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EMP-Induced Skin Currents on Aircraft

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ABSTRACT

The first step in assessing the coupling of EMP into an a aircraft system is to determine the electric current flowing on the outer skin of the aircraft when illuminated by EMP. With present state-of-the-art, however, it is not possible to calculate these currents in detail due to the extreme complexity of the aircraft surface geometry. Consequently, approximations are made of the surface geometry depending on the type of analysis to be used. To date, several techniques have been employed to estimate these EMP induced currents. For smooth structures above the resonance region, physical optics approximations may yield satisfactory results, and the geometrical theory of diffraction (GTD) can be used for the higher frequencies. Integral equation solutions are generally limited to objects that are less than a few wavelengths in size, but for typical aircraft, this spectrum includes most of the energy of EMP. This paper describes the numerical solution of a thin-wire time-dependent integral equation and subsequent predictions of the bulk axial skin currents on several aircraft excited by an EMP wave.

ACKNOWLEDGEMENT

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BACKGROUND

Transient responses of electromagnetic bodies may be obtained through transformation of frequency domain characteristics or through solution of time dependent equations directly in the time domain. Until recently, however, few time domain calculations have been performed for determining the electromagnetic characteristics of thin wire structures. In 1968, Bennett and Weeks(1) presented time-domain solutions for several electromagnetic objects employing a time dependent integral equation based on the magnetic field. About the same time, Sayre and Harrington(2) applied the thin wire approximation to a coupled set of equations based on the magnetic vector and electric scalar potentials and obtained results for the linear dipole and circular ring. Recently, Miller, et al.(3) and Poggio et al.(4) applied the thin wire approximation to a time-dependent version of the frequency domain Pocklington electric field integral equation. While some aspects of their analysis is similar to the previously listed efforts, they included in addition a 9-point Lagrangian interpolation scheme which permitted efficient treatment of more complicated wire structures as demonstrated by the analysis of the zig-zag antenna in (4).

The calculations presented here were obtained using a numerical solution based on the technique described in (3) and (4) with extensions to include analysis of structures containing several wires meeting at a common point. The numerical solution begins by approximating the structure geometry by a set of cylinders (wires), and subsequently calculating the currents on this set of cylinders. The moment method solutions of the integral equations are not "exact", but the errors arising from modeling the aircraft geometry far exceed the errors resulting from the moment method solution.

SOLUTION PROCEDURE

The theory and the numerical approach were presented in (3,4, and 5). A user's manual, program listing, and sample output is given in (6). This program is based on a moment method solution of the time dependent electric field integral equation

$$\hat{s}\cdot\bar{E}_{inc}(\bar{r},t) = \frac{\mu_0}{4\pi}\int_{C(\bar{r})} \frac{\hat{s}\cdot\hat{s}'}{R}\frac{\partial}{\partial t'} I(s',t')$$

$$+ C\,\frac{\hat{s}\cdot\bar{R}}{R^2}\frac{\partial}{\partial s'}\; I(s',t') \tag{1}$$

$$- C^2\,\frac{\hat{s}\cdot\bar{R}}{R^3}\,q(s',t')\,ds'$$

where $\bar{E}_{inc}(\bar{r},t)$ is the total electric field at observation point $\bar{r}$ at time t, $\hat{s}$ and $\hat{s}'$ are unit vectors parallel to $C(\bar{r})$ at $\bar{r}$ and $\bar{r}'$, C is the velocity of light, μ_0 the permeability of free space, I(s',t') and q(s',t') are the current and charge at the source point s', retarded time $t' = (t - \frac{R}{C})$ where $R = |\bar{r}-\bar{r}'|$, and $C(\bar{r})$ is the structure contour. Numerical solution of this euqation by the method of moments (using in this case, point matching and a 9-point Lagrangian interpolation scheme for the currents in space and time) reduces Equation 1 to the linear form

$$\underline{E}_{sca} + \underline{E}_{inc} = \underline{\underline{Z}}\,\underline{I} \tag{2}$$

where E_{inc} is the value of $\hat{s}_0\cdot\bar{E}_{inc}\ (r_0,t_0)$ at time t_0 for r_0 a wire radius away from $C(\bar{r})$ at the observation point s_0, and where E_{sca} is the electric field tangent to the wire segment at $\bar{r} = \bar{r}_0$ and $t = t_0$ due to earlier charges and currents.

