THE EMERGENCE OF STEALTH TECHNOLOGY

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Abstract—**During World War-II the intercontinental ballistic missile posed a major threat to aircrafts. This is when the Germans first started working on a technology which would almost make the aircraft unseen to the radar. This technology came to be known as stealth technology. Stealth uses a simple principle of absorbing and deflecting radar waves. This paper will discuss more on how the RCS of the aircraft can be increased, it will also discuss more on structure and design of the aircraft. The design and material will play important role in deciding the level of stealth achieved by the aircraft and it will conclude with moral implications of using stealth technology.**

KEYWORDS – Ferromagnetic particles, Low Observable (LO), Radar, Radar absorbing material (RAM), Radio waves.

I. INTRODUCTION

Stealth technology, it is also termed as Low Observable (LO) technology. This technology covers a wide range of techniques used with personal, aircrafts, military vehicles, submarines, and satellites to make them not in sight (ideally imperceptible) to radar, infrared, and other identification methods.

Since RADAR – an abbreviation for Radio Detection and Ranging – is a primary detection tool for aircrafts, while most technologies are concentrated at suppressing RADAR returns from aircrafts, but stealth technology tries to reduce other "observable" as well i.e., energy emission of any sort that may be seen by the opponent.

II. PURPOSE OF ITS EXISTENCE

During World War I, the Germans began studying cellon (cellulose acetate). They used it as a translucent covering material for military aircraft at first. Its primary goal was to decrease the visibility of military planes. However, it was a colossal failure. The two main disadvantages were that the aircraft was significantly more visible to radar due to the sunlight reflected from the material and that it degraded quickly due to the sunlight and in-flight temperature fluctuations. Because of these flaws, efforts to make the plane transparent were abandoned. Radar technology advanced dramatically in the late 1930s and early 1940s. Detecting aircraft got much easier as radar technology developed. This was employed by Germany, France, the United Kingdom, and the United States during World War II.

In the late 1970s, two plane templates were built to study and test the low observable technology, known as stealth technology. The entire project was confidential and only a handful knew the full potential of this technology. These two templates lead to the introduction of F-117A which was completely operational in 1983 and was used in the mission just cause (Panama) in 1989. After F-117A succeeded, the US air force expanded their stealth technology arsenal with B-1 and B-2 bombers known as F-22 and F-35.

III. RADAR

Radar is an object detection system used majorly in military operation. It is a basic tool for every nation defence to determine the range, angular velocity and location of objects. Radar is used in detecting aircrafts, ships, spacecrafts, guided missiles, motor vehicles, weather formations and terrain. A typical radar system consists of four basic components i.e., transmitter, antenna, receiver and indicator. There will be two types of antennas one is the transmitting antenna and receiving antenna but sometimes the same antenna is used for transmitting and receiving. The term RADAR was first given by the United States Navy in 1940as an acronym for radio detecting and ranging. Since its evolution it has been used in various fields. Some modern-day applications include air traffic control, radar astronomy, antimissile systems, marine radars, ocean surveillance, outer space surveillance, meteorological perception, self-driving cars etc. There are tens to few hundred types of radar system based on the field of operation and application. Few basic types are basaltic radar, continuous-wave radar, doppler radar, FMCW (Frequency Modulated Continuous Wave) radar, synthetic aperture radar. Early warning radar systems, target acquisition radar system, surface search radar systems, height finder radar systems, gap filler radar systems and the list go on.

