# The History of the Twentieth Century
## Episode 327
## "Radio Detection and Ranging"
### Transcript

[music: Fanfare]

In 1932, British Conservative Leader Stanley Baldwin famously declared, "The bomber will always get through," and indeed, the conventional wisdom of the time was that bombers flew so fast that by the time you spotted one coming, there would be no time to alert fighter aircraft to take off and intercept it.

But what if you could see them coming when they were still a hundred miles away?

Welcome to *The History of the Twentieth Century.*

[music: Opening War Theme]

Episode 327. Radio Detection and Ranging.

The First World War had been a nightmare for everyone. The woes of military planners and strategists might not count for much in comparison to the soldiers in the trenches, but it was a difficult time for them as well. Those people spent years looking for a way to break the trench-warfare stalemate on the Western Front. By the end of the war, new tactics that incorporated new technologies and new modes of fighting began to show the way toward breaking the deadlock.

Airplanes were a part of those tactics. Airplanes could do detailed reconnaissance of enemy positions, which allowed for precision artillery strikes that helped weaken the enemy's defenses. Aerial reconnaissance led to aerial defense: fighter planes meant to shoot down the enemy's reconnaissance flights. Airplanes got better as the war went along. They became capable of flying higher, faster, and over longer ranges.

These new capabilities introduced the prospect of dropping bombs from airplanes. By the end of the First World War, the first purpose-built bombers were in use, although the capabilities of these early models were still quite limited. They had a range of maybe 400 kilometers and could carry a few hundred kilograms' worth of bombs. I'm putting out these figures in metric because I sometimes get complaints from listeners outside the US that imperial units are confusing, and I fully understand. For my American listeners, that would be about 700 pounds of bombs and a range of about 250 miles.

These early bombers could not fly very high or very fast, weighed down as they were, which made them easy targets for enemy fighters. Even if there were no enemy fighters to contend with, their range limitations meant they were only capable of what we today call tactical airpower.

Tactical airpower involves the use of airplanes as an adjunct to ground warfare. The most common and obvious example is what today we call close air support, meaning airplanes drop bombs on the same enemy ground units that the army is attacking, something like flying artillery. A little imagination can lead you to more creative ways to use your bombers, such as attacking enemy artillery positions so they can't shell your forces, or bombing roads and bridges to hamper the movement of enemy ground units or interrupt their supplies.

The low capacity and high vulnerability of bombers in 1918 meant that their contributions to the war effort were minor and their potential little more than a pipe dream. But aircraft technology improved drastically between 1919 and 1939. I talked about this last week and in earlier episodes, particularly episode 284. Recall that by the 1930s, commercial passenger air travel was becoming a reality. Although airliners of the time were uncomfortable and dangerous by our standards, they could carry twelve passengers over long distances, amounting to thousands of miles—or kilometers even—which was a marvel at the time.

Any aircraft that can do that could also carry bombs over long distances. This concept takes us out of the realm of tactical airpower and into the realm of strategic airpower. When we speak of strategic airpower, we are no longer speaking of airpower used in conjunction with ground forces; we are speaking of airplanes used on their own to achieve strategic objectives.

That's very technical language, but it comes down to a very simple point. Basically, the distinction between tactical and strategic airpower comes down to dropping bombs on enemy military units on or close to the front lines, versus dropping bombs on targets far to the rear, which will increasingly mean civilian targets, although not only civilian targets. It could also include such military targets as supply dumps, bases, airfields, or ships in port.

There was a great fear in the 1930s about the potential use of mass bombings of civilians as a tool of strategic warfare. Much of this fear can be traced back to the writings of an Italian general named Giulio Douhet. Douhet studied the use of Italian air power during the war against the Ottoman Empire, episode 66. He concluded that aerial bombing was the most effective use of airplanes in warfare. During the First World War, he became a vocal advocate for Italy building a fleet of bombers and using them to break the bloody stalemate with Austria, so vocal in fact that he was court-martialed and imprisoned for his criticism of Italian military leaders.

After the war, Douhet wrote a book on the use of strategic bombing in future wars, titled *Il dominio dell'aria, The Command of the Air.* In it, he argued that the static trenches of the past war would never be seen again, because of airplanes, which allowed attacks in the rear and rendered defensive lines obsolete. Not only the trenches, but the armies in them, no longer mattered, because airplanes could simply fly over them and bomb targets in their rear. The army might as well not even be there!