Problem solution proceeds by first approximating the actual structure by a set of cylindrical segments, calculating $\underline{\underline{Y}} = \underline{\underline{Z}}^{-1}$ once (since $\underline{\underline{Z}}$ is independent of time), and calculating $\underline{I}$ by solving equation (2) sequentially at each time step for the desired form of $\overline{E}_{inc}(\overline{r},t)$.

NUMERICAL RESULTS

A typical result is shown in Figures 1 and 2. For this example, a set of 0.8m diameter cylinders were arranged to approximate the geometry of a 747 aircraft. The EMP wave used here (and also for the remainder of the examples) is shown in Figure 3. The EMP wave arrives from the front and left of the aircraft, the angle away from nose-on incidence was chosen so that the entire left wing was illuminated simultaneously, and the electric field of the EMP wave was chosen parallel to the left wing. Figure 1 shows the bulk axial current on the fuselage immediately behind the wings, and Figure 2 plots the magnitude of the current at various positions along the aircraft at select times. These currents are plotted perpendicular to the aircraft, and are shown in an isometric view taken from behind and above the aircraft. While Figures 1 and 2 are informative, the full potential of the data is not realized by this method of presentation. It has been found that a more effective means of data presentation is through the use of a movie composed of frames of the type given in Figure 2. Such a movie was made and will be viewed for eight additional examples.(7)

OBSERVATIONS

The currents on the various aircraft models studied here behave in similar and predictable manner. Although the peak currents occur near the center of the structures, the maximum currents seen near the ends of the structures are nearly as large as those in the center, but do not persist for as long a time. The value of the peak current was found to be roughly proportional to the overall length of the scattering structure, and worst case illumination was found to be broadside incidence in all cases considered here. For a given aircraft, the late time response was found to consist primarily of a dampened sinusoid at the frequency of the lowest resonance of the structure.

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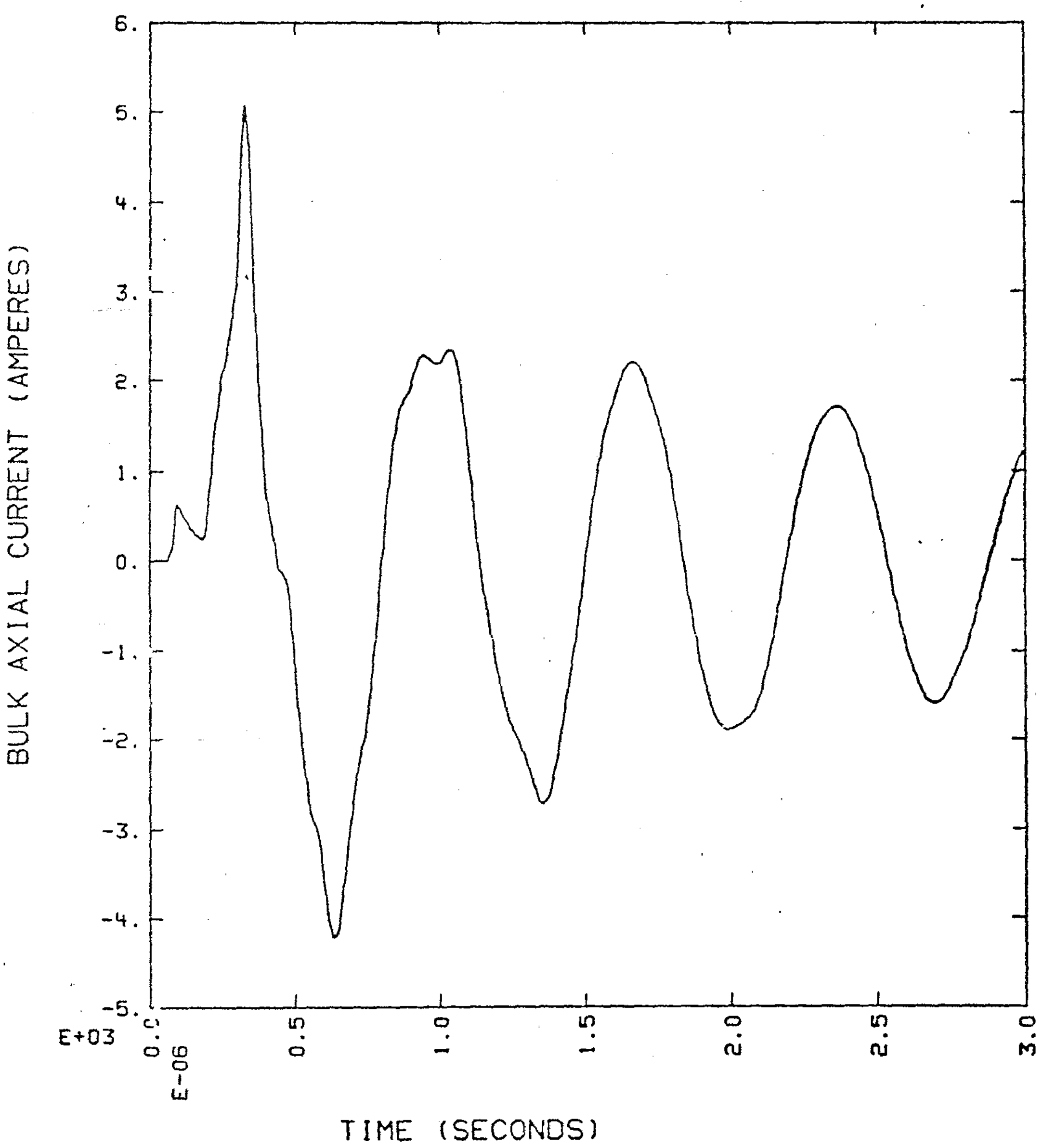