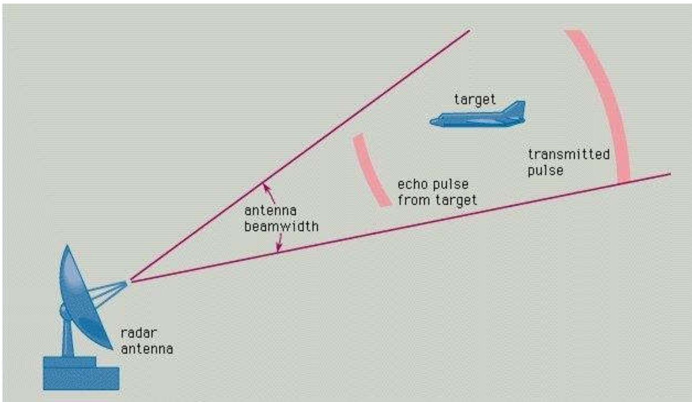


Fig (a) Principle of Radar Operation

History

Heinrich Hertz, a German physicist, demonstrated that radio waves may be reflected from solid objects in 1866. This enabled a system to detect objects from a great distance. Christian Hansmeyer, another German inventor, was the first to detect "the presence of distant metallic objects." He only succeeded in detecting a ship in a severe fog, but not in determining its exact location or distance. In 1915 a British physicist named Robert Watson- watt used this radio technology to assist the British air force during the World War 1. This help to the British government during the war was acknowledged and went on to lead the United Kingdom research established to make many advances using radio techniques. In 1939 the British had established a chain of radar stations along its south and east coasts to detect their enemies. Looking at Britain's addition of radar to its military nations like France, Germany, Italy, Japan, the Netherlands, the Soviet Union, and United States developed their own technologies that led to the modern version of radar.

$$P_r = \frac{P_t G_t A_r \sigma F^4}{(4\pi)^2 R_t^2 R_r^2}$$

Were,

P_t= transmitter power

G_t= gain of the transmitting

A_r=effective aperture (area) of the receiving antenna

This can also be expressed as $\frac{G_r \lambda}{4\pi}$

λ=transmitted wavelength

G_r=gain of the receiving antenna

σ= radar cross section or scattering coefficient of the target

F= pattern propagation factor

R_t= distance from the transmitter to the target

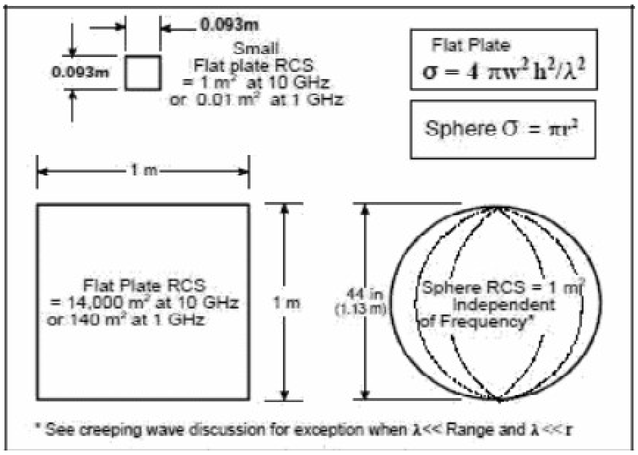
R_r= distance from the target to the receiver

IV. Radar Cross Section (RCS):

Basically, a radar cross section is defined as how detectable an object is for radar. the more the RCS, the easier for the radar to detect the object. There are certain criteria by which the radar works. For the radar it is the number of reflected waves which it can detect the object.

The factors which influence the reflected waves are

- The material which the target is made up of
- Size and shape of the target
- Electromagnetic properties of the target material



Figure(b) RCS vs. Physical geometry

Working of RCS

RCS can be considered as a projection to a specific area where the reflection of incident waves is accurate to the receiver. The specific area where the reflection of the waves is accurate is in a shape of sphere. When an aircraft is said to enter the sphere area, the aircrafts surface area is divided as 4π steradians in a sphere. For any solid shape other than a sphere the value of the RCS will be dependent upon its aspect relative to the receiver.

Shape	Radiation Direction	RCS - σ m^2
Sphere of dia. a.	Any	πa^2
Flat plate of area A	Normal to surface	$\frac{4\pi A^2}{\lambda}$
Cone of semi-angle δ	Parallel to axis	$\frac{\lambda^2 \tan^4\delta}{16\pi}$
Ellipsoid of revolution major and minor axes 2a and 2b resp.	Parallel to axis 2a	$\frac{\pi b^4}{a^2}$
Paraboloid with apex radius of curvature ρ	Parallel to axis	$4\pi\rho^2$
Circular ogive nose semi-angel, δ	Parallel to axis	$\frac{\lambda^2}{4\pi} \tan^4\delta$
Circular cylinder length L and radius a	Perpendicular to axis	$\frac{2\pi}{\lambda} a L^2$

Fig (c) Radar cross section of different objects

V. Radar absorbing material

Radar absorbing material are usually referred as RAM, they are particularly used in absorbing the radiation emitted from the radar. It reduces the energy reflected back to the radar by means of absorption. The idea of RAM is to create an impedance to the incoming radar wave. The main goal of RAM is to create attenuation to the radar wave once it enters the material. The lower the

RCS of an object the harder it is for the radar to detect the objects. RAM is used significantly in the reduction of the RCS.

