Controlling and Predicting of The Radar Cross Section of a Missile Shaped Object

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Abstract

Today's air-target missiles have advanced built-in systems for target seeking and navigation. By the use of radar, the missile can detect and track a target from a long distance.Radar is an electromagnetic system for detecting, locating and sometimes for recognition of target objects, which operates by transmitting electromagnetic signals, receiving echoes from target objects within its volume of coverage, and extracting location and other information from the echo. In this paper, controlling and predicting of the Radar Cross Section (RCS) of a missile shaped object is presented. The prime effort is to find the presence of complex and arbitrary objects by monostatic radar and utilizing their RCS signatures obtained by performing its simulations in MATLAB to classify the objects of the targets. The signatures are observed in MATLAB for further development to find accurate RCS of a missile shaped object. Results shows that simulating the RCS for the complex circular cylinder with two perfectly conducting circular flat plates on both ends with linear polarization and frustum with H=40cm, r_1=15cm, r_2=30cm. RCS in dB(m^2) starting at 25dB (m^2) and end at 25 dB (m^2) for data. But the RCS measured in dB (m^2) at 90° of the aspect angle reached 20dB (m^2), and at around 180° of the aspect angle a rise in RCS of 27 dB (m^2) was observed. From the overall results of the simulation, as researches, radar designers can be faithfully advised on the behaviour, range, the effective capture area, and the minimum detectable signal of RCS of missile shaped object.

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Introduction

Today's air-target missiles have advanced built-in systems for target seeking and navigation. By the use of radar the missile can detect and track a target from a long distance. The seeker illuminates the target with electromagnetic radiation and watches for echoing signals that are processed to reveal target information, (Yau and Richmond, 2017). With accurate information on the position of the target, the missile can guide itself towards it. When simulating target seekers, there is a great need for computationally efficient, quality target models (Gonca, 2018).

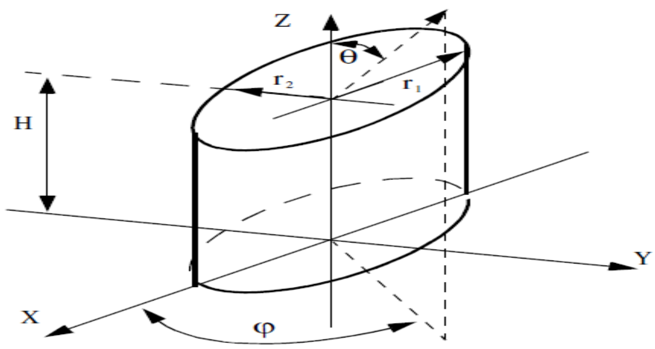
The models should provide high accuracy and still be simple enough for fast simulation. Radar is a method of using radio waves to detect, locate, track and identify distant objects. The word 'radar' is an abbreviation for Radio Detection and Ranging (Alves, 2019). Radar distinguishes itself from optical and infrared sensing devices by its ability to detect, and determine range and velocity of faraway objects under severe weather conditions. A typical radar system consists of a transmitter and a receiver, where the transmitter operates by radiating electromagnetic energy towards a target (Rajyalakshmi and Raju, 2018). When the target becomes illuminated, it reflects energy that can be observed by the receiver. Most radar systems do not transmit and receive at the same time; thus, a single antenna can be used on a timeshared basis for both transmitting and receiving. Such a radar system is said to be monostatic, (Virga and Rahmat-Sami, 2020). When different antennas are used for transmitting and receiving, the system is called bistatic. The strength of the reflections depends on the size of the target, its shape and electrical conductivity. Particularly strong reflections are obtained from metallic objects, such as ships and aircraft.

All objects illuminated by radar will reflect energy to some extent (Srikar, 2017). The radar cross section is a parameter used to characterise the scattering properties of a radar target. It represents the target's size as seen by the radar and has the dimensions of square metres. RCS area is not the same as physical area, but a measure of a target's ability to reflect radar signals in the direction of the receiving antenna. RCS of an object is the cross-sectional area that would produce reflection of the electromagnetic wave which is sent and observed in the Radar that functions as the source (Sidhu, *et al*., 2017). A larger RCS indicates that an object is more easily detected. Radar cross section is used to detect objects in a wide variation of ranges. Complex objects can be defined into many arbitrary objects, (Do-Hoon *et al*., 2018). The RCS information is used for numerous purposes, ranging from the design of novel stealth vehicles with reduced Radar signatures to the decision of Electronic Counter Measures (ECM) to engage against a certain threat. Complex objects can be derived from simple arbitrary objects like sphere, cylinder, rectangular, triangular and circular plates etc. The RCS must take into account the various factors such as noise, polarization, frequency, shape and material absorbing properties (Ksienski *et al*., 2015). We can construct a similar complex object such as an aircraft using the simple objects. In general, the RCS of a target is a function of the polarisation of the incident wave, the angle of incidence, the angle of observation, the geometry of the target, the electrical properties of the target and the frequency of operation. In this paper, controlling and predicting of the radar cross section of a missile shaped object is presented.