Once behind enemy lines, bombers could do the same kind of damage to a nation that an unopposed army could do: burn and sack and generally destroy the enemy country's ability to conduct a war. Bombers could destroy the enemy factories that equipped their military, as well as the railroads and ports that brought the equipment to the front lines. Bombers could destroy the communication lines that government and military leaders used to convey orders to the army; for that matter, they could destroy the government and military leaders themselves.

But more important than any of this, Douhet reasoned, bombers could inflict misery on the enemy's civilian population. Direct bombing of civilians would kill and injure some and lead the rest into terror and despair. The frantic civilians would then demand their own government end their suffering by capitulating; if the government refused, it would have a revolution on its hands.

Douhet later wrote a speculative novel describing a future war between Germany and France, in which a German bombing campaign forces French capitulation even before the French Army can be mobilized. Douhet would go on to speculate that in a future war, all that victory required was to defeat the enemy air force and achieve air superiority over the enemy country, because once the enemy leadership realized they could no longer prevent their cities from being bombed, they would surrender preemptively, as that would be the only way to avoid the coming rain of death and destruction. He calculated that as little as 300 tons of bombs, properly targeted, could force an opponent to surrender in a matter of weeks.

Now, I'll invite you to think back on our Great War episodes, and specifically the ones about submarine warfare. You'll recall I made the point then that before 1914, wars were generally fought by professional soldiers on battlefields at some remove from civilians. While civilians certainly had a stake in the war, and while civilians might well suffer from food shortages or diseases caused by the war, it was unusual and exceptional for civilians to be directly targeted by the enemy military, at least not in "civilized" Europe. (And I hope you heard those quotation marks.)

This is the reason why unrestricted submarine warfare against civilian ships was so appalling. Surface ships could and did capture enemy merchant ships, but it was standard procedure to demand surrender and take the crew of the ship prisoner before seizing it or sinking it. Submarines were too small to take prisoners, and for the most part too vulnerable to wait around for the crew of the enemy ship to evacuate, so they just fired torpedoes at the ship and sank it, and if civilians died, that was too bad.

It was only one side—the Central Powers—that was using these submarine tactics, so there was considerable propaganda value on the Allied side to play up the cruelty and inhumanity of sinking a ship like *Lusitania*, at the cost of hundreds of lives of innocent civilians who posed no threat to Germany, all for the sake of preventing a single shipment of arms from reaching a British port.

Given that people of the early twentieth century found that the sinking of passenger ships and merchant ships shocked the conscience, you might expect they would react with horror to the thought of the bombing of civilians far behind the front lines, and indeed they did. You'll recall I mentioned that world leaders of the 1930s thought about strategic bombing the way the next generation of leaders during the Cold War would think about nuclear weapons. There was no defense against them; all you could do was maintain your own offensive bombing capability as a deterrent and hope you'd never have to use it.

Douhet himself had no qualms about bombing innocent civilians, because in his calculus, the deaths of a few tens of thousands or hundreds of thousands today would end the war quickly and thus prevent another Great War, with the deaths of millions of soldiers on both sides. In a strange way, it would be a mercy.

For that matter, I imagine the U-boat commanders and their superiors who sent them out to sink Allied merchant vessels justified what they were doing in the same way. A few deaths today to shorten a war that otherwise will lead to many more killings.

Military arguments in favor of killing of a smaller number of people today in order to avoid the deaths of a greater number of people tomorrow will appear again and again in the twentieth century, and in fact you still hear them in our time. They are very convenient, because they allow military commanders to do things that would otherwise be considered unthinkable, and for that reason alone, they should be evaluated with a good deal of skepticism.

Other kinds of arguments that should be subjected to a good deal of skepticism are the ones that conclude strategic bombing can, by itself, win a war. There's a certain amount of careerism going on here. If the value of air units is primarily tactical; that is, as an adjunct to ground forces in the same way as say, artillery units, well, that is an argument for subordinating your air forces to the commanders of your army. The army plans and executes the battles, and the army should be able to order the air forces to attack when and where the army needs them as part of the larger plan, just as army commanders tell artillery units when and where to fire their guns.

