Stealth, Counter-Stealth Technology, and Techniques for Enhancing Stealth and Counter-Stealth

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Abstract: This study mainly focuses on stealth and counter-stealth technology, as well as various enhancing techniques of stealth and counter-stealth, and the recent developments in these fields. Plasma Stealth, IR Stealth, Magnetic Signature Reduction, Acoustic Signature Reduction, Active Cancellation Systems, Passive Cancellation Systems, and materials used for stealth are all discussed in this article.Signature reduction and operational tactics is a most effective combination. It also covers counter-stealth technology, Forward Scattering, VHF, UHF, HF OTH Radars, electronically scanned radars, Space-Based and AEW&C Radars, Radars with High Power Emitters and Extremely Sensitive Receivers, Multi-static Radars, Passive Radars, and Passive Emitter Location Systems.

Index Terms: Stealth and Counter-Stealth technology, RCS, Plasma stealth, RAMs, Radars

I. Introduction

The effective implementation of stealth increases the mission success possibilities and therefore aircraft, ships, and submarines can dominate the battlefield. All military platforms have visual, radar, thermal (infrared), and acoustic signatures. Stealth reduces these signatures and there are numerous strategies used to accomplish this reduction [1], [3]. All of these signatures are discussed in this paper.

For nearly half a century, stealth technology has been refined and assessed. It has been used operationally for more than two to three decades. On other hand, stealth technology is still a sensitive subject. Due to its secrecy, this technology is generally safeguarded under black programs [1], [6]. This is done to shield the technology from being exploited by the enemy.

There are various approaches to achieving RCS reduction. The one applies to shape the structure. In a conventional radar configuration, the transmitter and receiver are collocated, so the stealth aircraft, submarines, and ships are shaped to reflect the incoming radar signal in a direction other than directly back to the radar. Another approach is to absorb, cancel or scatter the incoming radar transmitter signals in order to prevent them from being reflected back to the radar receivers. This is achieved by the application of special coatings to the structure or by using special composites or materials during design.

The successive implementation of passive cancellation and active cancellation techniques are also helpful to achieve stealth. Cancellation is achieved by adding a skin to the surface of the platform which acts as a secondary scattered and cancels the reflected field from the primary target[1],[7].

Plasma Stealth Technology, also known as Plasma Active Stealth, is one of the methods for absorbing RF waves. Although there are few applications for this method, some experts believe it has potential for future stealth designs.
The solution to counter stealth is based on using passive receivers. A cell phone network can be used in a similar way to a multiple static radar network in terms of principle. The multiple RF signals scattered off a low visible vehicle's surface are collected utilizing mobile phone transmitter nodes spread out widely in a defended area. Data from numerous cell phone base stations can be processed using high-speed computers and processors within an air defence system to gather positioning and tracking information about stealth targets[1],[8].

To identify low observables, a variety of countermeasures can be used. Some of the proposed options are bistatic, multiple static and low-frequency radars. Similarly, high-altitude airborne and space-based radar systems have some geometrical advantages against stealth weapons due to their look-down capacity. Detection systems that are networked are also promising new ways to combat stealth. The signal-to-noise ratio would be improved by processing data from numerous nodes by increasing the effective number of transmitters or receivers, as well as the variety of kinds and deployment geometry. Each approach is capable of identifying low observables to some extent [1].

There are some areas where stealth aircraft could be improved. Stealth aircraft can't fly as fast as regular fighter planes and aren't as manoeuvrable. They also have a smaller payload because most of the payload is carried internally to reduce radar signature. Stealth aircraft are significantly more expensive than normal combat aircraft.

Signature

A signature is any one-of-a-kind indicator of the presence of certain material or troops; especially the characteristic electronic emissions emitted by a certain type of vehicle, radar, radio, or unit.

RADAR CROSS SECTION (RCS)

It is the incident radar beam's reflection is called RADAR CROSS SECTION (RCS).

LIDAR Signature

It is the same as Radar but the user LASER in place of the radar beam. Image of object called Laser Cross Section.

Infrared (IR) Signature

It is the Emission of infrared radiations by hot parts of the vehicle.

Acoustic Signature

It is the detection of Sound Emitted from the body and Using of SONAR comes under this category.

Visible Signature

It is the detection of the vehicle by Naked-eye or devices like Cameras, Night Vision devices, etc.

