AERODYNAMIC BODY SHAPING METHOD FOR A STEALTH FIGHTER AIRCRAFT

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Introduction

In the field of aviation the size and shape of the aircraft plays a vital role in determining aerodynamic performance. Shaping is a very important factor for achieving air worthiness parameters such as lift, drag, speed and also for cost considerations. Effective size of complex shape such as an aircraft can be measured by determining its Radar Cross Section (RCS). RCS is the size of the target as seen by the radar. For military applications the interest is in making an object's RCS small so as to make it difficult to identify military targets such as missiles, tanks, ships and aircrafts. The RCS reduction technique by aerodynamic body shaping is one of the basic methods of RCS reduction technology to achieve stealth. In other words stealth technology can be termed as RCS Reduction Technology.

Key words : RCS (Radar Cross Section), dbsm (Decibels Per Square meter)

RCS of a Complex Target

Complex targets are those for which the overall shape is complex. Complex targets such as aircrafts, ships and missiles have a variety of forms and shapes. The representation of such irregular geometry for which equations can be written may lead to errors. As such RCS of a complex target is a complicated function of viewing aspect angle and frequency.

With few exceptions, the high-frequency Radar Cross Section of a geometric shape can be attributed to combinations of the following analytic components:

- Specular scattering points
- Scattering from surface discontinuities

  i) Edges
  ii) Corners
  iii) Tips

- Creeping waves or shadow-boundary scattering
- Traveling-wave scattering
- Scattering from concave regions
- Multiple scattering points

Contributors to Aircraft Radar Cross Section

Consider the Fig.1 as shown as an example to illustrate complex target radar cross section.

- Radome- if radome is transparent, then radar wave "sees" inside the cavity containing A/C Radar. Black boxes inside may form retro-reflectors. If radome is opaque, than tip diffraction may occur.
- A smooth rounded surface may have a creeping wave for the K shown.
- Cockpit is a cavity and may be a large contributor to RCS.
- The propagation vector k is about tangent to surface. The incident wave encounters an edge which is a scattering device.
- Multiple reflections may occur. This may be more important for bistatic radar.
- Large flat areas may cause glints. "Flat" is in quotes because a surface may have n.k. and appear to be flat in radius of curvature.
- Ordnance and drop tanks contribute to RCS.
- Edge diffraction (like a wedge) occurs at sharp leading edges and trailing edges.
- Inlet cavities may give very large RCS.
- The rudder and elevator may form a right angle dihedral which acts as retro-reflectors.

Relative Size of Contributors to RCS

Consider Fig.2 shown the size of RCS depends on aspect angle. Magnitude stated is for maximum RCS from the item.

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Manuscript received on 24 May 2006; Paper reviewed, revised and accepted on 08 Mar 2007

