Monostatic Radar Cross Section Estimation of Missile Shaped Object Using Physical Optics Method

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Abstract

Stealth Technology manages many signatures for a target in which most radar systems use radar cross section (RCS) for discriminating targets and classifying them with regard to Stealth. During a war target’s RCS has to be very small to make target invisible to enemy radar. In this study, Radar Cross Section of perfectly conducting objects like cylinder, truncated cone (frustum) and circular flat plate is estimated with respect to parameters like size, frequency and aspect angle. Due to the difficulties in exactly predicting the RCS, approximate methods become the alternative. Majority of approximate methods are valid in optical region and where optical region has its own strengths and weaknesses. Therefore, the analysis given in this study is purely based on far field monostatic RCS measurements in the optical region. Computation is done using Physical Optics (PO) method for determining RCS of simple models. In this study not only the RCS of simple models but also missile shaped and rocket shaped models obtained from the cascaded objects with backscatter has been computed using Matlab simulation. Rectangular plots are obtained for RCS in dbsm versus aspect angle for simple and missile shaped objects using Matlab simulation. Treatment of RCS, in this study is based on Narrow Band.

Keywords: Normal incidence, Physical Optics, Radar Cross Section

1 INTRODUCTION

The estimation of RCS has been the field of focus in the recent years for various purposes. The research of radar cross section (RCS) of simple and complex objects is certainly significant to identify targets such as aircrafts, rockets, ships and other complex objects like missiles, with the purpose of improving their radar visibility in various frequency ranges. The complex shaped objects at high frequencies impose a challenging task for researchers to estimate RCS. Radar cross section diagrams are usually difficult to understand due to fact that they are two dimensional representations of three dimensional objects. Moreover, the difficulty in interpreting RCS diagrams is depend upon the geometry of the object and, sometimes on the techniques used to measure or calculate the RCS. Measurements are mostly affected by many external factors, such as instrumental errors, spurious reflections and interferences, which can degrade the experimental data. In order to identify the target more
precisely, it is necessary to analyze and understand RCS patterns generated by the targets. Although several RCS prediction methods exist for arbitrary three dimensional targets, most of them require a considerable amount of computer resources and processing time. In addition, the procurement of software, which implements these methods, usually represents a significant amount of investment in capital and training time. Hence there is a need for an inexpensive, user friendly, easy to use, RCS prediction software tool that will run on a standard computer and will be able to produce RCS predictions within small amount of time. In this study, physical optics (PO) method used to measure RCS. This provides the user the capability to model any three dimensional object with simple component shapes.

2 RCS OF SIMPLE MODELS USING PHYSICAL OPTICS METHOD

Cylinder, circular flat plate, truncated cone are simple models for computing RCS. Computation is done using Physical Optics (PO) method for determining RCS of simple models. RCS of complex models can be computed by describing the model as a collection of simple objects whose RCS are known. The total RCS is obtained by summing vectorially the contributions from individual simple models.

3 RCS OF A CYLINDER MODEL USING PO METHOD

For a circular cylinder of radius ‘r’ due to roll of symmetry, wavelength ($\lambda$) [1-7,6-9]

\[
\sigma_\theta = \frac{2\pi H^2 r}{\lambda}
\]

\[
\sigma = \frac{\lambda r \sin \theta}{8\pi (\cos \theta)^2}
\]

**Inputs**  Height of the Cylinder (H) is 1 mt and Radius of the Cylinder(r) is 0.5 mt

From Fig.2 it is observed that Peak RCS is obtained at 90 degrees.
4 RCS OF A CIRCULAR FLAT PLATE MODEL USING PO METHOD

Flat Plate $\sigma_{CFP} = \frac{4\pi A^2}{\lambda^2}$ and area of a circle $A = \pi r^2$ (3) & (4)

From Eq.3 and Eq.4

Then RCS of a circular flat plate $\sigma = \frac{4\pi^3 r^4}{\lambda^2}$ (5)

For normal incidence i.e. $\theta=0$ then $\sigma = \frac{4\pi^3 r^4}{\lambda^2}$

For non normal incidence, two approximations for the circular flat plate backscattered RCS for any linearly polarized incident wave are [7,9]

$\sigma = \frac{\lambda}{8\pi \sin \theta (\tan \theta)}$ (6)

$\sigma = \pi k^2 r^2 \left( \frac{2J_1(2kr \sin \theta)}{2kr \sin \theta} \right)^2 \cos^2 \theta$ (7)

Where $k = 2\pi/\lambda$

**Inputs** Radius of Circular Flat Plate=0.5 mt

![Fig.3 Circular Flat Plate](image)

![Fig.4 RCS (dbsm) v aspect angle(degrees)](image)
5 RCS OF A TRUNCATED CONE (FRUSTUM) MODEL USING PO METHOD

Half cone angle is ‘α’ then \( \tan \alpha = \frac{(r_2-r_1)}{H} = \frac{r_2}{L} \) for a cone take \( r_1 = 0 \)

![Fig.5 Truncated Cone](image)

