Model Discretization in Radar Cross Section Simulations

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***Abstract* — Radar cross section (RCS) simulation software are important tools for the analysis of the RCS of several types of targets. These simulation tools can generate precise results at a relatively low cost. However, in order to obtain reliable results from these simulations, it is necessary that the target, whose RCS is being simulated, be represented by a detailed CAD model. In this paper is shown how the simulated RCS of models vary as a function of the discretization of their surface.**

***Keywords* — Cylinders, modeling, radar cross sections, simulations.**

I. Introduction

With the development of faster and more powerful computers, the numerical simulation of electromagnetic scattering phenomena has become an efficient and reliable tool to analyze the RCS of military and civilian targets. Among the advantages of using simulations compared to open RCS measurements of full-scale targets, one can mention lower cost, better visualization of high reflectivity areas on the surface of the target and versatility. With a simulation tool, the RCS of a target can be analyzed with relative ease. RCS simulations can be done for several conditions, such as relative orientation between target and receiving antenna, configuration of the target, polarization of the receiving and transmitting antennas, frequency of the incident radiation, and target surface reflectivity and roughness, among others. Also, with a simulation tool it is possible to predict the RCS of a target still in development and alter its design before it reaches production stages. Despite these positive aspects, simulations can generate RCS values that do not correspond to the target being simulated if the target is not well represented by a model. In order to demonstrate how the discretization of a model can affect the simulation of RCS, an object with a relatively simple geometry, a cylinder, and an actual target, an air-to-air missile, were simulated for different levels of discretization of their surfaces.

II. Radar Cross Section

The RCS is a measure of the visibility of a target to radar; it is defined as if all the power that reaches a target were scattered uniformly in all directions.

The RCS in any given direction would be the area of that part of the beam intercepted by the target [1]. When the transmitting and receiving antennas are located at the same place, the RCS is said to be monostatic and is expressed as [2]:

$$\sigma = \lim_{r \to \infty} 4\pi r^2 \frac{|E_S|^2}{|E_I|^2}, \quad (1)$$

where r is the distance between the target and the radar antennas, and E_S and E_I are the scattered and incident electric fields, respectively. The RCS of a target depends on several factors such as the shape, target composition, polarization of the radar antennas, frequency of the incident wave, and orientation between target and antennas. Equation (1) is valid when the target is illuminated by a plane wave, that is, when the target is located in the far field of the radar. The far field approximation is given by $r \geq 2D2/\lambda$, where D is the largest dimension of the target and λ is the frequency of the incident wave [3]. Usually, due to the large range of RCS values for a given target, a logarithmic power scale is used with the reference value of $\sigma_R = 1\ m^2$ [3]:

$$\sigma_L = 10 \log_{10}\left(\frac{\sigma}{\sigma_R}\right) = 10 \log_{10}\left(\frac{\sigma}{1}\right). \quad (2)$$

Analytical solutions of (1) exist only for objects with simple geometries. For complex targets subject to very complicated boundary conditions (1) becomes intractable and it is necessary to resort to numerical methods to calculate the RCS. There are several electromagnetic simulation software packages in the market. In this study, the RCS of targets is simulated with the commercially available CADRCS software [4].

III. Simulation Tool

In order to run the simulations with CADRCS, a computer-aided design (CAD) model of the target was needed. The CAD model was imported into the Rhinoceros software and its surface was discretized into triangular elements by an automatic mesh generator. This mesh was then imported into CADRCS for the simulations. A 3.2 GHz Pentium 4 computer with 4 GB RAM memory was used in this work.

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With this computer, the simulation of targets with simple geometries usually require a few hours of computer time, while complex geometry targets may require many days.

IV. SIMULATIONS

CADRCS, like other software packages for electromagnetic scattering simulations, uses ray-tracing techniques combined with physical optics methods to predict the RCS of a target. This software also takes into consideration ray shadowing providing precise calculations of the RCS of targets larger than the radar wavelength [5]. With CADRCS, it is possible to simulate the RCS of a target under different situations, such as the distance between target and radar, reflectivity of the target's surface, frequency and polarization of the radar, among others. Details about the theory and methods used in CADRCS are considered classified material and are not disclosed to users.

