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Design and Analysis the Radar Cross Section of Complex Targets for Military and Civilian Applications

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Abstract—In aerospace industry, the importance of RCS in the aerospace industry. State the purpose of the comparative study and analysis of various geometries contributing to RCS prediction. Analyze how changes in frequency affect RCS and discuss the relationship between radar range and RCS. MATLAB to create models of different geometries. Outline the parameters studied (e.g., frequency of operations, radar range) and the tools used for simulation (e.g., MATLAB). This research paper describe design features that minimize RCS (e.g., absorbent paint, smooth surfaces) and list and describe the different geometries analyzed in the study. The software tools used (e.g., MATLAB, commercial RCS simulation software). Use MATLAB's plotting functions to visualize the results and analyze the variation of RCS and visual aids to demonstrate the variation of RCS with different parameters.

Keywords— Radar Cross Section, Statistical properties, Target aspect range, RCS signature.

I. INTRODUCTION

Radar (Radio Detection and Ranging) is a technology that was developed before World War II. The term "RADAR" was coined by the U.S. Navy in 1940 as an acronym for Radio Detection and Ranging. Radar systems are used for object detection, employing radio waves to determine the range, altitude, direction, or speed of objects. Radar can detect various objects, including aircraft, ships, spacecraft, guided missiles, terrain, and motor vehicles.[1]

The radar system operates by transmitting pulses of radio waves via its antenna. When these radio waves strike an object, part of the energy is reflected back to the radar receiver antenna. The time taken for the reflected waves to return helps in determining the distance to the object, while the direction of the received signal indicates the object's location. Modern radar systems have a wide range of applications, including:

- **Air Traffic Control**: Managing and monitoring aircraft movements.
- **Air-Defense Systems**: Detecting and tracking incoming threats.
- **Antimissile Systems**: Intercepting and neutralizing missile threats.
- **Marine Radars**: Locating landmarks and other ships for navigation and safety.
- **Ocean Surveillance Systems**: Monitoring activities and conditions in maritime environments.
- **Flight Control Systems**: Assisting in the guidance and control of aircraft.

Radar systems incorporate digital signal processing to extract useful information from the Radar Cross Section (RCS) of objects. The RCS is a measure of how detectable an object is by radar. It does not directly correlate with the physical cross-sectional area of the object. Instead, RCS depends on several factors: [2]

- Material of the target
- Absolute size of the target
- Relative size of the target
- the incident angle
- the reflected angle

A. *Factors Influencing Radar Cross Section (RCS)*

a) *Frequency of Operation: The* radar frequency affects the RCS, as different materials and shapes reflect radio waves differently at various frequencies.
b) *Object Geometry:* The shape and structure of the object influence how radio waves are scattered. Smooth, angled surfaces can deflect waves away from the radar source, reducing RCS.
c) *Material Properties:* The material composition of the object affects its reflectivity. Certain materials can absorb radio waves, thereby reducing RCS.
d) *Aspect Angle:* The angle at which the radar waves strike the object can significantly alter the RCS. An object may have a high RCS when viewed from one angle and a low RCS from another.
e) *Surface Coatings:* Special coatings, such as radar-absorbent materials, can reduce the RCS by

absorbing the radar waves instead of reflecting them. [3]

f) *Polarization:* The orientation of the radar wave's electric field can influence the RCS, as certain objects reflect differently depending on the polarization of the incident waves.

RCS is the property of the reflectivity of the target. It is not affected by the strength of the emitter and the distance between the emitter and the object [4].

B. Significance of RCS in RADAR Range Equation:

The following formula is makes it possible to determine the free space range of a radar system, or the hypothetic maximum radar range [5].

$$R_{\max} = \sqrt[4]{\frac{P_s G^2 \lambda^2 \sigma}{P_{e_{\min}} \left(4\pi\right)^3 L_{ges}}} \tag{1}$$

where,

P_t = Peak Pulse Power;
G = Antenna Gain;
σ = RCS of Target;
λ = Wavelength of RADAR Frequency;
k = Boltzmann Constant;
S/N = Signal to Noise Ratio required for detection;
T_0 = Absolute Temperature of RADAR Circuitry. [4]

In radar system analysis, parameters can be broadly categorized into physical constants or equipment parameters with well-defined values. These parameters play crucial roles in determining the performance and effectiveness of radar systems. [6]

Equipment Parameters

a) *Peak Pulse Power:*
  - This is the maximum power transmitted by the radar during a pulse. It is crucial for determining the radar's range and the strength of the returned signal.

b) *Antenna Gain:*
  - This measures how well the radar antenna focuses energy in a particular direction compared to an isotropic antenna. High gain antennas can detect weaker signals from distant targets.