Figure 1. Current on Fuselage behind Wings of a 747 Aircraft.

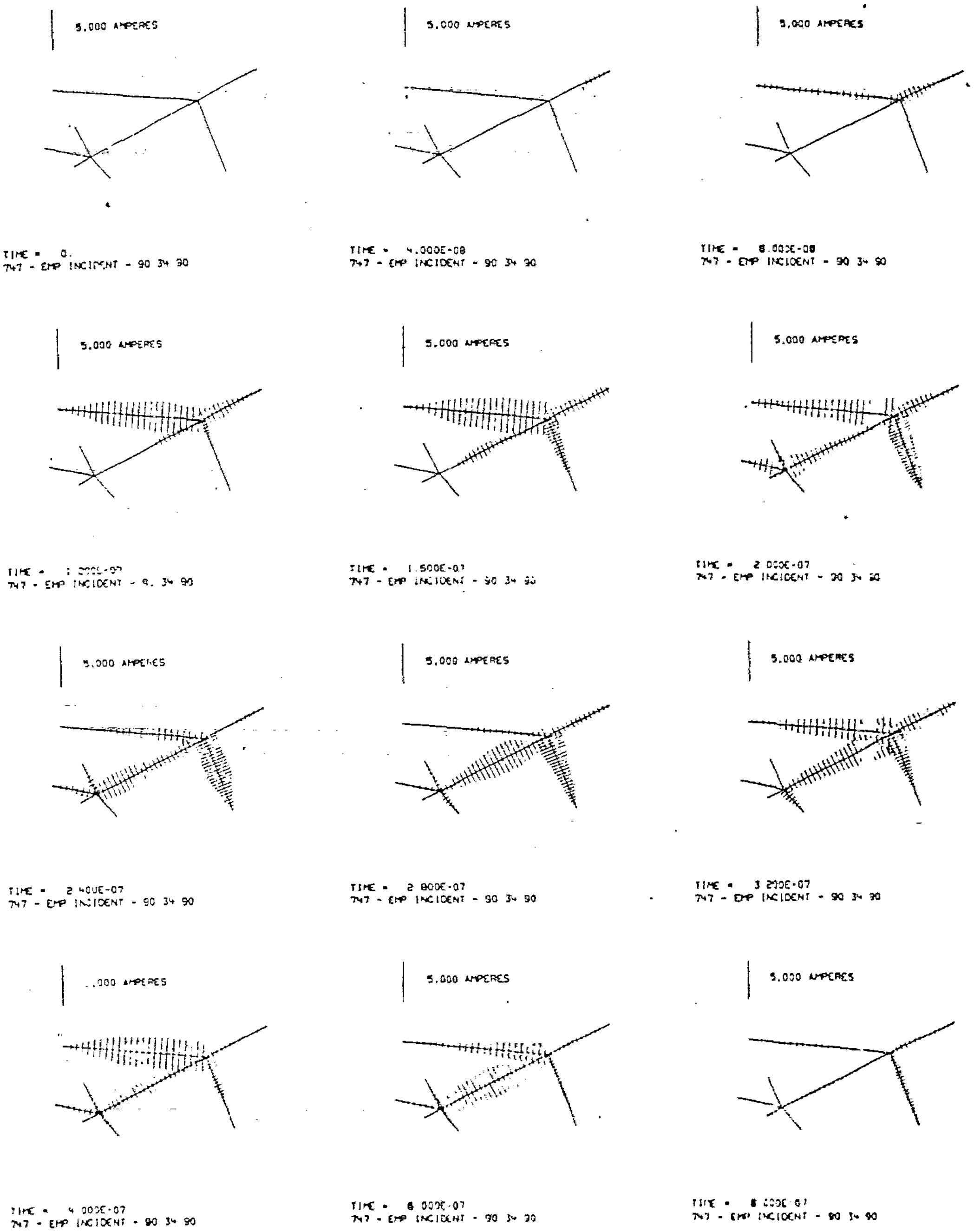

Figure 2. Temporal