Abstract — The work described in this paper includes use of a bounded wave simulator at NRaD's Time Domain Measurement Range for obtaining the transient scattering response of a particular airborne target. The target used for these tests is a scale model, requiring that the measurement data be scaled in order to compare the results to those obtained by numerical methods for the full size target. The theory, measurement procedure, and data processing techniques are also presented.

I. INTRODUCTION

Scale models of Navy ships and a transient electromagnetic test facility (NRaD’s Time Domain Measurement Range) have been used together to measure the effects of a simulated high altitude electromagnetic pulse on the shipboard antenna systems for years [1]. Recently, the capabilities of the Time Domain Range’s bounded wave simulator (BWS) have been extended to obtaining the scattering response of an airborne target due to a transient pulse [2, 3]. A diagram of the NRaD Time Domain Range BWS is shown in figure 1.

Figure 1. NRaD time domain measurement range.

A target placed within the confines of the BWS is hit with an electromagnetic impulse, then the scattered signal returns through the BWS to be measured in the control room below. Measurements are also made of the incident signal, as well as the background signal (i.e., with no target in place). As the signals return to the control room below the BWS structure, the waveforms are captured on an oscilloscope, then processed using Tektronix’s Signal Processing and Display package and NRaD’s Radar Cross Section program. These programs convert the waveforms from the time domain to frequency domain representations through the use of the Fast Fourier Transform. Further waveform processing allows the calculation of radar cross section (RCS), which is the basis for target identification efforts using resonant frequencies.

II. RADAR CROSS SECTION MEASUREMENT THEORY

Following the development of references [3] and [4], we define the radar cross section, or RCS, of a target by the following equation

\[ \sigma = \lim_{R \to \infty} \frac{4\pi R^2 |E_s|^2}{|E_i|^2} \]  

(1)

where E\(_s\) represents the magnitude of the field scattered by the target, E\(_i\) is the incident field strength, and R is the horizontal distance from the feed-point of the BWS to the front of the target. We wish to rewrite the RCS equation in terms of quantities that can be measured on the TDMR, in particular the incident and scattered voltages.

The incident electric field is simply equal to the height of the BWS at the target. Since the BWS has a slope of 19 degrees, the incident field may be rewritten as:

\[ E_i = \frac{V_i}{R} \]  

(2)

When the pulse generator produces an incident voltage pulse, the BWS may be viewed as a transmitting antenna. It has an intrinsic 100-ohm impedance (R\(_{in}\)) and a 100-ohm resistor is placed across the feed of the BWS to provide a match to the 50-ohm impedance of the source as shown in figure 2.

Figure 2. Circuit diagram with BWS as transmitting antenna.

When the pulse reaches the BWS, the target reflects part of the incident field, so that the BWS now acts as a receiving antenna. The pulse generator pictured above is no longer transmitting, but instead the reflected voltage at the BWS becomes the voltage source, as diagrammed below in figure 3.
The scattered electric field is related to the measured scattered voltage by the effective height, h_{eff}, of the BWS as a receive antenna. The feed resistor and the input resistance of the receiver combine in parallel to form a load resistance of R_L = 33 ohms. The measured scattered voltage V_s is therefore related to the scattered field strength E_s as given below:

\[ E_s = \frac{R_s + R_L}{R_L} \cdot \frac{V_s}{h_{eff}}, \]  

or

\[ E_s = \frac{100 + 33}{33} \cdot \frac{V_s}{h_{eff}}. \]  

Substituting expressions (2) and (3) for E_s and E_i into the RCS equation provides a basis for obtaining a target's radar cross section based on the measured values of V_s, V_i, and R:

\[ \sigma = 1.92 \frac{2\pi\eta R}{h_{eff}} \cdot \frac{V_i^2}{V_s^2}. \]  

This expression still requires that a value for the effective height of the bounded wave simulator be determined. Effective height [5] may be given in terms of effective aperture A_e, antenna impedance R_{ant} + jX_{ant}, and terminating impedance R_L + jX_L, as

\[ h_{eff} = \sqrt{\frac{h_{er}}{(R_{ant} + X_{ant})^2 + (X_{ant} + X_L)^2}}. \]  

Since X_{ant} = X_L = 0, this becomes

\[ h_{eff} = \sqrt{\frac{(100 + 33)^2}{(377)(33)}} A_e = 1.19 \sqrt{A_e}. \]  

The relationship between effective aperture and the gain of an antenna is

\[ A_e = \frac{4\pi}{\lambda} G, \]  

where G is the receive mode gain of the BWS, and \( \lambda \) is the wavelength. Substituting equation (8) into (7), we obtain:

\[ h_{eff} = 1.19 \sqrt{\frac{G \lambda^2}{4\pi}}. \]  

The gain of the BWS as used in the scattering measurements is difficult to determine analytically because the target is within the BWS canopy. However, the gain can be accurately determined empirically by the substitution method. In this method, the field radiated by a standard antenna, in this case a quarter-wave monopole, is compared to the field produced by the BWS. Since the gain of the standard is known, the BWS gain may be inferred. The procedure is to start with the lowest frequency of interest and work towards the higher frequencies in convenient steps. At each new frequency, the monopole is clipped so that its length remains at the quarter wavelength.

