Stealth

Rader Cross Section Reductions on Aircrafts

Name: GU JIATENG

Tutor: Dr Dan Brown

1. Contents

2. Intended Readers

This report is intended to be read by members of a research group who have an interest in physics and aeronautical engineering and wish to have a brief exploration of the development in RCS reduction technology

3. Executive Summary

- RCS reductions are the primary method to reduce radar observability.
- The main methods for RCS reductions are purpose shaping, absorption and trapping
- RCS reductions are accompanied by limitations such as high costs and poor aerodynamic performance

4. Introduction

Since radar was first invented to watch the sky, it has been a long history for the opponents trying to penetrate the warning system to deliver airstrike. Early attempts by the German were to cover the surface of the aircrafts with wood and cloth to reduce RCS. (H-299 bomber was an accidental invention.)

5. Radar Cross Section (RCS)

In the early 20th Century, Russian Mathematician **Petr Yakovlevich Ufimtsev,** first pointed out that RCS is also dependent on the physical geometry of the target, in his paper "Method of Edge Waves in the Physical Theory of Diffraction". The paper showed theoretical possibilities for large objects, such as military aircrafts, to reduce RCS. RCS is the hypothetical area required to intercept the transmitted power density at the target such that if the total intercepted power were re-radiated isotropically, the power density actually observed at the receiver is produced. And for a mono-wavelength radar wave, it is given by the equation: $P_r = \frac{P_t G_t}{4\pi r^2}\sigma\frac{1}{4\pi r^2}A_{eff}$. (Note, G_t is the gain of the radar transmit antenna,σ is the radar cross section of the target, A_{eff} is the effective area of the radar receiving antenna.) In this report, we will focus on introducing and evaluating some of the most commonly used radar stealth technologies.

6. Methods of RCS Reductions

6.1 Purpose Shaping

Ufimtsev's theory was first adopted by the engineers in Lockheed Martin to analyze RCS for various geometric shapes. Purpose shaping is to direct most of the reflected radar waves away from the incident direction. Hence, it will create a "cone of silence" along the direction of the aircraft's motion.

Fig 1. The planes at the front and the airfoils sweep backwards sharply. This greatly reduces rader echoes in the forward 45 degree direction.

6.1.1 Plane Alignment (facet)

According to optics and electromagnetic theories, curved surface usually reflect radar waves in a collection of directions, while in contrast, a plane only reflect them in one direction. Though SR-71 was the first aircrafts included RCS reduction at the beginning of the project, F-117 (Fig 1.) is recognized as the first stealth operational military aircraft. It employed "facet" methods. Technically, there is no curvature on F-117's surface. There are only planes and sharp transitions between planes so that there will be nothing normal to the incident radar waves. Hence, no radar wave will be reflected back to the transmitter. At the same time, the number of planes and angles are kept at minimum to reduce directions of radar signal reflection. Most of the incident radar waves are deflected away from the source to achieve radar stealth.

6.1.2 Flying Wing

Flying wing is an ideal stealth shape for aircrafts. It minimizes the number of leading edges, which in turn, reduces radar echo signals. German Ho 229 is the earliest stealth plane, though it was by coincidence. Its design was a flying wing. Northrop's B-2 "Spirit" bomber also adopted flying wing shape with some "zig-zag" shape at the tail, reducing its radar echo to as small as a 0.1 m^2 metal object.

6.2 Materials and Absorption

6.2.1 Materials of the Aircrafts

Metal, the most commonly used material in aero-engineering, is a good radar echo producer. Modern military aircrafts, such as B-2 Spirit and F-22 Raptor, use a lot of composite materials instead of metal. Those materials are blends of carbon and other chemicals. They are reflective.

6.2.2 Radar Absorbing Materials (RAM)

Usually non-resonant RAM are used to coat the reflective surface. They will absorb incident radar waves and convert a large percentage of them into heat. Resonant RAM are seldom used because, in contrast to non-resonant RAM, one type of this material only responds to create destructive interference pattern against one specific wavelength.

