Comparison of Simulations of the Radar Cross Section of Targets with Simple Geometry Using Different Simulation Tools

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***Abstract* — The radar cross section (RCS) of two metallic targets with simple geometry was simulated in the C and X-bands using two software. Although the overall RCS patterns obtained by the simulations were similar, differences exist and may be accounted for by the different methods and techniques used by the software to solve the same type of problem. Moreover, it suggests that care must be taken when interpreting the results from simulations.**

***Keywords* — Radar cross-section, simulation software, model.**

I. INTRODUCTION

The solution of real-life electromagnetic problems is a difficult task due to the complexity of Maxwell's equations and the corresponding boundary conditions; usually, only problems with simple geometries have analytical solutions or are manageable enough to be solved using simple numerical methods. As a result of the steady increase of calculation power and speed of modern computers, and advances in numerical methods, a large variety of simulation software are now available in the market to solve or simulate all sorts of electromagnetic problems, from the study of small objects such as microstrip antennas to the simulation of the reflectivity of large-scale structures, such as combat vehicles and ships.

Our research group is particularly interested in a particular application of Maxwell's equations, namely the calculation of the radar cross section (RCS) of real-sized targets. For this purpose, there are in the market several software that can be used to simulate the RCS of objects; some of them are dedicated exclusively to this type of tasks, whereas in other products, the RCS simulation is one of many features. In order to better understand and appreciate the quality of these simulation tools, we compared the RCS of a model airplane simulated by two different software; one is CADRCS, dedicated exclusively to the simulation of RCS [1], and the other is FEKO, a multi-purpose simulation software [2].

II. RADAR CROSS SECTION (RCS)

RCS can be defined as the measure of the amount of incident power intercepted by a target and reradiated back in the direction of the radar antenna. The RCS is denoted by $\boldsymbol{\sigma}$ and has units of area. Each target has a characteristic RCS and its value is an indication of the size of the target as seen by the radar [3]. The RCS depends on the shape and materials used in the construction of the target, distance between radar antennas and target, orientation of the target with respect to the radar antennas, and radar wave polarization and frequency [4]. Assuming that the power density of a radar wave incident on a target located at a distance r from the emitting radar antenna is P_i, and that the power scattered back to the receiving radar antenna is P_r, the RCS is expressed as [3]

$$\sigma = 4\pi r^2 \lim_{r \to \infty} \frac{P_r}{P_i} \qquad (1)$$

This equation is valid when the receiving radar antenna is in the far field, i.e., plane waves are scattered back to the receiving antenna. The far field condition is satisfied when

$$r \geq \frac{2D^2}{\lambda}, \qquad (2)$$

where D is the largest dimension of the target and λ is the radar wavelength.

Although RCS is expressed in a very simple and compact form, the solution of (1) is very complex, requiring complex numerical calculations. Examples of the RCS of some targets in the X-band are listed in Table 1. Note that these are approximate values; they are displayed in order to illustrate the typical range of RCS values The RCS usually varies over a wide range of values, and is usually expressed in dBsm (10.logσ).

TABLE I TYPICAL RCS VALUES [5]

Target	RCS (m^2)
Large commercial airplane	100
Large land vehicle	5-10
Man	1
Bird	0.01
B-2 stealth bomber	0.01

Depending on the application, the RCS of a target can be either maximized so that the target is better detected by radar, or minimized in order to render its detection as difficult as

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possible. Changes in RCS values can be achieved by modifying the shape of the target or coating its surface with materials with special characteristics.

III. SIMULATION SOFTWARE – BRIEF OVERVIEW

Both software, FEKO and CADRCS, used in this study are commercially available. They were chosen for because of their availability and also due to the different approaches used to calculate the RCS of targets.

FEKO uses the Multilevel Fast Multipole Method (MLFMM) [6] to solve the differential equation describing electromagnetic problems. MLFMM is an alternative to the more commonly used Method of Moments (MoM). One of MLFMM's main advantages over MoM is that it can be used for large objects. Basic functions model the interactions between all triangle elements used to model the surface of the target in both MoM and MFLMM. The main difference between MFLMM and MOM is that instead of computing the interaction between individual basic functions, MFLMM computes the interaction between groups of basic functions, resulting in significant gains in CPU time. The individual treatment of N basis functions in the MoM results in an N^2 scaling of computer memory requirements to solve the impedance matrix, and N^3 in CPU time to solve the linear set of equations. On the other hand, for the more efficient MFLMM, the scaling of computer memory is N.log(N), and N.log(N).log(N) in CPU time. Depending on the size of the problem, it can result in the reduction of solution time of orders of magnitude [2].

