Electromagnetic Stealth: The Fight Against Radar

Justin Wilson

Abstract— **During WWII, 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 how they apply to electromagnetics. After a better understanding of stealth technology is acquired, new radar systems will be investigated including a possible breakdown of stealth technology on the B-2 stealth bomber. This paper will then conclude with the moral implications of using and designing stealth technology.**

Index Terms— **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 VII. 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 VII.

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 VII. 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.

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.

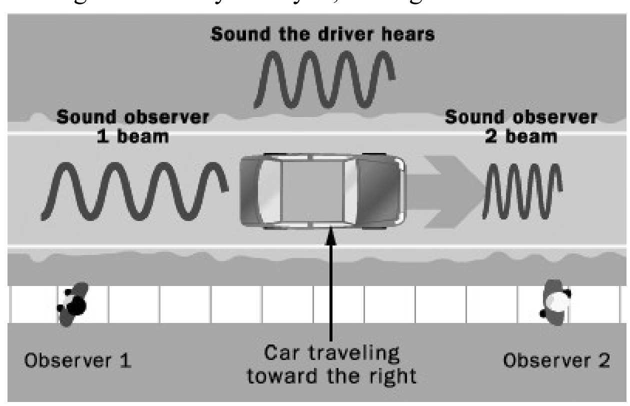

Figure 1: Audio Example of Doppler Shift VII

This can be explained with the following example presented by VII: "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. *The Radar Cross Section*

There are multiple characteristics that determine the range of radar systems. These variables are the peak transmitted power, wavelength of the system, a loss factor, the power of the noise within the receivers bandwidth, the ratio of the received echo to the amount of noise, and the radar cross section. The radar cross section (RCS) is the only factor that is controllable by the designers of the object under detection. For this reason, stealth designers seek to minimize the RCS of an aircraft.

In order to understand stealth technologies it is helpful to understand how the radar cross section is calculated and what it means. According to VII, "The radar cross section may be considered as the projected area of an equivalent reflector which has uniform properties in all directions. This equivalent reflector is a sphere which will return the same power per unit solid angle (steradian) as the aircraft." With a sphere, the aspect angle of the radar does not affect the amount of echo energy that is received. Thus, the energy received from an aircraft's echo, at a given aspect angle, is compared to the surface area of a sphere that will produce the same amount of reflected energy. compares the typical RCS values of birds and insects to typical RCS values of military aircraft.

TABLE 1
RCS OF VARIOUS FLYING OBJECTS VII

Object	RCS [m^2]
F-15 Eagle	405
B-1A	10
SR-71 Blackbird	0.014
Birds	0.01
F-22 Raptor	0.0065
F-117 Nighthawk	0.003
B-2 Spirit	0.0014
Insects	0.001

E. *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

A. *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.

B. 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.

1) Conductive Material Design

According to VII, Denys Overholser created a software program called EHCO 1, while he was working at Lockheed-Martin in the late 1960's. EHCO 1 used equations to simulate how electromagnetic waves reflect and scatter off of 3-dimensional conductive objects. These calculations and simulations were limited to flat panels and thus determined that a diamond shaped object would reduce the object RCS best VII. This is why the earlier stealth planes such as the F117-A and the Have Blue prototypes used faceted flat panel designs. The theory behind the calculations is actually quite simple. Using the law of reflection and geometry we can determine why the diamond shape works best. The law of reflection is easy to demonstrate using a mirror and laser as shown in Figure 3.

