Royal Air Force

AIR POWER REVIEW

Volume 10 Number 1 Spring 2007

Photo: RAF AHB

A Boeing Fortress B Mk III electronic warfare aircraft of RAF Bomber Command

To What Extent Did Royal Air Force Employment of Electronic Warfare Contribute to the Outcome of the Strategic Night Bomber Offensive of World War II?

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The war in the air is a technological war which cannot be won by a technologically inferior fighting force, however high its moral or dauntless its resolution'
(Luftwaffe 158 victory ace, Colonel Johannes Steinhoff.[2])

Introduction

During World War II offensive strategic air power evolved from principles little changed from the German Gotha raids of World War I to highly complex and technical operations. In particular, the night bomber offensive of World War II saw the first intensive employment of Electronic Warfare (EW), precipitating a race for technical supremacy arguably unprecedented in the history of warfare.

Many contemporary studies of the Royal Air Force (RAF) bomber offensive have suggested that the campaign was of little relevance to the final collapse of Germany. Indeed, RAF 'area bombing' of German cities has sometimes been accused of undermining the moral superiority of the Allies. Moreover, fuel shortages and the loss of the Luftwaffe's early warning network of radars and Command and Control (C2) facilities to advancing Allied land forces is generally cited as the primary factor in the final collapse of Germany's night defences.

This essay offers an alternative perspective that RAF employment of EW was the most significant factor in the campaign. Bomber Command EW allowed the RAF to limit the effects of increasingly advanced Luftwaffe C2 and fighter technologies, ultimately reducing German Air Defences (AD) to virtual impotence. It is also suggested that RAF navigational systems enabled quantum leaps to be made in bombing accuracy, given the conditions and technology available.

In reaching its conclusions, this essay examines the impact of the principle RAF and Luftwaffe EW technologies upon the strategic night bomber offensive against Europe during 1939-45. The EW capabilities examined include navigation, radar, passive detection, Signals Intelligence (SIGINT) including Electronic Intelligence (ELINT) and Communications Intelligence (COMINT), and Radio Counter Measures (RCM) jamming. The significance of such systems is compared with other factors in the campaign such as leadership, C2, and the wider strategic context of the conflict. RAF studies suggested that loss rates of 5% over a period of 3 months reduced the effectiveness of a bomber force to unacceptable levels, whilst losses of 7% made a force ineffective.[3] Therefore, for the analytical purposes of this essay, RAF losses exceeding 5% are considered unacceptable whilst those exceeding 7% are classed as unsustainable.

The campaign is examined in 4 stages. Firstly, the period from September 1939 to December 1941 saw extremely poor results from RAF night bombing due to unsuitable aircraft and navigation methods, while German military expansion had emphasised offensive rather than defensive operations. Consequently, Luftwaffe night defences were ill-equipped to challenge early RAF bomber sorties; however, the appointment of the inspirational Colonel Josef Kammhuber saw a rapid expansion of the night-fighter force, enhanced by improved C2 and Germany's technological lead in early warning and gun-laying radars. Nevertheless, Britain retained a lead in Airborne Interception (AI) technology which enabled RAF night-fighters to challenge early Luftwaffe intruder operations over Britain. Moreover, British AI radar contributed significantly to Britain's development of long range navigation capabilities. Overall, the period was characterised by stalemate between the RAF and the Luftwaffe as they each struggled to overcome early technical and organisational limitations.

The second phase, between January 1942 and July 1943, saw rapid developments by both sides. The Luftwaffe took an increasing toll on RAF bombers as the so called 'Kammhuber Line' was refined and Germany's own AI radar equipped night-fighters entered service. However, the RAF introduced a variety of navigation and RCM systems which improved bombing accuracy and enabled more effective penetrations of Luftwaffe defences. Despite innovative German technology, further RAF tactical refinements, under the leadership of the aggressive 'Bomber' Harris, led to RAF ascendancy during this period which included the 'Thousand Bomber Raids'. Nevertheless, RAF losses were barely sustainable and at times threatened to curtail the entire campaign.

The third phase commenced in July 1943 with the Battle of Hamburg. This was a pivotal operation in which RAF employment of 'Window' EW jamming paralyzed existing methods of Luftwaffe C2. After a brief period where RAF losses plummeted, Window precipitated an overhaul of German defences and the introduction of a wide range of innovative measures which allowed a rapid recovery by the Luftwaffe. RAF losses reached unprecedented levels in early 1944 and forced the withdrawal of a third of Harris' bombers from operations. Ironically, much of the Luftwaffe's success was due to passive tracking of the navigation and EW systems upon which the British crews were increasingly reliant. Only continued RAF RCM, diversionary tactics and expanding Allied aircrew training and aircraft manufacturing programmes prevented RAF failure.

From April 1944 the RAF regained the initiative from the Luftwaffe. The invasion of Europe and decreasing German fuel supplies were significant factors in this reversal. However, it is suggested that omnipotent RAF EW and, in particular, the formation of a dedicated Bomber Command RCM and intruder force ultimately proved decisive. Despite continued German technological developments during the last year of the War, Luftwaffe defences and C2 were systematically disrupted by this RAF EW supremacy.

The primacy of EW was illustrated in June 1945 when RAF and Luftwaffe personnel evaluated Bomber Command tactics during trials against the largely intact German C2 system in Denmark. It is suggested that these experiments, against an AD system unhindered by Allied land forces, proved that EW was the most significant single factor in RAF victory during the night bomber campaign.

September 1939 – December 1941: Stalemate

…only 5% of aircraft getting within 15 miles of their targets…I don't think it would have surprised anyone who was bombing in 1941.
Bomber Command Pilot[4)]

Faced with the threat of German aggression, Britain had emphasised defensive measures during its pre-war expansion. Therefore, in 1939 Bomber Command could muster a combined daily average of just over 200 of its principle aircraft types, the Whitley, Wellington and Hampden.[5] All 3 were characterised by inadequate performance, payload and defensive armament. Significantly, they also lacked any form of accurate long-range navigational system beyond dead reckoning navigation supported by radio fixes and astro-navigation. In contrast, Luftwaffe doctrine emphasised the offensive tactical employment of air power in support of land forces.[6] Indeed, Germany considered the possibility of nocturnal attacks by bombers so remote it possessed only small numbers of obsolete biplanes for night-fighting tasks in 1939.[7] The emerging EW capabilities of each nation reflected these priorities.

Part of the Chain home radar system

Britain had developed the Chain Home AD radar and its associated C2 system, and led the world in airborne radar technology. In contrast, Germany had focused upon the offensive potential of EW. The Knickebein (Crooked Leg) navigation system allowed accurate 'blind' bombing through cloud cover. However, in September 1939 Germany also possessed small numbers of Freya early warning and prototype Wurzburg gun-laying radars, each developed in complete secrecy.[8] Freya had a range of 75 miles but could not measure an aircrafts altitude whilst Wurzburg was a small radar with a range of 25 miles and an ability to plot an aircraft's position and altitude to extremely fine limits.[9] Yet despite German success in navigation and ground based radar, the Luftwaffe lagged behind Britain in night-fighter AI technology and C2. German disregard of such defensive EW capabilities would later prove significant. In contrast, the RAF's 80 Wing increasingly disrupted Knickebein and other German navigation systems from November 1940 in what became known as the 'Battle of the Beams'. The emerging significance of such EW techniques was not lost upon the RAF and wider British scientific community.

Early Bomber Command daylight sorties against German naval targets resulted in loss rates of up to 50% and forced Bomber Command to adopt a night strategic bombing policy in April 1940.[10] Unknown to Britain, the Luftwaffe daylight successes had been partly due to Freya radars detecting approaching RAF bombers at ranges of over 70 miles[11]. EW had already fundamentally influenced the campaign. In contrast, nocturnal RAF leaflet dropping over German cities had forced the allocation of single-seat Bf109D fighters to night defence duties. To aid vision and limit the glare from searchlights these fighters operated with their canopies removed but, lacking AI, the Bf109D proved severely limited in the role.[12]

Following the German bombing of Rotterdam on 14 May 1940, Churchill authorised attacks against point targets in mainland Germany. By 4 June 1940, RAF bombers had flown some 1700 night sorties over Germany for the loss of only 39 aircraft.[13] However, without navigation aids crews struggled to find their targets. One pilot describing a bombing raid against a railway station in Dusseldorf stated that upon reaching their target area German blackout procedures prevented them from locating the station. They then conducted a fruitless 'square search' of the city before dropping their weapons into the darkness.[14] This illustrates the problem of locating targets at night without appropriate navigation systems and the impotence of German night defences at the time. Furthermore, Germany also lacked the EW capabilities required to locate the bombers at night, beyond primitive sound detection systems.