In this work, two targets were simulated with CADRCS: a 2.75 m long cylinder with a diameter of 0.16 m and a model of a generic air-to-air missile (Fig. 1). The cylinder has the same dimensions as the cylindrical body of the missile. The cylinder and the missile model were created using AutoCad software.

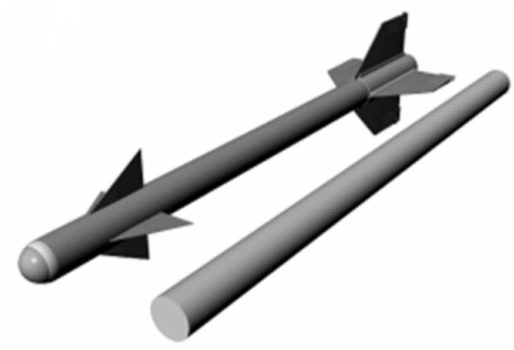

Fig. 1. CAD models of the cylinder and missile used in the simulations. The length of the cylinder is 2.75 m and its diameter is 0.16 m. The overall length of the missile is 2.89 m and the diameter of its cylindrical section is 0.16 m. The finspan and the wingspan of the missile are 0.47 m and 0.66 m, respectively.

From the CAD models, three meshes of the cylinder surface and two meshes of the missile surface, with different levels of discretization, were created. In the simulations, the models were illuminated by a 10 GHz plane wave with vertical polarization. A monostatic radar configuration was used. The targets were located in the far-field of the radar and their surfaces were assumed to be perfect conductors. The simulations were performed with the models rotating about their symmetry axis. RCS values were calculated at intervals of aspect angle of 0.1°.

A. Cylinder

The RCS of a perfectly conducting cylinder is constant with respect to the angular position when measured under the conditions mentioned above. Its RCS is given by [6]

$$\sigma = \frac{2\pi L^2 a}{\lambda}, \qquad (3)$$

where L is the length of the cylinder, a is the radius, and λ is the radar wavelength. For a frequency of 10 GHz, the RCS of the ideal cylinder is σ = 21.03 dBsm.

The discretization of the surface of the cylinder generates regular polygonal prisms whose faces are rectangles. The length of the edges of the polygonal bases is the only parameter used in the discretization of the cylinder. The comparison of the RCS of the ideal cylinder with the RCS simulated for three mesh models of the cylinder having different degrees of discretization is shown in Fig. 2. The base edges of these models are 20 mm, 7 mm and 2 mm and their surfaces were discretized into 3,174, 50,998 and 276,543 triangular elements, respectively.

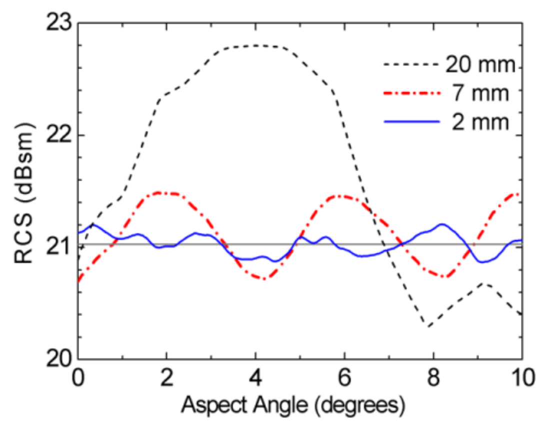

Fig. 2. Comparison of RCS simulations for three meshes of the cylinder surface. The base edges the models are indicated in the figure. The horizontal line at σ = 21.03 dBsm corresponds to the RCS of the ideal cylinder.

Fig.2 shows that the RCS of the models oscillate about the value of the RCS of the ideal cylinder. This can be explained by the fact that as the models rotate about their symmetry axis the rectangular faces of the prisms are illuminated by the radar and reflect as flat plates. For the mesh model with a base edge of 20 mm, the RCS varies by as much as 1.8 dBsm. In the case of a base edge of 2 mm, the RCS varies by about 0.4 dBsm. As a rule of thumb, the shape of a model should not deviate from the actual shape of the target by more than one tenth of a wavelength of the frequency used in the simulation. At the frequency of 10 GHz, this corresponds to a length of 3 mm. The mesh with the highest number of elements satisfies this rule, but there are still differences, albeit small, between the simulated and the analytical RCSs. These differences can be explained by the fact that the width of the models are about only five times as large as the radar wavelength and one can speculate that this can introduce errors in the numerical calculations. The use of physical optics methods to simulate electromagnetic scattering produces better results when the dimensions of the object being simulated are much larger than the wavelength of the incident radiation [3]. Another important result that can be observed in Fig. 2 is that, depending on the aspect angle, the RCS of a target may be overestimated or underestimated, which suggests that extreme care must be taken when representing a target with a model. Even when a reasonable discretization of the target is used, there is still the possibility that the simulation of its RCS will have a significant error associated with it.