If, on the other hand, an air force is capable of executing a strategic operation by itself, if it can defeat or cripple an enemy entirely by strategic bombing independent of the army, that is an argument for organizing your air force as a separate service branch, independent of the army, not having to take orders from the army, not being subordinated to the army. We've already seen one example of this. When Hermann Göring, the commander of the Luftwaffe, told Adolf Hitler that the Luftwaffe alone could destroy the Allied forces trapped in the pocket at Dunkirk without the need to send in the army, he was effectively telling Hitler that the Luftwaffe was and should be a separate force, capable of executing its own missions, without having to subordinate to the Army, and that he, Hermann Göring, should retain full control over the Luftwaffe and not have to share it with the Army.

It will be a military fact of life in the twentieth century that air force commanders will always stress missions that their air force can conduct independently, and that in turn means they will all, to one degree or another, embrace Giulio Douhet's theories about how air power alone can win a war, or at least deliver a decisive blow against an enemy, independent of land or sea operations.

Douhet died in 1930, at the age of 60, too soon to see his theory put to the test, but his ideas were well known and much discussed by the commanders of air forces in many countries.

With the benefit of historical hindsight, we can see that Douhet's argument rests on three assumptions about strategic bombing. Number one: that attacking bombers have a very good chance of getting through to their targets unopposed. Number two: that attacking bombers can deliver their bombs to their targets with a high degree of accuracy. Number three: that the sustained suffering a bombing campaign would inflict on the civilian population would break enemy morale and force capitulation.

These assumptions all sounded plausible in the 1930s. The Second World War would convincingly demonstrate that none of them, none of them, are correct. I'm going to set aside discussion of the second and third assumptions for a future episode and today focus on the first one.

Of Douhet's three assumptions, this first one seemed the most plausible in 1930. How exactly are fighter pilots defending their homeland supposed to locate, intercept, and shoot down enemy bombers before those bombers reach their targets and drop their bombs? Bomber planes of this era were not as maneuverable as fighters by any means, but they were almost as fast and were capable of flying at altitudes as high as ten kilometers, or six miles. Imagine the challenge of spotting one bomber, or even a group of bombers, flying at that altitude, then determining their probable destination, then communicating that information to fighter pilots on the ground, who now had to drop whatever they were doing, get into their fighters, take off, climb to the bombers' altitude, and rendezvous over the target before the bombers get there.

Military strategists of the time analyzed that scenario and concluded that fighter planes simply would not be able to do all this. At best, they might get in a few quick shots before the bombs began to fall. That was their public position, and that's what most strategists and political leaders believed. But by the late Thirties, a few people, working in secret, were developing a new technology that would completely change this analysis.

[music: J.S. Bach, *Goldberg Variations*]

Let's talk about radio waves.

Today, when we talk about radio stations, we usually talk in terms of frequency. Different radio stations broadcast on different frequencies. That's what those numbers on the radio dial refer to: frequency.

Radio "dial?" I am so old. I suppose you young people don't know what I'm talking about. Let's just say I'm talking about that number that comes up on your digital display when you tune your radio to a station.

As I say, today we usually speak in terms of a station's frequency. A hundred years ago, however, they usually spoke in terms of wavelength. The relationship between frequency and wavelength is straightforward: imagine a radio signal with a frequency of one cycle per second. Radio waves travel at the speed of light, which is 186,000 miles per second or just a hair under 300,000 kilometers per second. That means a one cycle per second radio signal would have a wavelength of 186,000 miles or 300,000 kilometers. I'm going to stick to kilometers for the remainder of this discussion, because the round number 300,000 makes the math much simpler and clearer.

A radio signal with a wavelength of 300,000 kilometers wouldn't be very useful, but if a signal of one cycle per second has a wavelength of 300,000 kilometers, you can easily see that a signal with a frequency of 300,000 cycles per second would have a wavelength of one kilometer. In the first half of the twentieth century, they would have referred to a frequency of 300,000 cycles per second as 300 kilocycles per second. Often they omitted the "per second" and would simply have said, "300 kilocycles." This is what radio comedian Fred Allen was talking about when he complained that every sponsor thought they were a "kilocycle Ziegfeld." He meant that they fancied themselves impresarios of the airwaves.