Faced with increasing RAF raids, the significance of Luftwaffe night-fighter defences increased. On 19 July 1940 Goring appointed Colonel Josef Kammhuber to formally establish a force of twin-engined night-fighters, the Nachtjagd. Initially, Kammhuber advocated aggressive 'long range night-fighting' intruder operations against RAF bomber airfields, commenting, '…vigorous and correctly launched long range night-fighter operations are, in my view, the most effective tactics of any kind of night-fighting.'[15]

EW again contributed to these intruder operations. In the hours preceding a bombing raid, RAF aircraft would test radios and other systems. By eavesdropping on such communications, the Luftwaffe Radio Monitoring Service, known as the 'Y-Service', was able to determine the approximate numbers of bombers planned to fly that night, and their departure airfields. Such COMINT allowed night-fighters to catch RAF bombers as they departed airfields in Britain and produced immediate results.[16] Prior to 1 August 1940, only 10 aircraft had been destroyed by Luftwaffe night-fighters.[17] In contrast, long range night-fighter operations over Britain accounted for almost 100 RAF aircraft within 12 months of commencing in October 1940.[18] Success for the Luftwaffe aircraft would undoubtedly have been greater had they been furnished with effective AI radar. In contrast, RAF Beaufighter night-fighters equipped with AI and controlled by the formidable RAF C2 system were able to account for 26 Luftwaffe intruders throughout the same period.[19] Despite the success of Kammhuber's tactics, Hitler wanted the German population to be able to see RAF bombers being destroyed over their own territory and intruder operations ceased in October 1941.

With Kammhuber's Nachtjagd still lacking AI radar, 'illuminated' night-fighter operations employing searchlights were conceived as the only realistic method to locate and attack bombers in the dark over Germany. This involved the establishment of a Helle-gurtel (searchlight belt) but this was limited by cloud and the time taken by searchlight crews to acquire bombers in the darkness. In October 1940 a solution arrived with delivery of production Wurzburg radars. The accuracy of Wurzburg allowed radar guided 'master-searchlights' to be introduced, as well as an increasing number of radar controlled Flak. Upon acquiring a target, the bluish beam of the master-searchlight's 200 cm lens would slew directly onto a bomber and attract smaller 150 cm unguided searchlights to 'cone' the target for engagement by Flak and night-fighters.

RAF losses rose immediately. Between June 1940 and February 1941 the average Bomber Command loss rate was under 2%.[20] However, attrition increased to 3.5% between July and November 1941 with losses of up to 21% recorded over Germany itself.[21] Including non-operational losses in England, the entire front line strength of Bomber Command had statistically been wiped out in the final 4 months of 1941.[22]

Following the first Ground Controlled Intercept (GCI) kill employing Freya information passed to a night-fighter, Kammhuber initiated 'dark night-fighting' GCI zones ahead of his Helle-gurtel. Whereas searchlight activity had previously indicated the likely presence of night-fighters, bomber crews now faced attack without warning. However, although the Wurzburg was extremely accurate, its range of 20 miles limited the time available to track targets. As a result the Wurzburg-Riese (Giant Wurzburg) was developed, with range doubled to 40 miles.[23] Despite these promising developments, by October 1941 around only 50 RAF aircraft had been destroyed in GCI engagements compared with 325 in cooperation with searchlights. In an attempt to refine the integration of EW data into Luftwaffe C2, Wurzburg-Riese information was displayed on a newly developed plotting system, the Seeburg-Tisch (Seeburg-Table), at each radar station. Using information from the radars, the position of a bomber and night-fighter were projected onto a horizontal map of the area. This allowed Fighter Controllers, known as Jagerleitoffiziers (JLO), to better direct engagements.

Meanwhile, RAF bombing accuracy remained compromised by poor navigational accuracy. Between June and July 1941, less than 7% of crews came within 5 miles of their targets on moonless nights.[24] Such poor bombing accuracy was aggravated by the increasing use of decoy 'fire sites' throughout Germany. These replicated cities under air attack with fires, explosions and even sparks from simulated tram cables, and diverted up to 69% of RAF bombs on specific raids.[25]

The first attempt to improve navigation was Gee, a radio aid employing ground transmissions from Britain to produce a complex grid of pulses. By interpreting the pulses on a display in the aircraft, navigators could determine their position to within 2 miles when up to 400 miles from the transmitters.[26] However, it would be March 1942 before sufficient Gee sets were available to commence full operational use. Therefore, by the end of 1941 it had been recognised that a city was the smallest feature which most crews could be guaranteed to hit given current navigational technology and precision targeting was abandoned in favour of an 'area bombing' policy.[27]

Meanwhile, it was clear that the Luftwaffe was employing radar by the increasing reports of night-fighter attacks independent from searchlights. It was essential that the nature of such radars be ascertained to enable countermeasures to be developed and EW would once again prove instrumental in the hunt that followed. By Spring 1941, SIGINT Wellingtons had located several radar sites and intercepted signals associated with both Freya and Wurzburg. Moreover, intercepts of German Morse code appeared to provide range and bearings on British aircraft from locations which coincided with the suspected radar stations. Such COMINT identified several other radar sites.

In this first phase of the night bomber offensive, the RAF and the Luftwaffe were severely hampered by technical limitations. Bombers proved unable to locate their targets whilst German defences struggled to find RAF attackers in the darkness. Yet, even at this early stage, EW had played a decisive role in shaping the RAF's campaign. Luftwaffe employment of radar had contributed to the decision by the RAF to switch from daylight to night operations. Similarly, SIGINT was assisting the RAF in mapping GCI sites and Gee promised to considerably improve RAF bombing effectiveness.

January 1942-July 1943: The EW battle Intensifies

I don't like high-frequency gadgets. I once went on a flight in southern Germany and ended up in northern Germany by mistake, all because of your high-frequency gadgets.
(Adolf Hitler, 1943[28])

Increasing Wurzburg production now allowed the development of the Himmelbett (four-poster bed) system, often referred to as the 'Kammhuber Line'. Himmelbett coordinated Freya and Wurzburg capabilities within a series of boxes approximately 20 miles wide. Following long range Freya detection, a 'Red' Wurzburg would obtain a target's altitude whilst a 'Blue' radar controlled fighters to within visual range of their quarry. In boxes close to the coast, early warning was augmented by 2 new radar types, Mammut (Mammoth) and Wassermann (Aquarius), each capable of detecting a target's position and altitude to ranges of 150 miles.[29] Himmelbett C2 methods combined with these new radars showed much promise but its efficiency was still hampered by the lack of effective night-fighter radar.

This shortcoming was remedied in February 1942 when the first Lichtenstein AI radars were delivered. Although less advanced than its British equivalent, RAF losses immediately increased from 2.5% to 3.7% between

February and May 1942. From June, the average was approximately 5% although specific raids resulted in losses of up to 15%.[30] Whilst some casualties were due to the clear summer nights, Germany's night defences were being transformed by EW.

