Radar Cross Section of Simple and Complex Targets in the C-band: A Comparison between Anechoic Chamber Measurements and Simulations

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Abstract— In order to validate RCS measurements performed in an anechoic chamber, experimental results are compared with simulations made using a commercial electromagnetic software package. The experimental part of this work was performed inside an anechoic chamber, with the radar operating in the C-band (6 GHz). Two metallic targets, a cylindrical body with four square fins and a section of an air-to-air missile, were used for the RCS measurements. In order to improve the accuracy of the experimental data, an active noise suppressing system, based on the principle of phase cancellation, was used. The simulation software FEKO was used to calculate the RCS of models of these two targets. The comparison of simulations and experimental data shows good agreement between them, validating the experimental methods used in the collection of RCS data, as well as the results obtained with the simulation software.

1. INTRODUCTION

Measurement of radar cross section (RCS) of objects is a complex task due to the many factors that may affect these measurements. Instrumental errors, spurious interferences and reflections are some of contributors that degrade the quality of the data. These problems are compounded when one is interested in reducing the RCS of an object, as in this case, the magnitude of these effects can overshadow the true RCS values. Many methods have been proposed and used for the measurement of RCS of several types of targets [1]. Depending on the size of the targets and radar frequencies used, RCS measurements can be performed on outdoor ranges or indoors, inside anechoic chambers [2]. In RCS measurements, it is important that the radar is illuminated by an electromagnetic wave which is uniform in phase and amplitude. For practical purposes, the maximum tolerance for amplitude variation over a target is 0.5 dB, and the phase should not deviate by more than 22.5°. These conditions characterize the far-field condition [3], given by

$$r = \frac{2d^2}{\lambda} \tag{1}$$

where r is the distance between radar and target, d is the largest dimension of the target, and λ is the wavelength of the radar. To ensure good measurements, errors produced by the instrumentation should neither exceed 0.5 dB nor vary in time. Also, the dynamic range of the system should be at least 40 dB when measuring targets with small RCS; dynamic range values in the order of 60 dB or higher are preferable when RCS reduction studies are conducted or when radar absorbent materials are used. In this study, measurements of the RCS of two objects were performed inside an anechoic chamber and a noise suppression circuit [4] was used to improve the accuracy of the data. These results were compared with those obtained from RCS computer simulations performed on the models of these objects using a commercial software.

2. ANECHOIC CHAMBER SET-UP AND METALLIC TARGETS

The experimental part of this work was conducted in the anechoic chamber at the Aeronautics Technology Center (CTA, Brazil) [5]. Figure 1(a) shows the antennas used for the measurements. The distance between target and antennas in the anechoic chamber was about 6 m. The radar operated at 6 GHz (C-band), in horizontal polarization and quasi-monostatic configuration. The high performance corrugated horn antennas, model ANSAT 1.8, are manufactured by Avibras (Brazil). Each antenna has a gain of approximately 17 dBi, symmetric radiation pattern and low level of secondary lobes, which produces a narrower radiation beam and less energy diffusion in regions outside the main beam. Also, these antennas are built so that the coupling between them is minimized.

The source of microwave radiation is a HP8360B synthesized CW generator and the signal receiver is a HP8593E spectrum analyzer. An active noise suppressing system based on the principle of phase cancellation was used to improve the accuracy of the experimental data [4]. This system samples the transmitted signals, discriminates signals from spurious reflections, and translates the phase of the received signals until they are canceled, reducing the noise to a minimum. Undesirable signals are minimized by the application of the canceling principle and by the inversion of phase. RCS measurements of two square flat plates made of aluminum and measuring 0.2×0.2 m and 0.3×0.3 m were used to calibrate the system. Also, an indirect calibration method [6] was used, taking into account some parameters of the system, such as antenna gain, distance between target and antennas, loss in cables, among others. The deviation in the RCS measurements was within 0.7 dB.

