Radar Cross Section of Targets in the X-Band: Measurements in an Open Range Facility and Numerical Simulations

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***Abstract* — This paper presents preliminary data of an ongoing study on the radar cross section (RCS) of targets with simple and complex surface geometry (a 90° dihedral corner reflector and a decommissioned air-to-air missile) at 10 GHz. Results from measurements carried out in an open range RCS facility are compared with computer simulation of the RCS of these two targets. The main objective of this study was to compare results in order to highlight some of the issues related to both methods of determining the RCS of an actual target.**

***Keywords* — Radar cross section, computer simulations, open range measurements.**

I. INTRODUCTION

The community of researchers interested in problems related to the electromagnetic scattering and measurement of radar cross section (RCS) of real-sized targets is now faced with an interesting predicament: Should one measure the RCS of a target on an open field or in an anechoic chamber, or is it acceptable to simulate the RCS of this target using one of the many software packages available in the market? Both approaches have advantages and disadvantages. It can be argued that measurements will always produce more realistic RCS values (provided that the equipment and experiment are well designed and of good quality), but they can be quite expensive and logistically difficult to carry out. On the other hand, simulations using computers have become more reliable and involve smaller costs, but their results depend on the quality of models used in the simulation and on the simulation software itself; besides, results from computer simulations need to be validated by experimental data. Usually, the researcher may be under pressure for choosing one method over another because it is not always possible to count on both methods (experimental and simulation) to determine the RCS of a target.

In order to better understand the differences between measurements and simulations, the RCS of two targets, a metallic 90° dihedral corner reflector and a decommissioned air-to-air-missile, was determined experimentally in an outdoor RCS facility and simulated with commercial software. Also, the RCS of these two targets was measured and simulated after their surface was covered with a radar absorbent material (RAM).

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This paper provides a description of the RCS facility, the RAM used, the method of characterization of the RAM, and the software simulation tool. We hope this will allow researchers who work with the numerical simulation of RCS to have a better understanding of how simulations and measurements compare. It's a continuation of an ongoing research carried out in our laboratory on studies of the RCS of complex targets and the production of RAM [1],[2].

II. TARGETS

The targets used in this study were a 90° dihedral corner reflector and a decommissioned air-to-air missile. The corner reflector is made of two 0. 5 m x 0.5 m aluminum plates welded together at a 90° angle. Figure 1 shows the CAD model of the missile used in the simulations. Figure 2 shows a photograph of the actual missile. The total length of the missile is 2.84 m, the diameter of the cylindrical body is 0.15 m, and the widest wingspan (tail wings) is 0.66 m. Its body, wings and fins are made of aeronautical aluminum. In the nose of the missile there is a heat-seeking device protected by a glass dome. The rocket nozzle is made of a non-metallic heat-resistant material.

The surfaces of the models of the corner reflector and missile used in the simulations were meshed into 4,096 and 377,000 triangular elements, respectively. The largest dimension of the triangular elements for the missile model was set at 2 mm. The RAM used in this study consists of sheets with a thickness of 2.5 mm. The dimensions of the CAD model were adjusted accordingly for the numerical simulations. The RAM was applied to the cylindrical body, wings and fins of the missile and over the whole surface of the corner reflector.

III. EXPERIMENTAL SETUP

Experimental data were collected in an open range RCS facility [1]. In this facility, the distance between the radar antennas and the target is 230 m. The target was mounted on a rotating table (rotation in azimuth) placed atop an 8-m high pylon. In order to minimize spurious reflections, the pylon was completely covered with commercial pyramidal carbon-black sheets radar absorbers (Fig. 3).

Two radar antennas are mounted on a metal structure and their position is fully adjustable so that they are at the same height as the target. The diameter of the antennas is 1.5 m.

The antennas are in a quasi-monostatic configuration, i.e., there is a transmitting and receiving antenna.

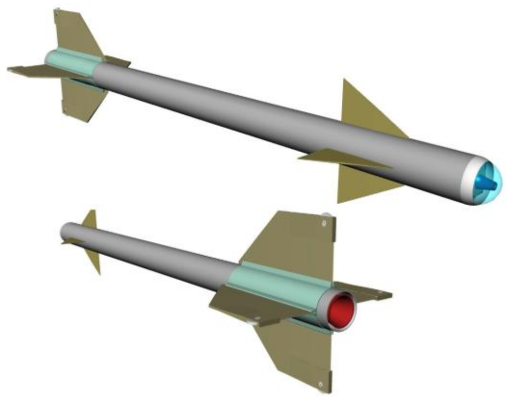

Fig. 1 Front and rear views of the CAD model of the air-to-air missile. Note the glass dome (light blue) protecting the heat-seeking device and the rocket nozzle cavity (red).

Fig. 2 Side view of the actual air-to-air missile.