In 1960, the General Conference on Weights and Measures adopted the *hertz* as the unit representing cycles per second, and since that time the preferred usage has been 300 kilohertz. The name was chosen to honor the $19^{th}$-century German physicist Heinrich Hertz, whose research contributed to the development of radio. In the metric system, they like to name units after scientists, unlike the superior imperial system, which likes name its units after more logical things, like feet and cups and barleycorns.

But I digress. In the early days of radio, this range of wavelengths—one kilometer and up—was dubbed "long wave," for obvious reasons. The very first radio communication systems, such as the one they were using aboard *Titanic* back in the day, broadcast in this range, for the simple reason that longer waves and lower frequencies are easier to generate.

The limitations of long wave radio are fairly obvious. A signal with a low frequency of just a few cycles per second can convey information only very slowly; it is not capable of transmitting music or human speech very well, let alone video.

This was fine for 1912. Radios of that time were used primarily to communicate between ships at sea and stations on land in Morse code. All that was required was that the radio transmitter produce a buzz that could be modulated into dots and dashes, and long wave could do that just fine. In fact, long wave radio was better for this purpose, because long wave radio can propagate around the curvature of the earth and be received over distances of thousands of kilometers. Also, longer waves can propagate around physical obstacles, like a building. A radio signal with a wavelength of, say, five kilometers, will pass by a house without even noticing it's there. Only objects of a size on the same scale as the radio signal's wavelength pose any kind of obstacle.

Similarly, the wavelength of a radio signal affects the size of the antenna needed to broadcast it. An ideal antenna is half a wavelength long; you can get by with a quarter of the wavelength, so this means that a long wave broadcasting antenna will need to be hundreds of meters long, at a minimum, and indeed, those early land stations that communicated with a ship or across the Atlantic between Europe and North America had enormous antennas.

When commercial AM broadcasting emerged in the 1920s, the Federal Radio Commission in the United States set aside frequencies from 530 to 1700 kilocycles for commercial radio stations. In Europe, they limited the upper end of the range to 1600. These correspond to wavelengths in the range of about 200 to 600 meters. At these frequencies, sound and music can be reproduced with a fidelity greater than the phonograph records of the time and the broadcast antennas can be kept down to a reasonable size.

The AM broadcasting band is part of a larger segment of the wavelength spectrum that the early twentieth century dubbed "medium wave" radio. These shorter wavelengths do not propagate around the curvature of the earth as well as long wave, and at the higher frequencies of the AM band, where the wavelengths get down to 200 meters, that's short enough that the radio waves might be blocked by a hill. In the US, the lower frequency, longer wave AM frequencies were assigned to bigger, more powerful stations so they could broadcast over long distances, while the higher frequency, shorter wave slots were given to smaller, more local stations that broadcast at a lower power and didn't aim to broadcast very far.

The next step up, after long wave and medium wave, is naturally short wave. Short wave begins at frequencies above three megacycles, which corresponds to wavelengths of 100 meters or less. In the early days, shorter wavelengths were regarded as limited in range and therefore less useful for communication or broadcasting, so these were set aside for amateur use. I mentioned this back in episode 238, where I also explained how the amateurs got the last laugh because although this is true as far as it goes, short wave signals can be reflected back from the Earth's ionosphere, which allows a short wave signal to be received over very large distances, many thousands of kilometers.

This is very useful, and it didn't take long for someone besides the amateurs to take advantage of it. One of the first was the BBC, which began its Empire Service in December 1932. King George V gave the first-ever Royal Christmas message over the Empire Service that same month. Initially, the Empire Service was intended for English-speaking listeners across the British Empire, but by 1938, the Empire Service was broadcasting in French, Italian, German, and Arabic. During the Second World War, the propaganda value of short wave became clear, as it allowed for broadcasts directly into enemy countries. The Empire Service changed its name to the Overseas Service, and the US government launched its own version, called the Voice of America. After the war, governments around the world turned to short wave radio to get their messages out. In 1965, the BBC changed the name of the Overseas Service once again; it has been known since as the BBC World Service.

As a side note, medium wave broadcasts can also bounce off the ionosphere, sometimes. This does not happen in the daytime because of ionization caused by the sun, but at night, and especially winter nights, and especially when the solar sunspot cycle is at its minimum, you can listen to AM radio stations over much longer distances, over a thousand kilometers.

In the 1930s, this simple breakdown of the radio spectrum into long wave, medium wave, and short wave nicely summarized the range of radio broadcasting.

