected German scientist, the document mentioned several military technical systems then under development in Germany. There were references to a remotely-controlled glider carrying an explosive warhead, homing torpedoes and remotely-controlled shells. There was a short description of a warning system able to detect aircraft out to a range of 120 km (75 miles) using ‘pulses reflected by the aircraft’. The report added that, during one of the British air attacks on Wilhelmshaven, the stations covering the northwest coast of Germany had detected the RAF bombers at a range of 120 km. That last statement was greeted with some disbelief. The German fighters’ reaction to these attacks seemed very slow, if there had been such a long advance warning (in fact that was due to other weaknesses in the control and reporting system). Certainly, the RAF fighter reaction would have been much faster.

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One available source could certainly have confirmed to RAF officers the existence of German radar at this time, had not inter-service secrecy prevented it. In December 1939, the German pocket battleship *Graf Spee* was scuttled off Montevideo in Uruguay. Five days earlier, the warship had suffered several hits in a battle with Royal Navy cruisers. The German captain had thought his ship could not fight her way back to a friendly port, so to prevent further loss of life he ordered her destruction.

The estuary of the River Plate is shallow, however, and when the demolition charges went off the warship sank only about ten feet before she came to rest on the seabed. At first light next morning, a flotilla of sightseeing boats put out from Montevideo to look at the shattered warship. Scores of photographs were taken, to be flashed round the world by news agencies. Most people failed to notice a strange feature on the close-up photographs of the smoking hulk: a structure rather like a bedstead on its side, mounted above the bridge.

British naval intelligence sent its own sightseer to Montevideo to look over the warship, radar expert L. Bainbridge Bell. He boarded the wreck and climbed up to the ‘bedstead’ structure – a feat requiring some agility, since the *Graf Spee* had developed a list. Afterwards, Bainbridge Bell reported that the structure was almost certainly the aerial system for a radar set, probably used for ranging the ship's guns. In this assumption he was correct, this was a *Seetakt* radar.

Armed with that information, naval intelligence officers in London examined other photographs of *Graf Spee* and observed that the structure was present, though hidden under a canvas cover, on photographs taken as early as 1938. That was a discomforting discovery, for even at the start of 1940 Royal Navy warships had no gun-ranging radars, and no British ship would receive one for well over a year. Bainbridge Bell's report was pigeonholed in the naval intelligence files, however, and R. V. Jones would not learn of it until 1941.

* * *

During the early months of 1940, the RAF scientific intelligence service picked up little information that could be connected with Luftwaffe radar systems. Although we now know that these were technically efficient, they were in limited use at that time. At that stage of the war the German strategy was primarily offensive, and the Luftwaffe therefore concentrated on systems like the navigational beams to aid bombers. Radar, as a purely defensive device at that time, had a lower priority. The British forces, being on the defensive, were compelled to adopt the opposite course.

In May 1940, as the RAF night bombing offensive against Germany began, a prisoner mentioned that the German Navy had experimented with a 'radio echo' device for measuring the range and bearing of distant objects. He said the Luftwaffe was working on similar systems, though these were not so far advanced. From the description, it seemed that the German system bore unmistakable similarities to the British coastal radar chain. There was much here that agreed with the statements made in the Oslo Report.

On 5 July, shortly after the reception of the first *Knickebein* beam signals by a British aircraft, one of R. V. Jones's intelligence sources passed him the gist of a secret Luftwaffe report dated a week earlier. This stated that German fighter aircraft had been able to intercept British reconnaissance planes on that day because of information from the '*Freya Meldung*' – the *Freya* warning. That seemed to confirm that the Germans had some form of aircraft detection system. On learning of Jones's interest, the source mentioned that a *Freya* site was operating at Lannion protected by a battery of light anti-aircraft guns. Lannion was a small village on the northern coast of Brittany. The report seemed to underline the importance of *Freya*, for German troops had entered the area only three weeks earlier.

There were two obvious ways to follow up: the site should be photographed from the air; also, a listening watch should be maintained for signals that could be traced to the site. Jones also tried a further approach, typical of the methods adopted in the strange craft of military intelligence: he researched the mythological background of the code-name, *Freya*. *Freya* was the Nordic goddess of beauty, love and fertility. Her most prized possession was an exquisite necklace called Brisingamen; to acquire this, she had sacrificed her honour and been unfaithful to the husband she loved. Heimdal, watchman of the Nordic gods, guarded Brisingamen. And Heimdal could see a hundred miles in every direction, by day or night. Jones cautiously reported to the Chiefs of Staff:

> It is unwise to lay too much stress on this evidence, but these are the only facts that seem to have any relation to our previous knowledge. Actually Heimdal himself would have seemed the best choice for a code-name for RDF [radar] but perhaps it would have been too obvious . . . It is difficult to escape the conclusion therefore that the *Freya-Gerät* is a form of portable RDF.

This was all good stuff, but it awakened a nagging suspicion in the minds of the War Cabinet. Might the Germans have captured intact a radar set left behind by the British Expeditionary Force in France? How else could the Germans have developed an operational radar system so quickly? On 7 July, Churchill minuted General Ismay, his chief of staff, about the matter:

> Ask the Air Ministry whether any RDF [radar] stations fell intact into the hands of the enemy in France. I understand there were two or three. Can I be assured that they were effectively destroyed before the evacuation?

General Ismay made the necessary inquiries, and replied that one radar transmitter had been left behind by the RAF at Boulogne, but this had been thoroughly destroyed. It was doubtful that the Germans could extract useful information from it. One of the Army's gun-laying radar sets might have been captured in a damaged state, but the others were carefully destroyed. The evacuation ship *Crested*

Eagle had been carrying an Army gun-laying radar when she ran ashore near Dunkirk, but a naval party had been put on board to destroy the set.

From German sources, we know that their forces had captured a nearly intact British mobile air-warning radar near Boulogne. Far from being impressed with the find, they regarded it as extremely crude and much inferior to the *Freya*. It was a fair assessment, for at that time the mobile British radars were considerably less effective than their static counterparts.

On 14 July, Jones received an intelligence report of a second *Freya* station in operation, this time at Cap de la Hague on the Cherbourg peninsula. Nine days later, the station played an important part in the operation in which dive-bombers sank the destroyer HMS *Delight*. At the time, *Delight* was about twenty miles south of Portland Bill. As she had never been closer than sixty miles from the *Freya*, and had neither fighter support nor balloons to reveal her position, the action showed that the radar gave cover on low-level targets at least as good as that from the latest British equipments.

In the second week in August, as the Battle of Britain was about to begin, Jones received the text of a secret Luftwaffe report which stated that *Freya* was designed to work in conjunction with the fighter defences.

Attempts to locate *Freya* on aerial photographs of the two sites now reported, at Cap de la Hague and at Lannion, met with no success. Photographs were taken from reconnaissance Spitfires flying at 30,000 feet and gave a definition just sufficient to enable the 300-foot *Knickebein* turntables to be picked out. All that could be said for certain was that the *Freya* had to be smaller than that.

In the meantime a radar expert from the TRE, Derek Garrard, set out on a radar hunt on his own account. He filled his car with borrowed receiving equipment, and drove to points along the south coast to look for unusual transmissions. The initiative was rewarded, though his first intercept was not connected with *Freya*. From a point near Dover he picked up radar transmissions on a frequency of 375 MHz, which could be linked with the shelling of British convoys passing through the Straits of Dover, from gun batteries situated near Calais. In fact, the signals came from a *Seetakt* radar – the same type as that examined on the *Graf Spee* many months before.

Garrard's find caused a commotion among radar experts in Britain; of those prepared to admit the possibility of the Germans having developed radar, few would accept that they had sets superior to those built in Britain. Yet, here was a German radar, working on a frequency so high as to be almost unusable in Britain, directing coastal gun batteries. If the Germans had learned their radar techniques from a British set captured in France, they had applied their new-found knowledge with remarkable despatch.

In the autumn of 1940 the introduction of improved reconnaissance cameras brought a great improvement in the quality of RAF aerial photography. The effect on the hunt for the German radar stations was immediate; on 22 November, a high-flying Spitfire returned with photographs of unprecedented clarity showing the village of Auderville near Cap de la Hague. Just to the west of the village were two unexplained circles side by side, each measuring some twenty feet across, looking like a pair of opera glasses laid lenses down. Dr Charles Frank, a physicist who had recently joined Jones's staff, examined the photographs through a stereoscope and saw that two consecutive frames did not form a perfect stereo pair, as they should have. A shadow associated with one 'circle' had changed slightly in the nine seconds between the first exposure and the second. During that time, a thin wide object on top of one circle had rotated through ninety degrees. In each case the shadow was about two millimetres long, but whereas in the first about a tenth of a millimetre wide, the second was two millimetres wide. The difference was hardly greater than the resolving power of the photographs, but it was enough to establish that here was something worth closer examination.

The next obvious move would be to lay on a low-level reconnaissance sortie to photograph the 'opera glasses' at Auderville. However, with Britain still under imminent threat of invasion, there were demands with a higher priority on the small force of photographic reconnaissance Spitfires.

In the interval, Jones received an Ultra decrypt which mentioned another German aircraft detection device called *Würzburg*. It appeared that one *Freya* and one – perhaps two – *Würzburg* sets were earmarked to go to Romania; also, two *Würzburg* sets were to be sent to Bulgaria. All had been allocated for coastal defence units. Perhaps, Jones reasoned, this represented the minimum number of radars necessary to provide continuous cover along the two nations' coastlines with the Black Sea. If that was so, he calculated that the range of *Freya* had to be at least fifty-seven miles, and the range of *Würzburg* to be at least twenty-three miles. At that time Jones did not know that the two radar systems complemented each other, but although his initial premise was wrong the maximum ranges he had postulated for the two systems were remarkably accurate. He now had clues on two distinct types of aircraft-detection apparatus used by the German forces, though neither had yet been clearly seen or heard.

Not until 6 February 1941 was a reconnaissance Spitfire available to take a low-level look at the 'opera glasses' at Auderville. The first mission was a failure, however. As the Spitfire sped through the area, the circular objects were missed in the gap between two successive frames of the oblique camera. The second low-level sortie, flown by Flying Officer W. Manifould six days later, was more successful. He returned with a magnificent close-up photograph, which showed that each circle was surmounted by a rotatable aerial-array. Unquestionably, this was a radar station (in fact it was a *Freya*).

Even as Manifould's photographs were being processed, a listening station in southern England identified pulsed signals coming from the direction of Auderville on 120 MHz. Signals on that frequency had been picked up earlier, but the listeners assumed that they came from the new VHF radios fitted to RAF fighters. Only when Derek Garrard examined the signals on a cathode-ray tube was their true significance recognised. Garrard plotted the bearings on their source, and found that these signals originated not only from Auderville, but also from transmitters situated near Dieppe and Calais.

Within four hours of each other, Jones received the low-level photographs and the report of the intercepted radar signals, after a hunt that had lasted more than a year.

* * *

Within a month of the recognition of the *Freya* signals, new pulsed signals were picked up on 570 MHz. In the spring of 1941 a special radio-reconnaissance unit, No. 109 Squadron, had begun flying sorties over occupied Europe looking for German radar transmissions. After dark on 8 May one of the unit's 'ferret'

Wellingtons flew a circuitous route taking in the Cherbourg peninsula and Brittany. In the course of the sortie, the plane's crew obtained rough fixes on nine radar sites.

In the months to follow, information on *Freya* stations came in thick and fast. By the end of October 1941 no fewer than twenty-seven of these radars had been located, strung out along the coast between Bordeaux in France and Bodö in Norway. No. 109 Squadron aircraft also brought back scores of fixes on 570 MHz transmitters. Yet the sources of these signals were evidently very small, for they defied all attempts to photograph an example.

One spectacular piece of intelligence obtained at this time was a strip of cine film showing a *Freya* station in operation, with the German crew tracking aircraft targets. Less spectacular, but far more important from the intelligence viewpoint, was the discovery that wireless plots from the *Freya* units could be overheard in England. When tracking an aircraft, the radar station passed distance-and-bearing reports by radio to a central air-defence headquarters. The 'code' used to pass the information was relatively simple, and easily broken. For example, on 10 October a listening station in England picked up a Morse transmission which read:

MXF = 114011 = 14E = X =254 = 36 = +

MXF was the radio call-sign of the *Freya* station; 114011 was the time of the plot in hours, minutes and seconds; 14E was the serial number of the plot. X indicated the number of aircraft present (X meant one, Y meant several and Z meant many); 254 was the bearing from the radar station, and 36 was the range in kilometres

British intelligence tapped this source for all it was worth. Reconnaissance aircraft, maintaining an accurate record of their flight path by photographing the ground directly below, flew over German-held territory so that the *Freya* stations would track them. Listeners in England then recorded the plots on the aircraft's progress. Afterwards, the bearings and ranges were back-plotted on maps. Several *Freya* stations were located and identified in this way. Once the various radar stations had been located and identified, the German plotting reports were used to provide up-to-date information on the movements of RAF raiding forces flying over German-held territory and beyond the range of radar stations in Great Britain.

While this was going on, No. 109 Squadron continued to bring back fixes on the sources of the 570 MHz transmissions. Yet still the device defied all attempts to photograph it. Clearly, it was much smaller than *Freya*. From agents' reports, Jones learned that these transmissions were connected with a fire-control device known as the *FMG*. Towards the end of 1941, news arrived that four *FMG* sets were operating in the area of Vienna, of all places. Unless Vienna – a city of great beauty but comparatively little military importance – was a radar equipment depot, it seemed reasonable to infer that the *FMG* device existed in considerable numbers.

Another important photographic clue came from the United States, at that time still neutral. The US Embassy in Berlin overlooked the Berlin Zoo district, where a couple of huge concrete flak towers had been built. A photograph arrived on Jones's desk showing the top of one of the towers; clearly visible was a large dish-shaped open-work radar reflector, of a type not seen before. Unfortunately there was nothing nearby to give scale to the object. A few weeks later, a Chinese scientist reported seeing the same device, which he described as paraboloid more than twenty feet in diameter, that could be rotated and elevated. He thought it might be used to direct the anti-aircraft guns. Jones saw that the new radar could not possibly be the 570 MHz radar known to exist in such profusion in German-occupied Europe. Otherwise, its large reflector would have been spotted on aerial photographs long before this. In fact, the Berlin Zoo photograph showed one of the first Giant *Würzburg* radars to enter service.

Still Jones had no picture of the small *Würzburg* equipment, but the hunt for one was nearing its end. Late in November 1941, Charles Frank was examining a medium-level photograph of the *Freya* station at Bruneval near Le Havre on the north coast of France. There he saw that a track had been trodden out along the cliff-edge: it ran from the *Freya* towards a large house, which seemed to serve as a headquarters. Just before it reached the building, the track swung to the right. It ended at a small black object about halfway between the house and the cliff top. Several people had considered it worth their while to tread out a path from the main radar station to the 'small black object'. Might that object play some part in the working of the *Freya*?

On 3 December Flight Lieutenant Tony Hill, a reconnaissance pilot, visited the interpretation centre at Medmenham in Buckinghamshire to discuss the photography of German radar sites. Squadron Leader Claude Wavell knew of Charles Frank's special interest in the Bruneval radar, and mentioned the mysterious black object to Hill. On the following day, on his own initiative, Hill took off in a Spitfire to look at Bruneval. He swept in low over the cliffs, and was past the emplacement before the startled defenders knew what had happened.

On his return, Hill discovered that his camera had failed to function properly. It was a cruel blow – but he had seen the device clearly, and was able to say that it looked 'like an electric bowl-fire and was about ten feet across'. If Hill was right, this might be the elusive source of the 570 MHz transmissions. On the following day, Hill bravely repeated the performance. This time the camera worked perfectly and the photographs he brought back were among the classics of the war. They showed the device exactly as he had described it, like an electric bowl-fire about ten feet across. Although it now seemed highly probable, the evidence was still not conclusive that this was the source of the 570 MHz signals. Until that was certain, countermeasures could not begin.

It is difficult to establish who first suggested the idea of pilfering the device at Bruneval. The notion was so obvious – it lay within 200 yards of the coast – that it might have occurred to several people. At all events, by the beginning of January 1942 such an operation was in the detailed planning stage. Clearly a commando raid launched from the sea would be doomed to failure; the device was situated at the top of high cliffs, protected by a sizeable German garrison. Even if the troops could fight their way to the top of the cliffs without suffering serious casualties, it was unlikely they could do so before the defenders had destroyed the radar.

The naval commodore in charge of Combined Operations, Lord Louis Mountbatten, suggested that parachute troops should be used instead. On 21 January the Chiefs of Staff agreed to this, and assigned C Company of the 2nd Parachute Battalion to the operation. An operational squadron of Whitley bombers would transport them to the target area, and a force of light naval craft would evacuate the raiders from the nearby beach when the mission was over. Intensive training began for what the men were told would be 'a special demonstration exercise' to be watched by the whole of the War Cabinet. The venture received the code-name 'Biting'.

Once the device had been captured, the task of dismembering it was to be undertaken by seven men of the Royal Engineers, commanded by Lieutenant D. Vernon. The eighth man in the team was from the RAF: Flight Sergeant C. Cox, a radar mechanic, who was to go along should his specialist knowledge be required. The dismantling party was given a British gun-laying radar – the nearest available equivalent to the expected German system – on which to practise its dismantling skills.

Vernon and Cox then received a special briefing on the anticipated layout of the German set. According to the planned time-table, they would have half an hour with the apparatus; in that time they were asked to make sketches and take photographs of the equipment, then dismantle it systematically starting at the aerial and working backwards through the receiver to the presentation gear. The operating frequency could be established beyond doubt by removing the aerial element from the centre of the 'bowl', and measuring it. The next target was the receiver and its associated presentation equipment. These would reveal whether any anti-jamming circuitry was built into the set. The transmitter was also wanted, so British scientists could examine German techniques for generating high powered pulses on ultra-high frequencies. Dr Jones also asked that a couple of prisoners be taken, radar operators if possible. These might be persuaded to reveal information on the methods of operating the radar and aircraft reporting.

All German signals equipment bore informative labels and inspection-stamps, and useful general intelligence could be obtained from these. Should the various units prove impossible to dislodge, Jones asked that the labels be torn off and brought back.

By the fourth week in February Jones had confirmation from other sources that the 'bowl-fire' was a radar code-named *Würzburg*, and that one of these sets was situated near the *Freya* station at Bruneval. By then all the military preparations for the operation were complete, but now the weather intervened. On the evening of the 24th the weather was unsuitable, as it was on the next two nights. The timing of the raid was critical; the attack had to take place on the night of a full moon, but also when the tide was on the rise so the assault craft would not be left stranded on the beach. The 27th was the last possible date for the operation for a month or more.

That evening the forecast was favourable and the Commander-in-Chief Portsmouth, Admiral Sir William James, signalled: 'Carry out operation Biting tonight 27th February.'

The twelve converted Whitley bombers of No. 51 Squadron took off from Thruxton near Andover. On board were 119 paratroops and the RAF flight sergeant, sitting huddled together and trussed up in their uncomfortable parachute harnesses. One soldier later wrote: 'The mugs of hot tea (well laced with rum) we had drunk before taking off began to scream to be let out. In that restricted space and encumbered as we were there was, alas, no way.'

Shortly after midnight on the morning of the 28th, the first sticks of paratroops leapt from their aircraft. Some ten seconds later the men tumbled on to the carpet of virgin snow some 600 yards to the south of the radar site. They hastily shed their parachute harnesses and cocked their weapons, ready to fight for their lives. But the half-expected rattle of German small-arms fire did not come. Their arrival had passed unnoticed. The sound of the Whitleys' engines faded into the night, leaving the men feeling very lonely and vulnerable.

As the men assembled into their small groups, their next move was not at all warlike: that tea just had to go. Major John Frost, the force commander, later wrote that this 'was certainly not good drill, as now was the time when a stick of parachutists was most vulnerable . . . but at least it was a gesture of defiance!'

The assault parties now moved on their assigned targets. One, led by Frost himself and comprising fifty men including the dismantling party, crept towards the radar site and the house nearby. A second party, under Lieutenant Timothy, took up covering positions to screen the force from attack from the landward side. The remainder made off to secure the beach and the escape route.

Frost's men silently surrounded the *Würzburg*, whose silhouette stood out sharply in the moonlight, and the nearby house. If the house was some kind of headquarters, it might be a centre for resistance. Frost himself stole round to the front door with a small party. Satisfied that all was ready, he gave the signal for battle to begin – a long shrill blast on his whistle. With four men at his heels, Frost burst into the house and began searching each room in turn. It proved something of an anti-climax, the only German present died trying to defend one of the upstairs rooms.

Outside, a fierce battle was in progress with almost continuous automatic fire punctuated by the bangs from exploding hand-grenades. Within minutes, all resistance around the *Würzburg* had been overcome. But, as that fight ceased, another began. There were about a hundred German troops stationed in the vicinity, and Lieutenant Timothy's covering force found itself being hotly engaged.

In the fight to seize the *Würzburg*, five of its six operators had been killed. The sixth man made off into the darkness, but in his haste he lost his sense of direction and stumbled over the cliff. Fortunately he managed to grab a projecting rock, and with some difficulty he climbed back to the top. He then found himself being helped over the edge by a British paratrooper. In no position to offer resistance, the man quietly surrendered.

With the *Würzburg* secured, Lieutenant Vernon climbed on top of the operating cabin and examined the aerial with the aid of a hand torch. He then photographed the aerial from each angle – an action no sooner made than regretted, for the light from the flashbulbs attracted bullets from several directions. Vernon then summoned his team and ordered one sapper to saw off the aerial element, while the remainder sought to remove the boxed components in the operating cabin. The aerial came away easily, but the boxes defied all attempts to dislodge them using screwdrivers. This was no time for finesse, for the bullets ricocheting off the cabin's walls were real enough. The men then brought into play their crowbars, and the equipment gave up the unequal struggle. One by one, the units were ripped from the console. The dismantlers had been at work for barely ten minutes out of the planned thirty, when Major Frost saw three lorries approaching with headlights full on. Almost certainly, these were German reinforcements. If the defenders brought into action weapons heavier than the rifles and machine guns they were already using, the raiding force would be at a severe disadvantage. Frost decided to settle for whatever the dismantling party had already secured, and ordered his force to withdraw to the beach. But now he learned that the shoreline was still in German hands.

What had gone wrong? Of the forty men detailed to secure the escape route, half had landed more than two miles from the planned dropping-zone. The senior officer present, Lieutenant E. Charteris, took a quick bearing on the lighthouse at Cap d'Antifer and worked out his position. He then led his men towards the radar site at a brisk trot, and arrived at the clifftop just as Frost was organising his own force to storm the beach. The combined assault teams rushed the German positions in their path.

Now the beach was in British hands and on it lay the wounded, the German prisoners and the items stripped from the *Würzburg*. Frost told his signallers to call in the naval craft to evacuate the force. It was high time to leave, for on the cliffs on either side of the beach the German forces were becoming increasingly active.

After a few minutes, the signallers reported they had had no success in contacting the boats. Frost fired red distress flares, but to no effect. Then, he later wrote, 'I moved off the beach with my officers to rearrange our defences. It looked as though we were going to be left high and dry, and the thought was hard to bear.'

Just as his troops had begun to take up positions for a final stand, Frost heard a cry: 'Sir, the boats are coming in!' He looked back and saw six snub-nosed assault craft sliding to a stop on the beach. With a sigh of relief he ordered his men to embark, while the boats' crews put down covering fire on the German troops at the top of the cliffs. With the roar of accelerating engines the landing craft backed away from the shore, while the brisk exchange of gunfire continued until the boats were well clear.

Safe aboard an assault craft, Major Frost learned the reason for the delay. While he had been signalling, a German destroyer and two patrol boats had passed within a mile of the small British flotilla but noticed nothing. Frost also learned that the pieces of the radar secured by his men were almost exactly what were needed. Mr D. H. Priest, a Telecommunications Research Establishment engineer who had received a temporary commission as a flight lieutenant for the occasion, examined the booty on the boat. Had the coast been clear, he would have landed and climbed to the radar site to look over the *Würzburg*, but this was not possible. When dawn broke, several Spitfires arrived over the craft and escorted them back to England.

The Bruneval operation was successful on almost every count. The raiders had captured most of the radar. Of the three prisoners, one was a radar operator. The paratroops suffered fifteen casualties – two dead, seven wounded and six missing. The dismantling party had done extremely well in the brief time available. The units it brought back included the receiver, the receiver amplifier, the modulator – which controlled the timing within the radar – and the transmitter. In addition, there was the sawn-off aerial element. The only unit which Jones had requested and not received was the presentation equipment.

If – as had nearly happened – the boxes had proved impossible to tear from their mountings, Jones might have had to make do with the labels alone. So it is interesting to see what could be learned from these. The labels indicated that the manufacturer was Telefunken, a company with factories in the Berlin area. The works numbers were particularly interesting. From previous experience with German serial numbers, Jones had deduced that the number allocated to the first production model of each component was 40,000. The earliest number found on the captured units was 40,144, the latest was 41,093. This suggested that the number of sets of components produced by the date of manufacture of the last item, was 1,093. The earliest inspection date, early November 1940, was stamped on a part of the transmitter; the latest, 19 August 1941, was on the aerial. This did not necessarily mean that 1,093 complete *Würzburg* sets had been turned out by the latter date, since a proportion of the component units would have served as spares. It was a principle of German design that servicing was facilitated by replacing component units, while the defective ones were returned to a central depot for repair.

Assuming that about half the production went into spares, Jones reckoned that around 500 of these radars were available by August 1941, and production was probably running at about 100 sets per month. For him the raid was particularly satisfying, since the intelligence gleaned either confirmed or added to the previous picture. No part of the picture had to be modified or discarded. An important side effect of the raid was that it gave British intelligence added confidence in the accuracy of the information it was receiving.

Scientists at the Telecommunications Research Establishment at Swanage made a thorough examination of the *Würzburg* units. In their view the equipment was considered 'straightforward and in no respect is it brilliant . . . On the other hand, it must be remembered that the equipment was made in 1940 and designed in 1939 or earlier.' In 1940, British radar techniques had not been sufficiently advanced to build a set working on 570 MHz with a range of twenty-five miles. While the German radar carried no specific anti-jamming circuitry, it could be re-tuned over a narrow range of frequencies to overcome electronic jamming.

After the Bruneval horse had been 'rustled', the German local defence commanders along the French coast made sure that the stable door was well and truly bolted. The remains of the *Würzburg* were removed, and a new set was installed in the main *Freya* compound. Within a few weeks, a dense barbed wire entanglement surrounded the compound. Other radar stations followed this lead. Every German radar station near the coast now became conscious of its vulnerability, and surrounded itself with barbed wire. That greatly helped Jones and his staff; there were several sites which were suspected to contain *Würzburg* sets, but in each case the existing aerial photographs had failed to show them. Now these sites obligingly ringed themselves with barbed wire – which showed up well on aerial photographs – to confirm the suspicions.

Not only in Germany were there repercussions of the Bruneval operation. The success of the raid highlighted a golden opportunity for a retaliatory attack on the Telecommunications Research Establishment, hub of British work on radar and situated near Swanage on the south coast of England. In the spring of 1942 the establishment made a rapid move to Malvern College, well clear of the coast.

* * *

Two weeks after the Bruneval raid came an event that was to have even greater significance to the development of countermeasures systems in Great Britain. On 11–13 February 1942 the German battlecruisers *Scharnhorst* and *Gneisenau*, and a flotilla of smaller ships, had left their temporary base at Brest, run the gauntlet of the defences covering the Straits of Dover, and successfully reached ports in Germany. In doing so they had inflicted a major blow to Britain's reputation as a naval power.

The operation had taken place under the noses of powerful British forces and was a masterpiece of boldness, careful planning and tight security. An important element in the success of the operation was the large scale use of ground jammers. As the warships came within range of the British coastal radars at the eastern end of the Channel, these jammers were switched on simultaneously.

Many of the best British radar operators were now serving in the

Mediterranean theatre, where the heaviest fighting was taking place. Those who replaced them at radars along the south coast of England were less experienced and they reported the clutter on their screens as 'equipment failure' or 'local interference'. As a result commanders did not appreciate the significance of the radar operators' difficulties until it was too late. This all came out during the far-reaching official inquiry after the event.

The escape of the German warships would have significant effects. At the beginning of 1942 several important British radars – those for coast watching, ground-controlled interception, airborne interception, AA gun-control and searchlight-control – all operated on frequencies in the 200 MHz band. A heavy German jamming effort in that part of the spectrum would pay rich dividends if there was a resumption of the night Blitz. Thus, by highlighting that fundamental weakness, the escape of the German warships greatly assisted the British cause. Work began immediately to develop new types of radar that worked in widely different parts of the spectrum. Once those were in place, the Germans would never again have the chance to knock out the radar system with so little effort.

* * *

During the spring of 1942, British intelligence gradually improved its picture of the Luftwaffe night air defence system. In March, news arrived of an inland *Freya* station at Nieuwekerken in Belgium, just to the north of the important night-fighter airfield at Saint-Trond. By this time many coastal *Freya* stations had been located, but inland stations were thought to be a rarity. A high-flying reconnaissance Spitfire was sent to investigate. The photographs it brought back showed a *Freya* radar set and a cluster of searchlights, but the latter were grouped round a radar with a large circular open-work bowl – like that photographed in the Berlin Zoo. The proximity to the airfield at Saint-Trond strongly suggested that this was some sort of night-fighter control centre. Shortly afterwards this was confirmed.

Then an agent reported a night-fighter control centre at Domburg on the Dutch island of Walcheren. And the subsequent high-level photographic reconnaissance revealed a *Freya* and two 'Berlin Zoo' radars there. A more detailed study of the Nieuwekerken site showed there were two 'Berlin Zoo' radars there, also. This called for a closer look at the new type of radar. On 2 May, a reconnaissance Spitfire ran in fast and low along the Dutch coast and past the Domburg site. Yet again Flight Lieutenant Tony Hill had pulled off a low-level scoop, for he returned with clear photographs of both 'Berlin Zoo' type radars. As the Spitfire swept past them, the two radars were pointing in different directions. So Hill's pictures showed the radar from two quite different angles. Equally important, at one of the sets an operator had been about to climb the ladder to the cabin. He stood watching, helpless, to become a human yardstick when the photographs were analysed.

One night two weeks later, a further ploy was adopted to elicit information about the range of this radar. An RAF Beaufighter night-fighter flew towards the Domburg area, closely watched by the British radar station on North Foreland. A German night-fighter rose to intercept, and a long and inconclusive engagement followed. Throughout it, the RAF monitoring service recorded the orders passed to the Luftwaffe pilot. In particular, they noted that he was not permitted to move more than forty miles from the radar station. This was a strong pointer to its maximum range. Soon afterwards, the 'Berlin Zoo' radar was identified as the Giant *Würzburg*.

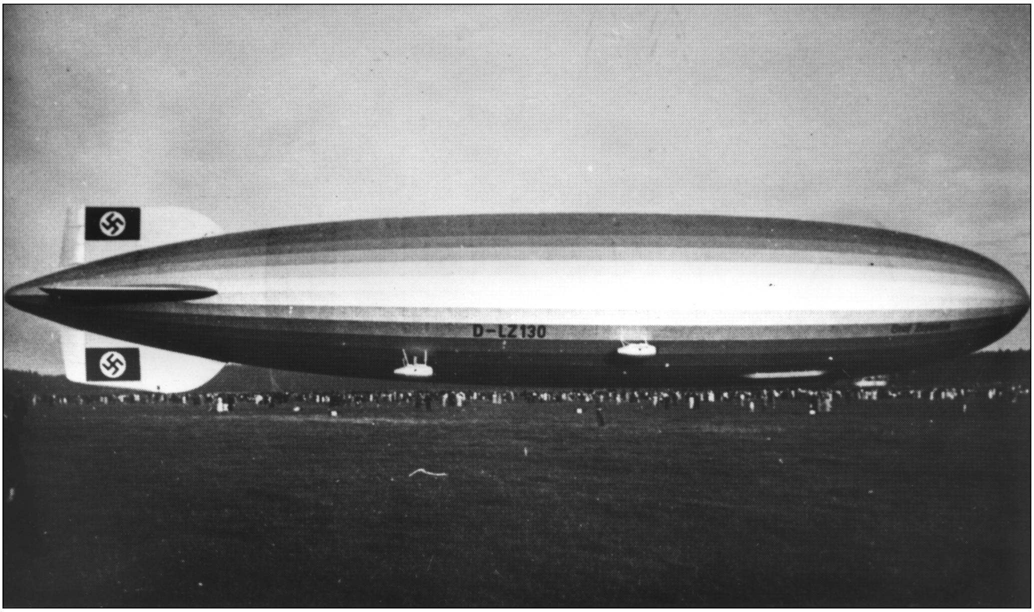
The next major item of intelligence came from a Belgian agent. He had managed to steal from a German headquarters a map showing the deployment of an entire regiment of searchlights. As luck would have it, the map covered the area around Saint-Trond. Marking the station at Nieuwekerken was a lightning flash, as were two more at Zonhoven and Jodoigne, some twenty miles on either side. Might these be fighter-control stations too? And if they were, was twenty miles the standard distance between adjacent sites? Reconnaissance photographs revealed that this was the case. By extrapolating the line, Jones and his staff soon picked out five further night-fighter control stations, strung out at regular intervals along an almost straight line.

During the summer of 1942, the clump of flags on the wall map in Jones's office sprouted shoots to either side of its original starting point in southern Belgium. The great radar hunt was on. Charles Frank christened the defensive belt the 'Kammhuber Line', and that appellation caught on in the RAF.

Agents were sent to areas previously calculated, to seek out the radar stations. Their catch was good; a paraboloid the size of a suburban house could hardly escape being the object of wonder and speculation by the local population. It should be remembered that at this time the 'man in the street' had never heard of radar. As a result the descriptive vocabulary of the inhabitants of the Low Countries was seriously strained; 'inverted umbrella' and 'magic mirror' were typical of the terms used. One Giant *Würzburg* was talked about so much that it became known as 'le fameux miroir d'Arsimont'.

During their flights over Belgium, Holland and northern France, RAF bombers dropped caged carrier pigeons. The birds' legs bore labels asking the finder to write in details of any large dish-like structures seen in the area, and then release the pigeons. This method alone assisted in locating three sites previously unknown to Dr Jones.

In the next chapter, we shall observe how this information was used to develop the first countermeasures to the Luftwaffe night air defence system.



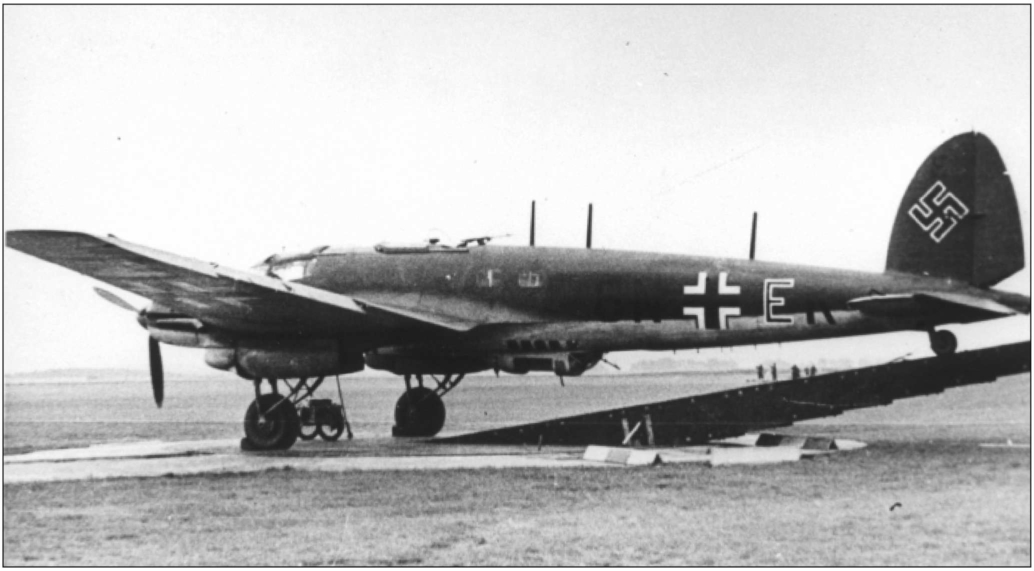
The rigid airship LZ-130 *Graf Zeppelin*, the last of these craft to be built, flew an electronic intelligence gathering mission along the east coasts of England and Scotland in August 1939.

Dr Ernst Breuning (right) led the listening team aboard the *Graf Zeppelin*. He described to the author how his team picked up signals from the newly erected British radar chain, but misidentified them as coming from a research station in Germany which was conducting experiments to measure the altitude of the ionised layers surrounding the earth.

The huge *Knickebein* beam-transmitter at Stollberg in Schleswig-Holstein. The aerial array was about 100 feet high, and was supported by railway bogies which ran on a circular track 315 feet in diameter to align the beam on the target.

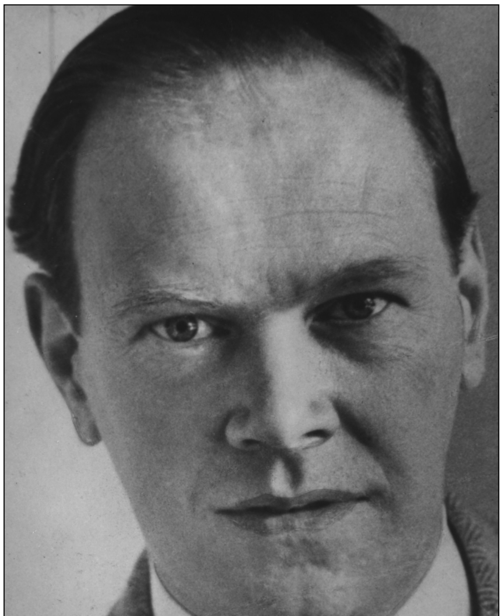
Heinkel 111 bomber of III/KG 26, the unit which employed the *Y-Gerät* beam system over Britain in 1940–41. Note the additional aerial for the system, mounted above the fuselage behind the cabin.

Wing Commander Edward Addison commanded No. 80 Wing during the 'Battle of the Beams'. Later he led No. 100 Group, which provided countermeasures support for bomber operations.



Heinkel 111 of Kampfgruppe 100 on the compass swinging base. Note the two additional aerial masts on the rear fuselage, belonging to the *X-Gerät* beam attack system.

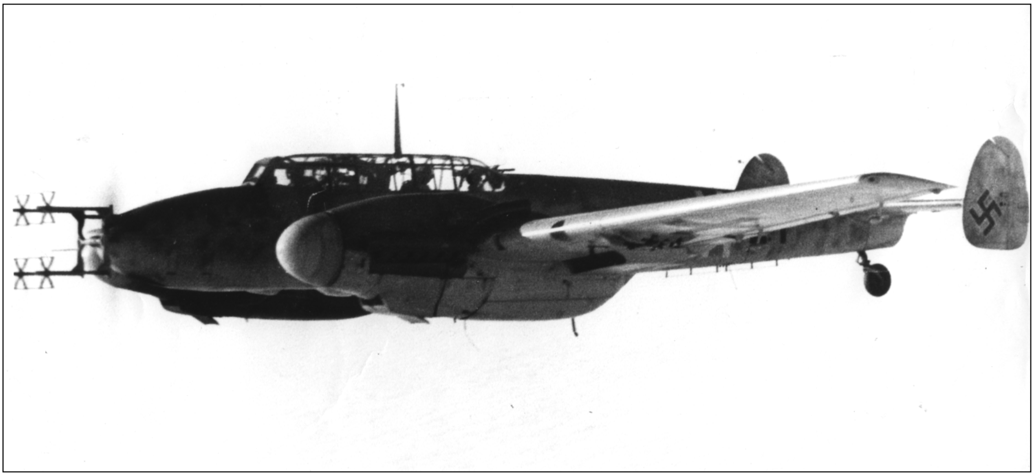
X-Gerät beam transmitter.



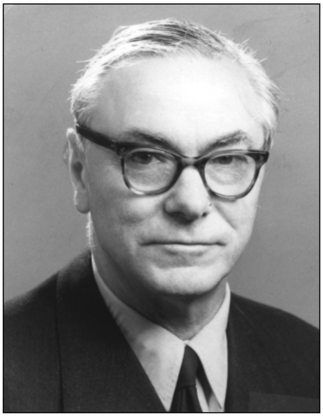
Dr R. V. Jones played a major role in uncovering the beam systems used by the Luftwaffe during attacks on Great Britain.

Left: The first photo to reach Britain showing that the Germans had radar in service. The *Graf Spee*, pictured in December 1939 after she had been scuttled off Montevideo. The aerial array of the *Seetakt* radar can be seen (circled) above the bridge.

Below: In November 1940 a reconnaissance aircraft took this photo of two unusual tub-shaped structures (circled and inset) at Auderville near Cherbourg. In February 1941 a Spitfire flew a risky low-altitude mission to get this close-up of the 'tubs', each of which was found to house a *Freya* radar.



Messerschmitt Bf 110 night-fighter, with the drag-producing aerial array of the *Lichtenstein* radar on the nose.



Above: Flight Lieutenant, later Wing Commander, Derek Jackson played a major role in the development of 'Window' metal foil strips to jam enemy radars including the *Lichtenstein*.

Left: Wassermann early-warning radar at Bergen aan Zee in the Netherlands. The surrounding houses give scale to the huge 130-foot-high aerial array.

Above: Generalmajor Josef Kammhuber, architect of the *Himmelbett* system.

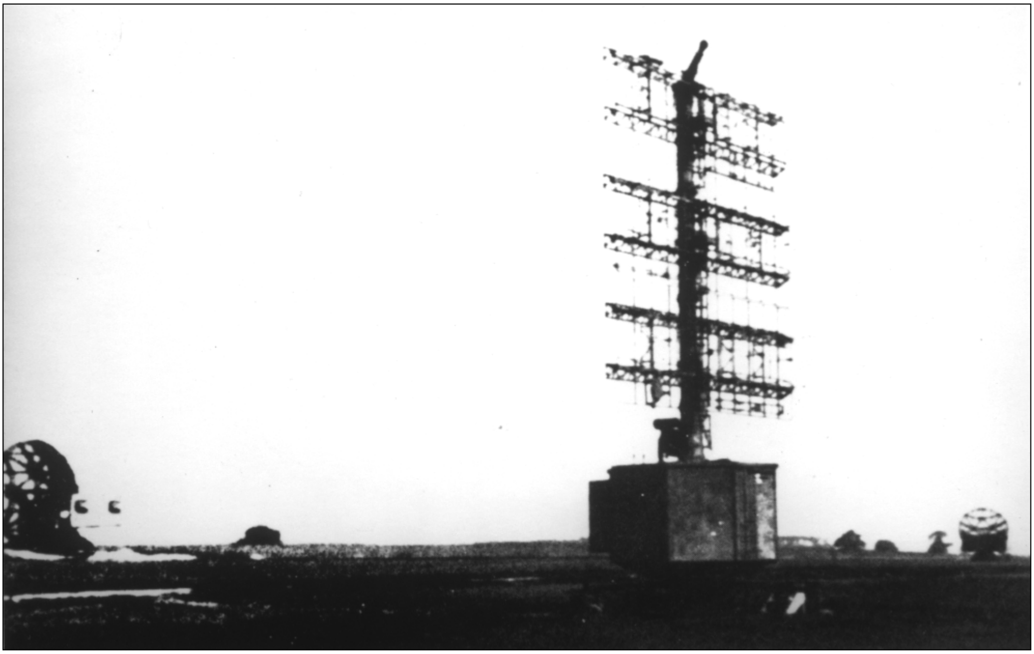
Left: Close-up of the *Würzburg* radar. Designed for use by flak and searchlight batteries, this radar was also used for a short time to direct night-fighters into action.

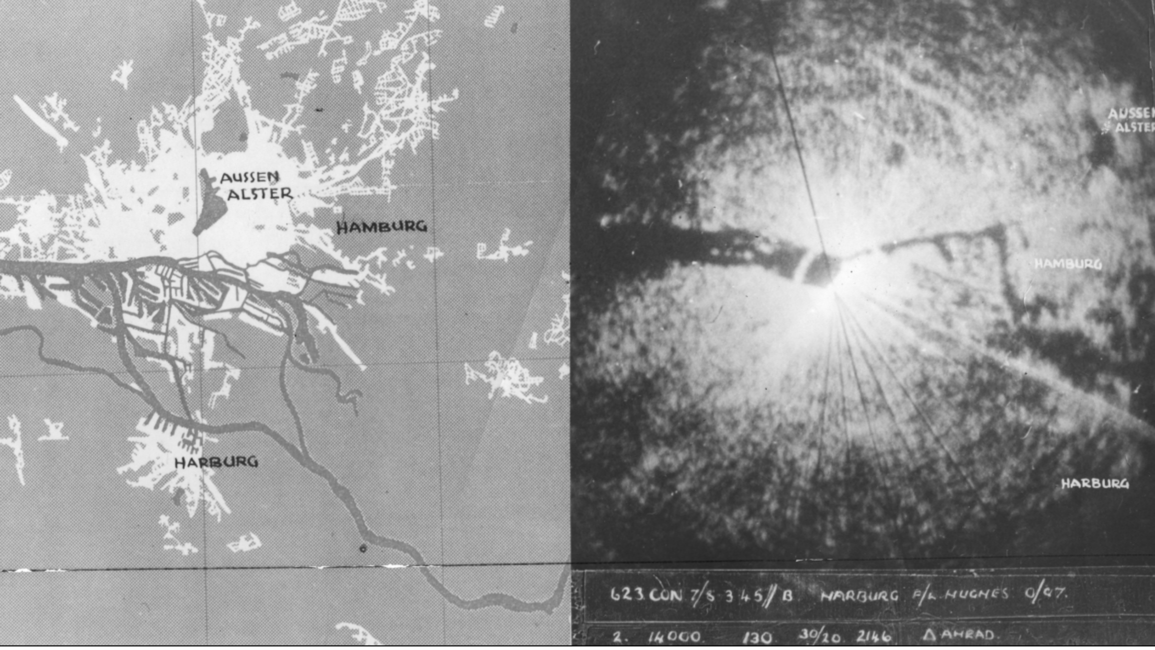
Reconnaissance photograph of the *Würzburg* at Bruneval, taken three months before the famous raid.

Low-altitude photo of the Giant *Würzburg* radar on the island of Walcheren, taken in May 1942.

