Sound and fury: sound and vision in early U.K. air defence

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ABSTRACT

To mount an effective national air defence after the outbreak of the first world war, Great Britain required early warning and tracking of aggressors beyond visual range. To achieve this, the early warning provided by wireless interception, "listening in" to attackers' radio traffic and tracing its origin by wireless direction finding, and acoustic (sound) location, tracking enemy aircraft engine noise - techniques almost totally independent of the ability to see the enemy – increasingly enabled fighters to attain the necessary height and position for interception, mobile gunners to set up their artillery, and blackouts to deny enemy dirigibles and aircraft accurate acquisition of their targets. The system relied upon the telephone, and later wireless, both acoustic means, to communicate information speedily between interceptors and listeners, control centres, and defence assets such as guns, aircraft and civilian air-raid warnings. These defences developed to prove effective against two overlapping phases of strategic bombing assault, first by Zeppelin dirigibles, and later by bomber aircraft. In both cases, wireless and acoustic techniques, though imperfect, provided a necessary early warning impossible to achieve by visual mean.

KEYWORDS

Great Britain; First world war; Zeppelin; wireless; intercept; sound locator

Introduction

Air defence, and associated technologies for interception, were not new in 1914. At the siege of Paris in the Franco-Prussian War, the besieged Parisians employed hot-air balloons to make their way in and out of Paris, and the besieging Germans naturally attempted to shoot these down[1]. In the context of the present paper, the purely visual warning of enemy approach was sufficient, for anti-balloon guns require little time to aim and fire - only a short period of advance warning was needed to bring them into action. In consequence, to counter hot-air balloons, typically operating by day, with very low speeds and limited manoeuvrability, an exclusively visual method of target acquisition proved adequate.

This paper examines how the significant extension of warfare into the third dimension after 1914 led, however, to the gradual development of sound, as opposed to vision, as the key sensory element in systems of defence against air attacks. This was not least because attacks by new kinds of airborne technology increasingly took place at night and/or in cloud and bad weather, when visual information on targets was difficult if not impossible to acquire.

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After 1914, Britain was first attacked by Zeppelin dirigibles flying across the North Sea, their assaults taking place at night. The Zeppelins employed wireless to assist their navigation; compass bearings from wireless stations in Germany and German-occupied territory of the Zeppelin's transmissions were radioed to the Zeppelin, allowing its navigators to fix their position by triangulation. Through wireless interception, 'listening in', the British gained early warning of attack while the Zeppelins were far beyond visual range. This early warning system allowed the British to employ their national telephone system both to order blackout, denying the Zeppelins visual acquisition of their bombing target, and, to intercept the Zeppelins, deploy mobile anti-aircraft (AA) guns; early in the war, the gun was the primary weapon as British fighter aircraft were then neither numerous nor capable enough to mount an effective defence.

Following the overloading and temporary collapse of the national telephone system during one Zeppelin raid in 1916, a robust system of local defence was built upon regional telephone networks to connect wireless intercept, sound locators and visual observers with AA guns and airfields. More capable fighters with more potent ammunition began to be deployed, gradually permitting more interceptions and the eventual defeat of warlike Zeppelin incursions. Although the fighter pilots' final acquisition of their Zeppelin target was visual, it would have been impossible for their primitive aircraft to achieve the height necessary for interception without timely advance warning provided by wireless interception and sound location.

Renewed German assault in 1917 by Gotha bomber aircraft flying across the English Channel, initially by day but later by night, forced a reappraisal of British air defence in south-east England. At first, visual observers on off-shore vessels were linked by telephone or by wireless to a central air defence control, which, in addition to using telephone contact to achieve defensive black-out and alert its guns, also deployed fighter aircraft, increasingly with the aid of wireless. Once again, the fighter pilots' final recognition of their bomber targets was visual, but their deployment to their intercept position and height would have been impossible without the early warning provided by wireless and sound intercept.

I show that several specific factors facilitated this British development. The most salient, of course, was the fact that Britain was forward in developing national air defence precisely because the nation was under national air attack, while Germany did not do so because it was not, in any meaningful sense. German Zeppelins' necessary use of wireless for navigation during their lengthy flights, laid the aggressor uniquely open to wireless intercept, accurate location, and then physical intercept. Of equal importance is the fact that the Royal Navy, to whom homeland defence was entrusted, required wireless intercept stations to listen to German surface vessel and surfaced U-boat transmissions, and precisely those same stations sufficed to intercept Zeppelin traffic; shore intercept stations were cheap and easy to build, and incremental investment was unnecessary. Additionally, in its close relationship with the Marconi firm, the Royal Navy possessed a source of triple richness – of inventive engineering research, of skilled staff, and of a pre-eminent training organisation through which to train more. A final factor is that of chance - Britain quickly obtained Germany's codebooks as used by the Zeppelins.

By contrast, the relatively few British attacks on Germany, late in the war, were mounted from France and Belgium, and so were short-range with little need for wireless navigation; in addition to thus having little to intercept, Germany did not possess any relevant British codes. Germany had also chosen to eschew the advances of Marconi in favour of establishing an indigenous industry under the leadership of such firms as Telefunken; this, of course, closed off the knowledge of technical advances such as those of Marconi's Captain Round, described in the body of this paper.

In the context of British air defence, the General Post Office fulfilled the role of providing and maintaining the nation's "nervous system", in the form of its national telephone network; this was the major carrier of communication between its sensors, such as sound locators, and defence assets, such as military headquarters, gun-sites and airfields, and civilian warning and black-out systems[2]. While a major enabler of national air defence, its labour-intensive laying of cables meant that any extension of the system was very slow, and its collapse triggered a significant reorganisation of defences. The Royal Engineers, who then provided Army signals, played a lesser role, as until 1916 homeland air defence was a Naval activity assisted by Marconi's and by the GPO; subsequently, the Army contribution was of higher profile, for example in sound-locator provision, but it was made plain to all that the Western Front was the Army's priority, over and above homeland air defence. This was the reason, for example, why the Royal Flying Corps in the UK, though not in France, were denied ground-to-air radiotelephony until 1918.

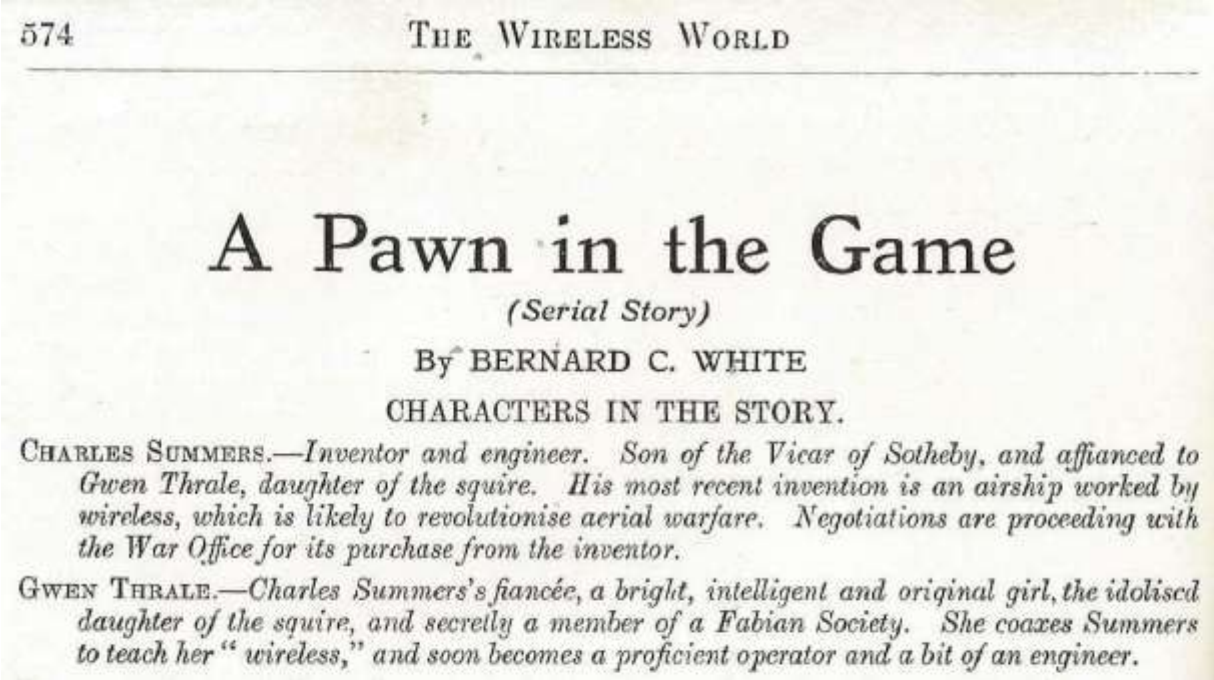
The concluding section of this paper summarises a paper in preparation to illustrate that, to achieve greater range and hence longer early warning, the British after the First World War would develop increasingly large coastal sound locators. However, by 1935, the increasing speed of bombers would render these efforts futile, and the programme was halted. The British air defence system built up after 1935 would increasingly be founded on the plotting of both the aggressor's bombers and of the defending fighters by means of radar and of radio direction-finding, with defending fighters directed to attack by radio-telephony. That system gained the victory of the Battle of Britain, though acoustic sound locators and visual methods developed in the First World War continued to be used by AA artillery during the night-time 'Blitz' in which German aircraft attacked strategic British cites during winter 1940-1. In 1944, assault by robotic cruise missiles, the V-1 'buzz-bomb' or 'doodlebug', would be met by almost equally robotic radar-trained and radar-laid anti-aircraft guns, such assault and defence having passed beyond visual and acoustic senses into the field of electronics.