Radio was used primarily for broadcasting, and secondarily for two-way communication. Can you use radio for anything else? Well, from the early days of aviation, air crews used radio stations for navigation. If you have a radio receiver with a rotating loop antenna, by turning the loop and listening for the maximum signal strength, you can determine the direction the radio signal is coming from. Do this twice with two radio stations in different locations and you can triangulate and determine your own position on a map. Recall that when Amelia Earhart was attempting to fly around the world, the US Navy dispatched a cutter to Howland Island, to help her find her way in the South Pacific, because the region lacked commercial radio stations. Alas, her navigator was not able to get a fix on the vessel's radio signal, and she didn't make it.

Anything else? Well, a Scottish radio engineer named Robert Alexander Watson-Watt spent the 1920s working in the British Meteorological Office, experimenting with ways of using radio to detect and track thunderstorms. Thunderstorms produce lightning, and lightning produces radio waves, so you can use a radio receiver to detect them. It would be more useful if you could get a radio fix on lightning strikes and pinpoint where they are, but that's tricky, because a lightning bolt doesn't last very long, so you have to get a fix on it quickly.

At the Met Office, as it was called, Watson-Watt helped develop a system called high frequency direction finding, known at first by the initials HFDF and later as "huff-duff." Instead of using a loop antenna that has to be manually rotated to get a fix, huff-duff uses a set of antennas and takes advantage of slight differences in the signal to display a blip on an oscilloscope that tells you instantly what direction the signal came from. It worked great for catching signals from lightning.

In the late Twenties, Watson-Watt and his team adapted huff-duff to measure the altitude at which terrestrial shortwave signals bounce back from the ionosphere. It turned out to be somewhere around 100 kilometers above the Earth's surface, though it varies.

There was at this same time an English chemist named Henry Tizard, who served in the RAF toward the end of the Great War and afterward did research on motor fuels. It was Tizard who devised the numerical system for rating the compression tolerance of gasolines. This is the system we call "octane ratings" and we still use it today.

Tizard was elected Rector of Imperial College London in 1929. A few years later came the bomber scare, and Tizard answered a call from the British Air Ministry to head a committee of scientists chosen to investigate the problem of bomber defense.

In 1935, a German newspaper published a report that German scientists working for the government on a secret project had developed a "death ray," a weapon that projected a beam that could kill and destroy instantly over a distance. Such weapons were already being described in science fiction stories, but here was a claim that researchers had actually built a real-life one. Tizard's committee inquired of Robert Watson-Watt, the engineer who could pinpoint lightning bolts and measure the ionosphere, whether something like this "death ray" was feasible, and if so, whether it could be used to shoot down enemy bombers.

Watson-Watt's team replied with a memo explaining the inverse square law. The inverse square law tells us that electromagnetic radiation diminishes proportionately to the square of the distance. For example, if you hold up a sheet of paper one meter from a light source, then draw it back to a position two meters from the light source, the amount of light hitting the paper is reduced not to half of what it was before, but a quarter of what it was before.

A quick calculation will show that even a tremendously powerful beam of electromagnetic radiation will quickly fade with distance. Aim it at a bomber flying ten kilometers overhead, and the bomber is unlikely even to notice it.

So much for the death ray, as disappointing as that may be. But Watson-Watt's memo didn't end there. A member of his team named Arnold Wilkins had taken note of the fact that airplanes flying past sometimes disrupt shortwave radio communications, presumably because the wavelength is short enough and the airplane large enough that it reflects some of the wave. The memo noted that it might be possible to detect an aircraft, perhaps even determine its direction and distance, by measuring those reflected radio waves. Watson-Watt and his team offered to study the matter in more detail if the Air Ministry was interested. And willing to pony up some money, the memo did not need to add.

Tizard's committee forwarded the memo to the Air Ministry. The Air Ministry very sensibly asked to see a demonstration before discussing funding. On February 26, 1935, Watson-Watt and Wilkins set up a receiver about ten kilometers from a BBC shortwave broadcasting station in Northamptonshire. While a member of Tizard's committee watched, the RAF flew one of its bombers, a Handley Page Heyford biplane, around the site, and Watson-Watt and Wilkins detected the BBC signal reflected off the airplane.