The developers of CADRCS consider the theory and methods used in this software to be classified material [1]. But, some authors have suggested [7] that this software combines physical optics with ray tracing techniques to calculate the RCS of a target. CADRCS also treats shadowed rays, allowing the simulation of the RCS of objects larger than the radar wavelength with a great level of accuracy. CADRCS also allows the simulations to be conducted under different conditions such as wave polarization, target reflectivity and surface roughness. The developers of CADRCS also claim that the software is capable of reproducing the results of an actual radar.

IV. SIMULATION MODELS

The models were constructed using the computer aided design (CAD) software Rhinoceros [8,9]. The models, hereafter denominated Delta and Hypo are shown in Fig 1. They represent, respectively, a simple model of an airplane, a hypothetical object. Although they are targets with apparently simple geometry, their surfaces are composed of elements (dihedrals, flat and curved surfaces, etc.) usually found in any type of vehicle or structure. The wingspan of the model Delta is 0.56 m, and its length is 0.55 m. The cylindrical body of the model Hypo has a diameter of 0.15 m and length of 0.32 m, the side of flat square panels measure 0.15 m

For the simulation using FEKO, the CAD model was imported directly into the software and a built-in Delaunay triangulator was used to generate a triangular element mesh.

The same meshes were used by both software in the simulations. The meshes of the models Delta and Hypo were composed of 26982 and 30202 triangular elements, respectively. They were generated taking into account the size of the triangular elements compared to the radar wavelength; the largest dimension of a triangular element was <0.25λ. In Fig. 2 is shown a detail of the mesh used in the simulations.

V. RESULTS AND DISCUSSION

Two different computers were used for the simulation, both PC computers with 4 GB ram, but their processor clock speeds were different. The computers used for FEKO and CADRCS simulations had 1.80 GHz and 2.20 GHz CPUs, respectively. The time needed to complete the simulations were very different, CADRCS needed a couple of hours for the full simulation, whereas FEKO took more than one day to obtain the same number of results.

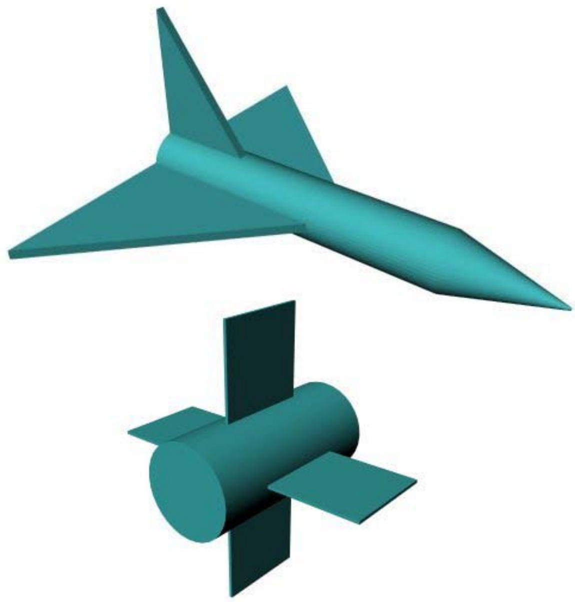

Fig. 1. CAD models used in the simulations. Delta (top), Hypo (bottom). Images not to scale.

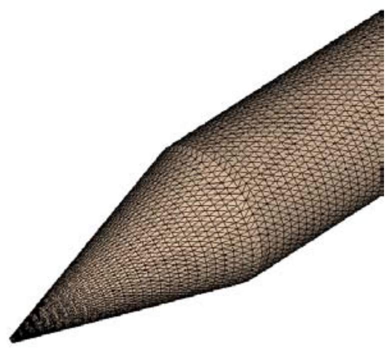

Fig. 2. Nose of the model Delta. Example of a mesh used in the simulations.

Simulations using the Delta model were carried out at 8, 10 and 12 GHz (X-band). In the case of the Hypo model, the simulation frequency was 6 GHz (C-band). The models were rotated in azimuth (yaw rotation) by 360° and RCS values were calculated at 1° intervals. A monostatic radar configuration and horizontal wave polarization were used. The distance between the Delta model and radar antenna was 6.5 m (near-field situation). The Hypo model was placed 1000 m away from the radar antenna in the simulations (far-field approximation). In the simulations, it was assumed that the surfaces of the models were perfect conductors.