In sum, this paper argues that the development of non-visual technique in air attack and defence over the period 1914 – 1945 represents a continuum in which sound at first supplements, and then increasingly supplants, visual means of target recognition for both aggressor and defender, a process whose inception in the First World War is described here. The argument of a paper in preparation, summarised below, is that this continuum would essentially be complete during the Second World War, after the advent of the fast bomber, and then of the cruise and ballistic missile, would render visual stimuli difficult, and then impossible, to incorporate as an active element of air defence.

Aerial threat and air defence in pre-1914 British speculative literature

One hundred years ago, British Marconi Company wireless operators reading *Wireless World,* formerly their company journal *The Marconigraph*, no doubt thrilled to Bernard White's yarn "*A Pawn in the Game*"[3], wherein inventor-engineer Charles Summer devises a wireless-controlled drone airship carrying a 'death ray' beam weapon linked to a searchlight target designator, and from "the Marconi tower in Caister" remotely controls its destruction of a German air fleet; when Charles collapses, there springs to the controls his fiancée Gwen Thrale, the local squire's daughter, described as "a bright intelligent girl, secretly a member of a Fabian society, whom Charles has taught to become a proficient operator and a bit of an engineer", and Gwen, with back-up target designation provided by a salt-of-the-earth searchlight operator, despatches the foe.

Air interception, radio-controlled drone technology, beam weapons, target designation and a female engineer hero – in 1913, indeed a daringly modern tale of air defence! Relevant to the present paper, the airship drone transmits by wireless back to the Marconi tower a display showing its position and those of the attackers as blue dots on a screen, but the drone's distance from the tower is assessed by a visual 'sighter', described as "similar to that used on 16-inch guns", spotting an identifying 'flash' from the drone; when, in battle, the display breaks down, a searchlight acts as visual target designator. But how did such speculation relate to the reality of the times?



574 THE WIRELESS WORLD

A Pawn in the Game

(Serial Story)

By BERNARD C. WHITE

CHARACTERS IN THE STORY.

CHARLES SUMMERS.—*Inventor and engineer. Son of the Vicar of Sotheby, and affianced to Gwen Thrale, daughter of the squire. His most recent invention is an airship worked by wireless, which is likely to revolutionise aerial warfare. Negotiations are proceeding with the War Office for its purchase from the inventor.*

GWEN THRALE.—*Charles Summers's fiancée, a bright, intelligent and original girl, the idolised daughter of the squire, and secretly a member of a Fabian Society. She coaxes Summers to teach her " wireless," and soon becomes a proficient operator and a bit of an engineer.*

Figure 1. Extract from 'Wireless World', June 1913. (Author's collection).

The reality of the German air threat.

In Germany, lighter-than-air technology had continued to develop as a weapon of war. Even before 1914, Kaiser Wilhelm's Germany had built a fleet of Zeppelin dirigibles, "cruisers of the air", which could launch direct aerial attacks on both coastal and inland targets[4] – an unprecedented threat to the civilian population. Indeed, initially, aerial assault on the UK was a novelty, and so on occasion the civilian population would react with terror and riot against the apparent powerlessness of the authorities to make an adequate defensive response to the assault, reliant as they at first were upon visual sighting and thus unable to give adequate civilian early warning, or to introduce such defensive measures as blackout – itself a means of denying the Zeppelin visual acquisition of its targets.

Figure 2. Zeppelin dirigible L2, later LZ18.
(Image Credit: Wikimedia Commons: Weltrundschau zum Reclams Universum 1913)

However, greater familiarity with that threat identified to the defenders that, as a means of air assault, the Zeppelin had many deficiencies[5]. Mechanically unreliable and highly flammable, it was also necessarily large (200m x 25 m diameter) and slow (typically 80 - 100 mph in still air), both features which made it an obvious visual target. To balance these disadvantages, German Zeppelin forces were able to mount attacks at night and in poor weather – the majority of autumn and winter nights in the UK – so that visual target acquisition by AA gunners was the more difficult, and often even impossible.

Sufficient Zeppelins were also available to mount attacks *en masse*, in groups which included decoys, such that genuine attacks might be masked. This was a particular concern to the British authorities, since the sounding of an air raid alarm when a Zeppelin was expected caused all lights to be doused and war manufacturing to cease, and false alarms caused by decoys meant significant lost production of such war materials as shells.

Because Zeppelins had a low top speed which North Sea head-winds reduced still further, several hours were required to traverse the North Sea. As a result, <u>if</u> Zeppelins could be accurately located and tracked during their approach from far out to sea, and <u>if</u> decoy attacks could be filtered out, then very early warning both to guns and to blackout critical manufacturing locations was possible. However, such long-range location and tracking, especially at night, in fog, in cloud or inclement weather, was clearly impossible by visual means.

Zeppelin use of sound (wireless) for navigation and target acquisition.

The solution would be found within the Zeppelin's own equipment, and by acoustic means - listening. Zeppelins were not without their problems, for that same wind which compelled a stately progress on the Zeppelins posed their navigators significant challenges. Accurate navigation of a massive lighter-than-air craft for many hours, typically in strong head-winds at night and in conditions of poor visibility, such as cloud or rain, defeated most: one very early raid, believed by that

Zeppelin's crew to be on target over Hull, in fact attacked King's Lynn[6], and this is but one of many examples. The new technology of wireless appeared to provide the answer. For wireless, a Zeppelin was an excellent platform; there was considerable space, engine capacity and weight-lifting capability for power supplies, and it was not difficult to deploy a long wire aerial. Using wireless, Zeppelins could seek bearings on their transmissions from direction-finding wireless stations in Germany or the occupied countries, and thereby locate themselves accurately in relation to their targets.

But early wireless signals were unavoidably also broadcast signals – they could be listened to by anyone with a suitable receiver; a Zeppelin's request for a compass bearing to be taken by a wireless direction finding station could be received and acted upon by friendly German wireless stations, or intercepted and used by the British enemy. A prime facilitator of Britain's increasing adoption of acoustic technique was, therefore, its enemy's use of wireless, and in the entirely non-visual technique of wireless intercept lay the essence of Britain's early-warning system.

The British air defences during the Zeppelin offensive; war-fighting assets, 1914.

Pre-war British doctrine placed little emphasis on homeland air defence by contrast, for example, with naval defence against sea-borne invasion; Erskine Childers' 1903 '*Riddle of the Sands'* [7], attracted considerably more public interest and concern than Bernard White's 1913 '*Pawn in the Game'*. The Royal Navy defended key targets as it defended ships – that is, with guns, and, as already described, these needed little advance warning, but did need sight of the enemy. The few searchlights to aid them at night were ineffective in fog, cloud or poor weather, which form the majority of UK nights. Critically, there were also far too few guns - when Zeppelin raids began, only 12 AA guns defended London as against 251 defending Paris[8].