Fig. 3 Open range RCS facility. Support pylon for RCS measurements (background; height, 8 m). The pylon is covered with pyramidal carbon black radar absorber. Pyramidal carbon black radar absorbers on the surface (foreground). Atop the pylon is a 1 m² metal plate used for calibration of the system.

The electronic circuit consists of an emitting and receiving modules. The emitting module is composed of a of synthesized microwave generator (Agilent, model E8257D), operating from 250 kHz to 40 GHz and power of 15.85 mW (12 dBm), coupled to a 20 W power amplifier operating from 0.8 GHz to 20 GHz (Amplifier Research, model 20ST1G18). The microwave generator is protected against return signals by an isolator circuit. The width of the radar pulse can be modulated from 10 ns to 42 s. The amplified signal produced by the generator is coupled to the transmitting antenna. The radar signal scattered by the target is collected by the receiving antenna. The signal is amplified by a low-noise amplifier and sent to a spectrum analyzer (Anritsu, model MS6226C). A DC blocker protects the spectrum analyzer from spurious signals. The radar frequency in this study was 10 GHz.

IV. Radar Absorbent Material (RAM)

The radar absorbent material (RAM) was produced by the dispersion of industrial-grade high purity carbonyl iron into a matrix of silicon rubber (60% w/w). The absorptive properties of this material in the X-band were characterized using the waveguide technique. In this technique, measurements of the energy reflected and absorbed by the material, and S-parameters were calculated. The measurement system comprises a Hewlett-Packard X752C waveguide with rectangular cross section coupled to a system consisting of a vector network analyzer Agilent 8510C, a frequency generator Hewlett-Packard 8340B (10 MHz – 26.56 GHz), and a S-parameter test Hewlett-Packard 8510A (45 MHz – 26.56 GHz) [3]. The complex values of the electric permittivity (ε) and magnetic permeability (μ) of the material as a function of frequency were calculated from the S-parameters using the software Agilent 85017E. The relative values of ε and μ at 10 GHz are $\varepsilon_r = 5.5 - 0.3i$ and $\mu_r = 1.5 - 0.5i$. Fig. 4 shows the absorption of electromagnetic energy of this material as a function of frequency.

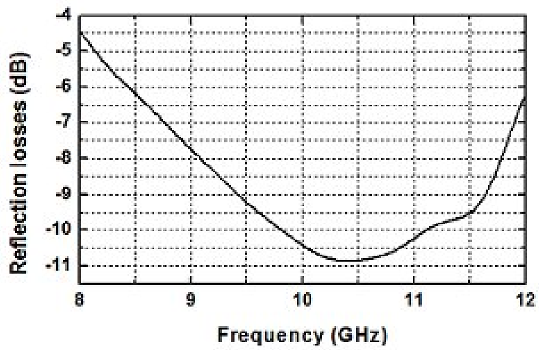

Fig. 4 Reflection losses as a function of the frequency. Iron carbonyl dispersed in a silicon rubber matrix. Thickness of the RAM is 2.5 mm.

V. Simulation Software

The simulation software used in this study was CADRCS [4]. This software combines ray-tracing and ray-shadowing techniques with physical optics to calculate the RCS of the target. According to its developers, CADCRS can calculate the RCS of a target larger than the radar wavelength with great accuracy, reproducing results from an actual radar [5]. Simulations using CADRCS can be carried out under different set of conditions such as wave polarization, target reflectivity and surface roughness. A PC running Windows Vista with a 2.20 GHz clock and 2 GB RAM was used for the simulation. For the simulation, the models were rotated in azimuth 360°, and RCS values were calculated at 0.5°

intervals. Simulation time for the missile model was about 48 hours for a total of 720 RCS values, and for the corner reflector model was about one hour for the same number of RCS values.

VI. RESULTS

We present first the case of the corner dihedral, which is an object with a simpler geometry, to illustrate the problems associated with the measurement, simulation and comparison of RCS data. The RCS of this object was measured with and without the RAM using the setup described previously. Simulations were carried under the same conditions. Figs. 5 and 6 show the results of the measurements and simulations. Note that the vertical scale is not the same in these figures; the measurements are given in dBm whereas the simulations are given in dBsm.

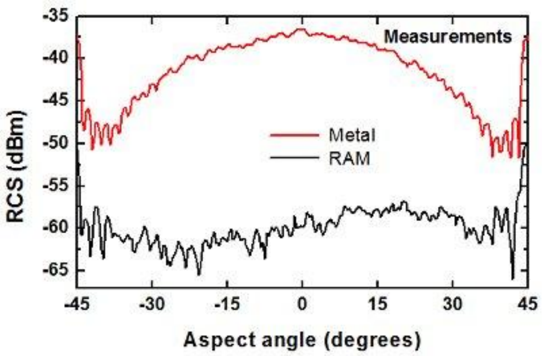

Fig. 5 RCS measurements of a 90° dihedral corner reflector. Radar frequency, 10 GHz. Metal surface and surface covered with a RAM. The aspect angle of 0° corresponds to the situation when the incidence of the radar wave is perpendicular to the vertex of the corner dihedral; at -45° and 45° the radar wave impinges perpendicularly on the surface of one the square plates.