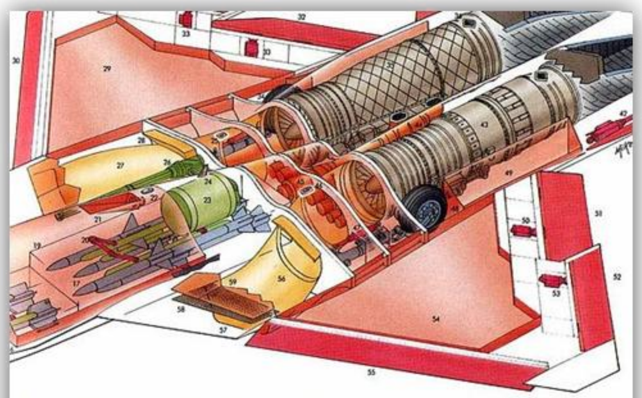

Fig 2. The intake of Northrop's YF-23 is curved. It well blocks and traps the incident radar waves to hide the engine blades.

6.3 Trap

Engine blade is one of the major contributions to radar wave reflections. Modern stealth designs usually bury the engine deep inside the body to block the incident radar wave. As shown by Fig 2, the intake of YF-23 prevents radar waves shining directly onto the blade. At the same time, incident radar waves will reflect around inside the intake. Only a negligible fraction of them will be able to escape. Among the escaped, only a small fraction will be in the direction of the receiver. Hence, the engine blades are kept out of the radar's "sight".

6.4 Latest and Possible Future Development

Powered by the advancement in electromagnetism theories and computer technology, we have achieved a great improvement in stealth technology. Besides shaping, which is the major area of improvement, engineers and scientists are focusing on the following two areas.

6.4.1 Plasma Stealth.

The principle of plasma stealth is to generate an ionized "layer" surrounding the aircraft to reduce RCS. Experimental data collected from the returning spacecrafts and payloads has shown that plasma layer is a good absorber of electromagnetic wave. However, the current obstacle is to produce the device both light and stable enough to be mounted onto aircrafts.

6.4.2 Active Intelligent Signal Cancellation

This is the technology to detect the incident radar waves and emit out-of-phase radar waves correspondingly to produce destructive interference patterns to cancel out the radar echo. It requires very powerful computers and very sensitive detectors and emitters.

7. Limitations

7.1 Aerodynamic Performance

Stealth designs sacrifice parts of aircrafts' aerodynamic performance for stealth. Extreme examples such as F-117 and B-2 are unstable on 3 axes, poor in maneuvability and unable to perform supersonic flight.

7.2 Costs

High costs incur in designing, manufacturing and operating. Stealth aircrafts' designs are much more complicated than normal aircrafts. Heavy financing is required to developing computer programs to analyze RCS and aerodynamic performance. The special materials used, small quantity of final products and attempts to keep secrecy dramatically rise the price of each aircraft. For example, 21 B-2 bombers, in total, cost the United States about 45 billion US dollars. Radar stealth aircrafts also have high maintenance requirement for their specially coated skin. Not mentioning the budget spent on short-lasting RAM, the specially built and air-conditioned hangars , and the maintenance team alone need a large amount of money to operate.

7.3 IntensifyingOther Aspects of Detection

Purpose shaping usually aims to reduce RCS in one direction. It directs radar waves to other directions and intensifies radar echoes in those directions. For example, F-117 has an intensified radar echo in the direction of the cone above the horizontal plane, which makes it more observable in that direction.

Non-resonant RAM transfer electromagnetic energy into heat, which increase the surface temperature and make aircrafts more vulnerable to infra-red detectors.

8. Conclusion

Other than radar stealth, visual, infrared and acoustic stealth are also very important today. Since F-117's first operational mission in year 1989, stealth planes have been recognized as the vanguards and the power multipliers in war. Their stealth ability allows them to deliver surgical airstrike against the key targets under most dangerous battle environment. With the increasing advancement in anti-aircraft technology, major military superpowers are focusing on developing more effective but yet cheaper stealth technology. F-35, as an example, is a good balance of stealth, aerodynamic performance and cost.

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