RCS of the Tail Swept Flying Wing and Comparison with Milestone Aircrafts

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***Abstract*—As the design for subsonic aircraft is gaining maturity, there exists a desire to tailor the performance of the aircraft to suit specific conditions. The fifth generation aircraft is concerned with the low observability design and prediction of the Radar Cross Section of the aircraft by enemy radars. The aim of the paper is to predict the Radar Cross Section of a possible future generation combat aircraft using the shooting and bouncing ray techniques and show its superiority in shape design over previous generation of aircraft. Since RCS is sensitive to aspect changes in flight, the monostatic RCS value is predicted in pitch, roll and yaw planes. The simulator is first tested and validated on benchmark targets which are publicly available in open literature before applying to aircraft scenarios. The XB-70 Valkyrie bomber, the F-16 and a possible futuristic Delta flying swept wing aircrafts is chosen for RCS comparison.**

***Keywords*—Radar Cross Section; Valkyrie, F-16, Tail Swept Delta Flying Wing**

I. INTRODUCTION (*HEADING 1*)

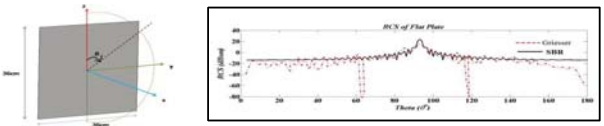
Since the last few decades, aircraft designers and researchers across the world have made significant progress in the design and development of 'generations' of fighter jet aircrafts. A typical jet fighter is distinguished by the class of engine, avionics, the air superiority and maneuverability it provides for each generation. The fifth generation of aircrafts is mainly concerned with the low Radar Cross Section (RCS) of the aircraft [1]. The RCS of the aircraft is defined about the observability of the aircraft by an enemy radar and is the hypothetical area, that would intercept the incident power at the target, which if scattered isotropically, would produce the same echo power at the radar, as the actual target [2]. The RCS of an aircraft has an apparent size as seen by the radar and is the coherent sum of the contributions from various scattering centers of the target. Several Methods exist in literature for radar prediction of the aircraft. These are typically classified as the high frequency methods, methods in the resonance region and the low frequency techniques depending on the electrical size of the target aircraft when compared to the wavelength of the impinging wave. For the computation of RCS of electrically large structures, high frequency asymptotic methods based on Ray Tracing and generalized Fermat's principle are used. The direct ray, the reflected and double reflected, diffracted, reflected diffracted, surface wave, and creeping waves are considered by coherent summation of each individual contribution of these ray paths.
The high frequency asymptotic methods include geometrical optics (GO), geometrical theory of diffraction (GTD), physical optics (PO), physical theory of diffraction (PTD), uniform theory of diffraction (UTD). The shooting and bouncing ray technique is a hybrid method that combines GO and PO for fast and accurate calculations of RCS at high frequencies. Since its introduction to the RCS community [2], the method has been successfully employed in radio wave propagation as well as RCS computations of cavities, inlets with protrusions, jet aircrafts [3-7].
With ever increasing maturity in the field of subsonic aircraft design, there exists the desire to tailor the performance of an aircraft to suit specific flight conditions. This has led to several adaptive-wing approaches which seek to improve aircraft performance by changing the wing shape in flight, resulting in RCS reduction. In this paper the RCS of a swept flying wing airframe is evaluated numerically based on the shooting and bouncing ray technique. The simulator is first tested and validated on benchmark targets which are publicly available in open literature. The method is then extended for RCS computations of electrically large aircrafts in the yaw, roll and pitch planes which are important and meaningful both from flight and radar view points.
A performance comparison in terms of RCS is made to show the superiority of the fifth generation planes over previous generations such as the XB-70 Valkyrie bomber [8] and the F-16 combat fighter airframes.

II. SHOOTING AND BOUNCING RAY TECHNIQUE-BENCHMARK VALIDATION

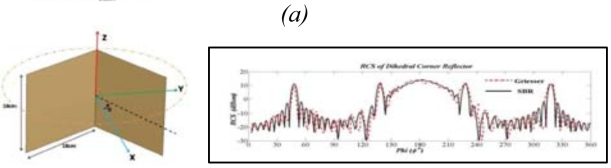
The Shooting and Bouncing ray Technique is well documented in literature and has been extensively used for RCS computational studies. Combined with Computer Aided Design and Graphical Modeling tools the method has been studied to evaluate RCS of complex structure of aircrafts. This work follows closely the methods of [6] and is used for validations with canonical objects first and then actual target models considered.

A. Monostatic RCS of a flat plate

The dimensions of the plate are shown in Fig.1.a .The backscattering is computed for different elevation angles and is shown in Fig.1.a. The EM backscattering is calculated for different elevation angles ranging from θ = 0° to 180°, while the azimuth angle is set to 0°. The incident wave is horizontally polarized. The operating frequency is taken as 10GHz so that the electrical size of the plate becomes 12λ. The specular return from the plate is the large peak at 90°, which is predicted with quite good accuracy. The sin x/x behavior is characteristic of a uniformly illuminated aperture.



