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ELECTROMAGNETIC SCATTERING

This interim scientific report summarizes the work carried out under the Air Force Office of Scientific Research Grant No. 77-3188(B) during the year ended 31 December 1978.

A continuing topic of research has been a study of Rayleigh scattering by homogeneous dielectric particles to obtain a better understanding of the roles played by the material and the geometry of a particle. As shown by Senior (1976), the far zone scattered fields are specified by a general polarizability tensor $\overline{\overline{X}}(\tau)$ which is a function only of the geometry of the scatterer and a material parameter τ representing either the relative permittivity or permeability. $\overline{\overline{X}}(\tau)$ is independent of the direction and polarization of the incident field and is a second rank symmetric tensor which is real if τ is real, but not otherwise. Symmetry of the particle about any two mutually orthogonal planes is sufficient to diagonalize the tensor, leaving us with at most three non-zero elements. The elements can be expressed as weighted surface integrals of certain potential functions or their normal derivatives for which integral equations have been derived. It has been shown that the solutions of these equations exist and are unique for all complex τ and for real $\tau > 0$, and that they satisfy the required zero induced charge condition at the surface. For real τ, $X_{jj}^{2} \le X_{jj}X_{jj}$, and a variety of upper and lower bounds on the diagonal elements have been established which, in a practical situation, could serve to specify the elements to an adequate degree of accuracy. However, we have not yet succeeded in bounding the trace of the tensor, nor in bounding the elements for one particle using the elements for a particle of different size and/or shape, e.g. a circumscribing or inscribed sphere for which analytical expressions for the tensor elements are available.

An important application of this work is to the scattering of infrared and, perhaps, optical radiation by atmospheric particles and aerosols. Aerosols having specific and well-defined shapes are frequently encountered, and the integral equations for the potentials have been specialized to the case of arbitrary bodies of revolution, rectangular parallelepipeds and hexagonal cylinders. Computer programs have been written to solve the equations by the moment method and, hence, to calculate the tensor elements in each of the three cases. Results for parallelepipeds of square cross section, various length-to-width ratios, and real τ have been reported by Herrick and Senior (1977 a,b), and compared with the data for right circular cylinders. Corresponding results for hexagonal cylinders (which are of particular interest in the context of atmospheric scattering) have now been obtained and, not surprisingly, they do not differ substantially from those for the corresponding cylinders of circular and square cross sections. In addition, the computer programs have been generalized to handle complex values of τ, and data computed for hexagonal ice crystals using the actual permittivity of ice in the ir range of frequencies. The results show how the geometry affects the material absorption, and the implications of this work on the theory of dielectrics have been examined. The above study was described in an invited talk (Senior, 1978b) at the XIXth General Assembly of URSI and will be reported in detail in the forthcoming Ph.D. thesis of Mr. Donald F. Herrick.

The other main area of research has been the study of scattering by impedance surfaces and sheets, and resistive sheets. The impedance boundary condition is a useful and effective method to account for the material properties of a (lossy) body, and converts what would otherwise be a two region problem into a boundary value problem for the exterior fields. In contrast to the boundary condition for a perfectly conducting surface (to which it reduces when the impedance η is zero), the surface impedance condition is intrinsically a vector one connecting two orthogonal components of the field, and except in special cases such as two-dimensional problems where the condition scalarises, the vector character can significantly complicate the determination of an analytical solution to a scattering problem. A case in point is a plane wave at skew incidence on a right angled impedance wedge. This is a problem that I have referred to earlier, but for the first time it is possible to report some progress. As recently shown (Senior, 1978a) by expanding the fields in Taylor series in the impedance η, the discrete (angular) spectrum is complete only if the compatability condition of Dybdal, et al. (1971) is satisfied by the (anisotropic) impedances of the two walls, and if it is not, an edge wave is excited whose amplitude is proportional to η^2 and whose form is similar to the wave emanating from the edge of a 'black' half plane. The complete solution has been obtained through terms $0(\eta^2)$, and consists of plane waves plus a (continuous) angular spectrum of waves. I have since extended it to include terms $0(\eta^3)$ in the hope of developing relations between the coefficients of consecutive powers of η and, hence, summing the expansion to produce a closed form expression, but the nature of the coefficients provides little hope of success.

An impedance sheet is simply a membrane of infinitesimal thickness at both sides of which an impedance boundary condition is imposed. It provides a reasonable mathematical simulation of an absorber-coated plate at frequencies for which the thickness is much less than the wavelength, and it is therefore of interest to explore its scattering properties in connection with, for example, the design of low cross section wings, fins, etc. for aircraft. Because of its infinitesimal thickness, the sheet supports electric and magnetic currents and can be regarded as a combination resistive and 'conductive' sheet whose electrical resistivity and magnetic 'conductivity' are related (Senior, 1978c).

A resistive sheet supports only electric currents, and sheets are commercially available having a wide variety of resistivities per square which are constant over a broad range of frequencies. It is this feature that makes the sheet attractive for cross section reduction purposes, particularly when the incidence is at or close to grazing (edge-on) with the electric vector parallel to the edge (the case when the corresponding metal sheet provides substantial backscattering).

Using an available computer program for the solution of an integral equation by the moment method, the surface and far fields have been determined for resistive strips having a variety of strip widths w and uniform resistivities R for an E-polarized plane wave at edge-on incidence. From the resulting data, the front and rear edge contributions have been extracted. It is shown that the former is the same as for a half plane having the same resistivity, whereas the latter is proportional to the square of the current at that point on a half plane corresponding to the rear of the strip (Senior 1978d). For strips of width less than about $\lambda/2$, the backscattering cross section is much less than if the resistivity had been tapered to zero at the rear edge, and for resistivities that are easily attained, the cross section can be 20 (or more) dB below that for the corresponding metal strip. For wider strips, only a small improvement over this could be achieved by tapering. The results have been written up for journal publication (Senior, 1978e).

Grant-Supported Publications

Senior, T.B.A. (1978a), "Skew incidence on a right-angled impedance wedge," Radio Sci. 13(4), 639-647.

Senior, T.B.A. (1978b), "Rayleigh scattering," invited talk at XIXth General Assemble of URSI, Helsinki, Finland, 31 July - 8 August; Abstract published in the Digest.

Senior, T.B.A. (1978d), "Backscattering from resistive strips," talk scheduled for National Radio Science Meeting, Boulder, Colo., 6-9 November; abstract to be published in Digest.

Senior, T.B.A. (1978e), "Backscattering from resistive strips," submitted to IEEE Trans. Antennas and Propagation.

References

Dybdal, R.B., L. Peters, Jr., and W.H. Peake (1971), "Rectangular waveguides with impedance walls," IEEE Trans. MIT-19(1), 2-9.

Herrick, D.F., and T.B.A. Senior (1977a), "Low frequency scattering by rectangular dielectric particles," Appl. Phys. 13, 175-183.

Herrick, D.F., and T.B.A. Senior (1977b), "The dipole moments of a dielectric cube," IEEE Trans., AP-25(4), 590-592.

Senior, T.B.A. (1976), "Low frequency scattering by a dielectric body," Radio Sci. 11(5), 477-482.

Senior, T.B.A. (1978c), "Some problems involving imperfect half planes," in Electromagnetic Scattering (Ed. P.L.E. Uslenghi), Academic Press, Inc., New York, N.Y.

Personnel

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