International Journal of Science and Research (IJSR)
ISSN: 2319-7064
SJIF (2020): 7.803

Aerodynamic and Stealth Analysis of a Conceptual Aircraft Based on Recent Advances of Stealth Technology

Arishmita Mukherjee

Department of Electronics and Communication Engineering, Institute of Engineering and Management

Abstract: ***The recent advances of stealth technology in aerodynamics requires ever progressing engineering to come up with aircraft designs that can provide optimum benefits. Every country and aviation giant focuses on inventing new designs to defeat ever evolving radars and climatic conditions at the same time. Generally, one comes at the price of the other, and trying to optimize both often results in harmful life cycle costs (LCC), that makes the product an engineering marvel, but not a viable option to fly on regular missions. Thus, a conceptual aircraft was developed with the help of Computer - Aided - Design (CAD) and a likewise model was deployed into other simulation software's to compute aerodynamic performance (CFD Analysis) and Radar Cross Section (RCS analysis) to judge all - round feasibility of the preliminary design.***

Keywords: RCS, CFD, LCC, CAD, Design

1. Introduction

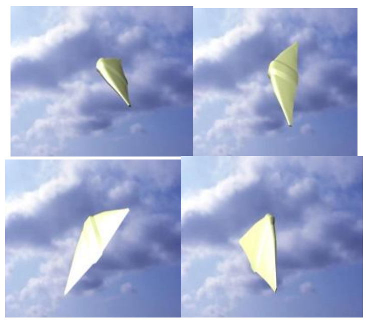
Stealth has become an increasingly important factor in the production of military aircrafts in the 21st century. Throughout history, since the world wars, work has always been put into making them as stealthy as possible in accordance with the technology of those times. While engineering marvels like Boeing B - 52 Stratofortress were hailed for their robust configuration, in present days, operating it would be a challenge in it's own stead. Having an RCS of 100 compared to that of 0.01 of a bird, it would alert the enemy radar from miles away, thus increasing the chances of fully destroying the mission.

States like America and China have invested a lot into stealth jets and bombers, the result of which is what is popularly known as the Northrop Grumman's legendary B - 2 Spirit Stealth Bomber. Made using supercomputer technology, this aircraft has an RCS similar to that of a bird, thus keeping the enemy radar unaware of a potential threat. Specifications are attached in the table below.

Parameter	Details
Wingspan	172 ft
Height	17ft
Length	69ft

Information obtained from US Air force website

The most important component of stealth is, arguably, the shape of the aircraft, so some structural inspiration has been derived from both the B - 2 and the F - 117A Nighthawk to implement a conceptual design, further enhancing it's credibility with consequent RCS and CFD analysis. This is a brief overview of the conceptual design from various angles. The engine inlets and outlets have been closed, as can be seen in the diagrams. RCS and CFD is affected by every minimal thing, like engines, choice of material, landing gear, etc., however, those details have been reserved for future calculations. Herein, the work shall be focused on primarily analysing how the body reacts with radars and fluids.



Snapshots taken from Catia v5

A similar model was implemented into the subsequent software's for ease of calculations and analysis.

2. Literature Survey

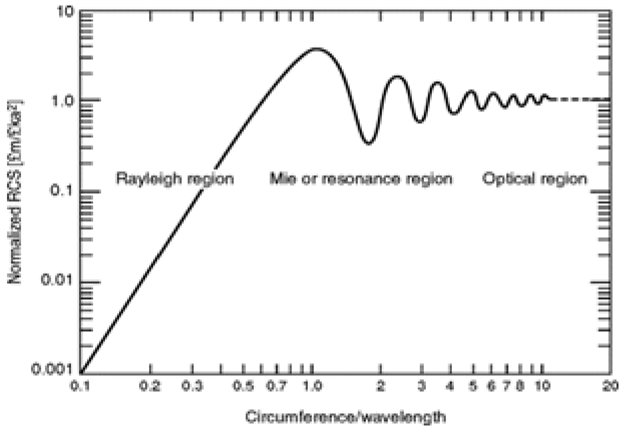
Ongoing research has always been done about stealth: since it is an ever evolving field of study, many researchers come up with their own solutions that have optimal outputs. Such studies were thoroughly analyzed to check the general trend of the designs, what each common feature contributed to, etc. As is obvious, the design here is heavily influenced by the B - 2 Spirit Stealth Bomber, while also retaining inspiration from the F - 117A Nighthawk and the prototype of Bird of Prey that was once developed by Boeing but never really released into the market.

