Analysis of Solver Methods on RCS Computation of the B-2 Spirit

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Abstract

This report presents an estimation of the radar cross section (RCS) of Northrop Grumman's B-2 Spirit stealth bomber. Using CST Microwave Studio, Altair FEKO, and various solver methods, including asymptotic ray tracing, finite difference time domain, finite integration technique, and the method of moments, the RCS is modeled both in simulation and with a scaled physical model in an anechoic chamber. The aim is to identify the most accurate and time-efficient RCS solving method.

1. Introduction

The RCS of the B-2 Spirit, a critical aspect of its stealth capabilities, remains a closely guarded secret. Our experiment aims to estimate this RCS using computational simulations and physical modeling. Employing various solver methods, we strive to find a balance between accuracy and computational efficiency.

2. Methodology

2.1 Estimating B-2 Spirit Characteristics

Due to the classified nature of the B-2 Spirit, exact dimensions are unavailable. We estimated a wingspan of 52.4 meters and a length of 21.0 meters. The aircraft's stealth composite or Radar Absorbing Material (RAM) is unknown, so our simulations used a Perfect Electrical Conductor (PEC) for simplicity.

2.2 Model Scaling and Complexity

To improve the accuracy of the provided B-2 Spirit model, the model was scaled from 1:18 scale to 1:1 scale. Adding features such as flaps, ailerons, and exhaust ports would increase the accuracy of the model. Using existing commercial B-2 Spirit models (Figure 1) with these features would be preferable, however, the model complexity increases processing time excessively. The provided B-2 Spirit model (Figure 2) was decided upon since its simplicity allowed for the fastest processing time and matched the real-world model most closely (Figure 3).

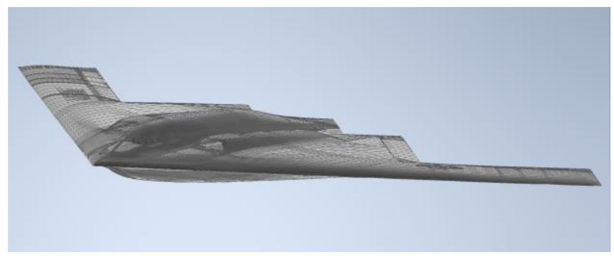

Figure 1: Commercial B-2 Spirit Model 1:1 including all known exterior features and interior features such as seats and avionics.

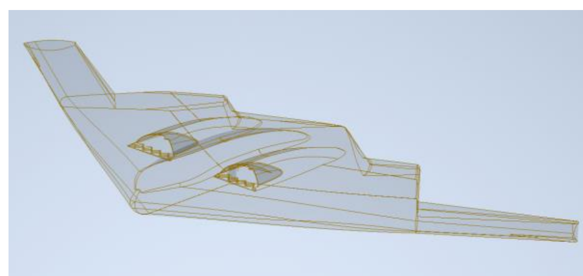

Figure 2: Provided B-2 Spirit model. This model is simplified for RCS processing and is missing many features.

Figure 3: Simplified 1:18 scaled model of the B-2 Spirit in the far field anechoic chamber.

2.3 Simulation Parameters

Parameters were defined to ensure continuity between solver techniques and software. The wingspan of the aircraft is set to 52.4 meters, the length is 21.0 meters, collection of 0 to 90 degrees theta at 10-degree increments, collection of 0 to 180 degrees phi at 10-degree increments, surface material of Perfect Electrical Conductor, and a sample size of 5 tests for each solver method. The theta and phi angles were constrained to ensure continuity between the real-world testing data and to reduce over computation time.

Additionally, the computer's specifications affect the processing time and capabilities of simulations. The computer used has an Intel Core i7-10750H CPU 16.0 GB of GDDR4 RAM, and a NVIDIA GeForce GTZ 1650Ti.

2.4 Simulation Solvers

The Asymptotic Solver for CST Microwave Studio used a Physical Optics Ray Tracing Solver Method to determine the RCS of the B-2 Spirit. Altair FEKO was used to determine the RCS of the B-2 Spirit using Method of Moments, Finite Integration Technique, and Finite Difference Time Domain are used in this software.

2.5 Simulation Setup

To compute the RCS using CST Microwave Studio, CST had to be optimized to utilize all processors in the computer. All six cores and the GPU were used for each simulation.

Solver parameters were inputted into the Asymptotic Solver, data was collected, and there were few issues when running the solver.

