Evaluating the Radar Cross Section of Maritime Radar Reflectors Using Computational Electromagnetics

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Abstract – This paper presents results from calculating the radar cross section (RCS) of two maritime radar reflectors using the method of moments. The Echomaster 152, although smaller in size, produces a higher maximum RCS than the Echomax 230 that includes three layers of corner reflectors. The Echomaster 152 also has deeper nulls in the RCS pattern, which means it is less detectable at those angles.

Keywords: Radar cross section, radar reflectors, ground plane, ocean, method of moments.

I. INTRODUCTION

Pleasure and commercial boats in the crowded harbors and bays of the United States use a horizontally polarized maritime X-band radar operating at 9.41 GHz. Large boats are easy to see with these radars, but smaller non-metallic hulls, like those of a sailboat, have a low radar cross section (RCS) and are difficult to detect. The RCS is particularly low from the fore and the aft, making them even more difficult to detect in those directions. Placing the reflectors at a high point on the boat, like the top of a sail boom, increase the detection range of the low RCS boats [1].

In order to be effective, the RCS of the radar reflector must be larger than the RCS of the boat. Also, the reflector/boat RCS should be large enough in all directions in order for other boats to detect it in time to avoid a collision. Several commercial reflectors claim to increase the RCS of sailboats. Two of the more popular reflectors are the Echomax 230 [2] and the Echomaster 152 [3]. Both reflectors make use of simple corner reflectors arranged to provide a high azimuthal RCS.

The impact of these reflectors has been analyzed and measured in free space [4]. Unfortunately, these RCS results do not consider the ocean, which has a tremendous effect upon the RCS of the reflector. This paper presents RCS results from modeling several types of reflectors with and without a salt water ground plane using the method of moments. The presence of a calm ocean greatly enhances the RCS of both reflectors in all azimuthal directions. The Echomaster 152 has a higher RCS at most angles than the Echomax 230, but the Echomax 230 has a higher minimum RCS than the Echomaster 152.

II. RADAR REFLECTOR MODELS

The goal of this effort was to evaluate and compare the RCS of two popular commercial radar reflectors in both free space and over an ocean ground plane. In addition, these RCS results are compared to the RCS of a cylinder and sphere. All the reflectors are assumed to be perfectly conducting. Figure 1 shows the four reflectors drawn at the correct relative sizes. For the calculations, each reflector is centered on the coordinate system with ϕ measuring azimuth angle and θ measuring elevation angle. The ocean is assumed to be in the x-y plane, so the orientation of the reflectors in Fig. 1 corresponds to how they would be deployed.

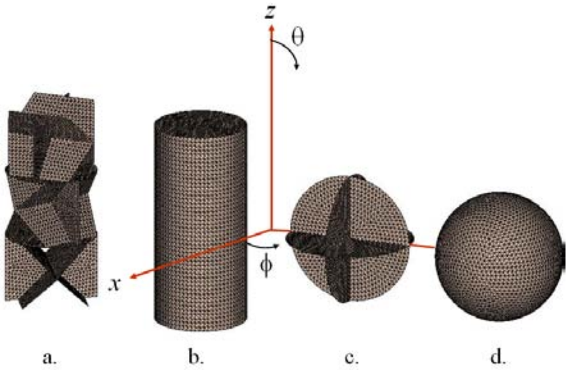

Fig. 1. FEKO CAD models of the reflectors: (a) Echomax 230, (b) cylinder, (c) Echomaster 152, and (d) sphere.

The Echomax 230 (Fig. 1(a)) consists of a stack of three aluminum quad-trihedral reflectors inside a cylindrical shell (Fig. 1(b)). Figure 2 is a photograph of the aluminum reflector outside of its plastic shell (laying on its side) Echomax 230. The Echomax 230 reflector is h=496 mm high and has a radius of r=153 mm [2]. A model of one layer of the Echomax 230 with dimensions appears in Fig. 3. Each layer displays a 30^o twist in order to create a more omni-directional RCS in the azimuth plane.

The second commercial reflector to be modeled is the Echomaster 152, whose geometry is shown in Fig. 1(c). It consists of three intersecting, orthogonal 305 mm diameter aluminum disks [3]. The sphere (Fig. 1(d)) has a radius of r=153 mm**.** It does not come with a cover.

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Fig. 2. Photograph of the Echomax 230 reflector and its plastic cylindrical cover.