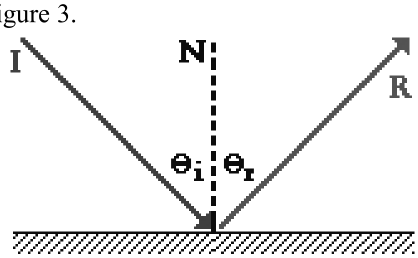

Figure 3: Specular Law of Reflection

The ray from the laser source is called the incident ray and it is labeled with an 'I'. The reflected ray is labeled with an 'R'. The angle formed between the normal and the incident ray is equal to the angle between the normal and the reflected ray. This type of reflection is called specular reflection. Reflections can also be scattered over a larger range of angles. This form of reflection is called diffuse scattering and is shown in Figure 4. Specular reflection occurs when the surface of reflection is flat and smooth (relative to the wavelength of the incident ray). Diffuse reflection occurs when the object has small abrasions or inconsistencies. In order for radar to be effective, the reflected ray must be directed along the same path as the incident ray.

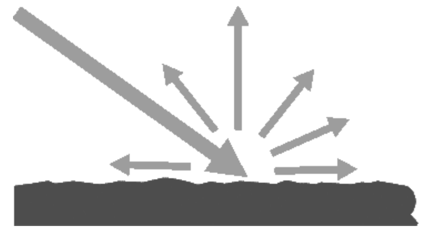

Figure 4: Diffuse Reflection

For flat, smooth objects the incident ray must be perpendicular, or normal, with the surface it is reflecting off of for radar to work. For rough surfaces, a portion of the incident ray would be directed back from any direction. For aeronautical applications, it is safe to assume that the surface will be smooth because un-smooth surfaces would have poor aerodynamic properties. With this assumption we will elaborate on spectral reflection. Take, for example, a large commercial aircraft, shown in Figure 5.

Figure 5: Front of 747

With curved objects, there are infinite tangent lines and thus, an infinite number of normal lines. With infinite tangent lines more radar signals are directed back to the radar antenna. This makes commercial aircraft easy to detect using radar. On the other hand, the first prototype stealth planes featured a diamond shape. This diamond shaped aircraft is composed of flat surfaces and there are a limited number of normal lines in which radar signals can be projected back on. Figure 6 illustrates how radar signals are redirected away from the aircraft and away from the radar antenna.

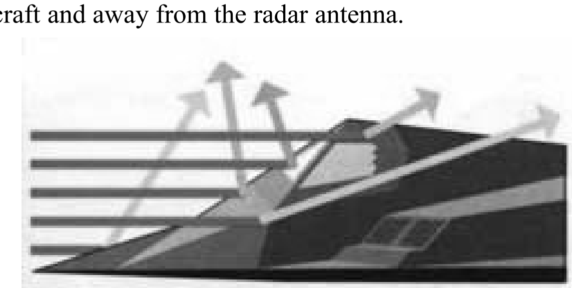

Figure 6: Redirected Radio Waves VII

The aircraft shown is an F117-A that was designed in the 70's and made known to the public in 1988.There are a few unfortunate consequences of a design as shown in Figure 6. The first, and major, disadvantage is that the aircraft that is designed with these flat surfaces have poor aerodynamics and lack agility, which is important for fighter aircraft. A second disadvantage to this shaping is in its ability to actually decrease the radar cross section of the aircraft. While this is a very good way to reduce the RCS of the aircraft for monostatic radar systems (radar systems in which the transmit antenna and receiver antenna are the same antenna), this shaping poorly reduces the RCS of the aircraft for bistatic radar systems (radar systems in which the transmit and receive antennas are separated by a large distance. If multiple receptors are used, then a reflection can be picked up by another radar station, different from the source, and the plane can be detected in that way. These disadvantages have lead to the development of different types of materials to build stealth planes with. These composite, non-conductive materials are used in the B-2 and F-22, allowing them to be more aerodynamic.

2) Non-Conductive Material Design

Composite materials were first used on the U2 spy plane which flew at altitudes of 80,000 feet. The composite materials and the flying altitude made it very difficult for radar systems of the 1950's and 1960's to detect the planes. The same is true today of composite materials but additional methods of stealth are used with the composite materials (such as absorbent paint, see section IIIC).