Under the newly appointed Air Chief Marshal Sir Arthur Harris, Bomber Command employment of Gee commenced on 8/9 March 1942 in a raid upon Essen. The industrial haze precluded visual refinement of Gee fixes and Essen records recorded only a 'few houses and a church destroyed'.[31] Gee's accuracy was, however, sufficient to enable bombers to be concentrated in a 'stream'. By routing this stream through a single Himmelbett box defences could be saturated, with similar effects against the Flak and searchlights over the target itself. This tactic was initiated over Germany in the 'Thousand Bomber Raid' against Cologne on 30 May 1942 when 3 waves of bombers were concentrated within 150 minutes compared to previous raids exceeding 7 hours.[32] Despite clear visibility favouring the night-fighters, losses in successive waves were 4.8%, 4.1% and 1.9% suggesting that Gee bomber streaming had enabled the defenders to be progressively overwhelmed.[33]

The Germans were quick to realise the significance of Gee, and a Y-Service unit formed in July 1942 to jam Gee's signal via a system codenamed 'Heinrich'. By August, Gee had been impaired over occupied Europe, although it remained sufficient for bomber stream tactics to be maintained.[34] With Gee jammed, and increasing numbers of Luftwaffe Lichtenstein and ground based radars, RAF losses again increased from an average of 3.7% between February-May 1942 to 4.5% during August-December 1942.[35] The latter figure is particularly significant when compared to the previous winter's losses of only 2.5%.[36] Indications of a German AI first came from ELINT, detecting unidentified signals on a frequency of 490 Megahertz (MHz), and COMINT. However, direct association with night-fighter activity was only obtained when an ELINT Wellington accompanied a raid to Frankfurt on 3 September 1942. Near Mainz, faint 490 MHz signals increased in strength until the aircraft was attacked by a JU88 night-fighter. Despite being forced to ditch the Wellington off Dover, the final link in Himmelbett's reliance upon EW systems had been confirmed and countermeasures were initiated.

Active jamming of German night defences commenced on 6/7 December 1942 during a raid against Mannheim. Defiants equipped with a 'Mandrel' jamming system circled over the North Sea to blind coastal Freya, Mammut and Wassermann radars. Meanwhile, Mandrel equipped bombers provided RCM along the route. This forced the Germans to embark on a lengthy programme to modify radars for alternative frequencies. Simultaneously, German control frequencies were targeted via 'Tinsel' communications jamming. Tinsel allowed a bomber's radio operator to activate a microphone in one of the bomber's engine compartments and transmit engine noise directly onto the Luftwaffe frequency.[37] This was an unpleasant surprise for the Luftwaffe and a night-fighter diarist noted of Mandrel and Tinsel's first use, 'Heavy jamming of Freya. It was nearly impossible to control the night-fighters'.[38] The result was an RAF loss rate reduced that night to 3.7%.[39]

Aside from the introduction of RCM, 1942 saw several other enhancements within Bomber Command. In August a dedicated Pathfinder Force (PFF) had been created, from experienced crews, to accurately mark routes and targets for the main bomber force using a variety of marker flares. Despite the jamming of Gee, the percentage of bombs plotted as being released within 3 miles of the aiming point rose from 35% to 50% following the instigation of PFF operations.[40] Of more significance to bomber offensive, however, was the introduction of 2 new navigation systems by Bomber Command, Oboe and H2S, which Harris described as introducing 'a new era in the technique of night bombing'.[41]

Like Knickebein Oboe relied upon 2 intersecting beams from transmitters in Britain allowing extremely accurate flight along a radius until a second beam provided countdown and bomb release signals for the navigator. Introduced on PFF Mosquitoes in December 1942, the high operating altitude of this superlative aircraft allowed Oboe signals to be received up to 270 miles from the transmitter, sufficient to cover the majority of the Ruhr.[42] The accuracy of Oboe Mosquito bombing was such that it aroused German suspicions that homing beacons had been placed in factories by agents.[43] The second system was H2S, a navigation radar first used operationally on 30 January 1943 which owed its origins to AI technology. Mounted beneath the bombers' fuselage H2S produced an image for the navigator of coastlines, rivers and even built up areas within a 6 mile radius. As it was carried by the bombers themselves, H2S offered more accurate navigation without reliance upon vulnerable external signals.

By April 1943, approximately 60% of sorties dispatched bombed within 3 miles of the aiming point compared to less than 30% prior to the introduction of H2S and Oboe.[44] However, the secret of H2S was compromised by the loss of a Stirling near Rotterdam. The discovery of this equipment, codenamed 'Rotterdam' by the Germans, shocked the Nazi technical community whose own research into such radars was in its infancy. Even Goring, whose interest in EW was limited, was concerned by the discovery:

> I expected the British…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 could be in the same race![45]

Besides navigational improvements, the RAF also introduced 2 threat warning devices in early 1943. The first, 'Monica', was a tail-warning radar which provided a series of beeps increasing in frequency as an aircraft approached from behind the bomber. In practice, Monica was unpopular due to the high rates of false alarms resulting from other bombers. 'Boozer' however was a passive system designed to warn of Wurzburg gun-laying and Lichtenstein night-fighter radars. Unfortunately, the increasing amounts of radars now being fielded meant that Boozer also provided almost constant warnings. Neither system reduced losses and Monica would soon be exploited by the Luftwaffe.

Photo: RAF AHB

Ju 88 R-1

On 9 May 1943 a Luftwaffe crew defected to Scotland with their Lichtenstein equipped JU88R. Examination of the aircraft confirmed that Lichtenstein was vulnerable to a simple jamming technique, known as

'Window'. This employed the dropping of metal strips cut to half the wavelength of the target radar to create false plots on an operators radar screen. Plans to jam the 53.5cm wavelength Wurzburg radars via Window were already well advanced and the Lichtenstein's wavelength of 61cm meant that metal strips approximately 27cm long would degrade both.[46] The British had known of this jamming principle for several years but feared that use of Window would compromise its secrets and allow the technique to be employed against their own radars. Ironically, Germany had already recognised the value of such metal strips and had avoided its use for similar reasons to the British. However, the differing approaches taken regarding the use of Window by each side illustrates the influence of leadership upon EW during the campaign.

Churchill himself had been closely involved in decisions regarding Window's deployment.[47] Harris too retained a sound understanding of the increasing technology employed by his Command.[48] In contrast, Goring's interest in EW was limited and he once remarked, 'radio aids contain boxes with coils, and I don't like boxes with coils.'[49] When presented with the results of experiments with Germany's own version of Window in 1942, Goring was so horrified that he forbade further experiments, even those aimed at developing countermeasures, lest the secret leak out to Britain.[50] Following the development by the British of modifications to limit the effect of Window on their own radars, Churchill himself authorised the operational introduction of Window from July 1943.[51] Goring's decision to ignore the question of Window was about to have enormous repercussions for Germany's defences.

To add to the challenges faced by the Luftwaffe RAF Beaufighters now started to accompany the bomber stream. Beaufighters were fitted with the British AI Mk IV radar and a system named 'Serrate' which passively homed onto Lichtenstein signals.[52] Within weeks the small number of Serrate Beaufighters had accounted for 23 night-fighters over Europe.[53]

The period between January 1942 and July 1943 saw a transformation in the night bomber campaign. In January 1942 Bomber Command had only 88 4-engined types out of a total of 802 bombers available for operations. By July 1943, this total had increased to 978 4-engined bombers and 51 mosquitoes out of a total of 1153 aircraft.[54] The Luftwaffe night-fighter force had also increased in size, from 132 serviceable aircraft in December 1941 to 371 in June 1943.[55] However, the Himmelbett Line's effectiveness had been reduced via the introduction of the bomber stream and RCM, whilst bombing accuracy increased by 43%, largely due to H2S, Oboe and PFF marking.[56] Losses resulting from Lichtenstein resulted in the RAF introducing EW threat warning systems. Despite the significance of EW in the bomber campaign, the German leadership failed to appreciate the importance of such technology. In contrast, Harris and Churchill took a personal interest in EW throughout the conflict and were about to inflict a crushing blow upon Germany.

