STEALTH TECHNOLOGY: THE FIGHT AGAINST RADAR

[1]SHARAD KUMAR, [2]SHASHANK MISHRA, [3]SHASHANK GUPTA

[1,2,3]Electrical Engineering Department ABES Engineering College,Ghaziabad.U.P

Abstract- During World war-II, radar and surface to air missiles posed an increasing threat to aircraft. It was at this time that stealth technology became an important topic of investigation. This paper will discuss the historical points that have lead to the rise of stealth technology. It will also discuss the different types of stealth technology and This paper will then conclude with the moral implications of using and designing stealth technology.

Keywords- Stealth, Low Observable, Radar

I. HISTORY

In the late 1930's and early 1940's radar technology was becoming increasingly used to detect aircraft. During WWII, Germany, France, Great Britain, and the United States all used this technology to navigate ships and aircraft and to detect approaching enemy aircraft. Radar itself did not pose a direct threat to the United States though because the radar technology was never integrated into the anti-aircraft defenses. This all changed for the United States and its allies during the Vietnam and Yom Kipper wars[1]. The United States needed to develop a way of evading radar in order to make its fleet of aircraft safer and more effective.

In the late 70's, two prototype planes were built to study and test low observable, better known as stealth, technology. The entire project was incredibly secret and only a handful of people knew the full potential of this technology. The two prototypes lead to the introduction of the F-117A which was fully operational in 1983 and then used in Operation Just Cause (Panama) in 1989[2].

After the success of the F-117A, the United States Air Force has expanded their fleet of stealthy aircraft such as the B-1 and B-2 bombers, the F-22, and the F-35[3]. Stealth technology is still being studied extensively and there are probably several highly classified projects going on right now that no one is aware of.

II. THE BASICS OF RADAR

A. Echo

There are two basic principles that are useful to understand before discussing how radar technology is used. The first of these principles is echo. Many understand an echo to be someone's voice bouncing off of something and coming back to them. This is a very accurate definition of what an echo is but it can be taken in a more broad sense to include all types of propagating waves, including light. Someone hearing their own voice is an example of sound waves hitting a surface and then reflecting straight back at them. A mirror is an example of light waves being reflected back at one's self. Light from an external source hits a body and bounces off in several directions. Some light waves propagate towards the mirror and then reflect off of the mirror back to that person's eyes. This same exact principle applies to radio waves. Radio waves are simply non-visible forms of light. The idea behind radar is to transmit a radio wave and then receive the reflection from an aircraft. The amount of time between the transmission and the reception can be used with a very accurate number for the speed of light to determine how far away the plane is from the radar station.

When you shout into the wall, the sound of your shout travels down the well and is reflected (echoes) off the surface of the water at the bottom of the well. If you measure the time it takes for the echo to return and if you know the speed of sound, you can calculate the depth of the well fairly accurately.

B. The Doppler Shift

The second principle that is used in radar is the Doppler Shift. One familiar case of Doppler Shift that will help to explain what it is and how it can be used in radar is that of an ambulance or car with its sirens or horn on. The sound that you hear as the vehicle is approaching you is at a higher pitch, or higher frequency, than the sound you hear when the vehicle is moving farther away from you, see Figure 1.

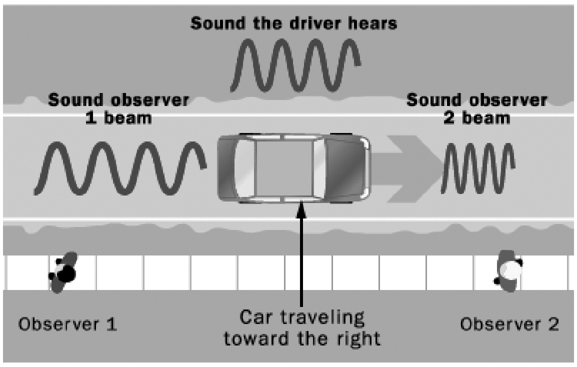


Figure 1: Audio Example of Doppler Shift

[4]

This can be explained with the following example presented by[4]: “Imagine that the car is standing still, it is exactly 1 mile away from you and it toots its horn for exactly one minute. The sound waves from the horn will propagate from the car toward you at a rate of 600 mph. What you will hear is a six-second delay (while the sound travels 1 mile at 600 mph) followed by exactly one minute's worth of sound. Now let's say that the car is moving toward you at 60 mph. It starts from a mile away and toots it's horn for exactly one minute.