The aspect angle at normal incidence (broadside) is \( \theta_n \) [7,6-9]. Thus, when a frustum is illuminated by a radar located at the same side as the cone’s small end, the angle \( \theta_n \) is \( \theta_n = 90-\alpha \)

Alternatively normal incidence occurs at \( \theta_n = 90+\alpha \). At normal incidence, one approximation for the backscattered RCS of a truncated cone due to linearly polarized incident wave is

\[
\sigma_{\theta_n} = \frac{8\pi(z_2^{3/2} - z_1^{3/2})^2}{9\lambda \sin \theta_n} (\sin \theta_n \cos \theta_n \tan \alpha)^2
\]  

Using Trigonometric identities Eq.8 is reduced to Eq.9

\[
\sigma_{\theta_n} = \frac{8\pi(z_2^{3/2} - z_1^{3/2})^2}{9\lambda} \sin \alpha \cos^4 \alpha
\]

For non-normal incidence, backscattered RCS due to linearly polarized incident wave is

\[
\sigma = \frac{8\pi \tan \alpha}{8\pi \sin \theta} \left( \sin \theta \cos \theta \tan \alpha \right)^2
\]  

Where \( z \) is \( z_1 \) or \( z_2 \) depending on whether the RCS contribution is from small or large end of the cone. Again using trigonometric identities assume radar illuminates the frustum starting from large end Eq.10 is reduced to

\[
\sigma = \frac{8\pi \tan \alpha}{8\pi \sin \theta} (\tan(\theta - \alpha))^2
\]

When radar illuminates the frustum starting from small end (radar is in negative \( z \) direction)

\[
\sigma = \frac{8\pi \tan \alpha}{8\pi \sin \theta} (\tan(\theta + \alpha))^2
\]
Inputs \( r_2 = 0.5 \text{mt} \) and \( r_1 = 0.3 \text{mt} \)

Fig. 6 viewing from small end to large end

Fig. 7 viewing from large end to small end

It is observed from Fig.6 that peak RCS is obtained at \( \theta_n = 56.15 \) degrees (Normal incidence) when viewing from small end to large end and from Fig.7 peak RCS is obtained at \( \theta_n = 123.8 \) degrees (Normal incidence) when viewing from large end to small end.

6 RCS OF MISSILE AND ROCKET SHAPED MODELS USING PO METHOD

RCS of complex models is calculated by describing the target as a collection of simple models whose RCS are known. The total RCS is obtained by summing vectorially the contributions from individual simple objects that of Cylinder, Frustum and Circular flat plate formulations. Result is obtained for missile and rocket shaped models using Matlab Simulation Software[9].

Shape-1 (MISSILE SHAPED MODEL)

\[
\begin{align*}
\text{Cylinder} & \quad \text{Cone} \\
\text{CFP} & \quad r_1 = 0 \\
\text{r}_2 & = 0.5 \text{mt}, \text{L}_1 = 1 \text{mt}, r_1 = 0, \text{L}_2 = 0.3 \text{mt} \text{ where r is radius and L is length of the object}
\end{align*}
\]

Shape-2 (ROCKET SHAPED MODEL)

\[
\begin{align*}
\text{Frustum} & \quad \text{Cylinder} \quad \text{Cone} \\
\text{CFP} & \quad \text{R}_2 \\
\text{R}_3 & = 0.6 \text{mt} \\
\text{R}_1 & = 0, \text{R}_2 = 0.3 \text{mt}, \text{R}_3 = 0.6 \text{mt}, \text{L}_1 = 1 \text{mt}, \text{L}_2 = 0.6 \text{mt} \text{ where R is Radius and L is Length of the object}
\end{align*}
\]

Fig. 8 RCS of missile (dbsm) v aspect angle(deg)

Fig. 9 RCS of rocket (dbsm) v aspect angle(deg)
7 RESULTS AND DISCUSSIONS

In this study, the results are computed for some models at frequency of 10Ghz. The RCS of simple shapes have been compared with published results and agreed well, while the RCS of cascaded shape like a missile could not be compared as they were no previous results published on matlab simulation of cascaded shapes. From the plots obtained for all the shapes it is observed that it is just the mirror image when viewing from large end to small end as that obtained when viewing from small end to large end. From Fig.8 it is observed that two peaks are obtained at normal incidence values of 90 degrees and 160 degrees in the figure due to two simple objects like cylinder and cone of missile shaped model whereas from Fig.9 it is observed three peaks are obtained at normal incidence values of 63.4, 90, 116.5 degrees due to three simple objects like frustum, cylinder and cone of rocket shaped model.

8 CONCLUSION

In this study, some investigations are made on RCS analysis of some models as relevant in the missiles using PO Method. Far field Monostatic RCS or Backscattered RCS is obtained for complex shapes in which rectangular plots are plotted for RCS in dbsm versus aspect angle for the simple and complex models using Matlab simulation. Monostatic radar cross section of missile shaped model was computed from Shape-1 and rocket shaped model from Shape-2 for a specified dimension and at a frequency of 10 GHz using physical optics method. Results obtained through the formulations using Matlab are in agreement in the range of 93 to 95% with results as obtained individually in isolation, which in fact validates the above assumptions.

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