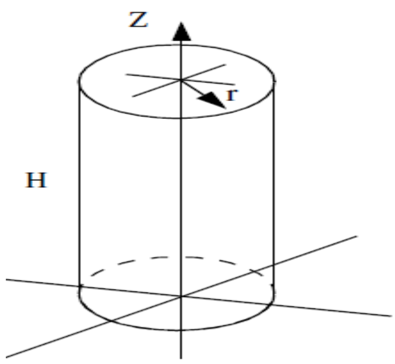
RCS of Simple Models Using Physical Optics Method

Cylinder and truncated cone are simple models for computing RCS of a missile shaped object. 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.

Cylinder: In differential geometry, a cylinder is defined more broadly as any ruled surface spanned by a one-parameter family of parallel lines. Figure1 shows the geometry associated with a cylinder. Two cases are presented: first, the general case of an elliptical cylinder; second, the case of a circular cylinder. The normal and non-normal incidence backscattered RCS for an elliptical cylinder due a linearly polarized incident wave are, respectively, given by:



(a)



(b)

Figure1: (a) Elliptical cylinder (b) Circular cylinder. The normal and non-normal incidence backscattered RCS for an elliptical cylinder due to a linearly polarized incident wave are respectively given by:

$$\sigma\theta_n = \frac{2\pi H^2 r_2^2 r_1^2}{\lambda(r_1^2(cos\varphi)^2 + r_2^2(sin\varphi)^2)^2} \quad [1]$$

$$\sigma = \frac{\lambda r_2^2 r_1^2 sin\theta}{8\pi(cos\theta)^2(r_1^2(cos\varphi)^2 + r_2^2(sin\varphi)^2)^2} \quad [2]$$

For a circular cylinder of radius r, then due to roll symmetry, Eqs. [1] and [2] respectively reduces to:

$$\sigma\theta_n = \frac{2\pi H^2 r}{\lambda} \quad [3]$$

$$\sigma = \frac{\lambda r sin\theta}{8\pi(cos\theta)^2} \quad [4]$$

Here, H=length of the cylinder, r = radius
In this paper, a monostatic RCS of a cylinder with r = 2*m* and *H* = 20m at frequency of 9.5 GHz are constructed. The simulation algorithm of cylindrical shaped object is performed using MATLAB function.

Frustum: A frustum is a horizontally cut cone. It has two radii-a smaller and a larger. The radar cross section varies depending on the side in which the frustum is projected, aspect angle and frequency of operation.

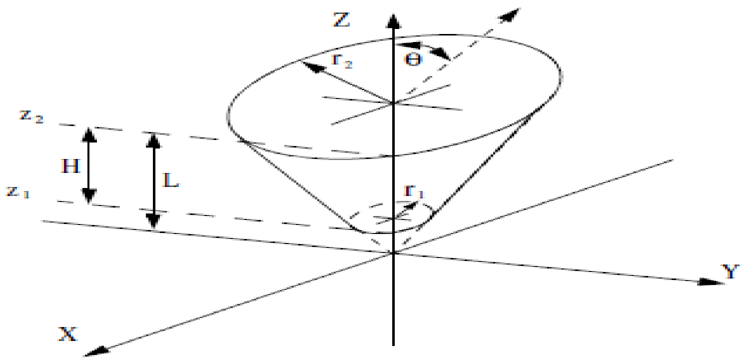


Figure 2: Truncated cone (frustum).

