Two Influential British World War 2 Technologies

Aram Soultanian

London HUA 2900

Dr. David Spanagel & Esther Boucher-Yip

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Introduction

When fighting a war, technology can provide one of the greatest advantages the military can possess. A country's ability to produce more advanced technologies and determine whether or not their technologies have been compromised is probably the difference between winning and losing. Every year, the United States spends billions of dollars developing and building stealth technologies used in state-of-the-art fighter jets and helicopters. The fifth generation F-35 Lightning II and F-22 Raptor have the RADAR Cross Section comparable in size to a golf ball and bumble bee respectively.[1] This makes these fighter jets virtually impossible to detect until it is far too late, and the plane has passed with its payload dropped.

The concept of stealth planes came from the development of RADAR systems in World War II. Today, not a single F-35 or F-22 has been shot down in combat or in air-to-air exercise and will likely not for another 5-10 years.[2] Additionally, the paranoia surrounding encryption began after Alan Turing and a group of codebreakers developed a machine to discover the exact setup of Enigma machines used by the German Navy. Military and private companies alike are prioritizing data security to ensure their data is only accessible to those authorized. The ability to know precisely when an enemy will attack allows preemptive safety measures such as evacuation and coordination of counter attacks, thus reducing the number of casualties. Therefore, developing war technologies are ultimately designed to save the lives of soldiers and civilians.

The scope of this paper is limited to the discussion of new technological breakthroughs influential to Great Britain's success in World War II: RADAR and Bombe. This paper discusses

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[1] Maj Gen Jeff Harrigian and Col Max Marosko, USAF, Fifth Generation Air Combat: Maintaining the Joint Force Advantage, *The Mitchell Forum*, 2016.
[2] Maj Gen Jeff Harrigian and Col Max Marosko, USAF, Fifth Generation Air Combat: Maintaining the Joint Force Advantage, *The Mitchell Forum*, 2016.

how the technological breakthroughs changed the way war was fought and that these technologies are far more important to society than just their impact on World War II. It is argued that these technologies stopped Great Britain from defeat against Germany's larger and more powerful military. Undoubtedly, without either of these technologies, many more lives would have been lost and the United Kingdom's aftermath certainly would not have been the same.

Beginnings of RADAR

In 1886, Heinrich Hertz observed that radio waves reflected off metal surfaces. Based on this principle, Christian Hulsmeyer in 1904 and L.S. Alder in 1928 performed advanced research on radio detection and location devices.[3] Christian Hulsmeyer received a patent for a radio wave transmission device that could detect objects and collision warnings on maritime vessels, but he never developed it.[4] Similarly, L.S. Alder of the Royal Naval Signal School applied for a patent based on "employment of the reflection, scattering, or re-radiation of wireless waves by objects as a means of detecting the presence of such objects," but was abandoned by the Admiralty Signals Department.[5] Radio wave transmission did not spark the interest of the Royal Navy until 1935 when the thought of world war was beginning to become a reality. Quickly understanding the potential of an enemy-aircraft locating device, the military concealed their development for security purposes and was tagged as Radio Direction Finding (RDF). RDF was coined by Sir Robert Watson-Watt and stood for Radio Direction Finding or Ranging and Direction Finding, but the second of the two was too descriptive whereas the first maintained secrecy and confusion unless one had the proper security clearance.[6]

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[3] Patrick A. Moore, *The Greenie: The History of Warfare Technology in the Royal Navy* (Stroud: Spellmount, 2011), 62.
[4] Moore, 62.
[5] Moore, 62.
[6] Moore, 273.

RDF worked by transmitting a high frequency radio wave energy from an original source. Any object in the transmission wave path would reflect part of the illuminating energy back to the source. The original detection provided a bearing and calculating the interval of time between each detection established the targets range. In February of 1935, Robert Watson-Watt demonstrated this reflection principle with the Daventry Experiment.[7] A description of the experiment by Patrick Moore explains, "This demonstration involved a Heyford Bomber aircraft flying into the beam of the BBC's shortwave (6 MHz) transmitter at Daventry and detecting the presence of reflection waves from the aircraft as an echo in a receiver eight miles away; the receiver was designed by Watson-Watt. The success of this demonstration secured initial funding from the Air Ministry for RADAR development work."[8] The Daventry Experiment was crucial to RADAR's later success. It fully demonstrated that reflected radio waves could be detected. Robert Watson-Watt grandfathered the fundamentals of RADAR technology which resulted in the crucial research that discovered how to find the distance, elevation and bearing of enemy aircraft and later submarine.

Royal Navy RADAR

Although the results of the Daventry Experiment were initially promising, the Royal Navy limited its funding and resources. Such restriction meant a slow developmental process and produced RDF equipment designed to run at a frequency of 75MHz. 75MHz had a wavelength of 4 meters, at the time, believed to be the largest acceptable wave to ensure the size of aircraft and still be sensible for fitting to major warships at least the size of cruisers.[9] To the dismay of the Royal Navy, test trials results were poor. The RDF system was capable of detecting aircraft and range, but it failed to measure the target bearing or elevation. Pressured by the Controller of the

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[7] Moore, 63.
[8] Moore, 64.
[9] Moore, 65.

