TECHNIQUES FOR DETERMINING THE MICROWAVE PROPERTIES OF THERMALLY DEGRADED SPACECRAFT HEAT SHIELD MATERIALS

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ABSTRACT

Techniques for determining the microwave properties of spacecraft thermal protection materials, such as subliming ablators, charring ablators, etc., under various thermal conditions are presented. Room temperature dielectric constants and loss tangents of the materials are obtained at several frequencies using standard cavity methods. High temperature dielectric properties can be inferred from real time transmission loss measurements in an arc tunnel. The dielectric properties of cold thermally degraded materials are inferred from transmission measurements in an arc tunnel and on an antenna pattern range.

An independent determination of the dielectric properties of thermally degraded materials was obtained by comparing aperture admittance measurements of a ground-plane mounted rectangular waveguide, under the ablation material, with aperture admittance calculations assuming various inhomogeneous dielectric properties. Also included, for comparison, are calculations assuming the conducting char layer is replaced by a perfectly conducting metal sheet.

SUMMARY

Highly instrumented, unmanned spacecraft will play a primary roll in the scientific exploration of neighboring planets. During atmospheric entry, the antennas required for radar and telemetry systems, as well as the primary structure of the spacecraft, must be protected from aerodynamic heating by a suitable heat shield material. Consequently, during some phase of entry, telemetry and radar equipment may be required to transmit and receive microwave signals through thermally degraded heat shield materials. Techniques for determining the microwave properties of such materials are the subject of this paper.

Since heat shield materials are developed primarily for their thermal properties, little or no room temperature dielectric properties are known. As a method of selecting suitable materials for transmission purposes, dielectric constant and loss tangent measurements using standard cavity

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techniques for 9 to 13 GHz and a coaxial non-slotted line technique for 2 to 6 GHz were employed. In summary, the most suitable materials have densities from approximately 178 to 683 kg/m^3, dielectric constants from 1.23 to 2.31 and loss tangents of 0.001 to 0.0896.

It was desired to measure the transmission loss in the 2 to 13 GHz range while the materials were being exposed to simulated entry heating conditions, which for typical vehicle antenna locations, are 0.22 to 0.89 MW/m^2. To satisfy these heating rate requirements, it was necessary to use a small test model. This model was not of sufficient size to permit accurate measurements in the desired frequency range. Therefore, scaling techniques were used and at the scale frequency of 35 GHz the test specimen is 5.79 λ_o by 9.44 λ_o ; which was large enough so that errors produced by sample size edge effects [1] were small.

Two real-time transmission loss recordings obtained during the arc-tunnel tests of a typical rigid charring ablator are given in figure 1. The calibration level is shown at the top right of the test record. The transmission loss values L_H and L_C represent the transmission losses for the hot and cool conditions of the specimen, respectively. All thermally degraded test specimens were sectioned to obtain approximations of virgin material and char layer thicknesses. Transmission loss recordings for other materials are presented in reference [2].

Computations of the plane-wave transmission loss for a lossy sheet are given in figure 2. The experimental data L_H and L_C measured at 35 GHz in the arc-tunnel are plotted for comparison. Measurements of the transmission losses using the cold specimens were made on an antenna range at 11 GHz and 35 GHz. The data obtained at 35 GHz were in good agreement with L_C and are not given in figure 2. The 11 GHz data given in figure 2 were obtained using a rectangular waveguide as the test antenna and were subject to errors produced by the small test specimens.

An independent determination of the dielectric properties of the cold thermally degraded materials was made at 11 GHz using a model of an inhomogeneous material, such as that shown in figure 6, and a theory [3], [4] for predicting the input admittance of a ground plane mounted rectangular waveguide covered with inhomogeneous materials. Previous studies [5] have shown that the above theory is still accurate even when the test specimens are smaller than those used in this program. The results of the experimental measurements and computations are given in figure 6.

Computations of the reflection coefficient assuming the char layer is replaced by a perfectly conducting metal sheet [6] are also included in figure 6.

The dielectric properties of the hot thermally degraded materials can be inferred using the same methods as demonstrated for the cold specimen since the material thickness remains essentially constant after the thermal test is completed.

