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SOUND PROPAGATION OVER UNEVEN GROUND AND IRREGULAR TOPOGRAPHY

Semiannual Report, February 1987 - July 1987

by

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INTRODUCTION

The goal of this research is to develop theoretical, computational, and experimental techniques for predicting the effects of irregular topography on long range sound propagation in the atmosphere. Irregular topography here is understood to imply a ground surface that (1) is not idealizable as being perfectly flat or (2) that is not idealizable as having a constant specific acoustic impedance. The interest of this study focuses on circumstances where the propagation is similar to what might be expected for noise from low-altitude air vehicles flying over suburban or rural terrain, such that rays from the source arrive at angles close to grazing incidence.

The objectives of the project, the experimental facility, and the early progress up through August 1986 have been described in the four previous semiannual reports [1,2,3,4]. The present report discusses those activities and developments that have resulted during the period, February 1987 through July 1987.

PERSONNEL

In addition to A. D. Pierce and G. L. Main, a third faculty member, Yves H. Berthelot, is a now also a co-principal investigator on the project. Also involved in activities related with the project are three graduate students: James A. Kearns, Nathaniel Chisholm, and Pei-Tai Chen. A visiting scholar, Professor Ji-xun Zhou of the Acoustics Institute of the Academy of Sciences of China (Beijing), has been working on the project since May. During the past reporting period, Dr. Berthelot, Professor Zhou, and James Kearns have been mainly concerned with the the experimental phases of the project, while Allan Pierce and Dr. Main have been working primarily on the theoretical aspects. Pei-Tai Chen has been assisting Dr. Pierce on some theoretical questions involving echoes, while Nathaniel Chisholm has been assisting with the computational aspects of the project.

Allan Pierce, Geoffrey Main, and Yves Berthelot visited NASA Langley Research Center on February 23, 1987, and discussed complementary NASA and Georgia Tech research activities with the NASA technical officer, Dr. John Preisser, with William Willshire, and with their colleagues.

MEASUREMENT OF ACOUSTIC IMPEDANCE

During the past few months a special effort has been made to determine experimentally the acoustic impedance of the surface coverings used in the laboratory experiments on sound diffraction by topographical ridges. As was discussed during the group's visit to NASA Langley on February 23, it was initially hoped that acoustic impedance could be determined simply by taking the ratio of the complex Fourier transforms of a direct signal and the subsequent signal that corresponds to a reflected wave from the surface of unknown impedance. Further refinement of the data processing technique and altering some incorrect procedures showed that such a method is indeed adequate to measure the magnitude of the reflection coefficient, but the technique was too crude to measure the phase of the reflection coefficient (especially at high frequencies). This indicated that a different technique was needed to achieve a reliable measurement of acoustic impedance.

After discussions at various scientific conferences with other groups engaged or experienced in acoustic propagation experiments, it was decided to use a technique described by Embleton, Piercy, and Daigle [5]. They use a relatively highly accurate theoretical solution (better than a plane wave reflection model) for the sound pressure level at a moderate to large distance caused by a point harmonic source at a specified height above a flat surface with given impedance. The model takes into account full wave effects and the possibiity of surface waves and predicts the sound pressure level at the receiver location relative to what would be expected if the flat surface were not present. This sound pressure level can be regarded as a function of frequency, sound speed in air, heights of source and receiver, and horizontal distance from source to receiver, as well as the real and imaginary parts of the surface impedance. The latter quantities are presumed to depend on frequency and flow-resistivity σ in a semi-impirical manner predicted by Delany and Bazley [6], such that

$$\frac{R}{\rho c} = 1 + 9.08\left(\frac{f}{\sigma}\right)^{-0.75} \qquad (1a)$$

$$\frac{X}{\rho c} = 11.9\left(\frac{f}{\sigma}\right)^{-0.73} \qquad (1b)$$

Here the left sides are dimensionless and the flow resistivity σ has the customary units of cgs Rayls (so the coefficients 9.08 and 11.9 have correspondingly awkward units).

The consequence of Eqs. (1) is that, for given source and receiver locations, there is a unique graph of sound pressure level (re open environment expected values) versus frequency for any given value of σ. Consequently, given that the theoretical model and the general forms of Eqs. (1) are correct, one can infer the value of σ from a plot of sound pressure level versus frequency. Once such a value of σ has been determined, one can then use Eqs. (1) to compute the real and imaginary values of surface impedance for any value of frequency.

