Simulations of the Radar Cross Section of a Pylon

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***Abstract* — Simulations of the radar cross section (RCS) of a four-column square-based support pylon were performed in order to find the orientation between a radar antenna and the pylon in which the radar return from the pylon is minimal. From RCS simulations at 2, 6 and 10 GHz it was found that the optimal positioning of pylon occurs when the side of the pylon is at an angle of about 20° with respect to the line-of-sight of the radar antenna.**

***Index Terms* — Modeling, pylon, radar cross sections, simulations**.

I. INTRODUCTION

A support pylon is probably the most visible structure in an outdoor radar cross section (RCS) range facility. The support pylon is used to hold a model, a full-scale model or the actual target above ground for RCS measurements. The target can be mounted atop the pylon at different pitch and roll angles and rotated in azimuth. Ideally, the pylon should be built with materials that have a very low radar reflectivity and/or be shaped in such a manner as to scatter radar waves away from receiving antennas. The reasons for this are obvious: the pylon should interfere as little as possible with the RCS measurements of the target. When the load is small, as in the case of a scale model or a small target, a pylon can be built with light materials invisible to radar, like styrofoam. Full size models and actual targets may require massive structures, made of steel, aluminum or reinforced concrete. These structures are usually constituted of columns inclined with respect to the horizontal plane and their cross sections have the shape of an ogive. The inclination of the column combined to the shape of its cross section has the property to diffract the incoming radiation towards the ground or away from the line-of-sight direction [1]-[2].

Our research group is in the process of establishing an outdoor RCS measurement facility in Brazil, the first one of its kind in this country. In this facility, RCS measurements of targets as small as plates with an area of 0.25 m^2 and up to real-sized fighter planes will be performed in the S-, C- and X-Bands (2-12 GHz). But, due to budgetary constraints, the design of the support pylon that will hold the targets had to be simplified, and a structure with a more conventional design was built. This structure, made of reinforced concrete, is composed essentially by a large number of flat surfaces, which are, depending on the viewing angle, excellent radar reflectors.

This study presents the results from RCS simulations of this pylon. These simulations were performed in order to find the best orientation of the pylon with respect to the radar to minimize its radar return.

II. THE PYLON

The pylon is a four-column square-based structure made of reinforced concrete. Horizontal beams are used to improve its rigidity and strength. The columns and beams have identical square cross-sections and their width is 0.2 m. The height of the pylon is 7.95 m. The inner distance between columns is 1.00 m. The horizontal beams are placed at 2.45 and 5.90 m height. An iron structure made of welded I-beams that houses a turntable assembly is mounted atop the pylon. The height of this structure is 0.2 m. The pylon can hold targets up to 2000 kg. Fig. 1 shows a picture of the actual pylon in the outdoor range.

Fig. 1. RCS support pylon. The pylon can be seen in the foreground. This picture was taken while the electrical wiring of the turntable was being installed. The height of the pylon is 7.95 m and its width is 1.4 m.

III. SIMULATION TOOL

To predict the RCS of the pylon one could resort to RCS measurements of a scale model in an anechoic chamber, calculate it analytically or use simulation software. It was agreed that the use of simulation software was the best choice, as the cost and time involved in building and measuring the RCS of a model, or using somewhat complex analytical calculations would be prohibitive.

The RCS of the pylon was simulated with the commercially available CADRCS software [3]. CADRCS simulates the scattering of electromagnetic waves off of a target. It uses ray-tracing techniques combined with physical optics methods to predict the RCS of a target. Also, CADRCS takes into consideration the shadowing of rays and as a result provides precise calculations of the RCS of targets larger than the radar wavelength [4]. CADRCS is a versatile simulation software as it allows the simulation of the RCS of a target under various situations such as different distances between target and radar, reflectivity of the target's surface, frequency and polarization of the radar, etc. Details about the theory and methods used in CADRCS are considered classified material and are not disclosed to users [5].

In order to run the simulations with CADRCS, a CAD model of the target is needed. The CAD model of the pylon is shown in Fig.2. The model of the pylon was imported into the Rhinoceros software and its surface was discretized in triangular elements by an automatic mesh generator. This mesh was then imported into CADRCS for the simulations. Since the structure of the pylon is composed of flat surfaces it was discretized into a rather small number of triangular elements totaling 2112. The surfaces of the structure that houses the turntable and the turntable itself were discretized into 8836 triangular elements due to the components with curved surfaces.