Such defence as might have been possible with the Royal Navy's few fighter aircraft was best described in the reminiscences of one Bentley Beauman, commissioned in the Royal Naval Air Service a day before the war broke out[9]. Two days later, he arrived on the Isle of Sheppey to report to Commander Samson, who greeted him by asking "Can you fly a Caudron?" "No, Sir". "Do you know the way to Hendon?" "No, Sir". "Very well, at dawn tomorrow, you will fly a Caudron to Hendon". Having duly crash-landed at Hendon, Beauman reported to Captain Murray Sueter, director of the Admiralty's Air Division, who told him "You are now the Defence of London from air attack". Receiving the hapless Beauman's response "I haven't got an observer or any armaments. What could I do if a Zeppelin does come over?" Sueter replied simply "I leave that to you".

Even setting aside this inability of the fighter successfully to destroy the Zeppelins once seen, there was need for the fighter to climb to an advantageous position from which to make an attack. For this, there were two pre-requisites – knowledge of the attacking Zeppelin's likely location had to reach the fighter pilot; and it had to do so typically at least two hours in advance of the interception, because the fighters of that period required at least two hours to climb to interception height. Only sound, in the form of wireless interception, could provide two hours' warning; wireless interception and early warning, including if possible filtering out decoys, were therefore critical to fighter interception.

From these inauspicious beginnings, Britain would develop the world's first national system of air defence incorporating wireless interception, wireless direction-finding, cryptanalysis and sound location; such technologies were almost entirely independent of the ability to see the enemy, and depended instead upon aural stimuli.

The first phase, 1914-5: wireless intercept, cryptanalysis and air defence against the Zeppelin.

On the outbreak of war the British government took over Marconi's Works, many of its wireless stations, and its staff. Marconi's Hall Street, Chelmsford, experimental station initiated wireless interception of German messages[10]. Marconi stations began to pass wireless intercepts to the Admiralty, and Rear-Admiral Oliver, Director of Naval Intelligence, shared these with Sir Alfred Ewing, a cryptographic enthusiast and Director of Naval Education, who forthwith assembled a code-breaking team from Osborne and Dartmouth Naval Colleges[11]. Oliver, meanwhile, set up two amateur radio enthusiasts in an intercept station at Hunstanton, the "Hippisley Hut"[12]. It is noted here that, if modest in their numbers, radio amateurs, whose expertise lay in listening for and reading weak signals against a background of noise, played a significant part in the provision of skilled wireless operators.

Fortunately for the British, the three most significant German code-books were obtained in the first months of the war, one from the German merchantman *Hobart* interned in Melbourne Harbour, Australia[13]; one salvaged by the Russians from the German cruiser *Magdeburg* stranded off Odensholm[14]; and one trawled up from the sunken German destroyer SMS 119 off Belgium[15]. The British now possessed the entire codes of the German Navy and Mercantile Marine, and the German Navy operated the bulk of the Zeppelins attacking Britain.

Nonetheless, however valuable in themselves, code-books are not a defence ***system***, for which there are required intercept stations, a decryption operation, and a centre for information display and decision, before the derived information can be communicated to military defence assets or civilian warning systems, and such assets had to be built up – not without mistakes; the decryption activity soon passed under the control of Admiral 'Blinker' Hall, who forged it into the 'Room 40' group, later to become renowned as the decryptors of the 'Zimmerman telegram' which would eventually bring the USA into the First World War in April 1917. Their decryption skills were less called upon for air defence; the Zeppelins used the code captured from the *Hobart*, with few changes during their years of assault - and those changes were easily broken. The parallel ability to locate the Zeppelin transmissions by wireless-direction finding would prove of equal, if not greater, value.

As visibility was critical in traditional war, so audibility was key in this new, beyond visual range, technology of warfare. Here, the British were aided by a technical advance: Marconi's direction-finding system, a modified Bellini-Tosi directional system, had been equipped with a sensitive valve amplifier developed by former Marconi Company engineer and now Intelligence Corps officer Captain H.J. Round, and this allowed wireless signals, weaker than those audible on a crystal receiver, to be amplified and heard[16].

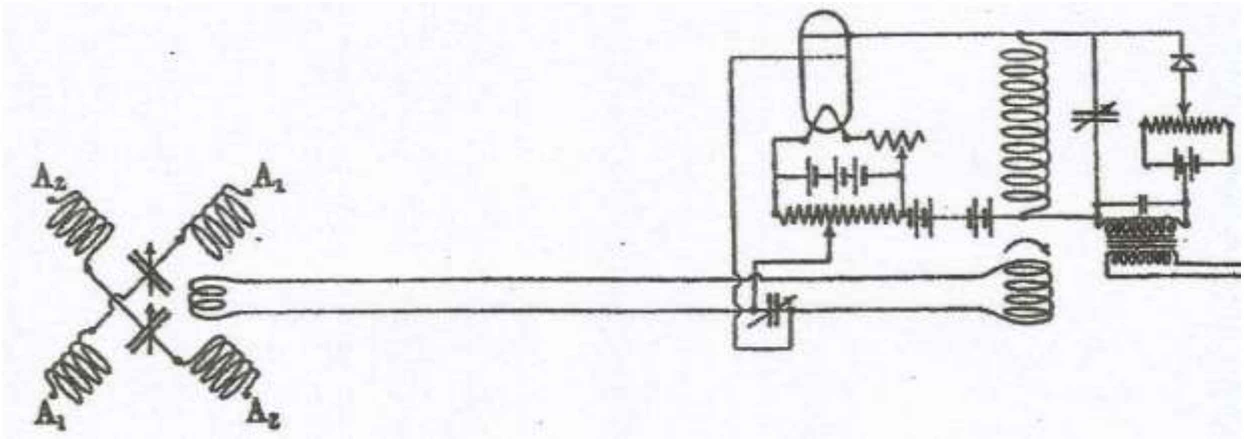


Figure 3. H J Round's D/F circuit incorporating a valve amplifier
(Image Credit: Capt. H.J. Round '*Direction and Position Finding'* IEE Journal, 1921 p.232).

Round's achievements were known to the War Office, and at the beginning of the war he was appointed to the newly-established Intelligence Corps and put to procuring two D/F stations for France; deployed at Blendecques and Abbeville in December 1914. Each station, in two lorries and a car, comprised Marconi/ Bellini-Tosi direction finders and receivers, 70 foot (22 metre) aerial masts, and 'Round' valve amplifiers.

In 1915, this system was offered to the Admiralty, who within months established intercept stations from Kent to the Shetlands; Figure 4 shows Captain Round's map of the main stations, depicting Aberdeen, Birchington, Stockton, Flamborough, York and Lowestoft together with German stations in Belgium and Germany.

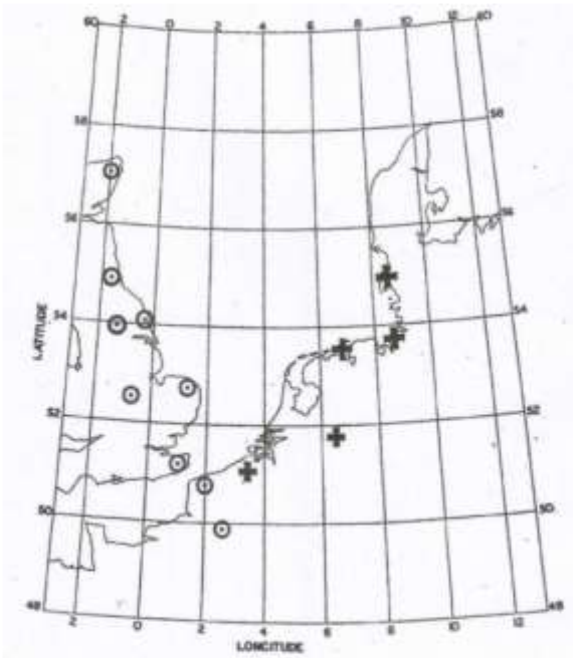


Figure 4. Map of British Intercept Stations and German Transmitters
(Image Credit: Capt. H.J. Round *'Direction and Position Finding'* IEE Journal, 1921 p.234).