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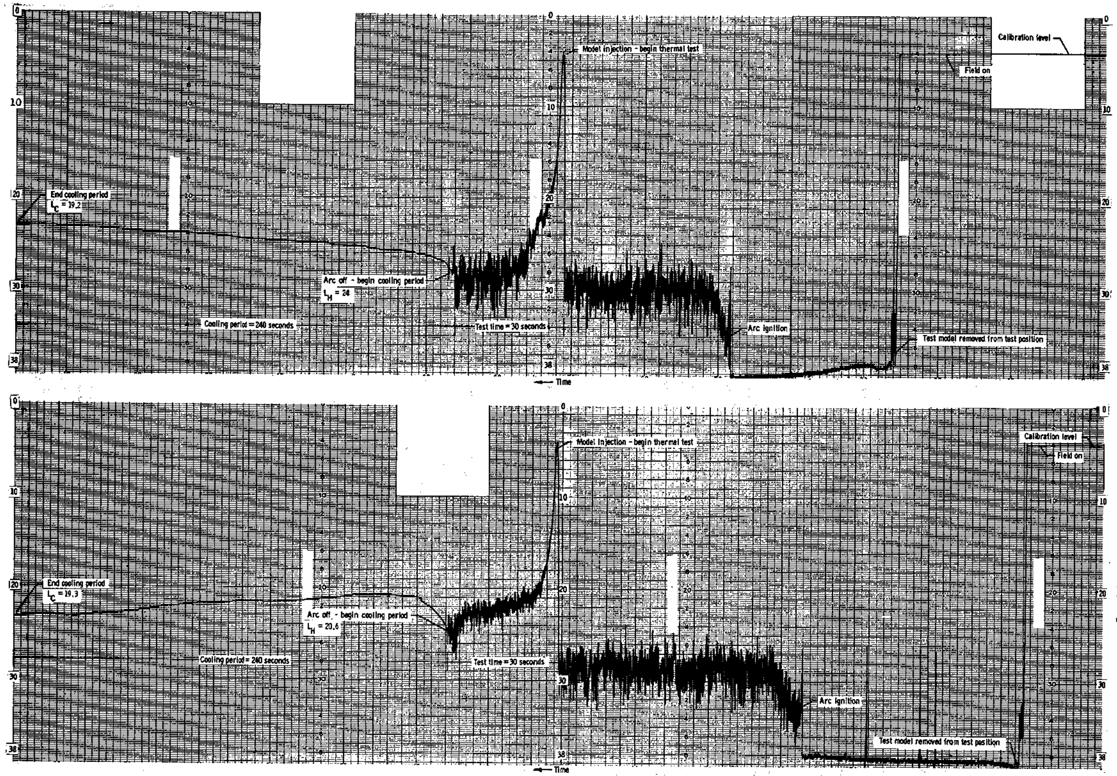

Figure 1. Transmission loss recordings obtained during arc tunnel thermal test of a typical rigid charring ablator.