Royal Navy to identify the naval applications for RDF technology, the 75MHz system was equipped to HMS *Saltburn* minesweeper in 1936.[10] Designated Type 79X, it utilized a simple array suspended between the masts of the ship which during trial detected aircraft elevation at 5000 ft and range of 17 miles but still no target bearing.[11] The disappointing results showed current valve technology at the time was not strong enough to produce sufficient transmission power at 75MHz. As a result, the Royal Navy switched the frequency to 40 MHz, a larger and lower power wave. The success of the new Type 79X meant two more exact copies, dubbed Type 79Y, were installed in HMS *Sheffield* and HMS *Rodney*.[12] With results better than expected during trials of the Type 79Y on the *Sheffield*, the RADAR system showed its capability to detect aircraft at 10,000 feet at a range of 53 miles, reducing to 30 miles at 3000 feet.[13] Such success led to subsequent funding and research. 40 production Type 79Y's joined the fleet starting in 1940.

Naval Staff's eagerness to utilize RADAR for precise range finding and, therefore, replace optical rangefinders, resulted in the combination of the Navy's Type 79Y and Army's Type 279 capable of displaying precision range and bearing. This combination was extremely labor intensive and difficult to use, so the demand for a universal RADAR device that could also be fitted to smaller vessels was high. Using new silica valve technology, capable of 1000 kW of power, and a frequency of 85MHz (3.5m wavelength), a new prototype Type 281 this time incorporated an electric motor operated aerial rotating system.[14] The Type 281 came just in time to detect and track the first German air raid over Portsmouth on July 11, 1940.[15] Its early success led to the

[10] Moore, 65.
[11] Moore, 65.
[12] Moore, 66.
[13] Moore, 110.
[14] Moore, 113.
[15] Moore, 114.

implementation of 36 Type 281’s all across the fleet by the end of 1940.[16] The continued success of RADAR meant hundreds of different models produced throughout the war. Each system either improved on the previous model or was newly developed for a new task.

The Royal Navy was the first to invest and believe in the potential abilities of RADAR. Quickly realizing just how RADAR could change the scales of war for maritime battle, proving to be a vital resource during the Battle of the Atlantic. Having sparked the interest of other military divisions, the Royal Navy invested more money and resources into RADAR technology. The funding and resources supported the development of larger, more powerful systems that would eventually lead to RADAR systems incredibly powerful for their size. This advancement opened a new world of opportunities including saving the lives of hundreds of thousands of Britons.

Chain Home and Battle of Britain

Built by the Royal Air Force, Chain Home was the codename for an early warning RADAR system.[17] In the late 1930’s, rumors spread of Germany claiming to have an air force similar in strength to the Royal Air Force. Upon further investigation, it became clear that Germany’s air force was not just similar in size, but it was larger and more modern as well. Britain quickly realized that it had very little chance of overtaking Germany, urging Britain to develop a home defense system against aerial attack.[18] Initial construction started in 1937 and became fully operational by 1938. The first five Chain Home RADAR stations began surrounding the southeastern coast. CH, as it was commonly known, was the first operational early warning RADAR system in the world. By 1939, Britain expanded CH to 18 stations, so that its RADAR

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16 Moore, 115.
17 "The prototype CH system – 1939… Chain, Home… Operational". Bournemouth University. 1995–2009
18 E G Bowen, *Radar Days* (Bristol: Adam Hilger, 1987), 26.

covered the entire east coast and half of the south coast.[19] CH bought enough time for the Royal Air Force planes to scramble into the air and cut off any impending raid before it even started. In 1940, Germany had just defeated France and the only European power not in their control was Great Britain. Planning to launch a full land invasion on Britain's coast, Hitler knew he must first take out the Royal Navy and gain control of the English Channel.[20] With an arsenal of 2400 fighter planes and an undefeated Luftwaffe (German military aerial force), in comparison to the abysmal 900 fighters the Royal Air Force had, taking air superiority and destroying coastal defenses seemed extremely possible.[21]

Chain Home worked as intended and allowed Britain to gain a significant advantage over Germany. Knowing the size of the raid, elevation, range and bearing, the RAF reduced casualties and fuel usage as well as prevented bombers from reaching their targets. The German's inferior planes were not armed nor protected enough, causing heavy casualties and leading to only night bombing runs. At one point the Germans bombed London for 57 consecutive nights during the end of 1940, referred to as "The Blitz". To Germany's surprise, even at night, the RAF heavily attacked the German's planes. The Battle of Britain was won by the success of the Chain Home system. Commander-in-Chief, Lord Douglas said, "I think we can say that the Battle of Britain might never have been won. . . if it were not for the RADAR chain." [22] For the first time during the World War II, Britain had the upper hand on Germany. After the war, overall commander of the German attack on Britain during the Battle of Britain, General Galland, revealed at the end of the war,

"the British had, from the first an extraordinary advantage, never to be balanced out at any time in the whole war; their RADAR and fighter-control network. It was for us and for our