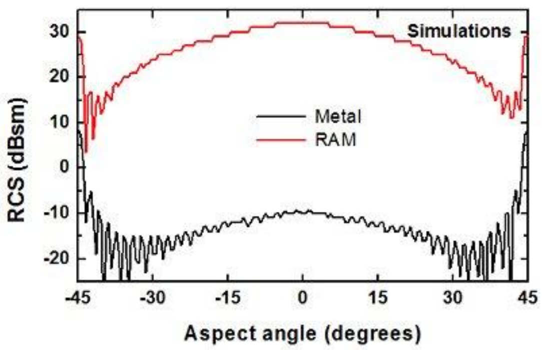

Fig. 6 RCS simulations of a 90° dihedral corner reflector. Radar frequency, 10 GHz. Metal surface and surface covered with a RAM. The aspect angle of 0° corresponds to the situation when the incidence of the radar wave is perpendicular to the vertex of the corner dihedral, at -45° and 45° the radar wave impinges perpendicularly on the surface of one the square plates

Experimental measurements of the RCS of the missile are shown in Fig. 7 and the simulated RCS of a missile with a metallic surface and with the surface coated with a RAM (attenuation, 10 dB) in Fig. 8.

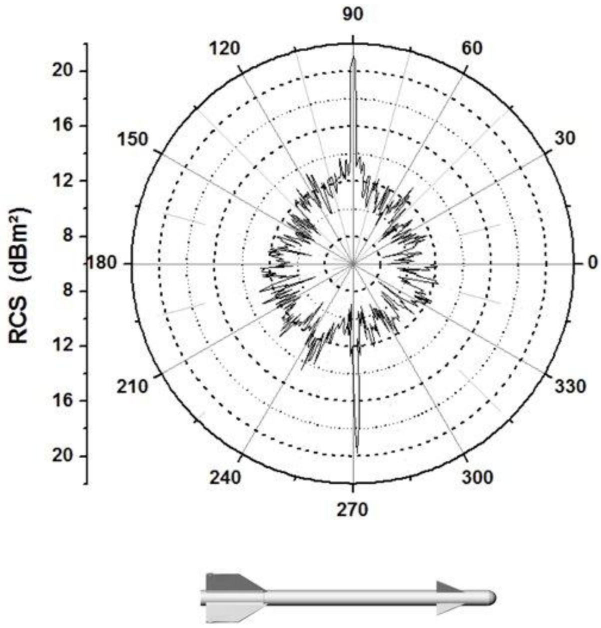

Fig. 7. Polar plot of the measured RCS of a missile. RCS units in dBm². The missile figure at the bottom shows the orientation of the missile . Radar frequency 10 GHz.

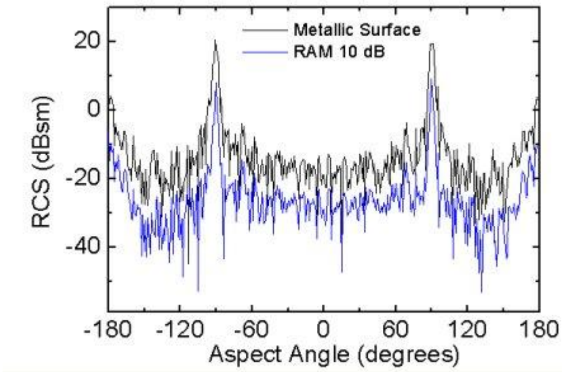

Fig. 8 Simulated RCS of an air-to-air missile. Metallic surface and surface coated with a RAM (attenuation, 10 db). Radar frequency 10 GHz.

Some interesting features are easily recognizable in both measured and simulated RCS patterns such as the side view RCS (-90° and 90°), the reflection of radar waves by the mirror of the heat seeking device (0°), and the RCS signature of the rocket nozzle cavity (+180°). But, differences between simulated and measured results are as important as similarities. The simulation uses models whose surfaces need to be discretized, resulting in deviations from the actual surface and simulations errors. On the other hand, whenever measurements are taken, there always are errors associated to the measurements themselves. Therefore, the comparison of simulations and measurements may be used simultaneously to better understand and predict the RCS of actual targets.

VII. CONCLUSION

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We believe that these preliminary results will provide some insight into the complexity to determine the RCS of an actual target. The results we have obtained so far indicate that differences will occur and they need to be explained satisfactorily. We believe that this study will provide some insight into the complexity of the problem and allow the researcher to obtain a better perspective of simulation of RCS.

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