STUDY AND ANALYSIS OF RADAR CROSS SECTION FOR TARGETS USED IN DEFENCE TECHNOLOGIES

A MAJOR PROJECT REPORT

SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF THE DEGREE OF

BACHELOR OF TECHNOLOGY
(Aerospace Engineering with Specialization in Avionics)

SUBMITTED TO
UNIVERSITY OF PETROLEUM AND ENERGY STUDIES, DEHRADUN

BY

Name of Students	University Roll No.
Anirudh Katyal	R890211005
Himanshu Tiwari	R890211016

SUPERVISED BY
Mr. Sudhir Kumar Chaturvedi
Assistant Professor
Department of Aerospace Engineering
UPES, Dehradun

April 2015

COLLEGE OF ENGINEERING STUDIES
UNIVERSITY OF PETROLEUM AND ENERGY STUDIES, DEHRADUN

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CERTIFICATE

I hereby certify that the work which is being presented in the B.Tech. Major Project Report entitled **"STUDY AND ANALYSIS OF RADAR SECTION FOR TARGETS USED IN DEFENCE TECHNOLOGIES",** in partial fulfillment of the requirements for the award of the **Bachelor of Technology in Aerospace Engineering** and submitted to the Department of Aerospace Engineering, COES, University of Petroleum and Energy Studies, Dehradun is an authentic record of my own work carried out during a period from **August, 2014 to April, 2015** under the supervision of **Mr. Sudhir Kumar Chaturvedi , Assistant Professor, Department of Aerospace Engineering**.

The matter presented in this Project Report has not been submitted by me for the award of any other degree elsewhere.

Anirudh Katyal **Himanshu Tiwari**

This is to certify that the above statement made by the student(s) is correct to the best of my knowledge.

15th April, 2015 **Sudhir Kumar Chaturvedi**
(Assistant Professor)

Dr. Om Prakash

Head of Department
Department of Aerospace Engineering

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ACKNOWLEDGEMENT

"Our first and foremost Gratitude to the ALMIGHTY"

It is with a sense of great satisfaction and pride that we are sitting down to pen out our major project thesis report. First and foremost we sincerely salute our esteemed Institution **University of Petroleum & Energy Studies, Dehradun** for giving this golden opportunity for fulfilling our warm dreams of becoming a bachelor.

The first and foremost person we would like to express our deep sense of gratitude and profound thanks to our guide **Mr. Sudhir Kumar Chaturvedi,** Assistant Professor, Department of Aerospace Engineering, UPES Dehradun for his valuable advice, suggestions, insurmountable guidance which played a vital role in carrying out our project work successfully. Our thanks to **Prof. (Dr.) Om Prakash**, Head, Department of Aerospace Engineering, UPES, Dehradun for his valuable guidance towards our project.

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Anirudh Katyal ________________

Himanshu Tiwari _______________

ABSTRACT

Any object illuminated by radar waves will scatter some of the incident energy. The radar cross section (RCS) is a parameter used to characterize the scattering properties of an object. It represents the size of this object as seen by the radar and has the dimension of square meters. The RCS area is not the same as physical area, but a measure of the ability of a target to reflect radar signals in the direction of the receiving antenna. RCS is defined as the area intercepting that amount of power which, when scattered isotropically, produces at the receiver an energy density equal to that scattered by the actual target. In aerospace industry, Radar cross-section is used to detect planes in a wide variation of ranges. For example, a stealth aircraft (which is designed to have low detectability) will have design features that give it a low RCS (such as absorbent paint, smooth surfaces, surfaces specifically angled to reflect signal somewhere other than towards the source), as opposed to a passenger airliner that will have a high RCS (bare metal, rounded surfaces effectively guaranteed to reflect some signal back to the source, lots of bumps like the engines, antennas, etc.). This project will therefore specifically deal with the Study and Analysis of various RCS of different Aircrafts viz. Military, Commercial, Training, etc. and based on this study the results so obtained will be simulated on MATLAB interface or any other suitable computing tool. There are various commercial software available which help in understanding of the main concepts of Radar Cross Section (RCS) and serve as a simulation tool for military and industrial applications. In this project we shall deal with the RCS (Radar Cross Section) parameter and its application in radar range calculations for the detection of targets. We shall also try to elucidate and compile basic facts related to RCS which are spread in the technical literature and difficult to find. The focus will also be to consider and track each and every condition (such as radar frequency, applicable target aspect range, and statistical properties) that should be taken into account when performing radar range calculations in order to obtain meaningful results. Also, through the visualization and analysis of simulations carried out in various computing tools we shall try to obtain a better understanding of key issues related to the calculation and interpretation of the RCS signature of actual objects and targets.

Keywords: Radar waves, Radar Cross Section, Radar Range, RCS Signature

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LIST OF ABBREVIATIONS

RADAR	Radio Detection And Ranging
PPI	Plan Position Indicator
RF	Radio Frequency
RCS	RADAR Cross Section
GHz	Gigahertz

LIST OF NOMENCLATURE

English Symbols

P_r	Received Signal Power in Watts,
P_t	Transmitted Power radiated by an isotropic antennae in Watts
G_t	Maximum Gain of an Antennae,
R	Distance from RADAR in Km,
A_e	Effective aperture area of antennae in m^2,
σ	RADAR cross-section (RCS) in m^2.
P_p	Peak pulse power in Watts
G	Antenna Gain
λ	Wavelength of RADAR frequency
T_o	Absolute Temperature of RADAR circuitary
B	Bandwidth
F_n	Noise figure of RADAR frequency
S/N	Signal to Noise ratio required for detection

Chapter 1: INTRODUCTION

This part of the report will provide a detailed overview of RADAR principles and technologies, including mathematical, physical and technical explanations.

1.1. Historical Overview:

The discovery and development of radar technology has not been a single handed work or invention of any individual or nation worldwide. As a result it is required to see the knowledge about “Radar” as an accumulation of many developments and improvements, in which many scientists from several nations took part in parallel. Nevertheless there have been several milestones in the past which highlight the discovery of important basic knowledge and inventions related to the concept of RADAR technology. Some of these include (in chronological order):

- In 1865, one of the renowned Scottish physicist, James Clerk Maxwell presented his “Theory of the Electromagnetic Field” which gave a description of the electromagnetic waves and their propagation. He also demonstrated that electric and magnetic fields travel through space in the form of waves, and at the constant velocity of light.
- This was followed by the discovery of Electromagnetic Waves by a German physicist Heinrich Rudolf Hertz, thereby demonstrating the Maxwell’s theory in the year 1886.
- A decade later, in 1904, a German engineer Christian Hülsmeyer invented the "telemobiloscope" for a traffic monitoring on the water in conditions of poor visibility. This was the first practical RADAR test. Furthermore, Hülsmeyer also applied his invention for a patent in Germany, France and the United Kingdom.
- Thereafter, in 1921, an American physicist, Albert Wallace Hull invented the Magnetron as an efficient transmitting tube. A year later, in 1922, two American electrical engineers, Albert H. Taylor and Leo C. Young of the Naval Research Laboratory (USA) located a wooden ship for the first time using the Electromagnetic Theory.
- In 1930, Lawrence A. Hyland of the Naval Research Laboratory, USA, located an aircraft for the first time based on the same principle theory of Electromagnetics.

- Eventually the year 1940 marked the development of various RADAR equipments in the nations of USA, Russia, Germany, France and Japan.

Driven by a number of war events and the development of the Air Force to major branch of service, the RADAR technology underwent a strong development boost during the World War II, and radar sets found widespread use during the "Cold War" along the inner German border.

1.2. Physical fundamentals of the RADAR Technology:

The basic principle of operation of a primary RADAR system is easy to understand. However, the theory can be quite complex at times. A thorough understanding of the theoretical aspects therefore becomes essential in order to be able to specify and operate primary radar systems correctly. The implementation and operation of primary radars systems involve a wide range of disciplines some of which may include building works, heavy mechanical and electrical engineering, high power microwave engineering, and advanced high speed signal and data processing techniques. Some laws of nature have a greater importance here. Radar measurement of range, or distance, is made possible because of the properties of radiated electromagnetic energy. The following paragraph, therefore, deals with the phenomenon of reflection of Electromagnetic waves.

The electromagnetic waves are reflected when they intercept an electrically leading surface. If these reflected waves are received again at the place of their origin, then it indicates the presence of an obstacle in the propagation direction. Electromagnetic waves propogate through air at a constant velocity, at approximately the velocity of light, which is nearly 300,000 kilometers per second or 186,000 statute miles per second or 162,000 nautical miles per second.