(a)



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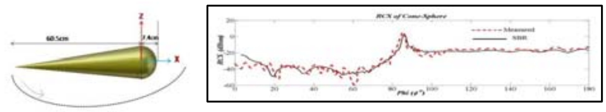


(c)

Fig.1. (a) Geometry of Flat Plate, Monostatic RCS
(b) Geometry of Corner Dihedral Reflector, Monostatic RCS
(c) Geometry of Cone Sphere,. Monostatic RCS of Cone Sphere

B. Monostatic RCS of a Dihedral Corner Reflector

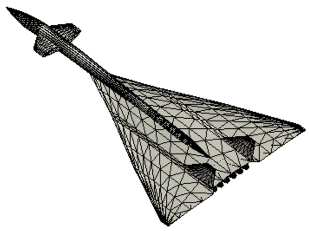
To examine the effect of multiple bounce, the dihedral corner reflector geometry as shown in Fig.1.b is considered for validations. This time the azimuth variation is considered for a fixed elevation angle as shown in Fig.1.b on the right side. In contrast to the pattern of a flat plate, the RCS pattern of a corner reflector is quite broad. This is true because the corner reflector is a reentrant structure, and no matter what its orientation, internally reflected waves are directed back toward the source of the incident wave. The broad central part of these patterns is due to a multiple-bounce mechanism between the participating faces, while the "ears" at the sides of the patterns are due to the single-bounce, flat-plate scattering from the individual faces. The backscattered results are compared with the experimental results of Griesser [9] plotted in the same graph and found to be in good agreement.

C. Monostatic RCS of a Cone sphere

The cone sphere illustrates fundamental characteristics of the scattering such as discontinuities and the curvature of the surface. The geometry and the CAD model are shown in Fig.1.c. The RCS Variation with respect to azimuth is shown in Fig.1.c on the right side. For agreement, results of the geometry and RCS [9]provided in open literature are used. Small differences between our results may be due to the meshing parameters of the CAD files and the methods used for simulation.

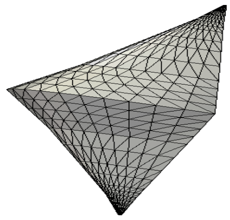
III. RCS OF FIGHTER AIRCRAFTS

One of the main aims of the paper is to predict the RCS of representative fifth generation aircraft using the shooting and bouncing ray techniques and show its superiority in shape design over previous generation of aircraft. For this representative models available in OpenVSP of the following aircrafts are considered and all shapes are considered metallic for analysis.



A. XB-70 Valkyrie bomber

B. F-16 model



C. Swept Wing Delta

Fig.2 Milestone Aircrafts.

A. RCS Simulations of XB-70 Valkyrie bomber

The aircraft designed in the fifties with a canard surface, a delta wing and six engines as a large, six-engine aircraft was capable of reaching Mach 3+ while flying at 70,000 feet. It was the prototype of the B-70 nuclear-armed, deep-penetration strategic bomber and well ahead of its time. It was designed to escape interception using the high speed, since Surface to Air Missiles had not made its presence at that point of time. The airframe being large in size, the RCS of the aircraft is very large and its straight and level trajectory is simple to intercept. Fig.3. shows the RCS patterns for OpenVSP CAD Valkyrie Bomber B70 aircrafts. In the Yaw plane very high spikes are seen perpendicular to the leading and trailing edges of the aircraft (90^0-45^0, 270^0-315^0) perpendicular to the flat side of the aircraft and directly off the nose(180^0) and perpendicular to the leading edges of the carnads, and from the tail due to inlets, nozzles and radomes. RCS variation is very high, from tail to leading wing (10 dB to 40 dB i.e. 100 sq.m to 100,000 sq m). In the Roll plane sweep, the peaks at 0^0 and 180^0 correspond to the leading edges of the aircraft, about 60dB which are significantly higher when compared to the yaw plane sweep. The peaks in the angular range from 60^0 to 120^0 and in the angular range $210^0$to 300^0 correspond to broadside reflections from the top and bottom of the aircraft. In the pitch plane, the dominant peaks are from the lower surfaces of the aircraft between 210^0 and 270^0 and significantly higher from the top surface of the aircraft. This may be due to exhaust and nozzles in the bottom surface.

