CLOSED FORM SURFACE RAY ANALYSIS FOR ANTENNAS LOCATED ON A CLASS OF AIRCRAFT WINGS

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ABSTRACT

An aircraft wing has been modeled as a hybrid of a right circular cylinder and a general parabolic cylinder. This hybrid structure model is successfully employed along with the Geodesic Constant Method (GCM) developed by the authors for the ray-theoretic EM analysis. Surface ray parameters have been derived in closed form and mutual coupling results have been obtained for wings designed for different flight regimes.

Introduction

Aircraft wings have a large and almost flat surface area, and are often used by aircraft designers for locating antennas over them. With the growing trend towards utilization of higher frequencies of the EM spectrum for aerospace communication, wings have come to be treated as electrically large scatterers and their curvatures and thicknesses can no longer be ignored in mutual coupling calculations between antennas located over them.

In this paper, a new method has been developed to derive the surface ray geometric parameters required in the high-frequency computations of antenna characteristics for radiators located on an aircraft wing which is modeled by finite sections of general parabolic cylinder (GPCYL) and the right circular cylinder. This hybrid quadric cylinder (h-QUACYL) is treated by the Geodesic Constant Method (GCM) which expresses all the surface ray geometric parameters in terms of the First Geodesic Constant, which itself can be determined in closed form. Actual results have been presented for wings designed for different flight regimes.

Formulation for Hybrid QUACYL Wings

As an example of a h-QUACYL, an aircraft wing, modeled by the sections of general parabolic and circular cylinders (Fig. 1), can be described by the two sets of hybrid parametric equations [1]. The GPCYL section is described as

$$\begin{aligned} x &= au & y &= u^2 & z &= z \end{aligned} \quad (1)$$

with the truncation limit for the GPCYL given by $|u| \leq u_t$. On the other hand, the circular cylindrical section is expressed as

$$\begin{aligned} x &= \rho \cos \phi & y &= L + \rho \sin \phi & z &= z \end{aligned} \quad (2)$$

with the required matching conditions $\rho = a u_t$ and $0 \leq \phi \leq \pi$ which implies

that a semi-circular cylinder is employed as the matching section.

Equations (1) and (2) describe a hybrid cylindrical aircraft wing where the two different cylinders intersect along the z-axis. Although two different sets of coordinate systems have been used for parametrizing the aircraft wing, the use of common rectangular coordinate bases (x,y,z) to describe the hybrid quadric surface leads to uniformity in the surface ray analysis. The junction transition point (Fig. 1) is determined as

$$z_t = z_f - \frac{\phi_f \rho(z_f - z_s)}{\rho \phi_f + SS_1} \quad (3)$$

$$\text{where } SS_1 = \frac{u_t(a^2 + 4u_t^2)^{1/2} - u_s(a^2 + 4u_s^2)^{1/2}}{2} + \frac{a^2}{4} \ln \left| \frac{2u_t + (a^2 + 4u_t^2)^{1/2}}{2u_s + (a^2 + 4u_s^2)^{1/2}} \right|$$

Since u_t (and hence ϕ_t) is known a priori, eq (3) leads to the complete determination of the transition point in both the coordinate systems. The ray analysis over the complete ray path from the source point S to observation point P is treated by separately analyzing the arc segments ST on the GPCYL and TP on the circular cylinder. The ray geometric parameters required for the high frequency antenna characteristics calculations [2,3] can now be easily calculated on the individual QUACYLS while the integral parameters like the arc length are derived as sum of the individual components over the two surfaces.

Another consequence of treating the ray geometric parameters on two different surfaces is that the moving Frenet-frame field vectors, i.e., the tangent, normal and binormal vectors, obtained at the source (on the GPCYL) and observation (on the circular cylinders) points via two different coordinate systems, appear as dyadic pairs in the electric field expression required in the mutual coupling calculations.

Numerical Results and Discussion

In aerospace engineering, aircraft wings are usually designed for three different flight regimes. The thickness of a wing is quantitatively expressed in terms of the thickness-to-chord ratio (T-C ratio) which is an important parameter in defining the wing shape. The typical values of the T-C ratio in the supersonic, high subsonic and low subsonic regimes are 3, 8, and 12% respectively.

High frequency mutual coupling results have been presented in Fig. 2 and 3 for the variation of the location of the observation slots along the u-parameter line since in this principal direction the curvature of the wing surface is non-zero. Our study shows that under identical set of conditions the mutual coupling is not sensitive to the variation in the thickness-to-chord ratio of the wing due to the relatively weak curvature effects of the GPCYL portion of the wing. This, in turn, minimizes constraints on the structural and aerodynamic engineers in choosing suitable wing shapes.

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Fig. 1 Mutual coupling between slots on a hybrid cylindrical aircraft wing.

Fig. 2 Mutual admittance vs. u -axis separation between two rect. slots on a high subsonic wing ($T-C$ ratio = 8%) of junction dia = 2λ
 $u_s = \sqrt{u_t^2 - 1} \cdot u_f$ on cir. cyl. $\Delta z = 0$ (const.).
 Magnitude (—), Phase (---).

Fig. 3 Mutual admittance vs. u -axis separation between two rect. slots on a high subsonic wing ($T-C$ ratio = 8%) of junction dia = 2λ
 $u_s = \sqrt{u_t^2 - 1} \cdot u_f$ on cir. cyl. $\Delta z = 0.5\lambda$ (const.).
 Magnitude (—), Phase (---).