B. Missile

The RCS of the missile was simulated with two different meshes. The meshes were composed of 14,275 and 357,211 triangular elements. The discretization of the meshes was the same used for the cylinder models with base edges of 20 mm and 2 mm, respectively. Fig 3 shows how the surface of the missile is represented by the two meshes. The difference between them is clearly visible in the curved surfaces of the missile, cylindrical body and nose dome. The discretization of the front fins and rear wings do not present this problem, since these surfaces are mostly flat or have large curvature radii.

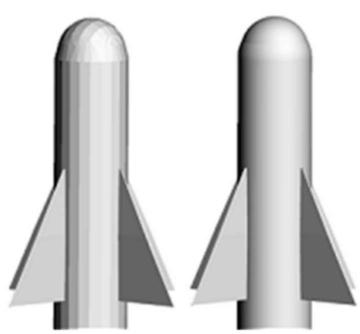

Fig. 3. Comparison of the mesh models used in the simulation of the RCS of a missile. In both cases the cylindrical body of the missile is represented by polygonal prisms. The base edges are 20 mm and 2 mm for the left and right models, respectively.

Fig. 4 shows the results of RCS simulations for these two meshes. The models were rotated about the symmetry axis by 90° and the RCS was simulated at angle intervals of 0.5°. The RCS in this case is essentially composed of three parts: the hemispherical nose; the cylindrical body; and the fins and wings of the missile. In the ideal case, the contribution of the hemispherical nose to the RCS should be independent of the aspect angle, and added to the RCS contribution from the fins and wings, and cylindrical body. At angles around 0° and 90° the contribution from fins and wings becomes important because at these angles they face directly toward the radar. When comparing the RCS obtained by the simulation of these two mesh models, one can see that the overall RCS pattern produced by the more detailed mesh is similar to that of a dihedral [3]. This was expected since the fins and wings are positioned at right angles. Also, the RCS of the least discretized model presents large oscillations due to the reflections from the rectangular faces of the polygonal prism that represent the cylindrical body of the missile. It was expected that the RCS simulation data distribution would be symmetric with respect to the angular position of 45° as a consequence of the symmetrical shape of the missile. While the most detailed mesh resulted in a RCS pattern that was mostly symmetrical, the simulations performed with the least detailed mesh showed some relevant asymmetries. Also, there were significant differences in the values obtained by the simulation of these two different meshes.

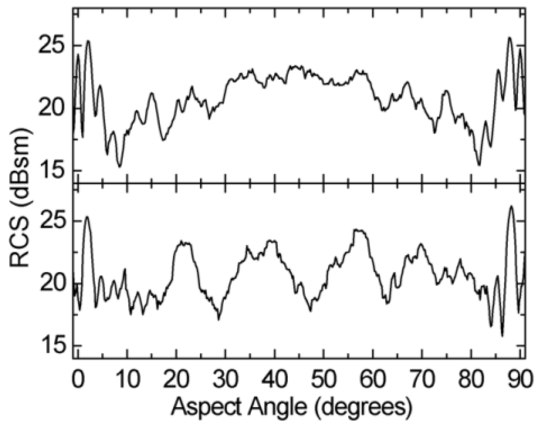

Fig. 4. RCS simulation of two mesh models of an air-to-air missile. The upper panel shows the RCS simulations for the more detailed mesh and the lower panel, for the less detailed one.

V. Conclusions

The simulation of electromagnetic scattering with computational methods is an efficient and fast way to obtain the RCS of targets. However, a cautious approach to the results of these simulations and their interpretation is necessary since they are highly dependent on the model of the target being simulated. One can see that, even for a target with a relatively simple geometrical shape as a cylinder, the results of simulations may change depending on how the surface of this model is discretized and yet, significant errors may occur even with a high degree of discretization.

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