July 1943-March 1944: Germany recovers from disaster

The enemy are reproducing themselves…it is impossible…too many hostiles…I cannot control you!
(Luftwaffe JLO encountering Window for the first time[57])

During the first minutes of 25 July 1943, some 746 RAF bombers en route to Hamburg started releasing 92 million strips of Window, creating radar echoes similar to a force of 11 000 bombers.[58]

Almost immediately Wurzburg radars, critical to the direction of night-fighters, Flak and searchlights were being swamped by responses. One radar operator described, 'an indecipherable jumble of echo points.'[59] Night-fighters suffered equally, 'My radar operator suddenly had more targets than could have been possible…I was picking up targets that didn't exist everywhere.'[60] To assess the impact of Window, Tinsel jamming had been suspended for the night and satisfied British COMINT operators listened to the results:

> We gained an impression of panic and confusion from the German controllers. They were highly agitated. Stress, fear, anger and bewilderment were evident in their voices.[61]

Bomber crews also recalled Window's effect:

> It was a magic effect…I felt reasonably safe over a target for the first time…The Master Searchlights and all the others were waving aimlessly about in the sky like a man trying to swat an ant in a swarm.[62]

Window reduced losses to a mere 1.5% on this first raid of what became known as the Battle of Hamburg.[63] In comparison, a raid to Hamburg in July 1942 in similar meteorological conditions had cost 7.2% of the bombers.[64]

To take maximum advantage of Window, 3 further raids were mounted against Hamburg within 10 days. Although Window remained effective, the Luftwaffe recovered more quickly than expected and loss rates grew to 2.2%, 3.6% and 4.1%. Nevertheless, in the words of one experienced Luftwaffe JLO, 'Window was the death sentence for [Himmelbett].'[65] With some already questioning Kammhuber's emphasis upon rigid C2, the Battle of Hamburg weakened his credibility still further. In November 1942 Kammhuber was sacked and replaced by General 'Beppo' Schmid. Schmid overhauled Luftwaffe C2, with Divisional Command Posts assuming responsibility for night-fighting from individual radar sites. These new bunkers employed huge vertical plotting boards to display the evolving battle and were christened 'Battle Opera Houses' by General Adolf Galland due to their internal resemblance to theatres.[66] Simultaneously the rigid Himmelbett C2 was replaced with a more flexible Reportage (running commentary) exploiting the fact that Window highlighted the route of the bomber stream as a whole. By monitoring the GCI broadcast, night-fighters infiltrated the stream and attempted to close visually with RAF aircraft. Additionally single-engine fighters were reintroduced to night-fighting duties over the target area in a form of illuminated night-fighting named Wilde Sau (Wild Boar). However, despite early successes during clear summer months, Wilde Sau proved prohibitively costly in landing accidents by single-engined fighters operating at night without blind-flying equipment.[67] One Wilde Sau pilot remarked on the desperation of the tactic, 'If you were above clouds and wanted to land, you just had to look for the 'duty hole in the clouds'. If you couldn't find it, you baled out. It was a matter of profit and loss'.[68]

However, Wilde Sau spawned the Zahme Sau (Tame Boar) method whereby large numbers of twin-engined night-fighters used Reportage to attack the bomber stream along its entire route. Zahme Sau was first used in strength during the RAF attack on the V-weapons test site at Peenemunde on 17/18 August 1943 and inflicted 7% losses.[69] A secondary advantage of Zahme Sau was that it reduced the amount of night-fighters operating within range of Serrate Beaufighters. In this respect at least, the introduction

of Window had proved detrimental to RAF operations.
Due to Zahme Sau's reliance upon the Reportage broadcast, RAF EW next targeted Luftwaffe communications. Monitoring stations in England determined the in-use frequency and informed bombers so that Tinsel jammers could be combined to overwhelm the commentary. This 'Special Tinsel' was first used in late August over Monchengladbach and reduced losses to 3.8%.[70] A more sophisticated communications jamming system named 'Airborne Cigar' (ABC) followed in October on specially equipped Lancasters. ABC aircraft carried a German linguist crewmember to monitor Luftwaffe communications and jam up to 3 separate frequencies. Additionally, ground based jamming named 'Corona' employed other German linguists in England to transmit false orders to night-fighters. The nicknames ascribed to such jamming by Luftwaffe crews give some indications of their effect. The warbling tone of ABC was known as Dudelsack (bagpipes), whilst the transmission of engine noise via Tinsel was named Seelenbohrer (Soul-borer).[71]

In the face of such jamming, the German forces Anne-Marie radio station was used as a crude means of fighter direction. For instance, Waltzes meant that fighters should go to Munich whilst jazz meant Berlin, and a further ground based jammer, 'Dartboard', was introduced to obliterate Anne-Marie transmissions.[72] Similarly, 'Drumstick' jamming from England obliterated Luftwaffe Morse commands. The introduction of such jamming often caught the Luftwaffe by surprise and degraded communications considerably until countermeasures could be introduced. Indeed, the introduction of ABC on a raid against Stuttgart reduced losses to 1.2% when combined with an effective diversionary raid.[73] The previous comparable raid to Stuttgart in April 1944 had resulted in losses of 5%.[74] Although Nachtjagd rapidly recovered from the shock of Window via Zahme Sau, Reportage and improved C2, Mosquitoes continued dropping bombs or flares with high degrees of accuracy via Oboe. Attempts to jam Oboe had met with limited success until an Oboe Mosquito was finally downed and its secrets compromised in January 1944. Within a week, Oboe signals were being jammed by a network of ground EW transmitters and associated bombing accuracy fell from a 90% hit rate to less than 25%.[75] However, the British had long anticipated that Oboe would be jammed and immediately introduced Oboe Mark II and III employing different centimetric wavelengths. To disguise the introduction of these new frequencies, the original signal was maintained as a decoy, a ruse which proved effective for over 6 months.[76]

By October, H2S was being fitted to main force bombers and further improved via 'Fishpond'. This modification provided warnings of aircraft approaching from below via a second radar display installed at the Wireless Operator's position. Such attacks were a favoured tactic of night-fighters and avoided a bomber tail gunner's field of fire. By November, 553 of 1030 H2S sorties were equipped with Fishpond, with the remainder of radars so modified by early 1944.[77]

The value of H2S and Fishpond, however, encouraged the majority of crews to operate radar throughout a sortie. Having rebuilt an H2S set from downed bombers, Germany developed several passive H2S detection systems. Naxos, was fitted to night-fighters from November 1943 and enabled the detection of H2S signals at up to 60 miles.[78] Korfu was a ground based equivalent augmented by Naxburg, a Wurzburg radar modified by the addition of a passive H2S detector. In addition a further passive system, Flensburg was fitted to night-fighters to detect RAF Monica tail-warning radars.[79] Moreover, the Germans now used RAF Identification Friend or Foe (IFF) transmissions to highlight bombers within the Window cloud. Unknown to the RAF, the Luftwaffe was now exploiting British EW systems to track the bomber stream literally from take-off to landing.

Despite the value of such passive EW systems, Lichtenstein remained severely degraded by Window. A solution was provided by Lichtenstein SN-2 using frequencies unaffected by Window and by early 1944, the majority of night-fighters were so equipped.[80] Moreover, many aircraft had been fitted with upward firing Schrage Musik (Jazz Music) cannon. This enabled night-fighters to formate beneath a bomber prior to attack, appearing no different on Fishpond than another bomber, before dispatching their prey at point blank range. Schrage Musik became the weapon of choice for Nachtjagd and accounted for 50% of night-fighter kills by 1945.[81]

During November 1943 - March 1944, the RAF mounted 32 major raids on Germany, 16 of which were against the German capital, in a period which became known as the Battle of Berlin. Not only was this to prove Bomber Command's biggest test, it was also to see the full weight of each sides EW capabilities thrown against the other. Bomber Command's navigational systems would be severely tested by the winter conditions, whilst its defensive and RCM technology would be facing the reorganised and re-equipped Luftwaffe night-defences.

Within a week Harris was forced to permanently withdraw Stirling squadrons from operations over Germany due to 15.2% attrition of the type within 3 raids.[82] The Stirling, the first of the RAF 4-engined heavy bombers, had a lower operational ceiling than the Halifax and Lancasters, and therefore, was more vulnerable to Flak and night-fighters. Additionally, Window was sometimes less concentrated at these lower levels due to wind dispersal.