You will still hear the six-second delay. However, the sound will only play for 54 seconds. That's because the car will be right next to you after one minute, and the sound at the end of the minute gets to you instantaneously. The car (from the driver's perspective) is still blaring its horn for one minute. Because the car is moving, however, the minute's worth of sound gets packed into 54 seconds from your perspective. The same number of sound waves are packed into a smaller amount of time. Therefore, their frequency is increased, and the horn's tone sounds higher to you. As the car passes you and moves away, the process is reversed and the sound expands to fill more time. Therefore, the tone is lower.”

One may ask, ‘How can this principle be used in radar?’ This Doppler shift can determine how fast an object is moving. In radar, the transmitted radio wave discussed earlier is sent at a known frequency. When the reflection is received, its frequency will be smaller, larger, or the same as the transmitted radio wave. If the reflection is the same frequency then the object isn’t moving, such as a helicopter hovering in one spot. If the reflection is at a higher frequency, then it is moving towards the radar tower and the amount of increase in frequency can be used to determine how fast it is moving towards the radar tower.

The same is true with a lower frequency reflection but in this case, the object is moving away from the radar tower.

C. Why Radio Waves

If the principles of echo and Doppler Shift are used together in radar systems, then radar would be able to detect the location and the speed of an aircraft. The previous examples used to describe these principles used sound waves. In contrast, radar uses electro-magnetic waves instead of sound waves. There are several reasons for this. The first is that sound waves cannot travel as far as light without significant attenuation. Secondly, electromagnetic echo is much easier to detect than a sound echo.

D. Applications of Radar

Radar has many uses in both military and civilian applications. In the military, radar is used to detect enemy aircraft and to guide friendly aircraft. The military also uses radar to detect above surface water vessels. Radar can also be integrated into anti-aircraft defense systems to enable anti-aircraft artillery to be more accurate. Radar can also be used to guide missiles to determine if they are on the correct path. In civilian applications, radar is used in air traffic control rooms and police use radar to determine if a vehicle is traveling to fast. Radar is also used to map out geographical locations and to observe the movement of objects in space such as planets, satellites, and debris. Another application of radar is in predicting sort-term weather patterns such as rain, thunderstorms and even tornados. There are many other applications of radar that I have not listed but from this list it is obvious that the world would be a very different place without radar.

III. STEALTH TECHNOLOGY

E. The Need for Stealth

There is one application of radar that pushed stealth technology into existence. That application is of the radar guided anti-aircraft systems. There are several different varieties to these systems. One system is to guide a turret to hit an enemy aircraft with a bullet. Such a system is shown in Figure 2.

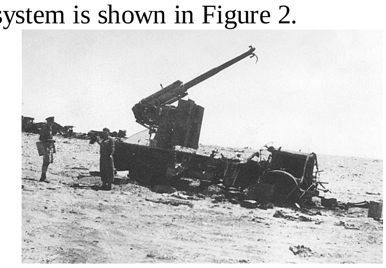


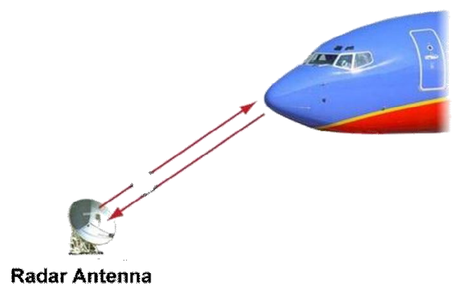
Figure 2: Anti-Aircraft Turret

Another system is to fire radar fused shells into the air. These shells emit their own radar signal and then determine the distance to planes around it. When it is close enough to a plane it explodes launching fragments in every direction. With these two types of systems, it became very dangerous to use aircraft to penetrate an enemy controlled area. The response to this deadly form of radar technology was stealth. Simply put, stealth makes it difficult for radar to detect the presence of an object in the air.