An example which has been studied by E.W. Sockett is the Admiralty's Stockton intercept station where Sockett's relative Peggy Wrightson was employed as an operator[17].

Figure 5. Former Admiralty intercept station buildings, Stockton, photographed in 1990 (Image Credit: E W Sockett, *'Stockton-on-Tees Y Station'*, Fortress 8, February 1991, p.53).

At these stations, such operators listened to the Zeppelin radio transmissions, and by using wireless direction finding, D/F, techniques, could take bearings on the transmissions; given at least two bearings, the transmitting Zeppelin could be located. The Germans, unaware of the increased sensitivity of Round's valve amplifiers, continued to use low-power wireless transmissions liberally, not realising that these were being monitored.

The capture of the German code-books realised a further benefit. Since the German codes could now be read, the interceptors could identify which raids were real and which were decoys, for the Germans had been told to leave their codebooks behind when it was a real raid, and to confirm by radio that they had done so[18] . As a result, when such a signal was received, the British military knew that the specific Zeppelin was engaged on an offensive mission, and so had some hours to prepare, because many hours were needed to traverse the North Sea against adverse head-winds.

Operational history, 1915-6.

The most successful initial defensive action took the form of British "intruder" bombing of Zeppelins in their hangars, for the few fighters in Britain had indifferent performance and armament to mount adequate defence, even with wireless intercept giving early warning – there were, for example, no suitable incendiary bullets to ignite the flammable Zeppelins. In addition, British night landing-grounds had inadequate lighting, and so crashes killed or maimed many fighter pilots.

The first Zeppelin raid took place in January 1915, after the British bomber raids on Zeppelin bases and factories. The German intent had been to attack Hull, but the raiders were blown off course by strong winds, with the result that German Navy Zeppelins L3 and L4 bombed Yarmouth, King's Lynn, and Snettisham, killing 4 and injuring 16[19]. In the following month, the Kaiser reluctantly agreed to bomb the London docks, but Zeppelin L8 was lost to engine failure, bad weather, and ground AA fire in the attempt. In the North, there followed two raids during April – one on Blyth and Wallsend, fruitlessly opposed by an RNAS aircraft from Whitley Bay, and one against Hull; here, the winds again proved too strong, such that Zeppelins L5 and L6 dropped their bombs on Suffolk and Essex. On 31 May, the first raid to reach London took place, by the German Army's LZ38; the first house to be hit was 16, Alkham Road, Stoke Newington[20]. Damage was caused over a widely scattered area, triggering reprisals against German-sounding businesses. 15 fighters took off, but only one caught sight of the Zeppelin.

Once Zeppelin raids against Britain had begun, the Zeppelins had used wireless freely – for example, always reporting as soon as they were airborne. Zeppelin transmissions giving their estimated position were likewise intercepted, and it was soon noted that reports of where the Zeppelins ***thought*** they were proved less useful than British direction finding (D/F) on the transmission to establish where each Zeppelin ***actually*** was. This resulted from the Zeppelins, buffeted in their lighter-than-air craft for hours over the North Sea, often in dark and stormy conditions, frequently being many miles from their estimated position. To validate their D/F assessments of the Zeppelins' positions, the British had the additional advantage of intercepting and decrypting the *German* D/F stations' position reports to the Zeppelins, as illustrated by the intercept station log book in Figure 6; the initials along the top of the page are British intercept stations (Lowestoft, York, Murcar, Scarborough followed by the German stations List, Nordholz and Borkum) with timed bearings, in degrees, of Zeppelin 'OG' from each station. The value of this non-visual information lay in the ability of the defences making use of it to impose blackouts, denying the Zeppelins the ability to fix their position or find their targets by visual means.

Communications between British wireless intercept stations, their Admiralty headquarters in 'Room 40', visual observers and the air defences, whether passive such as blackout, or active as in the case of AA gun sites or fighter airfields, was through the Post Office telephone network, an acoustic connection which would remain the 'nervous system' of air defence during the conflict.

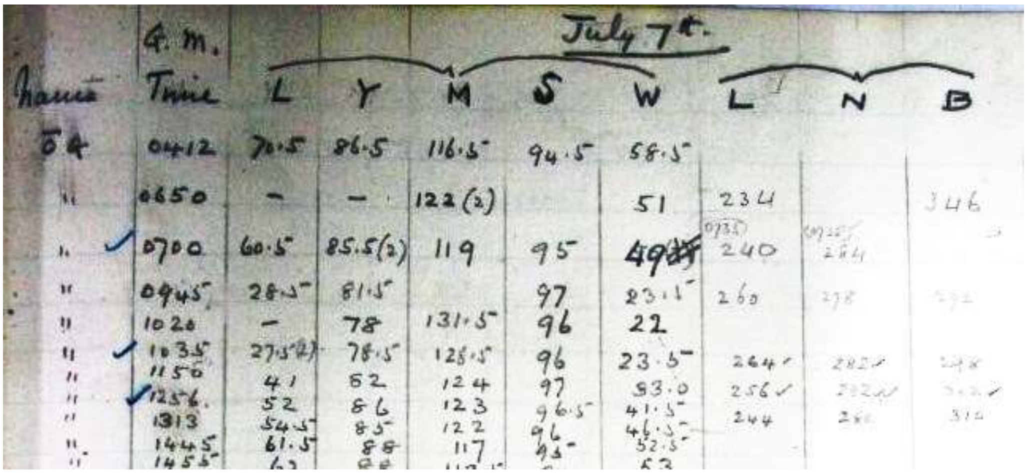


Figure 6. British intercept log
(Image Credit: Bodleian Library, Oxford, Marconi Archives).

During the summer of 1915, the German Navy suspended operations because of the short, light, summer nights, as did the Army, in its case because its Zeppelins had been redeployed to the Eastern Front. When darker nights returned on 9 August, the airships began to target London once more, and in increasing raids to cause significant damage and casualties.

In early September, Admiral Percy Scott was put in charge, promptly reorganised the defences, and very much on his own initiative brought over heavier mobile AA guns from France under the control of Commander Rawlinson[21]. These were better able to make use of the early warning provided by wireless so as to deploy to locations better able to intercept the Zeppelins – albeit, according to Rawlinson, these mobile deployments appear to have frightened the Londoners as much as the Germans; his account states that, at 9pm on 13 October 1915, his first night of action, he had to race his heavy guns across London, from Ladbroke Grove to the City; two hard-tyred trucks with blaring sirens and blazing headlights towed the swaying guns at 60 mph through a crowded Oxford Street, where everyone was in no doubt at all *"that the most pressing and most vital thing they had to do was TO GET OUT OF OUR WAY. ... flattening themselves against the shop windows… infinitely more fearful of a gun moving at such a terrific speed than they were of any German bombs*"[22].

Crashing through a road-works barrier, Rawlinson reached his post safely, and set up the guns in time to drive away Kapitan-leutnant Joachim Breithaupt in Zeppelin L15, who had already caused significant damage and most of the 47 killed and 102 injured in London that night[23]; shrapnel marks are still visible on Lincoln's Inn Chapel. Under Scott's reorganisation, visual target acquisition of course remained essential for the guns to be successful, but it should be emphasised that without non-visual early warning, the mobile guns would not have had time to take up their position to be able to fire on their enemy.

In contrast, by December 1915, the Royal Navy's few fighters were not enjoying good fortune; 20 raids involving 37 airships had been met by a total of 81 sorties of fighters – an average of four fighters per raid; but only 3 of those 81 fighters had made visual contact with a Zeppelin, and no combats had resulted [24]. However, very visible bomb damage had been caused – to the value of over £500,000 in London in September 1915 – and so the world's first national centralised system of air defence information and control "to give the earliest notice of the enemy's approach" had been recommended by S/Ldr. Babington to Admiral Scott, following a tour of the Paris defences[25].