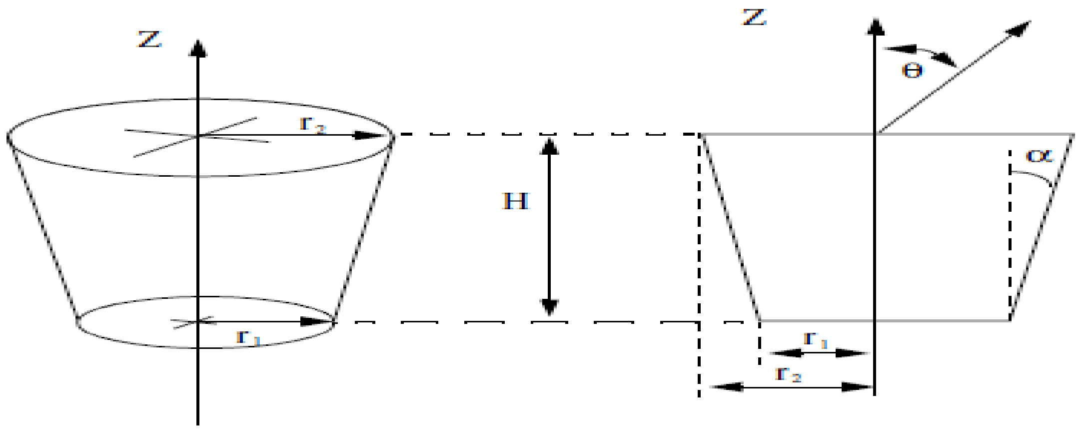


Figure 3: Definition of half cone angle.

The half cone angle α is given by the aspect angle at a normal incidence (broadside). Thus, when a frustum is illuminated by radar located at the same side as the cone's small end. At normal incidence, at the cone's smaller end, the angle θ_n is:

$$\theta_n = 90° - \alpha \quad [5]$$

Alternatively, normal incidence occurs at

$$\theta_n = 90° + \alpha \quad [6]$$

Approximation for the backscattered RCS of a truncated cone due to a linearly polarized incident wave is:

$$\sigma = \frac{\lambda z tan\alpha}{8\pi \sin\theta}(\tan(\theta - \alpha))^2 \quad [7]$$

At normal incidence, at the cone's larger end, approximation for the backscattered RCS of a truncated cone due to a linearly polarized incident wave is:

$$\sigma = \frac{\lambda z tan\alpha}{8\pi \sin\theta}(\tan(\theta + \alpha))^2 \qquad [8]$$

In this paper, a frustum with H=40cm, r_1=15cm, r_2=30cm and frequency of 9.5 GHz are simulated.

A Missile Shaped Models Using Po Method

Complex models for RCS are normally computed by coherently combining the cross sections of the simple shapes that make that target. In general, a complex target RCS can be modelled as a group of individual scattering centres distributed over the target. The total plot for the RCS here determines the RCS for all of the objects joined together. The index is the variable which tells us the number of initiations to be done to find complete RCS.

In this research, a circular cylinder with two perfectly conducting circular flat plates on both ends with linear polarization is simulated. H=1m and r =0.125m. Also, a frustum with H=40cm, r_1=15cm, r_2=30cm were also simulated together.

The simulation algorithms of complex shaped objects are performed using MATLAB functions.

4.0: RESULTS AND DISCUSSION

While simulating a Cylinder, observations during simulation of data resulted in the measuring for r = 2m and H = 20m. RCS in dB (m^2) started at 40 dB (m^2) and ended at 40 dB (m^2) for the data. But at an aspect angle of 90°, there was a drastic drop in RCS decreased to -37 dB (m^2).

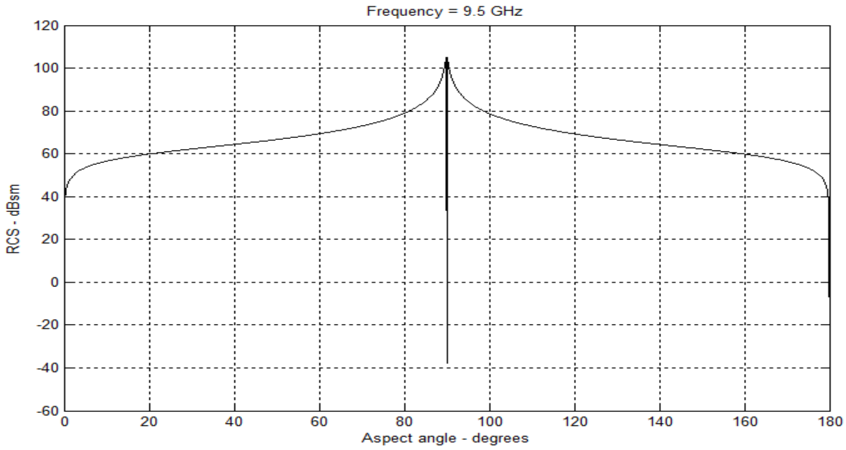


Figure 4: Cartesian plot for Cylinder Plate.