Oblivious to SN-2, Flensburg and Naxos, RAF losses mounted correspondingly. During November 1943, average losses over Germany were 4.1%, in December 4.4% and in January 6.3%.[83] More alarming for Bomber Command were the statistics from specific raids. The highest loss experienced in November was 6.2% against Berlin, whilst 8.7% failed to return on 2/3 December. Finally, 8.8% of bombers were lost during a raid on Magdeburg on 21/22 January 1944, almost exclusively to night-fighters; of this figure, 15.6% of the Halifax force was destroyed.[84] It is also significant to note that severe weather had grounded many night-fighters on 4 of the 9 raids where losses fell below 5%.[85] As the night-fighters were growing in lethality, so too was the effectiveness of the Luftwaffe Reportage, which was proving increasingly skilled at exploiting unrestrained use of H2S and Monica by the RAF. On at least one occasion, Luftwaffe ground stations were able to accurately track the progress of the bomber stream when only 40 miles from the British coast.[86] Indeed, General Schmid himself subsequently described H2S as 'the most reliable basis for plotting the enemy's courses.'[87] Such losses were unsustainable and Bomber Command suspended operations for a 2 week period from 1 February 1944.

While the EW initiative now lay with the Luftwaffe, the RAF was increasingly capable of absorbing such attrition. Between January 1943 and March 1944, the number of crews available to Bomber Command had almost doubled from 515 to 974.[88] In contrast, Luftwaffe night-fighter crew strength had only increased by 67 to 376 in the 12 months from March 1943.[89]

Despite continuing British losses, an H2S Mark III variant was introduced from November offering improved resolution and largely negating German attempts at seducing H2S bombing with radar reflecting decoy sites in open country. Indeed, to be effective against these new H2S wavelengths, 500 reflectors were required for every square mile; each reflector calibrated to within one-third of a degree to the others.[90] Throughout this period, an additional RAF navigation system, named G-H, was entering service. This was essentially an inverse Oboe, incorporating a transmitter-receiver unit to measure distance from ground stations in England. Offering accuracies similar to Oboe it could, however, be used by up to 100 aircraft simultaneously. However, G-H required considerable skill by aircrew as opposed to Oboe where the workload lay primarily with the ground stations to provide positional information. Nevertheless, from November G-H was introduced on both Mosquitoes and Lancasters.[91] More ominously for the Luftwaffe was the formation of Bomber Command's 100 Group, comprising Serrate and AI equipped Mosquito intruders, on 23 November 1943.

When operations over Germany recommenced losses remained high. On 19/20 February 1944, Leipzig was raided by 823 bombers for the loss of 78 aircraft, 9.5% of the force; of this amount, the Halifax crews suffered 14.9% of those losses. Like the Stirlings in November, Harris was forced to permanently withdraw Halifax Mark II and V squadrons from operations over Germany.[92] Only the Lancaster and Halifax III squadrons now remained to bear the burden of the night offensive.[93] Nevertheless, use of diversionary raids and 100 Group intruder operations had an increasing effect on the Luftwaffe. Raids to Stuttgart on 20/21 February and Essen on 26/27 March 1944 were particularly successful examples of diversionary tactics where losses fell to 1.5% and 1.3% respectively;[94] however, such diversionary tactics also diluted Bomber Command strength by a considerable measure.

The reduced losses associated with diversionary tactics also illustrate the lethality of night-fighters in comparison to Flak, and the continued significance of EW. On most nights, Window continued to degrade the Flak and searchlight Wurzburg radars, resulting in kill ratios favouring the SN-2 equipped night-fighters. Despite a doubling of heavy Flak batteries and an increase in the amount of RAF night sorties, the number of kills attributed to Flak barely increased during late 1943.[95] During a similar period, the fighter-Flak kill ratio was 2.7 to one.[96] In contrast, on 24/25 March 1944 extremely strong winds dispersed both Window and the bomber stream itself. Without their usual EW protection, 50 of the 72 bombers lost that night were attributed to radar guided Flak.[97] Moreover, when diversions failed the consequences were catastrophic, as was proved over Nuremburg on 30/31 March 1944. Ignoring diversionary mine-laying operations in the Heligoland area, the Luftwaffe took advantage of a clear night and enemy contrails to destroy 95 out of 795 bombers.[98] This 11.9% attrition was the single highest loss for Bomber Command during the entire war.

The period between July 1943 and April 1944 saw the significance of EW raised to unprecedented levels. Window crippled the existing Himmelbett system but precipitated tactical and technological changes enabling the Luftwaffe to

A BF-110 equipped with SN-2 radar

passively track radar emissions from the bomber stream. Meanwhile, despite RAF communications jamming, Zahme Sau tactics allowed a greater number of night-fighters to infiltrate the bomber stream. With improved EW systems, most notably SN-2, the night-fighters brought Bomber Command to its knees. Between November 1943 and March 1944 Bomber Command lost no less than 1047 aircraft, with a further 1682 damaged.[99] As a result, the RAF was forced to introduce elaborate deception tactics which depleted the number of bombers available over the intended target. The enforced withdrawal of Harris' Stirling and Halifax squadrons from operations over Germany, some 33% of his heavy bomber force, suggested that Luftwaffe EW was now dictating RAF tactics.[100] Yet the Nachtjagd had reached its zenith. The RAF was capable of absorbing such losses and the introduction of 100 Group was soon to prove decisive.

April 1944 – May 1945: RAF EW turns the tables

It has been reported that the attacks which take place so often at night now, are considerably more effective than daylight attacks…an extraordinary accuracy in attacking the target is reported.[101]
(Albert Speer, 19 January 1945)

From April 1944, Bomber Command was redirected against France and Belgium in preparation for D-Day, Operation Overlord. Further targets in France were associated with Operation Crossbow, the destruction of V1 sites. Bomber Command's experience of coordinating diversionary raids to frustrate Zahme Sau in recent months now proved beneficial to this entirely different scenario. Although diversions diluted RAF assets over targets, navigation and bombing accuracy had been refined to compensate and would now prove decisive in the most crucial period of the War.

In an echo of Bomber Command policy of 1939-41, targeting directives again specified railway marshalling yards, ammunition depots and airfields, rather than area objectives. However, the accuracy required for such a policy was now provided by the EW and tactical advances made by Bomber Command. By 1944 there were 11 approved bombing techniques, 9 of which employed Oboe, H2S or G-H.[102] The switch to multiple, precision attacks in France was a welcome change for bomber crews recently subjected to long flights deep into Germany. The new task would limit their exposure to night-fighters, and both Oboe and G-H would be available for all targets.

Recent experience of coordinating separate diversionary forces was now applied to accurately attack multiple small targets. Oboe bombing accuracy now averaged 680 yards, reducing to 380 yards when reinforced by visual means.[103] Such accuracy was vital when attacking targets within French towns and results greatly exceeded Harris' own estimates.[104] Between April and July 1944, Bomber Command dispatched 1249 sorties in over 100 operations against targets associated with Operations Overlord and Crossbow. Simultaneously, the proportion of bombs dropped on Germany declined from 40% to 8%.[105]

Significantly, Bomber Command's EW now proved relevant to the invasion itself. It was clear that coastal radars would pose a significant threat to Operation Overlord if they detected the approaching air and naval armadas. Accordingly, a new type of longer 'concertina' Window was deployed against coastal radars to simulate 2 large naval forces approaching the French coast further north. This Window was to be dropped by Bomber Command Stirlings and Lancasters, supported by Mandrel RCM jamming. However, to be effective the Window needed to be dropped accurately by formations of bombers gradually advancing in a complex rectangular pattern towards the French coast. This accuracy was provided by Gee and G-H.[106] Simultaneously, 29 bombers enticed night-fighters away from Normandy via Window spoofing and ABC jamming over the River Somme.[107] As Operation Overlord commenced, Bomber Command's EW had the desired effects. Luftwaffe night-fighters intercepted the Window 'bomber stream', and German naval artillery and E-boats attempted to engage the 'ghost' armada laid by the Lancasters and Stirlings.[108]

As Bomber Command busied itself over occupied Europe, 100 Group intruders were joined by a variety of larger aircraft. After initial operations with Mandrel and ABC equipped Stirlings and Halifax, modified B-17s and B-24s, whose higher operating altitudes enhanced the jamming ranges available, were delivered. Known in RAF service as the Fortress III and Liberator VI respectively, these aircraft carried large amounts of Window and 'Jostle'. Jostle was a powerful jammer capable of radiating 2000 watts over German VHF night-fighter control frequencies.[109] So effective were the combined impact of Jostle, ABC, Tinsel, Corona, Dartboard and Drumstick, that the latest night-fighter variants now carried an additional crewmember to assist with the bewildering range of systems required to overcome RAF RCM. However, even with numerous options for radio communication the Luftwaffe was still sometimes forced to revert to visual signals initially designed to support single-engine Wilde Sau fighters whose limited communications equipment demanded such measures. It is a measure of the impact of 100 Group RCM that the twin-engined Nachtjagd had also now been reduced to a complex series of star-shells fired by the Flak, searchlights and visual beacons to assist their navigation and direction.[110]

