APPLICATION OF A FINITE-VOLUME TIME-DOMAIN METHOD TO THREE-DIMENSIONAL OBJECTS¹

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Concurrent engineering approaches for the disciplines of computational fluid dynamics (CFD) and electromagnetics (CEM) are necessary for designing future high-performance aircraft. A characteristic-based finite-volume time-domain (FVTD) computational algorithm, used by CFD and now applied to CEM, is implemented to analyze the radar cross section (RCS) of the ogive and cone-sphere [9]. The technique utilizes a scattered-field formulation of the time-dependent Maxwell equations. The FVTD formulation implements a monotone upstream-centered scheme for conservation laws (MUSCL) for the flux evaluation and a Runge-Kutta multi-stage scheme for the time integration [2-4]. The results are obtained from the electromagnetic fields via a Fourier transform and a near-to-far field transformation [7].

Developmental FVTD work focused on augmenting the original code [2-4] to analyze scattering from closed-surface, single-zone, perfect electric conducting (PEC) 3-D objects using either a Gaussian pulse or sinusoid incident wave. A convergence check, used with a sinusoid incident wave, ends the simulation after the transients diminish and the bistatic RCS values are within 0.1 dB of the values calculated during the previous period. An amplitude check, used with a Gaussian pulse incident wave, ends the simulation run once the scattered electric field is 140 dB below the peak of the Gaussian pulse. In addition, specification of the direction and polarization of the incident wave gives monostatic and bistatic data. A bistatic-to-monostatic RCS approximation saves computer run time by a factor of nearly 40 [1].

Evaluation of the characteristic-based FVTD formulation and code for electromagnetic scattering problems was completed by comparing RCS results obtained from the FVTD code to results obtained from the Moment Method (MoM) code, CICERO, and empirical results published by the Electromagnetic Code Consortium (EMCC). The ogive and cone-sphere 3-D objects were used to complete the evaluation. The minimum grid point densities required by the FVTD formulation to accurately compute the diffraction occurring at the tips of the ogive and cone-sphere is discussed as is the traveling and creeping waves generated due to polarization, direction of incidence, and frequency.

The 1λ electrical length of the ogive at 1.18 GHz dictates that electromagnetic phenomena such as traveling waves and diffraction have to be calculated accurately. The surface grid point density required on the surface is 22-32 cells/ λ . Monostatic FVTD results, using the bistatic-to-monostatic approximation, are compared to empirical and MoM results in Figure 1. The plot of the monostatic RCS is for HH (transmit horizontal, receive horizontal) polarization. The tips of the ogive correspond to 0° and 180°. The FVTD results are within 2.5 dB of the MoM values and within 3.1 dB of the empirical RCS data.

The bistatic RCS values were calculated for the ogive at 4.0 GHz using a Gaussian pulse and a sinusoid incident wave. The incident wave was incident on a tip of the ogive. Figure 2 compares bistatic FVTD RCS results at 4.0 GHz for VV (transmit vertical, receive vertical) polarization to MoM RCS results. The curve, FVTD1, is the result using a Gaussian pulse and

¹ This work sponsored by the USAF Wright Laboratory

FVTD2 is the result for the sinusoid incident wave. The grid size was (76-125-75), in spherical coordinates (R, θ, ϕ), resulting in a grid spacing on the surface of 30-34 cells/ λ for 4.0 GHz. The results for the two incident waves are almost identical with the largest errors occurring at the tips in the backscatter and forward scatter regions.

Figure 1: Ogive Monostatic Radar Cross Section, 1.18 GHz, HH

Figure 2: Ogive Bistatic Radar Cross Section, 4.0 GHz, VV, Gaussian Pulse vs. Sinusoid Incident Wave

As the electrical size of the object gets larger, electromagnetic phenomenon such as diffraction contributes less to the RCS. Also, the diffraction becomes more of a local phenomenon and the grid point densities do not have to be as large to accurately compute

the propagation of the wave. Figure 3 illustrates the accurate computation of the RCS for the ogive with an incident wave at 0° for 9.0 GHz. The grid spacing on the surface is 15-18 cells/ λ , illustrating the lower grid point density requirement for electrically larger objects.

Figure 3: Ogive Bistatic Radar Cross Section, 9.0 GHz, HH

Figure 4: Cone-Sphere Bistatic Radar Cross Section, 3.0 GHz, VV, Tip-On Incidence

The cone-sphere results were similar to the ogive results. Figure 4 shows the bistatic RCS of the cone-sphere for a frequency of 3.0 GHz. For the object, 6.9λ at this frequency, the grid point

density requirement is at least 15 cells/ λ . The sinusoid incident wave is incident on the tip of the cone-sphere at $\theta=180^\circ$. The largest error of 2.1 dB occurs in the backward scatter area ($\theta=180^\circ$) at the tip of the cone-sphere.

The FVTD results for the ogive and cone-sphere were within 2.5 dB and 3.1 dB when compared to MoM results and empirical RCS data, respectively. The tests showed that a grid point density (GPD) on the surface of approximately 15-32 cells/ λ was required, depending on the frequency.

Acknowledgments

In support of this work, the authors wish to thank Dr. William Baker, Major Tom Buter, and Major Gerald Gerace of the Air Force Institute of Technology. The authors also wish to thank the assistance of Dr. J.S. Shang and Dr. Kueichien Hill from Wright Laboratory. In addition, this research was supported in part by a grant of HPC time from the DoD HPC Centers, CEWES (Cray 90) and Maui (SP-2).

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