Figure 7. Public information notice, 1915. The second paragraph asks the public to use the telephone to warn the authorities of attackers (Image Credit: HMSO 1915)**.**

It is not unknown for recommendations to become reality only after a disaster; so it was in this case, when reliance on visual sightings had had unintended, but disastrous, results. Inland of the coast, wireless bearings yielded less accurate results, and so the Admiralty asked the police to telephone reports of "any aircraft heard or seen within 60 miles of London", quoting the word "Airbandit" to gain instant priority. Because of the traffic volume limitations of the air defences' 'nervous system', the Post Office telephone network, this procedure proved self-defeating; when police, railways, civil and military authorities, and private individuals phoned to interchange 'Airbandit' information, the telephone trunk network became overloaded; on 31 January 1916 it collapsed, and several Midlands towns were bombed without warning to blackout having been given. Within a fortnight, on 10 February 1916, the Cabinet gave the War Office **unified** control of Britain's air defence[26].

February 1916: Redesign of the air defence system.

Arguably the first ever ***designed*** national air defensive system resulted. Though the British trunk telephone system was incapable of expansion in the short term, the human organisation was built around it. The British national defences were structured into local Warning Controls, including guns, lights, aircraft and passive defences such as blackout and air raid warning, with a mobile AA group capable of swift deployment.

This Army-controlled re-organisation of Britain's air defences gradually started to pay dividends. As examples, 39 Squadron's 24 planes included 6 Be12s with uprated engines and the incendiary Buckingham bullet, although British fighter aircraft did not at this date have wireless receivers in the aircraft, with the result that pilots had to be held back until the last moment to receive the latest information; once having taken off, the fighters were compelled to hunt for the Zeppelins visually, without further ground information or direction. However, Britain's ground-based defence assets now numbered 271 guns and 258 searchlights – certainly, less than their planned 490 of each, but a considerable improvement over 1914[27].

To counteract the fact that direction finding (D/F) became inaccurate once the Zeppelins approached the British coast, there was constructed a chain of sound locators to listen for the engine noise of the Zeppelins. From an early date, a wide range of scientific solutions to the problems of long-range threat detection and location, and of air interception, had been sought by the Admiralty, who had set up a Board of Invention and Research in July 1915. Section I of the Board, which dealt with airships and aircraft, conducted research both on night air defence and on sound locators[28].

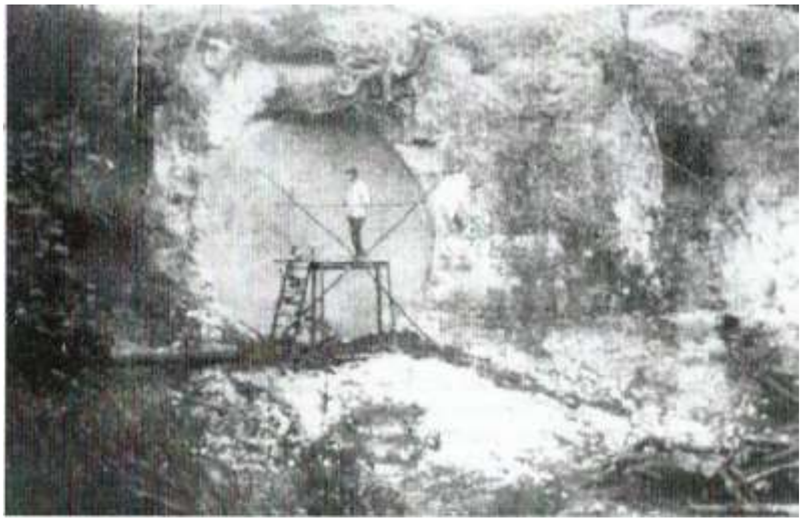


Figure 8. Prof. Mather's sound locator, Binbury, 1915
(Image Credit: Richard Scarth, *Echoes from the Sky,* Plate 1)

A Lt Richmond conducted the first of these experiments in 1915-6, followed by Professor Mather, who constructed a 4.9m chalk-cut "sound mirror" at Binbury, tested in July 1915 (Fig 8)[29]. However, later tests at Upavon proved disappointing, and the Army took no further general action in the south of England, although one more portable variant was sent to Capel Air Station, Dover, "for operational use"[30]. On the north-east coast, four sound locators of similar design survive, at Sunderland, Marske, Boulby and Kilnsea[31]; illustrated in Figure 9 is that at Kilnsea, on the Yorkshire coast near Spurn Head.

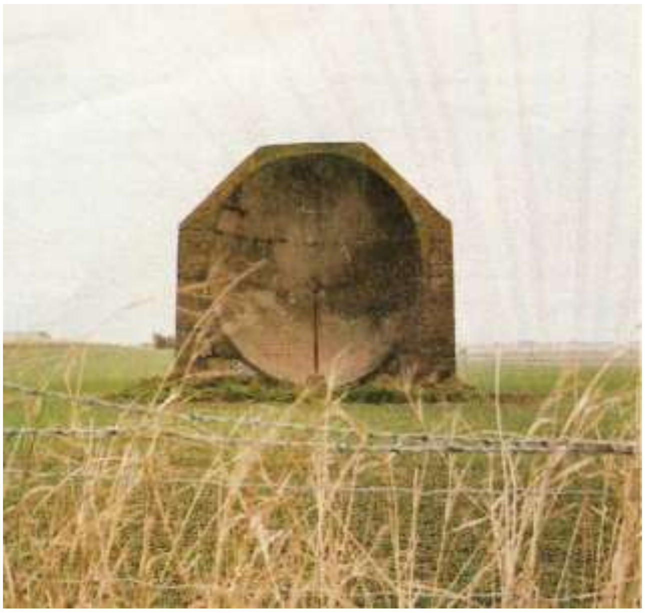


Figure 9. Concrete WW1 sound locator at Kilnsea, Yorkshire (Author's collection)**.**

More transportable versions of the sound locator were, however, in more general use, following the pattern of those used in France, and an example is illustrated in Figure 10. In an inspired and relevant perspective on recruitment, Commander Rawlinson appointed blind men to operate the sound locators, because of their heightened aural sensitivity[32].

Figure 10. Transportable WW1 sound locator
(Image Credit: Richard Scarth, *Echoes from the Sky* Plate 28)

An illustrative result of wireless intercept facilitating aerial defence was that, of a raid of 16 airships on 2 September 1916, three turned back after crossing the coast, and only two came closer to London than St Albans; *SL11* was shot down at Cuffley by Leefe Robinson, and the flames of its descent apparently unnerved four other airship crews, who promptly retreated[33]. The importance for this paper is that wireless intercept had given several hours of warning to the fighter pilots, who had had the time to climb to their patrol height (some 10,000 feet for Robinson). Six Zeppelins were lost in the last five months of 1916, a 14% loss per operation; the airship phase of assault thereafter declined rapidly.

It is appropriate at this point to illustrate the effectiveness with which Zeppelins were tracked by reference to the Marconi stations' 27/8 November 1916 intercept plot, showing a mass raid, many of whose Zeppelins turned back, and tracing the course of two airships eventually shot down into the sea. Strasser, the Zeppelin commander, was forced to admit that the fighters were gaining the measure of his Zeppelins[34].

