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Engineering Notes

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Finite Volume Time-Domain Computations for Electromagnetic Scattering from Intake Configurations

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Introduction

LOW observability is an important criterion in the design of modern combat aircraft. An important parameter to be considered from the aspect of observability is the radar cross section (RCS) of the aircraft. RCS is a measure of the reflective strength of a target subject to electromagnetic illumination, and, therefore, an aircraft with low RCS is less visible to a radar due to the low backscatter it generates. There are certain parts of an aircraft that contribute more to its overall RCS, the principal one being the air intake cavity terminated by the front face of the engine.[1] The electromagnetic radiation incident at the intake cavity is returned on reflecting from walls of the cavity and the engine front face, and an untreated, straight intake cavity is often the biggest contributor to the overall RCS of the aircraft. Contemporary low-observable aircraft reveal distinct design features such as the engine intake and the exhaust cavities being placed atop the wings for concealment and zigzag or serrated lips to scatter the radar reflections. The intake ducts are also S shaped and lined with radar absorbing material (RAM) to attenuate the incident electromagnetic radiation.

To arrive at a low-backscatter profile experimentally by shaping, or to study the effect of RAM application on the reflecting surfaces, can be time consuming and expensive. Numerical simulation of electromagnetic scattering from engine intakes involve dealing with the geometrical complexities brought about by the termination formed by the engine components.

In recent times, there has been an increasing trend toward numerical simulation of electromagnetic scattering by solving Maxwell's equations in the time domain in the finite volume time-domain (FVTD) framework (see Refs. 2 and 3). The main advantage of FVTD techniques lies in their ability to handle (in principle) complex geometries with different material properties for the whole range of frequencies within a unified framework. This makes FVTD techniques an attractive choice for the numerical simulation of electromagnetic scattering from complex jet engine intake configurations. Numerical simulation of electromagnetic scattering from complex three-dimensional external geometries with FVTD techniques have been widely reported in the open literature,[2,4] but the same is not true for relatively complex three-dimensional internal geometries such as engine intakes. In this Note, electromagnetic scattering from three-dimensional inlet cavities with progressively complex terminations are solved in the FVTD framework. These geometries can be considered canonical test cases toward demonstrating the capability of the FVTD technique in predicting electromagnetic scattering from relatively complex engine intake configurations with perfectly conducting surfaces.

Numerical Technique

The Maxwell's equations in freespace are solved using a higher-order characteristic-based FVTD technique (see Refs. 2–5). As in Refs. 4 and 5, higher-order spatial accuracy is obtained by employing the essentially nonoscillatory technique for numerical flux function evaluation. A scattered field formulation is used with the incident field representing a solution of the Maxwell's equations in freespace. The three-dimensional domain is discretized into hexahedral cells with the state vector defined at cell centers. For the perfectly conducting surface considered, the total tangential electric field is zero on the conducting surface. Standard characteristic boundary conditions are implemented at the outer boundary with the scattered field variables being taken as zero in the far field. Advancement in time is through a Runge–Kutta time integration, and a second-order spatial and temporal accuracy is chosen in this Note. Calculations are performed until the solution reaches a sinusoidal steady state, and the complex field in the frequency domain is computed from the time history of the solution by using a Fourier transform. The volume discretization is in a structured multiblock framework with clustering near the (perfectly conducting) walls and an average resolution of 20 grid points per wavelength on the surface of the scatterer.

Numerical Results

The first case solved for is a straight cylindrical cavity terminated at one end by a flat plate. The length of the cylinder is 2λ and the

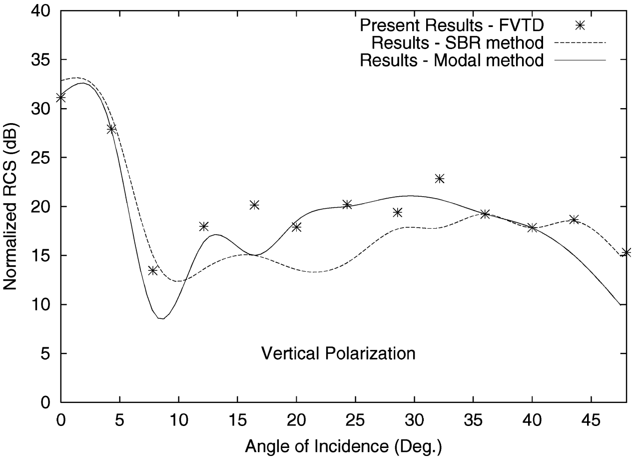

Fig. 1 RCS for a straight cylindrical cavity with a flat-plate termination.