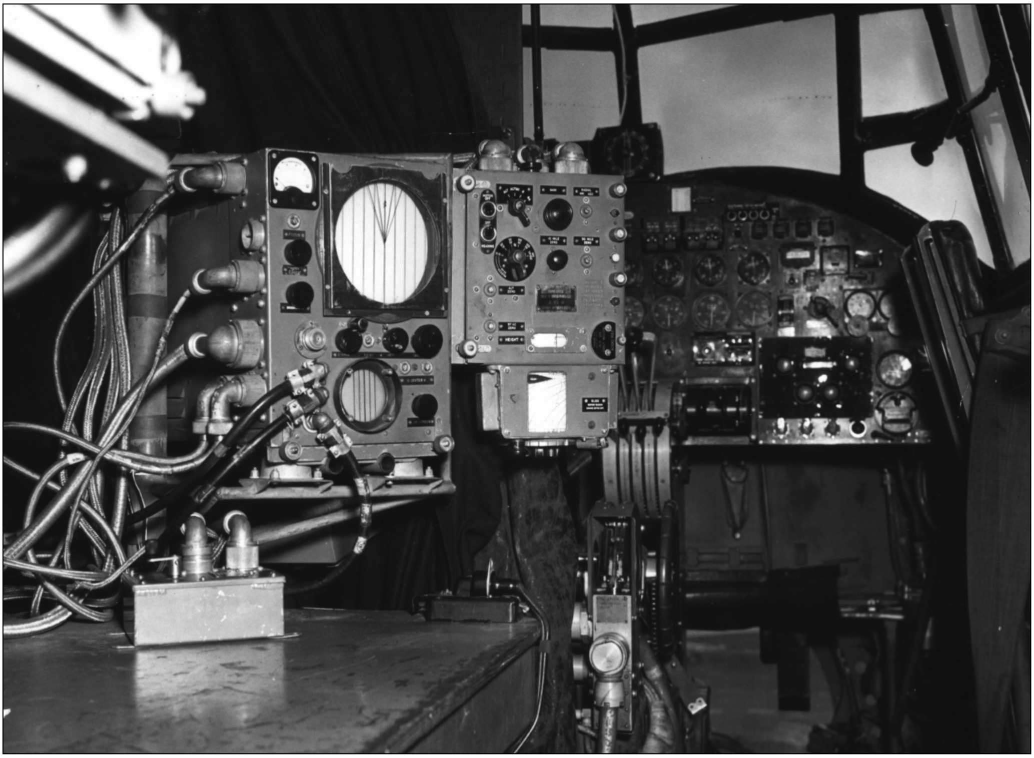
Following the Bruneval raid, German radar sites were surrounded with dense barbed-wire entanglements, which made them highly conspicuous on aerial photographs.

Below: Himmelbett station with a *Freya* radar (foreground) for long-range search and two narrow-beam Giant *Würzburg* radars (left and right) to track the movements of the British bomber and the intercepting night-fighter respectively.





H2S radar picture of Hamburg (right) compared with a map of the same area. The wide estuary of the River Elbe, pointing at the city from the west, served as a prominent navigation feature on radar.



H2S indicator in the navigator's position of a Lancaster bomber.

Aerial of a *Korfu* ground direction-finding station, which tracked RAF bombers by picking up the radiations from H_2S.

Generalfeldmarschall Erhard Milch held frequent conferences to discuss each step in the countermeasures battle as it appeared on the German side.

Oberst Dietrich Schwenke headed the Luftwaffe intelligence section responsible for monitoring technical developments by the Western Allies.

Generalmajor Joseph Schmid (right) took control of Luftwaffe night-fighter operations after General Kammhuber was ousted from that post following the 'Window' debacle in July 1943.

Major Hajo Herrmann (centre) seen with Reichsmarschall Herrmann Göring during an inspection of 'Wild Boar' night-fighter pilots. Major Herrmann had been instigator of those new tactics.

Ideal 'Wild Boar' conditions. Seen from above, a Lancaster bomber silhouetted against a cloud background by searchlights and fires on the ground, photographed over Berlin during the raid on 16 December 1944.

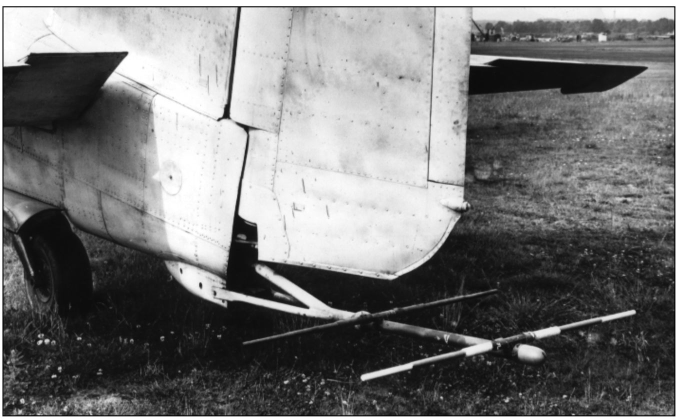
B-17 Flying Fortress modified as a jamming escort aircraft, before issue to No. 214 Squadron, RAF. The radome under the nose housed the scanner for the H2S radar.

Dr Robert Cockburn led the countermeasures team which designed and put into production many of the British jamming systems.

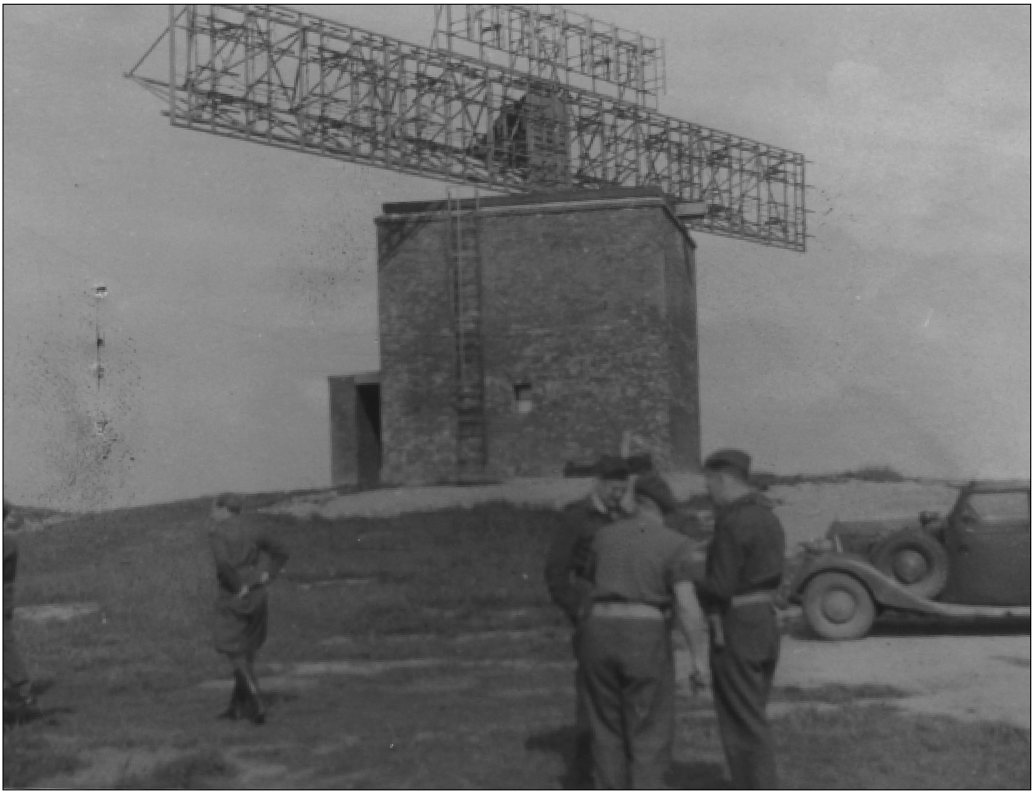
Above right: The 600-pound cylinder of the 'Jostle' high-powered VHF communications jammer, mounted on the rear of its special transporting truck. This jammer was fitted to the jamming escort Liberators and Flying Fortresses of No. 100 Group.

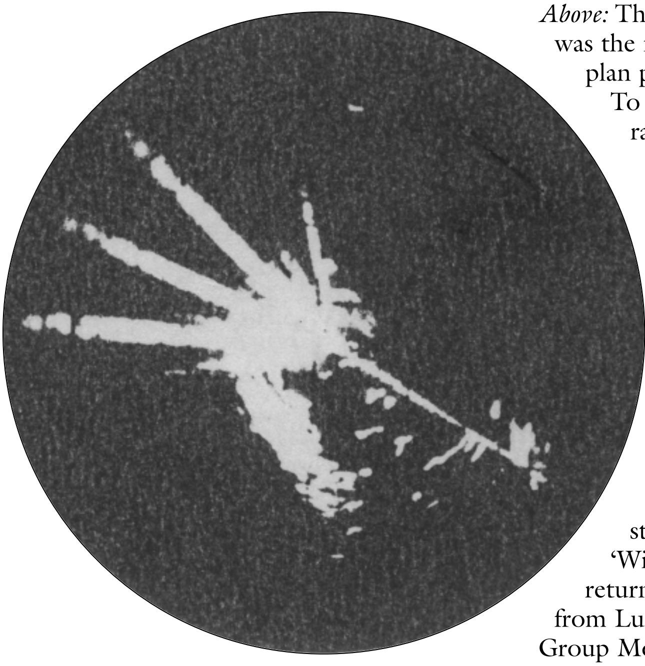
From the autumn of 1944 Luftwaffe night-fighters needed to be equipped to avoid RAF intruders, as well as engage bombers. This Ju 88 night-fighter carries the nose-mounted aerial array for the *SN-2* radar. The blister on top of the cockpit canopy houses the rotating aerial for the *Naxos* radar-homing and warning receiver . . .

Note the two upward-firing 20-mm cannon fitted in the fuselage . . .



Also the tail mounted aerial for *SN-2* to provide warning of Allied intruders closing in from behind.





Above: The *Jagdschloss* fighter-control radar was the first German radar to employ the plan position indicator type of display. To avoid electronic jamming, the radar had provision for the operator to select one of four separate operating frequencies.

Left: Effect of 'Mandrel' jamming on the screen of a *Jagdschloss* radar. The screen is north-aligned. The three large 'spokes' in the northwest quadrant point to three aircraft jamming as part of a 'Mandrel' screen. The caterpillar-shaped return heading south-southeast has the appearance of a bomber stream, though in fact it is 'Window' spoof. The scattered returns in the southeast quadrant come from Luftwaffe night-fighters and No. 100 Group Mosquitoes.

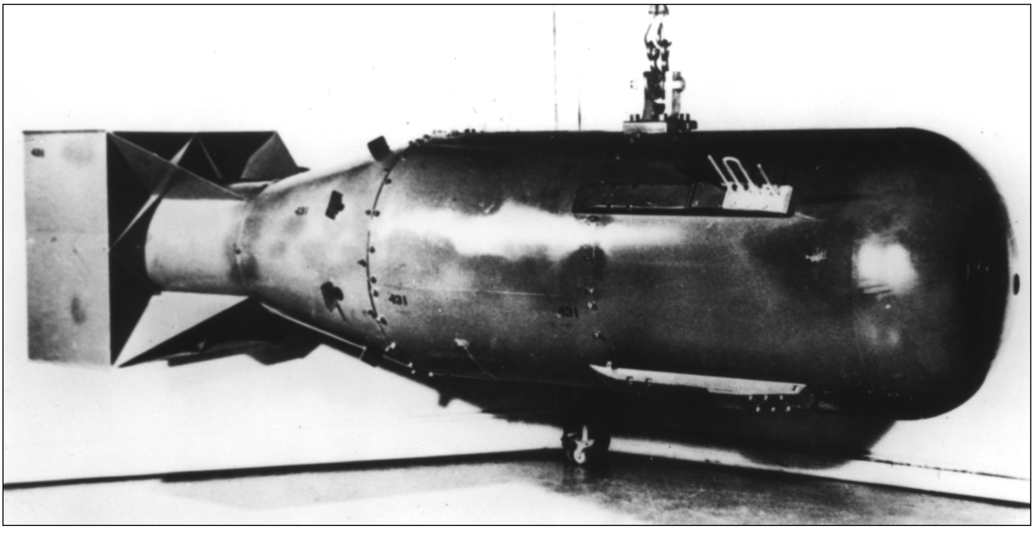
Above: Formation of B-17 bombers being engaged by a flak battery firing though an overcast. Note the effect probably caused by 'Carpet' jamming of the fire-control radars: although the bursts appear to be accurate in line, the shells have detonated at the incorrect range and well below the raiders' altitude.

Left: The APQ-9 'Carpet III' jamming equipment, used in large numbers to counter the German *Würzburg* and *Mannheim* flak-control radars.

Right: B-29 bombers pictured at one of the islands on the Marianas group. With assistance from radio-countermeasures, these aircraft made devastating attacks on Japanese cities and industrial targets for minimal losses in the spring and summer of 1945.

Above: The 'Tuba' equipment, designed and built at the Radio Research Laboratory at Harvard, was the largest and most powerful jamming system produced during World War II. The man standing at the base of the aerial gives scale to the special directional array developed for the jammer. 'Tuba' became operational too late to have any effect, however.

'Guardian Angel' B-29, which served as a jamming escort aircraft to provide cover for bombers attacking Japan. Eight jamming aerials are visible on this view of the aircraft.



'Little Boy', the atomic bomb which devastated the Japanese city of Hiroshima. The aerial elements of two of the four radar airburst fuses can be seen mounted on the side of the weapon.

Chapter 4

Towards the Offensive

> 'If you know the enemy and know yourself you need not fear the result of a hundred battles. If you know yourself but not the enemy, for every victory you will suffer a defeat. If you know neither you will always be beaten.'
>
> General Sun-Tzu

As German troops advanced deeper into the Soviet Union in the summer of 1941, it became clear in Britain that, after almost a year on the defensive, it was time to seize the initiative in the West. Clearly, an invasion of the continent was out of the question in the foreseeable future. For the time being the only readily available means of striking at the German homeland was through RAF Bomber Command. Prime Minister Churchill assured Russian Premier Josef Stalin that, when the weather improved in the spring of 1942, the RAF would launch a heavy air offensive against Germany and: 'We are continuing to study other measures for taking some of the weight off you.' Those 'other measures' would not materialise for a long time.

At that time, however, Bomber Command was going through a period of soul-searching. The fact that the Luftwaffe had found it necessary to develop radio aids to assist accurate navigation and bombing at night had led to some scepticism concerning the results the British bomber crews might themselves be achieving. After all, they had no such aids. One of the doubters was Air Vice-Marshal Robert Saundby, who took up an appointment as Senior Air Staff Officer at Bomber Command headquarters at the end of 1940. He told his staff that, when a force of bombers claimed to have dropped 300 tons of bombs on a certain target, all they could be certain of was that they had 'exported 300 tons of bombs in its direction'.

Professor Lindemann conducted his own investigation into the results of the RAF bombing, based on the photographs brought back by reconnaissance aircraft. The findings were highly disquieting: of the crews who thought they had hit the target, only one in three had in fact placed their bombs within five miles of it. In the case of targets in the Ruhr industrial area, the figure was as low as one crew in ten. After receiving the report in September 1941, Mr Churchill taxed the Chief of Air Staff with this:

> It is an awful thought that perhaps three-quarters of our bombs go astray . . . If we could make it half and half, we should virtually have doubled our bombing power.

As a long-term investment, development began on two radio devices to improve bombing accuracy: Oboe and H_2S. These will be described in later chapters. For the moment, the most urgent requirement was for a less ambitious radio aid that would improve basic navigational accuracy at night.

Fortunately work on such an aid was well advanced at the Telecommunications Research Establishment and the device, code-named 'Gee', was nearing the service trials stage. The 'Gee' (or Grid) system of navigation had been conceived in 1938, and work on the device had begun in earnest in the spring of 1940. 'Gee' employed three ground transmitters situated about a hundred miles from each other. These transmitters acted in unison to radiate a train of pulses in a set order. The aircraft carried a special radar receiver, which enabled the navigator to measure the minute time differences between the reception of the various signal pulses. By referring those time differences to a special 'Gee' map, the navigator could determine his position to within six miles, while flying up to 400 miles from the furthest transmitter. Closer to the transmitters, the accuracy was even better. In its concept 'Gee' was a great improvement over that of *Knickebein*, its nearest German equivalent. The latter gave an accurate positional fix only at the crossing point for a pair of Lorenz-type beams, whereas 'Gee' provided fixes for aircraft anywhere within its area of cover.

By the beginning of March 1942, sufficient 'Gee' receivers existed to equip about one-third of Bomber Command's aircraft. The device immediately became popular with crews, who affectionately nicknamed it the 'Goon box'.

The Luftwaffe captured its first 'Gee' receiver on 29 March, recovered from the wreckage of a Wellington bomber which came down in the sea off Wilhelmshaven. The device had suffered some salt-water damage, but that water had saved it from complete destruction. As the crew had abandoned the Wellington, one of them initiated the explosive detonator intended to destroy the box. The system had a built-in delay to give everyone time to get clear, and before it went off the water had smothered the charges.

The procedure adopted by Luftwaffe intelligence from this point on was similar to that used by R. V. Jones and his team in Britain. Intelligence officers and radio experts hunted for any further scraps of information relating to the new British system. Oberst Dietrich Schwenke, the intelligence officer in charge of the Luftwaffe section dealing with equipment captured in the West, discussed the find at a high-level conference held in Berlin on 26 May. He said the remains of this equipment had been recognised in several shot-down British aircraft, but in every case except the Wilhelmshaven incident and a second aircraft which had also crashed in the sea, the units had been smashed beyond repair when the demolition charge went off. Schwenke continued:

> The British [have developed] a new system which gives the pilot [*sic*] his position at all times. The equipment for this is the receiver I have just described. Tests have been carried out on it by Telefunken, but the set was unfortunately not received in good condition. Our experts are still not in complete agreement concerning the technical working of the equipment.

Schwenke went on to describe the working principle of 'Gee', and the way it was used. He added that the equipment was being installed as standard in the each of the RAF's principal heavy-bomber types – the Wellington, the Lancaster, the Stirling and the Halifax. He continued: 'I think it is being used not so much to find pinpoint targets, as to improve dead-reckoning navigation.'

Once a working receiver became available, Schwenke planned to install it in a Luftwaffe aircraft. It would then be possible to establish the accuracy of the system over Germany, using the British transmissions. The transmitters were known to be located in south-eastern England, in positions where they could cover the Ruhr industrial district. Schwenke said the possibility of jamming was under investigation, but first it was necessary to find out exactly how the system worked and the frequencies it used. He said the ground transmissions were fairly powerful, but he thought they could be jammed if more powerful jamming transmitters radiated on the same frequencies. Schwenke told the conference that Generalmajor Martini, head of the Luftwaffe signals service, would call a meeting shortly to discuss possible methods of jamming the system.

Oberst Pusch, a Luftwaffe signals specialist, was put in charge of the programme to initiate countermeasures against 'Gee'. At the end of July 1942, he formed a special unit – the 2nd Battalion of the Air Signals Radio Monitoring Regiment (West) – to jam the device. Dr Mögel, a senior Reichspost (German Post Office) technician, began work to convert several speech transmitters into makeshift jammers. These were then installed around important targets in Germany. Thus the Luftwaffe reaction to 'Gee' was an almost exact replica of that which took place in Britain two years earlier to counter *Knickebein* and the other German beam systems.

On 4 August 1942, the Luftwaffe began its jamming attack on 'Gee'. That night, thirty-eight bombers made a small-scale attack on Essen. In the aircraft carrying 'Gee', the navigators noted that in the target area the system's signals were swamped by enemy interference.

As in Britain in 1940, the initial makeshift jamming transmitters soon gave way to a more powerful jammer designed for the task. Code-named *Heinrich*, the new transmitters were set up all over German-occupied Europe. One even found its way to the top of the Eiffel Tower in Paris. Within three months so many jammers were operating that 'Gee' was virtually unusable over most of Germany and Western Europe. RAF navigators could rely on 'Gee' fixes only when they were clear of enemy territory – the same fate that had befallen *Knickebein* after the autumn of 1940.

* * *

The escape of the German battlecruisers *Scharnhorst* and *Gneisenau* through the English Channel in February 1942 drew attention to the strong need for a British organisation to jam German radars. Since the end of the 'Battle of the Beams', Dr Cockburn and his team had been 'champing at the bit' to be allowed to develop such systems but until now the official British policy was not to provoke a radar jamming conflict, for fear that there was more to lose than to gain from such an encounter. However, the Germans had now begun jamming in earnest, with no prompting from anyone. Moreover, they had demonstrated that they had an effective radar-jamming organisation in being. Cockburn therefore received permission to begin work to produce prototypes of the systems he had been planning for some time, to counter *Würzburg* and *Freya*.

The first two systems built were both designed for use against *Freya*. One, code-named 'Mandrel', put out noise jamming on the frequencies used by the German early-warning radar; its effect was similar to that of a car with unscreened ignition on a domestic television receiver. The other system, code-named 'Moonshine', was designed to spoof rather than jam *Freya*. The device received the pulses from the German system, then amplified and re-transmitted them. That enabled a single aircraft to produce the appearance on radar of a large force of planes flying in close proximity to each other. From the RAF point of view 'Moonshine' had the drawback that it could simulate only the sort of close formation adopted by daylight raiders. It could not produce a realistic impression of a night raiding force, where the aircraft flew in a much more diffuse pack. And, of course, the great majority of RAF bombing attacks at that time were flown at night. Nevertheless, even if the opportunities to use it were limited, the spoofer idea was judged worthy of pursuing on a limited scale. Accordingly a special RAF unit, No. 515 Squadron, was formed in April 1942 to make use of 'Moonshine'. The squadron received nine Defiants, two-seaters that were obsolete as fighters. They were the only aircraft with a reasonably high performance that were readily available. Installation of the spoofing equipment began immediately. We shall return to this unit, and to the 'Mandrel' noise jammer, in later chapters.

* * *

The first counter to the 'Kammhuber Line' of night-fighter control centres did not involve any sort of jamming. During the first two years of Bomber Command's night offensive, the bombers had made their own way to their targets. There was no attempt to keep the raiding force together – indeed, many crews attributed their survival to the fact that they did things differently from everybody else. A large number of bombers crossing the defensive line at widely separated points, over a period of several hours – that was the grist for which Josef Kammhuber had designed his mill.

As the workings of Kammhuber's line became known in Britain, however, a major weakness became apparent. The line comprised a number of adjacent boxes, each patrolled by a single radar-guided night-fighter. Each defensive box could engage only one bomber at a time and during that period – an average of about ten minutes – other bombers passing through that particular box were safe from fighter attack. Thus, if the raiders all adhered to the same route and were concentrated in time, they would overwhelm the defensive line at the chosen entry and exit points. All, except for the few unfortunates upon whom the fighter controllers focused their attention, would pass through the line unscathed. Hitherto navigation had not been precise enough to enable the bombers to be 'streamed'. Despite the jamming, 'Gee' now made that possible. The tactic of concentrating attacks in both time and space promised a further advantage: it would produce a similar saturation of the AA gun defences, reducing their effectiveness also.

Early in 1942 Dr B. G. Dickins, head of the operational research section at Bomber Command headquarters, wrote:

> Both *en route* over land to the target and in the target area, concentration in time and space, together with dispersion in height, will result in the minimum of aircraft casualties, by day and night. In a given area and time, the number of aircraft that can be engaged by searchlights and/or guns is limited. Thus, by passing concentrated streams of aircraft over a given route, the enemy will be presented with a difficult problem owing to super-saturation of his defences, so that our losses should be small. By passing a concentrated stream of aircraft at different heights over the area, the enemy will experience great difficulty in determining the exact course, and particularly the height, of individual aircraft. Should he resort to barrage fire, the dispersion in height will render this particularly ineffective.

The new tactic was first tried on the night of 30 May 1942, during the famous Thousand-Bomber Raid on Cologne. The attacking aircraft all flew the same route, and the period of attack was cut from about seven hours to two and a half – an average of seven aircraft bombing each minute. Forty-one bombers, 3.8 per cent of the force – failed to return. That was a significantly lower proportion than had been lost up to this time. The 'bomber stream' had been born.

Despite this success, the value of bunching aircraft at night remained a source of argument within Bomber Command. Initially the new tactic was unpopular; several aircraft returned to base with holes in their wings caused by incendiary bombs dropped from above. Also, mid-air collisions were seen to occur more often. Dr Dickins reduced the risks to a simple mathematical argument, by estimating the chances of a collision. He told the writer:

> It became quite obvious to us that while a collision was something like a half a per cent risk, the chance of being shot down by flak or fighters was a three or four per cent risk. So we could allow the collision risk to mount quite a bit, provided we were bringing down the losses due to other causes.

Josef Kammhuber's answer to the new tactic was to buttress his line with additional fighter boxes in front of and behind it, to increase the depth of the defences. In the autumn of 1942, RAF losses started to rise once more.

* * *

Towards the end of October 1942 Allied forces in Egypt launched their offensive at El Alamein. Eleven days later, after a series of hard-fought actions, they had broken through the enemy line and the Axis forces began a lengthy retreat westwards along the coast of north Africa. Now came the fruits of victory; the German forces had been well supplied with radar, and as they pulled back they were forced to abandon much equipment.

Derek Garrard flew to Egypt to see what items of radar interest he could pick up. When he returned to England, he approached Mr J. B. Supper at the Royal Aircraft Establishment at Farnborough. Supper, with a five-man team, agreed to receive the captured radar equipment and examine it. They had no idea of the magnitude of the task, however.

Soon captured equipment was arriving at Farnborough by the lorry-load. Supper's men were aghast when they opened the first crates. The filth, the smell, the shattered state of the equipment, the sizes and weights to be handled – these made the task of analysis seem almost impossible. It amounted to a major engineering project. Supper asked for large accommodation, mechanical handling equipment and a five-fold increase in the size of his team. The Director of the Establishment at Farnborough emptied one of the precious hangars of aircraft and made it available to Supper. Cranes, forklift trucks and men arrived to swell his team.

Garrard had laid down three main requirements for Supper's section: first, the collection of labels off the pieces of equipment from which valuable intelligence could be gleaned; secondly a general analysis of German radar techniques; and thirdly, a search for anti-jamming circuitry. As Supper became familiar with the German radars, he decided to try to restore one to full working order. A *Würzburg* had been recovered almost intact, and its missing and broken parts were replaced with items from other sets. To determine the circuit layout from the radar set itself took many hours of painstaking work – it was far more difficult than building a set from an existing circuit diagram. Supper's biggest worry was that some scarce component might be burned out by the premature operation of the set, before it was fully repaired; he had, for example, only one *Würzburg* transmitter valve. To prevent that, each unit had to be assembled and tested independently, and studied for compatibility with the others before it was passed as fit.

At last, the captured *Würzburg* was ready for testing. Supper recalled how they switched it on – and it worked, though not for long. It had its foibles and required nursing. Gradually they learned to tame it, and soon they 'saw' their first aircraft on its screens. Supper immediately telephoned the news to Garrard:

> Within a few hours he arrived at Farnborough, accompanied by Jones and Frank. The three of them were like schoolboys on their first visit to the Science Museum. They jumped on and off the wooden platforms surrounding the radar, they turned handles and knobs, and they touched every part of it with loving caresses.

Supper was puzzled by this display of exuberance. He had expected the intelligence people to share his pleasure at a fine job of reconstruction, but why this boisterous joy? Gradually it dawned on him that for over two years these men had pored over photographs, sifted and analysed reports from agents, and slowly and painfully built up a mental picture of German radar capability. Here for the first time was the tangible reality of their endeavours, a working *Würzburg* manned by a trained crew. And it had turned out to be exactly as they had expected.

Supper's team increased until it numbered some thirty-five men.

Working *Freya* and *Seetakt* radars emerged from the rubble, and Supper was able to tell Garrard in detail what to look for when he went 'beachcombing', to make good his deficiencies. Garrard would rarely let him down.

* * *

At the end of 1942 Bomber Command's picture of the Luftwaffe night air defences was reasonably complete except in one important aspect – there was little information on the nature of the interception device fitted to the night-fighters. Since the previous spring, radio-monitoring stations in England had noted a new code expression in the German fighter crews' vocabulary – *Emil-Emil*. From the intercepted conversations, it was clear that *Emil-Emil* was some form of target location device carried in aircraft.

On 23 July, two months after the first thousand-bomber raid, a night-fighter crewman was heard to say 'I have the enemy aircraft on *Emil-Emil*. Please give further vectors.' On 6 September, a ground station asked a fighter: 'I have vectored you to within two kilometres of the enemy aircraft, haven't you picked him up on *Emil-Emil*?' Also that night, a fighter pilot explained why he had broken off radio contact with his ground controller: 'I had an enemy aircraft on *Emil-Emil*, and broke off radio contact with you during that time.' The ground controller rebuked him, and said he had to maintain radio contact at all times.

By October 1942 the volume of radio traffic with references to *Emil-Emil* had reached such proportions that R. V. Jones concluded that almost the entire night-fighter force either had, or was about to get, the device. It was clearly very important, but what was it? Almost certainly it was some form of radar, or an infrared homer which detected the hot engine exhausts of the bombers. It was vital to know which of these two principles it employed; and, if it was a radar, its operating frequency.

In an attempt to find the answer, TRE set up a special monitoring station on the Norfolk coast. The radar receiver was sited in a depression in the ground so that – barring the most abnormal radio propagation – it was below the normal horizon and would pick up only those transmissions that emanated from aircraft. Within a few days the listeners found what they were looking for; a cine camera mounted in front of the cathode-ray tube photographed a series of pulses on a frequency of 490 MHz. The RAF did not use that part of the radio spectrum, and the rate at which the signals' sources changed their bearing indicated they were almost certainly coming from an airborne system.

The hunt was not over, however, for there was no proof that the aircraft concerned were night-fighters. They might, for example, be coastal-patrol aircraft carrying a quite different type of radar to search for ships. The only way to be certain was to send 'ferret' aircraft to trail their coats in front of the enemy. If a night-fighter with the 490 MHz radar intercepted one of these, it would immediately become evident. Jones had no power to hazard aircraft and men's lives in that way, so he requested Cabinet approval. This was immediately given, and the prime minister himself demanded vigorous action to settle the mystery of *Emil-Emil*.

The unenviable task of acting as live bait for Luftwaffe night-fighters fell to No. 1473 (Wireless-Investigation) Flight. The unit began sending individual Wellington 'ferret' aircraft to patrol over France, Belgium and Holland. Radar stations in England kept a careful watch on them, ready to flash a warning if they saw a German night-fighter closing in. The planes' special operators were briefed to listen for radar-type transmissions on frequencies around 490 MHz. Then, to be certain these came from a night-fighter radar, they were to allow the German aircraft to close to short range. Only then were they to make their escape, while the radio operator transmitted a coded message to base with the findings.

The initial flights were far less hazardous than the crews expected, for the Luftwaffe simply ignored the isolated aircraft. Although the 'ferrets' recorded suspicious signals in the 490 MHz band, the mystery remained unresolved. If the Luftwaffe refused to react to lone aircraft flying over coastal areas, it was decided that the 'ferret' aircraft would have to accompany raiding forces to their target. While that made the duty distinctly more dangerous for the listening-aircraft and its crew, it must be stressed that their degree of risk was no greater than that experienced by all the other aircraft in the force.

During the early morning darkness of 3 December 1942, a 'ferret' Wellington flew as part of a force attacking Frankfurt. Just to the west of Mainz the special radio operator, Pilot Officer Harold Jordan, picked up weak signals on 490 MHz. Those were the ones he had been briefed to look for, and for the next ten minutes he noted their characteristics – and observed that they increased in strength. Jordan warned the rest of the crew of what was happening. He then drafted a coded signal to the effect that 490 MHz signals had been picked up and almost certainly these emanated from a night-fighter's radar. Jordan passed the message to the plane's wireless operator, Flight-Sergeant Bill Bigoray, to transmit to England.

Any last doubts that the signals came from a night-fighter were dispelled, when they rose to a level that swamped Jordan's receiver. He shouted to the crew to expect an attack at any moment, and immediately afterwards the Wellington shuddered under the impact of exploding cannon-shells. Sergeant Ted Paulton, the pilot, threw the aircraft into a steep diving turn to shake off the assailant. The rear-gunner opened fire on the attacker, which he recognised as a Ju 88. Although he had been hit in the arm, Jordan wrote a second coded message confirming that the frequency given in his first report was without doubt that of a night-fighter's radar. Again the rear-gunner fired at the attacker, then his turret was put out of action and he was hit in the shoulder. The night-fighter attacked again, and this time Jordan received further wounds to his jaw and eye.

Then the night-fighter vanished, leaving the Wellington in dire straits. The throttle of the port engine had been shot away, while that to the starboard engine was jammed. Both engines were running rough, both gun turrets had been knocked out and the hydraulic system was shot to pieces. The starboard aileron no longer worked and both airspeed indicators were useless. Four of the crew of six were wounded.

Despite his own leg injuries, Bigoray tapped out Jordan's second coded message. He could get no acknowledgement, so he repeated the message many times in the hope that someone might hear it. In fact a ground station in Britain picked up the vital signal and sent a reply, but its acknowledgement was not heard because the Wellington's wireless receiver was wrecked. Doggedly, Bigoray continued tapping at his Morse key as the Wellington made its painful way back towards friendly territory. Finally, as it was getting light, the battered aircraft reached the coast of England.

Now there was a new problem: the aircraft was too badly damaged to risk a crash landing, so Paulton decided to put it down in the sea close to the shore. Yet one of Bigoray's legs had stiffened from its wounds, and he might not escape from the aircraft before it sank.

The only solution was to drop him by parachute; he landed safely near Ramsgate, with a copy of the second vital signal in his pocket. Paulton then ditched the aircraft about 200 yards off the coast at Deal. The crew inflated their rubber dinghy, but it was badly holed and useless. The men climbed back on the wallowing bomber, and a few minutes later a small boat picked them up.

A grateful Bomber Command showed its appreciation for the crew's devotion to duty in the only way it could. A few weeks later Jordan was awarded the Distinguished Service Order, Paulton the Distinguished Flying Cross, and Bigoray received the Distinguished Flying Medal.

In war, all too often, individual acts of extreme bravery have no real effect on the outcome. This act did, for it added the last significant piece to the jigsaw puzzle picture of the Luftwaffe night air defence system. By a combination of boldness, imagination, patience and good fortune, British intelligence had constructed that picture. In the months that followed, with few omissions, they would detect each change as it was made. Now the details of the system were known, the vulnerabilities of the various radio and radar devices could be exploited to the full.

Before we examine these, however, it is necessary to turn our attention to events many thousands of miles away, in the USA and the Pacific theatre of operations.

Chapter 5

The Coming of the Yanks

> 'We set sail in great secrecy, on a sea of uncertainty, in an unknown direction, with a green crew.'
>
> Dr Frederick Terman

On 7 December 1941, Japanese naval aircraft launched a powerful attack on US warships at the fleet anchorage at Pearl Harbor. The act caused considerable devastation and heavy casualties, and brought the USA into the war against Japan. Within a few days, Germany declared war on the USA also.

In the medium term, the huge US industrial capacity would play an overwhelmingly powerful role in the electronic countermeasures conflict. Yet some time would elapse before those resources could exert any effect.

Dr Frederick Terman, then head of the Department of Electrical Engineering at Stanford University in California, and a man of immense stature in the US electrical engineering community, was chosen to assemble an organisation to develop radio and radar countermeasures systems for the US armed services. On 12 February 1942, the very day the German battlecruisers made their dramatic dash through the English Channel shielded by radar jamming, Fred Terman took up his new appointment.

Terman established his countermeasures organisation at the Massachusetts Institute of Technology (MIT) at Cambridge. To conceal its true purpose, it was called the Radio Research Laboratory (RRL). Initially it was to be part of the Radiation Laboratory (Radlab) already established at Cambridge to develop new types of radar equipment. Yet, from the beginning, the work of the two groups was kept separate. Although most of those working on countermeasures could visit the Radlab to acquaint themselves with the latest radar developments, only a few of those working at the Radlab were given access to the RRL. The reason for this one-way passage of information was that those working on countermeasures obviously needed full access to available intelligence information on enemy equipment, but that was not necessary to those working on new types of radar.

Terman saw that he and his team were on a steep learning curve. As he later commented: 'We set sail in great secrecy, on a sea of uncertainty, in an unknown direction, with a green crew.' One of his first acts was to visit the Telecommunications Research Establishment, to learn about British work on countermeasures. In April 1942 he arrived at the TRE, where Dr Cockburn welcomed him and gave him a detailed tour. Terman saw the work on the improvised 'Mandrel' and 'Moonshine' devices to counter *Freya*. He was also given the latest intelligence on German radars.

The two men discussed how best to divide work between their two establishments. It was agreed that the TRE, which was the closer to the main theatre of operations and already heavily committed, should concentrate on solutions to the more immediate problems. At the same time the RRL, with resources yet to be committed, would concentrate on meeting the longer-term requirements.

Soon after Terman returned from England, in June 1942, the Radio Research Laboratory left the MIT and moved to the campus of the nearby Harvard University. As the staff settled into their new quarters, there was a period of re-organisation. Terman divided his group into four main sections: one to work on the design of a fully engineered US version of the 'Mandrel' jammer to counter *Freya*; one to work on a 'Carpet' jammer to counter *Würzburg*; one to develop a new radar intercept receiver, designated the SCR-587; and one to investigate the vulnerability of current and future US radars to jamming.

* * *

The first radar-jamming system from Dr Cockburn's team at the TRE to enter service was the 'Moonshine' spoofing equipment. While this could not reproduce the diffuse appearance of a night raiding force, on radar it gave a good likeness of a close formation of aircraft delivering an attack by day. And daylight attacks were the business of the US Eighth Air Force now establishing itself at bases in England.

By August 1942 the 'Moonshine' unit, No. 515 Squadron flying Defiant two-seaters, was ready for action. On the 6th the device underwent its first operational trial: eight Defiants, orbiting south of Portland, 'Moonshined' the same number of *Freya* early-warning radars on the opposite side of the Channel. Some thirty Luftwaffe fighters, the entire force in the Cherbourg area, took off to meet the 'threat'.

Eleven days later the spoofers diverted attention away from a real attack. While the 'Moonshine' Defiants and a hundred supporting aircraft assembled menacingly over the Thames estuary, US B-17 Flying Fortresses delivered their first attack, on rail yards at Rouen in France, with a strong fighter escort. The Luftwaffe fighter controller scrambled 144 interceptors to block the spoof attack, and sent only half that number to meet the real attack on Rouen.

In the months that followed, 'Moonshine' Defiants operated on twenty-eight occasions to support daylight attacks. Sometimes they misled the Luftwaffe, sometimes they did not. During these operations two further limitations of the spoofer came to light. Since the *Freya* radars all worked on slightly different frequencies, one 'Moonshine' was needed to deal with each one. But the Luftwaffe early-warning radar chain was constantly expanding, so a huge increase in the number of 'Moonshine' aircraft would be necessary to keep up with this expansion. Also, if the Defiants flew over German-held territory by day and were seen, the nature of the spoof would be compromised. That limited the method to supporting shallow-penetration attacks, which were becoming a rarity. The 'Moonshine' Defiants flew their last sortie in the autumn of 1942.

* * *

By this stage the German *Freya*, *Seetakt*, *Würzburg* and Giant *Würzburg* radars were well known to British intelligence, and this information was passed via the US intelligence service to Dr Terman's laboratory. As yet, however, the Allies knew nothing at all of the work on radar done in Japan.

On 7 August 1942, US Marines stormed ashore at Guadalcanal in the Solomon Islands to seize the partially completed airfield there. To one side of the construction site marines found a box-like operating cabin topped by a bedspring-like structure: a Japanese Mark I Model 1 early-warning radar. The captured radar set was shipped to the US Naval Research Laboratory (NRL) at Anacostia, Maryland, and restored to working order. Lieutenant Ralph Clark from the Navy Bureau of Aeronautics was one of those who examined it:

> I had a look at it and I remember being impressed how crude it was compared with our own early sets – and goodness knows, our first generation SCR-268, -270 and -271 sets were crude enough! Nearly all the tubes [valves] in the Japanese equipment appeared to be copies of types made by General Electric.

* * *

Before going further, it is important to review the state of Japanese radar development in mid-1942. In terms of quality, quantity and the range of uses to which it was put, Japanese radar lagged far behind that of the Western Allies and the Germans. And that gap widened with each month that passed. Due to the all-consuming rivalry between the Japanese Navy and the Army each service ran its own, entirely separate, radar research programme which naturally greatly diluted the development capacity of Japan's then small radio industry.

The Navy had deployed small numbers of Mark I Model 1 ground early-warning radars operating on 100 MHz (the equipment captured at Guadalcanal) and the Mark II Model 1 shipborne radar, for surface-search and gunnery-control and operating on 200 MHz, was undergoing trials on the battleship *Ise*. Interestingly, the Japanese Navy had developed the high-powered magnetron independently and its first microwave radar, the Mark II Model 2 operating on frequencies around 3,000 MHz, was undergoing testing on the battleship *Hyuga*. The Navy was also working on a surface-search radar for installation in aircraft, though this was not yet ready for production.

The Japanese Army had developed its own ground early-warning radar, the *Tachi-6*, which operated on single frequencies in the 68–80 MHz band. At this time the Army had no radars in service for searchlight or anti-aircraft fire-control. Yet at least one example of the American SCR-268 fire-control radar had been captured on the Philippines, and documents on the British 'Elsie' searchlight-control radar had been found at Singapore. Operational radars based on these equipments were under development, though none was yet ready for service.

Mention should also be made of the Japanese Army's Type A Detector system, which was widely deployed. Strictly speaking this was not a radar, but an electronic interference detection system. The transmitter radiated a continuous wave signal on frequencies between 40 and 80 MHz, at powers up to 400 Watts. The receiver was located several scores of miles away, and when aircraft flew between it and the transmitter that produced an interference pattern on the receiver screen. The device indicated the presence of aircraft flying between the transmitter and the receiver, but little else. It gave no reliable information on range, altitude, heading or the number of aircraft present. The greatest distance between a pair of Type A Detectors was more than 400 miles, between Formosa and Shanghai.

* * *

The chance capture of the early-warning radar on Guadalcanal caused a flurry of excitement at the RRL, and pointed to the urgent need to mount an Elint search effort in the Pacific theatre. If that radar had been sent to such an outlying point in Japanese-held territory, it seemed likely that radars were deployed in some numbers. As in Europe, the effort to counter the Japanese radars could not begin until there was a reasonably clear picture of the types, the numbers, the locations and capabilities of Japanese sets.

That requirement was easier to state than to achieve, however. Not only did the US forces possess no equipment capable of achieving this end, but the distances involved were vastly greater than those their British counterparts had faced when looking for German radars in Europe.

To meet the new need, technicians at the Naval Research Laboratory at Anacostia designed and built a small batch of intercept receivers suitable for installation in aircraft or ships. Designated the XARD, this equipment covered the spectrum roughly from 50–1,000 MHz. Six enlisted Navy radiomen received a hasty training in the operation of the device, and were sent to Hawaii to begin the search. A few Army SCR-587 search receivers were also sent out to the theatre.

In October 1942 the submarine USS *Drum* arrived on a war patrol off the east coast of Japan, where she sank three freighters. The submarine's primary mission was to seek and destroy Japanese shipping, and it took no special action to search for radar signals.

Yet the radioman logged signals from a small number of radar sets on the Japanese Home Islands.

At about the same time, a B-17E Flying Fortress fitted with the XARD equipment flew a series of Elint missions from the island of Espiritu Santo in the South Pacific. It conducted the search for radar signals over the Japanese-occupied areas on Guadalcanal and Bougainville. The operator failed to find any, though it is not known whether this was due to the novelty of the equipment or because there were none present.

* * *

In an effort to bring the US Army Air Force Elint reconnaissance effort on a more sound footing, in the autumn of 1942 that service established a countermeasures course for aircrew officers at Boca Raton in Florida. Those sent on the course had all qualified as airborne radar operators. The new course provided students with a theoretical background to the subject and included instruction in operating the SCR-587 receiver on the bench.

Soon afterwards, work began on a crash programme to modify a B-24 Liberator bomber for the 'ferret' Elint collection role. The work took place at Wright Field, Ohio, and Lieutenant Ralph Clark from the Naval Research Laboratory was one of those summoned to assist. He later recalled:

> Around Christmas 1942 a crash-program at Wright Field fitted a B-24 with the necessary receivers for a radar search of the Aleutians. I spent a week at Wright as we [the Navy and NRL] supplied most of the equipment. As well as an SCR-587 modified to tune down to 30 MHz, we fitted a Hallicrafters commercial receiver [an S.27], homing antennas and a breadboard model of a pulse analyser built by the Naval Research Laboratory.

While work was in progress on the aircraft, there was a further development in the countermeasures war in the Pacific. Following a reconnaissance of the Japanese-occupied island of Kiska in the Aleutian Islands in the North Pacific, a US aircraft returned with photographs of a pair of unusual structures at one of the enemy positions. It was thought the 'structures' might be radar sets. Here was an obvious target for the Liberator ferret.

Two officers who had graduated from the first Boca Raton countermeasures course, Lieutenants Ed Tietz and Bill Praun, were assigned to the crew of the ferret. Early in January 1943 the modification work was complete, and the two operators tested their receivers against radars along the west of the USA. At the beginning of February the B-24 flew to Adak in the Aleutians, its base for the planned Elint operations. But then the weather closed in, and for much of the month that followed air operations were impossible.

On the morning of 6 March 1943 the ferret B-24 took off from Adak and headed eastwards towards Kiska. Manning their intercept receivers, Tietz and Praun picked up the signals they were looking for. Tietz remembered:

> We heard the signals in our earphones of a 100 MHz radar scanning at a steady rate. They sounded just like the signals from the search radars I had listened to during our training flights over the USA. No different at all.

During the flight the operators logged signals from two Japanese radars close together in the frequency spectrum; these were Navy Mark I Model 1 sets similar to the one captured on Guadalcanal. Having measured the radars' frequencies, Tietz and Praun used a primitive analyser to determine the pulse width and repetition frequency of the signals. Then the crew set out to measure the volume of coverage of the sets during a series of circuits around the island at different altitudes. The operators noted where the Japanese radar signals faded out and faded in, and passed this information to the navigator who plotted them to show the 'holes' in the radar cover. It was a thoroughly professional effort. That initial ferret mission lasted about five hours, nearly half of which was spent in circling Kiska.

Further missions on 7 and 15 March served to refine the picture of the Kiska radars' coverage. During one flight the B-24 extended its search to the Japanese-held islands of Attu and Agattu to the west of Kiska. It picked up no radar signals from either island. The only contact with the Japanese was during the 7 March mission, when a floatplane followed the ferret at a respectful distance for several minutes, then broke away.

A follow-up bombing attack on the Kiska radars put both out of action for a time, but Japanese engineers effected repairs and the sets came back on the air.

Following its initial programme of missions over the Aleutian Islands, the ferret B-24 returned to Wright Field. Tietz and Praun reported their findings at the Pentagon, then went to the Radiation Laboratory and Radio Research Laboratory for further debriefings.

* * *

Despite these efforts, by the spring of 1943 the US forces still had only sparse information on Japanese radar. One Mark I Model 1 early-warning set had been captured on Guadalcanal, two had been located on Kiska and one more had been detected on Wake Island. In addition, there was a smattering of information on some unidentified radars on the Japanese Home Islands. Although a start had been made to Elint operations, there was a long way to go before there was a detailed picture of Japanese work in this field.

In the meantime, events in the European theatre were moving ahead rapidly and we shall now examine these.