This constant velocity thus allows the determination of the distance between the reflecting objects (airplanes, ships or cars) and the radar systems by measuring the running time of the transmitted pulses. This energy normally travels through space in a rectilinear path, and will vary only slightly because of atmospheric and weather conditions. By making use of special radar antennas this energy can be concentrated or directed in a desired direction. Therefore, the direction (in azimuth and elevation) of the reflecting objects can be measured. These principles can basically be implemented in a radar system, and allow the estimation of the distance, the direction and the height of the reflecting objects. The following figure illustrates the measuring of a round trip time of a microwave pulse, thereby defining the Principle of operation of RADAR.

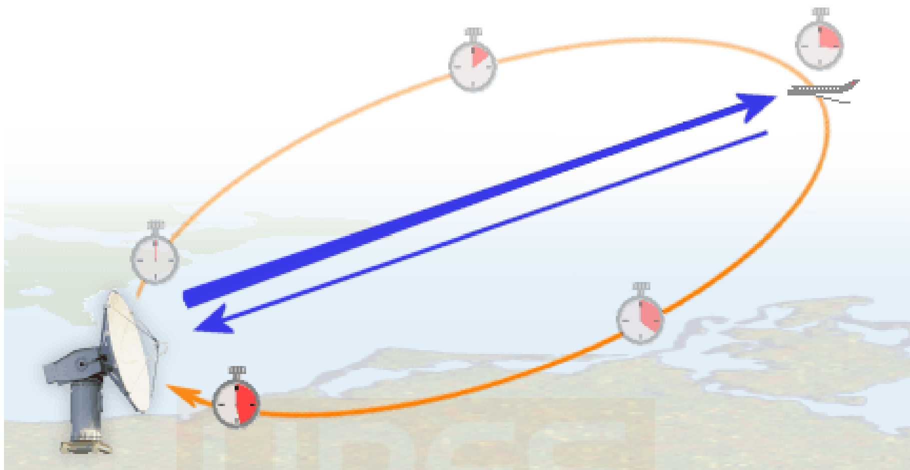

Figure 1.1: Radar principle: The measuring of a round trip time of a microwave pulse. [7]

(Source: RADAR Basics: http://www.radartutorial.eu, Retrieved September, 2014.)

1.3. RADAR Principle of Operation:

The electronic principle on which radar operates is very similar to the principle of reflection of sound-waves. If we shout in the direction of a sound-reflecting object (like a rocky canyon or cave), we shall hear an echo. Now, if we know the velocity of sound in air, we can estimate the distance and general direction of the object. The time required for an echo to return can be roughly converted to distance if the magnitude of velocity of sound is known. Radar uses electromagnetic energy pulses in a much similar way, as is shown in Figure 1. The Radio-Frequency (RF) energy is transmitted to and reflected from the reflecting object. A small portion of the reflected energy returns to the radar set. This returned energy is called an ECHO, just as it is in sound terminology. Radar sets use the echo to determine the direction and distance of the reflecting objects.

The term RADAR is an acronym made up of the words:

RAdio (Aim) **D**etecting **A**nd **R**anging

This term was officially coined as an acronym by U.S. Navy Lieutenant Commander Samuel M. Tucker and F. R. Furth in November, 1940. The acronym was then by agreement adopted in 1943 by the Allied powers of World War II and thereafter received general international acceptance. A RADAR system basically refers to an electronic equipment that detects the presence of objects by using reflected electromagnetic energy. Under some conditions a radar system can measure the direction, height, distance, course and speed of these objects also. Moreover, the frequency of operation of electromagnetic energy used for radar is unaffected by the conditions of darkness and can also penetrate fog and clouds. This permits radar systems to determine the position of airplanes, ships, or other obstacles that are invisible to the naked eye because of distance, darkness, or weather. On the other hand, modern radar systems can extract widely more information from a target's echo signal than its range but the calculation of the range by measuring the delay time is one of its most important functions.

1.4.Basic design of a RADAR system:

The figure 1 shows the operating principle of a primary radar set. The radar antenna illuminates the target with a microwave signal, which is then reflected and intercepted by a receiving device. The electrical signal picked up by the receiving antenna is called an echo or return. The radar signal is generated by a powerful transmitter and received by a highly sensitive receiver. All targets produce a diffuse reflection that is it is reflected in a wide number of directions. The reflected signal is also known as scattering. Backscatter is the term given to reflections in the opposite direction to the incident rays. Radar signals can be displayed on the traditional plan position indicator (PPI) or other more advanced radar display systems. A PPI has a rotating vector with the radar at the origin, which indicates the pointing direction of the antenna and hence the bearing of targets.

The basic elements of a typical RADAR System are as enlisted below:

- **Transmitter :**

The radar transmitter produces the short duration high-power RF pulses of high energy that are fed into space by the antenna.

- **Duplexer :**

The duplexer alternately switches the antenna between the transmitter and receiver so that only one of them is in operation at a time. This switching is necessary because the high-power pulses of the transmitter would destroy the receiver if energy were allowed to enter the receiver.

- **Receiver :**

The receivers amplify and demodulate the received RF-signals. The receiver provides video signals on the output.

- **Radar Antenna :**

The Antenna transfers the transmitter energy to signals in space with the required distribution and efficiency. This process is applied in an identical way on reception.

- **Indicator:**

The indicator should present to the observer a continuous, easily understandable, graphical picture of the relative position of radar targets. The radar screen displays the output produced from the echo signals in the form of bright blibs. The longer the pulses are delayed by the runtime, the further away from the center of this radar scope they are displayed. The direction of the deflection on this screen is the one in which the antenna points at any given instant of time.

1.5. The Radar Range Equation:

It is the most useful description of the factors influencing radar performance which gives the range of radar in terms of the radar characteristics. The following equation is referred to as the general RADAR range equation:

$$\mathbf{Rmax} = \left[\frac{P_p.\,G^2.\sigma.\lambda^2}{(4\pi)^3.k.\,T_0.\frac{S}{N}.\,L_s}\right]^{1/4} \quad \textbf{(1.1)}$$

In the Equation on the previous page, the abbreviations correspond to:

- Pr = Received Signal Power in Watts,
- Pt = Transmitted Power radiated by an isotropic antennae,
- Gt = Maximum Gain of an Antennae,
- R = Distance from RADAR,
- Ae = Effective aperture area of antennae,
- σ = RADAR cross-section (RCS).

This formula therefore makes it possible to determine the free space range of a RADAR system that is the hypothetic maximum RADAR range at which the target is separated from the RADAR system. The parameters in this formulation are predominantly either physical constants or equipment parameters with well-defined values. These parameters are listed along with their characteristic in the table that follows:

Table 1.1. RADAR Range Equation Parameters. [2]

(Source: Chaff Radar Cross-section Studies and Measurements technical report)

PARAMETER	DESCRIPTION	COMMENT
P_t	Peak Pulse Power	Equipment Parameter
G	Antenna Gain	Equipment Parameter
σ	RCS of Target	Parameter with large statistical variations
λ	Wavelength of Operation	Equipment Parameter
S/N	Signal to Noise Ratio	Equipment Parameter
B	Bandwidth	Equipment Parameter
Fn	Noise Figure	Equipment Parameter
k	Boltzmann Constant	Physical Constant

1.6. RADAR Cross-Section:

The size and ability of a target to reflect radar energy can be summarized into a single term, σ, known as the radar cross-section, which has units of m^2. This unit shows, that the radar cross section is an area. If absolutely all of the incident radar energy on the target were reflected equally in all directions, then the radar cross section would be equal to the target's cross-sectional area as seen by the transmitter. However, in practice, a portion of the energy is absorbed and the reflected energy is not distributed equally in all directions.

Therefore, the radar cross-section is quite difficult to estimate and is normally determined by measurement. The target's radar cross sectional area depends of:

- The target's physical geometry and exterior features,
- The direction of the illuminating radar,
- The radar transmitters' frequency,
- The type of the material used for the target.

The use of stealth technology to reduce radar cross section increases the survivability and decreases the target detection of especially military aircraft.

Calculation of the radar cross section:

Radar cross section (RCS) is basically defined as the measure of a target's ability to reflect radar signals in the direction of the radar receiver, that is it is a measure of the ratio of backscatter density in the direction of the radar (from the target) to the power density that is intercepted by the target. Since the power is distributed on the shape of a sphere, a small part of this $((4\cdot\pi\cdot r^2))$ can be received by the radar.