On 13 July 1944 an inexperienced JU88G night-fighter crew landed in Suffolk following a navigational error. Examination of the aircraft showed that it was equipped with both SN-2 and Flensburg, each unknown to British intelligence. The new operating frequency of SN-2 was quickly determined and it was apparent that Operation Overlord 'concertina' Window would also be effective against this new AI radar. Within days, such Window was being employed by Bomber Command.[111] Adolf Galland lamented the impact of these improved RAF EW methods, 'They had obstinately improved their tactics and instruments. Our night-fighters were blinded again… by new methods of interference.'[112]

Next, the JU88G Flensburg was evaluated against Lancasters operating Monica. The danger of the tail warning radar was now revealed as Monica emissions were detected by Flensburg at up to 130 miles.[113] Harris immediately ordered the removal of Monica from all Bomber Command aircraft and restrictions placed upon the use of IFF and H2S.[114]

Despite the deteriorating strategic situation of Germany in the summer of 1944, the Luftwaffe's technical capabilities remained, and they continued to introduce innovative systems in an attempt to counter RAF EW. A new radar designed to operate in the face of RCM, the Jagdschloss (Hunting-lodge) was capable of showing the entire 360 degree panoramic air situation. Jagdschloss operated in the centimetric frequency range which was more resistant to EW and produced extremely accurate positional data ideal for control of aircraft.[115] Although insufficient numbers of Jagdschloss were yet available, one experienced JLO recalled:

> It was technically the most advanced control device…we had a perfect picture of [the raid] approaching. Kill followed kill. There was no jamming on the equipment.[116]

With the secrets of SN-2 and Flensburg compromised, further measures were introduced by 100 Group. 'Modified Serrate' capable of detecting SN-2 emissions was fitted to 100 Group Mosquitoes. Additionally, a further system known as 'Perfectos' was added, which enabled RAF intruders to 'challenge' all Luftwaffe IFF in the area. The IFF sets would then reply, compromising the night-fighters position and confirming that they were hostile; a valuable advantage in airspace containing large numbers of friendly bombers. Although the Germans simply countered Perfectos by turning their IFF off, Luftwaffe C2 was now denied the ability to positively identify night-fighters within the bomber stream. The 100 Group intruders now initiated what became known as the 'Moskito panic' by Luftwaffe crews. One night-fighter pilot recalled the impact of 100 Group intruder ops, '…it was a strain on our nerves. [We used] extreme caution when we took off.'[117] Others resorted to extremely dangerous night flying to altitudes as low as 100 feet in an attempt to avoid the attentions of Mosquitoes.[118]

In October 1944 100 Group Fortresses were equipped with the 'Piperack' system designed to jam Luftwaffe SN-2 radars and compliment the concertina Window already in use. Increasingly, Fortresses and Liberators accompanied the bomber stream or conducted their own diversionary raids whilst Halifax aircraft maintained Mandrel screens. An indication of the impact of 100 Group can be gauged by an incident when a Fortress failed to receive a recall signal cancelling a raid. The aircraft continued alone to the Ruhr, dropping Window whilst conducting ABC and Jostle RCM. COMINT indicated the Luftwaffe believed a force of 50 aircraft had been involved rather than a lone Fortress.[119] In another raid on 22/23 March 1945 against Berlin, 100 Group Window dropping successfully diverted 6 squadrons of night-fighters from the intended target.[120]

Luftwaffe night defences were now facing an irreversible decline. Between August 1944 and January 1945 Bomber Command losses during the principle night raids amounted to only 1.3%.[121] Where higher losses were encountered it is significant that meteorological conditions were often such that night-fighters had not needed their degraded EW systems.

However, it would be naive to suggest that other factors were not relevant to the decline of the Luftwaffe's night defences. The loss of Germany's forward radar and Y-Service sites in France and Belgium significantly reduced the warning of approaching raids. An additional advantage was the forward deployment of mobile Oboe and G-H equipment which extended the range of these navigational aids into Germany, eventually covering

Berlin itself. Moreover, the quality of Luftwaffe aircrew declined rapidly from 1944 due to the curtailment of training in the face of reduced fuel production, itself a product of the strategic bomber campaign. This qualitative reduction initiated a vicious circle in the face of overwhelming Allied air superiority. Between January 1941 and June 1944 the Luftwaffe lost 31 000 aircrew. Yet between June and October 1944 a further 13 000 casualties were inflicted.[122] These losses were predominantly inflicted in daylight combat and had little direct effect upon the experten night-fighter crews still operating exclusively in darkness. Nevertheless, in the final months of the war, the Luftwaffe remained capable of meeting the EW challenges being faced. Small numbers of Me262 jet-fighters equipped with a new AI radar, Neptun (Neptune) finally challenged the invulnerability of high flying Mosquitoes and accounted for a disproportionate number during 1945.

The Nachtjagd also remained capable of launching large numbers of aircraft and inflicting unacceptable losses upon Bomber Command. In Operation Gisella on 3/4 March 1945, 200 night-fighters followed bombers returning from raids in Germany and destroyed 20 RAF aircraft over England.[123] On 16/17 March 1945, night-fighters accounted for 8.7% of a force of 277 Lancasters attacking Nuremburg.[124] Such figures contradict assertions that it was shortage of fuel and loss of territory which crippled the night-defences. Rather, such losses illustrate what happened when RAF EW protection was removed. In the case of Operation Gisella, the Luftwaffe intruders over England were unhindered by RCM. Similarly, RCM support over Nuremburg was negated by excellent visibility allowing night-fighters to visually acquire targets. One pilot who destroyed 7 Lancasters that night reported:

> Visibility could not have been better. There might have been between 20 and 30 of them, flying in loose formation. The Tommies must have taken [my JU88] for one of their own machines because not a single one of them took evasive action.[125]

In June 1945, following the German surrender, the RAF was presented with the opportunity to examine the Luftwaffe's AD infrastructure in Schleswig-Holstein and Denmark, which had been bypassed by advancing Allied land forces and remained virtually intact. Following a series of interviews with the Luftwaffe personnel and the examination of aircraft and equipment, 11 trials were flown. These 'Post Mortem' exercises involved the entire German AD network in Denmark, some 10 GCI sites and 40 individual radars linked to a Divisional Command Post.[126] These facilities were manned by experienced Luftwaffe operators with RAF observers able to note at first hand the results of their EW. The German 'defenders' faced a fully representative raid of RAF bombers. Although peacetime safety required trials be flown during daylight without the involvement of night-fighters, Post Mortem provided a graphic illustration of the significance of EW upon the outcome of the night bomber offensive.

Luftwaffe operators proved able to overcome Mandrel but failed to maintain situational awareness on the bomber streams advance. On the most elaborate Post Mortem trial, RAF bombers were totally lost by the German AD system and were able to simulate an attack and re-cross the Danish coast undetected. Whilst the real raid progressed, false contacts derived from Window had been plotted. In other cases, Window was assessed to have been dropped when none was present. Luftwaffe estimates of the size of the bomber formations were also inaccurate. On one occasion Window was misidentified as a force of 150 bombers. Significantly, on no occasion during Post Mortem did the Germans succeed in identifying decoy from genuine raids. Perhaps more tellingly, one Luftwaffe radar operator involved in Post Mortem confided that he needed to be a 'clairvoyant' to discharge his duties in the face of RAF EW.[127]

The final months of the war had seen EW's significance rise to its zenith. The navigational accuracy provided by Oboe, G-H and H2S was the foundation for Bomber Command's primary tactical innovations of PFF marking, diversionary raids and the bomber stream. Such capabilities proved pivotal in preparations for Operation Overlord within occupied countries. Meanwhile RAF RCM, and 100 Group in particular, denied the Luftwaffe the capability to defend their airspace. Such advances were of direct significance to what was arguably the War's campaign fulcrum, Operaion Overlord. The advance of Allied armies, the shortage of fuel and the decline in Luftwaffe aircrew standards undoubtedly played significant parts in the campaign's final year. However, the rarely acknowledged Post Mortem results suggest that EW was the most significant factor in the final demise of the Nachtjagd.