[19] S.S. Swords, *Technical history of the beginnings of RADAR* (London: Peter Peregrinus Ltd, 1986)
[20] Barrett, Dick. 2018. "The Radar Pages - Chain Home". Radarpages.Co.Uk.
[21] "Chain Home - Engineering And Technology History Wiki". 2018. Ethw.Org.
[22] E G Bowen, *Radar Days* (Bristol: Adam Hilger, 1987), 28.

leadership a freely expressed surprise, and at that a very bitter one, that Britain had at its disposal a close-meshed RADAR system, obviously carried to the highest level of current technique, which supplied the British Fighter Command with the most complete basis for direction imaginable. . . We had nothing like it. . ."[23]

Each station required four 360 ft tall masts, each 180 feet apart. Strung across horizontally were antenna wires emitting a frequency typically between 10 and 20 MHz with wavelengths ranging between 30 and 15 meters.[24] The transmission towers did not read the return signal, instead four separate 240 ft structures received the data**.** The CH steel antenna tower had a small angle of 1.5° which meant a plane flying low to the ground would not have been picked up until it was just a few miles away; far too late to scramble fighters.[25] At the time, low elevation aircraft posed little treat as bombers usually flew around 15000 feet. Germany realized that it could avoid CH RADAR by flying below 10000 feet at 50 miles away and could continue to avoid CH RADAR by dropping below 5000 feet at a range of 25 miles.[26] Germany was able to evade the CH RADAR until Chain Home Low (CHL) was developed in 1939 which could detect any plane flying above 500 feet.[27] By 1941, Britain had or planned to have 42 CH stations and 52 CHL stations, but German pilots discovered that by flying just 100 feet above the ground, they could avoid all RADAR. Later in 1942, Chain Home Extra Low (CHEL) emerged and could detect any plane above 50 feet, but at a much shorter range of about 30 miles.[28] CHEL came directly from the research and development on centimeter wavelength RADAR. Without Chain Home RADAR, London, certainly would have fallen and give rise to German invasion.

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[23] Bowen, 28.
[24] "Chain Home - Engineering And Technology History". 2018. Ethw.Org.
[25] "Chain Home - Engineering And Technology History". 2018. Ethw.Org..
[26] Barrett, Dick. 2018. "The Radar Pages - Chain Home". Radarpages.Co.Uk.
[27] Barrett, Dick. 2018. "The CHL (Chain Home Low) Air Defense Radar System". Radarpages.Co.Uk.
[28] Barrett, Dick. 2018. "The Radar Pages - Chain Home". Radarpages.Co.Uk.

Cavity Magnetron and Tizard Mission

Although Chain Home and existing radio technology were enough to fight German aerial assault during the Battle of Britain, it became obvious that RADAR performance needed to be improved. In 1939, Sir Henry Tizard organized a group of scientists to be given an in-depth view of the secrets of early Chain Home systems. The scientists determined that a small high-powered source capable of emitting ultra-high frequency radio wave was necessary. The Royal Navy requested a team to be formed by Professor Mark Oliphant to produce a radio wave generator able to transmit radio wavelengths of 10 cm.[29] While most worked on an electron tube microwave generator, John Randall and Harry Boot focused on magnetrons. Using ideas from Hertz single wire loop resonators, they formed the idea of incorporating cavity resonant circuits built directly into the magnetron.[30] Using a machined circular block of copper with six holes radially around a 1 cm central cavity in line with a tungsten wire cathode, a loop of wire was wrapped through one of the holes and through the copper to a glass vacuum sealed shell. On February 21, 1940 the cavity magnetron was tested in the magnetic field of a laboratory grade electromagnet, and the power generated was almost unbelievable.[31] With the help of Dr. E.C.S. Megaw from G.E.C. Laboratories in Wembley, they created the first real world prototype using a sealed off body and a lightweight permanent magnet, instead of demountable seals, vacuum pumps and electromagnet required for Randall and Boot’s lab device.[32] Their new design improved upon Randall and Boot’s initial concept build but still lacked consistent power outputs.

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[29] Stephen Phelps, *The Tizard Mission* (Yardley: Westholme Publishing, 2012), 99.
[30] Phelps, 101.
[31] Phelps, 102.
[32] Phelps, 99.

The first production cavity magnetrons produced 10kW of peak-pulsed power at 10 cm wavelength, like requested by the navy, rapidly giving way to advancing research towards smaller, more powerful devices and even shorter wavelengths. James Sayers and his team of researchers in 1941 created a way of fixing the common unstable outputs when pushed to higher powers. They used what would be known as strapping, to tie alternating hole segments instead of adjacent with copper wire to prevent mode changing. Evidently, not only did strapping improve the stability, but it also improved the efficiency and power output by over 50%, leading to 10 cm cavity magnetrons with 1 MW of peak power by 1941.[33] At the time, no electrical vacuum tube RADAR system could produce peak power in such a small package. Cavity magnetrons quickly became the favored generator of very high frequency radio waves in RADAR and communication devices. Even though significant research was being conducted in Britain on the cavity magnetron, much of the success proved pivotal to the war efforts were discovered by United States researchers after the Tizard Mission.