Mathematically, Radar cross section σ is as defined as:

$$\sigma = 4\pi \frac{P_S}{P_i} \qquad \textbf{(1.2)}$$

- **σ:** measure of the target's ability to reflect radar signals in direction of the radar receiver, in [m²]
- **P_i:** power density that is intercepted by the target, in [W/m²]
- **P_s:** scattered power density in the range r, in [W/m²]

The RCS of a target can therefore be viewed as a comparison of the strength of the reflected signal from a target to the reflected signal from a perfectly smooth sphere of cross sectional area of 1 m².

1.7 RCS for Point-Like Targets:

Some targets have large values of RCS owing to their size and orientation and consequently, reflect a large portion of the incident power. Since, RCS has a widespread ranging from 10-5 for small insects to 106 for large aircrafts hence; RCS is often stated in the logarithmic decibel scale as:

$$\boldsymbol{\sigma}(\mathbf{dBs}) = \mathbf{20.log}\ (\boldsymbol{\sigma})(\mathbf{in\ m^2}) \qquad \mathbf{(1.3)}$$

The table below enlists the RCS and their variation for some of the potential targets.

Table 1.2. Targets and their RCS variation. [1]

(Source: Radar Cross-section Measurement Techniques, Defense Science Journal)

TARGET	**RCS (m^2)**	**RCS(dBsm)**
Aircraft Carrier	100000	50
Cruiser	10000	40
Conventional Cruise Missile	0.5	-3.0
Medium Airliner or Bomber	40	16
Large Fighter	6	7.8
Small Fighter	2	3.0
Small Bird	0.00001	-50
Small Insect	0.000001	-60

Chapter 2: AIM AND OBJECTIVES

Aim:

Study and analysis of Radar cross section for targets used in defense technologies.

Objectives:

- To study and understand the concept and underlying principle of Stealth Technology.
- To understand the main concepts of RCS, its parameters, and its significance in Stealth Technology.
- To elucidate and compile the basic facts related to RCS which are spread in technical literature but difficult to find.
- To obtain a better understanding of key issues related to calculation and interpretation of the RCS Signature of various targets through visualization and analysis of simulations which shall be carried out on suitable computer interfaces.

Chapter 3: LITERATURE REVIEW

This part of the report contains the links to various sources such as published research papers, technical articles, journals, etc. which were consulted while undertaking this project, and will also present the substantive findings, as well as theoretical and methodological contributions to this topic, as derived from them.

Source: Radar Cross-section Measurement Techniques, Defense Science Journal, Vol. 60, No. 2, March 2010, pp. 204-212.

The Findings: The RCS parameter guides the detection range for a target and is therefore studied to understand the effectiveness of a weapon system. It is not only important to understand the RCS characteristics of a target but also to look into the diagnostic mode of study where factors contributing to a particular RCS values are studied.

Source: Chaff Radar Cross-section Studies and Measurements, TECHNICAL REPORT AFAL-TR-79-1114, May 1978.

The Findings: Efficient use of chaff for the protection of aircraft in tactical situations demands knowledge of the radar scattering characteristics which is a direct function of the Aircraft's RCS.

Source: Teaching RADAR Cross-Section Concepts to Undergraduates with a Simulation Software, *Mauro A. Alves, Mirabel. C. Rezende,* International Conference on Engineering and Technology Education, 188, March 02 - 05, 2008, São Paulo, Brazil.

The Findings: The visualization and analysis of the Software simulations serve as valuable teaching aids, helping students to obtain a better understanding of key issues related to the calculation and interpretation of the RCS signature of actual objects and targets.

*Note: Due to documentation constraints, all the Sources and findings have not been included in this section of the report.

Chapter 4: METHODOLOGY ADOPTED

4.1 RCS of Simple Objects and its determination:

The RCS definition as stated in Skolnik clearly specifies that RCS is a ‘fictional’ area. The term ‘area’ refers to the unit being m². ‘Fictional’ means that RCS can actually be much larger than the reflective surface, as the following formula shows:

$$\boldsymbol{\sigma = Ap * R * D} \tag{4.1}$$

Ap : projected object surface,

R : Reflectivity, re-radiated fraction of intercepted power,

D : Directivity, ratio of the maximum intensity of the radiator to the intensity of an isotropic source.

On one hand, the reflectivity is usually smaller than unity and material dependent, on the other hand, the directivity can be much larger and depends on the shape of the object.

4.1.1 RCS of Simple Reflector Objects:

For simple target objects, such as flat rectangular plates, cylinders, spheres, RCS can be calculated using Maxwell’s equations with certain boundary conditions. Figure 2 shows three simple objects with the principal dimension of 1 m and their RCS.

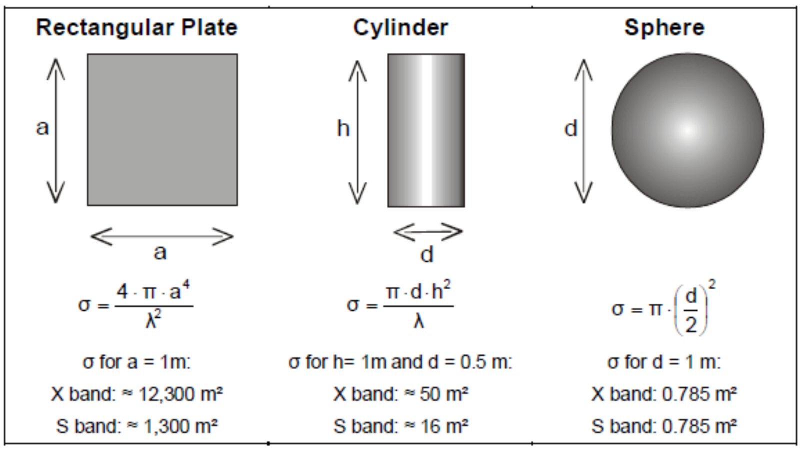

Figure 4.1. Simple Reflectors and their RCS Formulation [4]

4.2 RCS of Complex Objects and its determination:

A complex target may be treated as the one that consists of several reflectors within a radar resolution cell. A radar resolution cell is delineated by the radar pulse’s length and width of arc in the air. Following this definition, almost all real-world maritime as well as airborne targets are complex targets. For such targets there is no fixed relationship between a target’s surface area and Radar Cross Section Area. Hence, the RCS must be determined in another way. An obvious method of determining RCS is to put the object of interest, be it a ship or an aircraft, into a controlled environment and to use a calibrated radar system to measure the echo power. The target’s RCS can then be established using the radar range equation taking care of all system parameters and environmental losses. This is basically the procedure performed in so-called 'measuring ranges'. Measurements are usually performed for a 360° aspect arc, at various grazing angles, and often for different radar frequencies.

The larger and less mobile a target, the more expensive is the determination of RCS in measuring range. To save cost, a size-reduced model with appropriately scaled radar frequencies can be used. Another possibility is to simulate the measurements using computer-based methods. By means of construction plans, the target can be decomposed into simple computable reflector elements. The RCS at each aspect angle is then determined by summation of the RCS of the reflecting elements.

The method and mathematical formulation as presented in the Figure 2 has been taken from a literature and can be used as a reference to compute the RCS of various simple shapes, the combination of whose constitutes the reflecting area, that is, the RCS of an aircraft as a whole. The values of RCS provided above for different Frequency Bands can also be used to verify the results computed by us using MATLAB and thereby validate them.

Therefore, an attempt was to compute the RCS of the above mentioned figures (Rectangular Flat Plate, Circular Cylinder and Sphere) and the RCS so computed for each of them was plotted again the Frequency of Operation on a suitable graph using MATLAB. Also, prior to this, in order to gain a Hands-On-Experience on the Computing tool interface, execution of various simple formulation was done for different input parameters and suitable graphical representations were obtained. The familiarity with the interface, and methodology for computation of RCS and obtaining the corresponding plots was also accelerated and made extensive by the weekly tasks and assignments being assigned by the mentor. Finally, the results were obtained for the RCS calculation of Flat Plate, Circular Cylinder and Sphere for different frequency bands and suitable graphs were plotted indicating the variation of RCS versus the different frequency bands of operation(X-, C-, S-, L- Bands). The next section presents the Results so obtained along with the graphical plots.

Chapter 5: RESULTS AND DISCUSSIONS

This section deals with the practical aspects of the theoretical investigation conducted and reported in the above sections. The RADAR range equation consists of a number of parameters viz. wavelength, power transmitted, power received, antenna aperture, etc. The formulation clearly shows that the dependent variables such as Range of the target or RCS would vary as the function of the above listed parameters which are different for different radar systems and equipment configurations. It is therefore necessary to understand these variations and verify them with the aid of graphical interpretation which in turn may be obtained using suitable computing tools such as MATLAB. Also, the RCS of simple reflectors is seen to vary with the frequency (or wavelength of operation). As a result, such a variation can also be realized graphically in order to validate and generalize the results obtained from the mathematical formulation.