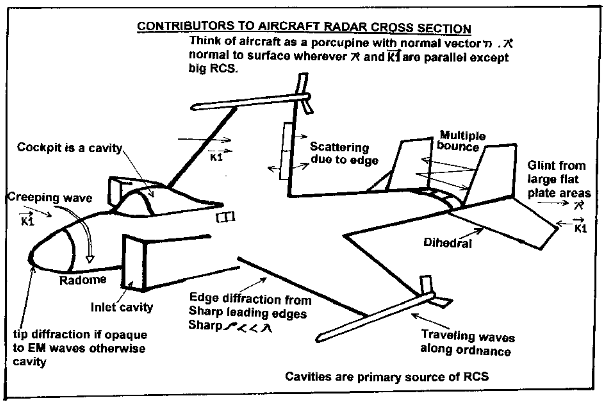

Fig.1

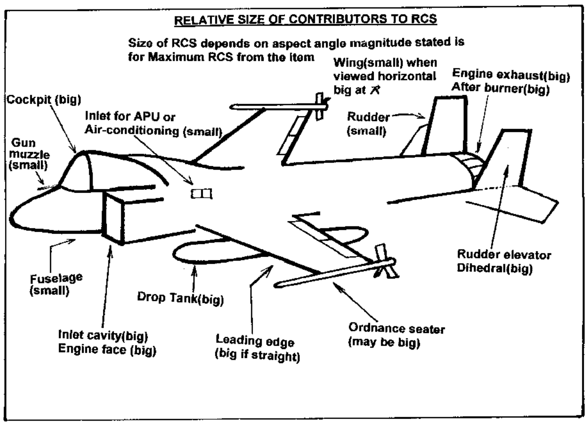

Fig.2

- Ordnance - Missile may have own radar which can have large RCS.
- Rudder- Elevator Dihedral - May be big due to action of retroreflector.
- Exhaust - Waves can propagate within the cavity and reflect from internal parts.
- Rudders- RCS is small except for glint at broad side.
- Wing - RCS is small except when viewed so as to see 'flat' area.
- Inlet for APU - The inlets for APU, air conditioning ducts and gun exhaust, gas, ports can be large in certain directions.
- Cockpit - Big contributor to RCS.
- Gun Muzzle- Scattering is due to surface discontinuities.
- Radome-Big antenna inside acts like a cat's eye in the dark.
- Fuselage - Recall a cylinder $\sigma = \pi \; \rho 1 \; \rho 2$
- Usually $\rho 1$ and $\rho 2$ are small compared to ρ of wing upper or lower surface.

Body Shaping Method for a Stealth Fighter

High Frequency and Resonance Region

In considering what type of shape, a specific perfect conduction body should take to minimize the back scatter RCS at selected aspect angles, it is of interest to examine the dependence of the various analytic components of the cross section with frequency.

This technique is useful in reducing the back scatter cross section of a target over a selected range of aspect angle. The object of shaping is to orient the target surfaces and edges so as to deflect the reflected energy in the directions away from the radar.

Selection of shape of a target depends on RCS and the aerodynamic performance prediction. Actually shaping usually does nothing more than shifting the regions of high echoes from one aspect to other.

Table-1 shows the dependence of RCS of number of components of frequency.

From the Table-1 it can be observed that for the RCS to become smaller with increasing frequency, no specular

Table-1

Scattering Components	Appx. Wavelength dependence
Specular Flat Surface	$\sigma \; \alpha \; \lambda^{-2}$
Curved Surface	$\sigma \; \alpha \; \lambda^{-1}$
Edge and Tip Single edge	$\sigma \; \alpha \; \lambda$
Multiple edge	$\sigma \; \alpha \; \lambda^{n}$
Tip	$\sigma \; \alpha \; \lambda^{2}$
Surface discontinuities	$\sigma \; \alpha \; \lambda^{2}$
Creeping Wave	$\sigma \; \alpha \; \mathrm{Exp}\,[-4\lambda^{-2/3}]$
Travelling Wave	$\sigma \; \alpha$ Const

contribution to the scattered field should exist. The body should in general present a tip towards the radar, with no edges capable of scattering a single visible diffracted ray. This requires an original ogive or conical shape with the cone or ogive base smoothly matched to and no discontinuity at the matching point, i.e. the cone sphere combination is most suitable.

The effect of shaping of a body into a configuration similar to that of a cone-sphere is to produce a low back scatter RCS over a range of aspect angles of about ± 45° around the tip. The question occurs as to the RCS at other aspect angles, as well as the bistatic cross section. At other aspect angles, the cone sphere return is dominated by the specular contributions from the conical sides and the spherical base. For parallel polarization and not too high a frequency, traveling wave effects cause some fluctuations in the RCS at rear aspects over the angular region $120° \leq \varnothing \leq 240°$. These fluctuations can be attributed to phase interaction between the specular component produced by the spherical base and a traveling wave component, reflected by the conical tip. This interpretation is validated by the absence of fluctuations in this region for perpendicular polarization.

RCS reduction is accomplished by use of smooth surfaces (cylinders and cones) avoiding large flat areas, cavities exposed to radar and discontinuities in conduction path. Fig.3 shows the body shaping of different components which reduces the RCS considerably.

- The direction of incident waves is an important consideration. If the aircraft is well illuminated from below, put engines on top of the wing.