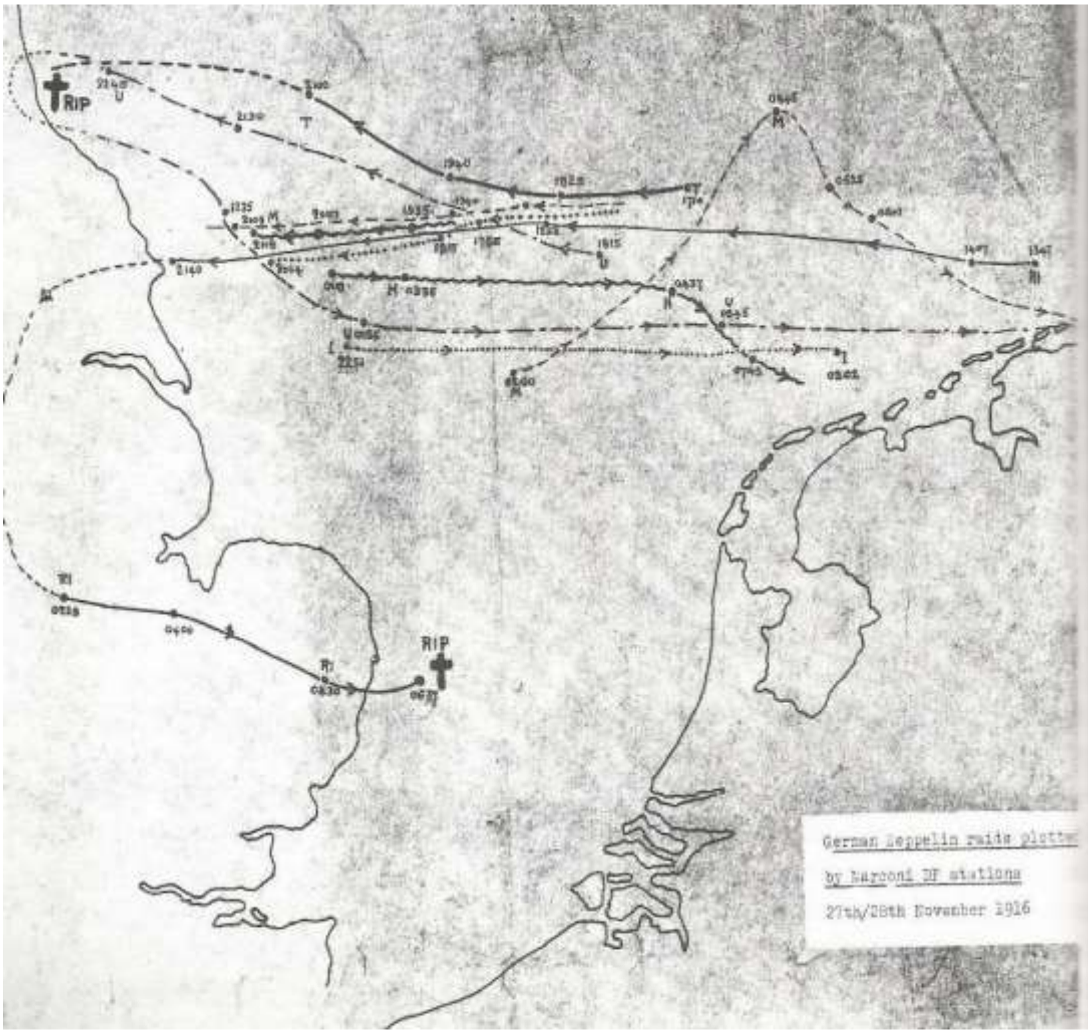


Figure 11. Zeppelin intercepts 27/8 November 1916
(Image Credit: Bodleian Library, Marconi Archives)

By the latter stages of this phase of air defence, the former Marconi Company engineer Captain Round had developed his amplifier to a cascade circuit, illustrated below, employing up to 11 valves, and enabling the audibility of weaker and weaker wireless transmissions[35].

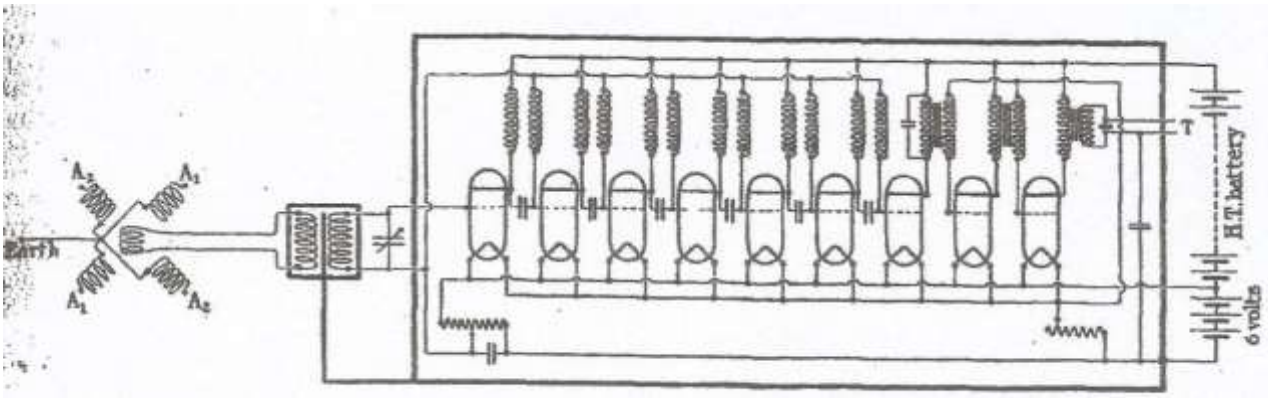


Figure 12. Round's cascade amplifier
(Image Credit: Capt. H.J. Round '*Direction and Position Finding'* IEE Journal, 1921 p.239).

The German Bomber Campaign, 1917-8.

The British defences had now to face a new phase of aerial attack, the aeroplane bomber, which was both faster and smaller than the Zeppelin. They had to do so at a time when increased demands from Admiralty (for guns) and War Office (for pilots for France) left the defences impoverished.

The Germans had formed the 3rd Bombing Squadron around Ghent and began the "Gotha Summer" day offensive on 25 May 1917[36]. On that date, 16 bombers raided Folkestone, causing 286 casualties. More raids over the next three weeks culminated in a 14 bomber daylight raid on Liverpool Street Station, with 594 casualties. Of 94 defending aircraft, only five even saw the Gothas[37]. None were shot down, for the raids achieved surprise and illustrated a weakness in the wireless intercept early-warning system - because these first manned-bomber raids took place in **daylight**, the Gotha bomber navigators did not require position information. There were thus no wireless messages to intercept, and as a result British fighters did not take off in time to gain sufficient height to attack the bombers.

In addition, the *speed of attack* had increased, and so as a result had the necessity for the speediness of *warning of attack*, of the bombers' course and of their likely target, all essential to get fighters up to intercept height in time, to get guns ready, and at night to order blackout.

However, this proved only a temporary setback; the British counter-move to gain longer warning times was to place **visual** observers on offshore lightships, equipped with wireless or with cable connections to provide early warning[38]; as their commander, Major General E.G. "Splash" Ashmore observed, the critical limiting factor in the dissemination of information at this date was the construction of extra telephone lines – an aural communication link.

Within weeks, the British defences mastered daylight interdiction, with German losses rising to 30%, forcing in August 1917 the German counter of moving to night bombing[39].

In the raids which followed, the German Gotha bombers, now navigating at night, once more requested D/F bearings, which could once again be intercepted. British intercept stations tracked the weather reports of German reconnaissance aircraft, which gave significant clues as to the targets for the following nights. Before December 1917, the night defences made no interceptions; after that date, an average of 10% of attackers was shot down.

The particular challenge in defending the main German targets in London and the South-East against night attack was the short flight-time of the attacking bombers, which in turn demanded as much warning time as possible for the fighters to climb to a favourable interception position. Only wireless interception could give the length of warning needed; and importantly, it was now essential for the information flows both from the warning sensors to the centralised control and from the central control to the assets of fighters and guns to be made as speedy as possible, by audible (telephone and wireless) links.

The British defence system had accordingly been gradually modified to speed information flows and action; the Midlands and North, being beyond German manned bomber range, were left unchanged, but south of Watford, the air and ground defences had been reorganised into a new command, the London Air Defence Area (LADA), and to head this, the aforementioned Major General Ashmore, both a gunner and a pilot, had been brought back from France[40]. General Ashmore had made a reality of the London Air Defence Area in which dedicated telephone lines had linked the wireless interceptors, sound locators and visual observers through local control centres to Ashmore's central control at Horse Guards, London[41].