5.1 MATLAB PLOTS: RCS CALCULATION OF SIMPLE REFLECTOR TARGETS:

This section deals with the MATLAB Program Codes which were used for the computation of RCS of various shapes viz. Flat Plate, Circular Cylinder, and Sphere. Also, the variation of RCS for different Frequency Bands, mainly X, C, S has been realized using Graphical Interpretation as shown below.

5.1.1 RCS INTERPRETATION OF FLAT PLATE:

The RADAR Cross Section Area due to Flat plate for a unit dimensions of the plate and various frequency bands (such as X, C, S) was calculated as per the formula given in fig 2. This calculation was performed using MATLAB and the corresponding variation of RCS with the frequency of operation was plotted. The x-axis denotes the frequency of operation and the y-axis holds the dependent variable, RCS which is seen to vary as the inverse of the square of wavelength of operation or in direct proportion with the square of frequency of operation. This relation can also be realized from the graphical plot that follows on the next page. The MATLAB code for the same is enclosed in the Annexure section.

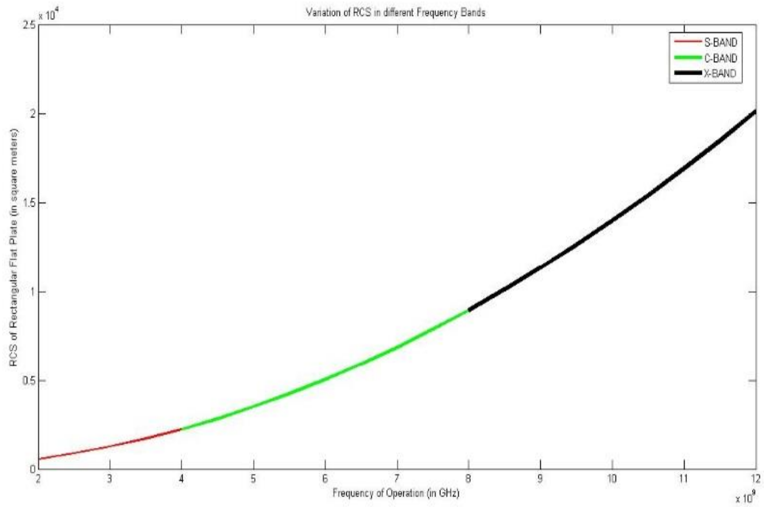

Figure 5.1: Variation of RCS of flat plate with frequency of operation

5.1.2. RCS INTERPRETATION OF CIRCULAR CYLINDER:

The RADAR Cross Section Area due to circular cylinder for unit diameter and height of the cylinder and various frequency bands (such as X, C, S) was calculated as per the formula given in fig 2. This calculation was performed using MATLAB and the corresponding variation of RCS with the frequency of operation was plotted. The x-axis denotes the frequency of operation and the y-axis holds the dependent variable, RCS which is seen to vary as the inverse of the wavelength of operation or in direct proportion with the frequency of operation. This relation can also be realized from the graphical plot that follows. The MATLAB code for the same is enclosed in the Annexure section.

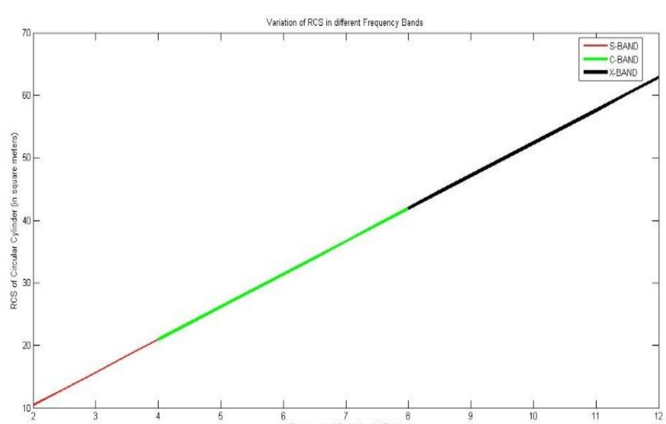

Figure 5.2: Variation of RCS of circular cylinder with frequency of operation

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.

5.2 VARIATION OF RCS Vs RANGE OF TARGET(Single frequency):

The following plot shows the variation of RCS with the Range of the Target from the RADAR system for a constant frequency of operation. The x-axis denotes the Range of the target and the y-axis holds the dependent variable, RCS which is seen to vary as the fourth power of the Range of operation. This relation can also be realized from the graphical plot that follows. The MATLAB code for the same is enclosed in the Annexure section.

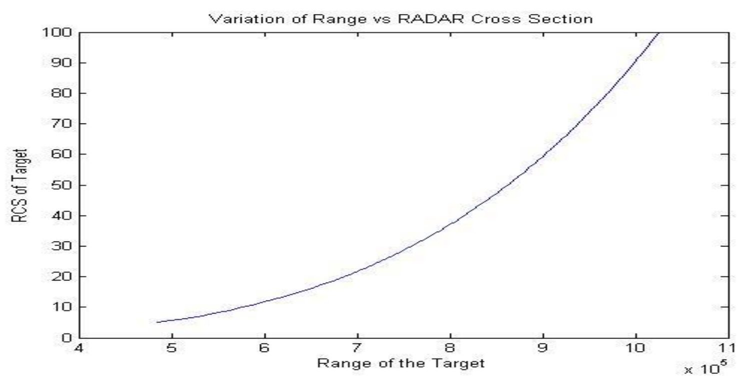

Figure 5.3: Variation of RCS with Range of operation for constant frequency.

5.2.1 VARIATION OF RCS OF THE TARGET FOR L-BAND.

The following plot shows the variation of RCS with the Range of the Target from the RADAR system for L-Band, that is, the frequency of operation ranges from 1-2 GHz. The x-axis denotes the wavelength of operation and the y-axis holds the dependent variable, RCS of the target which is seen to vary as the square of the wavelength of operation. This relation can also be realized from the graphical plot that follows. The MATLAB code for the same is enclosed in the Annexure section.

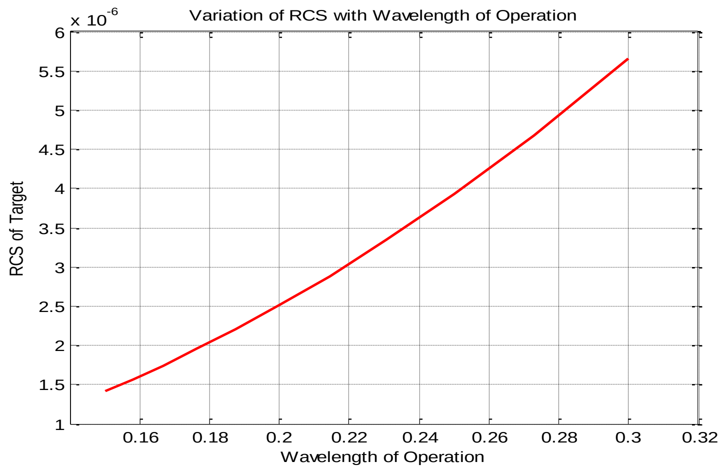

Figure 5.4: Variation of RCS of the Target for Different Frequency Bands. (L-Band only)

5.2.2 VARIATION OF RCS OF THE TARGET FOR S-BAND.

The following plot shows the variation of RCS with the Range of the Target from the RADAR system for S-Band, that is, the frequency of operation ranges from 2-4 GHz. The x-axis denotes the wavelength of operation and the y-axis holds the dependent variable, RCS of the target which is seen to vary as the square of the wavelength of operation. This relation can also be realized from the graphical plot that follows. The MATLAB code for the same is enclosed in the Annexure section.