The monostatic RCS of a target can be expressed as [6]

$$\sigma = \lim_{r \to \infty} 4\pi r^2 \frac{|E_S|^2}{|E_I|^2}, \qquad (1)$$

where r is the distance from the object to the observation point, $\boldsymbol{E}_S$ and $\boldsymbol{E}_I$ are the scattered and incident electric fields at the target. Equation (1) is valid when the target is illuminated by a plane wave. This 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 [7]. The units of RCS are in square meters, and due to the large range of RCS values, a logarithmic power scale is used with the reference value of $\sigma_R = 1\ m^2$ [7]:

$$\sigma_L = 10\log_{10}\left(\frac{\sigma}{\sigma_R}\right) = 10\log_{10}\left(\frac{\sigma}{1}\right). \qquad (2)$$

IV. Results

In Fig. 3 is shown the orientation of the pylon with respect to the radar. The objective of the simulations is to find the aspect angle θ in which the RCS of the pylon is a minimum.

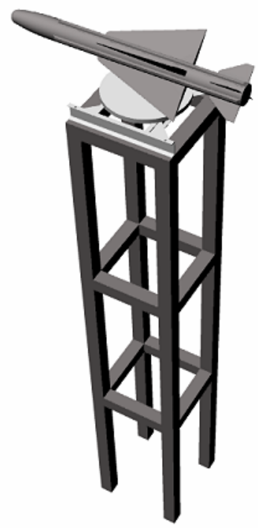

Fig. 2. Pylon for RCS measurements with a hypothetical target. Top view. The width of the pylon is 1.4 m and its height is 7.95 m. A structure that houses a turntable is mounted atop the pylon. The height of this structure is 0.2 m. The target, a generic missile, has a length of 3.15 m. It is included in the figure for scale. The braces holding the missile in place are hidden from view by its body.

RCS simulations of the pylon model were performed at 2, 6 and 10 GHz in vertical polarization with the radar in a monostatic configuration. The pylon was rotated about its vertical axis by 180° and RCS values were obtained at intervals of 0.25°. It was assumed that the pylon was a perfect conductor in the simulations. A 3.2 GHz Pentium 4 computer with 4 GB RAM memory was used in this study. The simulation time was about 90 min.

Figs. 4A, 4B and 4C show the RCS simulations of the model at 2, 6 and 10 GHz, respectively, as a function of the aspect angle. In these polar plots, the line-of-sight of the radar is perpendicular to the side of the pylon at 0°, 90° and 180°. At 45° and 135°, the line-of-sight of the radar is aligned with the corners of the pylon.

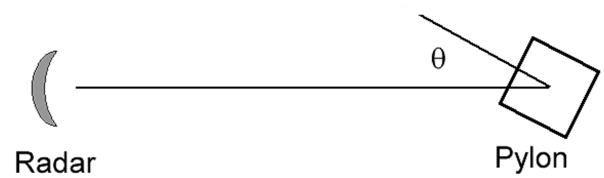

Fig. 3. Relative orientation of the pylon with respect to the radar. θ is the aspect angle.

The simulations show that the largest RCS values occur when the side of the pylon is perpendicular to the line-of-sight of the radar, at 0°, 90° and 180°. At 0°, the simulated RCS values at 2, 6 and 10 GHz are 36.06, 41.82 and 45.20 dBsm, respectively.