Theory:

What is RCS?

$$SNR = \frac{P_S}{P_N} = \frac{P_T G_T G_R \lambda^2 \sigma}{(4\pi)^3 R^4 k T_0 B F_n L}$$

There is a specific equation describing the amount of feedback a receiver will get, known as the radar range equation. From here, deliberation about RCS begins.



The Radar Cross - Section of a target is the concerned area that actually intercepts a radar's transmitted signals and reflects them back to the receiving radar. When the radar pulse is transmitted, it hits the target and gets scattered isotropically, some part travels back to the receiver. The radar will measure the power density of the reflected signals in dB, converting it into metre - squares to accurately visualize the size of the target. RCS is thus the ratio of backscattered power to the power density received by the target. It is denoted by the symbol $'\sigma'$ with a unit of metre - squares.

$$RCS\,(\sigma) = \frac{4\pi R^2 S_r}{S_t}$$

Where, R = Radar range
S_r = Backscatter Power
S_t = Power density received by the target

Factors on which Radar Cross Section depends:

- Transmitter signal frequency.
- Distance between target and the transmitter/receiver.
- Material used in the target
- Propulsion machineries in the target
- Avionics in the target like seeker, GPS, Altimeter.
- The aspect, orientation of the target to the radars.

Factors which we can control:

- Material used in aircraft (Using Radar Absorbing Materials)
- Structure of aircraft (Sharp nose, Blended wing)

Radar cross section (RCS) of the target is a measure of stealth, or low observability (LO) of an aircraft, and even missiles and ships.

There are two types of RCS that are mostly used for analysis purposes: Monostatic and Bistatic.

Monostatic RCS: To put it simply, monostatic RCS is calculated when the receiver and transmitter antenna are in the same location.

Bistatic RCS: Bistatic RCS is when the receiver and transmitter are in different locations.

These different methods are necessary to obtain a clear idea of how the design will interact with radars in different positions. The various methods of analysis shall be elaborated in the next part, for there can be quite a few depending on the necessity of the operations. Traditionally, monostatic radars perform the duty of sensor backbone of modern offensive and defensive weapons systems and signature collection methods. While predominant, the monostatic scenario is less general than bistatic and therefore seen as more restrictive. This restriction prevents engineers from exploiting bistatic's numerous advantages; however, it does provide a welcome simplification to vastly more complex bistatic situations. The sheer volume of data generated during a bistatic engagement or measurement scenario imposed a lot of limitations on its utility. Recent technological advances, however, have made the immense data load more manageable, so the opportunity to exploit bistatic's inherent flexibility is becoming more plausible. From an operational perspective, development of large sensor arrays which support numerous, distributed passive and active elements are more feasible. From a signature analysis perspective, an expanded feature set incorporating bistatic data may lead to more robust target identification models.

Computational Fluid Dynamics Analysis

Computational Fluid Dynamics (CFD) is the study of fluid flows using various numerical solution methods. Using the mechanism of CFD, one can analyze problems involving fluid - fluid, fluid - gas, fluid - solid, and likewise interactions. Technical fields where CFD analyses are often deployed are aerodynamics and hydrodynamics, where quantities like lift, drag or field properties like pressures and velocities are obtained. It is one of the major aspects for the acceptance of a good design.

CFD analyses can save time during the process of design and are therefore cheaper and quicker compared to conventional testing for data acquisition. Furthermore, in real life tests a limited amount of quantities is measured at a time, however in a CFD analysis all required quantities can be measured together, with a great resolution in space and time, thus providing a well rounded solution.

CFD analysis nearly approximates a real physical solution, so it is to be noted that these should not fully exclude physical testing procedures. For verification, tests should still be duly performed.

Paper ID: SR21804000154 DOI: 10.21275/SR21804000154

3. Methodology

Method for Calculating RCS:

For calculating the RCS, we consider three basic lines; prediction, reduction, measurement. For prediction, there are two methods that are widely used: analytical method and numerical method. The analytical methods are in the time domain or frequency domain where the target coincides with the coordinate systems (which can be rectangular, cylindrical and spherical), and it is separation of variables. Numerical methods are generally developed to solve RCS for complex targets. This method depends heavily on the utilization of time domain/frequency domain, target geometry, and scattering regimes.