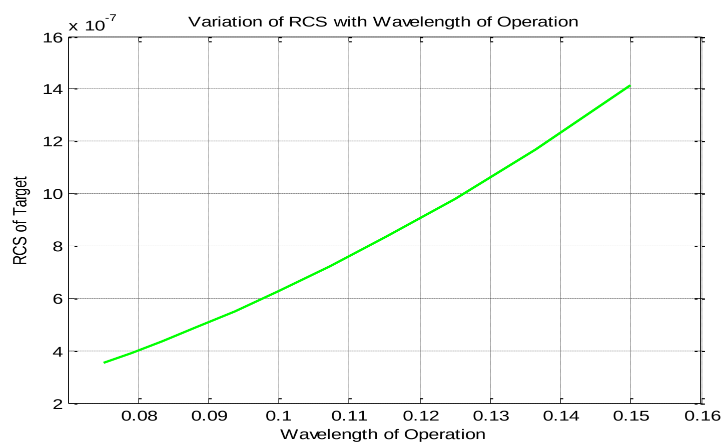

Figure 5.5: Variation of RCS of the Target for Different Frequency Bands. (S-Band only)

5.2.3 VARIATION OF RCS OF THE TARGET FOR C-BAND.

The following plot shows the variation of RCS with the Range of the Target from the RADAR system for C-Band, that is, the frequency of operation ranges from 4-8 GHz. The x-axis denotes the wavelength of operation and the y-axis holds the dependent variable, RCS of the target which is seen to vary as the square of the wavelength of operation. This relation can also be realized from the graphical plot that follows. The MATLAB code for the same is enclosed in the Annexure section.

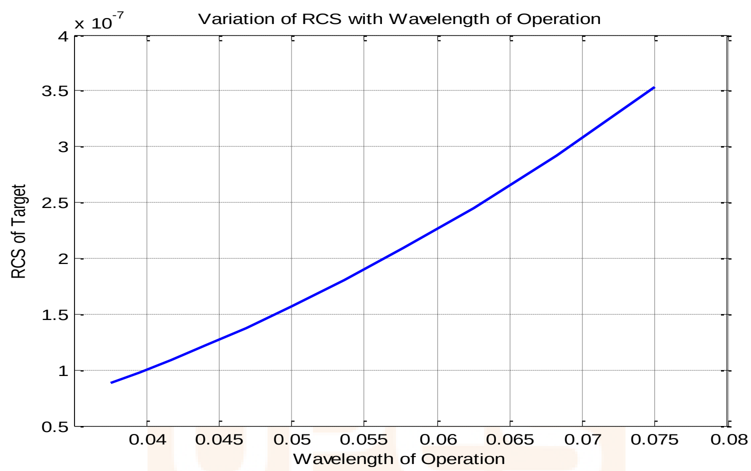

Figure 5.6: Variation of RCS of the Target for Different Frequency Bands. (C-Band only)

5.2.4 VARIATION OF RCS OF THE TARGET FOR DIFFERENT FREQUENCY BANDS.

The following plot(on next page) shows the variation of RCS with the Range of the Target from the RADAR system for L-, S-, C-Band, that is, the frequency of operation ranges from 1-8 GHz. The x-axis denotes the wavelength of operation and the y-axis holds the dependent variable, RCS of the target which is seen to vary as the square of the wavelength of operation. This relation can also be realized from the graphical plot that follows. The MATLAB code for the same is enclosed in the Annexure section.

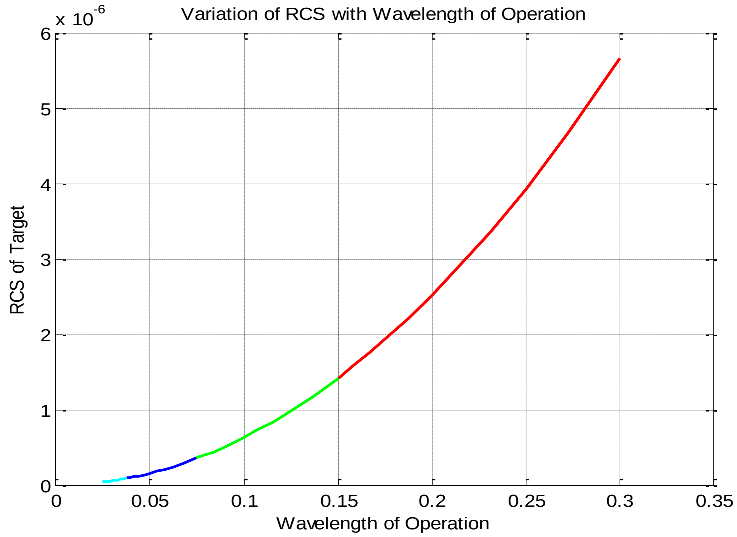

Figure 5.7: Variation of RCS of the Target for Different Frequency Bands. (All Bands Together)

5.3 VARIATION OF POWER RECEIVED Vs RCS:

The following plot (on next page) shows the variation of Power Received with the RCS of the Target for a constant frequency of operation. The x-axis denotes the RCS of the target and the y-axis holds the dependent variable, Power Received which is seen to vary linearly with the RCS. This relation can also be realized from the graphical plot that follows. The MATLAB code for the same is enclosed in the Annexure section.

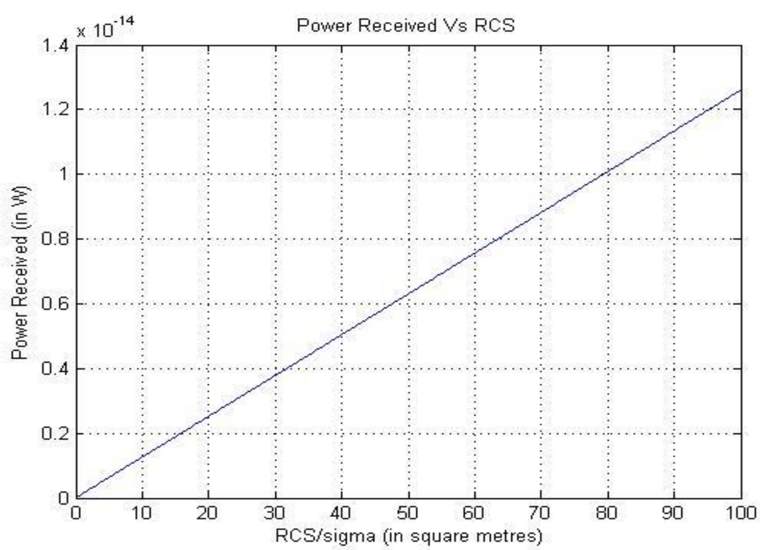

Figure 5.8: Variation of Power Received with RCS.

5.4 VARIATION OF RCS Vs RANGE OF TARGET: (Multiple Frequency Bands):

The following plot shows the variation of RCS with the Range of the Target from the RADAR system for multiple frequency bands. The x-axis denotes the Range of the target and the y-axis holds the dependent variable, RCS which is seen to vary as the fourth power of the Range of operation. This relation can also be realized from the graphical plot that follows. Also, in reference to fig.7, the red plot holds true for X-band whereas the green, violet and blue plots hold true for C, S and L Band respectively. The MATLAB code for the same is enclosed in the Annexure section.

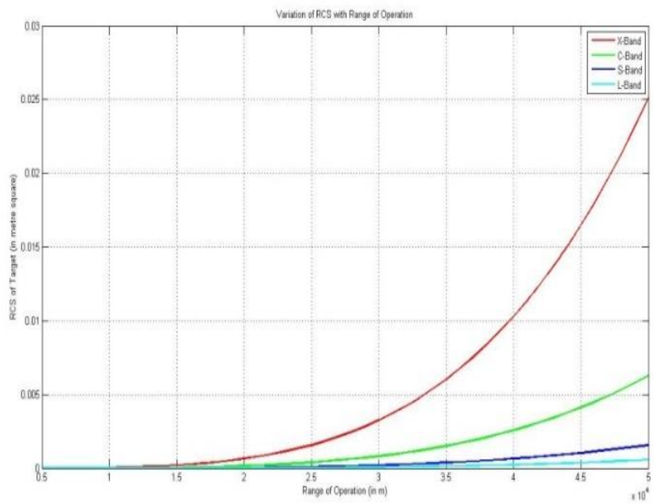

Figure 5.9: Variation of RCS with Range of operation for multiple frequency bands.

5.5 EFFECT OF ASPECT ANGLE ON RCS.

The following plot shows the variation of RCS with the aspect angle. The x-axis denotes the aspect angle in degrees and the y-axis holds the dependent variable, RCS which is seen to vary with the aspect angle. The magnitude of the RCS is converted into logarithmic one and correspondingly the x-axis holds the logarithmic magnitude of RCS. This relation can also be realized from the graphical plot that follows. The MATLAB code for the same is enclosed in the Annexure section.