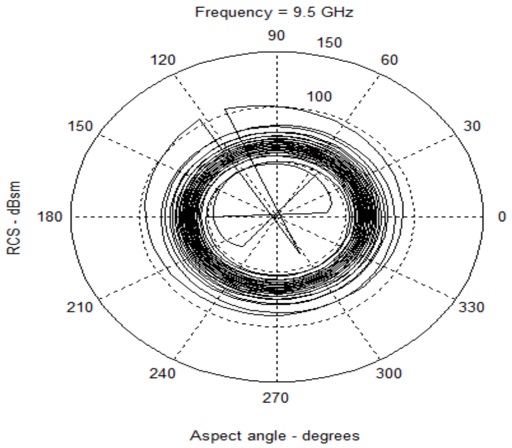


Figure5: Polar plot for Cylinder Plate.

While simulating for Frustum observations during simulation of data resulted in measurements for three sides namely rl, r2 and h as rl=15 cm, r2=30 cm and h=40 cm. RCS in dB (m^2) started at 95 dB

(m^2) and ended at 105dB (m^2) for data. But at the aspect angle of 41°, RCS falls to -20 dB (m^2) and rise again to 119 dB (m^2). This fall is as a result of increase in aspect angel from 0° to 41°. Also, at aspect angle of 130°, RCS falls drastically to -60 dB (m^2), and rise again to 105dB (m^2) at aspect angle of 180°. This is to say that the RCS of Frustum shaped object is not steady. It fluctuates as the aspect angle increases. Therefore, the Radar designers should take note of the variation.