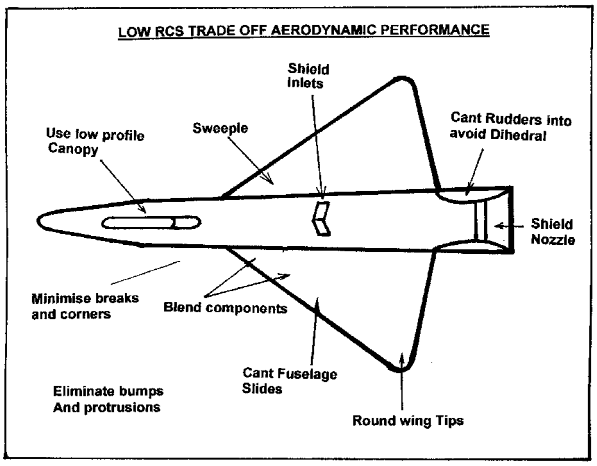

Fig.3

- Shield inlets: The inlets can be shielded by the fuselage. If engine performance permits the use of wire mesh over the inlet, the RCS can be reduced.
- Cant rudders inward: When a rudder elevator combination is used, the retroreflection of the dihedral is avoided.
- Nozzles: Shield the nozzles.
- Round wing Tips: Rounded Wing tip has small RCS.
- Blend components: Since waves are scattered by discontinuities in slope, curvature etc, blending minimizes the geometrical discontinuities.
- Minimize Breaks and corners: Avoid any shape resembling retroreflector.
- Put ordnance load inside the aircraft.
- Use low profile canopy.
- Sweep LE the air craft is frequently illuminated by a search radar from Nose-on aspect. A swept leading edge is one way to reduce RCS. Actually there are two philosophies in regard to leading edge shape.

  i) A straight leading edge concentrates a big RCS in a narrow lobe. If the search radar is never in that lobe, the aircraft can not be detected because of leading edge return.

  i) A curved leading edge spreads a small RCS over a wide angle. Although RCS is spread over a large angle, RCS is small.

Low Frequency Region

In the low frequency or Rayleigh region, shaping is in general completely ineffective as a means for cross- section reduction or to achieve stealth fighter characteristics, since the RCS depends primarily on the body volume rather than its shape.

Meaning of Stealth (Fighter) to Radar

The main effect of stealth (fighter/bomber) is the decrease in radar range detection capability. In other words the main effect of RCS reduced fighter/bomber is the decrease in radar detection probability. Radar cross section reduction (stealth quality) requirements can be estimated from the radar range equation in terms of detection range reduction. If a target of RCS σ 1 is detected at a range R 1, then with the same search radar, a target of

RCS = σ 2 is detected at a range R2. A 10 dbsm decrease in RCS = σ means i.e. $\frac{\sigma 2}{\sigma 1} = 0.1$.

$$\text{Range} = R2/R1 = \left(\frac{\sigma 2}{\sigma 1}\right)^{1/4} = (0.1)^{1/4} = 0.56$$

$$\text{Search Area} = (R2/R1)^2 = \left(\frac{\sigma 2}{\sigma 1}\right)^{1/2} = (0.56)^2 = 0.32$$

$$\text{Search Volume} = (R2/R1)^3 = \left(\frac{\sigma 2}{\sigma 1}\right)^{3/4} = (0.56)^3 = 0.18$$

Inference from this is that for a radar whose maximum detectable range is $\sigma 1$ = 100 Km, 10 dbsm RCS reduction means, radar range is reduced to 56%, radar search area reduced to 32% and this reduces search volume to 18%.

Conclusion

Even though physical size of normal fighter/bomber and stealth fighter/bomber may be same but stealth qualities make radar detection occur at a closer range.

Since stealth fighter/interceptor need not carry heavy armament the shaping technique described above is suitable for design of stealth fighter/interceptor for quick reaction, since aircraft guns are fitted inside the body.

With this shaping technique it is possible to achieve upto 20 dbsm RCS reduction.

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