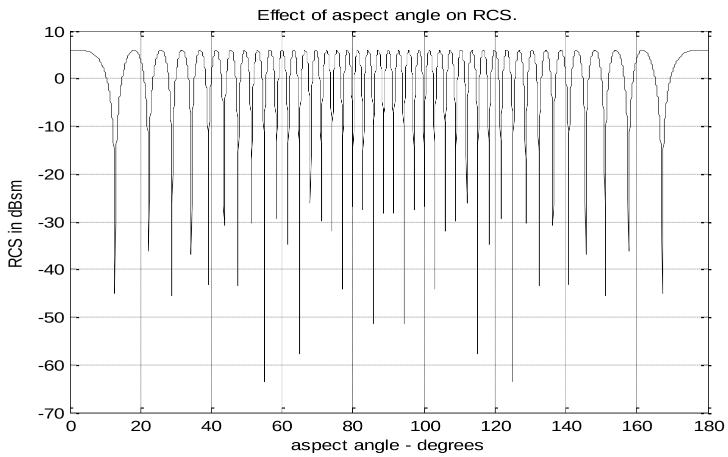

Figure 5.10: Effect of aspect angle on RCS.

5.6 RCS INTERPRETATION OF A COMPLEX TARGETS:

Having calculated the RCS of simple reflectors for various frequency bands, it is now possible to calculate the RCS of a complex target such a missile by summing up the contributions of various simple reflectors of which the target is composed. The following figure shows an example of a complex target.

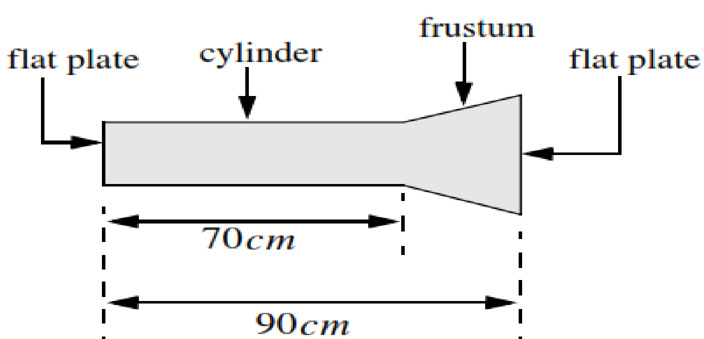

Figure 5.11: Example of Complex Target.

The total RCS of the complex target as presented in fig. 8 can be calculated by summing up the contributions due to the simple reflectors such as two flat plates, one circular cylinder and one frustum, of which the target is composed. The total RCS of the above mentioned target was calculated for L-Band with the aid of MATLAB. The graphical variation of the individual reflector RCS as well as the total RCS of the target with the frequency of operation is as shown below:

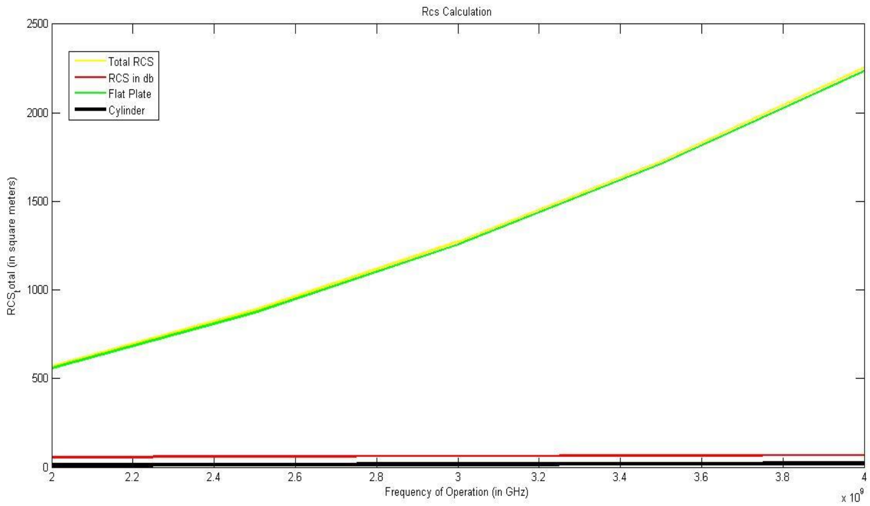

Figure 5.12: Variation of RCS with frequency of operation (Complex Target).

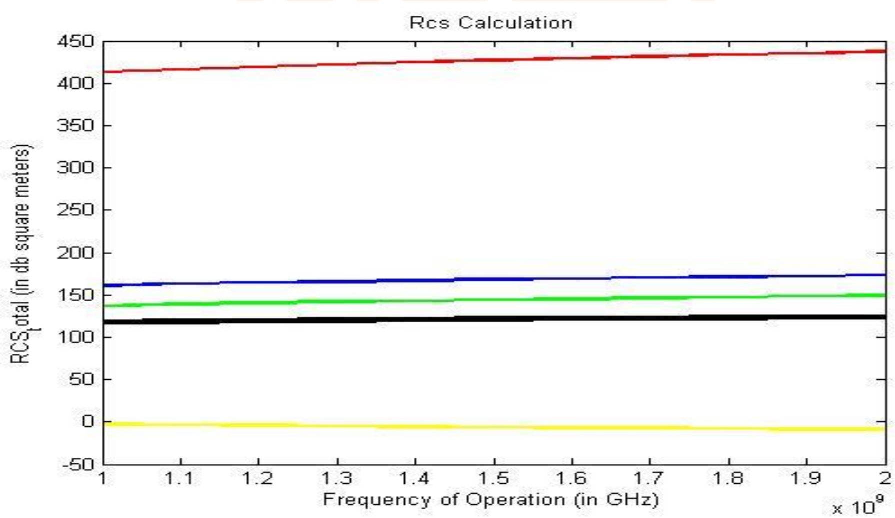

Figure 5.13: Variation of RCS with frequency of operation (on logarithmic scale).

Chapter 6: CONCLUSION AND FUTURE SCOPE

- A Preliminary study has been carried out about mathematical equation of radar range equation and this study from the various literatures were implemented in order to show the basic principle of the system.
- The basic study determines the various scopes in the field of Aviation electronics for the purpose to detect the targets, estimate its positions, retrieve its velocity and various texture analysis for the different types of targets.
- Also, a Preliminary study has been carried in order to gain an overview, physics, parameters and basic mathematical formulation of RCS.
- The basic facts related to RCS which are spread in technical literature but difficult to find have been compiled and consolidated and this has in turn helped in obtaining a better understanding of key issues related to calculation and interpretation of the RCS Signature of various targets through visualization and analysis of simulations which have been carried out on suitable computer interface.
- A successful attempt has been made to calculate the RCS for various Simple Reflectors for unit dimensions and different frequency bands and a corresponding graphical relationship between various parameters of operation has been obtained.
- A successful computation of RCS of a complex target composed of multiple simple reflectors has been carried out and the corresponding graphical representation showing the influence of RCS of each Reflector on the overall RCS of target has been obtained.
- A window application titled as “RADAR Cross- Section App” has been developed using Microsoft Visual Studio, which describes some of the key concepts related to RADAR technology and also helps the user to compute the RCS of simple reflectors as well as for complex targets.
- The investigation conducted through this project can serve as the basis for calculation of RCS of various objects used in Defense technologies for a given orientation with respect to the RADAR system.

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APPENDIX 1

MATLAB CODES

Code 1: Relation of Range of the Target with its RCS for constant value of frequency.

```
clc;
clear all;
close all;

%Input Parameters

P_t = 500000; % Power Transmitted by the Source (in Watt).
G = 1; % Transmitting Antenna assumed, isotropic transmitting Conditions.
lameda = 0.03; % The wavelength of the RADAR Wave (in m).
sigma = 5:1:100; % The values of variable RCS of different targets (in m2)
P_r = 0.0000000000001; %Minimum Power Received from the target (in W/ 0.1pW).
A = 5; % Aperture Area of Transmitting Antenna(in square metres).

% Entering RADAR Range Equation Formula.

R = ((P_t*G*(A^2)*sigma)/(4*3.14*(lameda^2)*P_r)).^(1/4);


% Plotting of Relation between Range Vs RADAR Cross-Section.

figure
plot(R, sigma)
xlabel('Range of the Target')
ylabel('RCS of Target')
title('Variation of Range vs RADAR Cross Section')

%End of Program
```