Two metallic targets were used for the measurements. The first target, a hypothetical missile, consists of a cylinder made of aluminum, having a length of 0.32 m and a radius of 0.075 m; four square flat aluminum plates measuring 0.15 m on a side are attached to the cylinder (Figure 1(b)). The second target is the front section of a decommissioned air-to-air missile (MAA-1 Piranha, Mectron, Brazil) (Figure 1(c)). Its body and fins are mostly made of aluminum, and its length is 0.72 m. For a frequency of 6.0 GHz, the hypothetical missile and the missile section lengths are 6.4λ and 14.4λ, respectively.

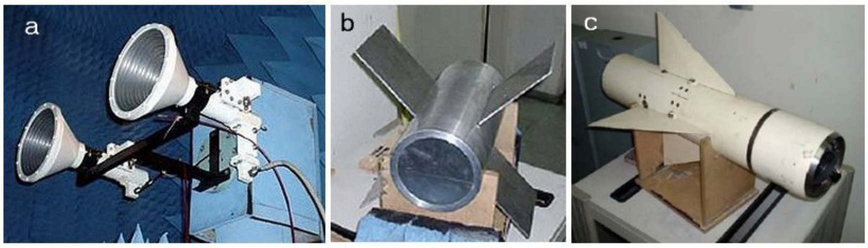


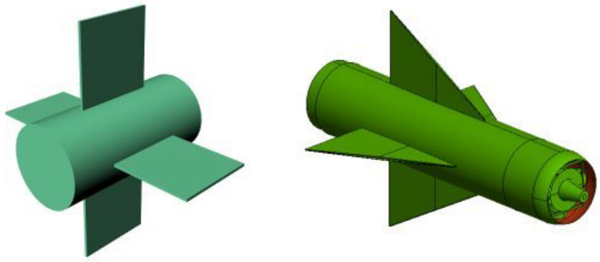
Figure 1: (a) Corrugated horn radar antennas, (b) hypothetical missile and (c) missile section.

3. OVERVIEW OF THE SIMULATION SOFTWARE AND MODELS

In the present study, the Multilevel Fast Multipole Method (MLFMM) [7], as implemented in FEKO software [8], was used for the RCS simulations. 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 structures. In both MoM and MFLMM, basic functions model the interactions between all triangle elements. MFLMM is different from MoM in 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 $N \cdot \log(N)$, and $N \cdot \log(N) \cdot \log(N)$ in CPU time. Depending on the size of the problem, it can result in the reduction of solution time of orders of magnitude.

Models of the targets used for the RCS measurements were created using Rhinoceros computer-aided design (CAD) software and imported into FEKO, where a Delaunay triangulator was used to generate surface meshes. Figures 2(a) and 2(b) show the models used in the simulations. The meshes are not shown due to the scale of the models. The surfaces of the hypothetical missile and the section of the air-to-air missile were discretized into 22.256 and 47.971 triangular elements, respectively. Note that since the RCS depends on the scattering of the microwave radiation illuminating an object, the external surface of this object is the most important feature to be taken into account in the simulations. Thus, to keep the problem treatable, the internal parts of the targets were not considered in the simulations.

The simulations were carried out using a PC with a 1.8 GHz Pentium processor and 1.7 Gbytes of RAM.

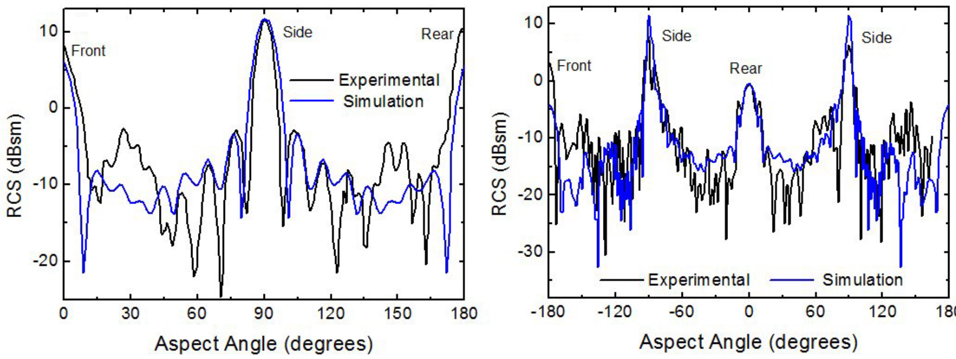


(a) (b)

Figure 2: CAD models (not to scale) of the (a) hypothetical missile, and (b) missile section.