C. RADAR Bands and their Characteristic Features:

Electromagnetic Spectrum and Radar Frequencies

The electromagnetic spectrum encompasses a vast range of frequencies, extending up to 102410^{24}1024 Hz. Due to the diverse physical characteristics of electromagnetic waves at different frequencies, the spectrum is subdivided into various bands. These subdivisions, which have evolved historically, are sometimes referred to by traditional names still in use today. However, a more modern and internationally standardized division is also applied. [7]

Electromagnetic Spectrum Subdivisions

1. **Radio Waves**: From very low frequencies (VLF) up to 300 GHz.
2. **Microwaves**: From 300 MHz to 300 GHz, commonly used in radar systems.
3. **Infrared**: From 300 GHz to 430 THz.
4. **Visible Light**: From 430 THz to 770 THz.
5. **Ultraviolet**: From 770 THz to 30 PHz.
6. **X-rays**: From 30 PHz to 30 EHz.
7. **Gamma Rays**: From 30 EHz to 30 ZHz.

The electromagnetic spectrum and the specific frequencies used by radar systems is crucial for optimizing radar performance. The choice of frequency impacts the radar's resolution, susceptibility to weather conditions, and overall detection capabilities. By balancing these factors, radar systems can be tailored to specific applications, ranging from air traffic control to weather monitoring and military surveillance.

Various Radar bands can be used for various applications in commercial or military aircraft. The Electromagnetic Spectrum which is specifically used for RADAR Applications is as shown in table 1.

II. RCS of Various Objects and their Determination

For simple target objects, such as flat rectangular plates, cylinders, and spheres, the RCS can be calculated using Maxwell's equations with specific boundary conditions. Below, we provide the RCS formulations for these basic shapes with a principal dimension of 1 meter.

Table 1: RADAR Bands and their Characteristics [8]

BAND NAME	FREQUENCY RANGE (in GHz)	APPLICATION
mm	40-300	RADAR Experiments
Ka	27-40	Airport surveillance
K	18-27	Detecting speeding motorists
Ku	12-18	Satellite transponders
X	8-12	Missile guidance
C	4-8	Long range Tracking
S	2-4	Long Range Weather forecasting
L	1-2	Long range air traffic control

This section aims to elucidate and compile essential facts related to Radar Cross Section (RCS), which are dispersed across technical literature and can be challenging to find. Additionally, the focus will be on considering all relevant conditions for meaningful radar range calculations and

obtaining a deeper understanding through simulation and analysis. [9]
To obtain accurate and meaningful results in radar range calculations, it is essential to consider various conditions:

A. *Radar range calculations*

a) Radar Frequency:
The chosen frequency affects both the detection range and resolution. Higher frequencies offer better resolution but are more susceptible to atmospheric attenuation.

b) Target Aspect Range:
The aspect range, or the angle between the radar and the target, influences the RCS measurement. Different angles can result in varying RCS values due to changes in the reflected signal.

c) Statistical Properties:
For complex targets, RCS can exhibit significant statistical variations [10]. It is crucial to account for these variations to ensure accurate range calculations.

d) *System Losses (Ls):*
Losses in the radar system, including feedline loss, antenna efficiency, and atmospheric absorption, must be considered in the range calculations.

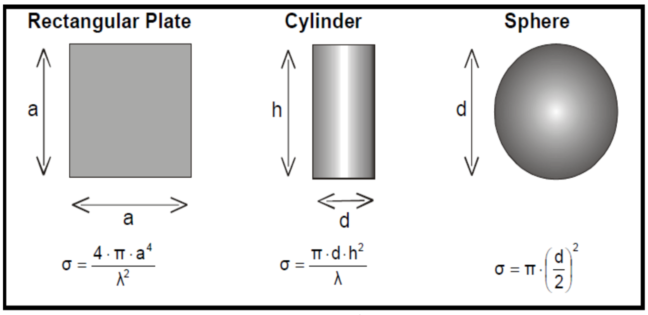

Figure 1. Simple Reflectors [11]

III. RESULTS

In this section, the results as obtained on implementing the above mentioned formula in figure 1 are being presented. The RCS of all the three simple reflectors viz. flat plate, circular cylinder, sphere can be calculated for varying RADAR bands as the RCS varies in direct proportion with the square of frequency of operation, or inversely with the square of wavelength of operation as can been seen from the formulation in figure 1. The efforts have been made to calculate the RCS for X,C,S bands and the results so obtained after implementation of the formula in MATLAB have been compiled in the tabular form as shown below in table 2 [11]. The corresponding variation of RCS for different bands has been plotted subsequently.

B. RCS Calculation of Simple Reflectors for Different Bands:

On referring to the formulation given in fig.1 and substituting the principal dimensions of the objects (a, h, d) as unity, that is 1m each, we can estimate the RCS of these simple reflectors for different bands of operation.