Development of Current on a 747 Aircraft.

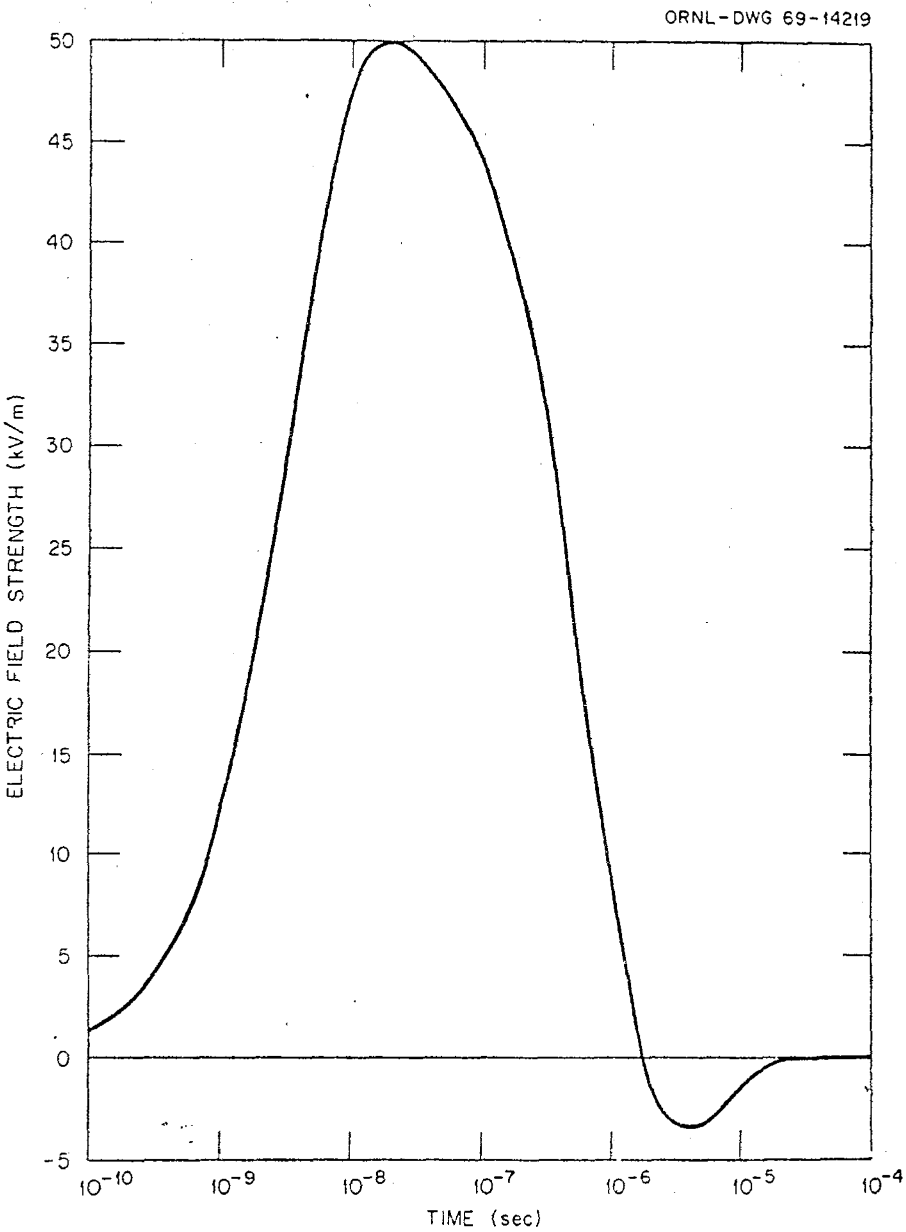

Figure 3. Typical Four-term Exponential EMP Wave.