Chapter 6

Doubts and Decisions

> 'We must be perfectly clear about the fact that the enemy is making every effort to outstrip us in the field of high-frequency technique and its operational employment. We must, therefore, pit all our technical and productive power against him, so as not to allow his tricks to become effective.'
>
> Dr Mögel of the Reichspost, in a lecture to Luftwaffe signals specialists, February 1943

As we have seen, the RAF's first attempt to strike at the Luftwaffe early-warning radar chain had centred on the use of the 'Moonshine' spoofing device. Yet, for technical reasons, this device could support only daylight attacks. To aid the night raiders Dr Cockburn and his team had also developed the 'Mandrel' equipment to jam, rather than spoof, the German radar. 'Mandrel' transmitted on spot frequencies in the *Freya* band, which then ran from 120–130 MHz. In the summer of 1942 'Mandrel' was rushed into production, and by the end of November there were sufficient sets available to allow the device to be used in action.

Initially the radar-jamming attack was aimed at the chain of *Freya* and the derived *Mammut* and *Wassermann* equipments, which all operated in the same part of the frequency spectrum. Nine Defiant aircraft of No. 515 Squadron, now modified to carry a 'Mandrel' instead of a 'Moonshine', were to orbit at points some fifty miles off the enemy coast. When their jammers came on, it was hoped they would 'take out' a 200-mile wide swathe of the German early-warning cover. To deal with the inland *Freya*s, used for directing the narrow-beam Giant *Würzburg* radars on to their targets, two bombers in each main force squadron carried a 'Mandrel' jammer. It was anticipated that these aircraft, distributed throughout the bomber stream, would slow the operation of Kammhuber's fighter-control system sufficiently to allow more bombers to cross the defensive line without being intercepted.

To slow the defences further, the bombers were now also able to jam the ground-to-air radio communications which played such a vital part in the interception process. Each RAF bomber carried the 'Tinsel' modification to its high-frequency communications transmitter. The device was crude but effective. In each bomber the wireless operator swept his receiver over his allocated frequencies until he heard a radio transmission in German. He then back-tuned his transmitter to that frequency, switched on a microphone installed in the bomber's noisy engine bay, and transmitted the engine noises on the German channel.

RAF Bomber Command's jamming offensive against Kammhuber's defensive system began on 6 December 1942, when 272 bombers set out to attack Mannheim. On that first night the jamming achieved considerable surprise effect. The Luftwaffe night-fighter force's official diarist noted: 'Heavy jamming of *Freya*. It was nearly impossible to control the night-fighters.' As hoped, the twin-pronged attack on the defences slowed interceptions to such an extent that many bombers had passed out of range of the Giant *Würzburg* radars before the night-fighters could establish firm contacts with their own radar. That night Bomber Command lost nine aircraft, 3.3 per cent of the attacking force. It was a significantly lower loss rate than usual at this time.

However, once the initial shock of 'Mandrel' had passed, the Luftwaffe radar operators became used to its effects. And, as professionals will, they devised various ways of avoiding the effects of the jamming. The simplest way was to 'de-tune' the radar by a small amount away from the jamming frequency. That was only a temporary palliative, but it enabled the operators to see through some of the jamming.

The more effective way to reduce the effect of 'Mandrel' was to modify the *Freya*, *Mammut* and *Wassermann* sets to operate on a rather wider spread of frequencies than before. Originally these radars had operated in the band 120–130 MHz; soon this stretched from 107–158 MHz. Since a single 'Mandrel' was effective over only a 10-MHz-wide band of frequencies, for a given number of jammers the power radiated on any one frequency was considerably reduced.

A further problem developed when bomber crews feared that German night-fighters might home on to the 'Mandrel' emissions.

To prevent that, 'Mandrels' were modified to radiate noise in two-minute blocks, separated by two minutes of silence. That made homing difficult, but it also reduced the strength of the jamming still further since at any time only about half the 'Mandrels' were transmitting.

By April 1943, the Luftwaffe had overcome the worst effects of the 'Mandrel' jamming, and RAF losses started to rise. Operating on the new spread of frequencies, the Luftwaffe early-warning radars were able to see through the 'Mandrel' screen with relative ease. The small Defiant aircraft lacked the room to carry additional jammers, so the operation of the screen was discontinued for a while.

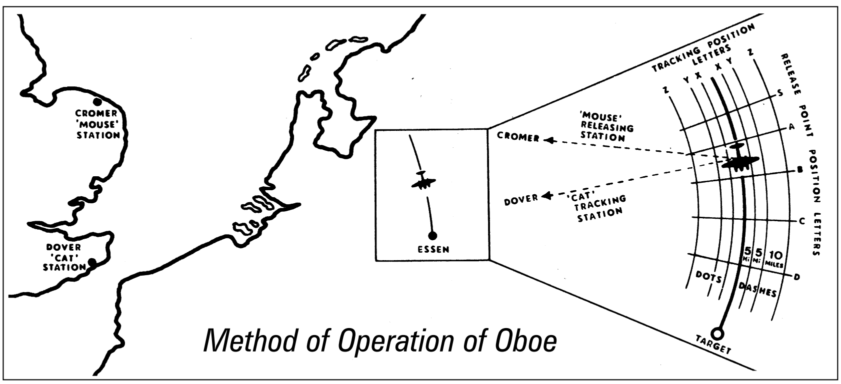
The 'Tinsel' noise jamming of the night-fighters' radio frequencies had a more lasting success. It caused much confusion, and those bomber wireless operators who understood German reported hearing lengthy repetitions of orders and signs of growing irritation. The immediate reaction to the jamming was to introduce higher-powered ground transmitters, to make it easier for crews to hear their orders above the jamming. Then RAF monitors heard the instructions to night-fighters being transmitted on frequencies in the 38–42 MHz band, a part of the spectrum previously used only by day-fighters. To avoid the noise jamming, night-fighters now carried an additional radio set. The older high-frequency sets continued in use, however, and for the rest of war the RAF bombers would continue to jam them.

There was an important lesson to be learned from the 'Mandrel' and 'Tinsel' episodes, a lesson to be borne in mind whenever one considers the value of jamming. In electronic warfare, victories are relative and never absolute. Enemy systems, both defensive and offensive, may be hampered or delayed for a while, but they can never be absolutely confounded. Given time, a resolute enemy will introduce new equipments or modifications to the old ones that can avoid much of the jamming. The two simple jamming systems, 'Mandrel' and 'Tinsel', had achieved a relative success for a few months. At small cost, they had forced the Luftwaffe to modify most of its early-warning radars to cover new frequencies, and to fit new radios to its night-fighters. Robert Cockburn's dictum, that 'a shilling's worth of countermeasures will mess up a pound's worth of radio equipment' had been proved correct. Some months of confusion and anxiety had been inflicted on the Germans, and about a hundred RAF bombers and their crews had been saved from the end they would otherwise have met.

* * *

While all this was happening, work at TRE was advancing rapidly on two new radar devices which bode fair to bring about a considerable improvement in the accuracy of Bomber Command's attacks at night or through cloud.

The first of these devices, code-named 'Oboe', exploited the fact that radar can measure the distance of an object to within fine limits, and that accuracy does not diminish with range. The system employed two radar-type transmitters on the ground, one situated at Dover and the other near Cromer. Each transmitter sent pulses to the aircraft, on a different frequency. At the aircraft the pulses triggered a special transmitter, a transponder, which sent out reply pulses. In that way the operators at the Dover transmitting station could measure the exact distance to the aircraft in the normal radar way. They then broadcast instructions to the pilot to fly along an exactly circular path, centred on the Dover transmitter and passing over the bomb-release point. The second transmitter, at Cromer, used the same method to track the progress of the aircraft as it headed towards its target. When the Cromer station observed the aircraft to be at the previously computed bomb-release point, it radioed the 'bomb-release' signal.



Method of Operation of Oboe

'Oboe' suffered from two major limitations. First, its maximum range was determined by the curvature of the earth. A bomber flying at 28,000 feet could use the system only out to a maximum of 270 miles from the more distant transmitter. Secondly, a pair of ground transmitters could control only one aircraft at a time. Yet the system atoned for these deficiencies by bringing a major advantage: the bombing it controlled was, by the standards of the day, extremely accurate.

Although the 270-mile maximum range ruled out the use of the system over much of Germany, the coverage of 'Oboe' took in the entire Ruhr industrial area which contained many valuable targets. The limit to the number of bombers that could use the system meant that it was best employed by Bomber Command's new Pathfinder Force. This had come into being in August 1942 to emulate, and it was hoped improve on, the methods used by Kampfgruppe 100 of the Luftwaffe during the night Blitz on Britain.

The second of the new radar systems developed by TRE to help improve the RAF's bombing accuracy was code-named H2S. This ground-mapping radar employed many innovative features. The heart of the system was the high-powered magnetron power source, which generated 10 kW pulses on the extremely high frequency – for those days – of 3,000 MHz. That frequency equated to a wavelength of about 10 centimetres, and accordingly radars working on these wavelengths were known as 'centimetric' equipments. During the early flight trials with centimetric radars, operators had noted that echoes from the ground came most strongly from built-up areas, less strongly from open land and least strongly from a calm sea. The great majority of Bomber Command's targets were, of course, 'built-up areas'. The radar echoes were displayed on a cathode-ray tube in such a way that the sweeping radar trace sketched out a passable representation of the surrounding countryside, just like a map.

H2S was independent of beams, beacons or ground transmitters of any kind. So, in effect, its range was limited only by the range of the aircraft itself. Such a radar could go a long way towards solving Bomber Command's most pressing problems, since it could be used by Pathfinder aircraft to locate and mark targets that were beyond the range of 'Oboe'.

The novelty and success of the ultra-secret magnetron that powered H2S raised an important question, however: what would happen if the Germans captured one? If they copied its design and incorporated it in their own centimetric radar for night-fighters, their defences might enjoy increased success against the British night raiders. One way to prevent a magnetron from falling intact into German hands would be to fit it with a demolition device, as had worked well for a time with 'Gee'. Yet the main body of the magnetron comprised a hefty a block of copper, with a labyrinth of cavities machined out of it. The primary difference between previous, low-powered magnetrons and the secret one was the manner in which those cavities were inter-connected, and that could not easily be camouflaged.

Explosives experts at Farnborough devoted considerable thought to fitting a destructor to the magnetron block, that would detonate and render the block and the system of connections unrecognisable. They calculated that a two-ounce explosive charge, held in contact with the block, would be sufficient and, during a test using the fuselage of a captured Ju 88 as 'guinea pig', the destructor successfully blew a 10-foot-long hole in the fuselage. Yet, even after that powerful explosion, it was still possible to determine the working of the magnetron from the fragments. Another idea was to use explosives to eject the magnetron from the aircraft, then blow it to pieces in mid-air using a second charge. That method was found to be too violent to merit further consideration; the recoil forces from the first charge were so fierce that they threatened to break up an aircraft in flight. The use of powerful acids was also considered, but that was also dismissed as impracticable. In the end, all idea of installing a demolition charge to the magnetron was abandoned.

In the end the offensive spirit won the day; despite the possible dangers, Bomber Command's Pathfinder Force had to have H2S. During the latter part of 1942, the radar went into production at high priority. Once it was used in operations over hostile territory, sooner or later an intact example of the precious magnetron would fall into German hands.

* * *

Early in 1943 two devices entered service to provide bomber crews with warning of an impending attack; these were code-named 'Monica' and 'Boozer'. 'Monica' was a tail-warning radar, designed to give warning of any aircraft entering the 45-degree-wide cone extending a thousand yards behind the bomber. When that happened, the device sounded a series of bleeps into the crew's earphones. As the range closed, the rate of the bleeps increased.

'Monica' gained immediate unpopularity with bomber crews, however, because of the frequency of the false alarms it generated. The device could not distinguish a friendly bomber from a hostile night-fighter, and as bomber streams became ever more concentrated the problem of false alarms became ever more serious. As a result many bomber crews flew with the device turned off.

The second of the warning devices, 'Boozer' was a passive device, consisting of a radar-type receiver tuned to the frequencies of the *Würzburg* gun-laying radar and also the *Lichtenstein* night-fighter radar. 'Boozer' produced no false alarms. When the aircraft was in the invisible beam of a gun-laying radar, an orange light illuminated on the pilot's instrument panel. If, on the other hand, a night-fighter radar was looking at the bomber, a red warning light illuminated. Even this system had its drawbacks, however. When the aircraft flew over a defended area the *Würzburg* warnings came on too frequently to be of value; and the device gave no warning of the approach of night-fighters that had no radar, or which had their radar turned off. If the red lamp went out, it might also mean that the night-fighter had closed to within visual range, and had its radar switched off as it moved in to make its attack.

* * *

In November 1942 Göring had appointed Dr Hans Plendl, the radio expert who had devised each of the bombing-beam systems used against Britain, as his Plenipotentiary for High-Frequency Research. That put him in overall charge of the radar development programme. Yet, as Plendl took up his new commission, it was a depressing picture that confronted him. Germany had only about one-tenth of her enemies' radar research capacity, and that was scattered across a hundred minor institutes and organisations that worked independently and often in competition with each other. Plendl's first action was to secure a Hitler Order recalling 1,500 scientists from the armed services. He then concentrated his available resources at a small number of specially established research centres.

Plendl's moves were in the right direction, yet they were too little and they came too late. There was an enormous amount of leeway to make up, and his enemies were not resting on their laurels. In the next chapter we shall observe progress being made on the most effective radar countermeasure to appear so far.

Chapter 7

The 'Window' Controversy

> 'Though deception in other activities be detestable, in the management of war it is laudable and glorious, and he who overcomes the enemy by deception is as much to be praised as he who does so by force.'
>
> Niccolò Machiavelli

The developments described in the previous chapter left unjammed the important *Würzburg* and Giant *Würzburg* radars used by the Luftwaffe to direct anti-aircraft guns and night-fighters, respectively. That was not to say that no consideration had been given to countering these systems, for that had given rise to one of the most controversial episodes of all. The idea of dropping large numbers of metal strips to saturate radar screens had been mooted in Britain as a theoretical possibility before the war. And it had popped up from time to time since.

In 1940, during the *Knickebein* scare, Professor Lindemann had suggested that, by dropping metallic strips to one side of a beam, it might be possible to push the beam away from the target. Dr Cockburn was able to prove with a sum 'on the back of an envelope' that the idea would not work. To collect enough energy for the system to have that effect, the strips would have to be released in the centre of the beam; but there they would produce no deflection at all.

In the summer of 1941, one RAF unit actually used the countermeasure over North Africa. That September a Wellington bomber of No. 148 Squadron had flown radio-investigation sorties over the German positions, carrying a naval search receiver with an unusual aerial arrangement. To their discomfort, the crew found that enemy AA gunners singled them out as a target even when there were other aircraft in the vicinity. The crew speculated that perhaps the Wellington's additional aerials produced an enlarged echo on the German radar screens. One night they tried dropping bundles of aluminium strips 18 inches long and an inch wide – the size of the aerial elements fitted to the investigation aircraft. Dropping the strips gave no relief from the AA fire, however, and the idea died a natural death. Possibly those AA guns had been controlled by sound locators, and the wind rushing past the aerials had increased the noise made by that particular aircraft.

Towards the end of 1941 scientists at the Telecommunications Research Establishment began a programme to test the use of metal strips against radar. Now the device received a name. According to Albert Rowe, the Superintendent of the TRE, Dr Cockburn called on him one day to discuss a suitable code-name for the metal strips. Rowe demanded only that the name should bear no relation to the device itself. He later recalled: 'I looked round the room. "Why not call it something like, Window?" I said.' And 'Window' it became.

Joan Curran, a member of Cockburn's team, conducted the initial trials with the device. She began by looking for the shape of foil that produced the largest radar echo, for the lightest amount of foil. At first she tried copper foil cut into various forms, but it soon became clear that such complications were unnecessary – simple oblongs with one dimension cut to about half the wavelength of the radar gave the best results. Curran also found that the best material for the purpose was the tinfoil used in the manufacture of radio-condensers.

By March 1942, Curran's initial technical investigation was complete. In the course of seventeen flights, she had observed the effect of 'Window' on British radars operating on a frequency of 200 MHz or greater. In her report she stated:

> It has been demonstrated that for frequencies of the order of 200 megacycles or more, echoes can be produced by jettisoning material from an aircraft, and that the quantities of material necessary to give rise to an echo equal in magnitude to that of the aircraft are not in any way excessive.

She noted that a bundle of 40 sheets measuring 8½ inches by 5½ inches produced an echo approximating to that from a Blenheim bomber, on the new British Type 11 ground radar. Significantly the Type 11 operated on 500 MHz, a frequency close to that of the German *Würzburg*. The effect of the foil lasted for about fifteen minutes if the bundle was released from about 10,000 feet. Ten such 'Window' clouds spread out over a mile would saturate the radar screen, making it virtually impossible to pick out the echoes from aircraft in the area.

During the initial TRE trials, scientists were asked to consider ways of concealing the true purpose of the 'Window', should the material fall into German hands. One idea was to sandwich the metal foil between two sheets of paper to disguise it as a propaganda leaflet. That idea did not survive long, however. If the tactic were as successful as Joan Curran's tests indicated, the Germans would realise soon enough the cause of their discomfort.

In April 1942 the Chief of Air Staff, Sir Charles Portal, ruled that the C-in-C Bomber Command was at liberty to use 'Window' to support his operations as he thought fit. The Vanesta Company received a large order to manufacture the strips. Due to the shortage of tin foil, aluminium foil was to be used instead and that worked just as well. At the same time Bomber Command's operational research section worked out suitable tactics for using the strips. Since each aircraft would carry only a limited quantity of foil, its use was to be confined to the target area.

Vanesta delivered the first consignment of 'Window' to Bomber Command early in May 1942, in time for the thousand-bomber raid on Cologne planned for the end of the month. Shortly before the consignment arrived, however, the portcullis slammed down. Air Marshal Portal withdrew permission for Bomber Command to use the countermeasure, pending further trials. Lord Cherwell (as Professor Lindemann had now become) had instigated the change. He felt that the trials of 'Window' against British radars had not been sufficiently comprehensive, and there might be serious problems if the Luftwaffe retaliated in kind. He therefore prevailed upon Portal to delay the introduction of this countermeasure, pending a more comprehensive series of trials against the range of British radars.

On Cherwell's insistence, the second series of 'Window' trials was conducted by a protégé of his, Dr Derek Jackson. Jackson had studied under the then Professor Lindemann at Oxford before the war, and had himself become a don and an acknowledged expert on spectroscopy. His father owned the *News of the World* and he had enjoyed life to the full. In 1935 he had ridden his own horse in the Grand National. When war came, Jackson had joined the RAF where he gained a reputation as a skilful night-fighter radar operator and now held the rank of flight lieutenant. Jackson's important asset was his ability to bridge the difficult gap between the scientist and the operational aircrewman.

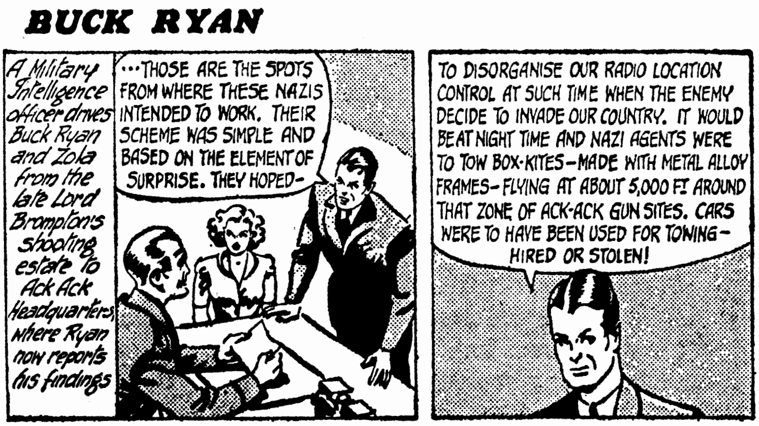
Derek Jackson used the airfield at Coltishall near Norwich as a base for his 'Window' trials which, to preserve secrecy, took place over the sea. Within a few days his initial trials were complete, and the results were ominous. The RAF's latest centimetric-wavelength radar for night-fighters, the AI Mark VII, suffered severely if there were 'Window' clouds present. The older AI Mark IV, which operated on 200 MHz, was also affected though to a lesser degree. Importantly, the tests revealed that the older types of radar working on lower frequencies (and therefore longer wavelengths) were less susceptible to 'Window' than the later sets working on the higher frequencies.

Lord Cherwell, supported by the C-in-C Fighter Command, Sir Sholto Douglas, and the Scientific Advisor on Communications, Sir Robert Watson Watt, formed a powerful lobby to maintain the prohibition on the use of 'Window' until the RAF possessed an effective antidote. At the same time, however, Watson Watt recommended that preparations to use the countermeasure be completed as soon as possible, in case the Luftwaffe used it in action first.

On 18 June 1942, Lord Cherwell discussed the 'Window' dilemma with Air Commodore Lywood, the RAF's Director of Signals. Cherwell said he would withdraw his objections, if some form of self-destroying tinfoil strip could be produced. Yet he accepted that there might be considerable difficulties in producing such a strip. Moreover, as soon as a bomber crashed in enemy territory carrying undestroyed 'Window', the secret would be out. And secrecy was the prime consideration.

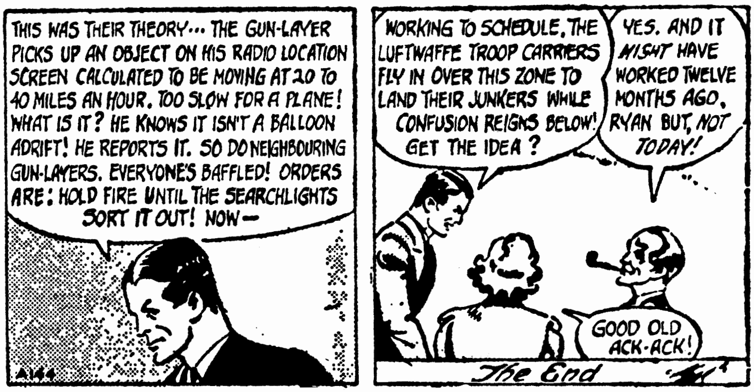
Ironically, even as Cherwell and Lywood were in conference, news-stands throughout Britain were selling a reasonably good working description of the 'Window' principle. In that morning's *Daily Mirror* the cartoon detective Buck Ryan yet again saved the country from downfall. The climax of the latest story line was that Nazi agents had planned to neutralise British 'radio location devices' by towing metal-framed box-kites around past selected AA gun sites. While the baffled gunners tried to discover what was happening, enemy troop-carrying aircraft were to sneak in and land their men.

As Buck Ryan finished his explanation of this latest piece of Nazi devilment, an army 'intelligence officer' congratulated him 'Yes, and it *might* have worked twelve months ago, Ryan. But *not today*!' How wrong he was. The next day Lywood sent a clipping of the offending cartoon to Lord Cherwell, with a covering letter: 'I don't know whether the Hun is a subscriber to the *Daily Mirror*. If, as I suspect, he is, the attached cutting seems a fairly good investment in basic ideas.'



The security service investigated the matter, though it did so with subtlety. Questioned much later by the author, the cartoon-strip's creator, Jack Monk, remembered only one unusual occurrence at the time. Soon after that cartoon strip was published, the *Daily Mirror* received instructions to send engravers' proofs of all cartoons to the Ministry of Information for censorship. No one could think why. The fact that Monk held no scientific qualification highlights the essential simplicity of the 'Window' idea. He had thought up the story unaided, and had no inkling of its wider implications.

In Britain the debate on when to use the countermeasure in action raged on. Sir Charles Portal and Lord Cherwell backed the line that the material should not be used until there was an antidote or the Germans used it first. On the other side of the argument, Bomber Command led a powerful lobby which argued for an earlier introduction of 'Window'. Air Vice-Marshal Sir Norman Bottomley, the Deputy Chief of Air Staff, supported the Bomber Command view, and said it should be used as soon as sufficient material had been manufactured. In his opinion, the RAF should exploit its available tactics while it could. He thought it unlikely that the Luftwaffe could retaliate before the winter of 1942, and by then the sought-after antidote to 'Window' might exist. Dr Robert Cockburn, head of the TRE jamming section at Malvern, also pressed for the early use of 'Window'. He believed that the *Würzburg* was the kingpin of the German air-defence system. In a paper which he circulated at this time, he drew attention to the results of ferret flights undertaken by Wellingtons of No. 109 Squadron:



> Every 109 Squadron investigation aircraft on any flight near or over enemy territory has been continuously held by two or three 53-centimetre [570 MHz, the *Würzburg* frequency] beams. It is an obvious inference that all aircraft operating over enemy territory are followed by 53-centimetre beams.
>
> From the serial numbers of captured equipment and from other data, it is almost certain that this equipment exists in hundreds.
>
> The known characteristics of the 53-centimetre equipment are such as to allow operation as an SLC [searchlight-control], GL [gun-laying] or GCI [ground-controlled-interception] radar.
>
> Positive proof of its use as an SLC and a GL has been obtained by 109 Squadron aircraft. It is perhaps relevant to mention that five aircraft have been lost during this investigation.

Cockburn concluded that if, as seemed certain, the *Würzburg* was the key to the night air-defence system, neutralising that particular radar would bring about a significant reduction in Bomber Command's losses.

In July 1942, Sholto Douglas received the results of the trials using 'Window' against each of the main types of airborne and ground radar used by Britain's defences. Strips of the correct length, about half a wavelength long, had been effective against every one of them. Moreover, Derek Jackson and other experienced radar operators expressed the view that no amount of operator practice would improve the position.

Sir Charles Portal wrote to Douglas about the serious dilemma the trials had created. On the one hand, it was possible to assume that the 'Window' idea had not occurred to the Germans. Yet on the other hand it was equally possible that they had the idea, but shrank from using it while the RAF bomber strength was the greater in the West. There was also a danger that the act of training Fighter Command operators to work in face of 'Window' jamming might compromise the secret.

On 21 July, Portal called a meeting to air the whole question. Sir Robert Watson Watt, Air Vice-Marshal F. F. Inglis (Assistant Chief of Air Staff, Intelligence), Lord Cherwell, Dr Jones and Sir Sholto Douglas were among the attendees. R. V. Jones supported the early use of 'Window', and submitted that the idea was so simple that it was unlikely that the Germans had not thought of it. It was even possible that the Luftwaffe had already stockpiled the material for operational use, waiting until there was a resumption of large-scale attacks on England. Lord Cherwell disagreed, expressing the view that the Germans had not thought of the device. He said it was important to conceal the fact that Fighter Command was conducting trials with the tinfoil strips. As one could never kill rumours completely, he thought an effective step would be to circulate a counter-rumour that the RAF had tried the strips but had found them to be ineffective. Air Vice-Marshal Inglis was instructed to take the necessary action.

The Chief of Air Staff summarised these decisions in a paper circulated on 30 July. He said the trials had produced sufficient evidence to show that it would be inadvisable to use 'Window' until the British had a radar system with a degree of immunity to it – always assuming that the Luftwaffe did not use it first. He had asked the C-in-C Fighter Command, Sholto Douglas, to press the development of night-interception tactics which did not rely on radar. He also asked for an investigation into whether a more efficient type of sound-locator could be produced, to back the radar network. For the present, he decreed that 'Window' should not be used over Germany. The position would be reviewed in three months time, in the following November.

Shortly before the November meeting, Jones received a vague report which suggested the Germans were working on a device similar to 'Window'. During a train journey, a Danish agent had overheard a conversation by a couple of Luftwaffe women auxiliaries. One said she worked at a night-fighter control station and made an obvious reference to radar – a detector able to 'see' the metal in an aircraft even in darkness. The woman went on to relate how, on one occasion, a British bomber flying over the Rhineland had deceived the 'detectors' by dropping 'aluminium dust'. Jones did not think the agent could have made the story up – such people had not proved good inventors in the past. Nor was it likely that German intelligence had anything to gain by gratuitously presenting the British with the 'Window' principle. In his view the woman had repeated a garbled account of Luftwaffe trials with the device.

Jones called on Lord Cherwell to discuss the report on the evening of 3 November, the day before the next top-level meeting on 'Window'. Cherwell's objection to the use of 'Window' by Bomber Command had centred on the belief that the Luftwaffe had not thought of it. Now it seemed that they had. Jones said he had no wish to see his old professor appear in a false position at the conference. Would he change his mind? Cherwell would have none of it. He said, not unreasonably, that it would be silly to change Air Staff policy on the basis of something someone had said on a German train. As Jones was leaving, Cherwell fired a parting shot in his direction: 'If you go into the meeting and try to get "Window" used, you'll find me and Tizard united against you.' Jones, knowing the barrier of mutual distrust and enmity that existed between Cherwell and Sir Henry Tizard, could not resist the retort: 'Well, if I've achieved that, by God I've achieved something!' The pair parted in laughter.

At Sir Charles Portal's conference on the following day Derek Jackson – now a Wing Commander – described in detail how best to use 'Window' to defeat the German radars. He also described ways to make the British radars less vulnerable to the counter-measure. Jackson reported that the latest British night-fighter radar, the AI Mark IX, had an automatic target-following device which should make it easier to distinguish between aircraft and 'Window' echoes. The prototype was due to fly soon and it could be in service by mid-1943. There was also a new American night-fighter radar, the SCR-720, which employed a novel system of scanning and display designed to allow it to work in the face of 'Window'. One such set was expected to arrive in Britain soon. There was also a new GCI radar, the Type 11 operating on a frequency of 500 MHz. Although this set had no special anti-jamming circuitry, it could be used in an 'anti-Window' role as it was being kept in reserve so the Germans would not learn of its existence. Six Type 11s had been delivered, and forty more of an improved model were being produced. The investigation into improved methods of sound location of aircraft had produced nothing of use, however.

At that point of the meeting, it seemed to Jones that the stage was set for permission to use 'Window' soon over Germany. But then came a surprise change in Bomber Command's official attitude. Unexpectedly Air Vice-Marshal Saundby, representing the command at the meeting, did not press for its early use. He later explained that he believed there would be only a limited number of countermeasures 'tricks' the force could use against the enemy. Once these had been exhausted, there would be nothing left. No single trick was likely to keep the Luftwaffe 'on the hop' for long. In Saundby's view there was a lot to be said for playing out each idea, before moving on to the next one. The 'Mandrel' and 'Tinsel' jammers were about to come into use, and he thought 'Window' should wait until the Luftwaffe had mastered the earlier countermeasures.

The decision of the meeting was, yet again, to withhold the use of 'Window' for the present. Fighter Command was to push ahead with experiments to counter any German use of the device, and evaluate the effectiveness of the new night-fighter radars. For its part, Bomber Command was to complete its preparations so that it could use the countermeasure at short notice. Sir Charles Portal said that he would review the matter in a few months' time.

In December 1942 the first example of the American SCR-720 night-fighter radar, arrived in Britain. The radar was installed in the nose of a Wellington bomber, to test its abilities in the face of 'Window'. The trials revealed that the new radar had a significant capability in this respect. The system of scanning and presentation allowed the radar operator to distinguish between the clouds of foil, and the aircraft that released them. When an aircraft released a bundle of early-type 'Window', the strips took about 10 seconds to blossom into a cloud giving an aircraft-sized echo. In that time the aircraft advanced by about half a mile. To exploit that factor, the SCR-720 had two screens. On one screen the operator viewed the air picture in range and azimuth in plan, with the hostile aircraft flying at the head of the 'Window' clouds. The second screen depicted a thin vertical slice of sky, and at the turn of a knob the operator could move that 'slice of sky' until its range coincided with the range of the target aircraft. By holding the target aircraft on the second screen in this way, the radar operator could disregard the clouds of foil blossoming behind it.

Manufactured by the Western Electric Company, the new American radar was redesignated the AI Mark X and ordered in quantity for the RAF. The first batch of production sets was due to arrive in Britain in July 1943.

* * *

Also at this time, the RRL at Harvard came up with an important contribution regarding the efficiency of 'Window'. Until now the British work on the countermeasure had all been experimental. At Dr Terman's request, the distinguished antenna expert Dr L. J. Chu conducted a theoretical study into the electrical behaviour of the dipoles during their fall. The famous astronomer Fred Whipple, recently recruited into the RRL, examined Chu's report and made an observation that would have considerable significance: that for a given weight of material, a larger number of narrow strips would be much more effective than a smaller number of wider strips.

At the time Terman could not conduct flight trials to confirm Whipple's findings, due to an ill-advised security clampdown on the testing of the foil strips in the USA. So Terman passed details of the findings to Cockburn who immediately arranged for tests to be made with the thin resonant strips. The new trials verified Whipple's conclusions, and the RAF placed a large order for thin strips cut to half the wavelength of the *Würzburg* radar. As these strips left the factories they joined the stockpile, ready for use when were needed.

* * *

In contrast to the long-running debates on 'Window' taking place in Great Britain and the USA, in Germany there was no comparable discussion. Although the early history of the countermeasure was similar in all three countries, the resultant decisions that were taken were quite different. During 1942 the Luftwaffe conducted trials over the Baltic, dropping bundles of foil strips while the effect was observed on various types of radar. There the device was known as *Düppel* (dipole), and signals experts gained the same impression as their British counterparts – the countermeasure could be devastatingly effective in preventing the tracking of aircraft by precision radars.

Generalmajor Wolfgang Martini, head of the Luftwaffe signals service, presented a report on the trials to Reichsmarschall Hermann Göring stressing the grave danger that might arise if RAF planes dropped the strips in quantity during attacks on Germany. By all accounts, Göring was horrified when he saw the report. He directed Martini to destroy every copy of the document, and ordered stringent precautions to prevent any leakage of information on the *Düppel* trials. Experiments with the strips were to cease immediately, even those directed at producing an antidote to the countermeasure. Göring had taken the decision and given his orders and, so far as he was concerned, that was the end of the matter. Later, Martini commented:

> It was thus extremely difficult to work out countermeasures because we dared not experiment with the little beasts for fear of their being discovered. Had the wind blown when we dropped the metal strips, people would have picked them up, talked about them, and our secret would have been betrayed.

At all costs, the British had to be prevented from learning of this simple tactic.

Thus, the two sides entered 1943 with clear but contrasting positions regarding the use of 'Window'/*Düppel*. In a later chapter we shall observe the outcome of the decisions they had taken.

Chapter 8

The Pace Hots Up

> 'I expected the British and Americans to be advanced, but frankly I never thought that they would get so far ahead. I did hope that even if we were behind we would at least be in the same race.'
>
> Reichsmarschall Göring, speaking in May 1943

The deliberate jamming of the *Freya* early-warning radar system from December 1942 should have alerted Luftwaffe radar experts that matters were likely to get a lot worse. Yet, when the RAF began this jamming, the initial reaction was one of relief that the British were not jamming *Würzburg* as well. It is hard to understand why they should have nurtured this belief. They knew that *Würzburg* had been the object of a specific – and successful – British combined operation to seize one of these radars. They also knew that they themselves had devised a simple method to render *Würzburg* unworkable – the release of metal foil strips in the radar's beam.

Yet Göring's decree forbidding further discussion or research into the use of *Düppel* introduced a touch of unreality into several high-level meetings at this time. When the possibility of *Würzburg* jamming was raised at a conference of Luftwaffe night-fighter controllers, Josef Kammhuber, now promoted to Generalleutnant, informed the gathering that 'according to a report he had received from the Experimental Station at Werneuchen, such jamming was not possible.' Kammhuber later admitted in private that he knew full well that this statement was untrue. Yet, he had to obey Göring's specific order concerning this type of jamming.

At a conference held in Berlin on 5 January 1943, Generalfeldmarschall Milch, Director General of Air Equipment, inquired whether the Luftwaffe might not develop jamming methods against British radar, similar to those being used by the RAF. Oberst Dietrich Schwenke, the officer heading the Luftwaffe intelligence operation in the West, told him: 'That is basically possible'. But then Oberst Victor von Lossberg, Milch's night-fighter expert, interrupted with a clear reference to Reichsmarschall Göring's edict:

> May I say that this has been discussed with Generalleutnant Martini, and he has urged that all attempts to jam enemy radar should cease for the present, as there is a perfectly simple means of jamming our whole radar system – a means against which we have no counter-measure.

Generalmajor Adolf Galland, Luftwaffe Inspector of Fighters, said that if every RAF aircraft carried a jammer, all he would need was to fit his fighters with homing receivers so they could home on the jamming transmissions. The trouble was, he said, that single aircraft carrying jamming transmitters could disrupt the radar system while the ordinary bombers went on to do their 'dirty work'.

The fact that neither the British nor the Americans had yet started jamming *Würzburg* struck Schwenke as strange, and he said so. 'That is significant inasmuch as we have far fewer *Freya* sets than *Würzburg* sets. The British must know the relationship of our *Freya* sets to our *Würzburg* sets.' Summing up, Generalfeldmarschall Milch said they had to reach a decision about jamming and how to counter it: 'How will our fighter-control system operate in the coming year and the one after that, if we don't put our house in order?'

Two days later, there came further tangible proof that the Luftwaffe was losing its grip on the situation. On 7 January there was a meeting between disturbed air-defence leaders in the Ruhr industrial area, and directors of the Krupp armament works in Essen. For the previous two weeks, individual Mosquito bombers had flown high across the city, going almost from due north to due south, dropping bombs with high precision regardless of the weather conditions. Were the British using some kind of infrared homing device? Or a radio beacon, perhaps planted by agents in the town? Whatever the method, Krupp workers were growing 'uneasy' about these sudden unannounced bombing attacks (to save unnecessary disruption, the sirens did not sound when single aircraft approached). The available evidence seemed to confirm the suspicion that the RAF was using a new method of radio-direction. It was noted that these precision attacks took place only at points within 250 miles of the English coast and German electronics experts confirmed that a Mosquito flying at 30,000 feet could indeed receive signals from transmitters in England at this range.

In fact the RAF had started to use 'Oboe' operationally on the night of 20 December 1942, when six aircraft used it to attack a power station in the Netherlands. During the week that followed, 'Oboe' Mosquitoes had gone out each night, in ones and twos, to test the system's accuracy against pinpoint targets.

* * *

The 'Oboe' raids would not be the only development in target-finding to cause unease to the Luftwaffe High Command early in 1943. By the middle of January ten Halifaxes of No. 35 Squadron and thirteen Stirlings of No. 7 Squadron had been fitted with the H2S ground-mapping radar; both units belonged to the RAF's Pathfinder Force. The new radar was first used operationally on the night of 30/31 January, during an attack on Hamburg.

Now the Luftwaffe leaders were at the dawn of a very rude awakening indeed. During the second attack using H2S, on Cologne on 2/3 February, a night-fighter shot down a Stirling of No. 7 Squadron near Rotterdam in Holland. When German technicians began their routine investigation of the wreckage the next day they found a device completely new to them. The secret of H2S was out. Oberst Schwenke reported the discovery to a high-level conference in Berlin nine days later. An initial examination of the equipment had revealed that the British had built a radar operating on a frequency far higher than the German scientific community had believed possible:

> I have to report that a new device has been found in a Stirling bomber shot down near Rotterdam. It is a centimetric radar device mounted beneath the rear of the fuselage. We have not yet established its exact purpose, but the device is exceedingly expensive. This is the first appearance of a decimetric [i.e. 10 centimetre] apparatus, for hitherto the British have given no hint of much progress in this field . . . Two units are missing from the equipment, out of a total of six or eight.

Generalfeldmarschall Milch asked whether that meant that the units had been lost, and Schwenke replied:

> We salvaged the equipment from an 80 per cent wrecked aircraft. The two missing units [one of which was the display unit with

> the radar screen] were not with the rest of the equipment, but were probably mounted up front with the pilot. For a time Lorenz and other experts believed it was a night-fighter warning set, but it is too complicated for that. It is suspected therefore that it is a night-fighter search- or warning-device, and simultaneously a navigation and target-finding device.

The crew of the night-fighter that shot the bomber down had noticed nothing unusual. Two members of the crew of the Stirling had survived the crash but '. . . both have obstinately and consistently refused to make any kind of statement; this strongly suggests that it is something special.' In addition there was evidence that the set was entering mass-production.

The H2S equipment – code-named *Rotterdam* by the Luftwaffe – went to the Telefunken Company in Berlin for examination. On 22 February, Generalleutnant Martini set up a special *Rotterdam* Commission (*Arbeitsgemeinschaft Rotterdam*) to devise counter-measures. The first session, with Dr Hans Plendl and other experts from industry and the services, took place at the Telefunken works that very day. The awful realisation that the British had made major advances in centimetric radar technique hung heavily over the meeting. Plendl later reported that in Germany even the most basic research into these techniques was in the early stages. Then, to clear his own flank, he added '. . . although German researchers had repeatedly drawn attention to the importance of such work.'

Small wonder, then, that it took several weeks to find out exactly how the new radar worked. Telefunken offered to manufacture six sets on the lines of the captured radar, to serve as prototypes for a mass-production model. At the same time, plans were discussed to build two systems to pick up the H2S signals. One, code-named *Naxos*, was to be a simple detector of centimetric waves. The other, *Korfu*, was a direction-finding receiver.

On 1 March 1943, the precious H2S units salvaged from the Rotterdam crash were destroyed during a heavy attack on Berlin, in which the Telefunken works was badly damaged. Yet, ironically, on that same night a No. 35 Squadron Halifax was brought down over Holland and parts of another H2S set fell into German hands. Again the display unit was not among the components salvaged, however. At a further meeting of the *Rotterdam* Commission three weeks later, attended by about thirty experts, a Luftwaffe official reported that an RAF prisoner had confirmed that H2S was a navigation aid used by the Pathfinder Force for the accurate release of target-marking flares.

On 23 March, Oberst Schwenke told Milch:

> The sets which have fallen into our hands have so far lacked their display unit, that is the unit containing the cathode-ray tube. However, prisoner interrogations have revealed that the device is certainly used to find targets, inasmuch as it depicts the territory over which it flies on a cathode-ray tube. The features of the countryside are shown bright or dark according to the intensity of the echoes: buildings and forests are bright, and all smooth spaces like water, fields, etc., are shown darker.

That indicated that the normal types of camouflage at important industrial targets, or fire decoy sites, would not deceive the device. Schwenke proposed that a special 'anti-*Rotterdam*' countermeasure be developed to produce false radar targets on the ground, perhaps using wire netting.

In the meantime, Telefunken engineers had reassembled the captured H2S equipment inside one of Berlin's huge concrete flak towers. There, safe from attack, its secrets were laid bare. A display system was improvised using German components. The same excitement that had gripped the Farnborough engineers, when they watched their captured *Würzburg* radar work for the first time, was replicated by their German counterparts as they viewed a recognisable representation of the city around the flak tower.

The truth about H2S came as a great shock to German scientists; the magnetron which gave usable power at a frequency they had previously considered unusable, the plan-position indicator form of presentation and the special circuitry for generating extremely narrow pulses – all made a profound impression. For once, even Reichsmarschall Göring was subdued. After reading an initial report on the *Rotterdam* device, he remarked:

> We must frankly admit that in this sphere the British and Americans are far ahead of us. I expected them to be advanced, but frankly I never thought that they would get so far ahead. I did hope that even if we were behind we would at least be in the same race!

* * *

For the Luftwaffe, the mystery of the precision attacks by Mosquitoes on Ruhr targets still remained; H2S seemed too bulky to install in the Mosquito, so the RAF had to have some other system. On 5/6 March 1943, the first heavy raid using 'Oboe' target-marking took place. Again, the target was the Krupp works in Essen. In the past, the Krupp complex had been particularly difficult to find, since it was usually hidden under a thick industrial haze. This night was no exception. Yet the first 'Oboe' Mosquito released its salvo of red target-marker bombs unhampered by the smog. Three minutes later a second Mosquito followed suit, followed seven minutes later by a third and so on throughout the thirty-three minutes of the attack's marking phase. Twenty-two Pathfinder Force heavy bombers then backed up the 'Oboe' marking with green target indicators. The crews of the main force bombers had been briefed that the method of placing the red markers was 'a new and very accurate one'. They were to attack these if possible, otherwise they were to aim at the green markers. At no stage was visual identification of the Krupp factory itself required. The attack was a resounding success for Bomber Command, and the armament works suffered severe damage.

The reader will note that by this stage of the war the RAF's target marking techniques had far outstripped those used by Kampfgruppe 100 over Great Britain in 1940 and 1941. The RAF Pathfinder aircraft carried special marker bombs, which burst with distinctive colours in the air or on the ground, to indicate the relative accuracy of each marking system. Moreover the RAF employed three times more Pathfinders than KGr 100, to renew the marking at regular intervals throughout the shorter period of attack.

After a second 'Oboe-led' attack on Essen, Generalleutnant Martini was summoned to Hitler's headquarters. There he found himself at the centre of a discussion on the RAF's new bombing tactics. The *Führer* said the Krupp works had been hit during a night attack through continuous cloud cover. It had been suggested that some new British radio-navigation aid might be responsible. Was this possible? Martini replied that it was. Göring, sensing trouble in store, interjected: 'Yes, *mein Führer*, but we also have such systems.' Hitler asked for details, and Martini outlined the operation of the *Y-Gerät* system. Hitler then said: 'I want to know whether, if you were to attack the main railway station at Munich from Leipzig with your system, you could hit it?' Without committing himself too deeply, Martini replied: 'I estimate that Munich is about 400 kilometres from Leipzig. If that is so, and if the station is 1,000 metres long by 300 wide, then I believe that some of the bombs would hit the target.' 'I hope this is correct,' commented Hitler, and he went on to order a demonstration of the *Y-Gerät* over Germany, under operational conditions, to show whether it functioned as Martini had said.

In due course the demonstration was carried out, the target being an uninhabited site near Bayreuth, under what Dr Plendl described as 'warlike conditions'. About half the bombs fell within 900 yards of the target, at a range of 225 miles from the beam transmitter. Considering the range, that was a fairly good result – though it was not as good as 'Oboe'. Martini, careful not to make the trial too realistic, omitted the jamming which had been the downfall of the German system during operations over Britain. The demonstration provided strong circumstantial evidence that the RAF was using some sort of radio device during its attacks on the Ruhr, but as yet no such equipment had been recovered from any aircraft shot down. That was hardly surprising, since at night the Mosquito's high performance rendered it almost immune from attack. Moreover 'Oboe', like 'Gee', carried an effective self-destruction device.

German radio-monitoring stations on the north coast of France had picked up the unusual 'Oboe' signals as early as the autumn of 1942. They noted that the signals usually occurred at night, and it seemed they were associated with activity by German patrol boats in the English Channel. Naval monitoring stations had picked up the signals, however, and readers will not be surprised to learn that the information was not passed to the Luftwaffe.

During the attack on Wuppertal-Barmen on the night of 29/30 May, described in more detail later in this chapter, the anti-aircraft defences tracked the passage of a lone Mosquito flying at high altitude over the target three minutes before the main force of bombers arrived. Its passage coincided with the release of target markers, but nobody had intercepted signals that could be associated with any kind of blind-bombing system. A further two months elapsed before a Reichspost radio expert, Dr Sholtz, correlated the signals picked up by the Navy, with Mosquitoes dropping target markers during a large-scale attack on Cologne. In the meantime, the 'Oboe-led' raids brought destruction to the Ruhr on a large scale. During the first six months of 1943, only two 'Oboe' Mosquitoes were lost in action; in neither case did the wreckage fall into German hands.