In 1940, Tizard realized that Britain's capacity to manufacture electrons vital to their war effort was quickly plateauing. Tizard recommended that Britain trade classified war technologies with the United States in exchange for America's manufacturing. Winston Churchill met with Franklin D. Roosevelt in August of 1940 at Savoy Hill House, once the Ministry of Defense building, now the Institute of Engineering and Technology headquarters. At the meeting Churchill brought a briefcase containing Britain's greatest war-time secrets, detailing rocket engines, rockets, RADAR and most importantly, the cavity magnetron. Later, in the United States, a group of American and British scientists as well as military officials toured American laboratories that were conducting research on microwaves. The group saw the most advanced microwave

[33] Phelps, 108.

technology America had, but a British live demonstration showed off the remarkable capability of the magnetron. As Bowen explains,

> "Briefly, we learned that there was a good deal of work on transmitting and receiving tubes at wavelengths around 40 to 50 centimetres *[sic]* which appeared to be well in advance of British work. At wavelengths around 10 centimeters, the Bell Telephone Laboratory and GE Schenectady had much to offer in receiver technology, while MIT, Stanford and the Bell Laboratory were well advanced with waveguides and horns on this wavelength. However, there was nothing, even in embryo, which matched the British resonant magnetron. We quietly produced the magnetron and those present at the meeting were shaken to learn that it could produce a full 10 kilowatts of pulsed power at a wavelength of 10 centimetres."[34]

Based on the monumental success of the demonstration, the Microwave Committee decided to manufacture the magnetron at Bell Laboratory. The development of the cavity magnetron in the United States allowed for new war aiding technologies not possible with vacuum tube RADAR.

Plan Position Indicator (PPI) displayed on a cathode ray tube screen were now consistently picking up all aircraft in range, both enemy and friendly. Thus, the need for a device to display friendly and enemy aircraft was crucial. The beginnings of secondary RADAR began with Identification Friend or Foe (IFF). IFF was a small transmitter and receiver mounted inside the fuselage of British aircraft detected radio waves. When the receiver inside the aircraft sensed the radiowaves transmitted from a ground location, it read, amplified and retransmitted the signal back, causing friendly fighters to flash on screen. Any non-flashing aircraft were automatically

[34] Bowen, 74.

thought to be enemies.[35] PPI clarified the battlefield reducing the likelihood of confusing friendly fighters for enemies, especially during inclement weather.

Advancements in radio technology created stronger and smaller RADAR systems. CH systems from land could only give pilots limited information regarding the location, altitude and direction by radio communication. For this reason, new Air Intercept RADAR technology allowed Britain to shrink RADAR units and fit them into aircraft, allowing pilots to actively track down enemy aircraft based on their own location.[36] This new technology made its first appearance in a small number of coastal aircraft called Bristol Blenheim If, as AI Mk.I, in May of 1940.[37] Continued developments of AI RADAR resulted in the AI Mk.IV installed on the Beaufighter by September of 1940; just in time for the heavy German bombing runs over London.[38] AI gave enough information about the position and range of the target at night, to enable the Beaufighter to be maneuvered behind an enemy aircraft until visual contact permitted engagement. Air intercept RADAR instantly became a great success as it confused, dwindled, and ended Germany's quest to take over Great Britain. In fact, when news reporters asked how RAF fighters were able to track and take down German aircraft at night, intending to keep AI a nation secret, military officials responded by lying. Military officials claimed that their pilots were eating carrots which contained large amounts of Vitamin A thereby improving their night sight abilities.[39]

Germany's supply of planes dwindled, and Britain was far from defeat. Germany chose to back off in hopes of invading Russia. Between Germany, Great Britain and supporting ally

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[35] Bowen, 99.
[36] Bowen, 49.
[37] Siler, Stetson M. "The History of Air Intercepts (AI) Radar and the British Nightfighter, 1935-1959." Air Power History 55, no. 4 (Winter 2008). 67
[38] Siler, *"The History of Air Intercepts (AI) Radar and the British Nightfighter, 1935-1959."* Air Power History 55, no. 4 ,67
[39] Smith, K. Annabelle. "A WWII Propaganda Campaign Popularized the Myth That Carrots Help You See in the Dark." Smithsonian.com.

countries, 3721 planes were shot down in the span of only three months during the Battle of Britain.[40] This can be compared to the 4800 planes shot down in over 50 different wars and conflicts during the last 75 years since the end of World War 2 in 1945.[41] After the war, T.P. Baxter said speaking about cavity magnetron, “When the Tizard Mission brought one to America in 1940 they carried the most valuable cargo ever brought to our shores. It sparked the whole development of microwave RADAR and constituted the most important item in reverse Lease-Lend.”[42]

RADAR was responsible for Britain’s early war success, and it continued to aid Britain’s military for the remainder of the war. RADAR allowed Britain to react to attacks attempted by Germany and gave military officials a window of time during which they could make critical decisions before these potential attacks. During these early successes of RADAR, Britain had already started creating a new piece of technology that provided specifics about German attacks in order to decipher German Enigma.