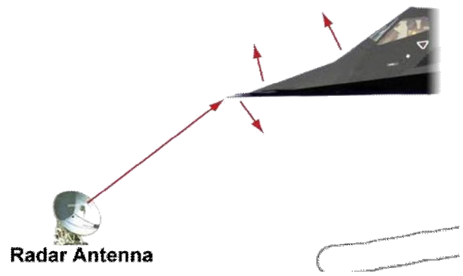
F. Shape of Aircraft

The overall shape of an aircraft can play a significant role in reducing its radar cross-section (RCS). Research into this form of stealth technology was the first to surface. The design of the shape of the aircraft is highly dependent on the type of materials that are used for the construction of the plane. Designs of the 1960's and 1970's used conductive materials, while designs of today use non-conductive, composite materials. The metal body of an airplane is very good at reflecting radar signals, and this makes it easy to find and track airplanes with radar equipment. The goal of stealth technology is to make an airplane invisible to radar. There are two different ways to create invisibility:

(1) Most conventional aircraft have a rounded shape. This shape makes them aerodynamic, but it also creates a very efficient radar reflector. The round shape means that no matter where the radar signal hits the plane, some of the signal gets reflected back:



(2) A stealth aircraft, on the other hand, is made up of completely flat surfaces and very sharp edges. When a radar signal hits a stealth plane, the signal reflects away at an angle, like this:



(3) In addition to the overall shape of this aircraft, there are a few other considerations that will help reduce the RCS of an aircraft. First, almost all stealth aircraft have their payload mounted inside the plane. Bombs and machine guns are not exposed and are stored inside the wings or center of the plane and only appear for brief moments while firing or releasing. Also, all landing gear is kept inside the plane. Second, the overall size of the aircraft should be relatively small. Third, vertical surfaces towards the rear of the plane are often angled in to reduce the chance of radar being incident at a 90-degree angle. Forth, reflective coatings are painted onto the cockpit so that radar beams reflect away from the aircraft instead of hitting objects inside the cockpit. Often objects inside the cockpit are odd shaped and difficult to make stealthy. These objects would stand out like a beacon if the glass were not coated with some sort of reflective paint. The last general consideration to make in the aircraft's design is to minimize intake cavities. Intake cavities make it impossible to reduce the radar reflections from the object inside of the cavity as shown in Figure 3.

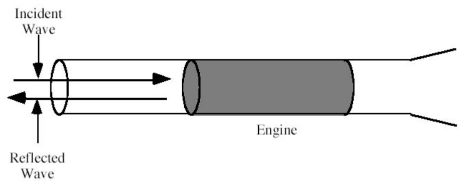


Figure 3: Straight Cavity

With respect to the engine, these cavities make highly reflective turbine blades visible to radar, which causes a significant increase in the RCS of the aircraft. Often, engine intakes incorporate an S-shaped duct, as seen in Figure 4, so that the turbine blades are not visible to radar.

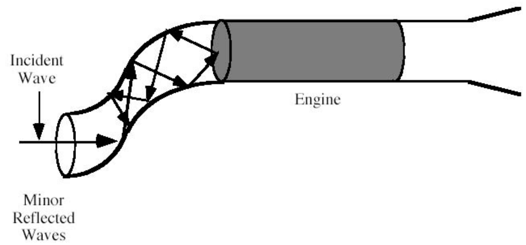


Figure 4: S-Shaped Cavity

Another method of reducing the effect from the turbine blades is to use absorbent paint. As of now, absorbent paint that can meet the demands of the turbine environment is very costly.

G. Absorbent Paint

Radar absorbent material (RAM) is probably the most common technology used to reduce an aircrafts RCS. An equivalent optical example would be black paint. An object that is painted black absorbs all the light that hits it (black is the absence of reflected light hitting your eyes). The idea behind RAM paint is to absorb the energy of the radio waves transmitted by the radar antenna. RAM contains carbonyl iron ferrite as the active ingredient. When radar waves hit the RAM coating a magnetic field is produced in the metallic elements of the coating. The magnetic field has alternating polarity and dissipates the energy of the signal. The energy that is not dissipated by the individual carbonyl iron ferrite elements is reflected to other elements as shown in Figure 5.