A number of measurements were made at discrete frequencies over the band of interest. For the BWS, it was found that the experimental gain was not independent of frequency. However, the maximum variation over the measurement range from 200 to 460 MHz was less than 0.1 dB. Thus, it was convenient to use the average gain, which was 16.17. Finally, using the measured BWS average gain of 16.17, the relationship for RCS given in equation (5) can be rewritten in terms of the measured voltages:

Note that this equation represents the RCS of the measured (scale model) target. Scaling must be performed along the frequency axis as well as on the magnitude of the RCS function in order to obtain an RCS that corresponds to the full-scale target.

In comparison to the full-size object, a model's dimensions are scaled down by a known scale factor, SF. Typically, the brass models used at the TDMR have a scale factor of 48, but for this study a scale factor of 2.93 was used. The dimensions are related by the following:

\[ L_{\text{full}} = SF \cdot L_{\text{mod}}. \]  

Because frequency is inversely proportional to wavelength, the full-scale frequencies will be lower than the corresponding model frequencies by the scale factor:

\[ f_{\text{full}} = \frac{1}{SF} f_{\text{mod}}. \]  

Finally, since radar cross section dimensions are in units of area (square meters), the magnitude of the RCS function must be scaled by the square of the scale factor

\[ \sigma_{\text{full}} = SF^2 \cdot \sigma_{\text{mod}}. \]  

RCS is often displayed in dBsm by taking 10 log \( \sigma \).

III. TARGET ID MEASUREMENTS

Because the structure of the BWS creates some "background" reflections even when no target is in place, it is necessary to isolate the response due to the target alone. This may be done by subtracting the background waveform from the (target + background) waveform. The isolated target signal and the incident waveform are then input into a program that calculates and scales the RCS to full-size.

The target used for these runs (see figure 4) was a 1:2.93 scale brass model of a full-size target previously tested. The first measurements were made with the target suspended in the center of the BWS with its fins at 0° rotation, then these measurements were repeated with the fins at 45°. For each orientation of the target, three measurements were made:

1. Background waveform
2. Target plus background waveform
3. Incident waveform

Figure 4. Sketch of target at (a) 0° and (b) 45° rotation.

Figures 5(a) through (d) illustrate the measurements made for the 0° case. Figure 5(a) shows the background waveform, 5(b) is the (target + background) waveform, and 5(c) displays the "target only" waveform obtained by subtraction of the previous two waveforms. The incident waveform is displayed in figure 5(d).
IV. MEASUREMENT RESULTS

As was determined through comparison of the RCS patterns for the 0° and 45° cases, the RCS of this target is fairly independent of "flying" orientation, or rotation about its central axis.

The frequency range for which these measurements are valid can be established by determining the point at which the noise overcomes the signal reflected by the target, i.e., where the RCS of the noise spectrum reaches the level of the target RCS. The measure of noise which is chosen for this example is a subtraction of two background measurements taken just moments apart. The difference between these background waveforms represents the "noise" that might remain after a \([\text{target} + \text{background}] - \text{background}\) subtraction is performed.

Figure 7 superimposes the RCS of the noise and of the target. Around 300 MHz (full scale), these levels become equal, indicating the upper frequency limit of the RCS measurement.

As a test of how well the RCS data obtained by the scale model measurements agree with those predicted by numerical analysis using the Numerical Electromagnetic Code (NEC) [6, 7], their graphs have been plotted together in Figure 8. The measured data used in this plot comes from the 45° fin rotation. At low frequencies, the computed curve rises steeply to cross the measured curve at about 12 MHz. Between 13 and 60 MHz, the computed curve follows the shape of the scale model measurements, but exceeds it by approximately 5 dB.

V. DISCUSSION

The data obtained through this work, consisting of one test at a fin orientation of 0° and one at 45°, were selected from several tests which were unusable due to high variations in background noise. One source of difficulties with these measurements is the increase in noise which occurs in the afternoons, preventing a good subtraction of background waveforms. This increase may be due to winds causing vibration in the BWS structure, temperature rise, or to increased transmissions from external sources. Monitoring of the background noise level over several days might help to establish the best time for low-interference testing; otherwise, it is important to obtain a clean background – background subtraction at the time of each test to establish validity.
RCS measurements on the full-size target have been performed on the Time Domain Measurement Range but were affected to some extent by the interaction between the target and the range. The equation for calculating a target's RCS is taken as the distance to the target (R) approaches infinity. This condition is interpreted as a need for the incident field strength to be uniform over the length of the target, which is not entirely met with a large target in the confines of the BWS. It is believed that the scale model in this study was sufficiently small with respect to the BWS to provide acceptable results. Further studies would be necessary to fully characterize the limits of allowable target size for accurate measurements.

Other topics which might merit further study include dependency of RCS on target orientation. Rotation about the central axis had little effect on the RCS of this target, but positioning has influenced the RCS results of past measurements and could factor into this case as well. Finally, a good demonstration of the target identification capabilities of the NRaD BWS system would be to perform RCS measurements on other targets of similar size and shape to attempt to distinguish between them. This has been successfully performed with model ships as targets [4, 8].

VI. REFERENCES