II. TECHNIQUES TO ENHANCE STEALTH

Shaping the structure

The shape of conventional aircraft, submarines, and ships disclose many surfaces that can reflect incident signals back to the radar including all cockpit instruments, inlets, compressors, turbine blades, funnel, stabilizers, payloads, and corners. Reducing RCS by designing the external structure of these assets with shifting curves, bends, arcs, and twists to reduce RCS. The structure of these military assets does not have regular reflection characteristics, and it generally absorbs the radar signal's energy inside the curve, reducing its energy. Reducing RCS by avoiding right angles between surfaces, Metal plates meet orthogonally at junction forming corner reflectors so that radar penetrating through the wall loses energy by bouncing off the wall. The RCS can also be reduced by placing the engines and munitions inside the wings of the aircraft.

Materials used for stealth Design

Metal matrix composites or advanced polymer composites such as CFRP have been used in modern aircraft to reduce the RCS so that radar systems or any other detection device are not able to detect aircraft. Coating or painting the structure of aircraft with special metallic finishing is the preferred way to prevent the penetration of RF signals through composites. Forms of composites, which consist of some poor conductors of electricity, such as carbon products, and insulators, such as epoxy resin, are used in the airframes to cancel the forms of creeping and traveling waves, by resisting electrical and magnetic currents which reradiate [1],[3].For the most part, a special class of polymer-based material is used on the surface of stealth aircraft, which works on the principle of absorbing electromagnetic wave energy to reduce the intensity of the reflected signal.

Iron ball paint, which contains microscopic metal-coated spheres suspended in epoxy-based paint, is one of the most frequent RAMs. The spheres have a ferrite or carbonyl iron coating. Electromagnetic radiation is absorbed by the ferrite or carbonyl iron molecules in iron ball paint, causing them to vibrate. With the emission of heat, the molecular oscillations decrease, and this is an effective process for dampening electromagnetic waves. The oscillations generate a modest quantity of heat, which is conducted into the airframe where it dissipates [9].

Neoprene sheet containing ferrite or carbon black particles is another sort of RAM. By converting radar signals to heat, this material functions in the same way as iron ball paint. Ferrofluids are colloidal compositions made up of nanoscale ferromagnetic particles suspended in a carrier medium (under 10 nm). Ferrofluids are superparamagnetic, which means that electromagnetic radiation polarises them substantially. Polarisation causes corrugations to appear on the surface of a fluid when it is exposed to a sufficiently powerful electromagnetic field. The electromagnetic energy employed to create these corrugations reduces or eliminates the reflected radar signal's energy. The material's composition and form are carefully selected to absorb radar signals at a specified frequency band [9].

By absorbing the incoming signal and converting the RF energy into heat, or by destructive interference, RCS can be reduced. Different RAMs are utilized to get desired RCS results over the maximum possible frequency range with their appropriate dielectric or magnetic properties. RAM technology is based on the design of achieving suitable impedance which poses good matching and absorption properties, allowing the RAM to accept and then reducing the intensity of the incident wave [4]. RAM’s dielectric properties can also be explained in terms of naturally occurring radar electromagnetic waves bouncing off conductive materials. The molecular structure of highly compressed materials, on the other hand, causes RF energy to be used up by producing heat. The heat is then transferred to the aircraft and dissipated, while the remaining RF energy loses its effectiveness, due to friction, inertia, and molecular oscillations. Finally, this results in less reflection back to the radar receiver [1], [2].

Figure 1 RAMsFoam and Thin Radar-Absorbent Sheets [1], [5]

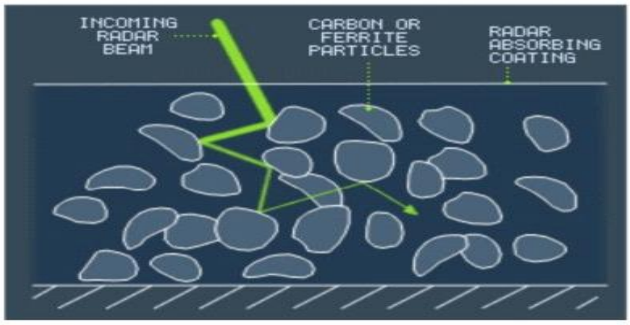

Figure 2 RAMs illustration [1],[2]

The destructive interference principle (also known as "resonant RAM" or "impedance loading") is based on coatings or the “Salisbury Screen" approach, which uses 53 cancellations of multiple reflections to reduce RCS. RAM is made up of a variety of materials. Low dielectric foam (epoxy), lightweight highly compressed foam (urethane), thermoplastic foam (polyetherimide), surface coating lightweight foam (urethane), thin MAGRAM silicone resin sheet, and metalized Kapton resistive card (R-card) are six RAM examples [1],[5].