****

Code 2: Variation of RCS of a Rectangular Flat Plate for different Frequency Bands.

```
clc;
clear all;
close all;

% Program to demonstrate the variation of RCS of a Rectangular Flat Plate for different
Frequency Bands

%Input Parameters for S-Band

f1=(2:0.5:4)*(10^9); % Frequency of operation in S-Band(2-4 GHz)
c=3*(10^8); % Speed of EMW(in m/s)
lameda1=c./f1; % Wavelength of EMW(in m)
a=1; %Side of a Flat Plate(in meter)

%Calculation of RCS for S-Band

sigma1=4*pi*(a^4)./(lameda1.^2); %RCS Formula for Flat Plate(in square meters)
disp(sigma1)

%Input Parameters for C-Band

f2 = (4:0.5:8)*(10^9); % Frequency of operation in C-Band(4-8 GHz)
c = 3*(10^8); % Speed of EMW(in m/s)
lameda2=c./f2;% Wavelength of EMW(in m)
a = 1; %Side of a Flat Plate (in meter)

%Calculation of RCS for C-Band

sigma2=4*pi*(a^4)./(lameda2.^2); %RCS Formula for Flat Plate(in square meters)
disp(sigma2)

%Input Parameters for X-Band

f3 = (8:0.5:12)*(10^9); % Frequency of operation in X-Band(8-12 GHz)
c =3*(10^8); % Speed of EMW (in m/s)
lameda3=c./f3;% Wavelength of EMW(in m)
a = 1; %Side of a Flat Plate (in meter)

%Calculation of RCS for X-Band

sigma3=4*pi*(a^4)./(lameda3.^2); %RCS Formula for Flat Plate(in square meters)
disp(sigma3)
```

```
% Plotting of Graphs showing variation of RCS for different Frequency Bands

figure
plot(f1,sigma1,'red','Linewidth',2) %Plot for RCS in S-Band
hold on
plot(f2,sigma2,'green','Linewidth',3) %Plot for RCS in C-Band
plot(f3,sigma3,'black','Linewidth',4) %Plot for RCS in X-Band
xlabel('Frequency of Operation (in GHz)')
ylabel('RCS of Rectangular Flat Plate (in square meters)')
title('Variation of RCS in different Frequency Bands')
hold off

%End of Program
```

****

Code 3: Variation of RCS of a Circular Cylinder for different Frequency Bands.

```
clc;
clear all;
close all;

% Program to demonstrate the variation of RCS of a Circular Cylinder for different Frequency
Bands

%Input Parameters for S-Band

f1=(2:0.5:4)*(10^9); % Frequency of operation in S-Band(2-4 GHz)
c=3*(10^8);% Speed of EMW(in m/s)
lameda1=c./f1;% Wavelength of EMW(in m)
h=1; %Height of the Cylinder(in meter)
d=0.5; %Diameter of the Circular Cross-Section of the Cylinder(in meter)

%Calculation of RCS for S-Band

sigma1=pi*d*(h^2)./(lameda1); %RCS Formula for Circular Cylinder(in square meters)
disp(sigma1)

%Input Parameters for C-Band

f2=(4:0.5:8)*(10^9); % Frequency of operation in C-Band(4-8 GHz)
c=3*(10^8);% Speed of EMW(in m/s)
lameda2=c./f2;% Wavelength of EMW(in m)
h=1; %Height of the Cylinder(in meter)
d=0.5; %Diameter of the Circular Cross-Section of the Cylinder(in meter)

%Calculation of RCS for C-Band

sigma2=pi*d*(h^2)./(lameda2); %RCS Formula for Circular Cylinder(in square meters)
disp(sigma2)

%Input Parameters for X-Band

f3=(8:0.5:12)*(10^9); % Frequency of operation in X-Band(8-12 GHz)
c=3*(10^8);% Speed of EMW(in m/s)
lameda3=c./f3;% Wavelength of EMW(in m)
h=1; %Height of the Cylinder(in meter)
d=0.5; %Diameter of the Circular Cross-Section of the Cylinder(in meter)
```

```
%Calculation of RCS for X-Band

sigma3=pi*d*(h^2)./(lameda3); %RCS Formula for Circular Cylinder(in square meters)
disp(sigma3)

%Plotting of Graphs showing variation of RCS for different Frequency Bands

figure
plot(f1,sigma1,'red','Linewidth',2) %Plot for RCS in S-Band
hold on
plot(f2,sigma2,'green','Linewidth',3) %Plot for RCS in C-Band
plot(f3,sigma3,'black','Linewidth',4) %Plot for RCS in X-Band
xlabel('Frequency of Operation (in GHz)')
ylabel('RCS of Circular Cylinder (in square meters)')
title('Variation of RCS in different Frequency Bands')
hold off

%End of Program
```

****

Code 4: Variation of RCS of a Sphere for different Frequency Bands.

```
clc;
clear all;
close all;

% Program to demonstrate the variation of RCS of a Sphere for different Frequency Bands

%Input Parameters for S-Band

f1=(2:0.5:4)*(10^9); % Frequency of operation in S-Band(2-4 GHz)
c=3*(10^8);% Speed of EMW(in m/s)
lameda1=c./f1;% Wavelength of EMW(in m)
d=1; %Diameter of the Circular Cross-Section of the Sphere(in meter)

%Calculation of RCS for S-Band

sigma1=pi*(d^2)./4; %RCS Formula for Sphere(in square meters)
disp(sigma1)

%Input Parameters for C-Band

f2=(4:0.5:8)*(10^9); % Frequency of operation in C-Band(4-8 GHz)
c=3*(10^8);% Speed of EMW(in m/s)
lameda2=c./f2;% Wavelength of EMW(in m)
d=1; %Diameter of the Circular Cross-Section of the Sphere(in meter)

%Calculation of RCS for C-Band

sigma2=pi*(d^2)./4; %RCS Formula for Sphere(in square meters)
disp(sigma2)

%Input Parameters for X-Band

f3=(8:0.5:12)*(10^9); % Frequency of operation in X-Band(8-12 GHz)
c=3*(10^8);% Speed of EMW(in m/s)
lameda3=c./f3;% Wavelength of EMW(in m)
d=1; %Diameter of the Circular Cross-Section of the Sphere(in meter)

%Calculation of RCS for X-Band

sigma3=pi*(d^2)./4; %RCS Formula for Sphere(in square meters)
disp(sigma3)
```

```
% Plotting of Graphs showing variation of RCS for different Frequency Bands

figure
plot(f1,sigma1,'red') %Plot for RCS in S-Band
hold on
plot(f2,sigma2,'green') %Plot for RCS in C-Band
plot(f3,sigma3,'black') %Plot for RCS in X-Band
xlabel('Frequency of Operation (in GHz)')
ylabel('RCS of Circular Cylinder (in square meters)')
title('Variation of RCS in different Frequency Bands')
grid on
hold off

%End of Program
```

****

Code 5: Variation of RCS of the Target for Different Frequency Bands. (L-Band only)

```
clc;
clear all;
close all;

%Program to understand the Variation of RCS of the Target for Different Frequency Bands.
(L-Band only)

%Input Parameters

P_t = 500000; % Power Transmitted by the Source (in Watt).
G = 1; % The Transmitting Antenna is assumed to under isotropic transmitting Conditions.
f1 = (1:0.1:2)*(10^9);
c = 3*(10^8);
lameda1 = c./f1 % The wavelength of the RADAR Wave for L-Band (in m).
R = (5000); % The value of constant Range(in metres).
P_r = 0.0000000000001; %Minimum Power Received from the target (in W/ 0.1pW).
A = 5; % Aperture Area of Transmitting Antenna(in square metres).

% Entering RADAR RCS-Range Equation Formula.

sigma1 = (R^4)*(4*3.14*(lameda1.^2)*P_r)./(P_t*(A^2));

% Displaying the RCS as calculated from the above formula.

disp(sigma1);

% Plotting of Relation between RADAR Cross-Section Vs Wavelength of Operation.

figure
plot(lameda1, sigma1,'red','Linewidth',2)
xlabel('Wavelength of Operation')
ylabel('RCS of Target')
title('Variation of RCS with Wavelength of Operation')
grid on

% End of the Program
```

______________________________***************______________________________

Code 6: Variation of RCS of the Target for Different Frequency Bands. (S-Band only)

```
clc;
clear all;
close all;

%Program to understand the Variation of RCS of the Target for Different Frequency Bands.(S-Band only)

%Input Parameters

P_t = 500000; % Power Transmitted by the Source (in Watt).
G = 1; % The Transmitting Antenna is assumed to under isotropic transmitting Conditions.
f2 = (2:0.2:4)*(10^9);
c = 3*(10^8);
lameda2 = c./f2 % The wavelength of the RADAR Wave for S-Band (in m).
R = (5000); % The value of constant Range(in metres).
P_r = 0.0000000000001; %Minimum Power Received from the target (in W/ 0.1pW).
A = 5; % Aperture Area of Transmitting Antenna(in square metres).

% Entering RADAR RCS-Range Equation Formula.

sigma2 = (R^4)*(4*3.14*(lameda2.^2)*P_r)./(P_t*(A^2));

% Displaying the RCS as calculated from the above formula.

disp(sigma2);

% Plotting of Relation between RADAR Cross-Section Vs Wavelength of Operation.

figure
plot(lameda2, sigma2,'green','Linewidth',2)
xlabel('Wavelength of Operation')
ylabel('RCS of Target')
title('Variation of RCS with Wavelength of Operation')
grid on

% End of the Program
```