Enigma

During World War II, messages encrypted by a machine called Enigma, communicated secret information to only those who possessed the correct encryption key. The Germans used several machines including the Lorenz SZ40 and Siemens Geheimschreiber whereas the British used a Type X machine.[43] Each machine could produce a variety of different ciphers, each thought to be totally secure to unauthorized decipherment without possessing the secret decoding instructions. Although it seemed impossible to decipher a message, captured instruction books,

[40] Moore, 246.
[41] Moore, 246.
[42] Sir Bernard Lovell, *Echoes of War: The Story of H2S Radar.* Bristol: Adam Hilger, 1991, 26.
[43] Andrew Hodges, *Alan Turing: The Enigma* (London: Burnett Books, 1983), 166.

operators' lack of care, and unrecognized flaws in the cipher system or by accident, allowed dedicated codebreakers to do the unthinkable and periodically crack the codes.

Early Enigma machines used a typewriter-like keyboard and a separate set of 26 letters. Behind the keyboard was a lamp board which would illuminate the letters from beneath. For each letter typed, the lamp board would illuminate, the two never being the same. The letter illuminated on the lamp board based on the keystroke was determined by the position of set of three rotors. Each rotor, almost gear like, had 26 teeth, one for each letter of the alphabet. Inside each rotor was a complex array of wires. After each key pressed had been enciphered, one of the rotors would mechanically shift 1/26 of a rotation, completely changing the circuit and thus the pattern between each key on the keyboard and its corresponding letter on the lamp board. Once 26 letters were enciphered, one complete revolution of the first rotor, the second rotor would slide 1/26 of a position. Since the position of the rotors continuously change, even repeated letters or common sets of letters such as "et" or "qu" would no longer appear in the same way or pattern.[44] For all three rotors to complete a full cycle and return to its starting position, a message would need to contain 26^3 (17576) different ciphers. No message would ever contain such a length and the cipher code would be changed after by moving the starting positions of each rotor.[45]

Recovering similar Enigma machines and reverse engineering the process, cryptologists were able to decipher intercepted messages at a realistic pace. Reversing the process required each of the three rotors to be in the exact same starting position as the original machine that enciphered the message. While each machine was given a code-book instructing how to change the settings each day, cryptologists used a more complicated method where an initial setup would be taken from the code book and a short message would be transmitted specifying the new starting points

[44] Hodges, 162.
[45] Hodges, 167.

for each wheel.[46] By trial and error, a codebreaker using an enigma machine was able to assess if a given combination of rotors gave a readable section of message in a span of 10 seconds, but it still took up to 48 hours to decipher the correct starting position. At that point, the majority of the information deciphered was moot, but still useful in understanding German war strategy and plans.

The Germans improved upon their three-rotor enigma machine by using a combination of any three code wheels, each with a different internal wiring, out of the five. There were five choices for the first rotor, four for the second and the for the last, thereby increasing the amount of possible combinations by 60 (5x4x3) to a total of 1,054,560 possible combinations.[47] Additionally, they added a plugboard to the front of the Enigma machine. The plugboard had 10 sets of wires, with 26 possible sockets, one for each letter.[48] When the two letters in the connection are paired, they switch adding an additional layer of security. The plugboard means that even if the three rotors of five are picked in the correct order and the starting positions are correct as well, all ten sets of wires would need to be in the correct sequence for a message to be properly deciphered.[49] The plugboard added the most number of additional combinations. The number of different possible ways to connect 26 letters is 26 factorial, but only 10 pairs were needed so six letters weren't needed, so six factorial could be divided. It also does not matter what order the connects are in, so an additional 10 factorial can be divided. Lastly, swapping two letters with itself also makes no difference and because there are 10 wires, 2^{10} can also be divided. Thus, the total number of combinations of the revised Enigma machine is 158,962,555,217,826,360,000 ($\frac{26!}{6! \times 10! \times 2^{10}} \times 1{,}054{,}560$), statistically impossible to guess and practically impossible to reverse engineer

[46] Hodges, 184.
[47] Hodges, 172.
[48] Hodges, 178.
[49] Hodges, 178.

without having the correct code books and processes by a human.[50] Regardless, Britain understood breaking Enigma could have colossal effects. Once Britain was able to decipher the secrets coming in and out of Germany, it would be able to determine the exact specifics of every impending attack and location of every German ship, army or plane, potentially saving the lives of thousands and ending the war.

Bletchley Park, Hut 8, Alan Turing and Breaking Enigma

As the second World War was imminent, the British government decided to evacuate the British cryptanalysts of the Government Code and Cipher School to Bletchley Park in the summer of 1939. Bletchley Park is a Victorian mansion in Buckinghamshire, 50 miles away from London. The group of codebreakers was under the command of naval officer, Commander Edward Travis. The increasing amount of German radio traffic showed Commander Travis and his early recruits that an enormous team of people would be required to assess and decode any information intercepted from German Enigma.[51] Britain sent radio operators around to various locations to listen and record German radio traffic, while Bletchley Park used Women's Royal Navy Service to decipher messages. The different buildings in Bletchley Park known as Huts, accommodated the thousands of codebreakers working on Enigma. The most important and well-known Huts were Hut 6 and Hut 8, which were dedicated to breaking German Naval Enigma. Eventually 10,000 people, all sworn to secrecy about their work known as Ultra, made up of clerks, engineers, mathematicians and intelligence experts worked at Bletchley Park. Over the course of World War II, Ultra would become one of the most important operations for Britain and the Ally powers, as it provided substantial sums of useful tactical information.

