Measurement and Interpretation of Radar Cross Section Data in an Educational Setting: A Comparison between Simulations and Experiments

Article · January 2009

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Measurement and Interpretation of Radar Cross Section Data in an Educational Setting: A Comparison between Simulations and Experiments

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Abstract— In order to improve the understanding of radar technology, and especially the interpretation of radar cross section (RCS) data by undergraduate students, we developed a study where the RCS of objects having simple and complex geometries were obtained using a simulation software tool and a radar training system consisting of an inverse synthetic aperture radar designed to operate at close range in an academic laboratory or classroom environment. The comparison of results obtained by both methods demonstrated the advantage of using simulations and experiments to interpret RCS data. Moreover, the simulations provided the students with an important visual information, and the radar operation allowed the students valuable hands-on experience with rather sophisticated equipment.

1. INTRODUCTION

Radar technology is ubiquitous in modern society. Its application spectrum is very wide, and new civilian and military uses for radar are currently being developed [1]. Radars can be used in rather mundane situations, such as speed detectors, or they can be carried on spacecraft to the far reaches of the Solar System to map the surfaces of unexplored bodies. Although contact with radar technologies happens on a daily basis, few undergraduate engineering students have a good grasp of the basics of radar operation and interpretation of radar data. This is understandable given that the mathematics and physics involved in the explanation of this type of phenomenon are complex. There are many aspects of radar technology that need to be understood; from the hardware that produces the signal to the software employed to analyze the radar return. In the present work, we focus on measurement and analysis of radar cross section (RCS) using two different approaches available to our students: an educational synthetic aperture radar system [2], and a commercial software [3, 4] that simulate the RCS of targets. The advantages of using two methods to measure the RCS of targets are obvious; in one hand, the student can interact with the equipment that produces and processes radar signals; on the other hand, the student uses simulation and other computational tools, such as computer-aided design (CAD) software, and graphing and data analysis packages, which are becoming ever more available to educators and students in the light of advances in computer hardware and software. Moreover, differences in results obtained by different methods can be used to demonstrate the main weaknesses and strengths of both experiments and simulations.

2. RADAR CROSS SECTION (RCS)

The RCS of an object is a parameter used to quantify the ability of this object to scatter radar waves incident upon it in the direction of a receiving antenna. It represents the size of this object as seen by the radar; the RCS is not the same as the physical area of the object, although it has dimensions of square meters. The RCS of an object depends on many variables such as the frequency and polarization of the incident wave, illumination and observation geometry, and the shape and intrinsic properties of the target [5, 6]. The RCS of a target can be expressed as

$$\sigma = \lim_{r\to\infty} 4\pi r^2 \frac{\left|E^{scat}\right|^2}{\left|E^{inc}\right|^2} \tag{1}$$

where E^{scat} and E^{inc} are the scattered field and incident fields at the target, respectively. Equation (1) is valid when the target is illuminated by a plane wave. This condition is satisfied by the far-field approximation, i.e., when the object is located at a distance at least $r = 2D^2/\lambda$, where

D is the largest dimension of the object, and λ is the wavelength of the radar [7]. Note that the calculation of scattered fields from a target using (1) is complex; analytical solutions of this equation exist only for objects with simple geometries. Therefore, in order to calculate the RCS of an object, one usually needs to resort to measurements or simulations.

3. EXPERIMENTAL SETUP

The radar setup is based on the Lab-Volt Radar Training System, which has been described in detail elsewhere [1, 7]. This system consists of six interconnected subsystems that allow training on analog and digital aspects of radar operation, radar tracking, electronic warfare, radar antenna steering, and radar cross section. Measurements were carried out in a laboratory using an inverse synthetic aperture radar, operating at 1–10 GHz at short range, and in the presence of noise and clutter, which is removed using time-gating and subtraction techniques during the measurement process. Fig. 1 shows a typical arrangement of the antenna and target in the laboratory. The target rests on a styrofoam rotating pedestal, invisible to radar waves.

Figure 1: Antenna, target and associated electronic equipment of the Lab-Volt Training System. The target rests on a cylindrical styrofoam pedestal.

4. SIMULATION TOOL

The commercial software CADRCS was used in the simulations. CADRCS combines ray-tracing techniques with physical optics to calculate the RCS of an object. Shadowing of rays is also taken into account, resulting in accurate RCS calculations for objects greater than the radar wavelength [8]. CADRCS is a user-friendly and versatile software requiring minimal training for use. CAD models of the targets were produced using Rhinoceros modeling software. After the CAD model of a target was generated, its surface was subdivided into triangular elements by an automatic mesh generator. The dimensions of the triangular elements were chosen so that the simulations produce optimal results; usually the dimensions of the elements were in the order of 0.1λ. The meshed object was then imported into CADRCS for the simulations. A Pentium 4 3.2 GHz PC computer with 4.0 GB RAM memory was used in this work. Detailed results from targets with simpler geometries were obtained within one hour.

5. TARGETS

Four metallic targets with different levels of complexity were used in the measurements and simulations. The CAD models of the targets (square flat plate, z-shaped plate, trihedron and cylinder) are shown in Fig. 2. The actual targets and models had the same dimensions. The surfaces of the flat plate, z-shaped plate, trihedron and cylinder were discretized into 1868, 3288, 4854, and 126576 triangular elements, respectively.