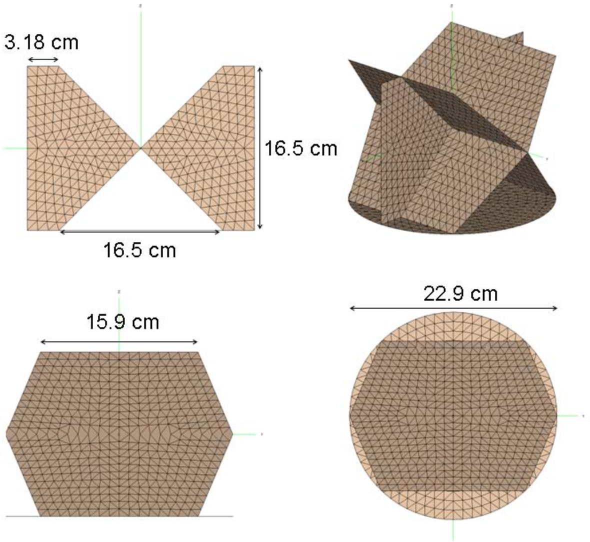

Fig. 3. Dimensions of one layer of the Echomax 230.

Two canonical RCS reflector shapes are also included in this study: cylinder and sphere. The cylinder in Fig. 1(b) has the same height and radius as the Echomax 230, and the sphere in Fig. 1(d) has the same radius as the Echomaster 152. The RCS of these reflectors is well known analytically, so they serve as a check for the method of moment's calculation of the RCS as well as having the desired omni-directional RCS pattern in the azimuth plane. The simple physical optics formulas [5] predict that the peak RCS of the cylinder, σ_{cyl}, is,

$$\sigma_{cyl} = \frac{2\pi r h^2}{\lambda} = 7.5 \text{ dBsm} \tag{1}$$

and of the sphere, σ_{cyl}, is,

$$\sigma_{sph} = \pi r^2 = -11.4 \text{ dBsm} \cdot \tag{2}$$

This data is used to check the computational results for accuracy.

III. COMPUTED RCS OF THE RADAR REFLECTORS

Most pleasure boats on crowded waterways use maritime radar. X-band maritime radars operate with horizontal polarization (ϕ – polarized) at 9.41 GHz with a wavelength of $\lambda = 3.19$ cm. This type of radar is commonly used by pleasure and commercial boats when near land. Boats far from land also have much larger and more powerful S-band radar. Only the X-band frequency will be considered here.

The RCS of these four reflectors are computed using the method of moments program, FEKO [6]. All reflectors have the same size triangular mesh with a maximum triangle side of $\lambda/5$. This triangle size resulted in the computed peak RCS of the cylinder and sphere matching the values in equations (1) and (2). Increasing the size of the maximum triangle side resulted in RCS values that did not match equations (1) and (2).

Each reflector is modeled in free space and in the presence of an infinite ocean ground plane. The free space RCS is calculated over $60^o \le \theta \le 90^o$ and $0^o \le \phi \le 90^o$. The range of elevation angles accounts for the difference in height between a radar on the larger boat and the reflector on the smaller boat and some motion of the boats. In addition, the RCS of the reflectors is calculated over an infinite ground plane having a permittivity of $\varepsilon_r = 55 + j31$ with a loss tangent of $\tan\delta = 0.56$. This ground plane corresponds to a calm ocean at a temperature of 14^o C and a salinity of 33 parts per thousand [7].

The first RCS calculations are done with the cylinder and sphere test cases. Figure 4 displays the computed results for the cylinder and the sphere. The ground plane significantly enhances both the RCS of the cylinder and of the sphere. As θ approaches 90^o, the RCS with the ground plane is about 6 dB higher than the free space RCS.

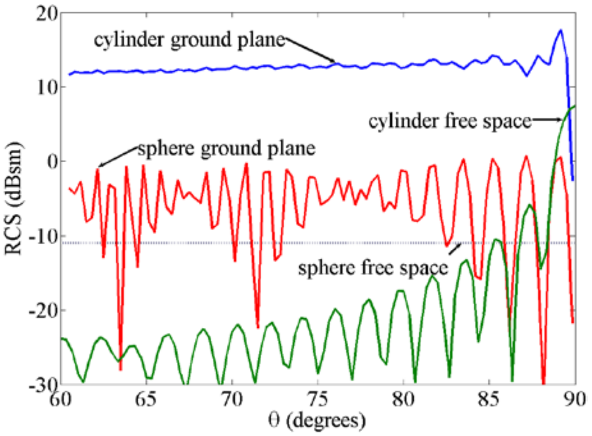

Fig. 4. RCS of a cylinder and sphere in free space and above a ground plane.