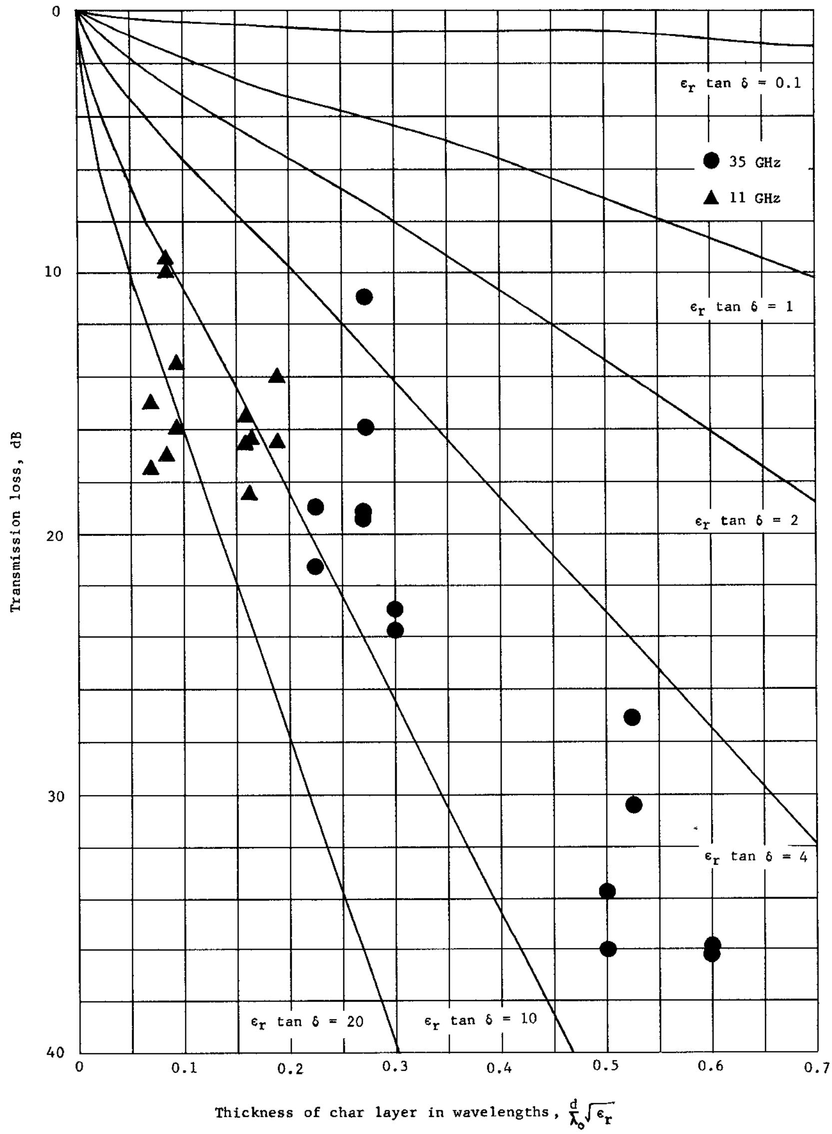

Figure 2. Calculated and measured transmission loss for a homogeneous lossy layer.

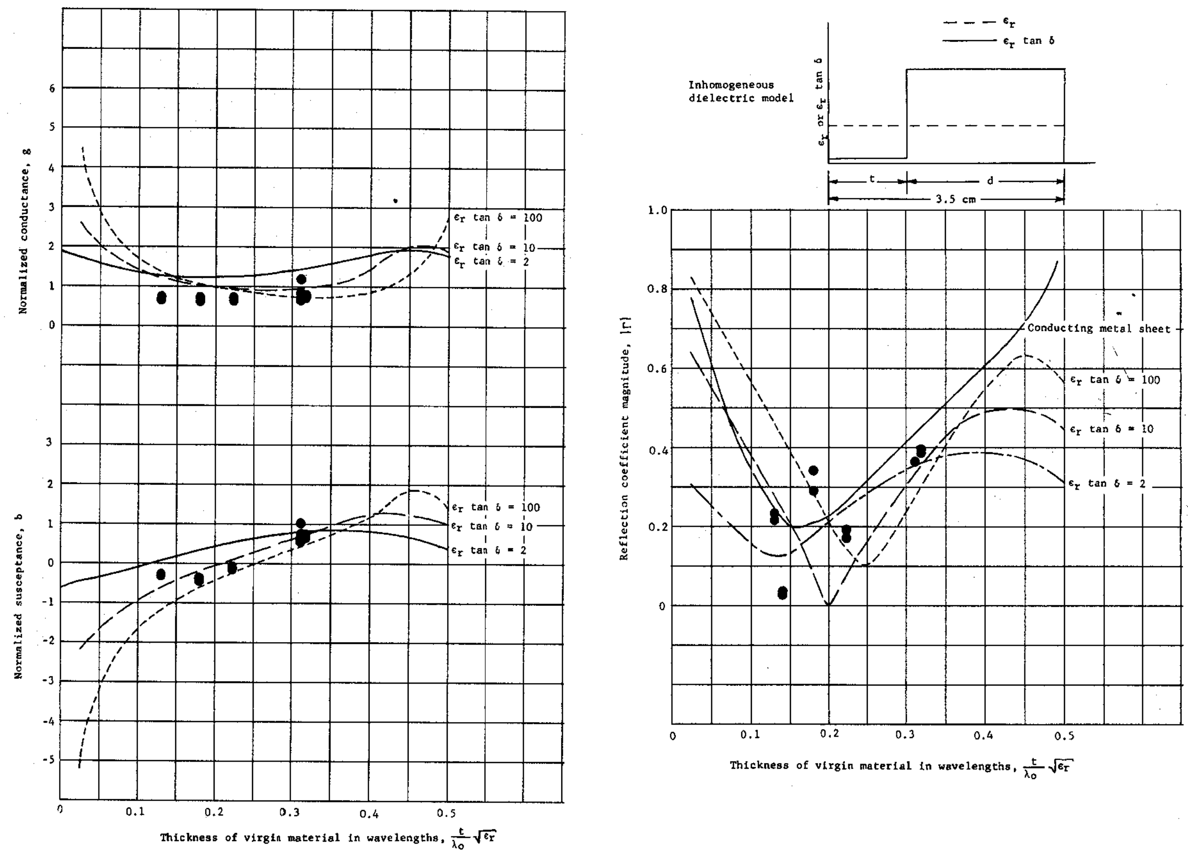

Figure 3. Calculated and measured input admittance of a rectangular waveguide radiating into an inhomogeneous lossy dielectric at 11 GHz.