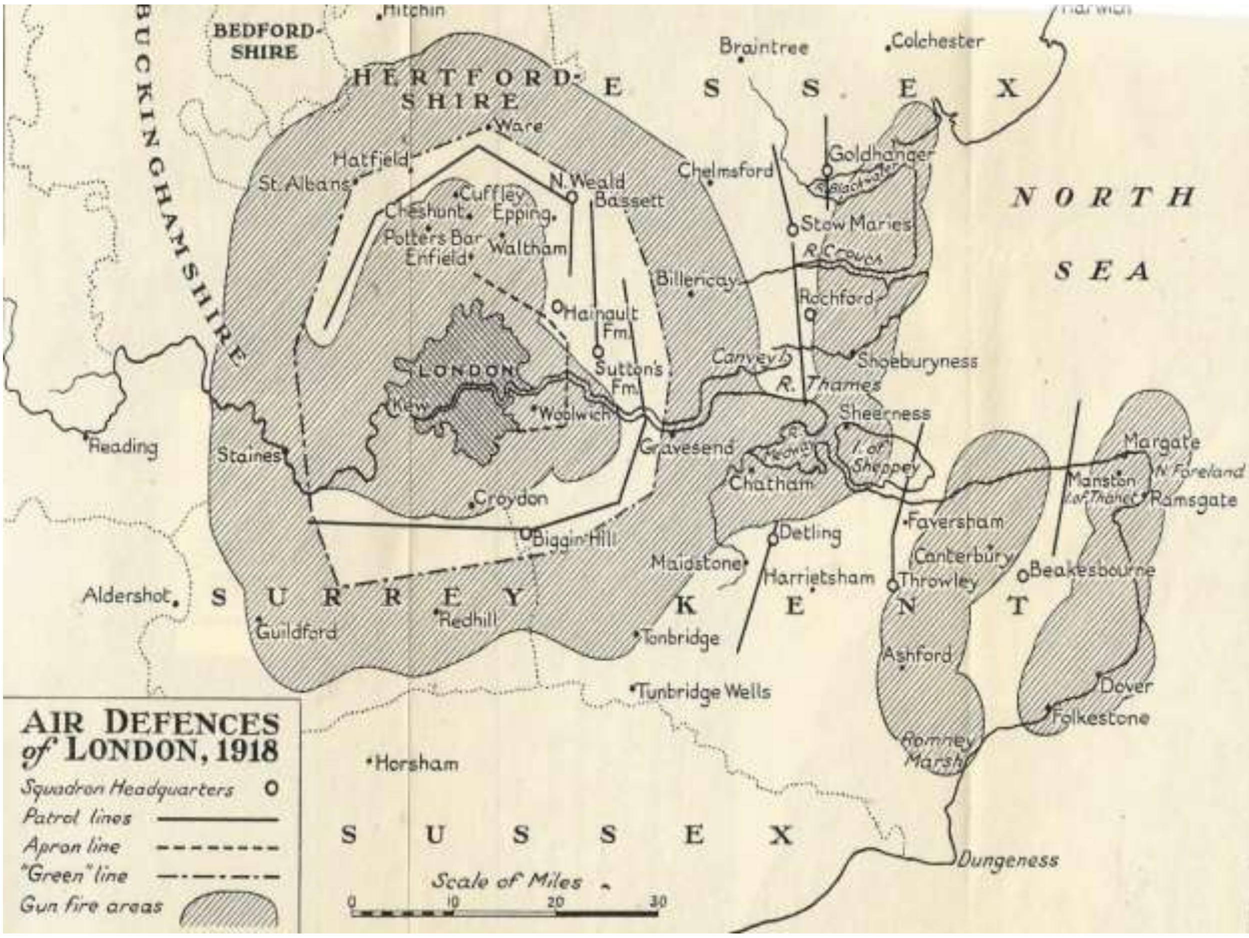


Figure 13. The London air defence area.
(Image Credit: E.B. Ashmore, *Air Defence*, Longmans, 1927)

Ashmore had prioritised his problems as, first, day defence; second, night defence; and third, possible resurgence of the Zeppelin. Analysing the existing system of defence against the day bomber, he had identified two key issues - ***for fighters, that their communications broke down at the point of ground/air control***, (a sound (wireless) problem, and for the guns, inaccurate height estimation, a visual problem.

As solutions, for the fighters, and until reliable wireless could be made available, Ashmore had deployed visual signals - large white arrows at searchlight sites (the troops there being unoccupied by day), while for the guns, he had developed a new system of barrage fire. The system was to make use of "wireless co-ordination" and "directional listening apparatus": Ashmore tirelessly promoted the use of sound locators for AA control[42].

The adapted system appeared vindicated for **daylight** defence on 22 August 1917 in a 10-Gotha raid, of which 3 were shot down (2 by guns, one by fighter), a critical feature being a long-range warning - visual, but 'wirelessed' from the Kentish Knock lightship[43] - which gave the guns 30 minutes to prepare.

The passive defences were also effective - under Ashmore's 1917 update of the "Airbandit" system, police and "coast watchers" telephoned sightings to his Horse Guards War Room, where areas of a map were illuminated with different coloured lights to represent the track and timings of attack. The telephone system was used to disseminate blackout warnings, and to order raising a balloon barrage[44].

However, active defence **at night** was ***not*** at first successful - in three key raids that autumn in which 131 defending flights were sent up against 49 raiders, there were only 8 sightings, leading to just 3 combats and one success. In the winter of 1917-8, only 18 combats resulted from 5 raids, and again only one bomber was shot down[45]. The guns could achieve little, for they relied upon visual target acquisition, and the searchlights then in use, while adequate to track the massive Zeppelins, could not follow the speedier, more agile, and much smaller bombers. Further progress had been made in building two sound locators on the South Coast, at Fan Bay and Joss Gap, both near Dover. The Fan Bay sound 'mirror', as it was called, is known to have been in action during a raid on 1-2 October 1917, when "sounds of enemy aircraft flying down the Channel some 12 – 15 miles out to sea, and inaudible to the gun crews, were detected by the mirror"[46], while during 1918 the site at Joss Gap was used for testing different designs of sound locator.

Ashmore again turned to sound (wireless) technology, and here the critical advance had at last been made with the development of relatively robust radio valves, allowing first the building of receivers which did not use cat's whiskers crystal detectors, and then of transmitters capable of telephony (speech) rather than Morse code communication. However, mere *availability* of technology was not the only issue - the *priority* for available equipment was the Western Front. 'In the middle of April' 1918, Ashmore said, 'we were able to make full scale trials of fighting machines equipped with receiving sets'; but he had not been idle and merely waited for this to happen[47]. He had meanwhile equipped bigger aircraft with such equipment as was available, to become wireless-fitted trackers, to accompany and fly above the incoming bombers, to give their position accurately to the ground, and thus via searchlights, to the fighters. 'By May', he attests, 'the wireless telephone had been installed in the fighting machines, and pilots were beginning to receive orders without difficulty'[48].

By May 1918, some fighters had been equipped with receivers (although ***not*** as yet transmitters) making ground guidance of them to intercept enemy aircraft a possibility. As a result, the German raid of 30 attackers on 19 May suffered a severe reverse. There were 12 combats, and 6 bombers were lost, 3 to fighters (of whom 84 flew that night) and 3 to AA guns[49].

By this time, says the unpublished *Official History of Wireless Telegraphy: R.N.A.S., R.F.C. and R.A.F* [50], "instruments which were proving to be the most efficient and useful were being ordered in thousands". In the summer of 1918, ground stations in Britain and in France had multiplied to over 1,000 and aircraft fitted for wireless to over 600, and for aircraft, a standardised equipment and infrastructure had developed; the 3-valve Aircraft receiver Mk 3 by Automatic Telephone Manufacturing; and - when eventually it arrived - the US-built 2-valve 20 watt telephony transmitter by General Electric, USA.

At the Armistice, only ten Zeppelins remained, and 40% of airship crew (369 men) had been killed in action, as had 225 bomber aircrew[51]. The material damage they had caused, though highly visible, was of no significance to the war. The British air defence system, increasingly based on warnings from beyond visual range and based on sound (wireless intercept and sound locators) had created an effective air defence where purely visual methods had proven inadequate.

Interwar and second world war developments.

Between the World Wars, bomber speeds increased significantly, from around 80 mph to some 240 mph. Clearly, this implied the need for longer-range detection to provide the same early warning, and the British developed increasingly large coastal sound locators to achieve that greater range. By 1935, the limits of sound-location technology had been reached, and the programme was halted. After that date, the British air defence system would be built upon the plotting both of the aggressor's bombers and of the defending fighters by means of radar and of wireless intercept. In the daylight Battle of Britain during the summer of 1940, the imperfections of the 'Chain Home' radar system meant that final visual acquisition of the bomber target was still important, but fortuitous clear skies enabled a defenders' victory.