Figures 5 through 8 plot the RCS over the azimuth and elevation angles of interest for the Echomax 230 and the Echomaster 152 reflectors. Each reflector is shown both in free space (Figs. 5 and 7) and at 5 m above an ocean ground plane (Figs. 6 and 8). Echomax specifies that the maximum RCS of their Echomax 230 radar reflector is 24 m^2 or 13.8 dBsm. The maximum computed result is 13.4 dBsm, so the computations appear to be accurate. The Echomaster 152 appears to give a larger RCS over a greater angular extent than the Echomax 230. It also appears to have the deepest nulls over the greatest area. Its maximum free space RCS is 17.2 dBsm which is close to that of a disk with r=153 mm (18.2 dBsm). The ocean ground plane boosts the maximum RCS of both free space models by about 8 dB and also produces much broader maxima.

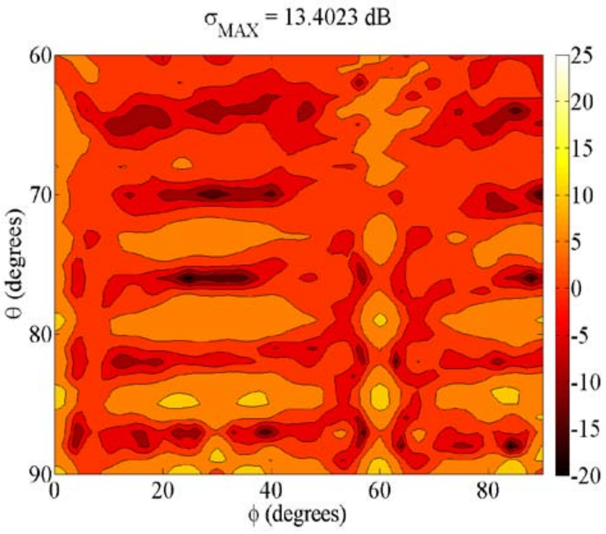

Fig. 5. RCS of Echomax 230 in free space.

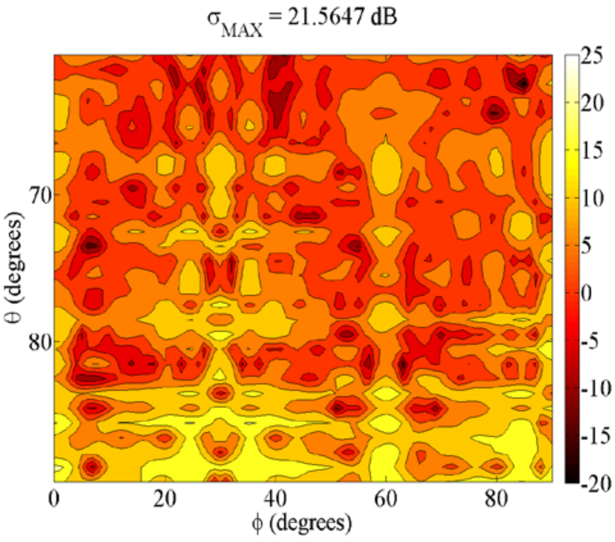

Fig. 6. RCS of Echomax 230 when placed 5m above an ocean ground plane.

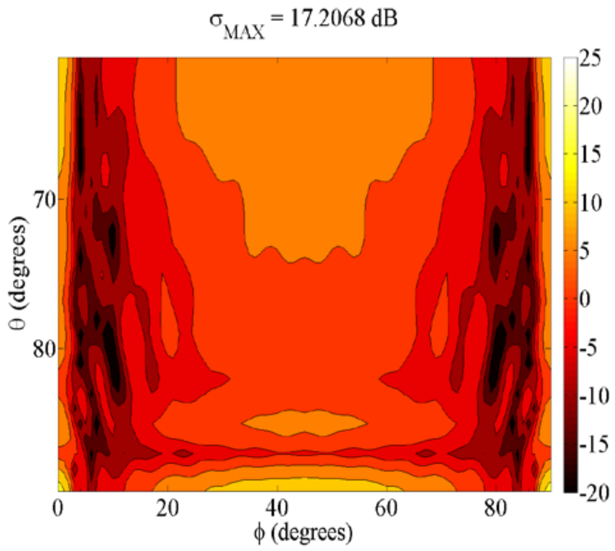

Fig. 7. RCS of Echomaster 152 in free space.