The sumpf and schornsteinfeger materials were the first to absorb radar signals. During World War II, the German military experimented using this coating on submarine periscopes to reduce their reflectivity within the 20 cm radar band used by the allies. After the invention of radar in the 1930s, absorbers became widespread. The Germans created "wesch" material, a carbonyls iron powder laden rubber sheet about 0.3 inches (0.76 cm) thick with a resonance frequency of 3 GHz, as a radar camouflage for submarines. They also created Jaumann Absorbers, a multilayer device made up of alternating resistive sheets and stiff plastic. Once the Americans have to be compelled to comprehend the Germans acting on a sort of fabric that would absorb radar waves, they started researching about the fabric and came with a material referred to as "HARP" for Halpern Anti-Radiation Paint led by Halpern at MIT Radiation laboratory.

In the early 1940s another American engineer named Winfield Salisbury created another. This absorber was called Salibury screen. This screen was developed with about 25% bandwidth at resonance. The production of this screens was handled by the US rubber company. At this time another absorber design that across was a long pyramidal structure with the inside coated with Salisbury screen and the apex in the direction of propagation. After the war i.e., the post war period was filled with development of broadband absorbers using sharp pointed geometric shapes that produce a gradual transition into the absorbing material. During this time the importance of ferrites was known. 60s and 70s saw work on circuit analog materials and significant absorber thickness reductions were demonstrated using ferrite underlayers. From then on and till day we are continuously seeing more optimisation techniques for Jaumann structures and invention of new techniques.

Use in stealth technology

RAM is basically used as paints. They are coated on the edges of metal surface. The thickness and the material can vary but the basic function of it i.e., absorbing energy from a ground or air-based radar station will be same. Recent technologies include dielectric composites and metal fibres containing ferrite isotopes. The paint on the material comprises of pyramid like colonies on the reflecting surface with the gaps filled with ferrite-based RAM. This pyramid structure successfully deflects the incident radar energy in the maze of RAM.

Types of RAMS

(i) Salisbury screen

Salisbury screen is a type of passive absorber which is constructed by placing a single thin resistive sheet a distance λ/4 above a perfect electrically conductors ground plane. The bandwidth of Salisbury screen can be increased by employing more resistive sheets spaced approximately λ/4 apart, often referred to as a Jaumann absorber.

(ii) Iron ball paint absorber

This is the most common used radar absorbing material. It contains tiny metal-coated sphere suspended in an epoxy-based paint. The sphere is coated with ferrite or carbonyl iron molecules makes the electromagnetic radiation to oscillate when it enters the iron ball paint. These oscillations are then dissipated as heat. These mechanism causes damping of the electromagnetic waves. A small amount of heat is generated by the oscillations which is conducted into the airframe where it dissipates.

(iii) Jaumann absorber

Jaumann absorber consists of several homogeneous resistive sheets separated by dielectric layers. It was first introduced in 1943. It basically consists of equally spaced two reflective surface and a conductive ground plane. It can be thought of a multi-layered Salisbury screen. The spacing between the layer is λ/4. Latest Jaumann absorber use dielectric surface that separate the conductive sheets.

(iv) Carbon nano tube absorber

Since Radar work in microwave frequency range, it was realised that the wave could be absorbed by multiwall nanotubes (MWNTs). These can be applied to the aircraft which would cause radar waves to be absorbed and therefore seem to have a smaller RCS. The carbon nano tubes can be painted onto the plane. There has been lot of research going about the application of MWNTs onto the plane, it has been found that in addition to the radar absorbing properties, the nanotubes can neither reflects nor scatter visible light, which is invisible at night. Moreover, it's like painting current stealth black making the aircraft more effective. This technique could be the next big thing in stealth technology but currently there are some restrictions on manufacturing.