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[50] Hodges, 178.
[51] Sinclair McKay, *The Secret Life of Bletchley Park*, (London: Aurum Press Ltd, 2010), 21.

Initially Bletchley Park struggled to provide useful information in a timely fashion. Bletchley Park accumulated stacks of intercepted German radio communications but were unable to decipher the majority of messages. Deciphering each message by hand through brute force was proving to be very unsuccessful. Alan Turing, one of the greatest mathematicians at the time and possibly ever, headed Hut 8, tasked to break Naval Enigma. Turing was deeply intrigued by the complexity of Enigma and the idea of machines working like humans. He saw solving Enigma, not as a vital aid to nation security, but as a math problem no person believed could be solved. In 1936, Turing published a paper called Computable Numbers which outlined the basic theory for the modern computer.[52] Turing's early thought process has been described as follows:

> "The Turing Machine opened the door to a new branch of deterministic science. It was a model in which the most complex procedures could build out of the elementary bricks of the states and positions, readings and writing. It suggested a wonderful mathematical game, the of expression and 'definite method' whatever in a standard form. Alan had proved that there was no 'miraculous machine' that could solve all mathematical problems, but in the process he had discovered something almost equally miraculous, the idea of a universal machine that could take over the work of *any* machine. And he had argued that anything performed by a human computer could be done by a machine. So there could be a single machine which, by read the descriptions of other machines placed up its 'tape', could perform the equivalent of human mental activity. A single machine, to replace a human computer!" [53]

This quote shows Turing's belief in the connection between human and machine that would lead to the fundamentals behind Bombe, an electro-mechanical device used by British cryptologists to help decipher Enigma. Turing realized when solving Enigma, he could create a machine that uses the same processes as a human codebreaker on a larger scale, effectively combining the power of

[52] Hodges, 109.
[53] Hodges, 109.

multiple codebreakers into one machine. As a member of the British Delegation, in 1939 Turing visited Poland and was briefed by Polish Intelligence on the Polish Bomba, an early prewar encryption decoder that faced significant technical problems after Germany enhanced their Enigma machines.[54] Based on his learnings of the Polish Bomba, by the end of 1939, Turing already began developing an improved machine called Bombe.

Bombe itself was not a decoding device but rather a complex machine used to discover the Enigma's original settings. In the most basic terms, Bombe was an electro-mechanical collection of 36 Enigma machines wired in a complex circuit to reverse the settings of the original Enigma. Alan Turing and his team worked tirelessly, researching, uncovering and analyzing potential flaws within Enigma with the hopes to figure out how to instantly discover the original setup of the Enigma machine. They found an exploit in the plug board of the Enigma machine. Turing discovered a constant variable within the plug board, the part responsible for the majority of the Enigma machine's complexness. Hodges explains Turing's discovery exploiting the fact that,

> "only one plugboard, performing the same swapping operation on the letters going into the rotors as on the letter coming out. It also exploits the fact that this Particular illustrative 'crib' contains a special feature- a closed loop. . . Alan was able to embody this idea in the design of a new form of Bombe at the beginning of 1940. . . relays performed simple logical function such as adding and recognizing. It was now their (Hut 8) task to make relays perform the switching job required for the Bombe to 'recognise'[sic] the positions in which consistency appeared, and stop."[55]

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[54] Hodges, 181.
[55] Hodges, 181.

Turing's breakthrough was the first time a computer could make independent decisions based on relevant information. Once Bombe understood the pattern created by a single plugboard, could apply the reverse, stopping when the combination was solved.

Turing created the initial concept of the machine based on this exploit, but it was Gordon Welchman, a mathematician and codebreaker from Hut 6 who realized Turing was not fully exploiting Enigma's flaw.[56] "Welchman not only saw the possibility of improvement, but he also quickly solved the problem of how to incorporate the further implications into a mechanical process. This process required only a simple piece of electrical circuitry soon to be called the 'diagonal board.'"[57] The implications of Welchman's findings meant that Bombe no longer needed to search for loops, creating less and smaller 'cribs,' increasing the speed and efficiency of the machine.[58] Had the German Enigma machine incorporated a variety of interchangeable plugboards, similar to the rotors, Enigma would have been significantly harder to break as the Bombe would have needed to test the hundreds of billion billion combinations. Even so, Bombe struggled to break the code. The Daily Key sent by a German operator to the German fleet included the instructions of how to set up the machine for the day's messages.[59] Since the Daily Key changed almost daily, the new key needed to be solved before the next key change to make any messages received that day of use. Bombe still lacked the information to successfully break the code in a timely manner despite the concentrated efforts of Turing and his team of code breakers.

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[56] Hodges, 182.
[57] Hodges, 181.
[58] Hodges, 183.
[59] McKay, 42.