****

Code 7: Variation of RCS of the Target for Different Frequency Bands. (C-Band only)

```
clc;
clear all;
close all;

%Program to understand the Variation of RCS of the Target for Different Frequency Bands.
(C-Band only)

%Input Parameters

P_t = 500000; % Power Transmitted by the Source (in Watt).
G = 1; % The Transmitting Antenna is assumed to under isotropic transmitting Conditions.
f3 = (4:0.4:8)*(10^9);
c = 3*(10^8);
lameda3 = c./f3 % The wavelength of the RADAR Wave for C-Band (in m).
R = (5000); % The value of constant Range(in metres).
P_r = 0.0000000000001; %Minimum Power Received from the target (in W/ 0.1pW).
A = 5; % Aperture Area of Transmitting Antenna(in square metres).

% Entering RADAR RCS-Range Equation Formula.

sigma3 = (R^4)*(4*3.14*(lameda3.^2)*P_r)./(P_t*(A^2));

% Displaying the RCS as calculated from the above formula.

disp(sigma3);

% Plotting of Relation between RADAR Cross-Section Vs Wavelength of Operation.

figure
plot(lameda3, sigma3,'blue','Linewidth',2)
xlabel('Wavelength of Operation')
ylabel('RCS of Target')
title('Variation of RCS with Wavelength of Operation')
grid on

% End of the Program
```


______________________________***************______________________________

Code 8: Variation of RCS of the Target for Different Frequency Bands. (All bands together)

```
clc;
clear all;
close all;

%Program to understand the Variation of RCS of the Target for Different Frequency Bands.(L-
Band, S-Band, C-Band, X-Band)

%Input Parameters

P_t = 500000; % Power Transmitted by the Source (in Watt).
G = 1; % The Transmitting Antenna is assumed to under isotropic transmitting Conditions.
f1 = (1:0.1:2)*(10^9);
f2 = (2:0.2:4)*(10^9);
f3 = (4:0.4:8)*(10^9);
f4 = (8:0.4:12)*(10^9);
c = 3*(10^8);
lameda1 = c./f1; % The wavelength of the RADAR Wave for L-Band (in m).
lameda2 = c./f2; % The wavelength of the RADAR Wave for S-Band (in m).
lameda3 = c./f3; % The wavelength of the RADAR Wave for C-Band (in m).
lameda4 = c./f4; % The wavelength of the RADAR Wave for X-Band (in m).
R = (5000); % The value of constant Range(in metres).
P_r = 0.0000000000001; %Minimum Power Received from the target (in W/ 0.1pW).
A = 5; % Aperture Area of Transmitting Antenna(in square metres).

% Entering RADAR RCS-Range Equation Formula.

sigma1 = (R^4)*(4*3.14*(lameda1.^2)*P_r)./(P_t*(A^2));
sigma2 = (R^4)*(4*3.14*(lameda2.^2)*P_r)./(P_t*(A^2));
sigma3 = (R^4)*(4*3.14*(lameda3.^2)*P_r)./(P_t*(A^2));
sigma4 = (R^4)*(4*3.14*(lameda4.^2)*P_r)./(P_t*(A^2));

 % Displaying the RCS as calculated from the above formula.

disp(sigma1);
disp(sigma2);
disp(sigma3);
disp(sigma4);

 % Plotting of Relation between RADAR Cross-Section Vs Wavelength of Operation.

figure
plot(lameda1, sigma1,'red','Linewidth',2)
```

```
xlabel('Wavelength of Operation')
ylabel('RCS of Target')
title('Variation of RCS with Wavelength of Operation')
hold on
plot(lameda2, sigma2,'green','Linewidth',2)
hold on
plot(lameda3, sigma3,'blue','Linewidth',2)
hold on
plot(lameda4, sigma4,'cyan','Linewidth',2)
grid on
hold off

% End of the Program
```

___________________________________*******************_______________________________________

Code 9: Effect of aspect angle on RCS.

```
clc;
clear all;
close all;

%Program to demonstrate the effect of aspect angle on RCS.

%Input Parameters

f=3*(10^9);
lameda=(3*(10^8)/f);
asp_deg=0:0.05:180;
asp_rad=(pi/180).* asp_deg;
scat_spacing=1;
elec_spacing = (2*scat_spacing / lameda).* cos(asp_rad);

% Computing the RCS(rcs = RCS_scat1 + RCS_scat2)

rcs = abs(1.0 + cos((2.0 * pi) .* elec_spacing)+ i * sin((2.0 * pi) .* elec_spacing));
rcs_db = 20.0*log10(rcs); % RCS in dBsm
figure (1);
plot (asp_deg,rcs_db,'k');
grid;
xlabel ('aspect angle - degrees');
ylabel ('RCS in dBsm');
title('Effect of aspect angle on RCS.')

% End of the Program
```

****

Code 10: Dependency of RCS on wavelength.

```
clc;
clear all;
close all;

%Program to demonstrate the dependency of RCS on wavelength

 %Input Parameters

freq_band = (300 - 1)*(10^9);
delfreq = freq_band / 500.;
index = 0;
for freq = 10^9: delfreq: 300*(10^9)
index = index +1;
wavelength(index) = 3.0e+8 / freq;
scat_spacing=1;
elec_spacing = 2.0 * scat_spacing ./ wavelength;
rcs = abs (  1 + cos((2.0 * pi) .* elec_spacing)+ i * sin((2.0 * pi) .* elec_spacing));
rcs = rcs + eps;
rcs = 20.0*log10(rcs); % RCS ins dBsm

% Plot RCS versus frequency

freq = 10^9:delfreq:300*(10^9);
plot(freq,rcs);
grid;
xlabel('Frequency in Hz');
ylabel('RCS in dBsm');
title('Dependency of RCS on wavelength')

% End of the Program
```

****

Code 11: RCS of complex target.

```
clc;
clear all;
close all;

% Program to calculate the RCS of combination of figures.

%Input Parameters for S-Band

f1=(2:0.5:4)*(10^9); % Frequency of operation in S-Band(2-4 GHz)
c=3*(10^8);% Speed of EMW(in m/s)
lameda1=c./f1;% Wavelength of EMW(in m)
a=1; %Side of a Flat Plate(in meter)

%Calculation of RCS for S-Band

sigma1=4*pi*(a^4)./(lameda1.^2); %RCS Formula for Flat Plate(in square meters)
disp(sigma1)

%Input Parameters for S-Band

f1=(2:0.5:4)*(10^9); % Frequency of operation in S-Band(2-4 GHz)
c=3*(10^8);% Speed of EMW(in m/s)
lameda1=c./f1;% Wavelength of EMW(in m)
h=1; %Height of the Cylinder(in meter)
d=0.5; %Diameter of the Circular Cross-Section of the Cylinder(in meter)

%Calculation of RCS for S-Band

sigma2=pi*d*(h^2)./(lameda1); %RCS Formula for Circular Cylinder(in square meters)
disp(sigma2)

sigma_t=(sigma1+sigma2);
disp(sigma_t);
rcs_db = 20.0*log10(sigma_t);
disp(rcs_db);

figure
plot(f1,sigma_t,'yellow','Linewidth',2)
hold on
```

```
plot(f1,rcs_db,'red','Linewidth',2)
plot(f1,sigma1,'green','Linewidth',2)
plot(f1,sigma2,'black','Linewidth',3)
xlabel('Frequency of Operation (in GHz)')
ylabel('RCS_total (in square meters)')
title('Rcs Calculation')
hold off

% End of the Program
```

****

LIST OF PUBLICATIONS

- A.Katyal, H.Tiwari, Sudhir Kumar Chaturvedi, Sonam Dobriyal, **Comparative Study and Analysis of Various Typical Configuration for Estimation of RCS**, 9th Uttarakhand State Science & Technology Congress, 26-28 February 2015, Dehradun. [Abstract Only]

- A.Katyal, H.Tiwari, Sudhir Kumar Chaturvedi, **Study and Radar Cross Section Estimation for Simple Reflectors**, National Conference on Advancements and Futuristic Trends in Aerospace Engineering, March 13-14, 2015, PEC University, Chandigarh.