VI. Working Principle of Stealth Technology

The essence of radar is to put out a burst of radar energy. If the radar comes into contact with an item, this energy is reflected back to it. The time it takes for the reflected wave to return to the radar antenna is measured, and the object's distance is calculated using the data. The aircraft's body makes it simple for radar to detect and track planes. The basic purpose of stealth technology is to avoid this and make the aircraft invisible to radar.This can be done in two ways

(i) The aircraft can be shaped in a way that the radar signals are reflected in different directions but not in the same direction of the receiving antenna

(ii) Another way is the aircraft can be covered in paints, absorbers which absorb radar signals and dissipate it as heat.

The stealth aircraft are designed in such a way that their surface is completely flat and have very sharp edges. The advantage of this design is when a radar signal hits an aircraft with this design the signal is reflected at an angle away from in all directions other than the radar.

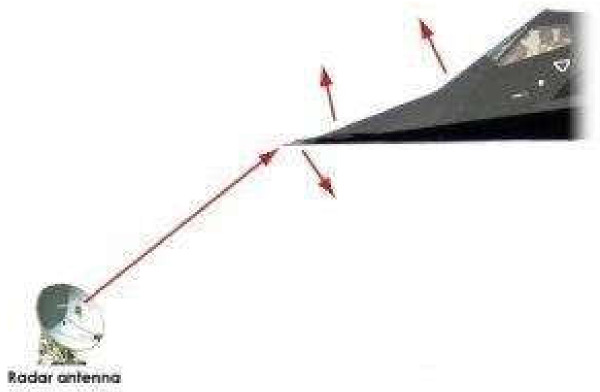


Fig (c) Scattering of radar waves

In addition to the already unique design and geometry, the surface of the aircraft is treated so as to absorb the incoming radar energy. With the unique design and treatment to the surface of the body of the aircraft, the aircraft will have an unusual signature on the radar. For example, the stealthy aircraft F-117A will have a signature of a small bird. The only exception is when the plane banks i.e., when the plane tips to the left or right. When this phenomenon happens one of the panels of the aircraft will reflect radar energy back to the receiving antenna.

Fig (d) Lockheed F-117 Night Hawk

VII. Implementation of stealth in War Planes

The breakthrough in radar technology was the primary reason for the introduction of stealth warplanes. In the 1930s, radar technology advanced dramatically, making warplanes clearly visible to foes. This was the primary motivation for incorporating stealth technology into warplanes. The first factor to examine is the radar cross-section (RCS). The RCS of an aeroplane determines its stealth. The lower the RCS of an aircraft, the more stealthy it gets.

- RADAR CROSS SECTION

Radar cross section is basically defined as the emission of certain amount of Radio waves uniformly into the sky no spherical shaped volume. It is done to specifically detect, locate and track an attacking aircraft. The emission of Radio waves takes please by radars and variously shaped antennas are used to give precise directional tracks of the enemy aircraft

The two factors which can reduce the RCS of an Aircraft is

1 The size and shape of the aircraft in detail.

2 The electromagnetic properties of the Air frame material.

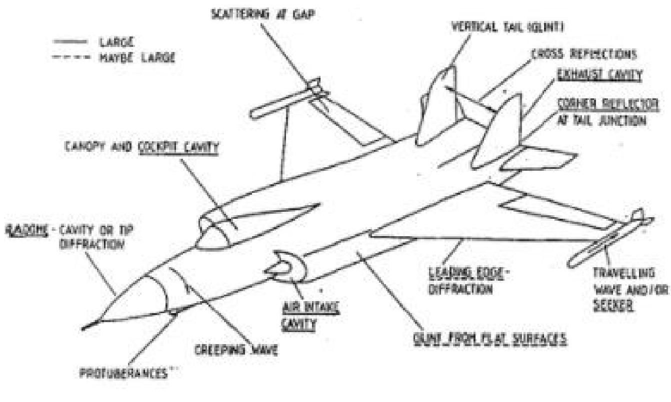


Fig (e) Contribution to the radar cross section

Considering the Above figure, we can totally see on how the RCS of an aircraft is decreased by the change in the shaping of the air craft. It drastically reduces the reflection of the incident waves in the general direction of the receiver. RCS of an aircraft can also be decreased by quoting (RAM) radar absorbent material on the aircraft. It basically absorbs the electromagnetic energy/radio waves emitted by the radar.