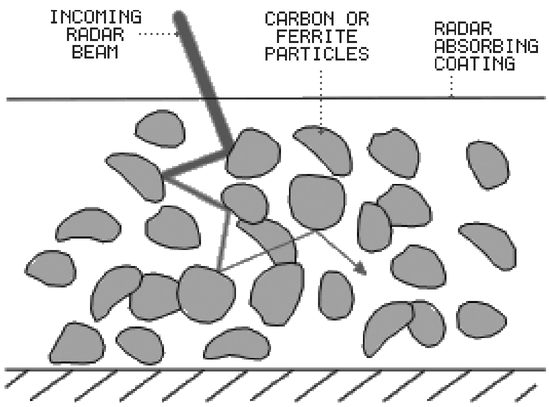


Figure 5: Incident Radar Beam Dissipated in RAM Coating

The majority of this energy is dissipated in the form of heat. The use of RAM coating is very effective but there are some drawbacks to this technology. First, the RAM coating is highly toxic. In hangers containing aircraft with RAM coatings, bats have fallen from the ceiling because of the accumulation of toxic fumes in the hanger. The second problem is that the aircraft looses some aerodynamic properties because of the paint, which causes additional heat problems. The third problem with RAM coatings is the expense. Applying the paint is a very time consuming process. The paint must be applied at a specific thickness, no bubbles can develop, and the surface of the plane cannot be compromised. The F117A Nighthawk fleet is in the process of being refurbished right now and a special robot is being used to apply the coating. Without the robot it would take a team of 5 painters 4.5 days to paint one F117A Nighthawk. Also, after each mission, the planes need to be inspected to determine that the paint is holding up to specifications. This testing increases the amount of time that the jet is inoperable. However, these disadvantages are currently determined to be a good trade off with the performance of the RAM coatings and thus it is widely used to achieve a significantly smaller radar cross section.

H. Active Radar Signal Cancellation

Some methods of reducing the RCS of an aircraft are not practically achievable. Active radar signal cancellation is one such method. Active signal cancellation is similar to active noise cancellation so it may be easier to consider the audible example of active signal cancellation. In active noise reduction (ANR), a second audio speaker is used to create a sound of equal magnitude but 180 degrees out of phase. The two audio signals, the noise and the anti-noise, combine and the result is theoretically zero. In active radar signal cancellation, a radio wave receiver on the aircraft detects incoming radar signals and then estimates the characteristics of the reflected radio wave and attempts to cancel the reflected radio wave with a second radio signal generated by the aircraft. There are two main problems with this method of stealth that make it impossible to implement. The first problem is that radar signals are traveling at the speed of light, which is must faster than the speed of sound. In essence, the electronics used to calculate the canceling radar wave would need to be able to compute the canceling radar wave faster than the speed of light.

This is impossible with today's technology. One suggested method of making this more feasible, at least for ships, is to have multiple poles extending from the surface. These poles would increase the amount of time that the generated signal could be calculated. For example, if the pole extended 20 meters from the ship's surface, it would have approximately 133ns to compute the signal and generate it.

The problem with this is that the poles would have to employ a different type of stealth because they will also be detected by the radar station.

There is a second problem with active radar signal cancellation that this suggested fix does not account for. In active noise reduction, an error microphone is used to determine how much error is being generated in the act of canceling the audio wave.

This error microphone incorporates negative feedback to eliminate the error and improve the noise reduction. With active radar signal reduction such error calculations cannot be done because of the lack of error detection. Therefore, the system is open loop and any error generated cannot be corrected. If active radar signal cancellation is ever used, it will be quite a long time from now before it is feasible.

I. Plasma Stealth

Plasma stealth technology is what can be called as "Active stealth technology" in scientific terms. This technology was first developed by the Russians. It is a milestone in the field of stealth technology. The technology behind this not at all new. The plasma thrust technology was used in the Soviet / Russian space program. Later the same engine was used to power the American Deep Space 1 probe. In plasma stealth, the aircraft injects a stream of plasma in front of the aircraft. The plasma will cover the entire body of the fighter and will absorb most of the electromagnetic energy of the radar waves, thus making the aircraft difficult to detect. The same method is used in Magneto Hydro Dynamics. Using Magneto Hydro Dynamics, an aircraft can propel itself to great speeds. Plasma stealth will be incorporated in the MiG-35 "Super Fulcrum / Raptor Killer". This is a fighter which is an advanced derivative of the MiG-29. Initial trials have been conducted on this technology, but most of the results have proved to be productive.