* * *

Why was the RAF still not attempting to jam *Würzburg*? At the end of the third week in March 1943, uneasy intelligence officers in Berlin had again raised the matter. A captured British document, instructing troops on how best to dismantle a *Würzburg* radar, contained details of the set captured at Bruneval. Clearly the British knew a great deal about the device, and the *Freya* too: 'It is a source of puzzlement for us,' Oberst Schwenke reported to Milch, 'that the *Würzburg* radar is not being jammed'.

On this occasion, what had caused the matter to be raised was the discovery of two new devices in the wreckage of British aircraft, as Schwenke reported:

> On 2 March, a directional aerial was found on the rear of an aircraft shot down at Twente in Holland – nothing else. The aerial gave immediate reason to believe that it was part of an active night-fighter warning device. Then, on 12 March, we found a further aerial in a Halifax near Münster, with part of its mounting still attached. The tags on this mounting are labelled 'receiver' and 'transmitter'. . . which proves that it is an active warning system, which radiates a radar beam at the enemy aircraft and employs the returning energy to detect it.

Schwenke was referring to one of Bomber Command's new warning devices, the 'Monica' tail-warning radar. He then described the 'Boozer' radar-warning receiver, which came into German hands on the same night as the second H2S. Schwenke continued:

> During the night of 1 March, a receiver fell from a Lancaster shot down over Berlin; the receiver fell in someone's back yard. They knew that it had something to do with the aircraft, but it only reached us on 12 March. It appears to be a broadband receiver taking in the frequencies of both *Lichtenstein* and *Würzburg*.

Experts from the Telefunken Company had examined the receiver, and RAF prisoners had been questioned. The prisoners had revealed that the device illuminated coloured lamps to give warning when one or the other radar pointed at the aircraft.

These finds afforded an interesting insight into RAF knowledge of German radar, and into the lengths it would go to protect its bombers. Schwenke's mood now was like that of the man who has heard a boot drop on the floor above, with a bang, and is bracing himself for the other to drop. He commented: 'It is still a mystery for us that the British are only jamming *Freya*, and not *Würzburg* and *Lichtenstein* as well.'

* * *

Dietrich Schwenke would not have to wait for much longer. On 2 April 1943, Sir Charles Portal held the 'Window' conference promised five months earlier. Much had changed since the previous discussions. Following the catastrophic defeat suffered by the German Army at Stalingrad, there seemed little risk that the Luftwaffe bomber force could extricate itself from the Eastern Front and resume large scale attacks on Britain. In addition the new American SCR-720 night-fighter radar, designated the AI Mark X in RAF nomenclature, was about to enter service. This had displayed a reasonable immunity to the effects of metal-foil jamming. Also, a new ground radar for the control of night-fighters, the Type 11, was being produced in useful numbers. Wing Commander Jackson had developed a 'Window' bundle weighing less than two pounds, with sufficient tinfoil to produce a 'heavy bomber' echo on radar. This meant that bombers could carry enough bundles to release them along their route instead of just at the target, giving them greater protection. Sir Arthur Harris, C-in-C Bomber Command, expressed the view:

> There is now a good possibility of saving one-third of our losses on German targets by using this counter-measure. The Command has nothing to lose and possibly much to gain by using it.

That view carried the day, and Sir Charles Portal recommended to the Chiefs of Staff that 'Window' be released for operations soon. In his report to the Chiefs of Staff committee, Portal estimated that 'Window' jamming would reduce bomber losses due to enemy action by thirty-five per cent, and it would take the enemy at least six months to evolve ways to overcome the effect of the jamming.

On that basis, he calculated that, had 'Window' been employed throughout 1942, 316 bombers and crews would have been saved. That figure was predicated on the Luftwaffe being unable to develop an effective countermeasure to 'Window' for half a year following its introduction, however. Just how unrealistic was that belief, Bomber Command would learn to its cost during the winter of 1943/44.

Air Chief Marshal Portal said he was not alarmed at the prospect of the Luftwaffe retaliating in kind, as he expected to have fifty Mosquitoes with the new AI Mark X radar in service by August, and eighteen Type 11 fighter control radars by the end of the year. Moreover, the small proportion of the Luftwaffe bomber force in the western theatre of operations could not sustain an effort of more than fifteen or twenty sorties a night against Britain. Portal concluded:

> The use of 'Window' will increase materially the effectiveness of our bombing offensive. The cost will be a possible increase in the effectiveness of the enemy's night bombing in this country and an increase in the difficulties of night air defence in overseas theatres. In the present strategic situation, however, the balance is overwhelmingly in our favour, and it is recommended that we should employ 'Window' as from 15 May 1943.

Portal asked the Chiefs of Staff for an early decision, so the necessary additional production could be put in hand. Yet now there was a strategic argument militating against the early use of 'Window'. The planned Allied invasion of Sicily was to begin in July. The Chiefs of Staff felt that if the Luftwaffe used 'Window' to support air operations at an initial stage of the landings, that invasion might be jeopardised. Accordingly, the introduction of the new jamming method was to be delayed until the beachheads were secure.

A few days later, a windfall presented the British intelligence services with another important link in their chain of information on the German night defences. On 9 May a German night-fighter crew defected to Britain, and landed at Aberdeen in a Ju 88 night-fighter fitted with the *Lichtenstein* radar. So here at last was the *Emil-Emil* device, whose radiations had been monitored with such gallantry by the 1473 Flight ferret aircraft six months before.

The captured aircraft was flown to Farnborough, where it took part in a several trial interceptions against British bombers. The *Lichtenstein* radar was found to have a performance broadly comparable with the early British AI Mark IV radar, although it did not compare with the latest sets. Significantly, the tests revealed that *Lichtenstein* was vulnerable to the strips of 'Window' designed to jam the *Würzburg*.

As if that was not enough, the RAF was now about to introduce another measure to oppress the defending night-fighter force. The idea of sending night-fighters to seek out and destroy their Luftwaffe counterparts was not new. But the difficulty of finding the enemy fighters, in a night sky full of friendly bombers, had always proved too daunting. Following the capture of the *Lichtenstein* radar, however, the Telecommunications Research Establishment built a special homing receiver – code-named 'Serrate' – to enable RAF night-fighters to home on signals from the radar.

'Serrate' Homer Picture

The extra length of the 'bones' on the right indicates that the German night-fighter is to the right of the attacking aircraft. This picture shows the method of *directional* indication; a second tube, turned through 90 degrees, indicated the target's relative *elevation* – if the bones of the second tube were of equal length, the target would be flying at approximately the same height as the attacker.

No. 141 Squadron, commanded by night-fighter ace Wing Commander J. R. 'Bob' Braham, was selected to receive 'Serrate' and the device was installed in the unit's Beaufighters. During June 1943 the squadron began operations over German-held territory and in the weeks to follow it claimed the destruction of twenty-three Luftwaffe night-fighters, nine of which fell to Braham's own guns.

* * *

At this time, the late spring of 1943, the Luftwaffe system of night-fighter close control was operating at the peak of its effectiveness. To see how the attackers and the defenders confronted each other, let us examine the action on the night of 29/30 May, when 557 RAF bombers attacked Wuppertal-Barmen in the Ruhr industrial area.

The raid was compressed into fifty-three minutes, giving an average of twelve bombers passing through the target area each minute. For that time this was a high degree of concentration, but it must be stressed that the bombers were flying in a loose gaggle rather than any sort of recognisable formation. If the width of this page represents a distance of one mile, a single heavy bomber to that scale would be roughly the size of the letter 'T'. To the same scale, when viewed from above, at the centre of the bomber stream there would be an average of between one and two 'T'-sized aircraft flying in an area the size of this page. Those bombers covered 3½ miles per minute, however, so they passed through a defended area sufficiently quickly to allow most to avoid interception by fighters or engagement by AA guns.

That night the Luftwaffe scrambled some fifty night-fighters to engage the raiders, the majority from Nachtjagdgeschwader 1. The first *Gruppe* to engage was II/NJG 1 based at Saint-Trond in Belgium, which put up thirteen Bf 110s and three Do 217s. Piloting one of the former was a rising star in the night-fighter force, Leutnant Heinz-Wolfgang Schnaufer. Schnaufer's combat report stated:

> At 2351 hours on 29 May I took off for a night operation in the area of Lurch [code-name of a *Himmelbett* station north of Liège]. At about 0035 hours I was directed on to an in-flying enemy aircraft at an altitude of 3,500 metres [11,400 feet]. It was located on the FuSG 202 [*Lichtenstein* radar] and after further instructions I made out a four-engined bomber at 0045 hours, about 200 metres away, above and to the right. I attacked the violently-evading bomber from behind and below at a range of 80 metres, and my rounds started a bright fire in the left wing. The blazing enemy aircraft turned and dived away steeply, hitting the ground and exploding violently at 0048 hours. It crashed 1.5 km to the south of Belven, 5 km north-west of Eupen, map reference 6134.

Before the night was over, Schnaufer and his radar operator, Leutnant Baro, would add two further victories to their score.

Although Josef Kammhuber's system was effective, it should be noted that it made inefficient use of resources. In May 1943 the Luftwaffe night-fighter force possessed about 380 serviceable aircraft, equipping five *Geschwader*. On the night of 29 May, only fifty or so fighters took off to engage. That represented less than one-seventh of the force's effectives. And of those, the only night-fighters actually to see action were those serving the dozen or so *Himmelbett* boxes in the immediate path of the raiders. That was the inevitable result of Kammhuber's policy of tying his night-fighters rigidly to specific sectors of the defensive line.

The destructive attack on Wuppertal-Barmen cost Bomber Command thirty-three bombers, and two more crashed on landing. Following the debrief of returning crews, RAF intelligence officers concluded that at least twenty-two bombers had fallen to fighter attack; that figure agreed exactly with the Luftwaffe claim for that night. Thus Heinz-Wolfgang Schnaufer and his radar operator, alone, had accounted for one-seventh of the Luftwaffe victory claim. This was a battle where a few talented individuals could have a disproportionate effect on the scale of losses inflicted on the enemy. Of the remaining losses, the RAF attributed seven to flak and the remaining four to 'cause unknown'.

* * *

To several Luftwaffe officers it seemed that Kammhuber's system, as well as being wasteful in resources, was too rigid. Major Hajo Herrmann, a highly decorated bomber pilot serving at the Luftwaffe staff college at Potsdam, put forward a proposal that single-engined fighters might also play a part in the night defences by engaging Allied bombers over the targets. There the bombers were often illuminated by searchlights, fires on the ground or Pathfinder flares, and were vulnerable to fighters attacking visually. If the local flak commander would agree to restrict the ceiling of the bursting shells to a certain altitude, Herrmann suggested, single-engined fighters could operate there without hindrance. After his previous experience Generalleutnant Kammhuber resolutely opposed the idea of operating fighters over the flak areas at night, however, and rejected the idea.

Hajo Herrmann refused to accept 'no' for an answer. Ignoring the chain of command he submitted his scheme to Kammhuber's superior, Generaloberst Weise, requesting permission to conduct an experiment along the lines suggested. When Weise agreed to give the idea a try, Kammhuber could not object.

Herrmann assembled a dozen volunteer bomber pilots, men with considerable experience in night flying. He also secured the use of a few single-seat fighters, Bf 109s and Focke-Wulf 190s, from day-fighter units. Herrmann and his intrepid band assembled at Mönchen-gladbach near the Ruhr, and waited for the next British attack. Herrmann had the agreement of the local flak commander, General Hintze, to limit the flak ceiling to 20,000 feet over Essen and Duisburg.

The next big RAF attack, on Cologne on 3/4 July, fell outside the area of Hintze's 4th Flak Division, however. Unaware of the potential problem, Herrmann and his pilots took off in their Focke-Wulfs and Messerschmitts and began a running fight with the bombers. But over Cologne the flak batteries engaged aircraft passing overhead without restriction, forcing Herrmann and his men to break off the engagement. Yet before they did so, the interlopers claimed twelve of the thirty bombers lost by the raiding force.

The following morning brought a swift congratulatory telegram from Generaloberst Weise. Then Herrmann was summoned from his bed to take a telephone call from Reichsmarschall Göring in person. Herrmann was ordered to go to the Karinhall, Göring's country retreat near Berlin, to report on the night's events. That evening Herrmann expounded his theory to Göring; the fighters allocated to the system would assemble over strategically placed beacons when a bomber stream approached. From there, they would be directed *en masse* to the target, where they would engage the bombers. The fighters would then pursue the bombers until they ran short of fuel, then land at the nearest airfield. The tactic was given the apt code-name 'Wild Boar' (*Wilde Sau*). The Reichsmarschall heartily endorsed the scheme, and ordered Herrmann to assemble a full *Geschwader* of ninety Messerschmitt and Focke-Wulf single-seat fighters to exploit the new tactics.

On 6 July, Hajo Herrmann outlined the new tactical method when he addressed a top-level conference in Berlin:

> I would like to stress the following. In the area of one flak division in the Ruhr, where the weather is moderately clear, one can reckon that an average of 80 to 140 enemy bombers are picked up and held by searchlights for longer than two minutes, during an air raid. The demand I make of my crews is that every aircraft held for more than two minutes is shot down. I would go so far as to say that if the British continue their attacks in weather conditions like these, they can lose an extra eighty aircraft every night, if I am provided with the necessary personnel.

Generalfeldmarschall Milch expressed his vehement agreement; how often had he watched a British bomber trapped in a searchlight cone, and longed that there could be a German fighter up there moving in for the kill. Now it looked as if it was going to come true. Milch asked Herrmann if he had enough pilots. Herrmann replied: '*Jawohl!* There are 120 crews!' 'And how many planes do you have?' 'In my experimental unit I have fifteen aircraft, and fifteen more have just been allocated to me.' Milch ordered that the aircraft Herrmann needed be made available immediately. Somewhat emotionally General Vorwald, a senior staff officer attending the meeting, exclaimed: 'At last the spell is broken!'

Herrmann stressed that he was not advocating single- or two-seater night-fighting as such, so much as a new concept. He wanted to produce a massed attack by all available forces, to be hurled against the bomber stream as soon as the target became known. Herrmann had promised Göring that his *Geschwader* could be ready for operations in three months – by the beginning of October. In fact, it would be thrown into the fray very much earlier than that.

Significantly for this account, at no point did Herrmann's scheme rely on electronic systems other than early-warning radar, radio beacons and VHF radio. In consequence (although nobody in Germany could have realised it at the time) the 'Wild Boar' tactics represented a possible counter to the RAF's impending introduction of 'Window' jamming.

On 16 July, a further high-level conference in Berlin looked at ways of extending the effectiveness of the 'Wild Boar' concept. Night-fighter control expert Major Günthner described a new system under development, which employed a system similar to the *Y-Gerät* used over Britain in 1941, to funnel night-fighters into the British bomber stream. He requested the provision of thirty night-fighters to be fitted with the new system, called 'Y-control'. 'Every week a city is being smashed, so we must act fast', said Günthner. Night-fighter ace Major Werner Streib said that if night-fighters could be fed into the RAF bomber stream, say, near the Scheldt estuary, they could pick off the bombers one by one. Generalfeldmarschall Milch commented: 'So they keep up with them, shoot them down one after the other and keep asking: "Next one please!"'

To overcome the problem of identification, the fighter pilots were to be instructed to attack only four-engined aircraft. 'Those are the worst ones anyway,' said Günthner. Oberst von Lossberg then mentioned that a new device was being produced for night-fighters, to enable them to home on the emissions from the tail-warning radar ('Monica') fitted to some RAF bombers. Milch ended the conference on a serious note:

> The best that can be achieved is that the enemy ceases to operate against us altogether. Until we can get things in order, however, the best we can hope for is to make his business a messy one. In that case there is only one worry for us, that in some way he catches us on the hop with some radar-trickery, and we have to start trotting after him again.

* * *

Also on that day, 16 July, the Reich High-Frequency Research Authority (*Reichsstelle für Hochfrequenz-Forschung*) was founded to expand the German radar and high-frequency electronics industries, and organise all fundamental research. Kammhuber, Milch and Dr Plendl agreed to hold regular meetings to air and resolve problems with radar. Soon, Plendl had 3,000 scientists working under him.

* * *

By the spring of 1943, just over a year after its inception, the US Radio Research Laboratory at Harvard was a fully effective organisation for the design and development of countermeasures systems. By then it had already designed and built small batches of four types of noise jammer suitable for airborne or shipborne use: the APT-1 'Dina' (tuneable to spot frequencies in the band 90–220 MHz), the APT-2 'Carpet' (450–720 MHz), the APT-3

'Mandrel' (85–135 MHz) and the APQ-2 'Rug' (tuneable to spot frequencies in the band 450–720 MHz). Thus development work was well advanced on a range of jammers covering the spectrum from 85–720 MHz, able to counter the majority of German and Japanese radars then in use. Yet, to the surprise of those who had worked to prepare them with such great urgency, at this time the US military issued no requirement for any of these systems in quantity.

The US Eighth Air Force, considered to be a likely recipient of the jammers, had begun its daylight bombing offensive in Europe over France in August 1942. In the year that followed it had delivered attacks in progressively greater strength and depth, and its losses had become progressively more serious. Yet, in contrast to the RAF night-bombers, it seemed that jamming the German radars would do little to reduce the American losses. The Eighth Air Force operated only when clear skies were forecast over its targets, so the bombers could aim their bombs visually. That meant the German anti-aircraft gunners could aim their weapons using optical systems, too. Thus it seemed that jamming the fire-control radars would do little to reduce losses. And in any case the majority of US bomber losses were caused by day-fighters, which did not carry radar.

* * *

Early in 1943 the first RRL personnel arrived in Britain to join the staff at the Telecommunications Research Establishment. Their arrival did much to strengthen the bonds between the two organisations, as Matt Lebenbaum, one of the newcomers, recalled:

> We arrived at the TRE at Malvern early in January 1943 and Dr Bob Cockburn, head of the British countermeasures development group, made us very welcome. He and his team told us anything we wanted to know, there seemed to be no security barriers so far as we were concerned. They gave us several reports to read, to enable us to familiarise ourselves with the general problems of what they were doing. My initiation at Malvern was one of the great experiences of my life.

Another American who joined the TRE at this time, Dr John Dyer, found the atmosphere at Malvern quite different from that of inexperienced enthusiasm he had left behind at Harvard:

> I was greatly impressed by what I saw. They had a lot of tremendous people there with whom I got on famously – and still do. But the first thing that struck me when I arrived there was how tired and drawn they all were. They had been hard at it working seven days a week with scarcely a break for nearly two years, and they were simply worn out.

The RRL engineers were integrated into the British research teams, and when they returned to the US after a few months they were able to take back many useful lessons.

* * *

The success of the B-24 ferret missions around the Aleutian Islands had demonstrated the value of this type of aircraft, and led to a requirement for others to be converted. The next three ferrets, all B-17s, were allocated to the Mediterranean theatre where they were to establish the positions of German radars as part of the preparations for the invasion of Sicily.

The new ferret aircraft carried a range of receivers: a Hallicrafters S.27, an SCR-587, an APR-3 wide-band receiver and an NRL-designed XARD. The aircraft also carried directional antennae to enable them to home on to the source of any radar signals found. The first B-17 ferret arrived at Blida airfield, Algeria, early in May 1943. There its countermeasures officers immediately contacted their opposite numbers on the RAF's No. 192 Squadron.

On 18 May the B-17 made its first operational test, with a flight along the North African coast. During the flight the operators picked up signals from *Freya* radars working on 122.5, 125.4 and 129.1 MHz, identified as coming from Trapani and Marsala in Sicily, and from Sardinia. A week later the ferret B-17 flew another operational test almost to the coast of Sicily, and picked up signals from five *Freya* stations. On the night of 14/15 June the ferret carried out its most ambitious mission so far, with a flight around Sardinia during which the crew logged numerous radar signals.

In the weeks that followed two more B-17 ferrets arrived in the theatre and the unit was officially designated the 16th Reconnaissance Squadron (Heavy) Special. Its B-17s carried exhaust flame dampers for night operations, and were painted in a non-standard mottle of black over olive drab with most of the markings obscured. To avoid the attentions of enemy fighters, the ferrets operated only at night. Crews found that, if they flew higher than 500 feet when they were within twenty miles of the enemy coast, they picked up signals from so many radars that it was impossible to sort them out.

As part of the final preparations for the invasion of Sicily, Operation 'Husky', launched on 10 July, several US Navy ships were fitted with the APQ-2 'Rug' jammer. Royal Navy warships carried the equivalent British Type 91 jammer. In each case the targets of the jamming were the German *Seetakt* coastal-search and gunnery-control radars, which operated on frequencies in the 370 MHz band and were sited at intervals along the coastline.

To cover the night approach of transport aircraft and gliders carrying airborne troops, eighteen Halifax and Wellington bombers of Nos. 420, 424 and 425 Squadrons, were fitted with British 'Mandrel' jammers. These were to put up a screen of jamming intended to blot out the *Freya* and *Wassermann* early-warning radars in the area. At the same time four USAAF B-17s, each fitted with an APT-3 'Mandrel' to jam *Freya* and an APT-2 'Carpet' to jam *Würzburg*, patrolled off the coast to protect the force against radar-laid anti-aircraft fire.

The airborne and seaborne landings on Sicily were completed with little interference from German and Italian forces, though there was considerable confusion on both sides. As a result, it was not possible to determine the effectiveness of the Allied programme of radar jamming in support of the landings.

* * *

At a high-level meeting on 23 June 1943, Sir Charles Portal had conducted a final review of the arguments for and against the use of 'Window' to jam parts of the Luftwaffe radar system. By then it was clear that the opposition to its employment was crumbling. Even Lord Cherwell, who had been one of the most formidable opponents of its use, now felt that 'on the whole the time is rapidly approaching when we should allow it to be used.' Bomber Command could start using 'Window' once the beachheads were secure in Sicily. Sir Arthur Harris was directed to make final preparations for his force to employ the aluminium foil strips.

In the meantime, the machinery had been set in motion to produce aluminium foil in the industrial quantities required to support a major bombing offensive: at least 400 tons – about 1,000 million strips – each month. Since late 1942, selected companies had been turning out the foil. Each strip measured 30 centimetres by 1.5 centimetres. A black paper backing was fixed on one side to provide stiffness while the foil side was coated with lamp-black so it would not show up in a searchlight beam. A bundle of 2,000 such strips produced a radar echo similar to that from a heavy bomber.

The final conference to discuss 'Window' took place on 15 July – the day before Generalfeldmarschall Milch expressed his fears of possible new 'radar-trickery' from the British. By then, Allied troops had established a firm foothold in Sicily. Nevertheless Herbert Morrison, the Minister for Home Security, was still concerned about the ability of the Luftwaffe to retaliate. He asked whether this could not be further reduced, by bombing German airfields. Sir Charles Portal said that would be a waste of effort, since the Luftwaffe bomber force in the west was 'weak, badly trained and over-extended'. Prime Minister Churchill supported that view, and said that he was personally prepared to take the responsibility for the introduction of 'Window'. Morrison then withdrew his objections and the last barrier to using the material was removed. The conference agreed that Bomber Command would be free to use 'Window' to support its night attacks from 23 July. In the next chapter we shall observe the effects of that decision.

Chapter 9

Operation 'Gomorrah', and After

> 'The attacks on Hamburg have affected the morale of the people. Unless we evolve a means of defeating these terror-raids soon, an extremely difficult situation will arise.'
>
> Generalfeldmarschall Milch, 30 July 1943

Thus fate was hastening the 'Window' controversy to its inevitable conclusion. For sound tactical reasons, Sir Arthur Harris decided that Hamburg should be the target for his next major series of attacks – Operation 'Gommorah'. During the short summer nights, long overland flights to the same target night after night would be hazardous for his force. Hamburg lay on the seaboard, and its distinctive waterfront and dockyard areas showed up unmistakably on the Pathfinders' H2S radar equipment. Harris warned that the so-called 'Battle of Hamburg' could not be won in a single night:

> It is estimated that at least 10,000 tons of bombs will have to be dropped to complete the process of elimination. To achieve the maximum effect of air bombardment, this city should be subjected to sustained attack.

* * *

Hamburg was the second largest city in Germany and the largest port in Europe. In 1940 the battleship *Bismarck* had taken shape there in the sprawling yards of Blohm & Voss. Now the three main shipyards were turning out U-boats as quickly as they could. Clearly Hamburg was a military target of the highest importance. By the third week in July 1943, the city had been raided ninety-eight times. Its defences were strong, with no fewer than fifty-four heavy anti-aircraft batteries, twenty-two searchlight batteries and three smoke-generating units. About twenty ground-control night-fighter boxes, served by six major airfields, covered the approaches to the port. In consequence, previous operations had cost the RAF dear.

On the afternoon of 24 July almost every operational crew in Bomber Command crowded into the stations' operations blocks for the briefing on the night's raid. The target announcement raised a disgruntled murmur, for the city had a formidable reputation. The men saw their route before them, lined in ribbons pinned across the wall maps: assemble over the North Sea, fly on an easterly course clear of the German defences, then turn south-east to deliver the attack. Then they were to withdraw from the target on a track parallel to that which had brought them in.

Next, the men heard the detailed plan of the attack: zero-hour was to be 0100 hours GMT. Three minutes before zero-hour, twenty Pathfinder aircraft were to release yellow target indicators and white illuminator-flares blindly on the indications afforded by H2S. One minute later, guided in by the flares already dropped, eight crews were to mark the target visually using red target indicators. At one-minute intervals thereafter throughout the rest of the attack, fifty-one 'backer-up' aircraft were to renew the target marking with green target indicators. More than ten per cent of the raiding force comprised Pathfinder aircraft, each releasing distinctively coloured markers to identify the type of marking. The main force of bombers was to commence its attack at 0102 hours, and the plan called for the last of nearly 800 aircraft to be clear of the target area forty-eight minutes later

There was an unusual addition to the briefing, as a special announcement from Headquarters Bomber Command was read out to the crews:

> Tonight you are going to use a new and simple counter-measure, 'Window', to protect yourselves against the German defence system. 'Window' consists of dropping packets of metal strips which produce almost the same reactions on RDF [radar] as do your aircraft. The German defences will, therefore, become confused and you should stand a good chance of getting through unscathed while their attention is wasted on the packets of 'Window'.

From the meridian of 8 degrees 30 minutes East on the way to the target, to 8 degrees East on the homeward flight, each aircraft was to drop one bundle of 'Window' per minute. The announcement laid stress on two aspects of this operation. First, the benefit from 'Window' would be communal. The metal foil giving the best protection would come from strips dropped from the bombers flying ahead of and above the aircraft, rather than those dropped from the bomber itself. That meant it was particularly important to stick rigidly to the briefed route and timing points to produce a concentrated bomber stream. Secondly, the 'Window' bundles would need to be dropped down the aircraft's flare chute. That would be not be easy and the crewman assigned to the task – the bomb aimer at first, then the flight engineer – would be hampered by the oxygen lead and intercom connections, the darkness and the general difficulty of making any physical exertion at high altitude. He would need to use a torch to see his stopwatch. Nevertheless, it was essential that bundles be released at the correct one-minute intervals. The announcement concluded:

> When good concentration is achieved, 'Window' can so devastate an RDF system that we ourselves have withheld using it until we could effect improvements in our own defences and until we could be sure of hitting the enemy harder than he could hit us.

* * *

It was still light at 2155 hours that evening, when the airfield controller at Oakington gave the green 'clear to take off' lamp signal to the aircraft at the head of the queue in front of him. At the controls of Lancaster G-George of No. 7 Squadron, Flight Lieutenant S. Baker pushed forward the throttles until each engine gave maximum power for take-off. He then released the brakes and the heavily-laden bomber began accelerating slowly down the runway. At a little over 100 mph, the machine lifted itself clumsily off the ground. The remaining aircraft followed it at half-minute intervals – one moving on to the runway, one beginning its take-off run and one lifting off simultaneously. Within minutes that scene was being repeated all over eastern England.

In the half-light bombers clawed for altitude, and began moving eastwards in an untidy mass like a swarm of bees. In all 791 bombers had taken off: 347 Lancasters, 246 Halifaxes, 125 Stirlings and 73 Wellingtons. Of those, forty-five aircraft returned early, one part or other of the complex machinery having failed to operate as it should. The remaining aircraft continued with their mission. Once over the sea, the bomb aimer in each aircraft flicked a switch to make the bombs 'live' – if they dropped now, they would explode on impact.

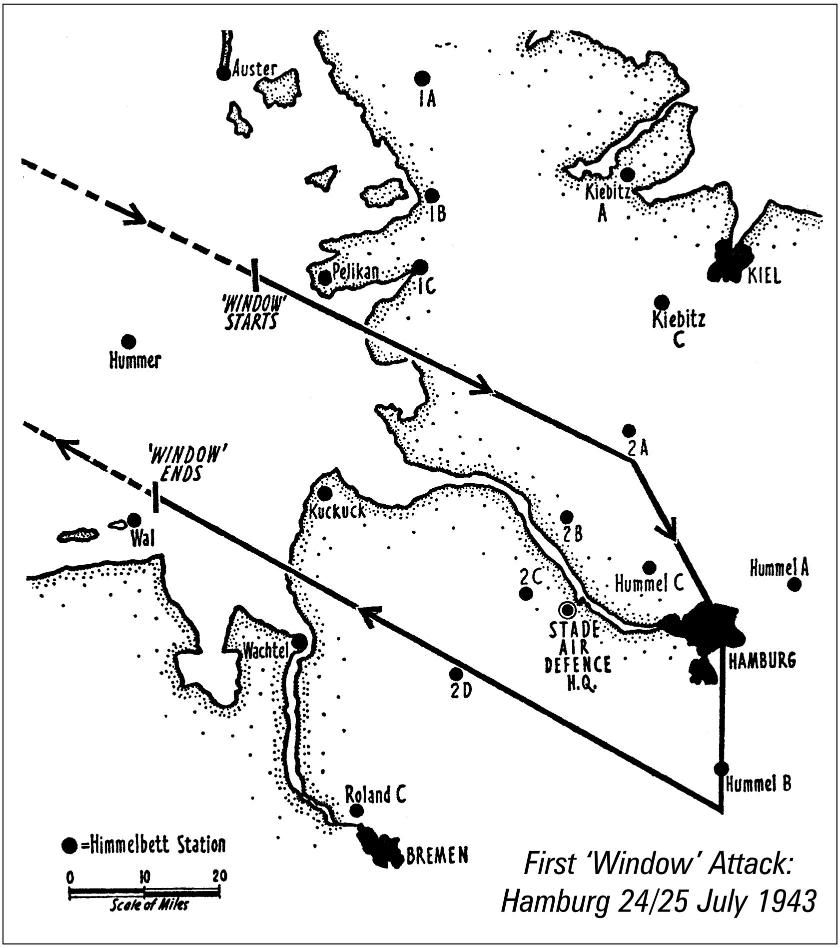
By midnight, the bomber stream was assembled over the North Sea, a mighty phalanx of aircraft spread over an area 200 miles long and twenty miles wide. The thundering mass of bombers moved eastwards at 225 miles per hour, 3¾ miles per minute. The weather forecast given out at the briefing told of a 17-mph wind from the northwest. But as the navigators plotted their 'Gee' fixes once every six minutes, the error of the forecast became clear: in fact the wind was from almost the opposite direction, at 12 mph. As the navigators corrected their bombers' headings to compensate for the new wind, attentive German eyes followed their progress.

The attack itself was coming as no surprise to the defenders. By studying the ground test transmissions from RAF bombers, the Luftwaffe listening service could predict the imminence of a major raid with a fair degree of accuracy. Heavy test traffic in the morning, and very little in the afternoon (when the bomber crews were being briefed, and the aircraft were being loaded with bombs and fuel), usually indicated a large-scale attack. If no attack had been planned, the test transmissions were usually spread evenly over both the morning and the afternoon. The listening-service forecast found confirmation shortly before 2300 hours, when the big *Wassermann* and *Mammut* early-warning radars overlooking the North Sea began passing reports on the progress of the raiders. At over a score of airfields in northern Germany, night-fighters and their crews were brought to readiness.

At 0015 hours, the leading bombers turned southeast into the Heligoland Bight, track 117 degrees. Four minutes later a restricted warning went out to military and civil defence headquarters, industrial buildings and hospitals: Air Danger 30 – air attack possible in the next 30 minutes. That was the cue for the local air defences to come to life. At flak sites around Hamburg, men ran to their weapons and began to ready them for action. Covers came off, barrels rose skywards and swung round to the northwest, shells were fused and radar sets warmed up. At the airfields at Stade, Vechta and Wittmundhaven, Lüneburg, Jagel and Kastrup, night-fighters scrambled and headed out towards their waiting beacons.

At 0024 hours the restricted alert was amended to Air Danger 15. Seven minutes later, the first public *Fliegeralarm* (Air Raid

Warning) was sounded – a series of two-second siren tones. For a full minute, the rising and falling blast echoed dissynchronously across the city from a hundred sirens, from Blankenese in the west to Wandsbek in the east, from Langenhorn in the north to Harburg in the heart of the docklands in the south. The inhabitants of Hamburg were not alone as they ran for their shelters; at Lübeck, Kiel and Bremen, Mosquitoes dropped target markers and a few small bombs in diversionary attacks. In each city, the full *Flieger-alarm* sent people scurrying for cover.



First 'Window' Attack: Hamburg 24/25 July 1943

At 0025 hours the leading bombers passed the 8½-degree meridian. From then on, at one-minute intervals, the bomb aimer in each aircraft released a bundle of aluminium foil into the night sky. As the leading aircraft crossed the German coast the flight engineer in each bomber crawled back to the flare-chute to relieve the bomb aimer of the 'Window' dropping task: the bomb aimer would soon have other tasks on hand. In each Pathfinder aircraft fitted with H2S, the large echo indicating the city of Hamburg slowly moved towards the centre of the screen. At 0057 hours, right on time, the first yellow target markers cascaded towards the ground. The Battle of Hamburg had begun.

The first report of anything out of the ordinary came from the *Hummer* radar box on the island of Heligoland. Nor was this surprising, for by now the 'Window' had appeared together with the bomber stream on the Giant *Würzburg* radar screens. Each cloud of foil remained effective for about fifteen minutes before the strips dispersed. So, with each minute that passed, on radar the apparent strength of the raiding force of 746 bombers increased in size by that number. The operators at *Hummer* complained that they were, 'disturbed by many apparent point-targets looking like aircraft, either stationary or slow moving. The picking-up of genuine aircraft is made extremely difficult. Once they have been picked up it is possible to follow them, but only with difficulty.' The *Auster* station on the southern tip of Sylt reported similar trouble. So, in turn, did the rest of the radar stations around Hamburg.

Circling over their appointed radio beacons, the German night-fighter crews waited with growing impatience for instructions from their ground controllers. But the latter could not help them. Soon the ether was thick with confused appeals and exclamations:

> 'The enemy are reproducing themselves.'
> 'It is impossible – too many hostiles.'
> 'Wait a while. There are many more hostiles.'
> 'I cannot control you.'
> 'Try without your ground control.'

In the waiting night-fighters, there were similar scenes of confusion as the drifting clouds of aluminium foil appeared on the screens of the *Lichtenstein* air-to-air radars. One Luftwaffe pilot who went into action that night later wrote:

> At 5,000 metres, my radio operator announced the first enemy on his *Lichtenstein*. I was delighted. I swung round on to the bearing, in the direction of the Ruhr, for in this way I was bound to approach the stream. Facius proceeded to report three or four

> targets on his screens. I hoped that I should have enough ammunition to deal with them! Then Facius shouted: 'Tommy flying towards us at a great speed. Distance decreasing . . . 2,000 metres . . . 1,500 . . . 1,000 . . . 500.'
>
> I was speechless. Facius already had a new target. 'Perhaps it was a German night-fighter on a westerly course', I said to myself, and made for the next bomber. It was not long before Facius shouted again: 'Bomber coming for us at a hell of a speed. 2,000 . . . 1,000 . . . 500 . . . he's gone!'
>
> 'You're crackers, Facius', I said jokingly. But soon I lost my sense of humour, for this crazy performance was repeated a score of times.

A few fighter pilots did get 'kills' that night. Feldwebel Hans Meissner of NJG 3, flying a Bf 110, made several attacks on 'Window' clouds. Then his radar operator, Unteroffizier Josef Krinner, noticed that one 'blip' seemed to remain almost stationary on his screen while the others all moved (moved, that is to say, relative to the Messerschmitt; the aircraft producing the 'blip' was moving on a similar course at roughly the same speed, so – on the radar screen – it appeared to be stationary). Krinner directed his pilot towards it, and the pilot caught sight of a four-engined Stirling and shot it down in flames. Another Bf 110 of NJG 3 caught a Halifax over southern Denmark, well outside the protection of the metal foil in the bomber stream; it too received no quarter.

The Pathfinders had done their work well, and at 0102 hours the first wave of main force bombers arrived over the city – 110 Lancasters of Nos. 1 and 5 Groups. The first thing to strike the bomber crews was the air of unreality over the city; the dreaded master searchlights – usually seen shining bolt upright before tilting swiftly over to trap some unfortunate bomber – were wandering all over the sky. Indeed, all the searchlights seemed to be groping blindly for their enemy. Where beams did cross, others quickly joined them. As many as a score of beams would build up to form a cone, apparently on nothing.

As it was with the ground-control stations, the night-fighters and the searchlights, so too with the guns. A gunner serving with an 88-mm gun of I Abteilung, 607th Flak Regiment, sited on the Harburg hills, recalled:

> We could hear excited voices coming from the radar cabin. There was a wild display of flickers on their cathode-ray tubes, clouding the whole of the screen. The battery-commander, Leutnant Eckhoff, telephoned at once to the nearest battery to us. The *Würzburg* there had been put out of action too.

On telephoning the divisional operations room, the battery commander learned that every flak radar set in Hamburg was out of action in the same way. The gunners abandoned predicted fire and loosed off round after round into a box in the sky centred on the bombers' predicted release point. But there was a lot of sky around each aircraft, and the chances of a shell bursting at just the right point in time and space were remote indeed.

Freed of the customary harassment from flak and searchlights during their bombing runs, the raiders delivered a remarkably concentrated attack on the parts of the city marked out for them. In the past, height had meant safety for the bombers. This was no longer necessarily the case, for the Lancasters in the first wave flying at the highest altitude received least protection from 'Window'. Some Lancasters attacked from as high as 23,000 feet, and these showed up on the *Würzburg* screens as clearly as a tree standing out from a low mist. No. 103 Squadron, whose Lancasters flew highest of all, lost three aircraft this night. Of the Stirlings, the bomber with the worst altitude performance, only three were lost. Altogether Bomber Command lost only twelve aircraft (1.5 per cent) of the large attacking force – four Lancasters, four Halifaxes, three Stirlings and one Wellington. Probably nine of these fell to night-fighters and three to the guns. Normally, the Stirlings suffered more heavily than the other types.

The new tactic had clearly been a great success. Had the raid cost the six per cent losses normal for a raid on Hamburg, Bomber Command would have lost about fifty aircraft that night. So about thirty-five or more bombers had been saved, by the dropping of forty tons of 'Window' – 92 million strips of aluminium foil.

On 25 July the *Führer* was roused early and told about the damage wrought in Hamburg. He also learned of the new British tactics, during the midday war conference. He turned to Oberst-leutnant Eckhard Christian, a Luftwaffe officer on the General Staff. 'This dropping of tinfoil – does that protect these airmen?' Christian replied that it jammed the *Würzburg* sets used to control the night-fighters. 'The *Würzburg* sets are showing targets everywhere, so they don't know any more where to guide the fighter to. The *Freya* system is not affected – they don't pick up this stuff.'

Hitler asked: 'What kind of sets has the British air force got? Do they pick this up or not?' Oberstleutnant Christian unhappily replied: 'I cannot say, *mein Führer*. But we assume so.' 'Do they pick it up, or don't they?' insisted Hitler. 'Find out!'

'*Jawohl*', replied Christian. 'And the Y-equipment being introduced into our night-fighter system is also unaffected by this tinfoil. That might well be the solution for us to get round this thing.' The trouble was, as he told Hitler, that this depended on the equipment situation, and deliveries were slow.

The answer was retaliation against Britain, but how? Luftwaffe bombers were finding difficulty in navigating to London and back. Hitler continued:

> And then I have to listen to some simpleton tell me, '*Ja*, *mein Führer*, if they come from England to Dortmund they can drop their bombs precisely on factory-buildings 500 metres long and 250 metres wide using their present radio beams.' The blockhead! We can't find London when it's fifty kilometres across and only a hundred and sixty kilometres from our coast.

Hitler's answer that day was to sign a decree ordering the mass production of the bombardment rocket later called the V-2, but that kind of retaliation would take time to bring into operation.

That morning, Reichsmarschall Göring put more urgent measures into effect. He telephoned Major Herrmann and said things had been 'very bad' in Hamburg. Could Major Hermann begin operations immediately with at least part of his special unit of 'freelance' single-seat night-fighters? Herrmann had no idea of the scale of the disaster, and told the Reichsmarschall that he needed more time. At that Göring became agitated and said that Herrmann had to do something as soon as possible. Herrmann promised to have at least twelve aircraft operating that night. Some hours later, he received a teleprinter signal from Göring setting out the details of the previous night's blow.

Working feverishly, Herrmann set up a special system to help the pilots of his single-seaters to navigate by night. The flak units at each big city were to fire distinctive combinations of parachute flares into the night-sky; for example, two flares fired to the same altitude indicated Hamburg, three flares stacked one above the other marked Brunswick. Searchlight units were also to co-operate with the night-fighters, by laying a horizontal searchlight beam along the ground pointing in the direction of the bomber stream.

The improvised defensive system was ready and waiting, when Bomber Command commenced its next big attack on Hamburg at 0057 hours on 28 July. The 722 bombers crossed the city from northeast to southeast, and after a quarter of an hour crews running in to bomb saw beneath them a carpet of fire covering much of the north-eastern quarter of the city. Into this inferno, succeeding aircraft dropped thousands of incendiary and high explosive bombs.

Throughout July little rain had fallen on Hamburg. In the earlier raid the city's water supplies had been disrupted and its civil defence headquarters Blitzed. The previous day had been hot, and the kindling was everywhere. Under the torrent of incendiary bombs, the fires soon took hold. The individual fires linked up and the conflagration grew steadily, until a mighty 'fire-storm' was raging unchecked across a large segment of the city.

Meanwhile, the RAF wireless intelligence service in England picked up Luftwaffe radio traffic which strongly suggested that the defences had undergone a marked reorganisation – as indeed they had. The listeners reported:

> Instead of the usual brief instructions as to course and height, ground stations were heard to give something of a running commentary regarding the course and height of the British aircraft and information about their being held in searchlights. The conclusion to be drawn is that the enemy has decided to use a system of much looser control of his fighters when interference from 'Window' made it necessary. In the traffic there were several direct references to fighters flying without ground control.

The operations by Major Herrmann and his recently formed fighter unit had not passed unnoticed. While the overall losses from this raid – seventeen aircraft – remained remarkably low, the rate was rising.

Further attacks on the city were expected and that afternoon Hamburg's political chief, Gauleiter Kaufmann, appealed to all nonessential civilians to leave. They needed no second bidding. Between dawn and dusk nearly a million civilians, many of them swathed in bandages, streamed out of the city. When night fell, virtually the only people left were those employed in the fire-fighting and defence services. Yet still Hamburg's ordeal was not over, for Bomber Command launched a third attack on the city. As the Pathfinders ran in to begin their marking at 0037 hours on 30 July, fires on the ground could still be seen burning from two days earlier. Now Hamburg's civil defences were wrecked, with even more water mains smashed and many roads blocked. The new attack carved out a further swathe of destruction across the already battered city.

But if Hamburg's gun defences were ineffective, Major Herrmann's men had some successes. The Bomber Command report on the action noted:

> The number of searchlights had been greatly increased both *en route* and in the target area. An outer belt stretched in a semi-circle round the town from the north-east to the south-west, and inside this other searchlights apparently acted as fighter guides, sometimes exposing horizontally for track indicating and to silhouette attacking bombers.

RAF listening stations reported that there was again a 'running commentary' broadcast to fighters on the location and heading of the bomber stream as a whole, rather than giving details of individual aircraft. The eavesdroppers noted that some Luftwaffe fighters appeared to have landed, refuelled and taken off for a second sortie – an unusual procedure at night, but one which would be encouraged in a freelance system. They also reported that some fighters used radio callsigns similar to those used by day-fighters.

During that third attack on Hamburg, only twenty-seven of the 777 bombers despatched were lost. The overall loss rate of 3.5 per cent was still low for this target, though it was an increase over that suffered during the first two 'Window' raids.

At a somewhat relieved conference at the Air Ministry in Berlin that afternoon, Generalfeldmarschall Milch declared:

> With his freelance night-fighting and a quickly organised technique, Major Herrmann has achieved the impossible in a very few operations, and things are rather more favourable with our night-fighting than was the case earlier.

But he went on to warn that there could be no doubt that the Allies were preparing to deliver further attacks. Next Oberst von Lossberg outlined his scheme for improving on Herrmann's ideas for combating the bomber stream:

> We can start with it a week from now. It is a way of keeping the mass [of night-fighters] in contact with the enemy all the way from the Scheldt estuary to the Ruhr and back. I feed solitary aircraft [into the bomber stream] . . . to shadow them. These shadowing aircraft will be guided to the vanguard of the invading bombers. That is where *Düppel* works to our advantage – any *Würzburg* can tell you where the *Düppel* is. Each shadowing aircraft will transmit homing signals, which will attract swarms of other night-fighters to it.

Once the night-fighters made contact with the bomber-stream, they would use their airborne radar to seek out individual aircraft. When they reached the target area they could switch to Herrmann's freelance tactics. In the meantime, Kammhuber's old system of night-fighter 'boxes' should remain intact, as it was useful for engaging the widely scattered bombers on their return flights.

At the Air Ministry in Berlin there was some confusion regarding the availability of *Düppel* in Germany. Night-fighter experts asked for supplies of aluminium foil strips, so they could develop tactics to counter them. Initially the men were told that the strips would take at least two weeks to manufacture. Then they were told that Göring had laid claim on the first deliveries of *Düppel*, for a retaliatory blow he was planning against England. Then Major Heinrich Rüppel, a leading night-fighter controller, was ordered to collect supplies produced at Werneuchen experimental station several months earlier. Rüppel had been present at the earlier meeting, when Kammhuber had declared that this type of jamming was not possible, so the major's surprise at learning that stocks had been manufactured and held all that time was understandable.

On the evening of 2 August, Bomber Command launched its fourth and last attack in the series against Hamburg but on this occasion the weather intervened. When the bombers arrived in the target area they entered an electrical storm with turbulent thunderclouds towering above them. As the brightly coloured target markers went down, they were swallowed up in the murk. It was as though the Gods of War had cried 'Enough!', causing the resultant attack to be widely dispersed. Generalmajor Kehrl, the city's civil-defence chief, afterwards reported that:

> The detonation of exploding bombs, the peals of thunder and the crackling of the flames and ceaseless downpour of rain formed a veritable inferno.