For Altair FEKO, the model was imported, material was set to PEC, frequency was set to 10.5 GHz, an incident wave was generated looped over multiple direction with the standard phi and theta parameters, a plane was generated, and a mesh was generated on the model. Several obstacles had to be overcome for the model to work. The triangle mesh was too small, so the model had to be simplified. Then, the number of vertices had to be reduced by merging them, overlapping triangles had to be deleted. and the voxel count had to be reduced.

2.6 Real World Setup

To measure the RCS of the scaled model of the B-2 Spirit, the far field anechoic chamber was utilized. The Field Fox VNA was utilized to collect S21 data from the horn transmit and receive antennas. A mount was also created for the B-2 Spirit model to secure the model to the anechoic chamber mount. Defining parameters was essential in processing the data in an accurate manner. First, the height of the B-2 Bomber on the chamber mount was recorded to be 54 inches off the ground. Next, the distance from the front of the model to the antenna was measured to be 108 inches. Considering human error, these measurements are expected to be slightly off.

The RCS of the empty chamber was first collected to subtract from future chamber measurements. Then, a calibration sphere of 7-inch radius was placed within the chamber to properly scale the collected RCS data. Next, the chamber measurement with just the B-2 Spirit model mount was measured. All calibration measurements were collected three times and the average of each was used. Lastly, the B-2 Spirit model was mounted in the anechoic chamber. There is a slight difference in the height of the B-2 Spirit model on the chamber mount, and the calibration sphere on the chamber mount, this will lead to further error in the data.

The RCS of the B-2 Spirit model had 180 points of measurements. The data was collected from the left wingtip to the right wingtip from the forward perspective of the model. The front 180 degrees of the model were measured. Each degree was incremented using the chamber mount system. The accuracy of the system was to the second decimal place (0.01 degrees).

3. Relevant Equations

The RCS is calculated using the formula: $\sigma = \frac{P_r G_t \lambda^2}{P_t G_r 4\pi R^2}$, where σ is the received power, G_t and G_r are the transmitter and receiver gains, λ is the wavelength, and R is the range.

3.1 Averaging Equation

To find the fastest and most accurate solver method, the average RCS and computation time of each solver method is compared against one another. Then the average of all the computation times and solver RCSs is computed. The solver with an average computation and RCS closest to the average of the whole set would be the most accurate.

4. Results

4.1 Physical Optics Ray Tracing Results

The Asymptotic Solver Physical Optics Ray Tracing Solution as seen in Figure 4, had an average processing time of 1 hour and 1 second. The average RCS of the B-2 Spirit from this model is $22.48dBm^2$.

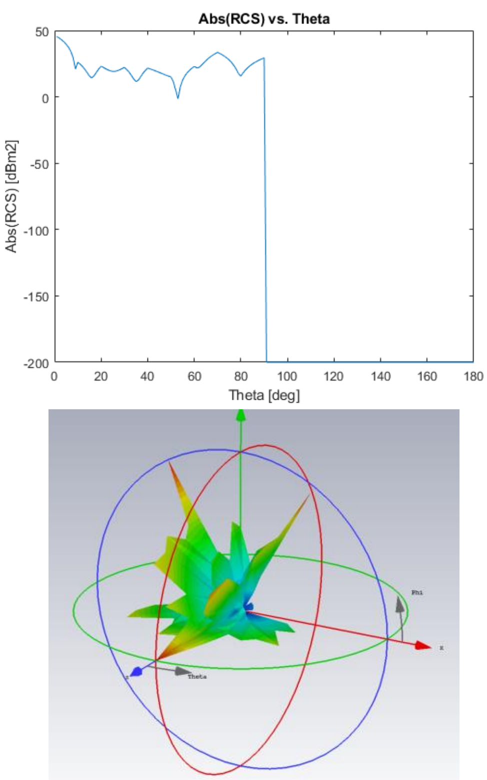

Figure 4: MATLAB Physical Optics Solution and CST Microwave Studio polarization data.

4.2 FEKO Results

The Method of Moments Altair FEKO solver (Figure 5) produced an average computation time of 38 minutes and 23 seconds, however, the solver failed to produce usable data due to the complexity of the craft. The computer used also experienced technical issues. The first computer had a power cord failure, and the device could not charge, so the experiment was continued on a secondary device. The secondary device had a power supply failure. Unfortunately, no other devices with the necessary processing power was available to continue the experiment. The data that is stored on the devices has not yet been recovered.

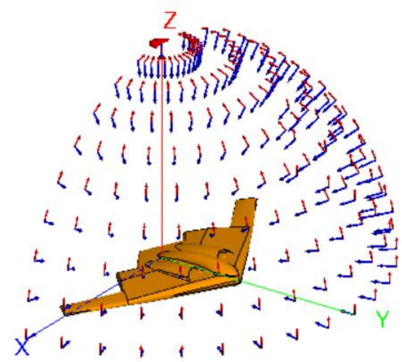

Figure 5: Altair FEKO Method of Moments 3D model visualized.