Battle of the Atlantic

The military desperately needed messages from the new code used in Germany's U-boats analyzed, putting increased pressure on Bletchley Park. Britain required millions of tons of imported resources and supplies from Ally countries every year to stay fighting. An account of the severity of Britain's resource crisis explains,

> "During the year after June 1940, U-boat sinkings were to deplete that stock by an average of 200,000 tons a month. This loss in capacity could just about be replaced. But anyone could see that a U-boat force just three times larger, enjoying a corresponding degree of success, would have a crippling effect both on the level of current supply, and on the total stock of shipping. Each U-boat was sinking more than twenty ships in its life-time, and there was no counter-strategy while the U-boat remained invisible."[60]

Without these resources, Britain would not have had the ability to continue fighting, which would have ended the fight against Germany. Bombe still relied on additional information provided by punch-card machines and code workers to reduce the amount of guessing and improve the conditions for more effective searching.[61] By looking at old messages from February and April, Britain discovered that the Germans were stationing weather-ships north of Iceland, and in the mid-Atlantic, transmitting weather reports in weather cypher using a German naval Enigma.[62] Executed raids on the weather vessels allowed Britain to cease the Enigma key's and code-books needed to decrypt current messages almost instantly for June 1941. Cipher material retrieved after boarding the U-110 U-boat, contained the making code-book for short-signaling reports and the

[60] Hodges, 181.
[61] Hodges, 185.
[62] Hodges, 200.

Navy's 'officer only' signal settings.[63] Bletchley Park critically needed more resources and staff but administrative delay slowed the process. Alan Turing, Gordon Welchman, and two others wrote directly to Prime Minister Winston Churchill, against protocol which prohibited an individual from going above their commanding officer. In secret and on their own initiative, the group,

> "Apart altogether from staff matters, there are a number of other directions in which it seems to us that we have met with unnecessary impediments. It would take too long to set these out in full, and we realise[*sic*] that some of the matters involved are controversial. The cumulative effect, however, has been to drive us to the conviction that the importance of the work is not being impressed with sufficient force upon those outside authorities with whom we have to deal. . . But if we are to do our job as well as it could and should be done it is absolutely vital that our wants, small as they are, should be promptly attended to. We have felt that we should failing in our duty if we did not draw your attention to the facts and to the effects which they are having and must continue to have on our work, unless immediate action is taken."[64]

After reading the letter, Churchill turned to his principal staff officer, General Ismay, and stated, "make sure they have all they want on extreme priority and report to me that this has been done."[65] The supplies authorized by Churchill enabled Britain to reroute supply ships, avoiding German U-boats and giving them a safe travel to Britain.

The additional resources and new information gathered from U-boats and weather vessels came with an unseen issue that almost entirely ruined the work on Bombe and everything and

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[63] Hodges, 200.
[64] Alan Turing, Gordon Welchman, Hugh Alexander, and Stuart Milner-Barry to Winston Churchill. October 21, 1941.
[65] Hodges, 279.

breaking Enigma. The potential threat German U-boats posed meant Britain did not just want to avoid them but wanted to destroy the ships entirely. Knowing the location of each ship sent by Germany to destroy supply ships destined for Britain, gave the Royal Navy the necessary information to cut off and destroy them. In one occurrence, Britain cut off and destroyed seven of the eight German battleships. Britain greatly overlooked the fact that knowing the location of all of Germany's ships and destroying them in one foul swoop when previously, Britain lacked the knowledge of any German ship's location would cause suspicion.[66] Luckily, Germany still believed that it was impossible to break Enigma, compromising their radio communication, and blamed the information leading to the location of their ships and subsequent attack on British Intelligence.[67] Had Germany known that Enigma was no longer secure, as Britain had managed to decrypt the messages, all Enigma communication would have likely been cut off or improved to make security significantly greater. Britain realized it could no longer exploit such information within the decrypted messages so easily. They first had to think about the potential effects, which often resulted in zero changes as it would be too risky if Germany found out.[68]

Analysis of Technologies

There is no doubt that the RADAR and Bombe technologies comprehensively influenced Britain's contribution to World War II. It is likely that Britain would not have survived as long as it did against Germany and millions more lives would have been lost if RADAR did not give Britain warning of impending attacks or Bombe could not decipher intercepted Enigma messages. Specifically, Bombe's ability to recognize Enigma patterns based on gathered information saved Britain during the Battle of the Atlantic. During the Battle of Britain alone, pilots and ground-

[66] Hodges, 201.
[67] Hodges, 201.
[68] Hodges, 201.

forces shot down 3,721 total planes within these three months.[69] In comparison, militaries shot down 4,800 planes in over 50 different wars and conflicts during the last 75 years or since the end of World War 2 in 1945. Not relying on a pilot's ability to fly in hostile situations while simultaneously having to keep track of all enemies actively trying to kill them due to AI RADAR meant that pilots could focus more of their attention to maneuvering and attacking enemy targets. Additionally, aircraft after World War II were able to detect enemy aircraft long before they were in visual range. This meant that pilots had the ability to decide whether or not to engage, and if so, they could plan formations and strategies far in advance allowing for more preparation and less chance of a life-ending mistake.