A. Model Delta – X-band

The comparisons of the RCS diagrams obtained by both software in the simulation using the Delta model are shown in Figs 3, 4 and 5.

From Figs. 3, 4 and 5 one observe that when the nose of the airplane was facing the radar antenna (0°) the RCS values are the lowest. This can be explained by noting that the radar waves did not illuminate any flat surface at this aspect angle, in fact, all surfaces of the model at this aspect angle scattered the most of the electromagnetic energy of radar waves away from the direction of incidence. At the aspect angles of 90° and 270°, the radar wave illuminates the sides of the model and the flat surface of the vertical stabilizer which results in high RCS values. At 180° the radar illuminates the rear of the model which is also a flat surface (see Fig. 1), producing also high values of RCS. At 40° the flat edges of the wings were perpendicular to the direction of incidence of the radar wave, resulting in moderately high RCS values.

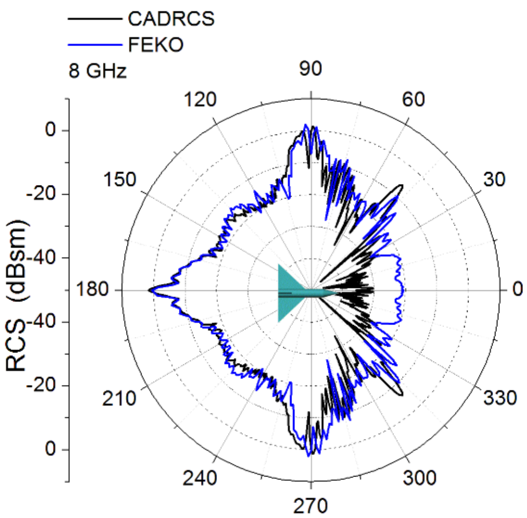

Fig. 3. Comparison of RCS simulation results. Model Delta, 8 GHz.

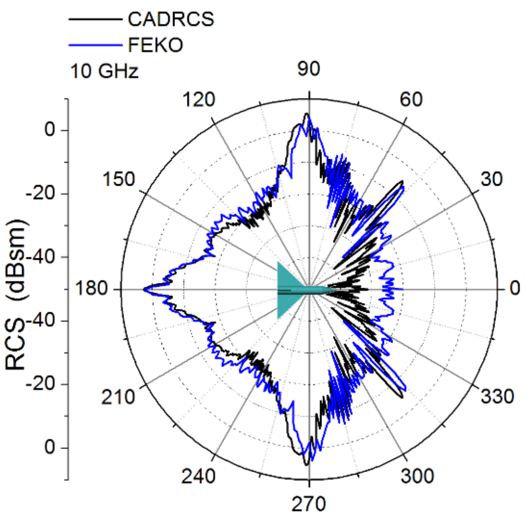

Fig. 4. Comparison of RCS simulation results. Model Delta, 10 GHz.

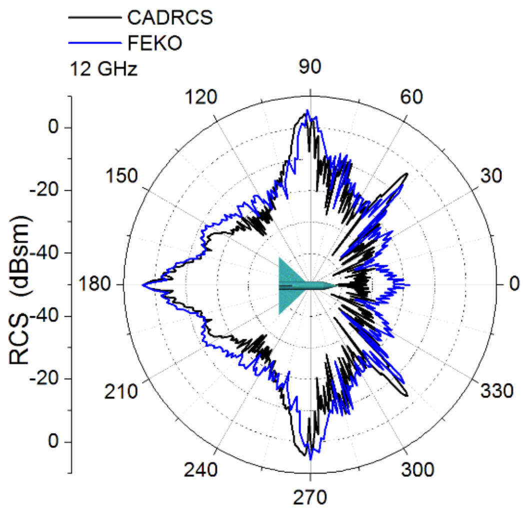

Fig. 5. Comparison of RCS simulation results. Model Delta, 12 GHz.