In composite materials, the amount of energy that is reflected from an incident radar signal is highly dependant on the dielectric constants of the composite material and the air, the incident angle, and the polarization. The first of these properties can be controlled by the designer of the aircraft but the second and third property cannot. The following equations, taken from VII, are useful in understanding how to choose the composite material properties.

$$n_1 \cdot \sin(\theta_1) = n_2 \cdot \sin(\theta_2) \qquad (0)$$

$$n_{1p} = n_1 \cdot \cos(\theta_1) \qquad (0)$$

$$n_{2p} = n_2 \cdot \cos(\theta_2) \qquad (0)$$

Equation (0) is called Snell's Law of Refraction and it simply states the relationship between the reflected angle, θ_1, and the transmitted angle, θ_2 (all angles with respect to the normal). Similar to the conductor case, the reflection angle is the same as the incident angle. Equations (0) and (0) are used to find the effective impedances valid for p-polarization waves. Similar equations exist for the effective impedances of the s-polarization waves, which use the secant of the angle instead of the cosine.

$$\Gamma_s = \frac{n_{2s} - n_{1s}}{n_{2s} + n_{1s}} \qquad (0)$$

$$\Gamma_p = \frac{n_{2p} - n_{1p}}{n_{2p} + n_{1p}} \qquad (0)$$

Equations (0) and (0) are used to find the reflection coefficients for s and p-polarizations, respectively. These values are then used in equations (0) and (0), to find the fraction of the incident power that is reflected and transmitted.

$$\frac{P_r}{P_{inc}} = \left(\left|\Gamma_p\right|\right)^2 \qquad (0)$$

$$\frac{P_t}{P_{inc}} = 1 - \left(\left|\Gamma_p\right|\right)^2 \qquad (0)$$

To minimize the reflected power, the design must minimize the effective impedance of the material. This is done by matching the dielectric constants of the material and air as closely as possible. When $n_1 = n_2$, θ_1 and θ_2 are equal, n_{1s} equals n_{2s}, and n_{1p} equals n_{2p}. This means that the effective reflection impedances are zero for both the s and p-polarizations, independent of θ. One concern with composite materials is that the transmitted ray will eventually hit something that will reflect the wave. One method of dealing with this reflection is to make the composite material also absorbent material. This technology is similar to absorbent paint which will be discussed in section IIIC

3) Other Shape Considerations

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 7.

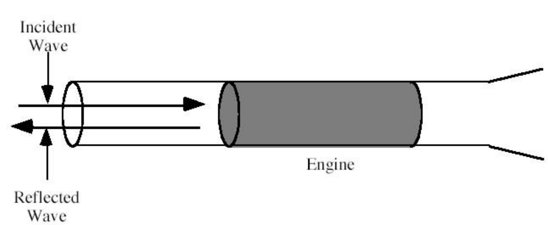

Figure 7: Straight Cavity

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 8, so that the turbine blades are not visible to radar.

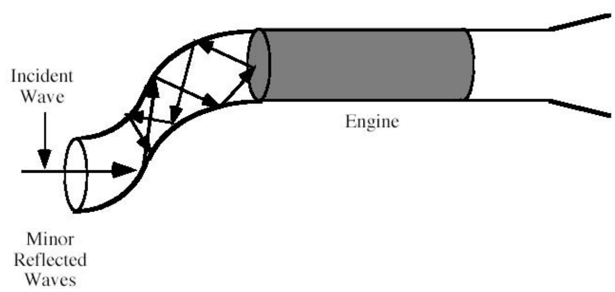

Figure 8: S-Shaped Cavity

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.

C. 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 9.

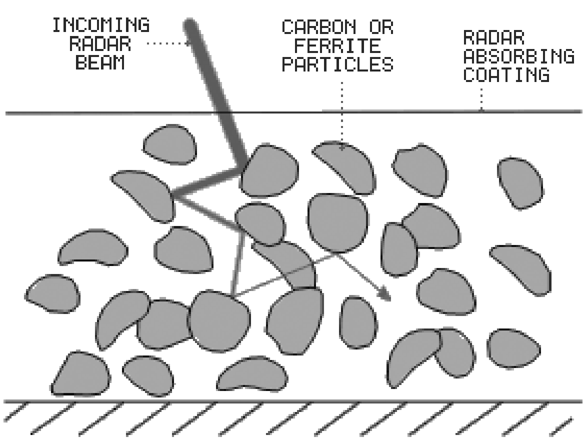

Figure 9: Incident Radar Beam Dissipated in RAM Coating

The majority of this energy is dissipated in the form of heat VII. 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 VII. 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.