The study of simple geometric shapes forms the basis for estimating the RCS of more complex targets. By combining the RCS values of individual shapes, one can approximate the RCS of composite objects commonly encountered in radar detection scenarios. MATLAB codes for computing the RCS of flat plates, circular cylinders, and spheres have been provided [12]. These codes serve as practical tools for researchers and engineers to simulate and analyze RCS values. The graphical plots of RCS variations for different frequency bands help visualize the non-linear relationship between frequency and RCS for various shapes. This aids in understanding how different parameters affect RCS and radar performance.

Table 2: RCS Calculations for different bands

TARGET	RCS OF THE TARGET
FLAT PLATE	For a = 1m, For X band, **σ = 13963.55 m^2** For S Band, **σ = 1256.6 m^2** For C Band, **σ = 5026.5m^2**
CIRCULAR CYLINDER	For h = 1m, d = 0.5m For X band, **σ= 52.3599m^2** For S Band, **σ = 31.4159m^2** For C Band, **σ = 15.7080m^2**
SPHERE	For d = 1m, For X band, **σ = 0.7854m^2** For S Band, **σ = 0.7854m^2** For C Band, **σ = 0.7854m^2**

IV. MATLAB PLOTS: RCS CALCULATION AND VARIATION ANALYSIS OF VARIOUS SIMPLE TARGETS:

MATLAB Program Codes for RCS Computation
This section provides the MATLAB program codes used for the computation of Radar Cross Section (RCS) for various shapes, including a flat plate, circular cylinder, and sphere. It also presents the variation of RCS for different frequency bands, mainly X, C, and S, using graphical interpretation [13].

```
% MATLAB Code to Compute RCS of a Flat Plate
% Define constants
c = 3e8; % Speed of light in m/s
a = 1; % Length of the plate in meters
```

```
b = 1; % Width of the plate in meters
% Frequency bands (in Hz)
f_X = 10e9; % X-band
f_C = 6e9; % C-band
f_S = 3e9;
% S-band
% Wavelengths
lambda_X = c / f_X;
lambda_C = c / f_C;
lambda_S = c / f_S;
% RCS calculation
sigma_X = (4 * pi * a^2 * b^2) / lambda_X^2;
sigma_C = (4 * pi * a^2 * b^2) / lambda_C^2;
sigma_S = (4 * pi * a^2 * b^2) / lambda_S^2; % Display results
fprintf('RCS for X-band: %f m^2\n', sigma_X);
fprintf('RCS for C-band: %f m^2\n', sigma_C);
fprintf('RCS for S-band: %f m^2\n', sigma_S);
```

In figure 2, the variation of RCS for a flat plate for different frequency bands has been presented. As is evident from the formula, the RCS value increases non-linearly for increase in the range of frequency bands [14]. The graphical plot presented in figure 3 depicts the variation of RCS for a flat plate for different frequency bands has been presented. As is evident from the formula, the RCS value increases non-linearly for increase in the range of frequency bands.

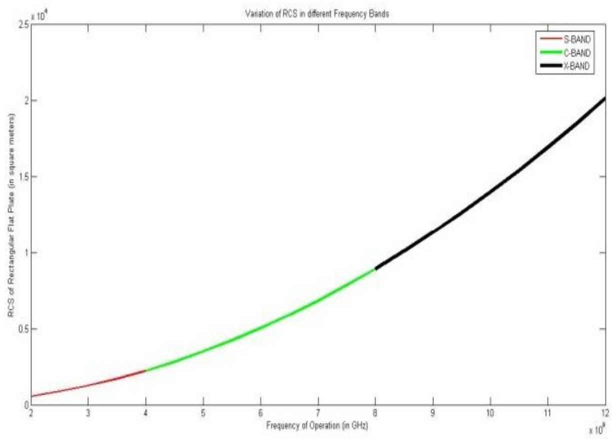

Figure 2. MATLAB Plot for RCS interpretation of flat plate

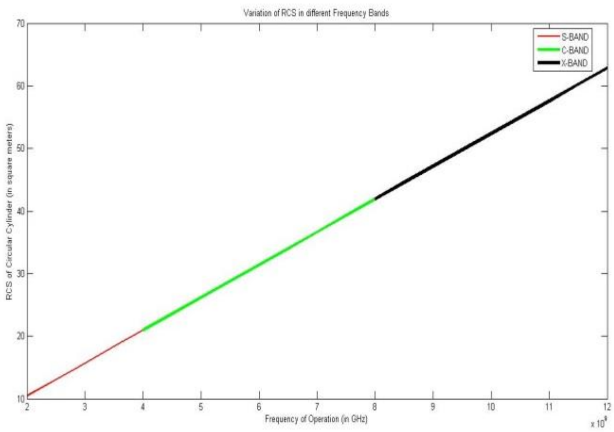

Figure 3. MATLAB Plot for RCS interpretation of circular cylinder

Since, for a spherical target, the RCS is a constant value as it is independent of the frequency of operation; therefore, plotting the variation of RCS of sphere with frequency of operation is absurd.