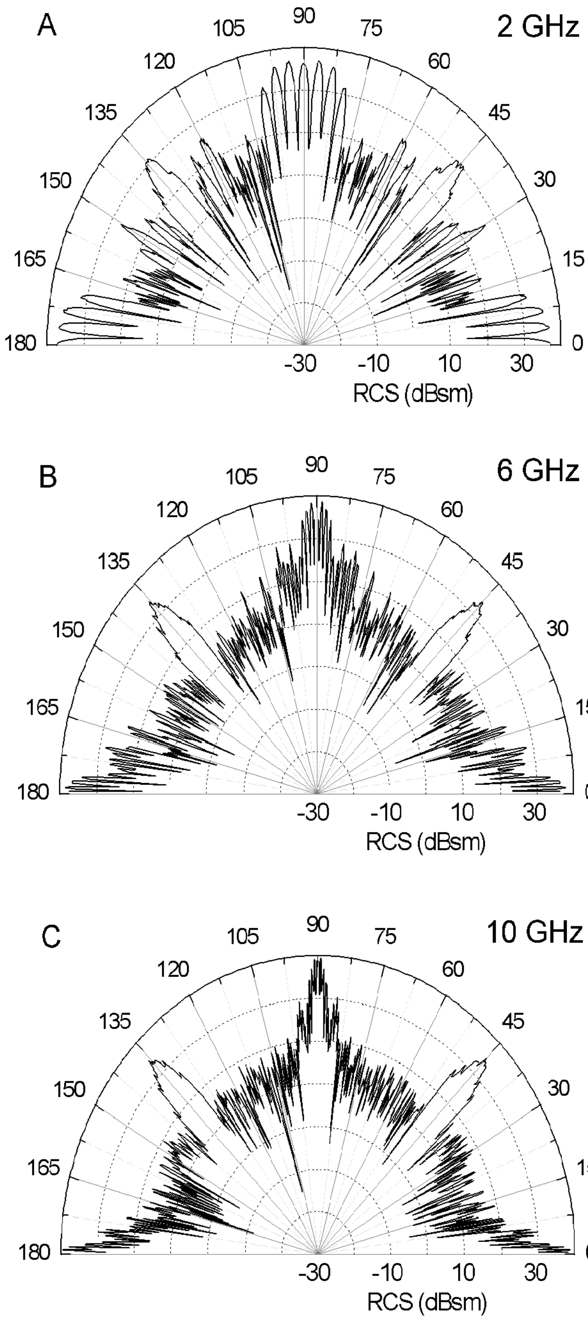

Fig. 4. Polar plots of the simulated RCS of the model of the pylon versus the aspect angle. Simulations performed at 2, 6 and 10 GHz are represented in the panels A, B and C, respectively. At 0°, 90° and 180°, the line-of-sight on the radar is perpendicular to the side of the pylon. At 45° and 135°, the line-of-sight of the radar is aligned with the corners of the pylon. RCS values were simulated at intervals of 0.25°.

From Fig 4 it can be seen that secondary maxima occur for the three frequencies at 45° and 135°. The simulated RCS values at 2, 6 and 10 GHz at 45° are 30.1, 33.7 and 34.8 dBsm respectively. The RCS simulated at 2 GHz has other maxima located at 30°, 60°, 120° and 150°; the RCS at these angles is 25.2 dBsm. To find the best orientation of the pylon, one can use the RCS simulations performed at 2 GHz as guidance. Although RCS changes from one aspect angle to the other are rather abrupt in the simulations, one can still determine an orientation that corresponds to a minimum RCS value. On Fig. 4A one can observe that between 13° and 28° the simulated RCS has relatively low values. This feature is also found on the polar plots for simulations at 6 and 10 GHz, Figs. 4B and 4C, respectively. Careful inspections of the values generated by the simulations show that the minimum RCS value at 2 GHz is –9.78 dBsm at 20.5°, at 6 GHz is 2.09 dBsm at 20.25°, and at 10 GHz is 4.48 dBsm at 20°. At these aspect angles, the RCS reduction with respect to the value simulated at 0° is about 45, 42 and 40 dBsm at 2, 6 and 10 GHz, respectively.

These data suggest that the best orientation between the side of the pylon and the line-of-sight of the radar should be about 20°. During the construction of the pylon it was not possible to orient the pylon with a precision of tenths of a degree, thus the value of 20° was chosen as the best attainable orientation. Note that the RCS of the pylon is still relatively large at this angle; to further decrease the RCS of the pylon, its surface will be covered with radar absorbing materials (RAMs).

V. Conclusion

The support pylon is an important component of a RCS outdoor range. Since its structure needs to be bulky and strong enough to support heavy loads, it is necessary to design the pylon in such a way to minimize its radar return. A simulation software was used to simulate the RCS of the pylon before it was built and the results thus obtained proved to be an invaluable aid as they allowed the determination of the best orientation of the pylon with respect to the line-of-sight of a radar.

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