On the morning after this attack, 3 August 1943, Milch again called his fighter experts to a conference in Berlin. He stressed that some permanent means had to be found to defeat the growing tide of jamming. He continued: 'I am beginning to think that we are sitting out on a limb, and the British are sawing that limb off . . . '

* * *

During the first six raids in which the aluminium foil had been used – as well as those on Hamburg there had been an attack on Essen and one on Remscheid – Bomber Command aircraft had flown 4,074 sorties. Of these a very high percentage, 83 per cent, had attacked their targets. The overall loss amounted to 124 bombers, 3.1 per cent of the force committed.

The effect of the new countermeasure on the defences had been devastating. Early in August Generalleutnant Martini reported:

> Since 25 July, the enemy has combined with his raids into Reich territory the dropping of 'Hamburg Bodies' ['Window'] primarily at night but in isolated cases in daylight too. The technical success of this action must be assessed as absolute . . . By these means the enemy has delivered the long-awaited blow at our decimetric radar sets both on the ground and in the air.

In its use, 'Window' had exceeded expectations. Dr Cockburn later commented that there had been a lot of trials, and people knew it to be a very powerful method. But:

> What we could not allow for were the cumulative effects which went right through the system, as it lost confidence in itself.

* * *

Some commentators have referred to the much-delayed introduction of 'Window' as a missed opportunity. In their view the countermeasure should have been employed much earlier, implying that it would have had the same impact but with a much greater overall saving in aircraft. This view is not supported by the evidence. Clearly Mrs Curran's leaflet-shaped tinfoil would not have brought the German defences to a standstill. Quite apart from its unsatisfactory reflecting characteristics, a bomber could carry sufficient for use only in the immediate area of the target. Thus the ground radar stations in Kammhuber's line would not have been affected. Not until June 1942 did R. V. Jones unravel the significance of the Giant *Würzburg* radars within the Luftwaffe fighter-control system. And only in December 1942 was it clear that the *Lichtenstein* night-fighter radar could fortuitously be jammed by the same size of 'Window' strips. Until those facts had been established there seemed little doubt, as Lord Cherwell argued at the time, that the British defensive system was the more vulnerable to the countermeasure.

Could RAF Bomber Command have achieved a degree of destruction similar to that in Hamburg in July 1943, had the countermeasure been used earlier? Again, it is a question of degree. The period from August 1942 to July 1943 saw an enormous increase in Bomber Command's striking power. The number of bombers involved in the heaviest attack in each month during this period was as follows:

1942	August	307	1943	January	205
	September	476		February	466
	October	289		March	457
	November	239		April	572
	December	272		May	826
				June	783
				July	787

It is also worth remembering that in mid-1942 most of the bombers were twin-engined, while in mid-1943 most were four-engined and carried twice the bomb-load.

At the beginning of 1943, the force's ability to place bombs accurately was greatly enhanced by the introduction of H2S and 'Oboe'. Not until May 1943, however, did operators gain sufficient familiarity with H2S to use the device effectively. That month would therefore seem to have been the earliest in which Bomber Command could have achieved the level of destruction that was inflicted on

Hamburg. Moreover, as we are about to see, the Luftwaffe would introduce new tactics to circumvent the effects of 'Window' sooner than had been expected.

In the opinion of Generalleutnant Kammhuber, stated after the war, the timing of the introduction of 'Window' had been exactly right. Had the countermeasure been used earlier, the German radio industry might have produced new radars able to operate in the face of it but in July 1943 there was no longer sufficient industrial capacity to spare. Then there were new pressures on the electronics industry, of which the competing demands of the V-2 bombardment rocket programme would prove the most severe.

* * *

By the beginning of August 1943, the British jamming attack had reduced the Luftwaffe night-fighter force to a state of near impotence. An increasing number of bombers carried the 'Monica' tail-warning radar and the 'Boozer' radar-warning receiver, and with growing effect the RAF bombers were exploiting their new radar bombing aids. This was the Gordian knot the Luftwaffe needed to cut.

Meanwhile, Luftwaffe leaders sought to salvage what they could from Kammhuber's system of night air defence. Generalmajor Adolf Galland, the Inspector of Fighters, attended the crucial meetings at the Air Ministry in Berlin following the introduction of 'Window'. He later summed up the mood:

> Never before and never again did I witness such determination and agreement in the circle of those responsible for the leadership of the Luftwaffe. It was as though under the immediate impact of the Hamburg catastrophe everyone had put aside either personal or departmental ambitions. There was no conflict between General Staff and war industry, no rivalry between bombers and fighters: only the one common will to do everything in this critical hour for the defence of the Reich, and to leave nothing undone to prevent a second national misfortune of this dimension.

On 31 July Generaloberst Hubert Weise, in overall charge of Reich air defences, advised his commanders that:

> . . . the present enormous difficulties of defence against the heavy night attacks caused by the jamming of radar demand extraordinary measures everywhere. All crews must understand clearly that success can come only through the most self-sacrificing operations.

He decreed that Major Herrmann's new fighter *Geschwader* was to commence operations over the targeted cities. Conventional night-fighter units were to engage bombers along their route to and from the target, and also over the target itself. That tactic, which Oberst von Lossberg had suggested, was code-named *Zahme Sau* ('Tame Boar').

The fighter division headquarters were to inform the air zone and flak commands immediately their fighters took off, and the latter commands were to keep the fighter divisions informed of the bombers' probable target and other developments. Night-fighters were to be scrambled at times calculated to bring them over the probable target at the same time as the enemy bomber formations.

At the target itself, various methods would be used to assist the fighters to find the bombers by visual means. If there was a thin layer of cloud there was a new tactic, code-named *Mattscheibe* ('ground-glass screen'). The searchlights would play their beams on the underside of the cloud layer, so the bombers could easily be seen by the pilots of fighters circling above. Once fires started at the target, that effect would be further enhanced. Radio countermeasures would not shield the bombers from tactics like these.

The new 'Wild Boar' tactics meant a period of readjustment for the German night-fighter crews. Under Kammhuber's system they had nearly always operated within a few miles of their own airfields, and always with the same radar ground-control station. Everything had been very gentlemanly. Now all that had changed; the night-fighters were to journey the length and breadth of Germany hunting their quarry, and land only when their fuel ran low.

The nerve centre of the new air-defence organisation shifted from the line of ground-control radar sites, to the fighter division headquarters. The 1st Fighter Division covered northeast Germany, with headquarters near Berlin; the 2nd Division covered north Germany, from Stade near Hamburg; the 3rd Division covered the northwestern approaches, from Arnhem-Deelen in Holland; the 4th

Division covered the western approaches, from Metz in France; and the 7th Fighter Division covered southern Germany, from headquarters at Schleissheim near Munich. Under Kammhuber's original system, these headquarters had served as 'clearing houses' for information on the progress of the battle. Now the main flow of information was reversed; the radar sites passed reports to the divisional headquarters, and the latter controlled the actions. The air situation map in each divisional operations room, covering much of Germany, replaced the *Seeburg* tables which covered only a few tens of kilometres. Now, one fighter control officer would order entire *Gruppen* of fighters to scramble and assemble at a radio beacon thought to be in the bombers' path. He would then broadcast a running commentary to the fighters, to direct them into the bomber stream.

The Luftwaffe first used these new tactics *en masse* on the night of 17 August 1943, when Bomber Command attacked the V-weapons research establishment at Peenemünde. To achieve bombing accuracy, the raiders flew on a night with a full moon. It was ideal 'Wild Boar' weather, but Bomber Command's skilful tactics that night pointed out a major weakness of the new system. Fifty-five of Major Herrmann's single-seat fighters, and 158 night-fighters, were scrambled but, due to a misinterpretation of a diversionary raid on Berlin by eight Mosquitoes, the chief operations officer of the 1st Fighter Division ordered the night-fighters to assemble over that city. Soon more than 200 planes were circling over Berlin. Below them, AA gunners loosed off round after round into the darkness. Standing on one of Berlin's flak towers, Generalfeldmarschall Milch watched in disbelief. The night-fighters fired the prescribed recognition signals, yet the guns kept firing because they thought that the volume of engine noises meant that there were hostile aircraft overhead – and so the night-fighters stayed in the area, because they thought the gunners must have information on enemy bombers nearby. Fortunately for the night-fighter crews, the shells were fused to exploded at altitudes below them.

When the first target indicators went down at Peenemünde, about a hundred miles to the north of the capital, the crews could see them clearly and realised they had been tricked. Despite orders to remain over Berlin, those with fuel remaining headed towards the glow. So did those night-fighters that had not yet reached Berlin.

These fighters arrived over Peenemünde in time to catch the final wave of the attackers, and shot down forty-one of them. It was a clear indication of the potential of the new system, for the seven per cent loss rate was higher than that being inflicted before the introduction of 'Window'.

The Peenemünde operation brought further victories for Wing Commander Braham's Beaufighters fitted with the 'Serrate' homing device. Trailing their coats off the coast of Holland, these aircraft lured five Bf 110s of 4th Staffel of NJG 1 into action. As the Luftwaffe crews moved in for the kill, they received an unexpectedly hot reception. Braham shot down two of them, and a third fell to another Beaufighter crew. A fourth Messerschmitt was engaged by 'friendly' AA gunners, and the fifth had to return early with engine trouble. It had not been a good night for 4./NJG 1.

These 'Serrate' actions all took place over the sea or near the coast, for the Beaufighter's limited range prevented it from going far into German territory. However, the new Luftwaffe 'freelance' night-fighting tactics meant its fighters tended to operate deeper inside friendly territory. As a result, the opportunities for No. 141 Squadron to engage German night-fighters would fall sharply as autumn approached.

After the fiasco over Berlin on the night of 17/18 August, Generalfeldmarschall Milch conducted an investigation to discover what had gone wrong. The blame was placed on the flak organisation and Göring now issued stringent orders limiting the flak ceiling over cities, so Major Herrmann's fighters could operate to maximum effect.

On the night of 23/24 August Sir Arthur Harris despatched 727 bombers to Berlin, intent on creating havoc similar to that wrought on Hamburg a few weeks earlier. It did not happen. Zero-hour for the attack was set at 2345 hours. RAF wireless monitors in England, listening to the broadcast commentary on the bombers' progress, heard the Luftwaffe controller mention Berlin as the possible target as early as 2238 hours. At 2304 hours, nearly three-quarters of an hour before the attack on the city was due to begin, all Luftwaffe fighters airborne were ordered to move to the capital. There followed one of those operations when the bombers' navigators seemed to be entering the phrase 'kite down' in their logs almost every minute.

Returning bomber crews reported seeing nearly eighty fighter interceptions and thirty-one attack-runs. Of the latter, twenty-three were within a hundred miles of the target and fifteen were actually over the target. That was an unpleasant innovation for the bomber crews, who previously had been spared this second hazard when over the flak areas. Remarkably, crews hardly noticed the flak over Berlin. Crews reported that there were belts of searchlights inside the capital and around it, all co-operating with the fighters. The result was a catastrophe for Bomber Command, which lost fifty-six aircraft – its highest loss to date. Of those lost, at least thirty-three had fallen to the fighter defences, no fewer than twenty of them over Berlin itself.

Twice more Harris sent RAF Bomber Command to Berlin, and twice more the new Luftwaffe tactics cost his force many losses. On the night of the 31st, Major Herrmann arranged for a German bomber unit to fly high over the RAF bomber stream and illuminate it with parachute flares. The night-fighters were also able to follow the bombers' progress by observing the target markers dropped by Mosquitoes at points along the route. RAF radio monitors intercepted traffic which indicated that aircraft were being drawn from areas as widely separated as Grove in Denmark, and Juvincourt and Dijon in France. Forty-seven bombers failed to return. On the night of 3 September, Harris mounted the final attack in the series, using Lancasters alone. This type had the best performance of the heavy bombers available, but even so twenty of them failed to return.

The three raids on Berlin caused considerable damage in western areas of the city. But the cost was 123 aircraft and crews, almost exactly as many as had been lost during the six large-scale attacks following the introduction of 'Window'. The main lesson Bomber Command drew from all this was the importance of concealing the identity of the target as long as possible. That could be achieved by evasive routing, and by using feint attacks designed to seduce night-fighters away from the real target area.

On the clear nights during the summer of 1943, Major Herrmann's interception tactics had proved highly successful. Indeed, the new freelance methods forced upon the Luftwaffe by the use of 'Window' seemed more effective than the close-controlled tactics used previously. Some of the cross-country flights now made by the Luftwaffe night-fighters were quite remarkable. On occasions, night-fighters based in northern Denmark intercepted raiders over

Stuttgart. The new tactics were characterised by their great flexibility, and by the controllers' skill in bringing to bear the largest possible opposition.

Yet those early successes achieved by Herrmann's buccaneering pilots had far-ranging consequences, which were not foreseen at the time. Instead of concentrating an adequate research effort on ridding the radar system of the effects of 'Window' and other types of jamming, the night-fighter organisation now devoted its efforts to a series of dazzling but temporary expedients. That allowed the radar-control system to fall into disuse, while all the time Bomber Command entrenched its position.

Another casualty of the 'Window' catastrophe was Generalleutnant Kammhuber. He was relieved of his command, and was effectively replaced by Generalmajor Josef Schmid who commanded the newly established I Fighter Corps. Schmid set about reorganising Kammhuber's defensive system. In an effort to extend the radar-tracking system to cover more of southern and eastern Germany, he redeployed radars from some of the stations in the original defensive line.

* * *

In an attempt to regain the initiative, Bomber Command now introduced additional radio-countermeasures. The weakness of the freelance tactics employed by the Luftwaffe was their dependence upon fighters receiving accurate and timely information on the position of the bomber stream. If fighter-controllers could not pass that information, the system would be set at nought. A renewed jamming effort was therefore applied to the ground-to-air communications channels.

The commentary broadcast on the bombers' movements went out from high-powered transmitters working in the high-frequency band between 3 and 6 MHz, and the VHF band between 38 and 42 MHz. The former band lay within the cover of the crude 'Tinsel' noise jammer, which transmitted engine-noises on the fighter channels. Previously the bombers' radio operators had searched for signals transmitted in German, back-tuned their transmitters to one of these and commenced jamming it. That was an inefficient method. To render this jamming more effective, Bomber Command introduced a new system known as 'Special Tinsel'. As soon as a monitoring station in England picked up the Luftwaffe broadcast commentary, it broadcast the frequency to all the bombers so all the 'Tinsel' jammers were tuned to the frequency in use. Working together in this way, the transmitters aboard several hundred bombers put out sufficient noise to blot out the commentary, especially in night-fighters that were close to the bomber stream.

That still left the Luftwaffe VHF band, but Dr Cockburn and his team were working at high priority on a new high-powered jammer to look after that one as well. We shall observe the impact of this system in the next chapter.

* * *

Between June and December 1943, the strength of the Luftwaffe night-fighter force rose from 554 twin-engined aircraft to 611. Accompanying that small rise in quantity was a greater one in quality, as the Do 217, and the older variants of the Bf 110 and Ju 88, gave way to improved versions of the Bf 110 and the Ju 88, and the new He 219. As autumn turned to winter, the new Y-control technique was also used to increase the effectiveness of the 'Tame Boar' tactic. Ground controllers began to direct fighter units into the bomber stream as soon as possible after it entered German-controlled territory, setting up long running fights which might last for over a hundred miles and include combats over the target itself.

In the meantime, the Luftwaffe had made progress with modification of the *Würzburg* fighter-control and gun-laying radars to enable them to operate with some effectiveness in the face of 'Window' jamming. They called the process 'de-lousing' and the first of the 'anti-Window' modifications, code-named *Würzlaus*, emerged just over a week after the RAF started dropping the aluminium foil. The prototype was demonstrated to Generalmajor Martini and Oberst von Lossberg at the Werneuchen experimental station during the first week in August.

Würzlaus employed the well-known Doppler effect, whereby a radar pulse reflected from an object moving either towards or away from a radar set returns at a different frequency from that transmitted. The 'Window' foil dropped from an aircraft quickly lost its forward speed. So, at a ground radar, the problem could be resolved by differentiating between the virtually stationary 'Window' cloud, and the fast-moving aircraft.

This method had an obvious snag, however. *Würzlaus* functioned only when the aircraft moved towards, or away from, the radar with a relative speed of more than about 13 mph. If the aircraft flew on a track tangential to the radar, it had insufficient net speed either towards or away from the radar. In that case, the device could not differentiate between an aircraft and a 'Window' cloud. Moreover, if the wind speed exceeded 13 mph, a 'Window' cloud looked no different from an aircraft. An improved version of the device was demonstrated to Generaloberst Weise and Generalmajor Martini in September, and on that occasion the results were reported as 'good'.

A second 'anti-Window' modification to the *Würzburg* was devised to overcome the snags of *Würzlaus*. Code-named *Nürnberg*, this employed the principle that the radar pulse reflected from an aircraft varied in strength due to the 'modulating' effect of the rotating propellers. The radar operator was equipped with a pair of earphones, so he could hear the returning radar pulses. If the radar was aligned on an aircraft, the operator heard a distinctive rustling noise. If the set was aligned on a 'Window' cloud, that effect was not present. This modification was not popular with operators, however, who found it difficult to use properly. Only a few skilful operators were able to get reasonable results with *Nürnberg*.

On 11 September, Dr Plendl reported plans for combining the two 'anti-Window' systems. On instructions from Generalfeldmarschall Milch, Plendl was charged with overseeing the *Nürnberg* system from the laboratory stage to the front line. Within three months, Plendl's technicians had modified 1,500 *Würzburg* sets in this way.

Meanwhile the Werneuchen experimental station was conducting the initial flight trials of the *Naxos-Z* device, which could home on H2S radar transmissions from a distance of about ten miles. Generalfeldmarschall Milch learned that five *Naxos-Z* sets would be manufactured each month and installed in night-fighters. Milch was delighted: 'We would have enormous results, if we could shoot down the Pathfinders before the rest!' (At that time, only Pathfinder aircraft carried the H2S radar.)

Still the Luftwaffe was at pains to discover exactly what RAF operators saw on their H2S screens. The captured *Rotterdam* equipment had made its first flight in June aboard a German bomber, but during that flight the cities beneath showed up only indistinctly.

Luftwaffe interrogators questioned hundreds of RAF prisoners, in a bid to discover whether the set was used for navigation or for actual target-finding. Yet at the beginning of September 1943 this was still an open question. At a conference in Berlin, Oberst Schwenke reported that the monitoring service's *Korfu* receivers provided ample proof that the H2S sets were switched on early in the flight, often while still over England. Generalfeldmarschall Milch asked: 'Have we worked out from the prisoner interrogations what the enemy can see?' Schwenke told him it was difficult to answer that question – the prisoners had not brought pictures with them: 'So far, our reports indicate only that they see very much more than we do.' Milch rejoined:

> They can very justifiably be lying, on the other hand. Any decent man would tell us a pack of lies. But it would be interesting to hear from somebody who is not a decent fellow, to find out what he can see when he's flying over Berlin.

Schwenke said that, while the prisoners agreed that it was possible to identify towns, some spoke of difficulties with the equipment, or complained that it was difficult to get a clear picture. When the H2S was in good order they could pick up towns from distances up to twenty-five miles away.

Milch then asked: 'How does the enemy differentiate between towns and the surrounding countryside?' 'They put it like this,' answered Schwenke. 'If I switch on [the radar] at a distance of eighty kilometres, the town rises on the horizon as a bright patch about the size of a 10-pfennig piece. There was just such a report about Nuremberg.' Around the bright patch of Nuremberg, the countryside was darker. General Heyne added:

> The town moves in like a bright moon. As the picture is always orientated with north at the top, the pilot [sic] has an excellent chance to recognise the position of the town in the picture – the '10 pfennig piece'. He knows exactly where the town is. Since he knows his course, and has his target markers, he can quickly determine his target for attack.

Milch said that the best countermeasure to this system was the night-fighters; the trouble was that the RAF could bomb in bad weather using H2S, when the night-fighters could not operate.

Someone at the meeting tactlessly commented: 'The British have tried this as a solution to the old problem of blind bombing.' Milch rounded on him 'They have succeeded! 'And they are not bombing "blind" – they can see!'

The fact remained that the RAF operators were switching their powerful H2S radar sets on as soon as they left the English coast, and the Luftwaffe monitoring service was exploiting this. That service's signals command had a favourite catchphrase: '*Aller Funkverkehr ist Landesverrat*' ('All radio traffic is high treason'). That axiom now applied to the RAF's radar transmissions. The Telefunken company adapted some *Würzburg* aerial dishes to accommodate *Naxos* receivers. This so-called *Naxburg* receiver could take precise bearings on the sources of H2S transmissions. The new device was set up near Essen and during its first test, on 22 September, it registered bearings on individual Pathfinder aircraft flying up to 160 miles away. Several more of these receivers were ordered, and a special organisation was formed to track RAF bomber formations passing over western Germany. In addition, a Luftwaffe signals regiment had found a way to trigger the Identification, Friend-or-Foe (IFF) transponders carried in RAF bombers, thereby getting range-and-bearing information on bombers not fitted with H2S. That was a useful back-up method to track bomber streams flying over German territory.

During the late summer of 1943, the Luftwaffe had plumbed the depths in the aftermath of the introduction of 'Window', but as autumn turned to winter it was overcoming its difficulties much faster than its enemies had thought possible. German scientists were developing new radar devices to counter the jamming, and homing receivers to enable night-fighters to single out and destroy H2S-carrying bombers. The increasing weight of electronic equipment carried in the bombers was providing the defences with the means to track and engage them. Now the Luftwaffe was about to consolidate its recovery, and hit Bomber Command harder than ever before.

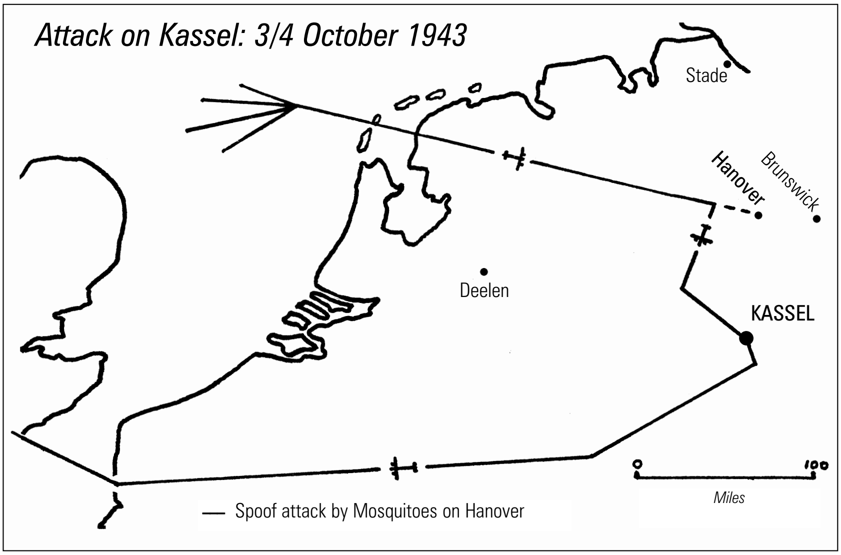
Chapter 10

Approaching the Climax

> 'It is very humiliating to see how the enemy is leading us by the nose in air warfare. Every month he introduces some new method, which it takes weeks and sometimes months for us to catch up with. Once handicapped by the enemy in any phase of warfare, it is exceedingly difficult to catch up with him. We have to pay very dearly for what we failed to do in air warfare hitherto. But that is to be expected.'
>
> Propaganda Minister Josef Goebbels,
> diary entry, 7 November 1943

As well as assisting bombing, the H2S radar was a valuable aid to accurate navigation *en route* to the target. For that reason crews were in the habit of leaving the radar on throughout the sortie. That enabled Luftwaffe ground stations to track the RAF bomber streams from take-off to the target, then back again. Based on this information, the tactic of hurling the night-fighters *en masse* against the bomber stream began to cause heavy losses.

RAF Bomber Command attempted to counter these tactics by the use of new deceptive measures. During the attack on Kassel on 3/4 October, the force of 540 heavy bombers and nine Mosquitoes flew in a straight line from the coast towards Hanover. At first the Luftwaffe controllers gave Hanover as the target, and ordered their fighters to assemble there. But at a point some thirty miles west of the city, the bomber stream turned south while the Mosquitoes carried straight on. The Mosquitoes dropped green target-markers and a few bombs on Hanover, forcing the night-fighters to stay there in expectation of a full scale attack. When the main force failed to appear, and the markers started to go out, the controllers ordered the fighters to head for Brunswick. Not until seven minutes after the first yellow target markers burst over Kassel did the Luftwaffe running commentary mention that city. The first fighters arrived there just in time to catch the final waves of the attack; twenty-four bombers, 4.4 per cent of the force, failed to return.



The new Luftwaffe night-fighter tactics should have done better against the bombers, but on this occasion the co-operation between the AA guns and the night-fighters had been poor. Moreover, the Luftwaffe had not made the best use of its radar-tracking stations. The reasons for the failure were discussed during a conference in Berlin on 5 October, with Generalfeldmarschall Milch in the chair. Oberst von Lossberg, who had himself flown a night-fighter during the action, described what happened:

> The flak reports: 'Large formation of enemy aircraft approaching', then the order is given 'Open fire!' and they let loose with their guns to all manner of altitudes. As a result one of the *Staffel*'s aircraft based at Venlo had its engine shot out over Bonn, and another was damaged over radio beacon *Otto* – both by flak, and this just to one *Staffel.* I myself came up against flak bursts and was forced to weave. During the attack on Kassel, the flak was so intense at every altitude that most night-fighters would not close in over the target. They waited outside in the dark, and in consequence had little chance [of catching the bombers]. Orders were received to fly around the flak zones, but how can that be done in cloud? The failure during the Kassel raid was, however, basically due to other reasons. The enemy formation flew by an unusual route to Kassel, and they made it difficult for us because they launched a feint attack [on Hanover]. They flew in on a

> course which suggested an attack on Hanover and then, about 60 km west of Hanover, the enemy formation turned south . . . towards Kassel.

Milch asked the obvious question: why had the night-fighters not pursued the bombers to the city? A representative from the air zone command told him that there was no proper radar cover in that area. Milch was not satisfied:

> That can't be the reason. Even if there was not complete radar cover, it should have been possible to establish the course of the enemy formation. I cannot understand why nobody noticed the enemy turn off 60 km west of Hanover. I am not attacking anyone personally, nor any organisation. I shall only say this: the system is not in order. I don't care who is to blame, it's all the same to me. But what does make me feel bitter is the fact that we cannot maintain control during our night operations, although hundreds of thousands of people are involved.

As for the night-fighters being engaged by 'friendly' anti-aircraft guns, Milch said it was obvious that the mutual co-operation system was not functioning:

> I am convinced that the commands are being given, but unfortunately they are not always carried out. It is all wrong. Ultimately, defeat or victory hangs on this question. Unfortunately this does not seem to be appreciated everywhere.

* * *

The Luftwaffe soon overcame the worst effects of the 'Special Tinsel' jamming of its fighter-control channels in the 3–6 MHz band. It set up several more high-powered transmitters, to broadcast the running commentary simultaneously on a number of different frequencies. If the RAF tried to jam all those channels, it would have to spread its jamming power very thinly.

The RAF had another card up its sleeve, however. Signals in the 3–6 MHz band will bend to follow the curvature of the earth, by reflecting off the layer of ionised gas surrounding the planet. Thus the signals would carry for several hundred miles, enabling high-powered ground transmitters in England to provide jamming support for RAF bombers deep inside German territory. Several transmitters at Rugby and Leafield, belonging to the Cable and Wireless Company, the Post Office and the BBC, were modified to cover the frequencies used by the Luftwaffe night-fighter force. Directional aerials beamed the signals eastwards, towards Germany. The transmitters were remotely controlled via a landline link from the RAF monitoring station at Kingsdown in Kent.

Originally, the intention had been to use the new device to transmit jamming noise, but speech transmissions were also possible. If the night-fighters relied on instructions from the ground to find the bombers, could not fake instructions be transmitted to send them astray? It seemed an effective and economical method of reducing bomber losses, but during the ensuing discussions it became clear that such tactics might prove a double-edged sword. While some Luftwaffe aircrew might be confused by fake orders regarding the target, it was unlikely that fighter-controllers on the ground, with good information on the track of the attacking force, could be deceived. Indeed, contradictions from a British 'ghost' controller might serve as a guide to the attackers' real intentions. If the target was Leipzig and the Luftwaffe controller ordered his fighters to assemble there, while entertaining doubts as to whether that was the real target, such doubts would disappear if the 'ghost' controller tried to divert fighters to Brunswick or another imaginary target. Because of this, the RAF 'ghost' controllers had orders not to mention any real or imaginary routing of friendly aircraft nor any target, genuine or otherwise. Yet, within these limits, there was plenty of scope for ingenuity.

The new tactic, code-named 'Corona', went into operation for the first time on the night of 22/23 October 1943. The bombers were detected by long-range radar as they left England, and twenty minutes later several hundred aircraft were reported crossing the Dutch coast between the Katwijk and Scheldt estuaries. The bomber stream was plotted heading southeast as far as the Rhine, and H2S bearings confirmed its track. A few Mosquitoes of a spoofing force continued to the southeast, but these were recognised as such by their high speed and the absence of H2S signals. Just south of Bonn, a Luftwaffe raid-tracking aircraft reported the release of flares to mark a turning point. When the bomber stream was first tracked, it had been heading for Frankfurt, and the night-fighters from three Luftwaffe fighter divisions – 179 aircraft – were ordered to a position northwest of the city. Now the course-change had been seen, the fighter-controller ordered all fighters to Kassel – and Kassel was the real target that night. The night-fighters hurried north, assisted by a following wind.

The Luftwaffe fighter-controller recognised that fake orders were being fed into the system by the British, because of the faulty pronunciation. He warned the night-fighters: 'Don't be led astray by the enemy' and 'In the name of General Schmid I order all aircraft to Kassel.' Becoming increasingly angry, the controller actually swore into his microphone, causing the 'ghost' controller in England to remark: 'The Englishman is now swearing!' The real controller shouted: 'It is not the Englishman who is swearing, it is me!' This was good knockabout stuff. Yet, despite the 'Corona' controller's efforts to draw night-fighters away from the bombers, the attackers suffered a heavy loss that night. Because the tracking aircraft detected the force's change of course towards Kassel, the Frankfurt 'spoof' attack was a failure. Bomber Command lost forty-two bombers, 6.9 per cent of the force. Even so, large parts of Kassel were hit in a raid which destroyed several important armament factories.

Gradually the most effective form for 'Corona' evolved. The Kingsdown monitors noted that when the Luftwaffe controller warned night-fighter crews of fog forming over their airfields, they would break off their operation early. So, broadcasting false warnings of fog became a useful tactic, though it would not succeed if overused. A useful spin-off of the tactic was when Luftwaffe controllers broadcast genuine fog warnings, some night-fighter crews refused to believe them and got into difficulties as a result.

Anything which raised the level of annoyance in Luftwaffe night-fighters was potentially a help to Bomber Command. 'Ghost' controllers would call up Luftwaffe air and ground radio stations, giving long test transmissions: 'One-two-three-four-five. Five-four-three-two-one. Monday-Tuesday-Wednesday-Thursday-Friday-Saturday-Sunday. Testing-testing-testing.' Anyone who has listened to such drivel on a loudspeaker system will testify to the annoyance it causes. For night-fighter crews orbiting over assembly beacons waiting for instructions, the effect was even greater. By requesting test-transmissions from the aircraft, a 'ghost' could tie up a radio frequency for several minutes at a time. After a few weeks the crews ceased to respond to these requests. So the 'ghosts' resorted to reading pieces from Goethe and turgid bits of German philosophy, and even to playing records of Hitler's speeches. All pretence of imitating the Luftwaffe fighter-controllers was given up.

* * *

At this time, RAF Bomber Command introduced another radio-countermeasures system to bedevil the Luftwaffe night-fighter control system. From the spring of 1943, the night-fighters were being fitted with VHF radios operating on the 38–42 MHz band. In reply, Dr Cockburn and his team at the TRE produced a jammer to cover these frequencies, code-named 'Airborne Cigar' or ABC for short. The Lancasters of No. 101 squadron were modified to carry the device, with two seven-foot long spar-aerials protruding from the upper fuselage and one under the nose. ABC required a full-time operator, so the aircraft had a position for an additional crewman in the rear fuselage. From October 1943, ABC aircraft accompanied all major bombing raids. One ABC operator recalled:

> In the Lancaster we sat in darkness, cut off from the rest of the crew. The nearest other crewman was the mid-upper gunner – his boots were at my eye level, about four feet further down the aircraft. We had a monitor receiver with a three-inch diameter cathode-ray tube. This represented the frequencies from 38 to 42 megacycles as a horizontal line, and any signals we picked up were shown as vertical blips which grew out of the base line. When we saw a signal we would tune in our receiver and listen to it. If it was a Luftwaffe message we would switch on one of our three transmitters and tune it to the receiver signal to obliterate it. The immediate result was generally a small movement of the signal up or down my tube, and it was just a question of following it. If the jamming got too bad, he would go off the air altogether. Later he would appear on a different frequency, but it was a matter of seconds to cover the new blip. Often the Luftwaffe controller would get rather angry. I sometimes felt a little sorry for him, trying to get through while I was stopping him.

* * *

During the autumn of 1943, the US Eighth Air Force based in England introduced a fundamental change in its tactics. Previously, accurate attacks had been possible only when there were clear skies and the bombs could be aimed visually. Yet the continually changing weather over northwestern Europe imposed severe constraints. Forecasts of cloud over the planned targets caused the frequent cancellation or diversion of missions. Or, worse, bomber formations might fight their way through the defences, suffering heavy losses, only to find the target shrouded in cloud when they reached it.

The problem of attacking unseen targets was one long familiar to the RAF night-bomber crews. And, as we have observed, the RAF had recently put into service the H2S ground-mapping radar and the 'Oboe' ground-controlled bombing system. In the summer of 1943 the Eighth Air Force formed its own Pathfinder Unit, the 482nd Bomb Group, with H2S- and 'Oboe'-fitted B-17s and B-24s to lead its attack formations. Later some of these aircraft were fitted with the H2X ground mapping radar, the US equivalent to the British H2S equipment.

The US Pathfinders went into action for the first time on 27 September 1943, leading an attack on Emden. The unit quickly demonstrated its value, and for the rest of the war Pathfinder aircraft led most US heavy bomber attacks. If the raiders found clear skies over their target, the lead bombardier made a visual bombing run. If the target was covered by cloud, he released his bombs on the indications from radar.

The move also affected the Luftwaffe flak batteries for, to engage bombers flying above cloud, the gunners needed to use radar-laid fire. If the fire-control radars were jammed, the accuracy of their fire would be reduced. In the autumn of 1943, sixty-eight APT-2 'Carpet' jammers from the initial production batch arrived at the bases at Snetterton Heath and Knettishall in England, for installation in B-17s of the 96th and 388th Bomb Groups respectively.

'Carpet', a spot-tuned device, radiated jamming over a narrow spread of frequencies about 500 kHz wide. To cover most of the 553–568 MHz band used by the *Würzburg* radars at that time, each plane in a combat-box formation of 20 bombers had its 'Carpet' equipment tuned to a slightly different frequency. In that way the formation as a whole jammed the required band of frequencies. In each aircraft the radio operator switched his 'Carpet' to transmit as the formation entered the flak zone, and switched it off as he left it.

During the initial attacks with 'Carpet', the two bomb groups carrying the jammer enjoyed significantly lower losses than those without it. During the attacks on Bremen, Gdynia, Münster and Schweinfurt on 8, 9, 10 and 14 October respectively, of the 186 sorties by bombers fitted with 'Carpet', fourteen (7.5 per cent) were lost. Of the 1,066 bombers without 'Carpet', 134 aircraft (12.6 per cent) were lost. Clearly, the jammer provided useful protection against ground fire. Headquarters Eighth Air Force now issued an urgent requirement for sufficient 'Carpet' jammers to equip every heavy bomber operating in the theatre.

On 20 December 1943 the Eighth Air Force used 'Window' (known as 'Chaff' to the Americans) for the first time. During an attack by 472 B-17s and B-24s on Bremen, aircraft from two groups in each of the three bomb divisions released the strips by hand from the open waist gun positions as they passed through flak zones. The material proved effective in reducing losses, and its use was extended to the entire force.

* * *

Suddenly the USAAF required large numbers of 'Carpet' jammers and huge quantities of 'Window/Chaff'. Dr George Rappaport from the USAAF Aircraft Radio Laboratory at Wright Field was sent to the Delco plant at Kokomo, Indiana, to inquire whether the company could meet a requirement for 15,000 of these jammers. Rappaport recalled:

> Bert Schwarz, their brilliant production engineer, showed me around the works. They had a very impressive production line going making other types of radio equipment, with parts moving around on belts and workers fitting components as they came past; it was just like the Charlie Chaplin movie *Modern Times.* As we walked around Bert looked rather unhappy and he kept scratching his head. In the end I said 'What's wrong, why can't you build the 15,000 for us?' He paused a while, then answered 'Well, 15,000 a week, that's an awfully tough rate . . . ' I looked at him in amazement and told him I did not want 15,000 'Carpets' per week, 15,000 in a year would do fine. Bert broke out into a smile. 'Oh,' he said, 'I'll have to reduce my production capacity to do that!'

* * *

The sudden requirement for 'Window/Chaff' in huge quantities posed a quite different sort of problem. The strips produced initially were 30 cm long and 1.5 cm wide, that width being necessary to give the strip the rigidity necessary to hold its shape when it was tossed into the airflow. Two thousand of those strips, weighing 1 lb 9 oz (765 gr), produced a radar echo about the size of a heavy bomber.

Initially the foil was chopped to size using the guillotine cutters employed by the paper trade but, as production was increased, the companies discovered that the metal foil was an almost perfect material to blunt the cutter blades. Production failed to meet the huge demand, and the stockpile of the material built up earlier was depleted at an alarming rate.

It will be remembered that Dr Chu at the RRL had determined mathematically that, to get the largest echo from a given weight of foil, a large number of very thin strips would make the most efficient use of the material. Harold Elliott, a member of the engineering design team at RRL, investigated the problem and came up with a novel solution. Matt Lebenbaum, one of those involved with the problem, told the author:

> Harold's 'Chaff'-cutting machine was the neatest thing you ever saw. It was rather like a lawnmower with 20 blades, every second one of which was ground back slightly. The blades were rotated at 800 rpm by an electric motor and the first blade cut the foil, the second bent it along its length to give a 'V' shape for rigidity, the third cut, the fourth bent, and so on. With the blades rotating at 800 rpm the cutter produced 8,000 'Chaff' strips per minute. I think Harold Elliott deserves great credit for his little machine, without which we might never have produced enough 'Chaff' to protect our bombers.

To go with his 'Chaff'-cutter, Elliot designed a device to sharpen the cutting blades when they became worn. The machine immediately went into production, and the first seventy-five machines were flown to Great Britain as priority cargo. Altogether more than 500 of these 'Chaff'-cutters were produced, and they would turn out a large proportion of the material used over Europe.

Not only did Elliott's machine produce 'Chaff' strips much faster than the earlier method, but the type of strip it produced was far more efficient. Elliott's machine produced strips about the same length as the earlier type, but they were only 1.3 mm wide. A V-shaped crease longitudinally down the middle of the strip provided the necessary rigidity. To produce a heavy-bomber echo required 3,600 of those strips, but they weighed only 3 oz (85 gr, or one-ninth the weight of the earlier bundle).

* * *

By September 1943 the Radio Research Laboratory had a strength of 600 personnel of all grades, of whom nearly 200 were engaged in research and engineering. The organisation continued to expand, though at a slower rate than previously.

Of the jammers developed at RRL at that time, the MPQ-1 'Tuba' transcended all others in the ambitiousness of its concept and its sheer physical size. This ground jamming system comprised two 25-kW transmitters. The equipment was carried in six large trucks and two trailers, and included three 75-kW diesel-electric generators to provide power. The target of this powerhouse of jamming was the *Lichtenstein* night-fighter radar, which operated on frequencies around 490 MHz. Beaming its output in a 30-degree arc extending eastwards towards Europe, in theory 'Tuba' would radiate sufficient power to produce 'white out' on the screen of any *Lichtenstein* radar within 200 miles of the jammer. The RAF placed an order for three 'Tubas' to protect its night bombers. We shall return to this device later in the chapter.

* * *

In the autumn of 1943 the RRL established a laboratory at Malvern, next to the Telecommunications Research Establishment, to provide technical support for the countermeasures equipments used by the US Army Air Force in Britain. Its full title was 'American-British Laboratory of Division 15', but invariably this was shortened to 'ABL-15'. Dr Cockburn described the arrival of the Americans:

> We at TRE were up to our ears in work and had been for such a long time, doing everything on a shoestring. By that time we were worked into the ground, it was very noticeable. Then suddenly this enormous fresh unit came in – in a short time ABL-15 was as big as our effort – with everybody beaming and

> shining with enthusiasm. There was great fraternity between ABL-15 and my department; we borrowed equipment from each other and that sort of thing. But from the start it was clear that it was a separate effort and they were working on different things for their armed forces.

* * *

On 3 November 1943, Air Chief Marshal Sir Arthur Harris minuted Prime Minister Churchill with an enticing offer:

> We can wreck Berlin from end to end if the USAAF will come in on it. It may cost us 400–500 aircraft. It will cost Germany the war.

This was the kind of promise Mr Churchill could not resist. However, the US strategic bomber force was still smarting from the severe losses suffered during its deep-penetration attacks in the summer and autumn of 1943; it could not 'come in on it'. Harris received authorisation to go it alone.

Though the nights were longer than they had been in the summer, the Reich capital remained a formidable target. An attack would involve a round trip exceeding 1,100 miles. Even taking the direct route, bombers had to cross 700 miles of enemy territory which would take at least three hours.

The first attack in the new series against Berlin was launched on 18 November 1943. Of the 444 heavy bombers taking part, only nine failed to return – a promisingly low rate. The command returned to the city three times more during November, and four times in the following month. On each occasion the losses were moderate, mainly as a consequence of bad weather over Germany.

* * *

Dr Plendl had given a great deal of thought to the problem of protecting German cities, and in particular Berlin, from night attacks. He produced a report on the capital's vulnerability to attacks by bombers carrying H2S radar, distributed to Göring, Milch, Martini, Armaments Minister Albert Speer and others. He said a jamming transmitter had been designed to counter H2S, code-named *Roderich*, but it needed to radiate far higher power if it was to be effective. Plendl continued:

> The only effective measure remaining to us is the active engagement of the aircraft equipped with *Rotterdam* [H2S] by 'homing' receivers. But these will enjoy success only so long as the enemy continues to leave *Rotterdam* continually switched on.

By the end of November 1943, the first aircraft was available with the *Naxos-Z* device, able to home on H2S transmissions from more than sixty miles away. The role of the new aircraft was to shadow the bomber stream and inform the fighter division headquarters of its position and heading so the latter could guide night-fighters in to intercept.

While the search for other solutions continued, the defenders had to rely on the more orthodox forms of deceit. By now there were large numbers of decoy fire sites in operation throughout Germany, with no fewer than fifteen such sites around the capital alone. The largest of these sites was situated fifteen miles northwest of Berlin, an elaborate affair measuring nine miles in diameter. It was almost a full-sized replica of the city made of plywood and cardboard, complete with a fake Tempelhof airfield. The sites produced simulated bomb explosions and houses on fire. Searchlight batteries and AA fire, combined with 'spoof' Pathfinder marking, served to give the sites a strong element of realism.

* * *

Early in the Battle of Berlin an 'Airborne Cigar' Lancaster had been shot down, and its equipment fell into Luftwaffe hands. On 30 November Oberst Schwenke reported on the find to Generalfeldmarschall Milch during a conference in Berlin:

> I have some interesting foreign intelligence, concerning a number of new things that have come to light. Three transmitters have been found in a Lancaster aircraft – in fact it was flying not with the normal seven-man but with an eight-man crew, one of whom was an additional radio operator. The set is called T.3160 and is apparently there to jam our VHF radio-telephone traffic.

Schwenke then reviewed the British jamming of the night-fighters' radios. This had begun on the high-frequency band (3–6 MHz) late in 1942, using the bomber's normal transmitter coupled to a microphone in the engine-bay (the RAF's 'Tinsel' device). The

Luftwaffe partially overcame the effects of this jamming by introducing a new VHF radio which worked in a part of the spectrum not covered by the bombers' communications transmitters. Now the RAF was jamming the VHF band too. Describing the captured ABC jammer, Schwenke said:

> It is a special VHF transmitter which cannot really be used for any other purpose as it is not employed in radio traffic at all itself. At present I cannot say how far this jamming can be defeated by appropriate countermeasures or frequency alteration.

Milch asked the obvious question, 'Could Luftwaffe fighters home on these enemy jamming transmitters?' Schwenke replied that any aircraft transmitter could be homed on, once its frequency had been established. Milch pointed out that the jamming transmitters would be tuned to Luftwaffe frequencies, so that should not be a problem. The trouble was, Schwenke said, that the RAF jamming aircraft switched on their transmitters for only short periods, to render homings impossible.

Schwenke went on to outline another issue, the RAF's introduction of the 'ghost' controller: 'Quite apart from this, the enemy now tries to upset our radio communication by cutting in on the traffic.' Milch asked: 'What are we doing about this?' He was told: 'For a week now we have been using girls to broadcast the radio-telephone instructions; that means the enemy will have to take girls into action with them!'

Evidently the Luftwaffe believed that the 'ghost' voice was airborne, like 'Airborne Cigar'. In fact the RAF would soon counter the latest Luftwaffe move by using German-speaking WAAFs to mimic the Luftwaffe women.

* * *

From the transcripts of the Berlin conferences, it was all too apparent that the Luftwaffe accepted that RAF Bomber Command was retaining the upper hand in the radio-countermeasures struggle. The Luftwaffe, in Milch's pithy phrase, was reduced to 'trotting after' its enemy. During a conference in Berlin in December 1943, a quarrel developed between Milch and General Wolfgang Martini, head of the Luftwaffe signals service. The subject was the Allied radar and jamming system. Milch protested:

> When I read your own comments on this, Martini, I must say I find them bursting with such pessimism that I am forced to ask, is it really justified? The *Reichsmarschall* [Göring] declares: 'Apparently we can't jam anything and the British can jam everything!' And all you say is, 'Yes, that's about it!'

Martini retorted that the reason for his pessimism was that so far the Luftwaffe had been unable to fly radio-reconnaissance missions over England. Moreover, the German electronics industry no longer had the manpower or the spare capacity to development new systems on the scale required. In response Milch proclaimed:

> The *Reichsmarschall* looks at it differently. He says quite openly: 'On our side we have only wool-gatherers! The British can do things much better than us!' For a while that might have been true, with an equipment like their *Rotterdam* [H2S].

Later in the conference, Milch became philosophical. He mused that the British were a seafaring nation, and therefore born navigators. The Luftwaffe, on the other hand, had its roots in the army. You could not call stopping at every crossroads and looking at the signposts 'navigation'.