4. RESULTS

For both measurements and computer simulation, the targets were rotated about an axis perpendicular to the main axis of their cylindrical bodies. Measurements were taken at 0.5° intervals, the simulated RCS was calculated at 1.0° intervals, intervals, and the targets were rotated 360° about the rotation axis. Since the far-field condition (1) is not completely satisfied in the measurements, the simulations were performed taking into account the distance between the target and the radar antenna. In this case, the targets were illuminated by the radiation pattern produced by a point source located at a finite distance, and the scattered near-field was calculated. This procedure is much more computationally intensive than the use of a plane wave to illuminate the targets. The simulation times for the hypothetical missile and the missile section were about 24 h and 90 h, respectively. Figures 3(a) and 3(b) show the comparison of measured and simulated RCS for the hypothetical missile and missile section, respectively.



(a) (b)

Figure 3: Measured and simulated RCS patterns. (a) Hypothetical missile and (b) missile section.

In both cases, one can observe that there is good agreement with respect to the overall RCS patterns but, upon close inspection, differences between the simulated and the measured RCS can be observed. The measured and simulated RCS patterns for the hypothetical missile show very good agreement for aspect angles between 60° and 120°, RCS lobes produced when the side of the target is illuminated by the radar are very similar in shape and amplitude. For angles between 15° and 60°, and 120° and 165°, the measured RCS pattern in asymmetrical. This asymmetry may be the result of surface irregularities or misalignment of the target with respect to the antennas. Figures 4(a) and 4(b) show the simulated electric currents on the surfaces of the models. This type of information is very important, because it allows the visualization of reflective regions on the surfaces of the models.

In order to compare the RCS patterns produced by the missile section, it is necessary to take into account that this target is a somewhat complex object. Features such as electronic circuitry, cables, rivets, connectors, etc., can alter significantly the symmetry of the RCS pattern produced by the target. On the other hand, the model of the missile section, although well constructed, did not have this level of detail, and therefore its RCS pattern is “simpler” and symmetrical. Still, the three main RCS peaks produced by the rear and sides of the missile section, −90°, 0° and 90°, show similarities in shape and amplitude.

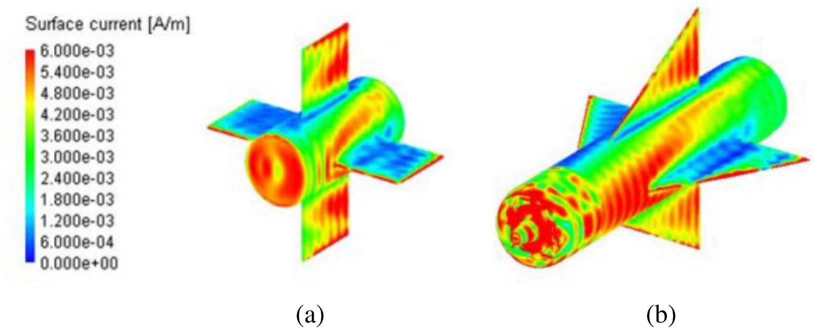


Figure 4: Surface currents on the models: (a) Hypothetical missile and (b) missile section. The radar wave makes an angle of 20° with respect to the direction defined by the main axis of the cylindrical bodies of both models.

5. CONCLUSIONS

The study of electromagnetic scattering is a challenging task due to the complexity of the phenomenon. In this paper, the RCS patterns produced by simple (hypothetical missile) and complex (missile section) targets were measured experimentally in an anechoic chamber and simulated with a simulation software. Despite the great care taken to produce both experimental and simulated results, differences were observed when comparing measurements and simulations. Simulations can be very time consuming, but they allow a better visualization of the phenomena; on the other hand, anechoic chamber measurements can be very precise. These differences serve to point out that measurements and simulations of RCS can, and should, be used simultaneously in order to better characterize a target being studied, as different RCS features can be described and identified using different tools.

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