V. CONCLUSION

This paper has elucidated the basic facts and concepts of the Radar Cross Section (RCS) parameter, which are currently widespread and difficult to obtain from technical literature. These essential facts need to be known and correctly applied to achieve meaningful radar range calculation results. The study and results presented in this paper provide a foundation for estimating the RCS of complex targets, which are often combinations of the simple shapes studied here. The paper compiles and explains the fundamental principles and formulas related to RCS, providing a clear and concise reference for further research and application. The accurate application of RCS principles and calculations enables more precise radar range predictions. This is crucial for both military and civilian radar applications, where accurate target detection and tracking are essential.

Future Work

The results of this work provide a solid foundation for further research into the RCS of more complex targets. Future studies could explore:

- The combined RCS of various composite objects.
- The impact of different materials and surface treatments on RCS.
- Advanced computational methods for more accurate RCS estimation.
- Real-world validation of simulated RCS results with experimental data.

By building on the foundational knowledge and tools presented in this paper, future research can continue to advance the field of radar technology and target detection.

Conflict of Interest

No Conflict of Interest

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Author's contribution

Dr Raja Munusamy is contributed the - study conception and design, data collection, analysis

Dr Sudhir Kumar Chaturvedi is contributed the - analysis and interpretation of results

Mrs Kokila Vasudevan - is contributed the Literature review and manuscript preparation

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REFERENCES

[1] Skolnik, M. L. "Introduction to Radar Systems,". New York: *McGraw-Hill* Book Company; **1980.**
[2] Cheney, Margaret and Borden, Brett. "Fundamentals of Radar Imaging," *Library of Congress Cataloging-in-Publication Data*; 2009: United States of America; **2009.**
[3] N.I. Landy, S. Sajuigbe, J.J. Mock, D.R. Smith and W.J. Padilla, "Perfect metamaterial absorber", *Physical Review Letters*, vol. **100,** pp. **2007402, 2008.**
[4] Sharma, K.K. "Fundamentals of Radar, Sonar and Navigation Engineering," *S. K. Kataria & Sons*; **2009.**
[5] Vladimir Díaz Charris, "Analysis of radar cross section assessment methods and parameters affecting it for surface ships," *Ship Science & Technology*, Vol. **6**, Issue.**11**, pp.**91-106**, **2012**.
[6] Ingo Harre. "RCS in Radar Range Calculations for Maritime Targets,"; V**2.0-20040206**, Corpus ID: **7112912, 2014**
[7] Williams, Cramp, Curtis "Experimental study of the radar cross section of maritime targets," *Electronic Circuits and Systems*, Vol. **2,** No**. 4**, **1978**.
[8] Civil Aviation Authority of Nepal, "Manual of Air Traffic Services," *CAAN Publication*, pp. **5-1-5-39, 2014.**
[9] S. Gu, J.P. Barrett, T.H. band, B.I. Popa and S.A. cummer, "Broad band low-reflection metamaterial absorber,", *J. Appl. Phys.*, vol. **108064913**, **2010**.
[10] Alves, M. A. and M. C. Rezende, "Teaching radar cross section concepts to undergraduate students with a simulation software," *Proceedings of the X International Conference on Engineering and Technology Education*, **108–113**, Santos, Brazil, **2008**.
[11] Knott, E. F., J. F. Schaeffer, and M. T. Tuley, "Radar Cross Section," Artech House Inc., Norwood, **1993.**
[12] Essen, H., S. Boehmsdorff, G. Briegel, and A. Wahlen, "On the scattering mechanism of power lines at millimeter-waves," *IEEE Trans. on Geoscience and Remote Sensing*, Vol. **40**, No. **9**, **1895–1903, 2002.**
[13] Stephen John Beaumont, "Information and Communication Technologies in State affairs: Challenges of E-Governance," *International Journal of Scientific Research in Computer Science and Engineering*, Vol.**5**, Issue.**1**, pp.**24-26, 2017**.
[14] Nishan Khadka, Sulav Parajuli, Aayush Bhattarai, Sanjaya Neupane, "A Study of Optimization of Aircraft Separation using the Time Based Separation at Tribhuvan International Airport," *World Academics Journal of Engineering Sciences,* Vol.**7**, Issue.**2**, pp.**1-7**, **2020**

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