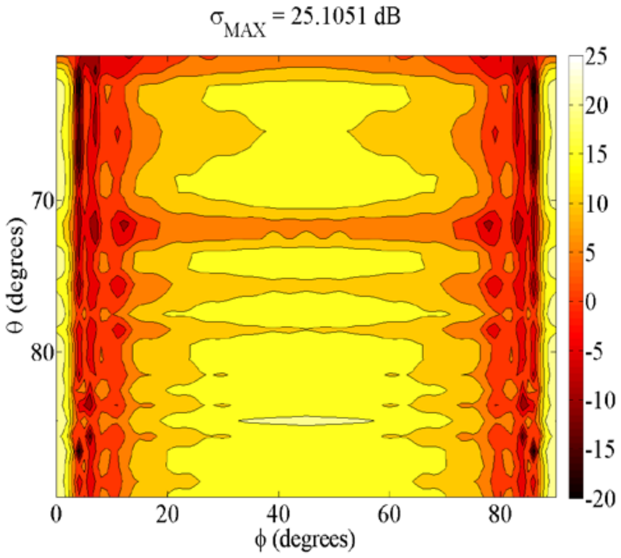

Fig. 8. RCS of Echomaster 152 when placed 5m above an ocean ground plane.

Figure 9 shows a plot of the free space RCS patterns for the two reflectors at $\theta = 90^o$. The Echomax 230 RCS has a lower maximum RCS, but does not have the broad nulls of the Echomaster 152. Inserting the ocean ground plane increases the overall RCS of both reflectors but maintains a similar shape as indicated in Fig. 10. This advantage is due to the stacked design that provides reflection from at least one of the corner reflectors at each angle of incidence. The elevation angles do not extend to $\theta = 90^o$ because the ground plane is assumed to be infinite in extent.

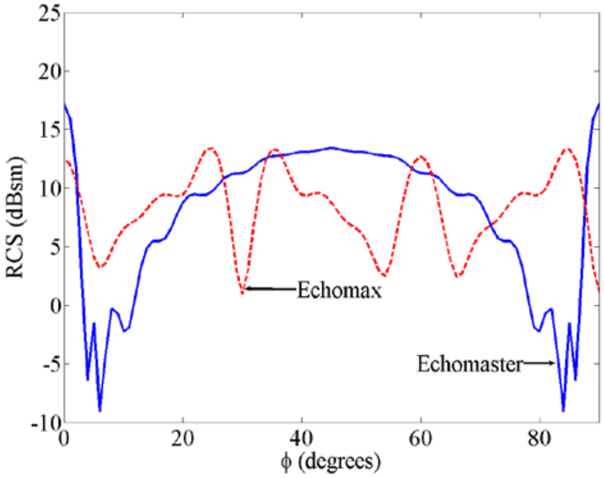

Fig. 9. RCS of Echomax 230 and Echomaster 152 in free space at θ = 90°.

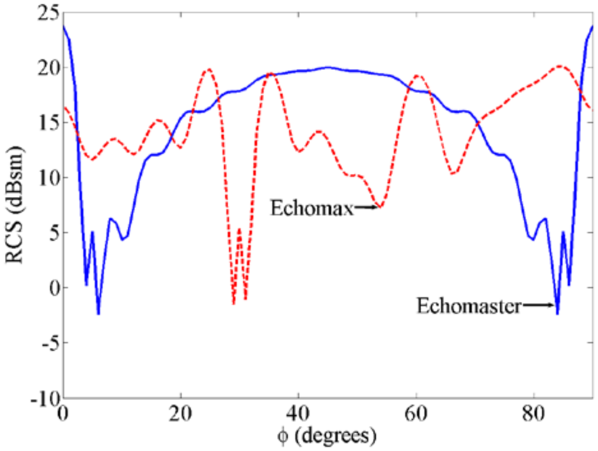

Fig. 10. RCS of Echomax 230 and Echomaster 152 above an ocean ground plane at θ = 89.5°.

IV. CONCLUSIONS

The results of this modeling study indicate that both the spherical Echomaster 152 comprised of three intersection orthogonal disks and the Echomax 230, which stacks three layers of corner reflectors, are likely to enhance the RCS of a small sailboat. Although the Echomaster 152 boasts a higher maximum RCS, it also displays the deepest nulls over a larger extent of azimuth angles. Including a ground plane representing the ocean in the calculations increases the average and maximum RCS for both models. The variability of the RCS patterns in both the azimuth and elevation angles suggests that the RCS highly depends on sea state, which causes the boat to pitch, roll, and yaw. Typically, the best RCS occurs when the sea is calm (RCS with ground plane), and the worst RCS occurs with waves (free space RCS).

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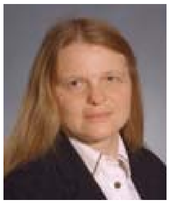

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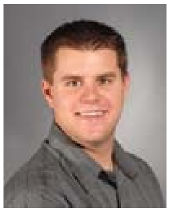

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