The comparison of RCS results obtained by both software shows that the overall RCS patterns are similar but that there are differences regarding amplitudes and features in the patterns. An interesting feature is observed at around 0°. Although the RCS values are low at and around this aspect angle, the differences between software are noteworthy. The differences observed may be a consequence of the approaches used by the software to simulate the RCS; probably effects such as wave diffraction, edge effects, creeping and surface currents and rounding errors are given a different treatment; a factor that can also affect the value of the RCS at this aspect angle is the fact that the tip of the model was illuminated directly by the radar wave, the small surface area of the triangular mesh elements at the tip may cause the modeled solution to diverge. Another feature is observed at and around 40°. At this aspect angle the flat surfaces of the wing edges are good radar reflectors, but the peak corresponding to this situation occur at slightly different angle values, this difference probably is caused by a small displacement of the position of the axis of rotation when the model was simulated. There are other differences, but these are small; they appear somewhat magnified due to the logarithmic scale. These differences are shown in Fig. 6.

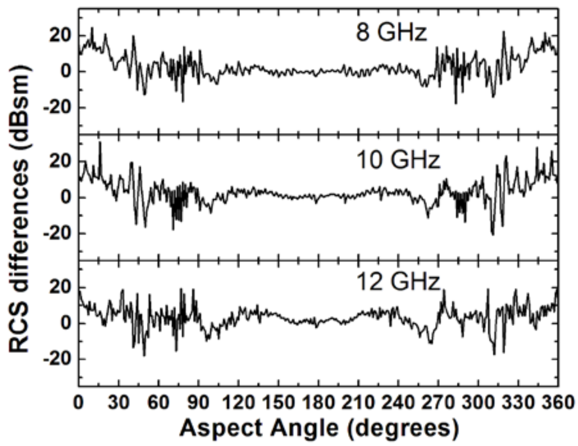

Fig 6. Differences between RCS values calculated by FEKO and CADRCS.

Results in Fig. 6 show that at 12 GHz the differences between results from FEKO and CARCS are smaller, regarding the nose of the model, but depending on the frequency, different parts do model behave differently. The oscillatory behavior may have resulted from the strong dependence of RCS on the aspect angle.

B. Model Hypo - C-band

In Figure 7 is shown the comparison of the RCS simulations for the Hypo model. It is clear from this figure that the flat panes (due to their area) are the main radar reflecting surfaces of this object, followed by the circular bases of the cylinder. The overall comparison is also satisfactory in this case. Note that the positions and amplitudes of the main lobes coincide reasonably well. Important differences are observed at aspect angles around 15°, 165°, 195° and 335°, an effect probably caused by multiple interaction of reflected radar waved from different surface elements of the model.

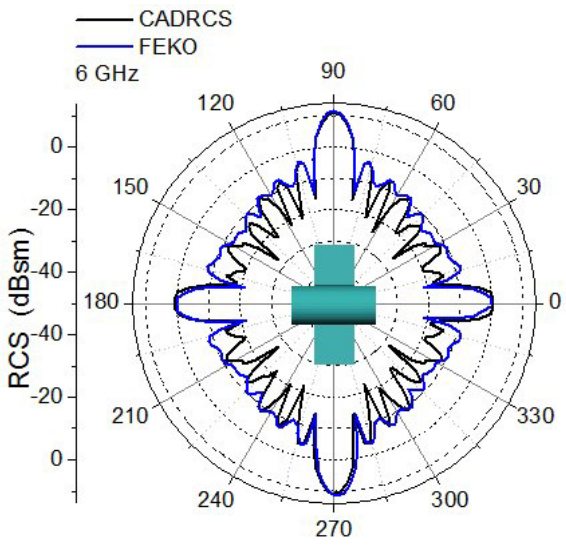

Fig. 7. Comparison of RCS simulation results. Model Hypo, 6 GHz

VI. CONCLUSION

Simulation software, such as the ones used in this study, can produce large amounts of data and results; but, they usually are expensive and not all institutions have enough funds to purchase more than one of these simulation tools. In this study, the simulation of the RCS of a model with a relatively simple geometry demonstrated that different software will inevitably produce different results. Although simulations play a very important role in the prototyping, design and improvement of various types of targets, the results thus obtained must be interpreted carefully. Also, a factor that must be considered is the computer that is used for the simulations, since the software use computational resources differently. Due to its characteristics and speed and based on the configuration of the computers used; FEKO seems to be better suited to handle small objects while CADRCS can simulate large structures.

ACKNOWLEDGEMENT

The authors would like to express their gratitude to the Brazilian Army (Exército Brasileiro) for the support received. M. A. Alves also acknowledges the financial support of the funding agency CNPq .

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