6. RESULTS

Measurements and simulations were performed at 9.4 GHz ($\lambda = 3.19$ cm), in a monostatic radar configuration, and vertical polarization. In our laboratory, the distance between the radar antenna and targets was about 6 m, which means that the far-field condition was satisfied; thus the far-field approximation was used in the simulations. The targets were rotated by 360°, in both the simulations and measurements. The cylindrical pins, shown in Fig. 2, coincided with the axis of rotation of the targets. RCS measurements and simulated values were obtained at intervals of 0.35°. The comparison of the RCS diagrams obtained from measurements and simulations of the four targets are depicted in Fig. 3.

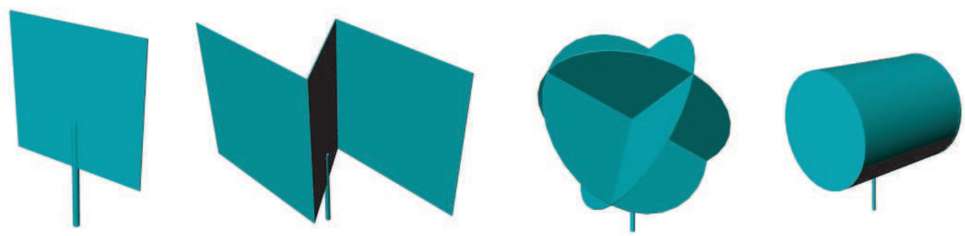

Figure 2: CAD models of the metallic targets used in measurements and simulations, figures not to scale. Flat plate, side = 0.2 m; z-shaped plate, height = 0.2 m; trihedron, diameter of circles = 0.3 m; cylinder, length = 0.3 m, diameter = 0.15 m. The cylindrical pin was used to fix the targets to the rotating pedestal.

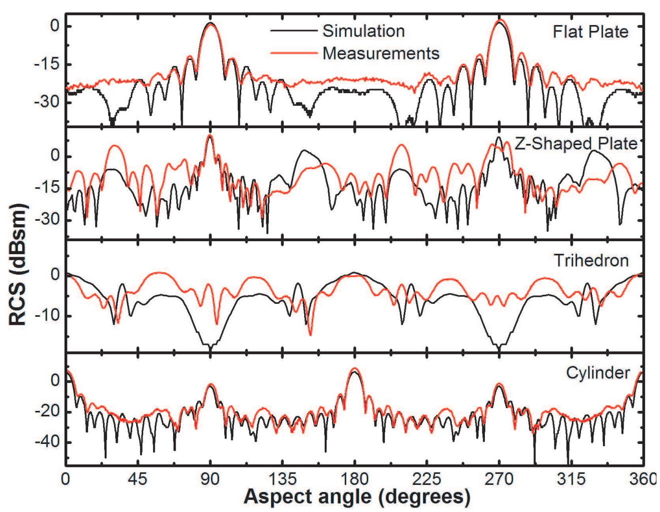

Figure 3: Simulated and measured RCS diagrams for the flat plate, z-shapped plate, trihedron and cylinder.

Inspection of Fig. 3 shows that the results can be used to divide the targets in two groups: the plate and the cylinder, which are convex objects; and the z-shaped plate and trihedron, which are concave objects. The RCS diagrams of the convex objects show that, in general, there was a good agreement between simulations and experimental measurements. The main differences in both cases being related to the radar sensitivity; the experimental apparatus did not record RCS values as small as simulated by the software. But, this type of result was expected because the equipment had limitations, being able to measure RCS values up to a certain instrumental limit. In both cases, the RCS diagrams show a good degree of symmetry and the main features, represented by the peaks produced by the flat surfaces of these objects (90° and 270° for the flat plate, 0°, 180°, 360° for the cylinder), have amplitudes that are similar, and within the experimental error of about 1 dBsm.

The comparison of the RCS diagram of the concave objects, the z-shaped plate and trihedron, shows that there are important differences between measured and simulated results. This can be explained by the fact that the reflectivity of radar waves by a convex object, and hence their RCS, are very sensitive to the angles formed by the surfaces that constitute this type of object. Differences of the order of 0.5° (or less) can alter significantly the reflectivity of waves due to interference effects, either destructive or constructive, that occur as results of multiple reflections of the radar wave by the surfaces of the object [4, 6]. The CAD models used in the simulations are idealizations of the actual targets, therefore, the angles and surfaces of the models are well determined. On the other hand, the shapes of the actual targets have minor imperfections. These imperfections, albeit small, are enough to interfere with the measured RCS patterns. Note that the values of main peaks of the measured and simulated RCS of the concave objects agreed well in amplitude, indicating that for certain aspect angles the surfaces of the targets facing the radar antenna coincided with the surfaces of the CAD models illuminated by the radar at these particular aspect angles.

7. CONCLUSION

The determination of the RCS of different targets demonstrated the relevance and importance of combining methods to explain physical concepts to undergraduate students. The process of setting up the radar training system and carrying out the measurements is an invaluable experience, and the reasons are obvious; the student is faced with the difficulties inherent in operating a complex measurement system, interpreting the data, and, at the same time, is rewarded with the satisfaction of accomplishing a difficult task. Likewise, simulation tools are a means to introduce the student to different software, numerical methods, and new problem-solving techniques. The simultaneous use of simulations and measuring instruments is synergic; the advantages and disadvantages of both methods are demonstrated, and the natural differences in results require the student to reason critically about the phenomenon being observed.

ACKNOWLEDGMENT

The authors express their gratitude to the Electronic Warfare Laboratory, CTA, São José dos Campos, SP, Brazil, for allowing the use of Lab-Volt Training System.

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