Geometrical Optics [GO]: This theory is majorly based on three concepts:

Rays are reflected from the surface like a mirror, rays passing through the surface from one medium to another are reflected, and energy flows perpendicularly to the surface with constant phase.

The Geometrical Optics theory has many features, such as:

1. It yields an infinite result for flat and singly curved surfaces.
2. The target radius of curvature should be larger than the wavelength.
3. It does not consider the polarization effect of excited fields, nor the diffracted fields like fields in shadow areas, thus heavily crippling its usage.
4. It fails if the specula point is near an edge.

Method of Moments [MoM]:

This technique is based on 'reducing operator equations to a system of linear equations written in matrix form'. The features are:

1. It is a frequency domain prediction.
2. It accounts for the entire electromagnetic phenomenon and the polarization effects for the excited field.
3. It is an integral equation based technique. One advantage of using this method is accurate results. It gives a direct numerical solution of these equations. It is also applicable to geometrically complex scatter.

Geometrical Theory of Diffraction [GTD]: The theory states that 'the incident ray excites a fictitious cone of diffracted rays, all subtending the same angle with respect to the edge as that subtended by the incident ray'. This method is an extension of the GO method to take into account all the non - zero fields in the shadow region. The drawbacks are:

1. It is used to compute the scattered fields further away from specular direction as well as polarization effects, which are built - in inherently.
2. It considers diffracted fields, like the fields in the shadow region.
3. The theory predicts infinite fields when the observation point is pierced by infinity of rays, like points lying on the axis of the body of revolution (BOR).
4. The observation point must be laid within the fictitious Keller cone, otherwise it results in zero.

Finite Difference – Time Domain [FD - TD]

It is a - 11 - time - domain based method, and the solutions can work for a wide frequency range using a single run simulation. The method belongs to a general class of 'grid - based differential time domain numerical modeling methods'. The time - dependent Maxwell's equations are discredited using the central difference approximations to the space, time partial derivatives. The output finite difference equations can be solved in software / hardware in a leapfrog manner: the electric components in a volume are solved at a given instant; then the magnetic field components in the same volume will be solved at the very next instant; and the process is repeated until the required transient or steady - state electromagnetic field behavior is evolved. This method takes into account the polarization effects and diffracted fields. Additionally, the method is also a differential equation technique.

Physical Optics [PO]

It is based on tangent plane, and far field approximation. In the tangent plane approximation the integration element is assumed to be a tangent plane to incidence. For far field approximation, the gradient of the Green's function is replaced by the Green's function itself, multiplied by a constant term. The features are:

1. The simplified integral equation can be exactly for a few special structures.
2. Since the polarization of the scattered wave is precisely that of the incident wave, it has no polarization.
3. It fails for wide non - specula angles.

We will use PO method - full ray tracing for further analysis. Altair Feko has been used to simulate the results, with far field configuration. Numerous other softwares like ANSYS Hfss, WIPL - D Pro can be used, even MATLAB codes like Pofacets that can be used to determine it. All of them have different methods of analysis, that include SBR+, Fresnel regions, etc, but Altair Feko was considered the best software for use in this experiment.

Details for Calculation of RCS

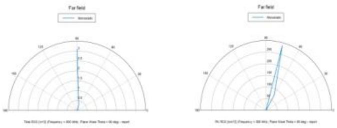
Parameter	Details
Frequency	500e6 Hz
Meshing	Fine

Wave	Plane, Loop over multiple directions with increment of 15
Faces	Perfect Electric Conductor, Physical Optics (PO) - full ray tracing

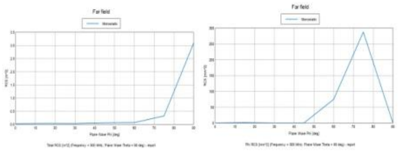
4. Results & Discussion

Monostatic RCS Calculation:

Polar Representation



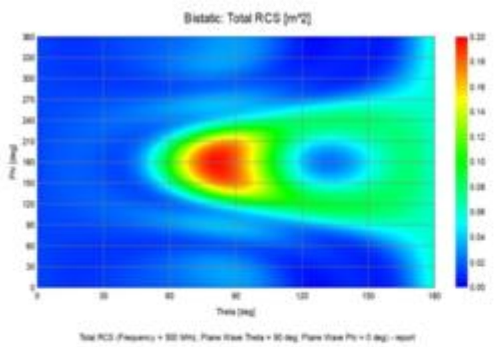
Cartesian Display

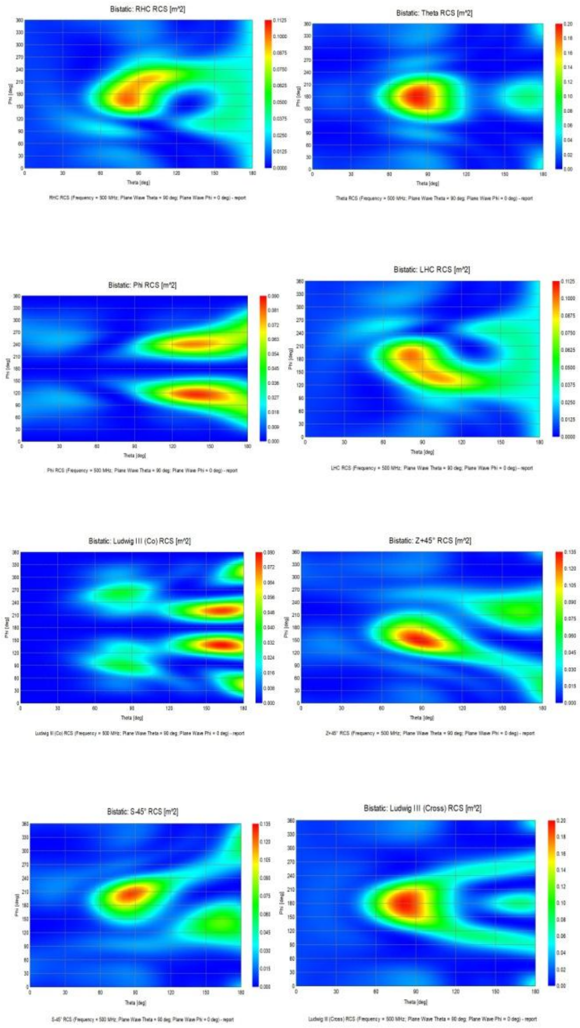


Bistatic RCS Calculation

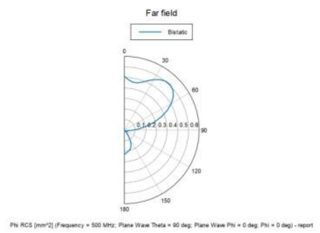
The following results were obtained according to the parameters listed below, detailing a conclusive idea of the interaction of the craft with the environment. Altair Feko allows three major representations: Cartesian, Surface, and Polar visualization for ease of analysis. All of them have been listed below.

Surface Representation

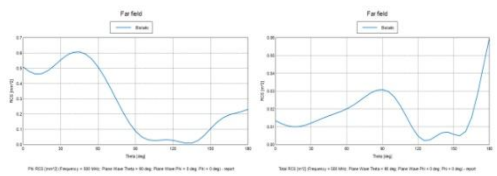




Polar Representation

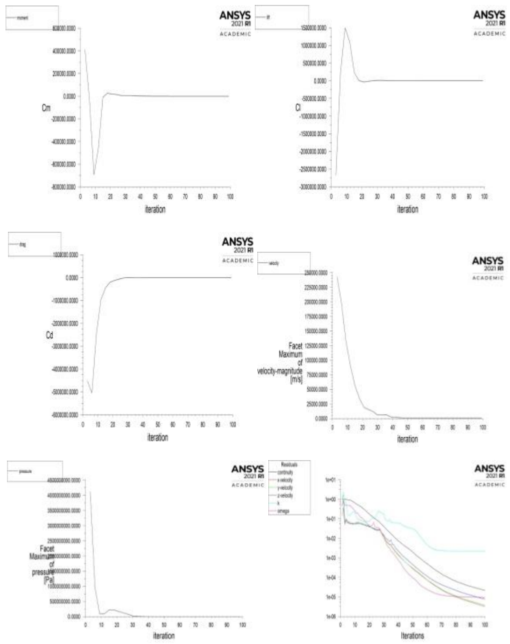


Cartesian Representation



Aerodynamic Analysis Results

The following results were obtained at inlet velocity of 500 m/s, a fine default meshing size.



According to the results, we can see that the observations were precisely in accordance with the general expectations.