* * *

On 16 December 1943, the RAF launched yet another attack on Berlin. The bomber stream was tracked by its H2S radar transmissions all the way to and from the target. As was now becoming common, the diversionary attacks by Mosquitoes were recognised as such by the light bombers' high speed, and the fact that they emitted no H2S transmissions. Yet the weather was unfavourable for night-fighting, and the Luftwaffe Fighter Corps complained of other impediments:

> Corps VHF radio jammed by bell sounds, radio-telephone traffic hardly possible, jamming of Corps HF radio by quotations from Hitler's speeches, Corps alternative frequency and division frequencies strongly jammed. Very sudden jamming of the Anne-Marie forces broadcasting station by continuous sound from a powerful enemy transmitter.

That last move was not made out of spite, for the RAF listening service had deduced the reason for the unbalanced musical selection coming from the Stuttgart broadcasting station. During attacks it now provided a crude means of indicating the position of the RAF bomber stream. Waltzes meant bombers were in the Munich area, jazz meant Berlin, church music Münster, Rhenish music Cologne, and so on. With the departure of the raiders, the station broadcast the march 'Old Comrades' then resumed normal transmissions. As soon as the crude – and it must be admitted desperate – stratagem was recognised, the RAF brought into use a special high-powered transmitter code-named 'Dartboard' to jam the broadcasts. That was the jammer that the Luftwaffe had heard.

As a last resort, the Luftwaffe took to broadcasting instructions to night-fighters in Morse code, which is difficult to jam. The RAF reacted by setting up transmitters in England, appropriately dubbed 'Drumsticks', to broadcast meaningless strings of Morse letters on the Luftwaffe frequencies. Only by broadcasting orders simultaneously on several channels, could the Luftwaffe fighter controllers avoid the worst effects of the jamming. That meant the frustrated aircrews had their work cut out searching the spectrum for an unjammed frequency, and even when they found one there was no guarantee it would remain that way for long. That was the effect of the combined offensive mounted by the 'Tinsel', 'Corona', 'Airborne Cigar', 'Drumstick' and 'Dartboard'.

* * *

The high-precision bombing attacks on targets in the Ruhr area still mystified the Luftwaffe, for the defenders had not succeeded in capturing an 'Oboe' airborne repeater intact. As a result, information on the system's working was sparse. The Luftwaffe allocated the mystery system the code-name *Bumerang* ('boomerang'). At one of the conferences, Generalfeldmarschall Milch referred to 'an extraordinarily accurate attack on the August-Thyssen blast furnaces'. He said only five bombs had been dropped, and all scored hits. Reichsminister Albert Speer added:

> It is certainly remarkable that for these last two months in an increasing number of isolated nuisance-raids, six, eight, or ten bombs have been dropped, usually through heavy cloud cover, of which 80–90 per cent have hit blast furnaces or power stations.

By chance, a radio monitoring station near Essen noticed, during an attack on Cologne, that the release of Pathfinder flares appeared to coincide with the transmission of the Morse signal 5T (dot-dot-dot-dot-dot-dash). In fact this was not a Morse signal, though the German listeners could be forgiven for thinking it was. The succession of dots indicated to the plane's navigator 'prepare to release', and he pressed the button to release the target markers when the dash ended. In November, twenty-one Mosquitoes made successive bombing runs on the Bochum Union steelworks. At a conference bringing together the works' civil defence officers, local flak officers and radio-monitoring experts, the flak officers perceptively noted that the aircraft followed 'a gently curving track, centred on the southern coast of England'. Once again, the bomb release had coincided with the transmission of the apparent Morse signal 5T.

As an initial countermove, a *Freya* radar was positioned south of Duisburg to measure the exact track and starting point of each Mosquito's bomb run. In each case, the run commenced about eight minutes before bomb release. That was a useful discovery; it gave just enough time for the sirens to be sounded in the threatened area.

Even Adolf Hitler became involved with the *Bumerang* controversy. Often the targets had been steelworks, so he ordered the intelligence services to investigate whether the enemy bombs carried some kind of infrared homing system to enable them to home on these targets. This drew the reply that examination of bombs that failed to explode had revealed no radio-control or other guidance system. SS chief Heinrich Himmler joined in the hunt, ordering his own security service to look for evidence that Allied agents might have planted radio beacons near vital targets. Again, the searchers drew a blank.

Gradually the mystery began to unravel, as Milch was told:

> The British have special Mosquito crews expert in radar technique, who have been under training for long periods. They drop their salvoes from altitudes of 25,000 to 30,000 feet blindly into the works. They have two devices on board for this, and with these they make two distance-measurements. Through these receivers, the instruction is radioed for the bombs to be released. It is up to us to jam this system at once.

On the instructions of Generaloberst Weise, the Reich Air Defence Commander-in-Chief, a jamming transmitter code-named *Karl* was built to jam the 'Oboe' frequencies. The transmitters were set up on either side of the 'Oboe' tracks, and during November 1943 the jamming became progressively more serious. Matters culminated on the night of the 19th/20th, during a twin attack on Ruhrort and Leverkusen, when the 'Oboe' system failed completely. In other areas the jamming was less effective, however. During an all-Mosquito attack on the Krupp works at Essen on 12 December, ninety per cent of the bombs scored direct hits in spite of the jamming.

On 7 January 1944, a Mosquito was brought down near Kleve. At last, Luftwaffe intelligence officers could inspect an example of the precious 'Oboe' equipment. Within three days, plans had been laid for a network of about eighty jamming transmitters to transmit 'noise' over the frequency range 220–250 MHz.

The RAF had enjoyed the unhindered use of 'Oboe' Mark I for about a year, which was longer than anyone could reasonably have expected. The counter to the jamming was an obvious one, that had been withheld until now: the introduction of the 'Oboe' Mark II operating on centimetric wavelengths.

On 30 January 1944, a *Naxburg* station picked up 'Oboe-type' signals on a wavelength of 9 centimetres transmitted from a high-flying Mosquito to its directing station in England. For a time this evidence was discounted, however, since the radio-monitoring service also picked up 'Oboe' signals on the old longer wavelength. The possibility that the 'old' signals were being transmitted as camouflage did not occur to the Luftwaffe for several months, during which time the 'Oboe' Mark II operations continued without interference.

* * *

In December 1943, Telefunken's Dr Rottgardt was forced to admit that the technique of ridding the *Lichtenstein* radar of the effects of metal-foil jamming remained inadequate:

> At present our technology has no answer to *Düppel* – and certainly none that could be employed in an aircraft. In fact we are not working on one, and I don't see any way in which one could.

The ideal solution was to produce a centimetric airborne radar along the lines of the American SCR-720/AI Mark X. But German techniques on such short wavelengths were inadequate for the task, and it would take well over a year to bring such a radar into service.

Telefunken's *SN-2* airborne interception radar, rejected by the Luftwaffe earlier, now suddenly came into its own. This modified ship-search radar operated on 90 MHz, a much lower frequency than that of *Lichtenstein*. (The new radar's full title was *Lichtenstein SN-2*, but to avoid confusion in this account it will be referred to throughout as '*SN-2*'). Although *SN-2*'s maximum range of four miles and its wide angle-of-cover represented valuable improvements over *Lichtenstein*, its long minimum range of 400 yards made it virtually unacceptable for the night-fighter role. Except on the brightest of nights, it was likely that the target aircraft would disappear off the radar screen before the night-fighter pilot made visual contact. Then somebody recognised that *SN-2* was unaffected by the type of 'Window/Chaff' then used by the RAF.

The Luftwaffe launched a crash programme to rush *SN-2* into production, and as sets became available they were installed in night-fighters. To overcome the problem of the long minimum range, as a temporary expedient these night-fighters also carried a simplified version of the earlier *Lichtenstein* equipment. That made for a weighty installation, with a forest of drag-producing aerials on the nose of the aircraft. The radar operator now had no fewer than five radar screens in front of him – three for *Lichtenstein* and two for *SN-2*. It was an inelegant solution to the problem, but in the short term there was no workable alternative. Work began at top priority to reduce *SN-2*'s excessively long minimum range, but some months would elapse before it bore fruit.

* * *

The new year brought a new overlord for the German radar research programme. Dr Hans Plendl retired from his post as Plenipotentiary for High-Frequency Research. Professor Abraham Esau, previously Plenipotentiary for Nuclear Physics, replaced him. During his year in office, Plendl had achieved a substantial amount. He had put radar research on a sounder footing, and he had laid the foundations for developing German centimetric-wavelength radars. He had worked tirelessly on the problems of defeating the effects of 'Window/Chaff'.

Yet Plendl had seen enough to realise that he had been fighting a losing battle. In a letter to Himmler early in January 1944, he spoke of the tenfold greater capacity of the Western powers, their vastly superior resources and raw materials, and their industries untouched by bombing. The German people could only hope to make up for that by enthusiasm and self-sacrifice: 'In my view,' Plendl continued, 'this is the only magic charm that can break the spell in the long run.'

Soon after Abraham Esau took up his appointment, he persuaded Hermann Göring to launch a nationwide competition to find the best method of defeating 'Window/Chaff'. An official circular invited competitors to 'give a method and means whereby either the jamming can be obviated or a distinction can be drawn between the jamming "targets" and the true target, when large clouds of *Düppel* are used.' The solutions offered had to be technically feasible and clear, and the solution had to be kept secret from those outside the group involved. There were six large monetary prizes for the best solutions, which were to reach the Air Ministry in Berlin by 1 April 1944. In the months that followed, Esau's department investigated no fewer than twenty-five separate anti-*Düppel* schemes. The schemes met with varying degrees of success, but it seems that none was judged worthy of a prize.

* * *

Even though the Luftwaffe had no complete answer to 'Window/Chaff', as 1944 opened RAF Bomber Command's losses over Germany began to rise alarmingly. Sir Arthur Harris was committing his entire force in an attempt to destroy major cities and in particular Berlin. The revitalised German defences were determined to prevent this. The night-fighter crews were flying to defend their own homes and loved ones, and they did so with bravery and determination. No longer was it on isolated occasions that the raiders suffered heavily.

The first of the costly actions took place on the night of 21/22 January, when 648 bombers set out to bomb Magdeburg. Fifty-five bombers failed to return; not since the disastrous attack on Berlin itself five months earlier had the RAF suffered so heavily. The bombers fought back hard, but the Luftwaffe losses amounted to only seven night-fighters. One of those was a Ju 88 piloted by the famous ace Major Prince zu Sayn-Wittgenstein, holder of the Knight's Cross with Oak Leaves and the highest-scoring German night-fighter pilot so far with eighty-three victories. His radio operator, Feldwebel Ostheimer, later described what happened after they took off on a 'Tame Boar' operation:

> At about 10 p.m. I picked up the first contact on my [*SN-2*] airborne radar. I gave the pilot directions and a little later our target was seen: it was a Lancaster. We moved into position and opened fire, and the aircraft immediately caught fire in the left wing. It went down at a steep angle and started to spin. Between 10 and 10.05 p.m. the bomber crashed and went off with a violent explosion. I watched the crash.
>
> Again we searched. At times I could see as many as six aircraft on my radar. After some further directions, the next target was in sight – another Lancaster. After the first burst from us there was a small fire, and the machine dropped its left wing and went down in a vertical dive. Shortly afterwards I saw it crash. It was some time between 10.10 p.m. and 10.15 p.m. When it crashed there were heavy detonations, most probably it was the bomb load. After a short interval we again saw a Lancaster. After a long burst of fire the bomber caught fire and went down. I saw it crash some time between 10.25 p.m. and 10.30 p.m. The exact time is not known. Immediately afterwards we saw yet another four-engined bomber. We were in the middle of the 'bomber stream'. After one pass this bomber went down in flames; at about 10.40 p.m. I saw the crash.

Obviously, Feldwebel Ostheimer's *SN-2* radar was unaffected by any of the British countermeasures. The account also shows the destruction that that could be wrought a single talented night-fighter crew.

Within a few minutes, Ostheimer had another target 'blip' on his radar. After a few course alterations, yet another Lancaster hove into sight. Wittgenstein closed in and delivered an attack, and the bomber started to burn. Then the fire went out, so the German pilot moved into position for another attack. Suddenly a series of explosions rocked the Ju 88, and its left wing caught fire. Ostheimer continued:

> As I saw this, the canopy above my head flew off and I heard on the intercom a shout of '*Raus!*' ['Get out!'] I tore off my oxygen mask and helmet and was then thrown out of the aircraft.

Ostheimer landed safely by parachute, but Wittgenstein was unable to escape from his cockpit. His body was later found in the wreckage. Only the night before, the intrepid pair had gone so close below a Halifax to make certain of hitting it with their upward-firing cannon, that the plunging bomber had struck their aircraft. They had been lucky to escape with their lives, but this time the night-fighter ace had not been so fortunate. Almost certainly the Ju 88 had been attacked by another bomber in the stream. Five 'Serrate' Beaufighters of No. 141 Squadron had operated over Germany that night, but none made any claim. It seems that Wittgenstein had fallen victim to a surprise attack from below – a form of attack that he himself had used to great effect.

Also that night, the Luftwaffe suffered another important loss. Not far from where Wittgenstein's Ju 88 crashed, there lay the wreckage of an He 219 night-fighter. Its pilot was also dead – Hauptmann Manfred Meurer, the third-highest-scoring night-fighter pilot with sixty-five victories. Meurer died when the bomber he had just shot down tipped on one wing and crashed into his aircraft. This was clearly a major hazard of such close combat.

By the beginning of February 1944, the equipment fitted to Luftwaffe night-fighters was showing a marked improvement. Twenty-eight *Naxos-Z* receivers had been delivered, to enable the night-fighters to home on individual aircraft radiating H2S signals. Also by then, 200 *SN-2* radars were installed in night-fighters and several hundred more were on their way. The RAF had yet to discover the existence of the new radar, and it remained unjammed.

Making the most of the new situation, the Luftwaffe took an increasingly heavy toll of the attacking bombers. On the night of 28/29 January, forty-three bombers failed to return out of 683 attacking Berlin. The following month was even worse. On 15 February, forty-two were lost out of 891 attacking Berlin. Four days later Bomber Command lost seventy-eight out of 823 attacking Leipzig, a success which the Luftwaffe attributed entirely to use of *SN-2* with its pursuit night-fighting tactics.

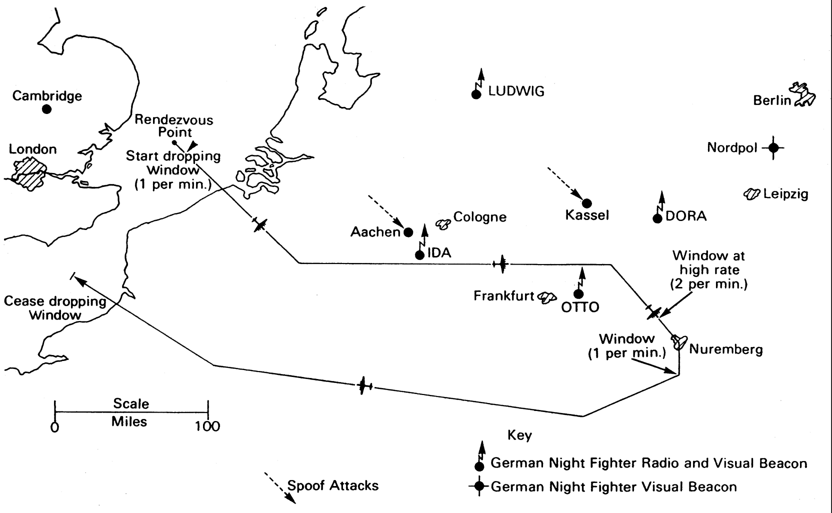
On many occasions, the Luftwaffe fighter controllers were able to see through the RAF's attempts to divert night-fighters away from the raiders. Yet, on the night of 20/21 February, there was a spectacular exception. That night about 200 aircraft from Bomber Command operational training units flew across the North Sea almost as far as Heligoland. In anticipation of yet another attack on Berlin, nearly the whole of the German night-fighter force assembled over southern Denmark. A short distance from the coast the training aircraft turned around and headed for home. Only then did the fighter controllers realise their mistake.

By then a larger force of bombers was reported nearing the Rhine, having flown across France. This was the RAF's main attacking force, comprising 598 bombers. When they realised what was happening, the Luftwaffe controllers ordered their fighters to Strasbourg. They could have saved their breath for the distance involved, about 400 miles, represented an hour and a half's flying time. Those fighters which arrived in the area with fuel remaining in their tanks did so long after the bombers had departed, after delivering a sharp attack on Stuttgart which therefore cost the RAF just nine bombers. This sort of deception impressed on Luftwaffe controllers the need to delay committing the bulk of their force, until the air situation was clear. Usually they could afford to wait since, during their deep-penetration attacks, bombers often spent two hours or more over Germany. During a follow-up attack on Stuttgart on 15 March, the RAF lost thirty-six bombers out of 863.

Bomber Command next penetrated deeply into Germany, to Berlin, on the night of 24/25 March. The Luftwaffe concentrated its forces around the capital in good time, and the raiding force suffered accordingly. Seventy-two bombers, out of the 811 despatched, were shot down. Even a successful attack on Essen two days later, which cost nine bombers out of 705, did not make up for that.

RAF Bomber Command's final visit to Germany in this series of attacks took place on the night of 30/31 March. It was to be Sir Arthur Harris' last attempt to smash a major city target before operational control of his force passed to General Eisenhower to prepare the way for the forthcoming invasion of Europe. The night's target was Nuremberg, and 795 bombers set out to attack it.

Even before the leading aircraft crossed the Dutch coast, the Luftwaffe was tracking the bomber stream by exploiting its H2S transmissions. As a result Mosquito spoof attacks on Cologne, Frankfurt and Kassel and other minor targets all failed. As before, the give-away was that the Mosquitoes did not radiate H2S signals. Luftwaffe ground controllers exploited this intelligence to the full, aiming to direct night-fighter units into the bomber stream as far to the west as possible. In this they were assisted by the bombers' routing, which ran in a straight line for hundreds of miles across German territory, with a turning point just short of the target. The controller of the 3rd Fighter Division ordered his twin-engined night-fighters to assemble over radio beacon *Ida* to the southeast of Aachen. At midnight, when the bomber stream was thundering past that beacon, there were 246 night-fighters airborne.



Attack on Nuremberg: 30/31 March 1944

Due to unusual meteorological conditions, the bomber crews faced an unexpected extra hazard that night. Each minute, the petrol burned in each aero engine produced about a gallon of water in the form of steam. Normally that steam was dispersed in the airflow, but on this cold night it condensed. Long white condensation trails chased remorselessly behind each bomber. It was a clear night, and the glow from the half moon gave the vapour trails a phosphorescent quality. That night the winds at altitude were stronger than forecast, with the result that the bomber stream began to lose cohesion. Even before it reached its first major turning point, it was moving on a front forty miles wide. The 3rd Fighter Division joined battle near

Ida, to start a running fight that would last for the next 200 miles.

As usual, the Luftwaffe radio communications were beset by every kind of jamming – bell sounds, quotations from Hitler's speeches, a continuous 'doodle-doodle-doodle' and even an electronically-generated wail which Luftwaffe crews nicknamed 'bagpipes'. And again Anne Marie musical transmissions were blotted out. Yet, with so many night-fighters already concentrated close to the bombers' path, the jamming achieved little. Unteroffizier Emil Nonenmacher of NJG 2 had taken off in his Ju 88 from Twente in Holland. Once airborne, he headed for *Ida* in the climb. He later recalled:

> As we climbed out of Twente we could see a great battle in progress: aircraft burning in the air and on the ground, much firing of tracer rounds. We kept on towards the scene of high activity for about five minutes, then suddenly we hit a bomber's slipstream. We were now in the bomber stream. It seemed that all around us there was activity – here an aircraft on fire, there someone firing, somewhere else an explosion on the ground. Yet it was a few minutes before we caught sight of the silhouette of a bomber. I looked up and saw a bomber flying obliquely over my cockpit. I tried to get into a firing position, but it was too difficult to line up on him. It did not matter, by then I had another bomber in sight, 500 metres away, in front and to the left. I accelerated to catch him when yet another bomber swung in front of me, about 150 metres in front. With so many targets I could take my pick, so I chose the nearest one and went after him.

Nonenmacher fired a short burst and saw hits on the bomber, then his guns jammed. While his crewman worked to clear the stoppage, the Lancaster escaped. He then found another bomber, and by then his guns were ready to fire:

> I moved into a firing position about 100 metres astern and a little below it. I pressed the firing button and saw my rounds striking the left wing, then both [left] engines caught fire. He began to lose height slowly. We saw the crew bail out, it was so clear. The bomber took about six minutes to reach the ground. When it crashed there was a mighty explosion.

By now the special Luftwaffe illuminating unit had also located the bomber stream. Its Ju 88s dropped strings of parachute flares, which could be seen from fighters scores of miles away which duly converged on the scene, like moths drawn to a flame. Aircraft of the 2nd Fighter Division arrived from northern Germany; the 1st Division came from the Berlin area, moving westwards almost on a collision course; the 7th Fighter Division came from southern Germany, via radio beacon *Otto*. It was an ideal night for the 'Tame Boar' tactics, and the night-fighters wrought fearful execution. A crewman aboard one RAF Pathfinder recalled hearing his pilot exclaim: 'Better put your parachutes on, chaps. I have just seen the forty-second go down.'

At the bombers' altitude, a 50-mph tail wind carried many of them to the east of their intended track, particularly during the final southeasterly leg approaching the target. Consequently, defending fighter controllers had difficulty in deciding the bombers' target. Not until 0052 hours, two minutes before the bombing was due to start, did the running commentary mention Nuremberg for the first time.

When the attack opened the single-seat *Wilde Sau* fighters were all too far from Nuremberg to go into action. One force orbited over radio beacon *Otto*, in anticipation of an attack on Frankfurt. Another force waited over beacon *Nordpol* to cover the twin threats to Berlin and Leipzig. Thus only the twin-engined night-fighters went into battle that night; about 200 of them saw action.

Over Nuremberg there were dense clouds rising almost to the bombers' altitude. When the Pathfinders released their markers, these were soon swallowed up in the murk. The few bombs that fell on the city caused little damage. So widely scattered was the bomber force as it withdrew that the Luftwaffe night-fighters lost track of it almost completely. For the most part, the surviving bombers were unmolested during their return flights. For Bomber Command the cost of the Nuremberg raid – the high point in the Luftwaffe's pursuit night-fighting phase – was very high indeed: ninety-four Lancasters and Halifaxes failed to return, nearly all of them shot down along the route between radio beacon *Ida* and the target. That part of the raiders' track was clearly marked by aircraft burning on the ground.

Both during and since the war there have been allegations that the Luftwaffe knew beforehand that the night's target was

Nuremberg, and had arranged its defences accordingly. Whatever the truth of the former suggestion, the dispositions of the 'Wild Boar' units – well clear of the city – make it clear that the latter was incorrect. The raiders suffered most of their losses before they reached the target, and relatively few bombers were lost during the return flight. Had foreknowledge of the target been the reason for the disaster one would expect that pattern to have been reversed, with the bulk of the losses being suffered over the target and during the return flight.

So ended the so-called 'Battle of Berlin'. The Reich capital had not been destroyed, although Bomber Command had lost more than twice the number of aircraft Sir Arthur Harris had predicted five months earlier. During the thirty-five major attacks between 18 November 1943 and 31 March 1944, the Command lost 1,047 aircraft destroyed and a further 1,682 damaged. Whatever its outcome, the Nuremberg attack would have marked the end of this phase in the campaign. Now the heavy bombers were needed to hit targets in France and the Low Countries, in preparation for the forthcoming invasion of Normandy. But even had Harris been allowed to continue his deep-penetration attacks on Germany, it is difficult to believe that his command could have continued to accept such punishing losses. In the night skies over Berlin, Magdeburg, Leipzig and Nuremberg, the Luftwaffe night-fighters had avenged their humiliation over Hamburg in the summer of 1943. They had demonstrated their remarkable resilience, and in doing so had come close to making the destruction of their homeland too expensive for the RAF.

* * *

The countermeasures system designed to impede Luftwaffe night-fighter operations, RRL's mighty 50 kW 'Tuba' ground jammer, had commenced transmissions in February 1944. From Sizewell in Suffolk, the device beamed a powerhouse of jamming across the North Sea towards Holland, Belgium and Germany. 'Tuba' was a magnificent technical achievement and it deserved to accomplish great things. Due to a flawed tactical concept and a mismatch in timing, however, it failed to achieve anything.

It will be remembered that the target of 'Tuba' was the 490 MHz *Lichtenstein* radar carried by Luftwaffe night-fighters. Yet this radar would pick up the jamming only when the fighter's nose pointed in the general direction of the jammer. At night, due to the poor visibility, Luftwaffe fighter pilots could deliver an attack on an enemy bomber only from the latter's rear hemisphere. That meant the RAF bombers could receive protection from 'Tuba' only during their homeward flights. The curvature of the earth imposed a further limit on 'Tuba's' effectiveness. RAF heavy bombers operated at altitudes of 22,000 feet and below, as did the night-fighters attempting to intercept them. At those altitudes the maximum effective range of 'Tuba' was about 175 miles, which meant the jamming petered out somewhat short of the German border.

Those two limitations were bad enough, but a further factor prevented 'Tuba' from having any effect at all. By the time 'Tuba' began transmitting, the *Lichtenstein* had virtually passed out of front-line service, having been replaced by the later *SN-2* radar. During the spring of 1944, 'Tuba' was turned on on numerous occasions to support RAF night attacks. Surviving German records make no mention of any difficulties that can be linked to the jammer, however. It is likely that the intended recipients never even noticed its thunderous crescendo.

* * *

While RAF Bomber Command was licking its wounds after its worst spell of losses, the US Eighth Air Force in Great Britain had made a full recovery from its earlier spell of bloodletting. By March 1944 the new P-51B Mustang escort fighter had become available in quantity, able to protect bomber formations all the way to targets deep inside Germany. In carrying out that role, the escorts inflicted heavy cumulative losses on the defending day-fighter force.

At the same time, however, the German flak defences had been greatly strengthened. Previously, fighters had caused the majority of US heavy bomber losses. From the spring of 1944, it was flak that caused the majority of losses. With the strengthening of the flak defences, the Luftwaffe made considerable efforts to circumvent the 'Carpet' and 'Window/Chaff' jamming aimed at the *Würzburg* fire-control radar. The Telefunken Company developed the *Wismar* modification which allowed the radar to operate on an extra band of frequencies, and shift frequency rapidly within the bands. The original *Würzburg* band, 553–566 MHz, was supplemented by a new band from 517–529 MHz. With practice, a good radar crew could shift frequency within the band in use in less than a minute. To change between bands required a mechanic to make the necessary adjustments, and took about four minutes.

By March 1944, a substantial proportion of the *Würzburg* sets had been fitted with *Wismar*. By that time most *Würzburg* radars carried the *Würzlaus* and *Nürnberg* modifications to provide relief from the effects of 'Window/Chaff'. The Luftwaffe radar operators soon discovered to their discomfort, however, that *Wismar* was not fully compatible with the 'anti-Window/Chaff' modifications. If operators shifted its frequency using *Wismar*, the *Würzlaus* required to be re-adjusted and that took a lot longer than an engagement was likely to last.

Also at this time a new type of flak-control radar, the *Mannheim*, entered service in the Luftwaffe. Another product of the Telefunken Company, the *Mannheim* featured several improvements over the *Würzburg*. Yet, surprisingly, the new radar operated on the same band of frequencies as its predecessor, it carried the same anti-jamming devices and it was similarly susceptible to Allied countermeasures. For that reason the two radars will be considered together in this account.

* * *

In the spring of 1944 Great Britain was one huge armed camp, packed with men and equipment assembled for the forthcoming invasion of northern Europe. Electronic countermeasures would have a vitally important part to play in that venture, as we shall observe in the next chapter.

Chapter 11

In Support of the Invasion

> 'A landing against organised and highly trained opposition is probably the most difficult undertaking which military forces are called upon to face.'
>
> General of the Army George Marshall

> 'Confusion now hath made his masterpiece.'
>
> Shakespeare, *Macbeth*

Whatever its outcome, the invasion of northern Europe in June 1944 was bound to have decisive importance. Should it fail, Allied losses would almost certainly be so great that Adolf Hitler need not fear for his western territories for a considerable time to come. If it succeeded, the end of the Third Reich would be in sight. Those were the issues, and they were important enough to warrant the preparation of the most elaborate programme of radio-countermeasures ever devised.

If the invasion was to achieve tactical surprise, the first priority was to destroy as many as possible of the radar stations erected along the coasts of France and Belgium as part of the formidable German 'West Wall'. Along the northern shores of France and Belgium, no fewer than ninety-two radar sites kept watch out to sea. These sites operated the menagerie of German ground radars – the long range *Mammut* and *Wassermann* sets, the Giant and the standard *Würzburg*, the *Freya* and the naval *Seetakt*. For the invaders, that multiplicity of 'radar eyes' made the jamming problem more difficult than anything previously attempted. Yet the problem of deception promised to be even more formidable. To keep Luftwaffe fighter controllers guessing for half an hour or so as to the real target of an RAF bomber force moving at 225 mph was one thing; to conceal a mighty invasion fleet moving at ten knots, for ten hours or more, was quite another.

The planners devised a step-by-step programme of radio-countermeasures to support the invasion. First, the radar stations were to be located accurately, then the majority would be knocked out by air attack. On the night of the invasion, feint invasion forces would try to draw German attention away from the genuine landing areas. At the same time, heavy jamming would be turned on against any radar stations that remained operational in the invasion area.

By the spring of 1944 R. V. Jones's scientific intelligence department had assembled a comprehensive picture of the German coastal radar network, but that picture had to be kept constantly updated because the radar sets, especially mobile ones like the *Freya* and the small *Würzburg*, could move quickly and be operational at a new site within a few hours of their arrival. To assist the plotting of the radar stations, Dr Cockburn's team produced a ground direction-finder – 'Ping Pong' – which could measure the bearing of a radar transmitter to an accuracy of a quarter of a degree. Three of these equipments were positioned along the south coast of England, where they provided fixes on radar stations on the other side of the Channel. Once a radar's approximate position had been triangulated in this way, its location was confirmed by photographic reconnaissance.

It fell to the RAF's Second Tactical Air Force to deliver the required attacks on the German radar stations. These opened on 16 March 1944, when twelve Typhoon fighter-bombers of No. 198 Squadron set about a *Wassermann* early-warning radar near Ostende on the Belgian coast. The formation crossed the coast shortly after midday at 8,000 feet as though heading for an inland target. Once past the coast, the four aircraft in the main attack force dived to low altitude and streaked in at treetop height towards the towering aerial. As they did so, the rest of the Typhoons dived straight in to strafe flak emplacements guarding the radar station. The four aircraft in the main attack force each launched eight 60-pound rockets at the aerial structure, scoring several hits. As the raiders sped away from the scene, however, the *Wassermann* tower remained upright. So, that afternoon, the squadron delivered a second attack on the radar. Despite more rocket hits, the battered tower still remained standing.

Although the aerial tower was still upright, the radar had not escaped unscathed. The Achilles' heel of the *Wassermann* tower lay in the turning mechanism. The aerial array was mounted on a rotating sleeve, which turned on a fixed vertical cylinder, and to lower the tower to the ground for repair it had to be facing in a certain direction. The exploding rocket warheads had distorted the sleeve, preventing the tower from being turned to the required direction for lowering. Thus the tower was rigidly locked in the vertical position, and the structure had to be dismantled before repair work could begin. In fact, that particular radar would still be off the air when the invasion began.

As the RAF soon discovered, the *Mammut* radar also had weaknesses. The rear of the fixed aerial array was a mass of feeder cables, which had to be carefully adjusted to give the correct beam shape. Then the radar had to be checked in a series of calibration flights, in which an aircraft carefully flew set patterns and the radar operators tracked it. The feeder cables were attached to the rear face of the aerial array, where they were vulnerable even to machine-gun fire. If several feeders were cut, the *Mammut* was out of action until they were repaired and the tedious calibration process was repeated.

In the months before the invasion, Mosquitoes, Spitfires and Typhoons of Second Tactical Air Force flew nearly 2,000 sorties against radar targets in France and Belgium. At a high cost in aircraft, they put out of action all but sixteen of the original ninety-two sites. All the narrow-beam *Mammut* and *Wassermann* sets, the most difficult to jam, were put out of action. When D-Day dawned, no German radar remained in full operation in the invasion area.

* * *

As the programme of attacks on the German radar sites took effect, the first dedicated US radio-countermeasures unit in England began forming: the 803rd Bombardment Squadron based at Sculthorpe. In May 1944 the squadron, equipped with eight B-17 Flying Fortresses, transferred to Oulton in Norfolk. These aircraft carried combinations of 'Carpet' and British 'Mandrel' jammers, typically nine of the former and four of the latter. Later an additional B-17 joined the unit, fitted out as a ferret aircraft with SCR-587 and Hallicrafters S.27 receivers. The squadron became operational early in June, just in time for the invasion.

* * *

By this stage of the war, the Allied intelligence services were gaining a wealth of information from intercepted German signals.

Communications jamming would interfere with that flow, so it could be permitted only in exceptional circumstances. Yet there was a need to have a capability in this area, lest the forthcoming land battle enter a critical phase where such jamming might swing the balance. During 1943, the RRL had designed a family of communications jammers to operate on the frequencies used by German aircraft and tank radios. Two of these jammers, the airborne ART-3 'Jackal' and the ground MRT-1, went into limited production. During flight testing at Wright Field, Ohio, the former proved a bit too effective for comfort, as Lieutenant Colonel George Haller, in charge of the trial, recalled:

> During the lead up to the invasion we conducted tests with a new type of communications jammer, the ART-3 'Jackal', a frequency modulated device to jam the German tank communications on the 27 to 33 MHz band. What we did not realise, however, was that the radios used by some Ohio police departments used the same frequencies as the German *Panzers*. One afternoon, during a test of our airborne jamming of these tank frequencies to determine its effectiveness, there was a serious bank robbery in one of the small towns near our base. The robbers were able to make their escape due to our jamming of the police radios. The FBI soon figured out what the problem was and our laboratory was subjected to a thorough investigation to see if there was any connection between us and the robbers. Fortunately we were found to be clean.

* * *

Also at this time there was a crash programme to install 'Mandrel' and 'Carpet' jammers to some 200 of the warships and landing craft scheduled to take part in the invasion. That work engaged most of ABL-15's resources for several weeks. As well as installing the equipment, it was necessary for a staff member to visit each ship to instruct the radioman how to switch on the jammer at the appropriate time. Also, he had to explain to the skipper of the craft the purpose and operation of the equipment. Some skippers quickly understood the purpose of the equipment and were enthusiastic to have it. Others gained a mistaken idea that jamming might attract radar-directed fire on to their ship, and were lukewarm or in a few cases openly antagonistic to it. The ABL technicians did their best to correct this attitude, whenever they encountered it.

* * *

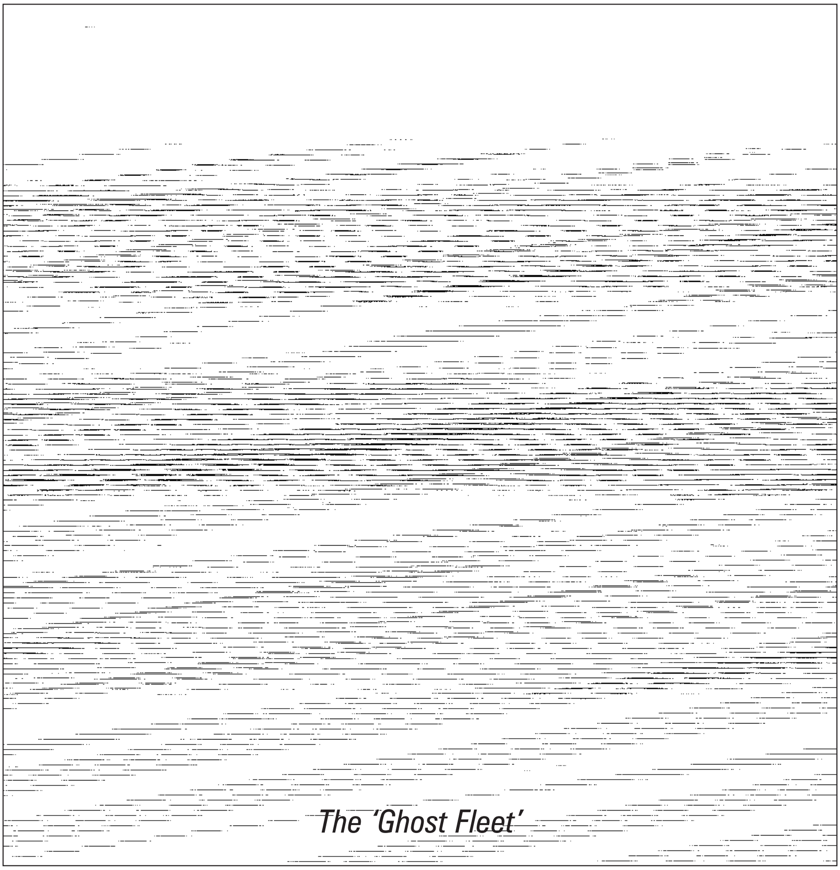
Throughout the early spring of 1944 the British and American teams at Malvern (henceforth referred to as 'the Malvern teams') put the finishing touches to the most elaborate piece of spoofery yet attempted: the simulation on German radar screens of two full-scale 'invasion fleets'. The simplest way to achieve that would have been to use large numbers of full-sized ships. But the invasion stretched Allied shipping resources to the utmost, and none could be spared for that purpose. So the countermeasures teams devised a way of producing on radar a response which would look like a real invasion fleet, but which employed no full-sized ships at all.

Essentially, the idea was to lay out a huge radar reflector covering a square with sides sixteen miles long – an area of 256 square miles – and have it appear to move across the English Channel at eight knots. The reflector would consist of 'Window/Chaff' clouds at specially calculated spacings, sown by aircraft flying carefully designed patterns. Joan Curran, who had conducted the initial Window trials in 1942, did the mathematical calculations for the spoof.

Wing Commander Derek Jackson devised a new type of 'Window/Chaff' for the operation. The *Seetakt* coast-watching radar, and the *Freya*, both worked on a much longer wavelength than the AA gun-laying *Würzburg*. So the strips to confuse these systems had to be much longer than those already in use. For the spoof the strips needed to be nearly six feet long, which meant they would be unmanageable in the narrow confines of an aircraft. To solve the problem, Jackson designed a new type of strip that folded concertina-fashion into manageable lengths. A small weight at the bottom of the strip ensured that, after release from the aircraft, the zigzag unfolded to the correct length.

Taking the *Seetakt* as the more difficult of the two radars to be spoofed, the 'ghost fleet' was designed to be effective against that one: if it worked against *Seetakt*, it would certainly fool *Freya*. The naval radar's beam was fifteen degrees wide, so ten miles from the radar its beam was four miles wide. Placing 'Window/Chaff' clouds within two miles of each other, along the width of the 'ghost fleet', would therefore produce a continuous 'blip' in azimuth on the

Seetakt screen. The depth perception of the German radar was such that it could not discriminate between targets less than 520 yards apart. The aircraft sowing the strips were to fly at 180 mph, three miles per minute. So dropping twelve bundles per minute would produce clouds at 440-yard intervals, sufficient to produce a continuous 'blip' in range.



The plan was to mount two 'ghost' fleet operations on the night of the invasion. The larger operation required eight aircraft flying in two waves of four, with the second wave eight miles behind the first. The aircraft in each wave flew in line abreast, with two miles between aircraft. Maintaining that formation, the aircraft flew a succession of oblong patterns each measuring eight miles by two miles. To give the 'fleet' a realistic rate of advance, at the end of each seven-minute orbit the formation moved forward by one mile. That produced an apparent rate of advance of seven knots (8 mph).

To add a further touch of realism, other aircraft would orbit over the English Channel transmitting with ‘Mandrel’ jammers. However, the orbit positions of these aircraft would be chosen so that German radar operators would just see through chinks in the jamming and discern the approach of the ‘invasion fleet’.

Thus far, all was theory. A few weeks before D-Day Dr Cockburn gained control of the two bomber units that were to mount the operation: No. 218 Squadron with Stirlings and No. 617 Squadron (the ‘Dam Busters’) with Lancasters. He visited each squadron and explained what he wanted. Then he arranged for the crews to rehearse the complicated flight patterns. Captured *Würzburg*, *Freya* and *Seetakt* radars were moved to Tantallon Castle on the Firth of Forth, and set up to look out to sea. There, far from the gaze of the German radio-monitoring service, the ‘ghost-fleet’ spoof underwent a full-scale test. It was completely successful.

The carefully planned and rehearsed spoof operation had a major weakness, which critics of the scheme were quick to point out. ‘What will happen,’ they asked, ‘if the Luftwaffe sends reconnaissance aircraft to the area, and their crews see with their own eyes that there is no invasion fleet there at all?’ Dr Cockburn told this author his standard reply to the question:

> Imagine the scene: a frightened under-trained young conscript radar operator sees the ‘ghost’ fleet on his screen and reports it to his headquarters as the long-expected enemy invasion force; so do his colleagues at other radar stations along the coast. Soon there appears a nice broad arrow on the situation map at headquarters: the ‘ghost’ fleet is now a military fact. If aircraft were then to fly into the area and report it clear of ships, would their reports be believed? Probably not. The operation was to take place at night and the aircraft might be far off their intended tracks. Once a broad arrow representing an enemy attack appears on the situation map at a military headquarters, it is a military fact and it takes a lot to remove it.

Few people with a military background would argue with Cockburn’s analysis, though it remained to be seen if his confidence would be proved well-founded ‘on the night’.

* * *

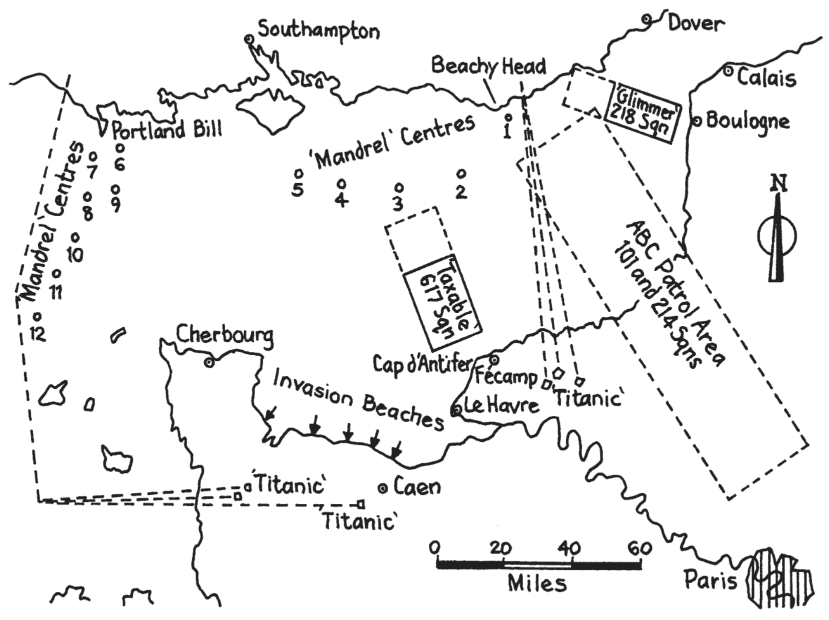
While the Second Tactical Air Force waged its war of attrition against the radar sites, RAF Bomber Command dealt with targets that were beyond the fighter-bombers' destructive capabilities. First to be attacked was the radar-jamming station on Mount Couple near Calais. This had jammed British radars during the dramatic escape of the German battlecruisers from Brest in 1942, and now it might be used to provide jamming to support a German counter-attack in the invasion area. A week before D-Day, a force of 111 Lancaster and Halifax bombers put down an accurate concentration of bombs across the station compound, wrecking most of the buildings. Mount Couple had caused its last mischief. Two other important communications stations, at Au-Fevre near Cherbourg and Berneval-le-Grand near Dieppe, suffered similar fates. Another important target in this series of attacks was the headquarters of the German listening service in the west, situated at Urville-Hague near Cherbourg. Two nights before the invasion, 96 Lancaster bombers demolished the site.

* * *

It was still light on the evening of 5 June, the eve of D-Day, when the first part of Dr Cockburn's spoofing programme opened. To prevent German patrol aircraft with their high-discrimination radars from seeing through the spoof, Cockburn had resuscitated a device not used since 1942: the 'Moonshine' repeater. This device, it will be remembered, picked up the pulses of enemy radar, amplified them and sent them back to produce a very large response on radar. Four RAF air-sea rescue launches fitted with 'Moonshine' were to cruise beneath the drifting clouds of foil strips in the 'ghost-fleet' areas, replying to signals from German airborne radars in the area.

While the greatest seaborne invasion force in history set sail for Normandy, the four 'Moonshine' boats rumbled across the Channel heading for areas further east. Each boat towed a float, above which swung a barrage balloon almost as big as the launch itself. This was 'Filbert', a 29-foot-long naval balloon with a 9-foot-diameter radar reflector inside the envelope. Each 'Filbert' produced a radar echo similar to that from a 10,000-ton ship. Fourteen small naval launches accompanied the 'Moonshine' boats, each flying one balloon and towing a float from which there flew another. Three 'Moonshine' launches and six smaller launches headed for Cap d'Antifer north of Le Havre. That was the target for one 'ghost fleet', Operation 'Taxable'. One 'Moonshine' launch and eight smaller launches headed for Boulogne the target for the other 'ghost', Operation 'Glimmer'.

Just after midnight the 'Moonshine' operator in a 'Glimmer' force rescue launch observed signals from a German airborne radar on his cathode-ray tube. He turned on his transmitter, and the game was on. During the next two hours, he logged signals from eight different aircraft. All but one of them, of short duration, he 'Moonshined'. Some 50 miles to the west, 'Moonshine' operators in the 'Taxable' force also picked up airborne radar transmissions and returned them 'with interest'.



Deception Operations: night 5/6 June 1944

Above the small boats, bombers flew their oblong orbit patterns and sowed the 'Window/Chaff' clouds for the two 'ghost fleets'. No. 617 Squadron, with Lancasters, flew the 'Taxable' spoof towards Cap d'Antifer. No. 218 Squadron, with Stirlings, flew the 'Glimmer' spoof against Boulogne. It was testimony to the advances made by British radar technique by mid-1944 that squadrons of aircraft could orbit for three or four hours over such featureless areas of sea, out of sight of each other but maintaining precise formation. A crewman of No. 617 Squadron who took part in 'Taxable' later told this writer:

> At the time I was rather concerned about what the Germans would do when they saw Taxable. We knew that we were bait and expected just about every night-fighter in creation to roll up at any moment. Our Lancaster was packed full of 'Window', from nose to tail. If we were forced down in the sea, there would be little chance of our getting out before the aircraft sank. We finished 'Windowing' at 4 a.m., by which time it was just beginning to get light. The sky seemed to be full of transport aircraft and gliders: the 'Red Berets' were going in. We hoped we had made things a little easier for them.