D. 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.

E. Plasma Stealth

Plasma stealth technology is the leading edge technology and is still under considerable research. The motivation to use plasma stealth is similar to that of radar absorbent materials.

According to VII and VII, electromagnetic waves have been observed to be absorbed by or bend around plasma fields for decades. If a plasma cloud could be created around the outside of an aircraft, electromagnetic waves would be absorbed by the stealth instead of reflecting back to the radar antenna.

Figure 10: A Familiar Form of Plasma

Before discussing the advantages, disadvantages, and feasibility of this technology, let us first discuss what plasma is and some of its other applications. In normal gases, each atom is electrically neutral. It is composed of equal number of protons and neutrons. If this gas is heated up enough, one or more electrons from the gas atoms will release from the pull of the nucleus, causing the atoms to be ionized. If this process happens to a significant number of gas atoms in a given volume, that gas becomes plasma. For this reason, plasma is often called the fourth state of matter. Because a significant amount of the gas is electrically charged, the electrical properties of the plasma behave differently than the properties of the gas. In most cases the ratio of neutral and ionized atoms determine the behavior and usefulness of the plasma VII. There are two forms of plasma that are quite common on earth, fire and lightning, but plasmas are also used in water purification, synthesis of ceramic powders, lasers, propulsion, and plasma displays.

As mentioned previously, the plasma aids in absorbing the radar signals. The absorption takes place when the electromagnetic waves encounter a charged particle. During this encounter, a portion of the electromagnetic wave's energy is transferred to the charged particles. This effect can be explained better using a somewhat related example. Microwave ovens work by emitting an electromagnetic wave with a frequency that causes water particles to vibrate. In this case, the water absorbs the electromagnetic energy and heats up the water. Similarly, if one were to put a lit candle into a microwave, the flame would absorb the energy from the candle (the result is quite interesting but I wouldn't recommend doing this if you value your microwave and/or your home).

Another interesting result of a plasma cloud around an aircraft is that electromagnetic waves, or radar waves, tend to bend around the cloud and past the aircraft. This, however, is minimal in decreasing the RCS of an aircraft. According to Halerewicz in VII, a more feasible way of reducing the RCS is to use the frequency oscillations of the plasma to change the frequency of the incoming radar waves. This change in frequency would cause the radar waves to become useless.

Plasma stealth technology has three major advantages. The first is that the RAM painting is not necessary when a plasma cloud is used. This means that the cost and maintenance of RAM coatings are avoided. Second, plasma clouds also provide a heat shield that separates the plane from super heated air VII. Lastly, the plasma cloud would smoothen airflow across the fuselage of the aircraft making it more aerodynamicVII.

There are a few disadvantages to plasma stealth technology that are currently being researched. The first problem is creating the plasma cloud. One suggestion, which has been posted on VII, is to have some sort of energy source on the leading edge of the plane that would ionize the air. Since the air will flow along the plane anyway, the ionized gas will then follow the planes surface and coat it entirely. Then, on the tail of the plane, you would charge it opposite of the leading edge to neutralize the plasma. The rest of the plane would need to be insulated so that the plasma didn't neutralize until the tail of the plane. One such plasma generator was developed in 1999 by the Keldysh Scientific Research Center. The plasma generator only weighed 100kg but used power on the order of megawatts VIIVII. One solution for the high power requirement is to only use the device when absolutely necessary. A second solution is similar and more practical. Several smaller plasma generators would operate for different locations on the plane. And thus, only sections that detect enemy radar signals will generate a plasma field.