Passive cancellation

Coatings of resonant absorbers are utilized in this technology to cancel incoming signals by reflecting one from the front and the other from the opposite side of the layer. The presence of an opposing face wave that travels one-half wavelength longer than the one reflected from the first layer is necessary. If the thickness is correct, the second reflection will have a 180-degree phase difference from the first layer reflection, cancelling the first and second waves. This method is based on the thickness of the layer or one-fourth of the wavelength match. The method is also called as Salisbury screen. A resistive screen in front of the reflective backplate reflects half of the incoming radar beam (blue wave in Figure) back to the incoming direction (purple wave in Figure), while the other half goes through and reflects from the grey plate (red wave in Figure). Red and purple waves cancel each other when the distance between these two plates is one-fourth the wavelength of the radar signal. This cancellation is characterized as a narrowband approach since such a thickness is only effective for specific frequencies.

On another side, from a RAM application techniques perspective, dielectric and magnetic loss mechanisms are categorized as broadband absorbers, and they can be used to cover a greater frequency range than passive cancellation coatings.

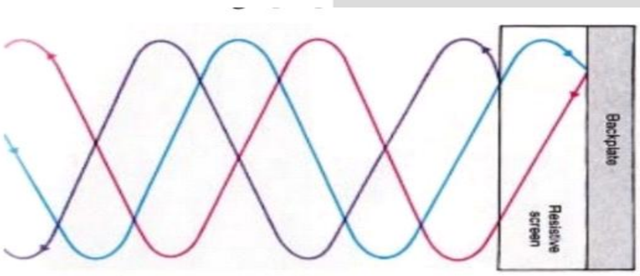

Figure 3 The Salisbury Screen [1], [3]

Figure 4RCS by Scattering the Incoming Signals [1],[4]

Active cancellation

This technology employs the insertion of secondary sound that is specifically designed to negate the primary radar signal reflected from the structure, hence eliminating unwanted noise. By altering and retransmitting the incoming radar signal, the aim is to decrease the RCS while cancelling the reflected radar signal. The execution of such a technique necessitates knowledge of the incident angle, intensity, wave type, and received signal frequency, as well as a system capable of analysing the echo of its structure and generating cancellation pulses.

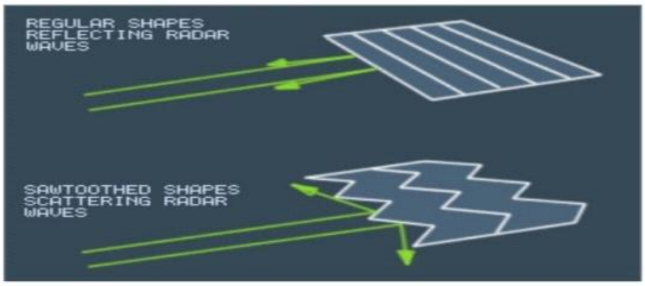

Figure 5 Serrated Shape for RCS Reduction Measures [1], [2]

Plasma Stealth Technology or Plasma Active Stealth

Plasma is a mixture of positively and negatively charged ions at a quasi-neutral state with a total electrical charge almost equal to Zero. Its free electrons build a strong response against electromagnetic radiation. Radar frequencies, polarizations, and power densities can all be absorbed and scattered by it. RCS and LRCS are thus reduced by covering the structure of assets with plasma.

Figure 6 Plasma engulfed aircraft (source nanopdf.com)

IR Stealth

Because of molecular vibrations, electrons oscillate. These oscillations allow electromagnetic coupling, which results in energy emission. Infrared radiation is the name for this type of emission (IR). The wavelength spectrum of infrared radiation ranges from 0.78 nanometers to 14 micrometers, and the amount of radiation emitted is mostly determined by the physical temperature of the item (proportionally). The molecular structure of a substance and the surface conditions influence its emissivity properties. The material absorbs or reradiates IR energy that comes from another body, depending on its emissivity characteristics. Material specifications affect absorption and reflection properties.

Because IR detectors and missile guidance systems can exploit a target's IR emissions to detect it, IR energy considerations are vital in a stealth design. To prevent detection, decoys or flares must be used to reduce an aircraft's IR signature, and the sensor must be jammed by releasing high-power signals at the detector.