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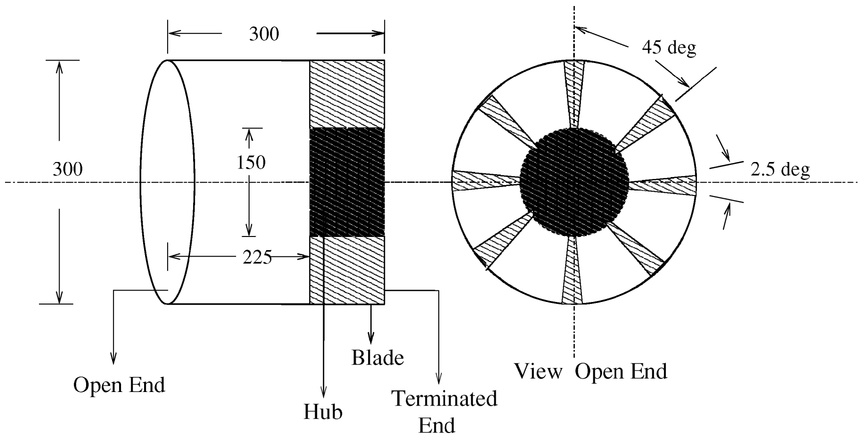

Fig. 2 Schematic representation, not to scale, of cylindrical cavity terminated by an array of straight blades, dimensions in millimeters.

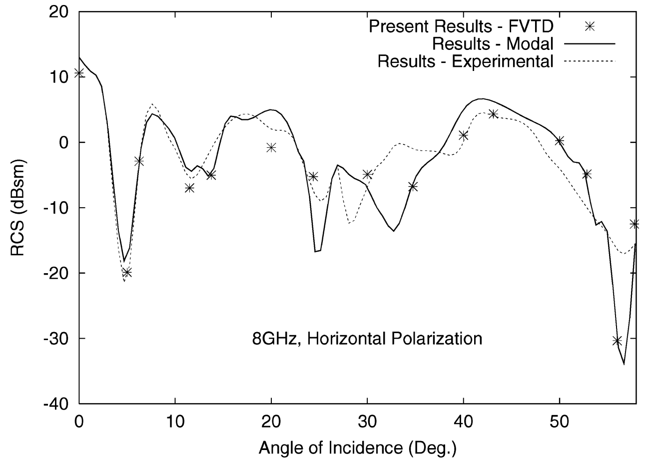

Fig. 3 RCS for a straight cylindrical cavity with blade termination, horizontal polarization.

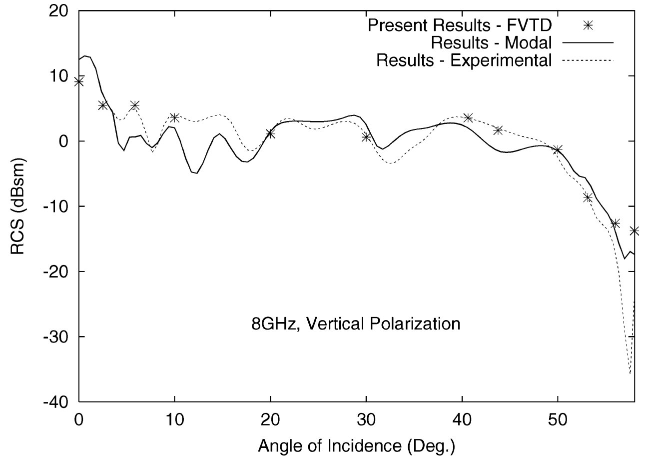

Fig. 4 RCS for a straight cylindrical cavity with blade termination, vertical polarization.

diameter is 4λ, where λ is the wavelength of the continuous harmonic incident electromagnetic wave. All surfaces are assumed to be perfect electric conductors (PEC). Figure 1 shows a comparison of results using the present technique and that with modal analysis, as well as with the ray bouncing method in Ref. 6. The results show the monostatic RCS (normalized with wavelength) for vertical polarization as the angle of incidence of electromagnetic illumination is varied in the plane of symmetry of the cylinder. In Fig. 1, 0 deg indicates incident illumination along the axis of the cylinder.

The second case again considers a straight PEC cylindrical cavity, but with a more complex termination compared to the preceding case. The termination is a flat plate mounted with a cylindrical hub and an array of straight blades.[7] The blades run from the tip of the hub to the flat-plate termination and model the front face of a jet engine. The schematic of this configuration along with its dimensions are shown in Fig. 2.

Figures 3 and 4 show results for horizontal and vertical polarizations, respectively, at a frequency of 8 GHz with 0 deg in Figs. 3 and 4 indicating incident illumination along the axis of the cylindrical cavity. Results from the present FVTD computations are compared with that from experiments and the formally exact mode matching (MM) technique in Ref. 7, and good agreement in results can be seen.

Summary

The FVTD technique based on a higher-order characteristic-based method for flux evaluation is used to compute the RCS of three-dimensional cylindrical cavities terminated at one end with terminations of increasing geometrical complexity. These internal geometries can be considered representative test cases for demonstrating the capability of the FVTD technique in predicting electromagnetic scattering from jet engine intakes, which is often the biggest contributor to the overall RCS of combat aircraft. Results obtained agree well with experimental results and those from other numerical techniques, including those that can be considered formally exact. The strength of the FVTD technique is in dealing with complex geometries, which makes it an attractive choice for modeling electromagnetic scattering from engine intake configurations.

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