The second shortcoming with plasma stealth technology is that the plasma layer that would surround the plane would also block the pilot's radar. According to VII, the designers of the Russian SU-35 tested a plasma generator similar to the one mentioned previously. In this model the generator switched frequently to let its own radar out at a set interval. Probably the best solution to this problem is to use a different type of stealth technology on the antenna itself and eliminate the presence of plasma around the radar antenna.

The third drawback is that when the ions neutralize they will give off light and not all ions will neutralize either. These left over ions will neutralize later creating a visible path that points directly to the plane. This visual path is called a plasma trail and can also be used to lock on planes but this can be overcome by either flying very high or by operating only during the day. Figure 11 shows the plasma trail left by the space shuttle Columbia shortly before the tragic events of February 1, 2003. The plasma trail shown is normal to space shuttle reentry. It is caused by the super heating of air around the space shuttle which ionizes the surrounding gas. This gas then neutralizes behind the space shuttle and gives off light.

Figure 11: Columbia Plasma Trail

Disadvantages aside, this exact technology is being implemented in the Russian "AJAX" hypersonic aircraft project VII. How the Russian plasma generator works is a secret that will not be published for quite some time but there have been some guesses posted on internet discussion boards. One person speculates that an electromagnetic field should be generated. But this may be a problem as well because the electromagnetic field could be detected. Another suggests using a corona source that continuously breaks down or a pulsing tesla coil (which would in turn produce an EM field). Another suggestion is a plasma laser. A common problem with each of these sources is that they are often very large and use a large amount of power.

I think that considerable improvements can be made to plasma stealth technology. I also think that with a few years of research in this area and quite a bit of money most if not all of the shortcomings of plasma stealth technology will be solved. When this happens the advantages will leave RAM coatings and bulky flat panel, poor aerodynamic designs in the past.

IV. 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 VII, 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.

V. Ethical Considerations

For this section there are a few questions that I would like to ask the reader. These questions apply both to Christians and non-Christians. I will give my own thoughts one each question but I urge you to come to your own conclusions.

First, is stealth technology more prone to being used for evil or for good? This question largely depends on what one defines to be evil. Is it evil to destroy terrorist buildings if there aren't any people inside? Is it evil to destroy terrorist buildings if there are people inside? Is it evil to destroy communications buildings if no one is there? Is it evil to destroy them if someone is there? Is it evil to destroy hospitals, market places, community centers, and housing developments? The odds are that the answer to at least one of these questions was yes. Some readers may even be able to give a convincing argument for saying yes to each of these questions. The truth to the mater is that stealth technology allows air forces to do all of the above without any warning being given to the targets. What good can come out of stealth technology? For one, thousands of pilots for the United States have returned from missions unharmed because of stealth technology. That certainly is a good thing. Above surface ships use stealth to protect the thousands of Americans onboard from enemy attack. That certainly is a good thing.

My second question is, "Let us assume that stealth technology is used for more evil than it is for good, is it morally right to design this technology?" There are probably very few people who would answer this question exactly the same. I believe the reason for a large number of different answers stems from the fact that this question is somewhat of a gray area or a "disputable matter." Roman's 14 speaks about such matters. Paul says this with regards to disputable matters, "Each one should be fully convinced in his own mind." Specifically, he states with regard to clean and unclean food (a spiritual matter), "I am fully convinced that no food is unclean in itself. But if anyone regards something as unclean, then for him it is unclean." From this chapter in Romans I have come to a conclusion about the morality of stealth technology and designing it. Christian designers of stealth technology, and any other technology for that matter, must be fully convinced that what they are doing is in accordance with God's will, for each of us will give an account of himself to God. All technology can be used for good or for evil and this simple truth must be realized in the design process. All designers, Christian and non-Christians alike, should consider the uses of their design and if possible make design changes that help prevent the design from being used for evil.

VI. 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.

VII. Resources

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