Conclusion

Few campaigns remain as controversial as the RAF strategic bomber offensive against Germany, and contemporary studies often cite the lack of fuel and Eisenhower's armies as the principle factors in the Nachtjagd's demise. Throughout the many debates on the subject, however, the impact of EW is often neglected.

In 1939, RAF concepts of the self-defending daylight strategic bomber force were quickly shown to be flawed. Early Freya radars played a key role in this realisation, and the subsequent decision by Bomber Command to adopt night tactics. However, the RAF lacked the navigational capability to mount a strategic night offensive. The rudimentary dead reckoning navigation then employed by bomber crews resulted in targeting errors measured in tens of miles as entire cities were missed in the blackout below. This weakness was further exploited by the German employment of sophisticated decoy and fire sites. It is therefore suggested that lack of an effective navigational capability was the most significant weakness of Bomber Command's early operations. The solution was provided by navigational systems such as Gee, H2S, Oboe and G-H.

As the efficiency of RAF navigation improved, so too did the defences it was required to penetrate and EW was also at the forefront of Germany's efforts. Radar was central to the mounting toll of RAF bombers inflicted by Kammhuber's Himmelbett system. The introduction of Lichtenstein on Luftwaffe night-fighters was the final element required to complete the German defences. In response, the RAF introduced the bomber stream to overwhelm German defences and a variety of EW devices. The unrestrained employment of EW systems such as tail warning and navigation radars allowed the Germans to plot RAF bombers with considerable accuracy. Meanwhile, the RAF expanded their EW efforts by jamming Luftwaffe early warning radars and communications via such systems as Mandrel and Tinsel. However, it was the introduction of Window which changed the entire nature of the night campaign. At a stroke Himmelbett was made virtually obsolete, and the Battle of Hamburg precipitated an unparalleled shock wave through the Nazi leadership, Milch himself commenting after Hamburg that 'I am beginning to think that we are sitting out on a limb. And the British are sawing that limb off'.[128]

This galvanised the Luftwaffe into measures which saw the lethality of their night defences rebuilt. Wilde Sau, Zahme Sau and Reportage facilitated a rapid recovery throughout the winter of 1943-44. Moreover, the blinding of Wurzburg and Lichtenstein by Window expedited deployment of the SN-2 AI radar and further EW passive detection measures. Within months the Luftwaffe had not only recovered from Hamburg, but was inflicting unprecedented losses upon Bomber Command. But Zahme Sau relied upon Reportage which was heavily targeted by RAF communications jamming and this forced Luftwaffe night-fighters to carry increasing amounts of radio equipment which both degraded aircraft performance and complicated C2.

Respite for Bomber Command was initially provided by subordination to Operation Overlord and Operation Crossbow tasks which reduced exposure to German defences. However, it is suggested that RCM and communications jamming by the RAF was ultimately responsible for the terminal degradation of Luftwaffe night defences. Once the secrets of SN-2 and Flensburg were laid bare the final Luftwaffe advantages were removed. RAF intruders equipped with a phalanx of EW devices precipitated the Nachtjagd Moskito Panic, whilst expanded RCM and Window spoofs saw bomber losses plummet to less than 1% over Germany itself.

Nevertheless, other factors also influenced the campaign. German and British leadership displayed very different attitudes towards EW. Goring in particular never appreciated the significance of such technology and lost all credibility in the eyes of his aircrew. In comparison, Churchill and Harris each took a personal interest in the fielding of key EW capabilities. More significant to the Luftwaffe, however, were the loss of early warning stations to the Allied advance and increasingly tenuous fuel supplies. These undoubtedly had a major bearing upon operations and are often cited as the primary causes of the Luftwaffe's decline, yet even in the final months of the war, sufficient fuel remained for night-fighters to operate in large numbers and inflict heavy losses upon Bomber Command. However, such occasions were invariably when circumstances negated the value of EW.

The pre-eminence of EW in Bomber Command's night offensive is strongly reinforced by the Post Mortem exercises against a German AD system unfettered by Allied armies. The results from Post Mortem definitively demonstrate the impotence of Luftwaffe night defences when exposed to RAF EW, which reflected experiences over Germany in the final year of the war. The ability of a large and anticipated RAF bomber force to penetrate Luftwaffe defences, accurately navigate to and 'attack' a simulated target, and egress without being plotted by the Germans is mute testimony to the significance of EW.

The influence of EW was evident from the very first weeks of the bomber campaign. Such technology raised navigational accuracy to unprecedented levels, facilitated effective weapons delivery in all weather conditions, and reduced the world's most sophisticated AD system to impotence. When RAF EW could not be effectively applied, losses were immediately incurred. Whilst the advancing Allied armies and the Luftwaffe's own critical fuel supplies were significant, they did not prevent the Nachtjagd from flying in large numbers even in the final weeks of the conflict. It is therefore suggested that RAF EW technology was the primary factor in the maintenance of Bomber Command's effectiveness throughout the strategic offensive, and was instrumental in the final collapse of Germany's night defences. This study concludes with the words of the most respected commander of Germany's wartime fighter defences:

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.
(General Adolf Galland, 5 January 1945.[129])

Bibliography

Books

Baker, David (1996), Adolf Galland: The Authorised Biography, (London, Windrow and Greene Ltd).

Bowman, Martin (2000), de Havilland Mosquito: Part 1, Wings of Fame, Vol 18, pp.38-91.

Bowman, Martin W and Cushing, Tom (1996), Confounding The Reich: The Operational History of 100 Group (Bomber Support) RAF, (Sparkford, Patrick Stephens Limited).

Bowyer, Michael J F (1980), The Stirling Bomber, (London, Faber and Faber).

Cox, Sebastian, ed (1998), The Strategic Air War Against Germany 1939-1945, The Official Survey of the British Bombing Survey Unit, (London, Frank Cass Publishers).

Donald, David, ed. (1994), Warplanes of the Luftwaffe, (London, Aerospace Publishing).

Jones, Geoffrey (1978), Raider: The Halifax and its Flyers, (London, William Kimber and Co Ltd).

March, Daniel J and Heathcott, John, ed. (1997), The Aerospace Encyclopedia of Air Warfare, Volume One 1911-1945, (London, Aerospace Publishing).

Galland, Adolf (1971), The First and the Last, (London and Glasgow, Fontana).

Hastings, Max (1992), Bomber Command, (London, Penguin).

Hill, Robert (1977), The Great Coup, (London, Corgi).

Hinchliffe, Peter (1996), The Other Battle: Luftwaffe Night Aces Versus Bomber Command, (Shrewsbury, Airlife Publishing Limited).

Isby, David C, ed. (2003), Fighting the Bombers: The Luftwaffe's struggle against the Allied Bomber Offensive, (London, Greenhill Books).

Lorant, Jean-Yves and Goyat, Richard (2005), Jagdgeschwader 300: 'Wilde Sau' Volume One June 1943 - September 1944, (Hamilton, MT 59840 USA, Eagle Editions).

Lovell, Sir Bernard (1991), Echoes of War: The Story of H2S Radar, (Bristol, Adam Hilger).

March, Daniel J, ed. (1998), British Warplanes of World War II, (London, Aerospace Publishing).

Middlebrook, Martin (2000a), The Battle of Hamburg: The Firestorm Raid, (London, Cassell & Co).

Middlebrook, Martin (2000b), The Nuremburg Raid: 30-31 March 1944, (London, Cassell & Co).

Middlebrook, Martin (2000c), The Peenemunde Raid:17-18 August 1943, (London, Cassell & Co).

Middlebrook, Martin (2001), The Berlin Raids: RAF Bomber Command Winter 1943-44, (London, Cassell & Co).

Middlebrook, Martin and Everitt, Chris (1987), The Bomber Command War Diaries: An Operational Reference Book, 1939-1945, (Harmondsworth, Penguin).