B. Representative F-16 Light Weight Combat Aircraft

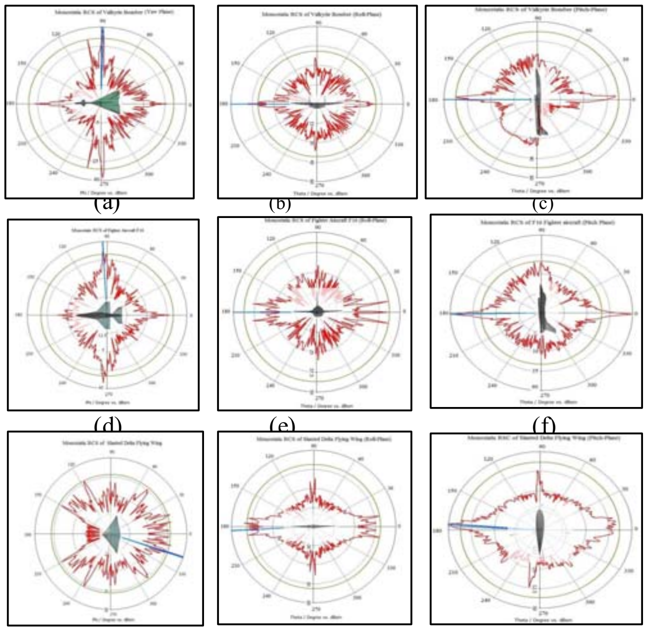
This aircraft developed in the seventies is a single engine light weight aircraft optimized for RCS and with advanced avionics and aerodynamics, meant to be a workhorse for the United States Air Force. Fig. 3 d, e, f shows the computed RCS pattern in yaw, roll and pitch planes respectively of the aircraft using the shooting and bouncing ray method. In the yaw plane, the dominant peaks are from the cropped tapered delta wing tips at 90^0 and 270^0 respectively. Otherwise RCS is almost constant around 20dB in the yaw sweep. In the Roll plane, the dominant peaks are at 0^0 and 180^0 followed by peaks at the nose and the tail. In the pitch sweep, the dominant peaks are in the angular range from 60^0 to 120^0 and in the angular range 210^0 to 300^0 correspond to broadside reflections from the top and bottom of the aircraft. The pattern is asymmetric about the axis and RCS is higher on the bottom side due to reflections from the engine.

C. The Tail-Swept Flying Wing Futuristic Stealth Aircraft

This is a strong candidate for the future generation Unmanned Stealth Tailless flying wing configuration being considered for analysis. It is touted to have better stealth electromagnetic characteristics compared to other flying wing configurations and therefore considered for analysis. In the yaw plane, Fig 3g the RCS is close to 0 dB over all azimuth angles except in the angular range from 120^0 to 150^0 and 180^0 to 210^0 where the RCS is close to 5dB. In the roll plane (fig.3h) , RCS values over the angular sweep is close to 0 dB except around 0^0 and 180^0 where the RCS is close to 35dB, followed by spikes of RCS values of about 10dB at $90^0$and 270^0. In the pitch sweep, (Fig 3i) the dominant peaks are again at $0^0$and 180^0 and spikes at 90^0 and 270^0.

IV. CONCLUSIONS

The desire to tailor the performance of the aircraft to suit specific conditions has led to the development of a myriad number of configurations and reduced RCS is an important factor for the design, development and utility of the aircrafts. With the advent of Surface to Air Missiles, the overwhelming priority for aircraft survivability and evasion from detection is the stealth characteristics apart from aerodynamics built in the design and development process itself. As can be seen, from the above simulation and analysis for the different generation of aircrafts, the Valkyrie aircraft though ahead of performance in time, had a very high RCS. The F-16 with a smaller RCS has been a prolific fighter of the western world, harder to spot and has survived for the last forty years. In order to preserve the stealthiness and keep the RCS as low as possible, new configurations have emerged with almost zero RCS. The paper has also analysed one such configuration and simulations in the pitch, roll and yaw planes.



(a) (b) (c) (d) (e) (f) (g) (h) (i)

Fig.3. Polar Plot RCS of:Valkyrie Aircraft (a,b,c), F-16 Model (d,e,f)and the Swept Wing (g,h,i) Configurations in Yaw Roll and Pitch Planes

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Biodata:

Dr SM Vaitheeswaran, is working as Principal Scientist , CSIR-National Aerospace Laboratories and has the concurrent position of Associate Professor AcCSIR-NAL, a Deemed University established by an act of Parliament, in 2010. The primary focus of the research has been in the use of vision system for guidance, navigation and control, in the field of Unmanned Aerial Systems. He has worked with and developed basic knowledge in embedded systems, electronics, aerodynamics and control solutions to perform system design and integration work in all of the areas before building the unmanned system itself. Work includes designing and building low-latency computer vision as applied to the autonomous navigation of visually-guided ground and mini flying quadrotors in GPS denied environments, Vision Based Thermal Localization, Mission Planning issues for Maritime Patrolling and Surveillance, Vision Based Autolanding Technologies for fixed wing aircrafts and quadrotors.