When the two 'ghost fleets' arrived at their stop lines some ten miles off the coast of France, the floats with the 'Filbert' balloons were anchored in shallow water. The naval launches then laid a smoke-screen and broadcast over loudspeakers recordings of the squeals, rattles and splashes germane to several ocean-going ships dropping anchor. Their task of deception complete, the boats then beat a hasty retreat. In the event, both spoof operations took place without German interference.

While the 'Taxable' and 'Glimmer' 'ghost fleets' moved laboriously towards the coast of France, other mischief was afoot. Under Operation 'Titanic', 29 Stirling and Halifax bombers of Nos. 90, 138, 149 and 161 Squadrons made simulated paratroop drops south of Caen and near Cap d'Antifer. *En route* to the 'dropping zones' the bomber crews released 'Window/Chaff' to increase the apparent number of planes involved. Over the dummy landing areas, they unloaded special fireworks designed to reproduce the sounds of battle when they hit the ground. A few men of the Special Air Service were also dropped, with orders to 'make a lot of noise'.

While all this was happening a huge armada of transport aircraft, laden with several thousand paratroops, droned towards the real dropping zones in Normandy. They presented a perfect target for Luftwaffe night-fighters: more than a thousand heavily laden planes, many of them lacking armament or even the means to detect an attacking fighter's approach. Had only a few defending fighters been able to infiltrate the gaggles of transports, they could have wrought savage destruction. The hundreds of gliders and their towing aircraft were even more vulnerable for, at the first sign of danger, the tugs' crews would have had to cast adrift the gliders and leave them to their fate.

On either flank of the transport planes' routes, scores of Mosquito night-fighters kept careful watch over their charges. Yet, even they could not guarantee that determined German crews would not penetrate their escort lines. To distract Luftwaffe attention from those lucrative targets, twenty-four Lancasters of No. 101 Squadron and five Flying Fortresses of No. 214 flew a 'ghost' bomber stream' along the line of the River Somme. Each aircraft released large quantities of 'Window/Chaff', while its special equipment operator jammed the Luftwaffe fighter-control channels using 'Airborne Cigar'. From then on, if a Luftwaffe night-fighter intercepted a transport plane, it would be a chance meeting for the fighter would receive no help from the ground.

The Luftwaffe controllers sent all available night-fighters to engage the 'ghost' bomber stream – but when they arrived in the area where the jamming was most dense, they could not be contacted again and the would-be hunters flew around chasing the clouds of metal foil strips. One Lancaster was shot down, but its crew was saved. Meanwhile, the transport planes unloaded their human cargoes over Normandy and headed for home. Not a single transport aircraft fell to fighter attack.

Over 200 ships escorting the seaborne invasion fleet carried jamming transmitters, and as they approached the invasion area all were switched on. That veritable powerhouse of jamming cluttered the screens of those German radar sets that survived the mayhem of the previous weeks. There was nothing subtle about this, the final trick in the Allies' radio-countermeasures repertoire. It blinded the defenders as cruelly and effectively as pepper thrown into their eyes. Only one German radar station observed the approach of the naval armada, but such was the level of confusion that its warnings went unheeded.

The first certain indication that a seaborne invasion force was moving towards the coast of Normandy came at about 0200 hours on 6 June: observers on the eastern side of the Cherbourg peninsula reported hearing the distinctive rumble of many ships' engines. No conceivable jamming effort could have achieved more than that, for the invaders' approach had passed undetected until then.

Dr Cockburn had predicted that, 'Once a broad arrow representing an enemy attack appears on the situation map at a military headquarters, it's a military fact and it takes a lot to remove it.' His prognosis is borne out by German records of the morning's events. A telephone message logged at 1015 hours on D-Day at the forward echelon of the Luftwaffe High Command (by which time the spoof operations had been over for about six hours) contained a clear reference to Operation 'Glimmer'. After reviewing what was known about the landings along the coast near Caen, it went on to state:

> During the early morning darkness, artillery fire fell at the following places: Grandcamp, Colleville, Arromanches. There are no reports on the positions of the ships doing the firing. Between 0600 hours and 0700 hours coastal observers reported six large warships, including battleships, and approximately twenty destroyers at a position ten sea miles west of Le Havre. Further reports on assemblies of ships: at 0645 hours to the north of Lesardrieux [west of St-Malo], where it has been specifically reported that no landings have taken place up to now. *According to reports from reconnaissance aircraft, ships were assembling during the morning off Dieppe and Le Treport. The reports of ships assembling off Calais and Dunkirk at 0400 hours have not, so far, been confirmed.* [Author's italics]

As a result of reports from German radar operators along that stretch of coast, a full invasion alert was declared for the Calais–Dunkirk area.

Operation 'Taxable' appeared to draw only slight attention. Despite a search through available German records, this writer found no report that could be linked to the spoof. It is possible that the earlier fighter-bomber attacks on radar installations in this area had been so thorough that no radar survived to see the approaching 'fleet'.

Had the German chain of coastal radar stations functioned even half as well as it should have, the defenders would have had ample warning of the invaders' approach. Yet, such was the level of confusion at German Army headquarters during the early morning darkness on D-Day that, when news of real landings in the Normandy area came through, these were thought to be feints. The defenders braced themselves for the main assault to commence further east, and only on the afternoon of D-Day was the position sufficiently clear to allow the German armour to be committed to battle. By then Allied troops were ashore in strength, and no power at Adolf Hitler's command could dislodge them.

Chapter 12

The Final Months of the War in Europe

'Confound and Destroy'

No. 100 Group motto

During the early months of 1944, British intelligence had gained its first clues on the *SN-2* airborne radar which had brought about such an improvement in the effectiveness of the Luftwaffe night-fighter force. The number of contacts by RAF long-range night-fighters carrying the 'Serrate' homing device had fallen considerably. That in itself was an indication that the standard *Lichtenstein* radar was going out of service. Yet the heavy losses suffered by the RAF bombers *en route* to and from targets were evidence that the Luftwaffe had replaced *Lichtenstein* with something better.

As we now know, Hermann Göring had ordered a crash programme to re-equip his night-fighters with *SN-2* radar. The thousandth set had been delivered to the night-fighter force early in May 1944. From prisoners, British intelligence knew of the existence of a device called *SN-2*, but there was no detailed information on its nature. It seemed this was not the only innovation, for prisoners had spoken of two other devices fitted to night-fighters, *Flensburg* and *Naxos*. Again, their exact nature was far from clear. The RAF despatched radio reconnaissance aircraft over German territory to listen for transmissions from these sets, yet the task proved more difficult than the earlier search for signals from the *Lichtenstein* radar. The problem was that *SN-2* operated in the same part of the frequency spectrum as the later *Freya* ground radars. Thus an operator hunting in the right place for the new signals, would pick up trains of pulses all seemingly familiar and accounted for. *Flensburg*, which homed on the 'Monica' tail-warning radar fitted to RAF bombers, and *Naxos*, which homed on H2S, were of course passive-homing devices, so they emitted no radiations at all.

The first hard evidence regarding the new Luftwaffe radar came from the camera-gun of an American long-range fighter escorting bombers during a daylight attack. The pilot had pounced on a Ju 88 night-fighter and shot it down. When the film of the engagement was processed, it was noticed that the nose of the Luftwaffe aircraft bore a large and unfamiliar aerial array. The photograph provided R. V. Jones's intelligence office with plenty of material for speculation, but not enough to devise countermeasures.

Then, by a remarkable stroke of luck, the Luftwaffe solved the problem by itself. During the early morning darkness on 13 July 1944, a twin-engined aircraft circled the RAF airfield at Woodbridge in Suffolk. Taking it to be a returning Mosquito, the runway controller flashed a green light to give the aircraft permission to land. The aircraft touched down and taxied to the end of the runway, where it switched off its engines. The crew climbed out and were standing on the apron, stretching their legs, when the bus arrived to pick them up. So it was that an RAF flight sergeant suddenly found himself confronted by three Luftwaffe aircrewmen. The surprise was mutual, but the British NCO produced a Very pistol and forced the new arrivals to surrender.

The 'Mosquito', it now transpired, was a fully equipped Ju 88 night-fighter. Its inexperienced pilot had flown a reciprocal compass course and headed west instead of east. He was indeed lucky to reach Woodbridge; when RAF technicians sought to take a sample of fuel from the aircraft's tanks for analysis, they found there was insufficient even for that purpose.

The captured Ju 88 carried two electronic systems that were ominously unfamiliar to British intelligence: *SN-2* radar and *Flensburg* homing equipment.

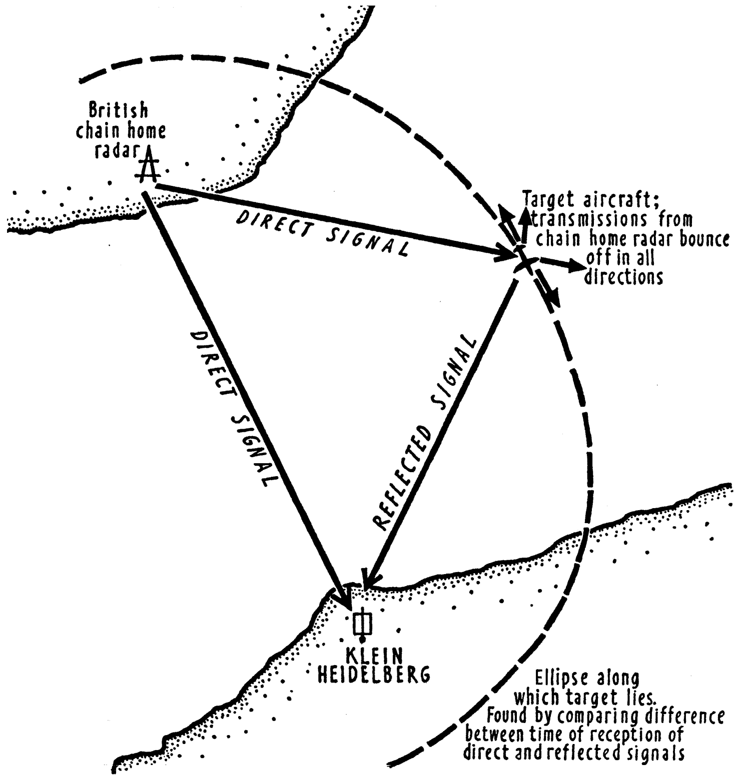
The *SN-2* worked on a frequency of 85 MHz, so the standard types of 'Window/Chaff' used by Bomber Command had no effect on it. Fortunately for the RAF, however, the concertina-like lengths of foil developed for the invasion fleet spoofs were effective against radars working on that frequency. Within ten days, Bomber Command had started using the zigzag foil strips over Germany. The immunity from jamming enjoyed by *SN-2*, during its eight-month operational life, was at an end.

It fell to Wing Commander Derek Jackson to evaluate the *Flensburg* device. He arranged for a Lancaster bomber, with its 'Monica' switched on, to fly westwards from Farnborough airfield at 15,000 feet. As it did so, Jackson orbited at the same altitude over Farnborough in the Ju 88. He was still picking up the 'Monica' signals from the Lancaster when the bomber was over Exeter, 130 miles away. The homer gave precise directional indications, and Jackson had no difficulty in homing on to the bomber. To establish whether several 'Monica' radars close together would confuse *Flensburg*, Jackson repeated the trial a few days later using five Lancasters. He found the tuning of the device was so fine that again he could easily home on individual bombers.

The danger from the RAF tail-warning radar was clear enough: it was more likely to cause bomber losses than reduce them. When news of Jackson's trials reached the ears of Air Chief Marshal Harris, the latter asked: 'What would happen if there were about a hundred bombers, all transmitting with "Monica"? Wouldn't there then be confusion of the signals?' Jackson replied that he could not answer that question, on the evidence of a trial involving only five aircraft. To give a true answer, he needed to test the device against a much larger number of bombers. Harris agreed, and told one of his staff officers arrange it. In the new test, seventy-one Lancasters flew a circular route from Cambridge via Gloucester and Hereford and back to Cambridge, all with 'Monica' switched on. Yet again Jackson orbited over Farnborough airfield in the Ju 88, observing the *Flensburg* screens. He picked up the first bombers at a range of forty-five miles, and the chase was on. Using *Flensburg* alone, he directed his pilot on to individual Lancasters time and time again, as the device's fine-tuning made short work of the mass of signals. After that demonstration Harris took characteristically decisive action: he ordered the immediate removal of 'Monica' from all bombers in his command.

At about the same time, Bomber Command came finally to realise the danger of the indiscriminate use of airborne transmitters, and revised its policies concerning these. Crews operating 'Mandrel', 'Tinsel' and 'Airborne Cigar' jammers had already been told to turn them on only when they were near or over enemy territory. Now they were forbidden to switch on their IFF identification transponders over enemy territory, except in emergencies. And the H2S radar was not to be switched to transmit until the bombers were within forty miles of enemy territory, when they would be seen by ground radars anyway.

Those moves made life much more difficult for the Luftwaffe signals service, for the jamming had forced its raid-tracking organisation to lean heavily on just these sources of information. By now the Luftwaffe had set up a chain of *Naxburg* stations along a line from Schleswig-Holstein in the north to the Black Forest in the south, to track the sources of H2S radar signals. One such set, situated on high ground at Feldberg in the Black Forest, had been able to track RAF bomber streams by their H2S emissions, all the way from the English Channel to southern Germany.



Klein Heidelberg

Naxburg was of course a passive device exploiting British radiations. So was the ingenious *Klein Heidelberg* long-range detection system. This used transmissions from a 'Chain Home' radar station in Great Britain, to 'illuminate' aircraft for it. The operating principle of the device was as follows. The *Klein Heidelberg* receiver was locked to the direct transmission from the British radar station. It also picked up echo signals reflected off aircraft flying within the radar's angle of view. The *Klein Heidelberg* screen displayed two 'blips'. One represented the pulse coming on the direct route from the 'Chain Home' radar. The second 'blip' indicated echo signals reflected off the aircraft, picked up by the German receiver after having travelled a greater distance. The direct-line distance between the German and the British ground stations was fixed and known. So the aircraft's position lay along on an ellipse, whose foci were two ground stations. The position of the aircraft on that ellipse was found by taking directional bearings on the echo signals.

Under ideal circumstances *Klein Heidelberg* could determine an aircraft's position to within six miles, and the station on the Danish island of Rømo could plot aircraft up to 280 miles away. By the time the Rømo station became fully operational in mid-1944, however, Bomber Command rarely routed its aircraft over southern Denmark. As a result, the unusual device had little effect on the night battles.

Also in the summer of 1944 the Luftwaffe introduced a new ground radar for night-fighter control, code-named *Jagdschloss*. Unlike its predecessors, this had been designed from the outset to work in the face of hostile jamming. It could switch at will between four frequencies in the band 129–165 MHz, to avoid jamming. *Jagdschloss* had a range of ninety miles, good enough for the task of controlling night-fighters engaged in 'Tame Boar' operations.

The success of the invasion of France resulted in a complete change in the conditions under which Bomber Command attacked targets in Germany. Early in August 1944, the armoured spearheads broke out of the ring of steel surrounding the Normandy beachhead. Within a month, almost the whole of France was in Allied hands. Previously, the Franco-German frontier had been of little significance during RAF night operations, and the Luftwaffe had not expended much effort on constructing an aircraft-reporting system in that area. Now, the loss of France left a gaping hole in the Luftwaffe early-warning radar chain. From now on, most RAF attacks on targets in Germany were routed over France.

* * *

During 1944 the Luftwaffe redoubled its efforts to neutralise the RAF's H2S and 'Oboe' bombing aids, but met with only moderate success. A favoured solution against H2S was to erect large numbers of corner reflectors, to produce a response on radar screen similar to that from a real city. Engineers set out hundreds of metal tetrahedra in the vicinity of a few important cities, so that expanses of open countryside gave radar echoes like those from a built-up area. Similarly, areas of water could be adorned with radar reflectors mounted on rafts to conceal their true nature. The idea failed, however, because the reflectors had to be constructed to very fine tolerances, and huge numbers of reflectors were required to produce a convincing result. For example, to spoof the Mark III version of H2S, which operated on a wavelength of 3 centimetres, each reflector had to measure about 9 feet across. Each face had to be perfectly flat and at a right angle to the other faces, to within one-third of a degree. Five hundred such radar reflectors were needed to produce each square mile of the spoof 'town'. There were attempts to alter the distinctive radar shapes of Kiel and Wilhelmshaven, but in each case too few reflectors were used. RAF bomber crews operating in those areas reported no difficulties that could be attributed to this measure.

The jamming of 'Oboe', the RAF's precision blind-bombing aid, also presented difficulties. We saw how, during an 'Oboe' attack on Rheinhausen at the end of 1943, the Luftwaffe discovered how to jam the Mark I 'Oboe' and caused the raid to fail. Thereafter, the RAF brought into service Mark II and Mark III systems, which operated on centimetric wavelengths and were very much more difficult to jam. The original Mark I transmitters continued to radiate signals, however, to give the Luftwaffe something to jam. Only in July 1944, during an 'Oboe' attack on the Scholven synthetic oil plant, did the Luftwaffe monitoring service pick up the bomb-release signal on the 9-centimetre wavelength. That signal was transmitted four minutes before the original Mark I release signal. Now the Luftwaffe listeners realised the truth: the Mark I signal had been used these last five months only as a camouflage, and on this occasion the transmitter had been switched on four minutes too late.

* * *

As related earlier, the RRL's mighty 'Tuba' jammer was the most powerful system of its type to be deployed in action during the conflict. It was not the most powerful equipment to be conceived, however. To counter the V-1 flying bombs launched against London in large numbers during the summer of 1944, the RRL came up with a highly imaginative proposal. The V-1 was invulnerable to radio-countermeasures in the normal sense of the word, for it employed no radar- or radio-guidance system whose signals might be jammed. Guidance was by means of a magnetic compass controlling a gyroscope, feeding corrections to the vehicle's rudder via a servo system. Nevertheless, one of the laboratories affiliated to RRL devised a way to jam it. Dr Guy Suits explained to the author:

> Their idea was to form a magnetic loop employing existing railway lines, suitably interconnected, all the way around London – a circumference of about 60 miles. This loop would be energised with a hefty current to make it into a giant magnetic deflector. They worked out a system which required something like 1,000 amps direct current, to provide the necessary magnetic field to deflect the compass of a flying bomb at 1,000 feet. The power requirement for the system would have been of the order of 20 to 30 megawatts, which would have meant dedicating quite a large [commercial] power station for this purpose. The system was very seriously considered and design work began on some of the necessary equipment.

While the jammer was still in the conceptual stage, however, Allied troops overran those areas in Northern France from which most flying bombs were being launched. So the idea came to nothing. Yet that V-1 jammer holds the record for the most powerful electronic countermeasures system to be considered, ever.

* * *

The disconcerting speed with which the Luftwaffe seemed to recover from the effects of 'Window/Chaff' exercised senior officers at Bomber Command headquarters. What if the Germans came up with some major advance in night-fighting which rendered RAF night operations too costly to continue? Air Marshal Saundby, Sir Arthur Harris' deputy, summed up the mood during a conversation with this writer:

> We were always worried lest German scientists should make some technical breakthrough that would dramatically increase the

> effectiveness of the defences. We continually took up every device in order to prepare at every point – so that if the Germans did come up with any technical breakthrough we hoped that one or other of our gadgets could be modified to counter it.

The need was for proactive measures, to ensure that no single technical development from the enemy could achieve such an effect.

With the continual widening spread of the frequency bands used by German radars, ever more jammers were needed to provide bombers with the necessary cover. Yet there was a limit to the number of systems that could be squeezed into a bomber aircraft. The obvious next step was to create a force of specialised jamming escort aircraft, that would carry batteries of jammers instead of bombs. At first it seemed that a couple of squadrons, with about thirty such aircraft, might provide the degree of support required. But it soon became clear that nothing less than a unit of group strength – about a hundred aircraft – would suffice.

During the spring and summer of 1944 a new RAF unit, No. 100 Group, began to assemble for the purpose of supporting the night bombing operations. The group's commander, Edward Addison, had commanded No. 80 Wing during the battle against the radio beams in the dark days of 1940 and 1941.

Now promoted to Air Vice-Marshal, Addison set up his headquarters at Bylaugh Hall in Norfolk. The group then received a motley collection of squadrons to build up his force. There was No. 515 Squadron, Fighter Command's jamming unit, in the process of re-equipping from obsolescent Defiants to almost as outdated Beaufighters. There was the veteran No. 141 Squadron equipped with the 'Serrate' homer, changing from Beaufighters to Mosquitoes. Two more squadrons, Nos. 169 and 239, each had a few Mosquitoes but no trained crews. No. 214 Squadron, intended to be a heavy jamming unit with Flying Fortresses, had no aircraft at all. The only fully operational unit was No. 192 Squadron, a ferret unit equipped with Halifaxes, Wellingtons and Mosquitoes. No. 199 Squadron also later joined the new group, equipped with Stirling bombers, each carrying a battery of 'Mandrel' jammers.

As things stood, No. 100 Group was in no position to support anybody. Yet Addison moved quickly to get it ready for operations. The first Flying Fortresses for No. 214 Squadron were delivered to the Scottish Aviation Company at Prestwick, where engineers worked in great secrecy to modify them for their new role. Mufflers riveted to the exhaust pipes screened the bright exhaust flames, for these aircraft, unlike most Flying Fortresses, were to fly by night. Their noses sprouted bulbous blisters housing H2S scanners, and the bomb bays were sealed up and fitted with racks to house the jamming gear. Initially, each Flying Fortress was fitted with eight 'Mandrel' transmitters, to cover the frequencies used by the *Freya*, *Mammut*, *Wassermann* and *Jagdschloss* radars. Each aircraft also carried an 'Airborne Cigar' installation with three transmitters, to blot out the Luftwaffe VHF communications channels. In each Flying Fortress there were positions for two extra crewmen, to operate the jammers.

Once the invasion was over, Nos. 199 and 214 Squadrons took up their designated task of supporting the night raids. One of their main tactics was to put up a so-called 'Mandrel' screen, similar to that put up by the Defiant converted fighters of No. 515 Squadron eighteen months before. The converted heavy bombers radiated much more power, of course, and they could remain on station for much longer than their smaller predecessors. Typically a dozen large jamming aircraft, operating in pairs, orbited over friendly territory in positions about fourteen miles apart, radiating jamming. In that way they formed a line running parallel with the front line and about eighty miles back from it, radiating jamming to conceal aircraft movements behind that line from Luftwaffe early-warning radars. During August 1944, the group put up 'Mandrel' screens on sixteen separate occasions.

To distract the defences still further, No. 100 Group's converted bombers flew 'Window' spoofs from time to time. A typical spoof employed up to twenty-four aircraft, flying in two lines of twelve aircraft in line abreast. About two miles separated the aircraft in each line, and the second line flew about thirty miles behind the first. All the aircraft released one bundle of 'Window/Chaff' every two seconds. In that way, the small force of aircraft would produce a radar echo-reflector resembling a bomber stream with some 500 aircraft. It was for the Luftwaffe fighter-controllers to divine whether the returns on their screens came from a 'Window' spoof, or a real bomber stream. Since attacking bombers also normally released large amounts of 'Window/Chaff', that presented a very real problem.

Air Vice-Marshal Addison had expected that the spoofing formations might suffer heavily; these small forces of aircraft were intended to draw upon themselves the wrath of the defenders, so that the real bombers could get through to their targets unscathed. In the event, however, their losses were no higher than those of other Bomber Command units. Although the feint operations often drew large numbers of German fighters towards them, the skies surrounding the spoofing aircraft were saturated with 'Window/Chaff' which made it difficult for the defending fighters to find the bombers.

Throughout the summer and autumn of 1944, No. 100 Group continued its expansion and re-equipment programmes. No. 223 Squadron with Liberators joined the force, as did No. 171 Squadron with Halifaxes. At the same time No. 199 Squadron had its elderly Stirlings replaced with the higher-performance Halifaxes. The effectiveness of the jamming escort aircraft was further enhanced by fitting the group's Flying Fortresses and Liberators with 'Piperack', a transmitter to jam the *SN-2* night-fighter radar. Three more Mosquito units arrived to stiffen the Group's night-fighter arm, Nos. 23, 85 and 157 Squadrons; all three were fully formed and experienced units. The last two were equipped with the latest AI Mark X radar (alias the SCR-720), which had now been cleared for use over German territory. Eventually most of the group's other Mosquito night-fighter units would also be fitted with the new radar, too.

The group's Mosquitoes also began to carry two important new devices to enable them to home on their German counterparts. The first was a variant of 'Serrate', the Mark IV, which enabled the hunters to home on emissions from the German *SN-2* night-fighter radar. Like most homers, however, this gave only azimuth and relative altitude information on the enemy plane. The second new device for No. 100 Group, code-named 'Perfectos', went one better. It sent out pulses to trigger the IFF identification sets in Luftwaffe planes in the area. When a German aircraft radiated the coded reply signal, that provided the crew of the Mosquito with its azimuth, elevation and range.

With the arrival of the newer aircraft and equipment, No. 100 Group's tactics became more imaginative and aggressive. The unit mounted 'Mandrel' screen and 'Window' spoof operations almost every night when the weather allowed, regardless of whether a real bombing operation was planned. 'Mandrel' screens would conceal the real and the spoof bombing forces moving in behind them. Often the spoof force would emerge from the screen first, to draw the Luftwaffe night-fighters in one direction. Some time later the real bomber stream would emerge from a different direction, escorted by the Flying Fortresses and Liberators blanketing the ether with their 'Piperack' transmissions. By such means, No. 100 Group maintained a steady pressure on the over-extended Luftwaffe night-fighter force, and its dwindling reserves of high-octane fuel.

* * *

In the middle of 1944 No. 100 Group brought into service the most powerful airborne jammer built so far, code-named 'Jostle IV'. Dr Robert Cockburn later described how this device came to be produced. The earlier wartime successes had gained for his section at TRE a great deal of prestige:

> I was riding the crest of a wave. I was on various committees, and if I said something was good it usually got in. Eventually it became perfectly obvious that we needed a high-power communications jammer. It was easy to write down on a piece of paper how much power was needed. My contacts with industry were good and they were a little short of work.
>
> The next thing I knew was that Metropolitan-Vickers asked me to go and look at this jammer they had built. I was thinking of something about the size of a large biscuit tin, but by the time all the protective devices, the pressurisation, the aerial insulators and all the rest were in, 'Jostle IV' really was a damn great thing. I was scared out of my wits, because I suddenly realised that no paperwork had passed about this at all. They had done it entirely on my say-so. Then I got a most angry letter from Headquarters – I was given an Imperial rocket. Did I realise that there had been no authority, no finance?

It must indeed have been disconcerting for Cockburn's superiors to find themselves saddled with a half-million pound bill about which they had known nothing.

Whether or not the 'Jostle IV' contract had passed through unorthodox channels, when the transmitter appeared it was a formidable apparatus. It radiated 2 kW of continuous noise jamming. The main unit was contained in a cylinder the diameter of a large dustbin and twice as high, and weighed 600 pounds. The container was pressurised, to prevent arcing at high altitude. That bulk, and the requirement for additional electric generators to provide the necessary power, meant it could be carried only in specialist jamming aircraft. The target for its jamming was the 38–42 MHz VHF band used by Luftwaffe fighters.

As 'Jostle IV' transmitters became available, they were installed in the Flying Fortresses and Liberators in place of the earlier 'Airborne Cigar' jammers. The new jammer greatly complicated the task of the Luftwaffe fighter controllers. The latter had now to make greater use of the 3–6 MHz band used earlier; but this was already the target for the 'Tinsel', 'Corona', 'Dartboard' and 'Drumstick' jamming.

* * *

German radar operators soon came to recognise the various tactics employed by the new RAF group. In the autumn of 1944 the Luftwaffe circularised *Jagdschloss* radar stations with an instruction booklet on how best to operate in the face of the RAF jamming and 'Window' spoofs. Radar operators were warned that the RAF often attempted to force the defenders to scramble night-fighters too early, thereby weakening the defences when the real raid came in later that evening:

> The correct control of our fighters is possible only when we are in possession of a clear picture of the air situation, which means the faultless tracking of all formations. There is no doubt that this is made more difficult by the release of *Düppel*.

Radar operators were told to study the trace left on the main range tube of their *Jagdschloss* screens. The *Düppel* clouds quickly fell behind the enemy formation. A long track containing numerous 'blips', not unlike that from a large bomber stream, then resulted. After a few minutes a trace looking like a 'caterpillar' formed behind the bomber stream, while the spoof left a trace that looked more like a number of 'small surf waves'. During this phase the head of the enemy formation could be clearly seen, and any change in the bombers' heading could be determined quickly. After about ten minutes, the original *Düppel* began to settle and an attentive operator could recognise the aircraft targets in the clouds of foil. However, the report admitted, 'the faultless tracking of an air target still offers great difficulties'.

Only after half an hour would the *Düppel* cloud settle sufficiently for a *Jagdschloss* operator to plot single targets and bomber formations without error. Before that time, estimates of the number of aircraft present were largely guesswork. One of the most important effects of radio-countermeasures was the delay imposed on the working of the defences, as radar operators sought to clarify the air picture.

* * *

The wide ranging operations over Germany by No. 100 Group's Mosquito night-fighters led to changes in the equipment fitted to their Luftwaffe counterparts. The German aircraft were now modified with an additional rearwards-looking aerial for *SN-2*, allowing the radar operator to search his rear sector for a Mosquito closing in. Also, the installation of the *Naxos* equipment became general in Luftwaffe night-fighters. The RAF policy of restricting the use of H2S had reduced its value for finding the bomber stream but the receiver also picked up transmissions from the Mosquitoes' AI Mark X radars, providing a useful warning if one was prowling in the area.

Despite these changes the Mosquitoes took a mounting toll of the Luftwaffe night-fighters, destroying one or two during each major incursion. That small number was more important than it might sound. Aviation fuel was in short supply in the Luftwaffe, and only the most experienced night-fighter crews now took off to combat the Bomber Command attacks. Each such crew lost was irreplaceable. No. 100 Group's operations caused a steady erosion in talent which rocked the foundations of the Luftwaffe night-fighter force. No longer could defending night-fighters cruise about at leisure over their homeland, looking for bombers to shoot down.

There can be no doubt of what the best of the Luftwaffe night-fighter crews were capable of, when they got into the bomber stream and could fight unhindered. Major Heinz-Wolfgang Schnaufer amassed 121 confirmed night-victories by the end of the war, far surpassing the eighty-three victories of Prince zu Sayn-Wittgenstein.

Schnaufer's greatest success in a single twenty-four-hour period was on 21 February 1945. He shot down two bombers in the early morning darkness, and seven more that evening.

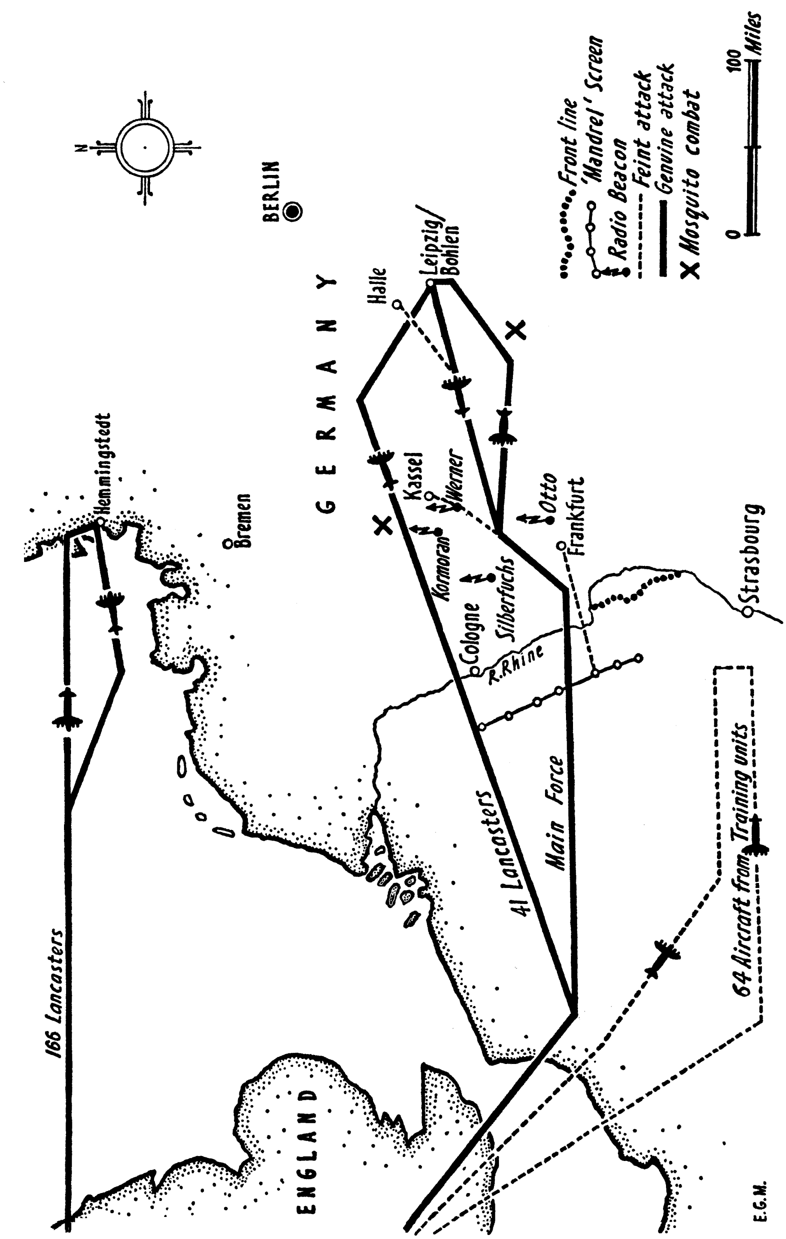
No. 100 Group could not claim the sole credit for the sudden decline in Bomber Command's losses from the autumn of 1944, yet the unit's jamming, spoofing and intruding activities undoubtedly helped ensure that the Luftwaffe never recovered from the initial blow. An impressive tribute to the group's work was given at a conference at the Air Ministry in Berlin on 5 January 1945. Generalmajor Adolf Galland, commanding the entire fighter force, recalled the great achievements of the Luftwaffe night-fighters earlier, but:

> Today the night-fighter achieves nothing. The reason for this lies in the enemy's jamming operations, which completely blot out ground and airborne search equipment. All other reasons are secondary.

* * *

During the early months of 1945, Bomber Command's tactics of deception and radio-countermeasures reached a fine degree of perfection. Just how fine can be assessed from the operation on the night of 20/21 March 1945, which can be examined in detail. That night the targets were the synthetic oil refinery at Bohlen, just south of Leipzig, and the oilfield at Hemmingstedt in Schleswig-Holstein far to the north. Zero-hour for the Bohlen attack was 0340 hours on the 21st and the Hemmingstedt attack was to open fifty minutes later.

As darkness fell on the 20th, Bomber Command launched its now-usual pattern of diversionary attacks. First there was a large-scale nuisance raid on Berlin by 35 Mosquitoes, beginning at 2114 hours. Just after 0100 hours on the 21st the main Bohlen attack force, comprising 235 Lancasters and Mosquitoes, headed south-east across the English Channel. A few miles to the south of it flew its accompanying feint attack force, comprising sixty-four Lancasters and Halifaxes flown by crews on the final stages of their training. Ahead of both forces, as they crossed the north coast of France, was an eighty-mile-long 'Mandrel' screen erected by seven pairs of Halifaxes from Nos. 171 and 199 Squadrons. These threw up a wall of jamming through which, it was hoped, the Luftwaffe early-warning radars would not be able to see. At 0155 hours the Bohlen attack force split into two. Hidden behind the 'Mandrel' screen, forty-one Lancasters broke away and headed off to the northeast.



Attack on Bohlen: 20/21 March 1945

Now the Luftwaffe radar operators' problems really began. While the real and the fake bomber streams headed for the German frontier, fourteen Mosquito fighter-bombers of Nos. 23 and 515 Squadrons fanned out in ones and twos, making for the airfields the Luftwaffe night-fighters were expected to use that night. Once there, they orbited for hours on end, bombing and strafing any movement seen. At 0300 hours the feint bomber force, flown by crews still undergoing training, had almost reached Strasbourg. It then turned about, and went home. As they did so two bomber forces making their separate ways to Bohlen burst through the 'Mandrel' jamming screen. Seven Liberators of No. 223 Squadron and four Halifaxes of No. 171 Squadron flew five minutes – about eighteen miles – ahead of the larger Bohlen force. These aircraft laid a dense lane of 'Window/Chaff' to conceal the strength of the force following them. Once it was past the Rhine, the more southerly of the two streams bound for Bohlen turned northeast, towards Kassel.

Thus far there was no way for Luftwaffe fighter controllers to determine the bombers' target for the night. The controller of the Central Rhine defence area, Major Heinrich Rüppel, seriously underestimated the strength of the two approaching formations. In his estimation each force comprised about thirty aircraft, and he thought both might be 'Window' feints. As the reports from the ground observation posts began to come in, however, it became clear that the southernmost of the two forces was much larger than estimated; no amount of jamming could conceal the roar of more than 800 aero engines.

Rüppel pondered the possible targets for the night. One force was heading for Kassel from the south, the other might turn towards the city at any moment. Although the situation seemed reasonably clear, that was often the case with spoof attacks. There was not much time for thought, either; if he waited until the situation was completely clear, the bombers might have completed their attack before his fighters could engage. Eighty-nine night-fighters had been scrambled, and these now orbited beacons near their home airfields while awaiting instructions. Rüppel ordered almost the whole of his force to radio beacons *Silberfuchs*, *Werner* and *Kormoran* to the south and west of Kassel. The remaining night-fighters he ordered to beacon *Otto* near Frankfurt, to cover the possible threat to that city.

At first it seemed that Rüppel's guess concerning the bombers' intentions was correct when, from Kassel, there were reports of signs typical of the opening of an attack. At 0308 hours brilliant coloured flares blossomed over Kassel, and a few bombs detonated there. In fact, the 'Windowing' Liberators and Halifaxes had taken their feint right up to the city, and twelve Mosquito bombers had added to the effect by dropping flares and bombs. But this was not the main force of bombers, and no further attack befell Kassel that night.

Twenty-five miles from Kassel, the larger and more southerly bomber stream turned east, with thirty-three Mosquito night-fighters guarding its flanks. A Mosquito of No. 85 Squadron picked up identification signals from a Luftwaffe fighter on its 'Perfectos' device, homed on their source and shot down a Bf 110. At about the same time, a Luftwaffe night-fighter caught up with a 'spoofing' Liberator of No. 100 Group and shot it down. Only one member of the crew survived.

The rest of the Liberator's crew did not die in vain. The Luftwaffe night-fighters continued to orbit Kassel for some twenty minutes after the feint began. Not until 0330 hours did the fighter-controller realise he had been tricked. He ordered his force to head eastwards after the bombers and six minutes later the running commentary finally gave Leipzig, the city nearest to Bohlen, as the probable target, but by then it was too late for most of the night-fighters to catch up. As the night-fighters turned eastwards and sped away in pursuit, the leading bombers were already within thirty miles of Bohlen.

Even now the night's spoofery was not over. At 0320 hours the larger of the two forces heading for Bohlen split yet again. Even as the first target markers went down over on Bohlen, at 0340 hours, other target markers were falling on the important Leuna oil refinery some twenty miles to the northwest. Four Flying Fortresses of No. 214 Squadron and two Halifaxes of No. 199 Squadron had laid a second 'Window' trail away from the main Bohlen attack force. Then, together with twelve Lancasters, they marked Leuna as if for a full-scale attack. Leuna was right in the path of the onrushing Luftwaffe fighters, and the spoof attack delayed their arrival at Bohlen still further. One Lancaster crew paid the supreme price for the valuable minutes of delay inflicted on the Germans.

A total of 211 Lancasters now reached the main target, Bohlen, and carried out a highly concentrated strike on the oil refinery lasting eleven minutes. Five Flying Fortresses of No. 214 Squadron and a Liberator of No. 233 Squadron provided jamming support over the target. Not until 0410 hours, as the last of the bombers were leaving Bohlen, did the first of the Luftwaffe night-fighters arrive over the target. In each night-fighter the radar operator encountered heavy jamming, but in spite of that they brought down two bombers over Bohlen, and three more during the bombers' withdrawal.

At this time the Mosquito crew that had shot down the Bf 110 near Kassel also brought down an He 219 to the west of Leipzig. That was the second of the two Luftwaffe night-fighters claimed by No. 100 Group that night.

The night's operations were still not over for, at 0417 hours, events came to the boil over northern Germany. First 27 Mosquitoes attacked the city of Bremen and, while Luftwaffe attention was focused on this force, 166 Lancasters swept in low across the North Sea, below the horizon of the early-warning radar cover. This was the second of the night's main attacks, bound for the oil-plant at Hemmingstedt. The force kept below 5,000 feet, maintaining strict radio silence until it was close to the target. Then the bombers made a rapid climb to 15,000 feet and commenced their attack at 0423 hours. A Liberator, a Flying Fortress and a Mosquito provided jamming cover during the attack, which lasted sixteen minutes.

The Hemmingstedt raid passed almost unnoticed by the Luftwaffe raid-tracking organisation. It was never appreciated as a major attack, and the bombers were already pulling away from the target when the first radar plots were reported on 'weak formations'. The sole loss was one Lancaster, which fell to a night-fighter near the target.

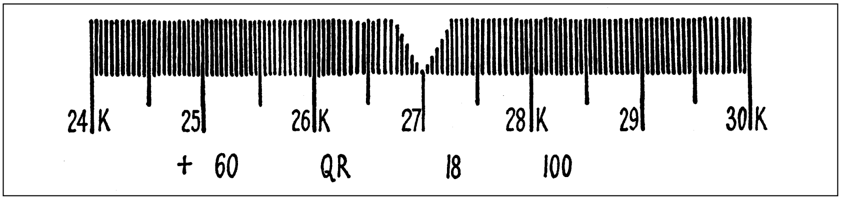
Bombers claimed the destruction of two Luftwaffe fighters, to bring the total RAF claim for the night to four. Luftwaffe records show a loss of seven night-fighters. What happened to the other three will probably never be known, but it is not difficult to speculate. A tired pilot, trying to land on a dimly lit airfield patrolled by RAF intruders, might misjudge his approach and crash. A crew might return to base just a little too low for safety, and fly into a hillside. A cautious Luftwaffe wireless operator might switch off his identification equipment to prevent an RAF Mosquito homing on it with 'Perfectos', and be shot down by 'friendly' anti-aircraft fire. Such losses, which were frequent, were the result of No. 100 Group's efforts as surely as those shot down in combat.

* * *

During the final months of the conflict German scientists evolved a partial answer to the H_2S airborne radar – a jamming transmitter which produced sufficient power in the 3,000 MHz band to affect the British radar. Code-named *Postklystron*, the device was effective only over short ranges, however. The sole target to receive this type of protection before the war ended was the vitally important oil refinery at Leuna. By then, however, the H_2S Mark III was in operation. The new radar worked on frequencies in the 9,000 MHz band, which was outside the cover of the German jammer.

By April 1945 the Luftwaffe had at last developed the means of jamming the Mark II and Mark III centimetric 'Oboe' system, and achieved moderate success. Also by then, the Luftwaffe was on the point of introducing a range of centimetric-wavelength radar sets into large-scale service. For night-fighters there was *Berlin* radar, and for AA gunners there was the *Egerland* designed to replace the now barely usable *Würzburg* and *Mannheim* equipments. For the long-suffering fighter-controllers on the ground there were the *Jagdschloss-Z* and *Forsthaus-Z* centimetric wavelength GCI radars to replace the earlier *Jagdschloss*. In each case prototypes had been built, but none existed in quantity. Within a few months these could have posed a formidable threat to the bomber forces once more, since neither the electronic nor the 'Window' jamming techniques then in use would have affected them.

Finally, the Luftwaffe was on the point of overcoming a major impediment to effective night-fighting, the jamming of its ground-to-air communications channels. Several *Bernhard* transmitters had been erected throughout Germany, each with a large aerial structure about seventy feet high and almost as broad. This focussed the transmissions into a narrow beam, which rotated in azimuth once per minute. A growing number of night-fighters were being equipped with the corresponding airborne receiver, *Bernhardine*. This interpreted the system's coded signals, and printed them out on paper tape in the manner of a teleprinter. The airborne receiver also printed out the bearing of the aircraft from the ground station, and identified the station concerned with a code-letter. Once every minute, as the narrow-beam transmission swept past the aircraft, the airborne *Bernhardine* receiver printed a new bearing or orders, or repeated the old ones. The information was presented in the form of a simple code, thus:



The bearing of the aircraft from the ground station was read, in tens of degrees, by taking the number seen at the apex of the 'V' (in this case 270 degrees, or due west). The letter printed every twenty degrees along the bearing scale identified the Bernhard station concerned: 'K' indicated the transmitter was at Leck in Schleswig-Holstein. The running commentary on the movement of raiding forces was transmitted in standardised form, and it was printed below the bearing information. The air situation reported in the example shown decoded as follows:

+ = beginning of message
60 = altitude of the leading aircraft in the bomber stream (i.e. 6,000 metres)
QR = head of bomber stream at grid reference QR (near Mainz)
18 = course of bomber stream 180 degrees (due south)
100 = estimated strength of raiding force (i.e. 100 aircraft)

Because it relied on beamed high-powered transmissions, and because teleprinter signals, like Morse code, have good 'break-through' qualities, the *Bernhard* system would have been almost impossible to neutralise using a conventional jammer such as 'Jostle'. The system was scheduled to enter large-scale service late in the summer of 1945, but the Reich had been overtaken by other events by then.

On 8 May 1945, the war in Europe came officially to an end. But that still left the Allies engaged in a major war against Japan, which was also reaching its climax. The use of countermeasures in that theatre will be described in the next chapter.

Chapter 13

Climax in the Pacific

> 'We must take a powerful armament with us from home, in the full knowledge that we are going to a distant land, and that the expedition will be of a kind very different from any which we have hitherto made among our subjects against some enemy in this part of the world.'
>
> Nicias of Athens: Address to the Athenians before the expedition to Syracuse, 415 BC

At the end of 1943 the US Army Air Force took delivery of its first examples of the new and innovative Boeing B-29 Superfortress. This was the first heavy bomber to be fitted with a pressurised cabin, and its defensive armament of twelve 0.5-inch machine guns and one 20-mm cannon was the most powerful yet seen. Significantly for this history, the B-29 was the only bomber type to enter service during the conflict to be fitted with a ground-mapping radar from the design stage. With a maximum all-up weight of sixty-seven tons, the B-29 was more than twice as heavy as the B-17 and the B-24 bombers it was to replace. It could deliver 6,000 pounds of bombs to a target 1,700 miles from its base, a superb performance no other bomber of that time came close to matching. The new bomber was to be used initially in the Far Eastern theatres of operations, where its excellent range performance could be used to the full.