IR signal reduction is focused on engine exhausts. The backside of an engine is the primary source of infrared radiation in an aircraft, and when the afterburner is used, there is a significant increase in heat. The engines' IR signature is reduced by using exhaust masking and situating the engines on top of the body and wings. An IR detector can quickly detect the hottest areas of the tailpipe over the aircraft's rear conical region. Sensors can only detect the hot sections of the nozzle surface outside of this sector. The modification of exhaust geometry is another way to reduce IR signature. Exhausts with a flat and wide design are particularly effective in this regard. The second significant source of IR radiation, after engine heat, is kinetic heating of the aircraft body. Closed-loop cooling systems and special materials, such as IR signal absorbent material, can be utilized to dissipate heat from the body, the engine, and the exhaust system. Another way to limit kinetic heating is to dump the heat into the fuel. At high Mach numbers, however, the high temperature caused by kinetic heating is unavoidable [1].

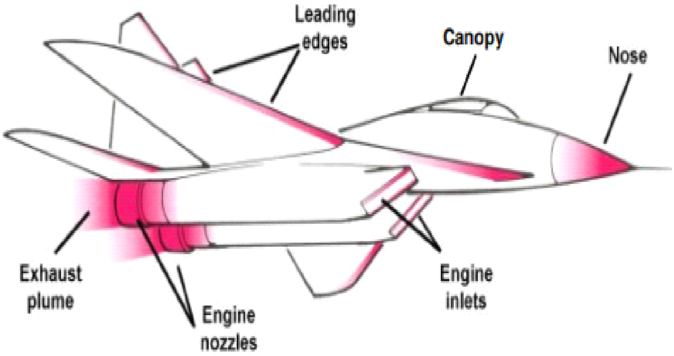

Figure 7 Aircraft thermal radiation sources (source www.aerospaceweb.org)

Acoustic Signature Reduction

Acoustics in stealth play a vital role in submarine stealth as well as for ground military vehicles. Submarines use extensive rubber mountings to isolate and avoid mechanical noises that could reveal their location by passive sonar signals. Stealth aircraft try to avoid being tracked by sonic booms.

Magnetic Signature Reduction

A vessel traveling on a water surface or underwater creates some disturbance in the earth's magnetic field. It can be minimized by the counter magnetic field of suitable strength and in-depth understanding of the vessel. Non-magnetic materials should be utilized to construct the vessel.

III. TECHNIQUES TO ENHANCE COUNTER-STEALTH OR ANTI-STEALTH

Counter-stealth or anti-stealth tactics are used to negate or reduce the military's stealth advantages. While one side attempts to increase an aircraft's survivability by minimizing detectable signal traces, the opponent, on the other hand, uses those same characteristics to improve detection capability and diminish the effectiveness of stealth technology. Traditional monocratic radar systems that cover the microwave band are typically defeated by stealth technologies. Radar-based air defence systems are designed to first detect targets before attempting to attack them. The basic principles of engagement for effective counter stealth purposes are early warning (EW) detection radar and acquisition radar, tracking with fire control radars, developing a fire control solution, slewing, and arming the weapons for firing position, fusing the warhead, and conducting damage assessment [11].

All current stealth aircraft were designed to counter X-band radars, but those are rendered useless if the radar operates in s-band, and even more so if the radar operates in L-band. The wavelength of the radar is the cause of the stealth aircraft being tracked; radar working in L-band produces wavelengths with size relative to the aircraft itself and should exhibit scattering in the resonance region rather than the optical region, so that most existing stealth aircraft will go from sightless to visible [12].

Transmitting more energy and utilizing a more sensitive receiver are two ways to improve radar detection capability. Although this enhances effectiveness, it necessitates an increase in size and weight, which reduces mobility and raises costs. Furthermore, increased receiver sensitivity means more clutter and a higher number of false targets. Extra clutter and erroneous targets clog up the instrument, slowing down the radar's computational performance. Only very advanced processors, which are also more expensive, can sort out these effects [1],[3].

Despite these disadvantages, increasing the radar transmitting power and receiver sensitivity allows it to obtain greater target reflections. As a result, higher reflected power improves the radar's ability to form the target's signature on the radar.

Radar scanning technology and processing ability are two further features worth considering. Normally, traditional radars cancel out signals that are below a certain threshold value and only show targets that are relevant. The energy returned from low observables is often below the threshold because of their minimal RCS values, and so the target is undetected. Electronically scanned radars, on the other hand, with their fast-scanning speeds, may evaluate suspicious signals over a longer period of time, examining targets of interest with the main broadcast beam and many received beams.