VIII. Modification

The most common and successful method of detecting and tracking an aeroplane is via radar. Because radar was so good at detecting and tracking aircraft, everyone sought to figure out how to strike the enemy while avoiding being noticed by the radar.

Radar detects aircraft by sending out electromagnetic waves into the atmosphere. When the antenna (receiving end) is stuck by an aeroplane, the electromagnetic waves reflect back to the antenna (receiving end).

Because of their cylindrical shape at the front end and tail at the back end, conventional aircraft are easily detectable by radar.

Metals are also one of the most common causes of aircraft detection. The waves are reflected and sent back because of their tremendous reflecting properties. An alternative, for all these problems Radar Absorbing Material (RAM). It is a specialist class of polymer- based material applied to stealth aircraft to reduce the RCS of the aircraft, which makes it harder for the radars to detect them. They are also used in unmanned bombing aerials systems like Boeing X-45.

Radar absorbing material is applied to whole of the external skin or to the more of the areas where the reflection of the radio waves is high. Example surface edges - it basically works on the principle of absorbing waves emitted by the radar and minimizing the reflection of radio waves from surface edges. RAMs are combined with other stealth technologies, such as planar design and hidden engines, to make the military aircraft almost invisible to the radar.

Information about the composition of RAMs is guarded by the military. Most RAMs consist of ferromagnetic particles embedded in a polymer matrix having a high dielectric constant. One of the most common RAMs is called iron ball paint, which contains tiny metal-coated spheres suspended in an epoxy-based paint. The spheres are coated with ferrite or carbonyl iron. When electromagnetic radiation enters iron ball paint it is absorbed by the ferrite or carbonyl iron molecules which causes them to oscillate. The molecular oscillations then decay with the release of heat, and this is an effective mechanism of damping electromagnetic waves. The small amount of heat generated by the oscillations is conducted into the airframe where it dissipates.

Another type of RAM consists of neoprene sheet containing ferrite or carbon black particles. This material, which was used on early versions of the F-117A Nighthawk, works on the same principle as iron ball paint by converting the radar waves to heat. The USAF has introduced radar-absorbent paints made from ferrofluidic and nonmagnetic materials to some of their stealth aircraft. Ferrofluids are colloidal mixtures composed of nano-sized ferromagnetic particles (under 10 nm) suspended in a carrier medium.

Ferrofluids are superparamagnetic, which means they are strongly polarised by electromagnetic radiation. When the fluid is subjected to a sufficiently strong electromagnetic field the polarisation causes corrugations to form on the surface. The electrom3agnetic energy used to form these corrugations weakens or eliminates the energy of the reflected radar signal. RAM cannot absorb radar at all frequencies. The composition and morphology of the material is carefully tailored to absorb radar waves over a specific frequency band.

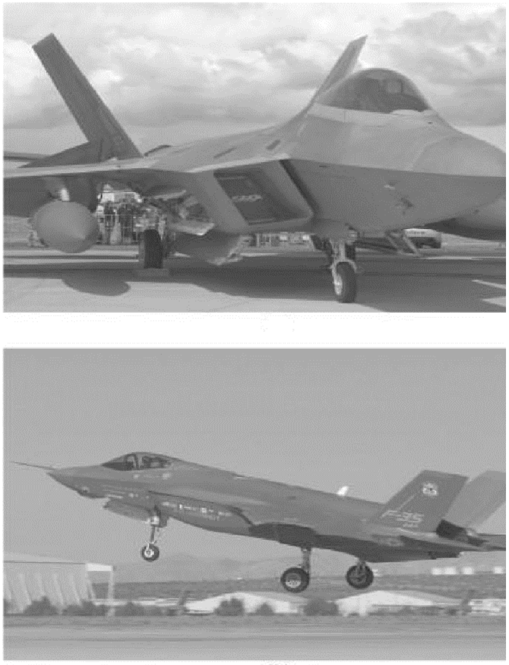


Fig (f) Lockheed F-22 Raptor

IX. Shaping

Shaping place an important role in making an aircraft stealthy. First the radar glint areas in an aircraft are identified and certain combination of techniques are used to minimize the returns of the electromagnetic waves to the receiving antenna.