At this time Allied intelligence officers still had little information on the composition and capabilities of the air defences on the Japanese Home Islands. The general view, however, was that the Japanese forces probably did have radars more advanced than those discovered so far, and that these were being held back for the defence of the homeland.

To assist in the collection of intelligence, one B-29 in four carried an APR-4 intercept receiver and an additional crewman, called the 'Raven', to operate it. A few B-29s also carried the ARR-5 communications search receiver. During their initial attacks on the Japanese homeland the B-29 units were to pick up what information they could on the defences, hoping not to encounter too many unpleasant surprises in the process.

In April 1944 the first B-29 unit to become operational, 58th Bomb Wing, deployed at bases around Kharagpur in northeast India. Forward operating bases with limited facilities were also being prepared in China, from which the B-29s were to mount attacks on Japan itself. The 58th Wing went into action for the first time on 5 June 1944, when ninety-eight B-29s carried out a daylight attack on rail yards at Bangkok, Thailand. Sixteen Superfortresses carried intercept receivers and radio-countermeasures officers. Some teething troubles remained after the bomber's hasty introduction into service and five aircraft were lost during the attack, none of them to enemy action.

The Ravens picked up several signals from the well-known Japanese Navy Mark I Model 1 radar. They also reported nine intercepts from an unknown radar working in the 68–80 MHz band. This was the Army *Tachi-6* equipment, which had entered service in 1942 and was widely deployed. The discovery of the radar at this late stage, when more than 200 were in service, testifies to the inadequacy of the Allied Elint effort in the China and Southeast Asia theatres up to mid-1944.

Ten days later, on 15 June, the 58th Wing mounted its next operation – against Japan itself. The target was the Imperial Iron and Steel Works at Yawata on the island of Kyushu. For the attack the B-29s deployed to their forward airfields near Hsinching in China, the bases nearest to Japan that were available to the Allies. Even so, with a round trip of some 2,400 miles, this was to be the longest-range aerial bombing mission yet attempted. Sixty-eight B-29s took off, and followed each other northeastwards towards the enemy homeland. One of the Ravens who flew on that mission, Lieutenant Tom Friedman, told the writer:

> We were scheduled to reach the target around midnight and attack singly, so there was no attempt to assemble in formation. During the long approach flight I moved into the waist gunner's position to gaze out at the panorama of ancient China spread out below me in the late afternoon. As dusk fell I crawled back to the windowless, crowded radar compartment, to my position in the aircraft. The countermeasures equipment had been a late

> addition to the B-29's inventory and, in spite of its great size, there was little spare space inside the pressurised compartments. The racks for my equipment had been squeezed in between the bulkhead and the chemical toilet. As the twelfth man in the aircraft, my 'seat' was the lid of the toilet itself – a subject for numerous wisecracks on the appropriateness of my position!

Friedman had been briefed to monitor the range 75–300 MHz, with an occasional foray up to 500–600 MHz to see if the Japanese had anything similar to the German *Würzburg* radar. As his B-29 neared enemy territory, Friedman heard the first Japanese radar signals on his APR-4. It was an Army *Tachi-6* early-warning set, familiar to B-29 operators after the Bangkok raid. Friedman continued:

> So our approach had been detected well before we reached the coast of China and several hours before our target. It remained to be seen what use if any the enemy would make of this information. As we neared the coast of China further signals came in from other early-warning radars, on frequencies around 80 MHz and around 100 MHz. The strengths of the signals slowly increased until at times I thought we passed directly over the sites. A glance at the scope of the bombing radar behind me showed the mainland of China receding to the southwest. Over the sea we passed through some rough weather and our big plane was tossed violently. With no safety belt for my improvised 'seat', I had to brace myself between the countermeasures equipment and the back of the bombing radar.

The turbulence gradually passed and the B-29 continued on until it passed over the small island in the Strait of Tsushima briefed as the initial point for the bombing run.

> By this time the enemy radar activity had risen to a crescendo. It was an eerie feeling to know that far below us our every move was being carefully watched on the enemy scopes and noted on their plotting boards. The $64,000 question was what could, or would, they do about it? Busily I logged the characteristics of each set of radar signals in turn, carefully noting the time of each so that, after the flight, the positions where the signals had been received could be plotted. The enemy radars in the target area

> included some of the 80 MHz sets I had picked up initially, the Mark I Model 1 set on 100 MHz (similar to the one I had seen at Eglin, captured on Guadalcanal) and there was some activity at 150 and 200 MHz which I took to be either gun-laying or searchlight-control sets. I found nothing at all during my incursions into the 500–600 MHz band.
>
> Nearly a score of enemy radars were following us during our bomb run. From time to time I switched my earphones from the search receiver to the regular interphone [intercom], and could hear the chatter of the gunners and the bombardier as they noted the searchlights' beams around us and the flashes of the bursting [anti-aircraft] shells . . . I glanced around and saw our radar man toggle the bombs at our aiming point, the anchorage beside the Yawata steel works, then I returned to my receiver as I felt the bomber swing on to the opposite heading for home.

On the way back to Hsinching, Friedman logged a similar set of signals to those he had found on the way out, until the last of them faded away as his bomber crossed friendly territory. The flight lasted just over fourteen hours.

Seven B-29s failed to return from the Yawata mission, but in each case the loss was believed to have resulted from an accident or a mechanical failure. Analysis of the countermeasures operators' logs gave the first hard information on the Japanese radar network in China and the Home Islands. Signals from several Army *Tachi-6* radars were logged. Similarly the Navy Mark I radar, operating in the 100 MHz band, was heard over most of the route.

A large number of signals were recorded between 175 and 220 MHz in the target area, off the tip of Korea, and in the vicinity of Nanking. Almost certainly these came from Navy Mark I Model 2 early-warning sets, and Mark VI Models 1 and 2 and *Tachi-1* and *-2* searchlight and fire-control radars. Despite the presence of those signals, the mission yielded no positive evidence of radar-controlled anti-aircraft fire or searchlights. Anti-aircraft fire was moderate and generally inaccurate, and it seemed to depend on the illumination of the plane by searchlights. There were numerous cases of planes being 'coned', but only after one light had first found it.

That initial attack on Yawata had taken the defences by surprise, and their reaction was weak and poorly co-ordinated. Although the defenders had more than two hours' warning of the B-29s' approach to the target, the anti-aircraft gun defences had been ineffectual. The report said there was no evidence of radar-fitted night-fighters (in fact the Japanese still had none in service).

Following the Yawata mission, the B-29s struck at other targets in Japan. The countermeasures operators' logs from these missions confirmed the impression gained during the earlier attacks: Japanese radar technology was about equal to that of the Western Allies early in 1941. These radars posed no serious threat to the heavy bombers, but the new series of attacks would undoubtedly spur the Japanese to improve their air defences.

The B-29 units based in India, flying via forward bases in China, made nine attacks on targets in Japan. Almost everything required at their forward bases, including all the bombs and aviation fuel, had to be brought in by air either by the B-29s or their supporting transport planes. It was the shortage of airlift capacity, rather than the strength of the Japanese defences, which restricted these early Superfortress operations. The final B-29 attack on Japan from China took place on 6 January 1945. From then until the end of March 1945, the India-based B-29s restricted their attacks to less-distant targets in Japanese-occupied territories.

Meanwhile, US XXI Bomber Command had deployed its B-29s to airfields on the newly captured islands of Guam and Tinian in the Marianas group. Between the end of October 1944 and the end of March 1945, XXI Bomber Command flew fifty missions of which twenty-nine were against Japan itself. Then the B-29 units in India transferred to the Marianas and were absorbed into XXI Bomber Command.

As XXI Bomber Command built up its strength on the Marianas, Stanley Kaisel arrived as a technical observer from RRL to assist with maintaining the countermeasures systems. He later recalled:

> I arrived in Saipan in November 1944, just as the XXI Bomber Command was preparing to launch its first B-29 attacks on Japan. The heavy bombers had come over from the US with their full complement of countermeasures equipment, but immediately on arrival the active jammers had been removed. Initially there was no call for electronic jamming and we did not want to give the Japanese any advance warning for what was in store for them.

> The APR-4 receivers were left in the aircraft, however, and during the initial attacks the crews were able to bring back a great deal of useful information on the Japanese electronic order of battle.

Until early in March 1945 the majority of B-29 attacks on Japan had taken place by day, with the aircraft releasing their bombs from altitudes above 20,000 feet. At these altitudes the bomber crews often found difficult weather conditions, however, and the high clouds, turbulence and strong winds often made it hard to bomb accurately. Taking into account the weakness of the Japanese defences, Major General Curtis LeMay, commanding XXI Bomber Command, ordered a radical tactical experiment. For a single maximum-effort night raid on Tokyo, he ordered his crews to attack from altitudes between 5,000 and 6,000 feet. That was beneath the effective engagement altitude of the Japanese heavy anti-aircraft guns, and an altitude where radar bombing would be considerably more accurate than from high level. Because he perceived that enemy night-fighters posed little threat, for this mission the B-29s' gun positions, except that in the tail, were to be unmanned and had their ammunition removed. The 1½ tons thus saved, and the reduced fuel load needed because the bombers would not have to climb to high altitude, would allow the B-29s to carry twice the weight of bombs as on previous attacks, six tons instead of three tons. It was a bold decision, as the official US historians afterwards commented:

> For the all-out effort against Japan . . . LeMay was to launch a series of maximum-effort incendiary strikes, delivered at low altitudes. It was a calculated risk and like most such decisions, it required great courage on the part of the commander. If losses should prove as heavy as some experts feared, the whole strategic campaign would be crippled . . .

Understandably, the B-29 bomber crews assigned to the mission did not greet the new tactics with wholehearted enthusiasm. Long schooled in the belief that safety from enemy defences depended on flying as high as possible, many felt that, at the comparatively low altitude briefed, their B-29s would be 'sitting ducks'.

In spite of the crews' misgivings, LeMay's new tactics were successful. On 9 March 1945, a force of 325 Superfortresses took off for the heaviest attack yet mounted on Tokyo. The concentrations of incendiary bombs started huge fires, which laid waste large sections of the Japanese capital. Tokyo's AA gun defences were the most powerful in Japan, but the smoke from the great fires made it difficult for them to engage the bombers. Thirteen B-29's failed to return from the attack; one went down over the target after being hit by ground fire, seven others were listed as 'missing' – probably to the same cause – and the remaining five ditched on the way home and their crews were rescued. That loss represented just over four per cent of the attacking force, a figure comparable with earlier, less destructive, attacks on Japan. From then on low-altitude night attack became the primary method of hitting Japanese cities, and in the ten days that followed Nagoya, Osaka and Kobe suffered similar raids.

* * *

At the beginning of April 1945, XXI Bomber Command decided to unleash the B-29s' radio-countermeasures capability. No sudden increase in the effectiveness of the Japanese air defences prompted this decision, but it was argued that there was little point in holding back a weapon which might help reduce B-29 losses still further.

The main sources of early-warning for air-defence operations came from the Army Type A Doppler warning system, the *Tachi-6* static early-warning radar (68–80 MHz) and the *Tachi-18* mobile early-warning radar (100 MHz). For the ground control of fighters, these radars operated in conjunction with a few *Tachi-20* height finders (94–106 MHz). The Japanese Navy employed its Mark I Model 1 (100 MHz) and Mark I Model 3 (146–165 MHz) radars for early-warning. In fact, there was never any shortage of warning on the B-29 attacks. Whether the bombers came from China or the Marianas, they made long approach flights in full view of radars in occupied China, or on the Nanpo Shoto islands and the radar picket boats positioned off the coast.

For control of the searchlights and heavy anti-aircraft guns of 75-mm, 88-mm and 120-mm calibre, the main Army radars were the *Tachi-1* and *-2* (185–205 MHz), the *Tachi-3* (72–84 MHz) and the *Tachi-4* (187–214 MHz). The main Navy radars for this purpose were the Mark IV Models 1, 2 and 3 (187–214 MHz). The Japanese had fragmented their meagre research effort to produce several different types of searchlight- and fire-control radar, but without taking the elementary precaution of spreading their operating frequencies to make them less vulnerable to jamming. Yet, even at this late stage of the war, the fire-control radars were in short supply and many AA gun and searchlight units had none. There was also a shortage of AA ammunition and, if targets could not be tracked on radar or illuminated by searchlights, the gun batteries were forbidden to employ barrage fire. There were instances when B-29 raids by more than a hundred aircraft were met with fewer than a hundred rounds of heavy AA fire.

Since the Japanese early-warning radars posed no real threat, the US jamming was concentrated against the searchlight- and fire-control radars operating in the 72–84 and 185–214 MHz bands. The B-29s first used their active countermeasures capability on 7 April 1945, during a daylight attack on industrial targets on the main Japanese island of Honshu. One bomb wing with 107 B-29s attacked the Nakajima aero-engine plant northwest of Tokyo. At the same time 194 aircraft hit the Mitsubishi engine plant at Nagoya. For the first time during a raid on Japan, the Tokyo attack force was escorted by P-51 Mustang fighters operating from Iwo Jima.

Between them the Superfortresses carried 247 jamming transmitters, APT-1 'Dinas' and APQ-2 'Rugs'. In addition each bomber carried a large quantity of 'Rope', rolls of metal foil 400 feet long and half an inch wide. After release a small cardboard 'parachute' attached to the outer end of the foil strip caused the roll to unwind, to produce a long vertical streamer of foil to jam radars working on long wavelengths.

The B-29s flew in standard daylight attack formations, with nine to eleven aircraft per squadron and squadrons following each other at approximately half-mile intervals. Each squadron acted as a self-screening unit, with ten APT-1s pre-set to barrage-jam the 185–205 MHz band, and two APQ-2s spot-jamming any radars on frequencies outside the main barrage. To counter the *Tachi-3* radars operating on frequencies between 72 and 84 MHz, aircraft in the lead of each column of squadrons were to drop ten bundles of 'Rope' per minute. Losses were light, though Japanese fighters and AA guns engaged both raiding formations. Five B-29s (1.6 per cent of the force) did not return It was believed three bombers fell to Japanese fighters and two to AA fire.

From then on, the B-29s used their countermeasures during both day and night attacks. At night the bombers attacked in a loose stream like that employed by the RAF over Europe. That gave a much lower concentration of electronic jamming and ‘Rope’ than by day.

Meanwhile, under a crash programme the Japanese electronics industry boosted the production of fire-control radars. Coupled with improved tactics, this led to an increase in B-29 losses during the night attacks. This phase culminated on the night of 25/26 May 1945, when the force of 464 bombers raiding Tokyo lost twenty-six planes (5.6 per cent). This was not a crippling loss by the standards of the air war over Europe, but it led to a review of the jamming options available to XXI Bomber Command.

To jam the *Tachi-3* radars operating in the 72–84 MHz band, B-29s carried ARQ-8 jammers pre-tuned to barrage-jam that band. A programme was also launched to fit out about half the B-29s as spot-jamming aircraft, each with three APT-3 jammers, an APR-4 receiver to tune them to the radar’s frequency and an extra crewman to operate these systems.

The additional jammers worked well enough in protecting daylight attacks but for night raids the density of jamming was insufficient to protect the widely spaced aircraft. So the decision was taken to fit a few B-29s with jammers in place of the bomb load, along the lines of the jamming aircraft used by the RAF’s No. 100 Group during attacks on Germany. Each bomb wing modified four B-29s as jamming aircraft, each carrying six or more jamming transmitters. The first of these aircraft became operational in June 1945, and in the weeks to follow others joined them to screen night attacks. Lieutenant Harry Smith, a radio-countermeasures officer with the 58th Bomb Wing, described the role of these aircraft:

> For obvious reasons the RCM B-29s soon gained the nick-name ‘Guardian Angels’, and I flew several missions aboard them. The RCM operator’s job was to switch on the barrage jammers at the correct time, then use his spot jammers to take out any enemy radars not covered by the main barrage. Normally the ‘Guardian Angels’ would precede the main force of bombers to the target area, then begin jamming and fly racetrack patterns over the target at altitudes above 12,000 feet. The lowest ‘Guardian Angel’ would orbit clockwise, the next one up counter-clockwise, and so on

> up the stack. Since we arrived in the target area first, the gunners on the ground would start off by trying to engage us. That part of the mission could be very exciting and sometimes we took damage. But soon afterwards the main force of bombers would start to come in at altitudes around 5,000 feet and they took the heat off us.
>
> As soon as the Guardian Angel B-29s started operating there was a dramatic reduction in the number of aircraft lost or which returned with damage. Overnight, the status of the RCM officer rose from 'mere passenger' to 'fantastic guy'. After the success of the first such mission our Wing Commander became very enthusiastic and wanted the protection of 'Guardian Angels' even when we were attacking targets where there were no threatening radars. Sometimes we could talk him out of the idea if it was a daylight raid. But at night he usually wanted us to go along even if there was nothing on the ground to jam; he would say 'To Hell with that, the aircraft are modified so let's use them!'

* * *

The B-29 raids tore the heart out of many of Japan's cities, and systematically wrecked the country's industrial base. Yet, even worse was in the offing. Under the strictest secrecy a B-29 unit, the 393rd Squadron of the 509th Composite Group, made final preparations to deliver attacks using atomic bombs. The unit's Electronics Officer, Lieutenant Jacob Beser, was allowed to choose the radio-countermeasures suite he took on the mission. He selected a mix of APT-1, APT-4 and ARQ-8 jammers, to protect the bomber if it was engaged by radar-laid AA fire.

Apart from the conventional Japanese defensive systems, there was another matter concerning Beser. To detonate the bomb at exactly 1,900 feet above the target, to inflict maximum blast damage, the early atomic weapons carried four separate radar fuses. These were modified APS-13 tail-warning radars (410–420 MHz), mounted around the circumference of the bomb with the directional aerials pointing forwards. There were worries that signals from a Japanese radar might trigger one of the bomb's radar fuses prematurely, in which case the B-29 might be incinerated in the fireball from its own weapon. Although no known Japanese radar operated in the 410 MHz band, there was a chance that such a radar existed or might be introduced. There was also the possibility that a second harmonic signal from a radar operating on, say, 205 MHz, might come through strongly enough to trigger one of the radar fuses.

To reduce the risk of a premature detonation of the weapon to that cause, during the B-29's bombing run Beser had to monitor the frequency of each bomb-fusing radar in succession, using his APR-4 receiver. If he encountered transmissions that might trigger the bomb, at any time up to bomb release he could switch off some or all of the radar fuses. As a last resort, he could leave the detonation of the weapon to the back-up barometric or impact fuses.

Jacob Beser was the only man to fly on both atomic bomb missions, against Hiroshima on 6 August and against Nagasaki on 9 August 1945. On neither mission did radar-controlled anti-aircraft guns attempt to engage the B-29, and at neither target did he detect transmissions that might have triggered the bomb prematurely.

The two atomic bomb attacks brought the war in the Pacific to an abrupt halt, much to the relief of the soldiers and sailors preparing to invade the Japanese Home Islands.

* * *

Between June 1944 and August 1945, B-29s flew more than 27,000 sorties, in the course of 277 raids on targets in Japanese-held areas or the Home Islands. Losses known or believed to have resulted from enemy action totalled 214 aircraft, or less than 0.8 per cent of those taking part. The majority of the fifty-eight losses to fighter attack occurred during daylight missions, before long-range escort fighters became available in April 1945. Similarly, most of the forty-eight losses to AA fire took place before the countermeasures campaign took effect. Following the introduction of the 'Guardian Angel' B-29s to screen raiding forces in June 1945, losses during the night attacks fell markedly.

Chapter 14

In Retrospect

> 'To inquire if and where we made mistakes is not to apologise. War is replete with mistakes because it is full of improvisations. In war we are always doing something for the first time. It would be a miracle if what we improvised under the stress of war should be perfect.'
>
> Vice-Admiral Hyman Rickover

Immediately following the end of World War II, Allied air-intelligence officers and scientists swarmed over the territory of their vanquished foes. Among their priority targets was determining the effectiveness of the various radar-countermeasures and tactics used against the German and Japanese air defences.

For its part, the RAF was particularly interested to discover the effects of No. 100 Group's campaign of radio-countermeasures in support of the bomber offensive. The war had been over just thirteen days when two Halifax bombers landed at Jagel near Hamburg. The aircraft brought an RAF investigation team, commanded by Air Commodore Roderick Chisholm, Senior Air Staff Officer of No. 100 Group, and consisting of senior officers from Bomber Command, Fighter Command and Second Tactical Air Force.

Now the RAF officers had the chance to question many of the Luftwaffe crews who, on occasion, had dealt such punishing blows to Bomber Command. One of those who took part in the examination of Luftwaffe equipment was Wing Commander Derek Jackson, who had done so much to prepare 'Window' for service. Later he had flown as radar operator during the flight-trials of the two Ju 88 night-fighters the RAF had captured during the war. There was a startling sequel to Jackson's trials with the *Flensburg* device, which homed on emissions from the bombers' 'Monica' tail-warning radar sets. It will be remembered that as a direct result of Jackson's trials in the summer of 1944, 'Monica' had been removed from RAF bombers. Jackson now learned that the Luftwaffe had developed a ground direction-finder to give bearings on the 'Monica' transmissions, in addition to the airborne *Flensburg* equipment. Both systems had been extremely useful. Then in September 1944, for some reason the Luftwaffe could not fathom, RAF bombers ceased to emit these signals and rendered the German systems useless.

The value of British radar transmissions to the Luftwaffe was brought home to the investigators when they spoke to a night-fighter crewman who had fought on the Eastern Front. He commented: 'Night-fighting was difficult there, because the Russians were so backward in radar that they had no transmissions on to which we could home!' The interrogators also learned that the appearance of the Mosquito night-fighters accompanying raids deep into Germany had caused consternation. Luftwaffe night-fighter crews were much in awe of both the aircraft and its advanced radar, and had an exaggerated impression of the Mosquito's capabilities. Every loss, no matter how caused, was attributed to the seemingly omnipresent Mosquitoes. The Luftwaffe pilot's earnest prayer was said to be: 'Dearest Hermann, give me a Mosquito!'

In their efforts to avoid the Mosquitoes' unwelcome attentions, Luftwaffe fighter pilots would often resort to dangerous flying. Pilots spoke of making night cross-country flights at altitudes below 150 feet, dropping to 100 feet in the vicinity of their home airfields. One pilot, Hauptmann Hans Krause, was wont to line himself up on his home runway at 10,000 feet, then enter a high-speed descent with a landing at his airfield at the end of it. The advantage of this method, he said, was: 'If you were shot down by a Mosquito, you had plenty of time to bail out!'

During the final weeks of the war in Europe, Adolf Hitler had decreed that his retreating troops should leave behind nothing of possible value to the enemy. In accordance with that order much of the Luftwaffe air-defence system – on which so much effort had been lavished – succumbed to the demolition charges. Even at the end of the conflict, however, there remained areas of Europe that had never felt the impact of war. In Denmark, for example, the Luftwaffe air-defence system was still in full working order at the time of the German surrender.

That presented RAF intelligence officers with a unique opportunity to resurrect the system and determine its strengths and weaknesses. The Luftwaffe air-defence network in central Denmark, comprising ten large radar sites with forty individual radars linked by landline to the fighter-control centre at Grove, was chosen for Operation 'Post Mortem'. Luftwaffe radar operators and fighter-control personnel were brought from their prisoner-of-war camps, to operate the various pieces of equipment.

There followed a series of live exercises without parallel in the history of warfare. With RAF officers looking over their shoulders, the Luftwaffe personnel were told to react in the normal way to the indications from their equipment. The series of exercises fell into eleven parts, using raiding forces of up to 200 RAF bombers. Each radio-countermeasures tactic, and each type of jamming, was re-enacted to determine its effectiveness – though, to minimise the risk of collision, the exercises were flown in daylight.

The first 'Post Mortem' exercise took place on 25 June 1945. The tests revealed that the RAF jamming had obliged the Luftwaffe to employ a system which, at best, provided only very loose control for its night-fighters. Thus, if the night-fighters' airborne radars were also jammed, it was extremely difficult for any but the most experienced crews to achieve results. On the other hand, the tests revealed that the 'Mandrel' screen had not been as effective in denying early-warning of the raiders' approach as the RAF had hoped. During 'Post Mortem' it seemed that there was always an operator at a radar set or a listening post somewhere who saw what was happening behind the screen of jamming. It should be remembered, however, that by that time some of the Luftwaffe radar operators had accumulated more than two years' experience of observing RAF jamming on almost a nightly basis. Such people were not easily fooled. The only certain way to reduce the early-warning time had been for the attacking force to approach at low level.

The 'Window' spoofs were more successful. Throughout the series of exercises, Luftwaffe controllers usually made a poor showing when trying to assess the size of raiding forces dropping 'Window/Chaff'. On occasion their plots underestimated or exaggerated the number of aircraft present by factors as high as ten. During one exercise the Grove situation map showed a series of plots on a force estimated at 150 bombers; in fact no bombers were present in that area, only metal foil dropped half an hour earlier from a small feinting force. At other times 'Window/Chaff' was reported as being dropped, when there was none. On no occasion – and this was important – could the Luftwaffe controllers tell with certainty which were the real attacks and which were the feints. One radar operator confided to his RAF watcher that for his job one needed to be something of a clairvoyant.

Even when jamming failed to deprive the defenders of early-warning, it still made it difficult to maintain a steady flow of accurate plots on the bombers' progress. Sometimes the plotting failed in spectacular fashion. During the final exercise in the series, the bombers were accurately plotted on the Grove situation map until they crossed the west coast of Denmark. The force then simulated an attack on Frederika, in eastern Denmark, and re-crossed the west coast without appearing on the Grove map at all. During that period, other plots had been confidently shown on the situation map. First there had been a 'Window' spoof, then a series of plots that must have originated in the imagination of the fighter-control officer, for it bore no relation to what was really happening.

With the end of 'Post Mortem', RAF disarmament teams set about dismantling and demolishing the remaining German radar stations in the British zone of occupation. Examples of most of them were removed to Great Britain for detailed examination. One radar that found its way to Farnborough was a venerable old *Freya*, Serial No. 1, built in 1936. A great deal had happened since then.

* * *

Because flak had caused the majority of US bomber losses during the final year of the war in Europe, USAAF intelligence officers made a particularly detailed study of that aspect of the defences. They interviewed people at all levels in the flak organisation, from generals to radar operators and technicians. From the answers received the interrogators concluded that, where cloud conditions by day made radar-tracking necessary, the combined use of 'Window/Chaff' and 'Carpet' jamming reduced the effectiveness of radar-controlled flak by approximately three-quarters. That reduction was significant if one considers that, between the beginning of September and the end of December 1944, fully half of all Eighth Air Force missions over Europe encountered eight-tenths or more cloud.

The interrogators noted that the commencement of electronic jamming of the *Würzburg* sets in October 1943 by the USAAF caused the Germans some concern. Plans were made to spread the *Würzburgs* over a wider frequency band, and for the development of techniques for shifting frequency rapidly. Initially the barrage of 'Carpet' jamming was probably quite thin and no 'Window/Chaff' was used. However, when the USAAF commenced dropping 'Window/Chaff' during its daylight attacks from December 1943 onwards, the combination of that with electronic jamming was very successful in preventing the defenders obtaining accurate radar fire-control information. The compendium report on the interrogations went on:

> By the summer of 1944, the Germans apparently were beginning to be able to cope with 'Window' jamming and 'Carpet' jamming fairly effectively as the amount of electronic jamming was decreasing and the operators were becoming experienced in working against 'Window'. However, the Germans claimed that in the summer the 'Window' dropped began to increase appreciably, and it continued to increase until the quantities dropped were so great that even *Würzlaus* [the system designed to counter 'Window/Chaff'] was ineffective most of the time . . . On top of this increase in the quality of 'Window' jamming, the sudden increase in the amount of electronic jamming in October 1944 caught the Germans entirely by surprise and proved to be very effective. All of the scientists, engineers and military personnel agreed that the most effective means of jamming was the combined use of 'Window' and 'Carpet', and that the tactics employed by the USAAF were very effective in jamming their *Würzburg* radars . . .

Flak personnel said that one of the most important reasons for the lack of success of the anti-jamming programme was the continual lowering of the level of intelligence and experience of operators. Many experienced but able-bodied operators and technicians had been drafted into the infantry. Their replacements were old men or young women who had only a brief training course before they were sent into the field. The technical personnel interrogated felt that a good operator could do a lot to overcome the effects of jamming; but good operators were scarce.

* * *

Following the end of the Pacific war in August 1945, there was a similar detailed examination of the effects of countermeasures on the Japanese air defence system.

Some time earlier, a German U-boat had brought to Japan a complete *Würzburg* radar together with details of the functioning and operation of the *Würzlaus* system to counter 'Window/Chaff'. As we have already seen, in Europe this radar had been jammed to the point of near uselessness, yet it was far superior to any Japanese equivalent. The Army planned to mass-produce a Japanese version of the *Würzburg*, but only a prototype existed when the war ended.

In the US compendium report, the Japanese deployment of radar anti-jamming systems received curt treatment:

> This subject can be summed up in one word: "none".

In the absence of such systems, the report went on to outline how Japanese AA gunners reacted to the US jamming:

> Against electronic jamming they had practically no means of counteracting its effect. In some cases azimuth was obtained by a crude sort of [direction-finding] on the source of the jamming signal by using the point of maximum disturbance on the receiver-indicator, and the range was obtained, if possible, by some radar not too badly jammed . . . The Japanese Army had received from Germany the general principles of the *Würzlaus* method and had done considerable work experimenting with it. However the Army operators decided they could read through our 'Rope' well enough and so this method was never used in the field.

* * *

What effect did the various radio-countermeasures have on the course of the Second World War? Without doubt No. 80 Wing's jamming attack on the Luftwaffe navigational beams played an important part in Britain's survival during the hard winter of 1940. Had No. 80 Wing failed, the Luftwaffe might have caused considerably more destruction at a time when Great Britain was at its most vulnerable. The raids caused massive damage and heavy casualties, but things could have been a lot worse. Preventing that from happening was unquestionably a major achievement. Next in importance was the success of the invasion of northern France, which owed much to the effectiveness of the jamming and spoofing efforts. Without this support, the fight to secure the beachhead in Normandy might have resulted in far more casualties than was the case.

The value of the jamming support given to the RAF bombing offensive on Germany is more difficult to quantify. Because it is impossible to prove a negative, one cannot say for certain how many bombers would have been lost had there been no jamming. It seems likely, however, that the various jamming methods reduced RAF bomber losses between December 1942 and the end of the war by something of the order of one per cent. Yet, over a long period, that amounted to a saving of more than 1,000 bombers and their crews.

In the case of the American daylight attacks on targets in Europe, initially it was fighters attacking visually that inflicted most of the losses. Radar-jamming could provide little relief from that threat. Against flak it was a different matter. When cloud or (over Japan) darkness forced AA gunners to rely on radar-controlled fire, jamming greatly reduced its accuracy. As a 'ball park figure', radio-countermeasures probably saved about 600 US heavy bombers over Europe, and a further 200 during operations against Japan.

Only twice did countermeasures bring about a near-collapse of an enemy air-defence system. The first was the devastating initial effect of 'Window' on the German air defences at the end of July 1943. The second was over Japan in 1945, when the USAAF jamming paralysed the Japanese night-air-defence system. For the rest of the conflict radio-countermeasures brought about a somewhat smaller, though still significant, reduction in bomber losses.

Yet the effects of jamming went far beyond the saving in aircraft, for those could be replaced relatively easily. Even more important than that was the saving in trained crews. Moreover, the protection of the jamming helped sustain the morale of bomber crews, while lowering that of the defenders. There can be no doubt that the Allied radio-countermeasures effort during World War II was a remarkably cost-effective investment.

Appendix A

Main Types of German Surface Radars

Note: These radars all ran to numerous sub-types, so the data given are representative for the type only.

Freya
Role: early-warning radar
Production: 1,000
Entry into service: 1938
Peak power: 15–20 kW
Pulse repetition frequency: 500
Frequency range: 120–130 MHz initially; 57–187 MHz at the end of the war
Maximum search range: about 100 miles

Seetakt
Role: surface-vessel-reporting and gun-ranging radar
Production: about 200
Entry into service: 1938
Peak power: 8 kW
Pulse repetition frequency: 500
Frequency range: 368–390 MHz
Maximum range on ships: about 20 miles, depending on height of aerial array above the surface

Mammut
Role: early-warning radar
Production: about 20
Entry into service: 1942
Peak power: 200 kW
Pulse repetition frequency: 500
Frequency range: 120–130 MHz initially; 120–150 MHz at the end of the war
Maximum search range: 185 miles

Wassermann
Role: early-warning radar
Production: about 150
Entry into service: 1942
Peak power: 100 kW
Pulse repetition frequency: 500
Frequency range: 120–130 MHz initially; 119–156 MHz at the end of the war
Maximum search range: 175 miles

Jagdschloss
Role: ground-controlled-interception radar
Production: about 80
Entry into service: 1944
Peak power: 150 kW
Pulse repetition frequency: 500
Frequency range: 129–165 MHz
Maximum search range: 112 miles

Würzburg Model D
Role: flak- and searchlight-control radar
Production: 3,000–4,000
Entry into service: 1940
Peak power: 7–11 kW
Pulse repetition frequency: 3,750
Frequency range:
A Band, 553–566 MHz (initial operating band)
B Band, 517–529 MHz (introduced autumn 1943)
C Band, 440–470 MHz (introduced end 1944)
Maximum search range: 25 miles
Maximum tracking range: 15 miles

Mannheim
Role: flak- and searchlight-control radar
Production: 400
Entry into service: 1943
Peak power: 15–20 kW
Pulse repetition frequency: 3750
Frequency range: as for *Würzburg* D
Maximum search range: 19 miles
Maximum tracking range: 12.5 miles

Giant Würzburg
Role: ground-controlled interception, also flak-control
Production: about 1,500
Entry into service: 1941
Peak power: 7–11 kW
Pulse repetition frequency: 1,875
Frequency range: A and B Bands as for *Würzburg* D
Maximum search range: 40 miles
Maximum tracking range: 22 miles

Appendix B

Main Types of Japanese Surface Radars

Note: These radars all ran to numerous sub-types, so the data given are representative for the type only.

Japanese Army Radars

Type A
Role: bi-static Doppler-interference detector, for long-range early-warning
Production: about 100
Entry into service: 1941
Power: built in 3, 10, 100 and 400 Watt versions.
Frequency range: 40–80 MHz
Maximum range: up to 440 miles

Note: this was not strictly a radar, but it is included here for completeness

Tachi-1
Role: searchlight and AA-gun-control radar
Production: 30
Entry into service: 1943
Peak power: 5 kW
Pulse repetition frequency: about 1,000
First used: 1943
Frequency range: around 200 MHz
Maximum range: about 12 miles

Tachi-2
Role: searchlight and AA-gun-control radar
Production: 35
Entry into service: 1943
Peak power: 10 kW
Pulse repetition frequency: 1,000
Frequency range: around 200 MHz
Maximum range: about 25 miles

Tachi-3
Role: searchlight- and AA-gun-control radar
Production: about 150
Peak power: 50 kW
Entry into service: 1944
Frequency range: 72–84 MHz
Maximum range: about 25 miles

Tachi-6
Role: early-warning radar
Production: 350
Entry into service: 1942
Peak power: 10–50 kW
Pulse repetition frequency: 500 or 1,000
Frequency range: 68–80 MHz
Maximum range: 185 miles

Tachi-7
Role: early-warning radar
Production: about 60
Entry into service: 1943
Peak power: 50 kW
Frequency range: around 100 MHz
Maximum range: 185 miles

Tachi-18
Role: early-warning radar
Production: 400
Entry into service: 1944
Peak power: 50 kW
Frequency range: 94–106 MHz
Maximum range: 185 miles

Tachi-31
Role: searchlight- and AA-gun-control radar
Production: 70
Entry into service: 1945
Peak power: 50 kW
Frequency range: 187–214 MHz
Maximum range: 25 miles

Japanese Navy Radars

Mark I Model 1
Role: early-warning radar
Production: about 80
Entry into service: 1942
Peak power: 5 kW
Pulse repetition frequency: 530–1,250
Frequency range: 92–108 MHz
Maximum range: about 90 miles

Mark I Model 2
Role: early-warning radar
Production: about 300
Entry into service: 1942
Peak power: 5 kW
Pulse repetition frequency: 750–1,500
Frequency range: 187–214 MHz
Maximum range: about 90 miles

Mark I Model 3
Role: early-warning radar
Production: about 1,500
Entry into service: 1943
Peak power: 10 kW
Pulse repetition frequency: 400–600
Frequency range: 146–165 MHz
Maximum range: about 90 miles

Mark II Model 1
Role: shipborne air- and surface-search radar
Entry into service: 1942
Peak power: 5 kW
Pulse repetition frequency: 500–1,100
Frequency range: 185–210 MHz
Maximum range: 90 miles on an aircraft; 18 miles on a large ship

Mark II Model 2
Role: shipborne surface-search and fire-control radar
Entry into service: 1942
Peak power: 2 kW
Frequency range: 2,857–3,125 MHz
Maximum range: 22 miles on a large ship

Mark IV Model 1
Role: searchlight and AA-gun-control radar
Production: 80
Entry into service: 1943
Peak power: 30 kW
Frequency range: around 200 MHz
Maximum range: 30 miles

Mark IV Model 2
Role: searchlight and AA-gun-control radar
Entry into service: 1944
Peak power: 30 kW
Pulse repetition frequency: 1,000
Frequency range: around 200 MHz
Maximum range: 30 miles

Appendix C

Air Forces, Equivalent Ranks

Royal Air Force	*Luftwaffe*	*US Army Air Force*
Marshal of the RAF	Generalfeldmarschall	–
Air Chief Marshal	Generaloberst	General (4-star)
Air Marshal	General der Flieger	Lieutenant General
Air Vice-Marshal	Generalleutnant	Major General
Air Commodore	Generalmajor	Brigadier General
Group Captain	Oberst	Colonel
Wing Commander	Oberstleutnant	Lieutenant Colonel
Squadron Leader	Major	Major
Flight Lieutenant	Hauptmann	Captain
Flying Officer	Oberleutnant	1st Lieutenant
Pilot Officer	Leutnant	2nd Lieutenant
Warrant Officer	Stabsfeldwebel	Flight Officer
Flight Sergeant	Oberfeldwebel	Master Sergeant
Sergeant	Feldwebel	Technical Sergeant
–	Unterfeldwebel	Staff Sergeant
Corporal	Hauptgefreiter	Sergeant
Leading Aircraftman	Obergefreiter	Corporal
Aircraftman 1st Class	Gefreiter	Private 1st Class
Aircraftman 2nd Class	Flieger	Private

Glossary

Code-Names, Equipment Designations and Unit Terms

AA Anti-aircraft.

ABC Abbreviation for 'Airborne Cigar'.

'Airborne Cigar' Airborne transmitter which jammed the Luftwaffe fighter-control frequencies in the VHF (38–52 MHz) band.

AI Airborne Interception; British designation for night-fighter radar equipment.

'Abdullah' British radar-homing device, to enable fighter-bombers to home on the German *Würzburg* gun-control radar.

APQ-2 'Rug' US-designed airborne jammer to cover the band 450–720 MHz.

APQ-9 'Carpet III' US-designed airborne jammer to cover the band 475–585 MHz, spot-tuned on to the victim radar frequency using an APR-1 or an APR-4 receiver.

APR-1 and APR-4 US-designed radar intercept receivers, almost identical systems produced respectively by Galvin Mfg Co. and the Crosley Corp. Initial coverage 100–950 MHz, later expanded to 40–3,300 MHz by the use of a range of plug-in tuning units.

APT-1 'Dina' US-designed airborne jammer to cover the band 90–220 MHz.

APT-2 'Carpet' US-designed airborne jammer to cover the band 450–720 MHz; produced in very large numbers.

APT-3 'Mandrel' US-designed airborne jammer to cover the band 85–135 MHz.

ART-3 'Jackal' US-designed airborne jammer to jam German tank communications in the 27–33 MHz band.

'Aspirin' British ground jammer to counter the *Knickebein* navigational aid.

'Benjamin' Ground jammer to counter the German *Y-Gerät* bombing aid.

Berlin German AI radar operating in the 10-centimetre wavelength band, introduced into service in small numbers before the war ended.

Bernhard German ground-to-air communication system.

Bernhardine Airborne receiver for *Bernhard* signals.

'Boozer' Radar warning receiver fitted to RAF bombers, to set off an alarm if the aircraft was being tracked by the *Lichtenstein BC* or *Würzburg* radar.

'Bromide' Ground jammer to counter the *X-Gerät* bombing aid.

'Carpet' See APT-2.

'Chaff' US code-name for 'Window'.

'Chain Home' British early-warning radar operating initially in the band 20–50 MHz.

'Corona' British operation, mounted from a ground station in England, to broadcast spoof orders to Luftwaffe night-fighters.

'Domino' Ground jammer to counter the *Y-Gerät* bombing aid.

Düppel German code-name for metal foil dropped to confuse enemy radar.

Egerland German centimetric radar AA fire-control system, comprising the Marbach tracking radar and the Kulmbach surveillance radar. This equipment was about to go into production when the war ended.

'Figet' British ground jammer to jam Luftwaffe fighter-control channels.

Flensburg Airborne radar receiver, to enable Luftwaffe night-fighters to home on emissions from the British 'Monica' tail-warning radar.

Freya German ground early-warning radar. Operated initially in the band 120–130 MHz, later widened to 57–187 MHz.

'Gee' British hyperbolic navigational aid.

Geschwader Luftwaffe flying unit with a nominal strength of three *Gruppen* each with 30 aircraft, plus a Staff flight with four. Each *Geschwader* was designated for a set role, e.g. *Jagd* (fighter), *Nachtjagd* (night-fighter), *Kampf* (bomber), etc.

Giant Würzburg German fighter control radar. Operating frequencies as for *Würzburg*.

'Glimmer' Feint seaborne invasion which took place near Boulogne, in support of the invasion of France.

'Grocer' British airborne jammer to counter the *Lichtenstein* radar fitted to Luftwaffe night-fighters.

Gruppe The basic Luftwaffe flying unit. Strength early in the war was three *Staffeln* each with nine aircraft, plus a Staff flight with three.

'Headache' Generic term for the measures taken to jam the *Knickebein* navigational aid.

Heinrich German ground jammer to counter the British 'Gee' navigational aid.

Himmelbett Luftwaffe system of close-controlled night-fighting.

H2S British airborne ground-mapping radar to aid bombing.

H2X US-designed and built ground mapping radar to aid bombing.

Jagdschloss Fighter-control radar introduced by the Luftwaffe late in the war, its first equipment to employ the plan position indicator form of display. Operated on frequencies in the 129–165 MHz band.

'Jostle' Airborne high-powered communications jammer to jam Luftwaffe night-fighter-control channels in the VHF band.

Klein Heidelberg Luftwaffe ground passive system for aircraft detection, using reflected radiations from British 'Chain Home' ground radars.

Knickebein Luftwaffe beam navigational aid.

Korfu Luftwaffe ground radar receiver, which gave bearings on aircraft transmitting with H2S radar.

Lichtenstein BC Luftwaffe night-fighter radar operating on frequencies around 490 MHz.

Mammut Luftwaffe early-warning radar. Operated initially in the band 120–130 MHz, later widened to 120–150 MHz.

'Mandrel' British airborne jammer to counter the *Freya*, *Mammut* and *Wassermann* early-warning radars. Initial coverage 118–128 MHz, later produced in several versions to cover the band 29–215 MHz.

Mannheim German radar used to direct AA guns and searchlights, intended to replace the *Würzburg*. It was produced only in moderate numbers, however. Since it operated in the same frequency bands as the *Würzburg*, both radars were similarly vulnerable to Alied jamming.

Mattscheibe Luftwaffe tactic to silhouette bombers flying above cloud at night, by shining searchlights on the base of the cloud.

'Meacon' British ground device to imitate the transmissions of German radio beacons, to provide German aircraft with false radio bearings.

'Moonshine' British radar-repeating device, to produce a false picture on German ground radars.

'Monica' Tail-warning radar fitted to RAF night-bombers.

Naxburg *Naxos* receiver with the aerial mounted in a *Würzburg* dish, to produce a ground system to track the movements of RAF bombers radiating H2S radar signals.

Naxos Airborne radar receiver, to enable Luftwaffe night-fighters to home on emissions from the H2S radar.

Neptun Luftwaffe night-fighter radar operating in 158–187 MHz band.

Nürnberg Modification to the *Würzburg* gun-laying radar, to give relief from Window/Chaff jamming.

'Oboe' Radar bombing aid carried by some RAF Pathfinder aircraft.

'Perfectos' Airborne transmitter/receiver to trigger the identification friend or foe (IFF) equipment fitted to Luftwaffe night-fighters, and receive the reply signals so the RAF night-fighter could home on these emissions.

'Piperack' British airborne jammer to counter the Luftwaffe *SN-2* night-fighter radar.

Postklystron German ground jammer to counter the British H2S bombing radar.

'Rope' Long lengths of Window/Chaff which unfolded or unwound after release, to counter radars working on frequencies below 200 MHz.

Rotterdam German code-name for the British H2S radar signals.

'Rug' See APQ-2.

Seetakt German naval radar for coast watching, and to direct fire from ships' guns and coastal batteries. Operated in 368–390 MHz band.

'Serrate' Airborne radar receiver, to enable RAF night-fighters to home, initially, on emissions from the *Lichtenstein BC* radar fitted to their Luftwaffe counterparts. The later Serrate VI enabled RAF fighters to home on the *SN-2* radar.

SN-2 Luftwaffe night-fighter radar operating in the 73–91 MHz band, later widened to 118 MHz.

SPR-1 Shipboard version of the APR-1 radar intercept receiver.

Staffel Luftwaffe flying unit with a nominal strength of about nine aircraft. That number varied greatly in some units as the war progressed.

'Taxable' Feint seaborne landing on Cap d'Antifer, in support of the invasion of France.

'Tinsel' Modification to the high-frequency transmitters fitted to RAF bombers, to broadcast engine noises on the Luftwaffe fighter-control frequencies.

'Tuba' US ultra-high powered ground jammer, to jam the *Lichtenstein* night-fighter radar.

Wassermann German early-warning radar. Operated initially in the band 120–130 MHz, later widened to 119–156 MHz.

Wilde Sau 'Wild Boar'. Luftwaffe tactic to use single-engined fighters at night to engage bombers over the target.

'Window' British name for metal foil dropped to confuse radar.

Wismar Modification to *Würzburg* and *Mannheim* radars, to enable them to switch frequency rapidly between bands.

Würzburg German radar used to direct AA guns, searchlights and, for a short time, night-fighters. Operated initially in the band 553–566 MHz, later widened to 440–566 MHz.

Würzlaus Modification to the *Würzburg* gunlaying radar, to give relief from 'Window' jamming.

X-Gerät Luftwaffe beam bombing aid.

Y-control Method of controlling Luftwaffe night-fighters using modified *Y-Gerät* equipment.

Y-Gerät German beam bombing aid.

Zahme Sau 'Tame Boar'. Luftwaffe tactic, designed to enable twin-engined night-fighters to intercept night-bombers *en route* to and from the targets, thus setting up long running battles.

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