The "track-before-detect" method is used in a comparable operating mode that does not require a threshold. To distinguish the genuine goal from the clutter and other unwanted data, this technique employs "computing-intensive algorithms." This discrimination takes place by tracking all received signals over a set length of time, then identifying and cancelling bogus targets based on their "irrational and unrealistic actions [1],[3]." All forms of radar counter stealth capabilities will benefit from these types of applications.

Forward Scattering, VHF, UHF, HF OTH Radars

These radars are not affected by RAM or shaping measures since it fulfils the physics of resonance or Raleigh scattering regions. When compared to ordinary higher frequency radars, it can identify stealth aircraft from a greater distance. For the purposes of early warning, this is the preferred method.

Radars with High Power Emitters, and ExtremelySensitive Receivers

The range of detection and tracking precision increased in these radars because sending more power to stealth aircraft means getting more power reflected back to the receiver. Sensitive receivers also increase the possibility of detecting a target with a low signature.

Electronically scanned radars

Electronically scanned radars with faster scan speeds may track and engage multiple targets at the same time.

Bistatic, Multi-static Radars, Passive Radars, and Passive Emitter Location Systems

Due to the decreasing effectiveness of RCS reduction methods, which are focused on combating monostatic radars with shaping procedures, a viable solution to detect stealth airframes has emerged. To overcome the next generation of stealth assets, which focus reflections at very few angles with narrow lobes, multi-static radar networks with numerous units may be needed.

Space-Based and AEW&C Radars

Look-down radar improves anti-stealth qualities and is difficult to jam when it covers a wide area or has a long detection range.

IV. CONCLUSION

Enhancing stealth and counter-stealth technology is vital for any defence force aiming for superiority over their opponents. For next-generation stealth assets, optimization of stealth designs and ongoing research into new materials are essential.By comparing stealth and anti-stealth technology, it's possible to demonstrate the potential vulnerability of stealth aircraft.By using the limitations of stealth technology, counter-stealth technologies develop. Therefore, counter-stealth technologies are becoming more and more relevant, and research in this field is ongoing around the world.

References

[1] Serdar Cadirci, RF stealth (or low observable) and counter-RF stealth technologies implications of counter-RF stealth solutions for Turkish Air Force (Master's thesis), Monterey, California: Naval Postgraduate School, March 2009.

[2] F/A-22 Media Library, Figure, HYPERLINK "http://f-22raptor.com/ HYPERLINK "http://f-22raptor.com/st_getstealthy.php"st_getstealthy.php(Accessed February 2009).

[3] Doug Richardson, "Stealth Warplanes: Deception, Evasion, and Concealment in the Air," MBI Publishing Company, New York, 2001.

[4] Dimitris V. Dranidis, "Airborne Stealth in a Nutshell-Part I," the Magazine of the Computer Harpoon Community http://www.harpoonhq.com/waypoint/, (Accessed February 2009).

[5] Federation of American Scientists Systems Assessment Group, Missile Technology Control Regime Annex Handbook "Item 17 Stealth," (Accessed February 2009).

[6] Bill Sweetman, "Stealth Aircraft: Secrets of Future Airpower," Motorbooks International Publishers and Wholesalers Inc., 1986.

[7] K.M. Yong, and M. Matthew, "Radar Cross Section Reduction: Geometric Control of Discontinuities Using Serrated Edges (Master's thesis)," Naval Postgraduate School Monterey CA, March 1998.

[8] Tao Yue, "Scouting for Surveillance, Detection of the B-2 Stealth Bomber and a Brief History on Stealth, The Tech Online Edition, http://tech.mit.edu/V121/N63/Stealth.63f.html, (Accessed October 2008).

[9] 13 - Polymers for aerospace structures, Available online 27 March 2014, Introduction to Aerospace Materials, Woodhead Publishing Limited, 2012.

[10] Tao Yue, "Scouting for Surveillance, Detection of the B-2 Stealth Bomber And a Brief History on Stealth, The Tech Online Edition, http://tech.mit.edu/V121/N63/Stealth.63f.html, (Accessed October 2008).

[11] Allen E. Fuhs, and David C. Jenn, "Fundamentals of Stealth with Counter Stealth Radar Fundamentals: Applied to Radar, Laser, Infrared, Visible, Ultraviolet, & Acoustics," Naval Air Warfare Center Weapons Division China Lake, CA, Lecture Notes, 1999.

[12] Swayam Arora, Raman Preet Kaur, Stealth Technology and Counter Stealth Radars: A Review, Vol.3, Issue 12 (December 2013), PP 15-19.