Otter, Patrick (1993), Maximum Effort III: The Untold Stories, (Hull, Hutton Press Limited).

Overy, Richard (1997), Bomber Command 1939-45: Reaping the Whirlwind, (London, Harper Collins).

Price, Dr Alfred (1978), Instruments of Darkness: The History of Electronic Warfare, 2nd edn. (London, Macdonald and Jane's Publishers Limited).

Price, Dr Alfred (2005), 'Confound and Destroy', RAF: The Official Magazine, Issue 7, pp. 66-72.

Pritchard, David (1989), The Radar War: Germany's Pioneering Achievement 1904-45, (Wellingborough, Patrick Stephens Limited).
Probert, Henry (2001), Bomber Harris: His Life and Times, (London, Greenhill Books).

Smith, J R and Kay, Anthony (1975), German Aircraft of the Second World War, (London, Putnam).

Weal, John (1999), Luftwaffe Nachtflieger Part 1, Wings of Fame, Vol 14, pp.104-125.

Weal, John (1999), Luftwaffe Nachtflieger Part 2, Wings of Fame, Vol 15, pp.102-125.

Webster, Sir Charles and Frankland, Dr Noble (1961), The Strategic Air Offensive Against Germany 1939-1945: Volume I: Preparation, (London, Her Majesty's Stationary Office).

Webster, Sir Charles and Frankland, Dr Noble (1961), The Strategic Air Offensive Against Germany 1939-1945: Volume II: Endeavour, (London, Her Majesty's Stationary Office).

Webster, Sir Charles and Frankland, Dr Noble (1961), The Strategic Air Offensive Against Germany 1939-1945: Volume III: Victory, (London, Her Majesty's Stationary Office).

Webster, Sir Charles and Frankland, Dr Noble (1961), The Strategic Air Offensive Against Germany 1939-1945: Volume IV: Annexes and Appendices, (London, Her Majesty's Stationary Office).

Westermann, Edward B (2001), Flak: German Anti-Aircraft Defenses, 1914-1945, (United States of America, University Press of Kansas).

Internet Sources
Josef Kammhuber, (http://en.wikipedia.org/wiki/Josef_Kammhuber).

List of World War II Electronic Warfare Equipment, (http://en.wikipedia.org/wiki/List_of_World_War_II_electronic_warfare_equipment).

Luftwaffe Night Fighter Control Methods: Part 3, (http://gyges.dk/Wilde%20&%20Zahme%20Sau.htm).

Navigational Aids Oboe AMES Type 9000, (http://www.radarpages.co.uk/mob/navaids/oboe/oboe3.htm).

RAF Strategic Bombing: From Art to Science and Back, (http://www.stable.demon.co.uk/general/bomb.htm).

Schrage Musik and The Wesseling Raid 21/22 June 1944, (http://www.207squadron.rafinfo.org.uk/wesseling_schrage_musik.htm).

Notes
1
2 Isby (2003), p.157.
3 Webster and Frankland (1961, Vol IV), p.446.
4 Overy (1997), p.75.
5 Webster and Frankland (1961, Vol I), p.129.
6 Isby (2003), pp.14-15.
7 Hinchliffe (1996), p.23.
8 Freya was a mythical Nordic goddess whose guardian, Heimdal, could see 100 miles.
9 Price (1978), p.60.
10 Webster and Frankland (1961, Vol IV), p.110.
11 Middlebrook & Everitt (1987), p.26.
12 Hinchliffe (1996), p.31.
13 Price (1978), p.62.
14 Westermann (2001), p.90.
15 Isby (2003), p.63.
16 Hinchliffe (1996), p.47.
17 Isby (2003), p.63.
18 Hinchliffe (1996), p.48.
19 id.
20 Middlebrook & Everitt (1987), pp.91-122.
21 ibid, pp.219 & p.126.
22 Hastings (1992), p.126.
23 Pritchard (1989), p.74.
24 Hastings (1992), p.108.
25 Westermann (2001), p.126.
26 RAF Strategic Bombing: From Art to Science and Back', http://www.stable.demon.co.uk/general/bomb.htm/ accessed 8 March 2006.
27 Hastings (1992), p.123.
28 Price (1978), p.138.
29 ibid, pp.67-69.
30 Hinchliffe (1996) p.98.
31 Middlebrook & Everitt (1987), p.246.
32 Price (1978), p.105.
33 Middlebrook & Everitt (1987), p.273.
34 Price (1978), p.104.
35 Middlebrook & Everitt (1987), pp.268 & 333.
36 ibid, p.237.
37 Price (1978), p.112.

38 Price (1978), p.129.
39 Middlebrook & Everitt (1987), p.329.
40 Webster and Frankland (1961, Vol I), p.434.
41 ibid, p.435.
42 Price (1978), p.124.
43 ibid, p.133.
44 Cox (1998), p.49.
45 Price (1978), p.131.
46 Hinchliffe (1996), p.144.
47 Price (1978), p.114.
48 Probert (2001), p.232.
49 Price (1978), p.48.
50 ibid, p120.
51 ibid, p.149.
52 Although a new AI Mark X radar immune to Window was available, security concerns prohibited its use over occupied territories until 1944.
53 ibid, p.166.
54 Cox (1998), p.41.
55 Webster and Frankland (1961, Vol IV), p.502.
56 Cox (1998), p.46.
57 Price (1978), p.157.
58 ibid, p.155.
59 Westermann (2001), p.214.
60 Middlebrook (2000a), p.128.
61 bid, p.129.
62 ibid, pp.137-138.
63 Middlebrook & Everitt (1987), p.411.
64 ibid, p.290.
65 Middlebrook (2000a), p.129.
66 Galland (1971), p.139.
67 Hastings (1992), p.238.
68 Hinchliffe (1996), pp.212-214.
69 Price (1978), p.169.
70 ibid, p.173.
71 Hinchliffe (1996), p.196.
72 Price (1978), p.188.
73 Hinchliffe (1996), p.195.
74 Middlebrook & Everitt (1987), p.377.
75 Price (1978), p.191.
76 ibid, p.219.
77 Lovell (1991), p.209.
78 ibid, p.234.
79 Price (1978), p.215.
80 Hinchliffe (1996), p.193.
81 Isby (2003), p.224.
82 Middlebrook (2001), p.118.
83 Middlebrook & Everitt (1987), pp.452-469.
84 id.
85 id.
86 Middlebrook & Everitt (1987), pp.465.
87 Isby (2003), p.123.
88 Webster and Frankland (1961, Vol IV), p.428.
89 ibid, p.502.
90 Price (1978), p.218.
91 Webster and Frankland (1961, Vol IV), pp.15-16.
92 Middlebrook & Everitt (1987), p.473.
93 Despite its designation, the Halifax Mark III entered service after the Mark V and was capable of flying at higher altitudes than the Mark II and V.
94 ibid, pp.474 & 485.
95 Westermann (2001), p.229.
96 ibid, p.228.
97 Middlebrook & Everitt (1987), p.484.
98 ibid, p.487.
99 Price (1978), p.198.
100 Middlebrook & Everitt (1987), p.447.
101 Webster and Frankland (1961, Vol III), p.121.
102 ibid, p.122.
103 Middlebrook & Everitt (1987), p.490.
104 Cox (1998), p.18.
105 Webster and Frankland (1961, Vol IV), p.158.
106 Price (1978), p.208.
107 ibid, p.209.
108 ibid, p.210.
109 ibid, p.222.
110 Hinchliffe, (1996), p.298.
111 Price (1978), p.214.
112 Galland (1971), p.245.
113 Price (1978), p.215.
114 id.
115 Hinchliffe (1996), p.293.
116 id.
117 ibid, p.260.
118 Price (1978), p.239.
119 Bowman & Cushing (1996), p.108.
120 Price (1978), p.230.
121 Middlebrook & Everitt (1987), pp.592-641.
122 Hastings (1992), p.336.
123 Middlebrook & Everitt (1987), p.674.
124 ibid, p.682.
125 Hinchliffe (1996), p.330.
126 Price (1987), p.240.
127 ibid, pp.240-242.
128 ibid, p.163.
129 ibid, p.226.