4.3 Real World Results

Collating the real-world results posed a significant challenge. Reading, processing, and displaying the 224 .s1p files was not achieved successfully. Further research with Robert Rucker would be required to process the data and determine the RCS of the B-2 Spirit model.

5. Result Analysis

5.1 Solver Method Analysis

Although obstacles prevented the collection of data from all solver methods, the Physical Optics Ray Tracing Solution (PO) likely would have the fastest computation time and the most accurate RCS of the craft. Although the Asymptotic Solver was not as fast as the Method of Moments Solver (MoM), it did produce usable data whilst the Method of Moments did not. The data from the Physical

Optics Ray Tracing Solution is likely the most accurate because PO ray tracing is best suited for large smooth objects like the B-2 Spirit, whilst MoM is best suited for smaller objects, the Finite Integration Technique (FIT) is specialized for broadband applications and may not be the fastest at single frequency or high frequency scenarios, and the Finite Difference Time Domain Solver (FDTD) is best suited for wide band scenarios with complex structures.

The accuracy of the solver methods is dependent upon the analysis method that each solver utilizes. For MoM, FIT, and FDTD, the methods had difficulties computing the complexity of the craft, even considering the model was already simplified. More computational power, or further simplification of the model may be necessary to determine the RCS of the B-2 Spirit with these methods. Thus, MoM, FIT, and FDTD are slower and less accurate than PO Ray Tracing.

5.2 Solver Result Analysis

The RCS of the B-2 Spirit is generally considered to be 0.1 square meters or 0.01 square meters when analyzing the front of the craft. When converting this unit to decibels per meter squared, the accepted RCS of the B-2 spirit is between -10dBsm and -20dBsm. This value differs from the collected average value of 22.48dBsm. This discrepancy may be due to several factors. First, the target frequency of 10.5 GHz may be outside the range that the B-2 Spirit was designed to scatter energy at. Secondly, this experiment did not include Radar Absorbent Material, which could greatly reduce the RCS of the craft. Lastly, the B-2 Spirit may be optimized to scatter energy at different angles, like from ground targets.

6. Conclusion

This study aimed to estimate the Radar Cross Section (RCS) of the B-2 Spirit stealth bomber using various simulation methods and a physical model in an anechoic chamber. Despite the challenges posed by the complexity of the B-2 Spirit's design and the limitations of computational resources, our findings provide valuable insights into the RCS estimation of stealth aircraft.

The Physical Optics Ray Tracing Solution (PO) emerged as the most promising method in terms of balancing accuracy and computation time. It demonstrated a capability to produce usable data, unlike the Method of Moments, which faced technical and computational issues. The PO method's suitability for large, smooth objects like the B-2 Spirit makes it a strong candidate for accurate RCS estimation of similar stealth aircraft.

However, the discrepancy between the estimated RCS value of 22.48dBsm and the widely accepted RCS value of the B-2 Spirit, which ranges between -10dBsm and -20dBsm, highlights the complexities involved in accurately modeling stealth characteristics. Factors such as the exclusion of Radar Absorbent Material in our simulations and the specific frequency range used for testing could account for these differences. Additionally, the stealth optimization of the B-2 Spirit, particularly for deflecting radar waves from ground-based radars, might not have been fully captured in our models.

Since this experiment had several obstacles preventing the full collection of data, revisiting this topic in the future will improve the RCS estimation of the B-2 Spirit and enhance the computational data of the different solver methods. Accounting for the radar absorbent material in future studies would also greatly improve the model.

This experiment offers a practical demonstration of radar techniques and analysis, underscoring the critical role of defining parameters such as theta and phi in influencing the outcomes and the Radar Cross Section (RCS) of the target. Our findings reveal that factors extending beyond the target's design, particularly the resolution and complexity of the simulated target, significantly impact the results and present notable challenges in solver method analyses.

The study highlights the paramount importance of selecting appropriate tools and methods tailored to the specific requirements of RCS estimation.

Utilizing the correct solver methods is not merely a technical choice but a strategic decision that directly affects the accuracy and feasibility of the results.

Moreover, this research emphasizes the need for comprehensive considerations in modeling. By accounting for various variables, including target design, material properties, and solver capabilities, we gain a deeper and more nuanced understanding of the RCS of the B-2 Spirit. This approach not only enhances the current understanding of stealth technology but also paves the way for developing more accurate and sophisticated models in future studies.

7. References

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