5. Conclusion

It can be observed that the results obtained were according to the preliminary hypothesis of how it should be, thus solidifying the claim with accurate details. While many important parameters have not been considered simply for the reason of focusing on one particular arena, these parameters are important in the analysis and will consequently improve performance if incorporated correctly. One of the major points is RAM, Radar Absorbing Material that is used in aircrafts to effectively deal with incoming radar signals. The selected colour happens to be of importance, too. The famous Lockheed SR - 71 Blackbird was mostly made of titanium (later made with a titanium alloy) and it proved to be quite an invulnerable machinery in it's own stead, albeit with its own disadvantages. Likewise, the B - 2 Spirit Bomber employs a sophisticated AHFM coating, which is radar absorbent. The choice of materials goes a long way to improve the results.

Similarly, one cannot overlook the aeroacoustics of the engines. When taken into consideration, it can greatly affect the analysis in a negative way. However, since the body focuses on a blended wing shape with no additional space assigned for carrying the propulsion system, it is easier to expect lesser interference in the calculations because of it. Acoustics still play a crucial factor in the detailed analysis, though, and are definitely scope for future improvement.

Electronics systems in the design will also play a significant role, the electromagnetic workings of the various signals while on a mission is definitely a point to consider. However, that shall complicate calculations unnecessarily in the present area of research, and can be shelved as a later idea.

Flight orientation is also very important when it comes to radar analysis: varying angles of attack with respect to the enemy radar subjects the craft to various levels of vulnerability, and should be duly stressed upon while constructing large scale bombers or jets. In most cases, structural design has a lesser part to play in it than proper flight methods, and it definitely contributes to better performance overall.

6. Future Scope

The structural analysis shows that this aircraft can have future applications when deployed to a more realistic scale. More considerations like engine systems, avionics systems, etc., will have to be taken into consideration, but a basic study proves the feasibility. Some more features were added onto the basic structure to obtain a structure like the figure attached below, which has more space for engine accommodation and weapons bay, etc.

The pointed absences of ailerons have been attributed to the fact that its functionality will be substituted by the principle of differential thrust of engines. With an appropriate propulsion analysis, the craft promises to be a considerable help to military operations. Likewise, the field of stealth remains one of the most dynamic explorations in the aerospace industry. Every advancement in the fields of structures, propulsion, electronics, brings with it a new scope of analysis, a promise of an even better design with more optimized results. This work is thus subject to innumerable scopes of improvement.

References

[1] A New Method for Analyzing Integrated Stealth Ability of Penetration Aircraft by Li Ying, Wu Zhe, Huang Peilin, Liu Zhanhe School of Aeronautic Science and Engineering, Beijing University of Aeronautics and Astronautics
[2] 'Fast coating analysis and modeling for RCS reduction of aircraft' by Haotian ZENG, Xunwang ZHAO, Qin SU, Yu ZHANG, Hao LI Shaanxi Key Laboratory of Large Scale Electromagnetic Computing, Xidian University, Xi'an 710071, China
[3] 'Research on Stealth Aircraft and its effect on radar system in modern Warfare' by Navdeep Banga. International Journal of Current Research Vol.9, Issue, 08, pp.55654 - 55658, August, 2017

[4] ‘Analysis of RCS of Low Observable Aircraft in VHF Band’ by Yi - Ru Jeong, Chan - Sun Park, Young - Kwan Ko, and Jong - Gwan Yook, Hindawi International Journal of Antennas and Propagation Volume 2018, Article ID 5435837
[5] ‘Integration Analysis of Conceptual Design and Stealth - Aerodynamic Characteristics of Combat Aircraft’ by Cheng Liangliang, Yue Kuizhi1, Guo Weigang, Yu Dazhao
[6] ‘PO/MEC - based bistatic scattering model for complex objects over a sea surface’ by Rochdi M, Baussard A, Khenchaf A in Proceedings of the 2010 IEEE Radar Conference; Washington, USA
[7] Yue K, Sun C, Liu H (2014b) Numerical simulation on the RCS of combat aircraft for mounted missile. J Syst Eng Electron 36 (1): 62 - 67
[8] Yue K, Sun C, Ji J (2014a) Numerical simulation on the stealth characteristics of twin - vertical - tails for fighter in Journal of Beijing University of Aeronautics and Astronautics 40 (2): 160 - 165.
[9] CFD Analysis of conceptual Aircraft body by Manikantissar, Dr. Ankur Geete in International Research Journal of Engineering and Technology (IRJET) e - ISSN: 2395 - 0056 Volume: 04 Issue: 01, Jan - 2017 issue
[10] Design and Simulation of a Single Feed Multi - band Dual Polarized Microstrip Patch Antenna by Mohamed A. Elmansouri