Well, that was enough to satisfy the Air Ministry. Wilkins left the Met Office to head a new research project, located on the North Sea coast of Suffolk. By June, they were able to detect aircraft as a distance of 25 kilometers with a system of two antennas, one to send a radio signal, the other to listen for any trace of it being reflected back. By December, they were up to 100 kilometers, and the British government allocated £60,000 for the construction of five stations around the Thames Estuary, capable of detecting bombers approaching London.

By 1937, the five stations were built and tests began. The tests showed that even with early detection of incoming bombers, it was still a challenge to get that information to the right fighter squadron and get their planes in the air before the bombers passed them by. The commander of the RAF Fighter Command, Air Chief Marshal Hugh Dowding, devised a system, known as the Dowding system, to minimize the RAF's reaction time. When the stations detected incoming aircraft, they would communicate that directly to Fighter Command headquarters in London by telephone, where that information would be added to a big map. Individual sector commands would be notified by Fighter Command of incoming bombers detected in their sector, and then sector command would be responsible for interception. Fighter pilots received orders only from their own sector command, and thus this hierarchical system minimized confusion.

When the Second World War began, Britain had 21 operational detection stations in a network called Chain Home, the covered most of the eastern and southern coasts of Great Britain.

The UK was not the only country working on radio detection. Research was also going on in Germany, Japan, and the United States, but in those countries, research focused more on the detection of enemy ships at sea rather than aircraft. As you know from our episodes on naval warfare, knowing the position of your enemy's ships is more than half the battle. Radio detection promised to revolutionize naval warfare.

The US Navy had a practical detection system by the late Thirties, and it was they who dubbed the technology "radio detection and ranging," which quickly became reduced to the military acronym RADAR, and frequent use of the acronym has turned it into a common noun, spelled in lower case letters.

The US Navy developed the highest frequency system of the time, capable of generating frequencies as high as 200 megacycles, yielding a wavelength of an astonishing 1.5 meters, which is valuable, because shorter wavelengths allow for shorter, more convenient antennas, and the shorter the wavelength, the clearer and more accurate the return signal will be.

Detecting ships at sea was much easier and potentially much more valuable to these other countries, but the British kept their focus on detecting airplanes, and for good reason. The United Kingdom was about to become a target of history's first strategic bombing campaign, the first-ever attempt to win a war through the use of air power alone.

But that is a story for the next episode. We'll have to stop here for today. I thank you for listening, and I'd especially like to thank Benjamin for his kind donation, and thank you to Richard for becoming a patron of the podcast. Donors and patrons like Benjamin and Richard help cover the costs of making this show, which in turn keeps the podcast available free for everyone, so my thanks to them and to all of you who have pitched in and helped out. If you'd like to become a patron or make a donation, you are most welcome; just visit the website, historyofthetwentiethcentury.com and click on the PayPal or Patreon buttons.

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I don't credit my sources as often as I should, but here's one I simply have to mention: it's the academic blog titled *A Collection of Unmitigated Pedantry,* by Bret Devereaux, who is a scholar of both ancient history and military history. His writings on aerial warfare helped me organize my thoughts for today's episode, and I suspect many of my listeners would enjoy reading it. Again, that's *A Collection of Unmitigated Pedantry,* at acoup.blog.

Next week is a bye week for the podcast, but I hope you'll join me in two weeks' time, here on *The History of the Twentieth Century.* Now that we've set the scene, it's time to look at the Battle of Britain, in two weeks' time, here, on *The History of the Twentieth Century.*

Oh, and one more thing. Robert Alexander Watson-Watt was born Robert Alexander Watson. He adopted the hyphenated surname because he claimed to be a descendant of James Watt, the inventor of the steam engine, though no proof of this has been found.

He was granted a knighthood in 1942, in recognition for his work on developing radar. That same year, he traveled to the United States to advise the US military on radar and air defense.

After the war, the British government awarded him £50,000 for his service to the nation. Later he moved to Canada. In 1956, he was pulled over by a Canadian police officer for speeding, ironically after being caught by the officer's radar gun. Watson-Watt told the officer that if he had known that radar was going to be used in this manner, he never would have invented it.

Later he moved to the United States, where he appeared on the television game show *To Tell the Truth*. He spent the final years of his life back in Britain, where he passed away in 1973, at the age of 81.

[music: Closing War Theme]