Reducing the RCS of an aircraft makes the aircraft invisible to the radar. So, the most important profile of the aircraft must be selected. Generally, the front part of the aircraft can be modified using special aero dynamic shapes, such as delta wings and blending them into the fuselage. Right angles are a big "NO" for stealth aircraft.

For the lower back scattering of the waves from ground radar, the engine inlets must be placed at the top of the body and the tail fins stabilizes should be canted inwards. All the weapons must be carried from the inside of the plane and the antennas should be covered or hid from the view of special radomes. Example the Tom hawk cruise missile reportedly uses of selectively transparent radome to supress the reflection.

Few features of the aircraft must be sacrificed to achieve certain desirable features.

By mounting engine inlets at the top or fuselage, it cuts the back scatter when the aircraft is flying over the radar. Only drawback of placing the engine at the top is, it may create airflow problems to the engines during the high – angle – of attack. Also moving the engine inside means, less weapons or less fuel capacity. Many advancements in the aircrafts are made and are successful to but they have kept it confidential from the public.

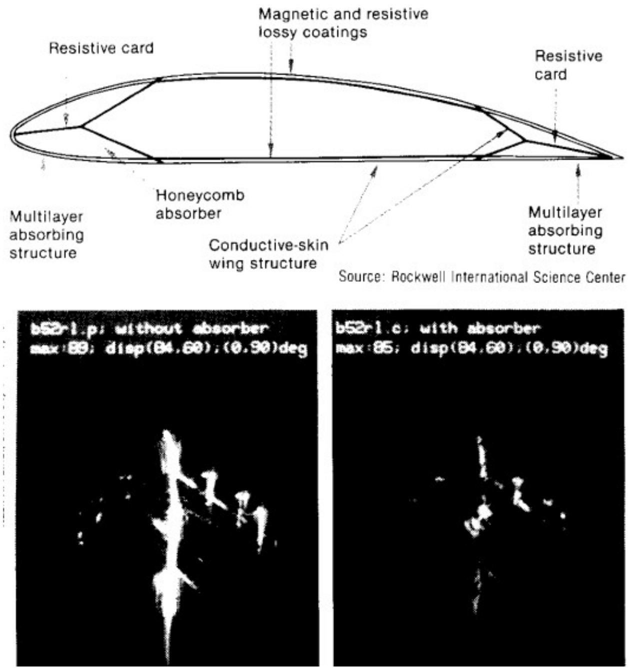


Fig (g) The aircraft wings in the fig are using a mix of material and aero dynamic structure to reduce the RCS of the aircraft. Radar absorbing structure at the edges are optimized to absorb radio radar waves.

X. Plasma stealth

Plasma stealth which is still being researched on, is a great technology which might even work better than Radar Absorbing Material (RAM). Basically, plasma which is a fully ionised quantity of air with low density that comprising of equal positive and negative ions, has the property of interacting with EM energy. Plasma is also known as the 4th state of mater. If an aircraft were to be enclosed with a covering of plasma, the incident radar energy would interact with plasma and will get cancelled. The main advantage of plasma stealth is that, it not only directs the radar energy away but it also interacts with it and attenuates it. Hence, a stealth system which is based on plasma stealth will either be near to impossible for the bi-static or multi-static radar system. But plasma stealth is just a topic and has still not be incorporated in any of the aircrafts.

CONCLUSION:

Stealth technology is the future of air wars. The more advanced the stealth technology, the more confident and stronger the country becomes. Stealth technology can also be implemented in ships, submarines and transport planes. Stealth with both the adversarial sides would confer the benefits to both the attacker and also the defender. It's been seen that the defender needs to acquire the enemy for defence to be effective. Thus, for the defender incorporating stealth isn't as important an attribute because the ability to detect the intruder. Almost all nations with a desire to keep up powerful military forces are pursuing aircraft programmes, either indigenously or unitedly with other technologically more advanced countries. Access to stealth technology is probably going to be the key deciding actor within the relative effectiveness of air forces within the twenty-first century. The most important requirement is to be able to avoid being detected. More than countries fighting over it, "it's a fight between technologies".

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