The air battle then moved into the night 'Blitz', and here German experience through their 'volunteer' Condor Legion in the Spanish Civil War stimulated their development by 1940 of directional radio beams for accurate navigation; the beams' output was the sound stimulus of a tone in the bomber pilots' headphones to guide their course and advise them of the time of bomb release, such that visual acquisition of their target, while useful, was now not essential.

During late 1940-1, the British counter was the development of a more accurate ground-based radar and a system of bomber and fighter radio tracking and fighter interception guidance, which, coupled with effective airborne intercept radar, gained the advantage over the attackers in the final weeks of the Blitz, when ground control by radio-telephone could bring the defending fighter to within yards of their quarry regardless of adverse weather, and airborne radar in the fighter helped conclude the 'kill'. Both radar and sound locators aided ground-based anti-aircraft gunnery and searchlights, while ground-based electronic warfare techniques ('jamming') in which visual capabilities played no part whatever, helped defeat accurate bombing.

The next distinct phase of assault, in 1944, was that of the cruise missile, which in 1944 was the robotic V-1 pilotless aircraft, 'buzz-bomb' or 'doodlebug', with its own internal guidance system. The V-1's speed meant that human interpretation of radar information was now too slow to ensure interception, and therefore the target information from the centimetric radars was fed through a predictor directly into the anti-aircraft guns' training and laying controls. The role of the humans involved, apart from servicing and maintenance, was simply to feed ammunition into the guns and perform any emergency over-ride needed. As such, this position, where both attack and defence had become electro-mechanically robotic and hence non-human, may be taken as the limiting case of a continuum of the move from optical to acoustic information inputs; this level of air assault and air defence had need of neither.

Conclusion.

In UK First World War air defence, the aggressor primarily struck at night and often in poor weather, when solely visual means of defence were of limited value. The primary requirements in such conditions were timely early warning and location of the attacker by non-visual means; without these, AA guns, and more importantly fighter aircraft, would have been of little value.

I have argued that, with the increasing speed of successive air aggressors (Zeppelins, bomber aircraft), the necessity was for early warning and attacker location far beyond visual range even in daylight and good weather, to allow fighters to gain interception height, guns to be readied and, at night, blackout of likely target areas implemented.

The only technologies capable of meeting those requirements were those of wireless interception and direction-finding, and for closer targets, sound location; all are non-visual technologies. Transmission of continually-updated target information throughout the ground-based defensive system hinged upon telecommunications, both by telephone and by wireless, and then, as technological advances permitted, upon wireless communication to and from fighter aircraft in flight. Again, all are non-visual technologies, though communication to fighter aircraft relied on visual means in its early stages.

The national air defence system resulting developed through stages of imperfection to become the world's first integrated air defence system, exercising unified control over all air defences, active and passive. In its key sensors, and later in its command and control functions, the system relied increasingly upon audible, not visual, stimuli, to achieve highly effective results in the defeat of the unprecedented threat of homeland air attack in the First World War. Fundamentally the same system, enhanced with the non-visual sensor of radar, would be developed to achieve similar success in the Second World War, during the 1940 Battle of Britain; later in that conflict, the defences would successfully counter the challenge of high-speed robotic attack by integrated electro-mechanical defence, eliminating the human sensory and decision-taking functions as too slow. Overall, this paper argues that the story of UK air defence in these years is one of progression along a continuum from visual to non-visual means of early warning, target acquisition, and elimination of the threat.

Notes.

1. Fisher, *Airlift 1870.* The development of visually-aimed anti-aircraft artillery from rifle to specially mounted guns on 4-wheel waggons may be traced through pp. 21, 45, 49, 55, 65, to 82-84, where observation posts are linked by non-visual telegraph.
2. Slingo, *Engineering Department*, POST 30/4304A.
3. White, 'Pawn in the Game', pp. 105-111, 194 – 201, 265 – 270, 325 – 9, 376 – 381, 442 – 6, 514 – 8, 574 – 8, 636 – 641, 699 – 704, 760 – 6.
4. Raleigh, *War in the Air*, pp 180-2 on the views of Captain Sueter and Mr O'Gorman in their report to the Technical Sub-Committee of the Committee on Imperial Defence, June 1912.
5. Robinson, *Zeppelin in Combat*, Appendices A & B.
6. 19/20 January 1915, by Zeppelin L4 (K-Lt von Platen-Hallermund); Robinson, *Zeppelin in Combat*, p.86; Cole and Cheesman, *Air Defence,* p.25; Ashmore, *Air Defence,* p.6.
7. Childers, *Riddle of the Sands*.
8. Jones, *War in the Air*, Vol. II, p.75; Ashmore, *Air Defence*, pp 3-4; Cole and Cheesman, *Air Defence,* pp. 56 – 9; Rawlinson, *Defence of London* Appendix, p.261.
9. Massingberd, *Obituaries*. Bentley Beauman
10. Baker, *History of the Marconi Company,* p.159.
11. Beesly, *Room 40,* Chapter 2, pp. 8-20.
12. Bruton, *Hippisley Hut*.
13. Beesly, *Room 40,* pp. 3-4, 25-6.; Matthews, *SIGINT*, p. 92.
14. Beesly, *Room 40,* pp. 4-6, 22-5; Matthews, *SIGINT*, pp. 92-3.
15. Matthews, *SIGINT*, p.93; Beesly, *Room 40*, p. 27.
16. Round, Direction and position finding, pp. 224-247.
17. Sockett, Stockton on Tees Y Station, pp. 51-60.
18. Gannon, *Inside Room 40,* pp.232-3.
19. Robinson, pp. 84 – 88; Cole and Cheesman, *Air Defence,* pp. 24 – 28 on the British response.
20. Robinson, pp. 95 – 6; Cole and Cheesman, *Air Defence,* pp. 56 – 9.

21. Rawlinson, *Defence of London* Chapter II, pp. 20 – 32.
22. Ibid., pp. 23-4.
23. Castle, *London 1914 – 17*, pp 40 – 46; casualty figures p.43.
24. Cole and Cheesman, *Air Defence,* Chapter V; Ashmore, *Air Defence*, p.12 and Appendix.
25. Rawlinson, *Defence of London*, op. cit., p.161.
26. Cole and Cheesman, *Air Defence,* pp. 42-3; Ashmore, *Air Defence,* p.18.
27. Cole and Cheesman, *Air Defence,* p. 95.
28. Board of Invention and Research: *Organisation*, ADM 212/158.
29. Scarth, *Echoes*, pp.16-9.
30. Ibid.,, p.19.
31. Sockett, Yorkshire's Early Warning System, pp.181 – 188.
32. Rawlinson, *Defence of London,* pp. 108 – 114.
33. Jones, *War in the Air*, Vol. III, pp. 222-226; Ashmore, *Air Defence* p. 23; Cole and Cheesman, *Air Defence,* pp. 161-166.
34. Robinson, *Zeppelin in Combat,* p.210 and Chapter XV, 'Caution is Ordered'.
35. Round, Direction and position finding.
36. Ashmore, *Air Defence,* p. 33.
37. Cole and Cheesman, *Air Defence,* p. 213; Ashmore, *Air Defence*, p. 34; Jones, *War in the Air*, Vol. V, pp. 36-8.
38. Ashmore, *Air Defence*, p. 31.
39. Ibid, pp. 45-6 and Chapter V 'Night Aeroplanes 1917'.
40. Ibid., p. 41; Cole and Cheesman, *Air Defence,* pp. 219 – 221.
41. Ferris, *Airbandit*, p.44.
42. Rose, Radar and Air Defence, pp.225-6.
43. Cole and Cheesman, *Air Defence,* p.291.
44. Ashmore, *Air Defence,* pp. 92-4.
45. Ibid., p. 74; Cole and Cheesman, *Air Defence*, pp. 352 – 361.
46. Scarth, *Echoes*, p.22.
47. Ashmore, *Air Defence*, p.84.
48. Ibid., p.92.
49. Ibd., pp. 86-90; Ashmore papers 66/75/1.
50. Air Ministry, *History of wireless telegraphy*, p.212
51. Ferris, *Airbandit*, p.60.

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