IV. THE FUTURE OF STEALTH TECHNOLOGY

Stealth technology is clearly the future of air combat. In the future, as air defense systems grow more accurate and deadly, stealth technology can be a factor for a decisive by a country over the other. In the future, stealth technology will not only be incorporated in fighters and bombers but also in ships, helicopters, tanks and transport planes. These are evident from the RAH-66 "Comanche" and the Sea Shadow stealth ship, Sea Shadow (IX-529) is an experimental stealth ship built by Lockheed for the United States Navy to determine how a low radar profile might be achieved and to test high stability full configurations which have been used

V. THE FIGHT AGAINST STEALTH

After stealth technology became quite effective, radar technology began to improve as well. New radar technology is currently being researched that will cause current stealth capabilities to become obsolete. It is well known that older short-wave radar technology used by Russia is able to detect stealthy aircraft considerably better than long-wave radar. Fortunately for stealth technology, all surface-to-air weaponry is based on long-wave radar so the systems cannot be combined to provide devastating results.

The devastating results come from the Czech Republic. In the early 1990's, a company in the Czech Republic was able to design a new detection device called the Tamara. The Tamara is a complex system that receives large numbers of signals at any given time. The basic method of detection is to look for signals emitted from the stealthy aircraft. Even though the aircraft can significantly reduce the amount of electromagnetic energy that reflects off of it, it cannot reduce its own emissions as well. So just how effective is the Tamara detection system?

At this point, things begin to get quite political. In 1999, an F117-A was shot down over Yugoslavia. This also happened to be the first F117-A to be brought down in combat since their introduction in the 1980's. Did this happen because of the Tamara? At the time, the media speculated that it was indeed the Tamara system that was used to detect the stealth craft. The U.S. government does not go this far though. They do not give any credit to the Tamara system and they say that its effectiveness is not much better than a standard radar system. They blame the incident on flight plans being leaked from NATO meetings. The government claims that the plane was easier tracked because the tracker already knew where it was going to be and when it was going to be there. So, with the government so adamant about the Tamara not being effective, what grounds can one use to defend the Tamara system? Well, it is quite interesting that Russia, China, and Iraq have all tried to get their hands on it in one way or another. That must mean that there is something special about it. Also, the United States did everything in its power to make sure that the above countries were not able to get the system. Again, the politics cloud the issue, but I would have to say that there is some validity to the effectiveness of the Tamara system.

Another system that could effectively make American stealth technology obsolete is currently being worked on and there isn't very much information on it. The theory behind this new detection system is quite simple though. Present day radar systems send an electromagnetic system into the air and then wait for a response, as described previously.

These new detection systems will send signals from above the target and wait for a reply. If there is not a reply, that means that something stealthy has absorbed the emitted signal! The system may be an aircraft that flies over the earth scanning the ground looking for "blank" spots or it may be in the form of satellites doing the same thing. Another way that this idea could be carried out is by using the electromagnetic emissions of stars to determine where aircraft are from the ground. These ground-based systems would scan the sky for aircraft by noticing if certain stars are not visible or if their radio emissions are dimmer than normally. According to[7], virtually the entire sky is covered with radio emissions from stars. This "radio map" is well known and can be used to compare to collected data. The disadvantage to the system of checking for "blank" spots is that the amount of computer computations needed is quite large. The system is very good at tracking planes once the target has been identified, but it is does not find objects as quickly as a conventional radar.

The reason for this is that the system must scan a large area and then compare that total area to a known value. Depending on the resolution and the area covered, which can be a very large number of comparisons.

CONCLUDING REMARKS

Radar and stealth technologies have become significantly more advanced in the last fifty years and this trend will continue because the two technologies are against each other.

It is somewhat of an arms race except it isn't between specific countries. It is a fight between technologies.

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