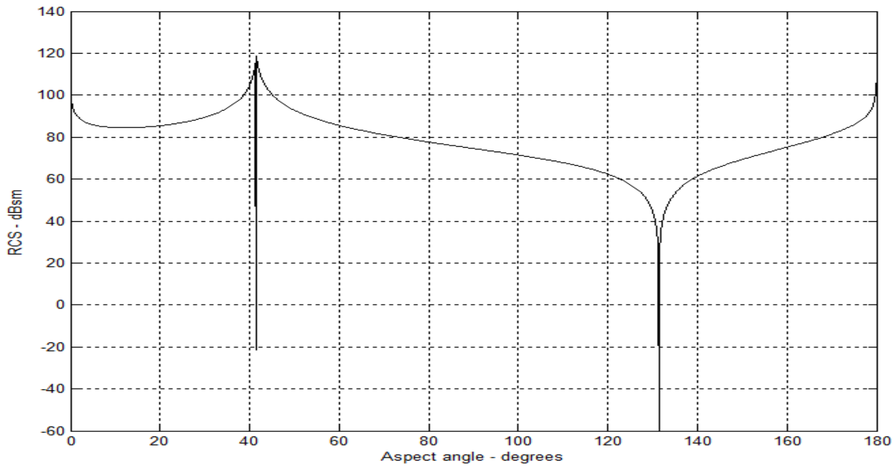


Figure 6: Cartesian plot for Frustum plate

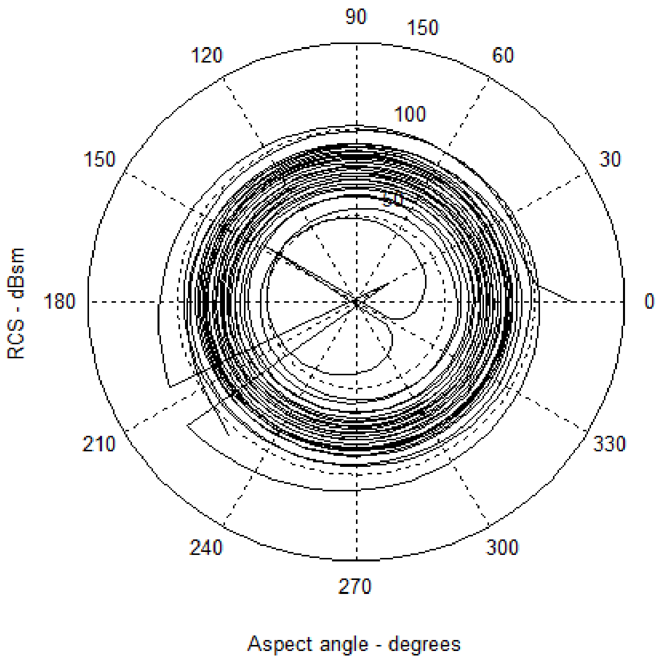


Figure 7: Polar plot for Frustum plate

While simulating the RCS for the complex, a circular cylinder with two perfectly conducting circular flat plates on both ends with linear polarization was simulated with H=1m and r =0.125m. Also, a frustum with H=40cm, r_1=15cm, r_2=30cm were also simulated together. Objects observations during simulation of data resulted in RCS in dB(m^2) starting at 25dB (m^2) and ending at 25 dB (m^2) for data. But in RCS measured in dB (m^2) at 90° of the aspect angles, it reached 20dB (m^2) and at around 180° of the aspect angles we have seen rise in RCS to 27 dB (m^2).

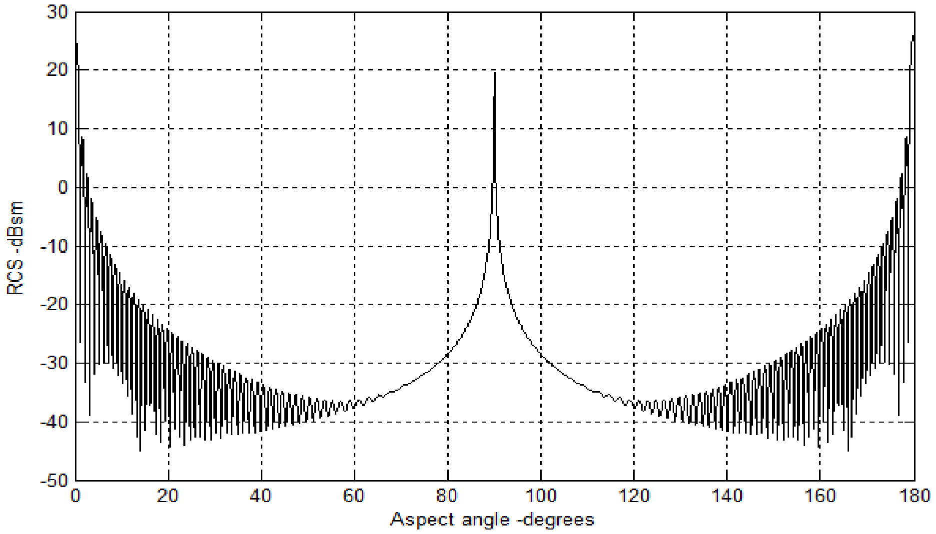


Figure 8: Cartesian plot for Complex object

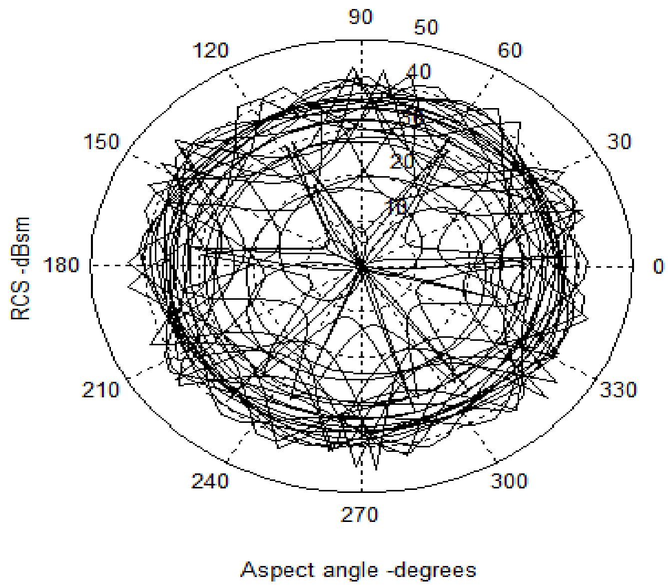


Figure 10: Polar plot for Complex object

Conclusion

In this paper, controlling and predicting of the radar cross section of a missile shaped object has been presented.

From the overall results of the simulation, as researches, we can faithfully advice the radar designers on the behavior, range, the effective capture area, and the minimum detectable signal of RCS of different targets with different size and shapes. This information can serve as a yardstick for the Radar designers to rely upon in predicting, designing and implementing an accurate RCS of different targets which will enable the military and other relevant agencies that uses these Radar systems to accurately track, locate and detect targets despite their sizes and locations.

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