Clearly, Britain would not have lasted the Battle of Britain if not for Britain's various forms of RADAR. The Naval, Chain Home, and Air Intercept RADAR each gave Britain the necessary military advantage needed to defend its country. Without RADAR, Britain would have had no way of detecting impending attack other than with the eyes of their spotters limited by visibility. By the time German planes would have been in sight, it would have been far too late to evacuate civilians, prepare for attack and launch a counter assault. The lives of hundreds of thousands of Britons could have been lost. Additionally, not only could hundreds of British aircraft have been destroyed, but hundreds of German aircraft would not have been destroyed. Not only did Britain defend its country, but it also significantly weakened Germany's air arsenal and resources which could have been used to attack various other Ally countries. Had the Battle of Britain been lost in 1940, Alan Turing and the work being done at Bletchley Park to contribute to deciphering Enigma would not have been successful. To reiterate, if the Battle of Britain was lost, Alan Turing would not have the opportunity to break Enigma as the Battle of Britain ended before Enigma was

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[69] "The Battle of Britain- Aftermath", Ministry for Culture and Heritage, *New Zealand History (Government Website)*, 2012.

cracked. If Alan Turing had not deciphered Enigma, or his marvel was leaked to Germany, resulting in a full cease of use or complete redesign of Enigma, it would have likely changed the course of World War II for the Allied forces.

One possibility of a war and world changing event is discussed by Jack Copeland, professor of philosophy at University of Canterbury, New Zealand, and is the idea of the United States, "dropping of a nuclear weapon on Berlin [instead of Japan]." [70] By the time the United States had a working version of the Atom bomb, Germany had already surrendered just a few months prior. Although true, it is overlooked that many historians argue that Alan Turing's breaking of the Enigma machine shortened the war by two or three years and saved the lives of 14 to 21 million people.[71] With this in mind, Britain and America would not have known the decisions transmitted in and out of Berlin from Germany's top military leaders similar to that of Japan. Thus, Germany's unpredictability would have posed a larger threat similar to Japan.[72] For this reason, it is possible that the United States could have dropped one nuclear bomb on Japan and another on Berlin, significantly changing the outcome of World War II and the world as we know it today.

Conclusion

It is clear that Britain's RADAR and Bombe technologies were instrumental in Great Britain's success against Germany's larger and more powerful military during World War 2. While each technology was a breakthrough in its own right, neither technology without the other would have produced even remotely similar results, as the two technologies heavily relied on the success of the other. For this reason, I cannot confidently determine one technology as more influential as

[70] Jack Copeland. "Alan Turing: The codebreaker who saved 'millions of lives'." *British Broadcasting Corporation*, 2012.
[71] Jack Copeland. "Alan Turing: The codebreaker who saved 'millions of lives'." *British Broadcasting Corporation*, 2012.
[72] E G Bowen, *Radar Days* (Bristol: Adam Hilger, 1987), 165.

the other. Since neither would have been particularly successful without the other, making it fair to say RADAR and Bombe were equally important to Britain’s success in World War II. But beyond Britain and World War II, the world has benefited from the work Alan Turing- father of computers- published based on his obsession to create machines that think like and resemble humans. Furthermore, the development of RADAR in Britain and the United States from the Tizard Mission is far bigger than just its effects on World War II.

Initially, I believed that after my research, I would have a clear answer as to which was more influential to Britain during World War II. Now I have realized that these two technologies have far greater importance to our everyday lives, than just their effects in World War II. It is difficult to imagine what life today would be like without AI computers doing what humans cannot or RADAR ensuring safe aircraft travel or even daily weather reports.

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World War Two began in September 1939 when Britain and France declared war on Germany following Germanyâ€™s invasion of Poland. Although the outbreak of war was triggered by Germanyâ€™s invasion of Poland, the causes of World War 2 are more complex.Â In 1936 Hitler ordered German troops to enter the Rhineland. At this point the German army was not very strong and could have been easily defeated. Yet neither France nor Britain was prepared to start another war. Hitler also made two important alliances during 1936. The first was called the Rome-Berlin Axis Pact and allied Hitlerâ€™s Germany with Mussoliniâ€™s Italy. The second was called the Anti-Comitern Pact and allied Germany with Japan. World War Two was a time when huge advances were made in medicine and these medical advances were a direct response to new weaponry that had been developed betw.Â War, by producing so many and such appalling casualties, and by creating such widespread conditions in which disease can flourish, confronted the medical profession with an enormous challenge â€“ and the doctors of the world rose to the challenge of the last war magnificently.â€Brian J Ford. The very nature of warfare between 1939 and 1945 forced the medical world to rush forward the pace of advance in medicine. World War Two was historyâ€™s biggest conflict. To help guide you through some of the major events involved we have compiled a list of 100 facts across ten pertinent topic areas. Whilst far from comprehensive, this provides a great starting point from which to explore the conflict and its world-altering ramifications. Build-up to World War Two. 1. Nazi Germany engaged in a rapid process of rearmament through the 1930s. They forged alliances and psychologically prepared the nation for war. 2. Britain and France remained committed to appeasement. This was despite some internal dissent, in the face