Our implementation of this technique is to experimentally determine (using our spark source and taking ratios of Fourier transforms) the sound pressure level (which here, strictly speaking, is an excess attenuation in dB) versus frequency and also plot simultaneously theoretical curves that correspond to different values of σ. The inferred experimental value of σ corresponds to that of the theoretical curve which best matches the experimental sound pressure level versus frequency curve. acoustical preperties of fibrous aborbent materials

Some typical results are shown in Figs. 1 and 2, which depict the predicted and the measured SPL-versus-f curves for sound propagating over carpet and plywood, respectively. For both sets of data, the source height is two centimeters and the receiver height is 0.3 cm. For the data shown in Fig. 1 (carpet), the horizontal separation distance between source and receiver is 80 cm. For the data shown in Fig. 2 (plywood), it is 100 cm. It is inferred from these figures that for plywood σ is approximately equal to 80,000 cgs Rayls. For carpet , σ is approximatey 1500 Rayls cgs. These values, when inserted into Eqs. (1) predict values of R and X at the characteristic laboratory experiment frequency of 20,000 Hz which are about the same as the values of R and X for asphalt covered ground and grass covered ground, respectively, at the characteristic field experiment (outdoors) frequency of 1000 Hz.

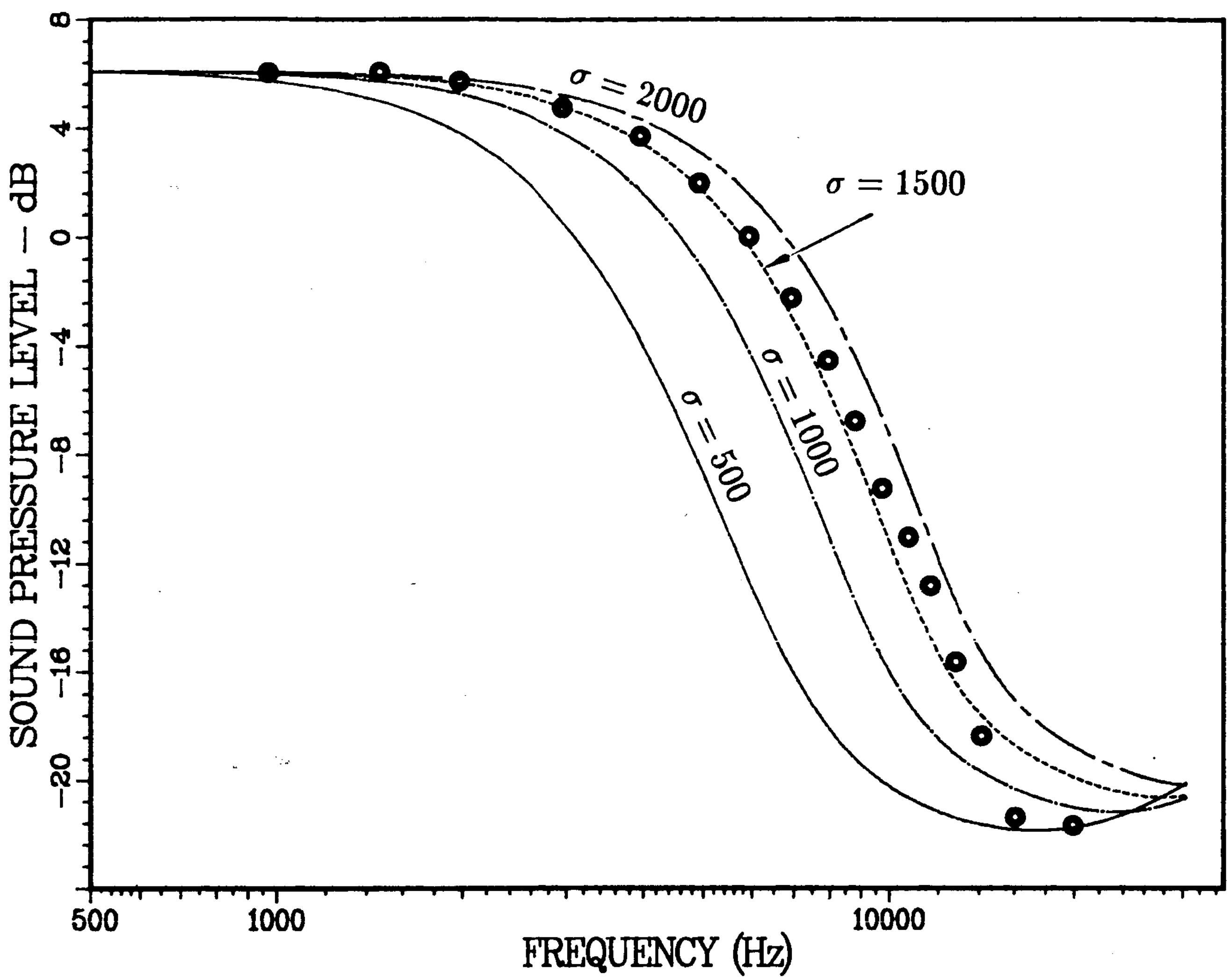

Figure 1. Typical results for determination of flow resistivity σ of carpet material on plywood. Shown are predicted and the measured SPL-versus-f curves for sound propagating over carpet; the source height is two centimeters and the receiver height is 0.3 cm; the horizontal separation distance between source and receiver is 80 cm. From the data shown it is inferred that σ is approximatey 1500 Rayls cgs.

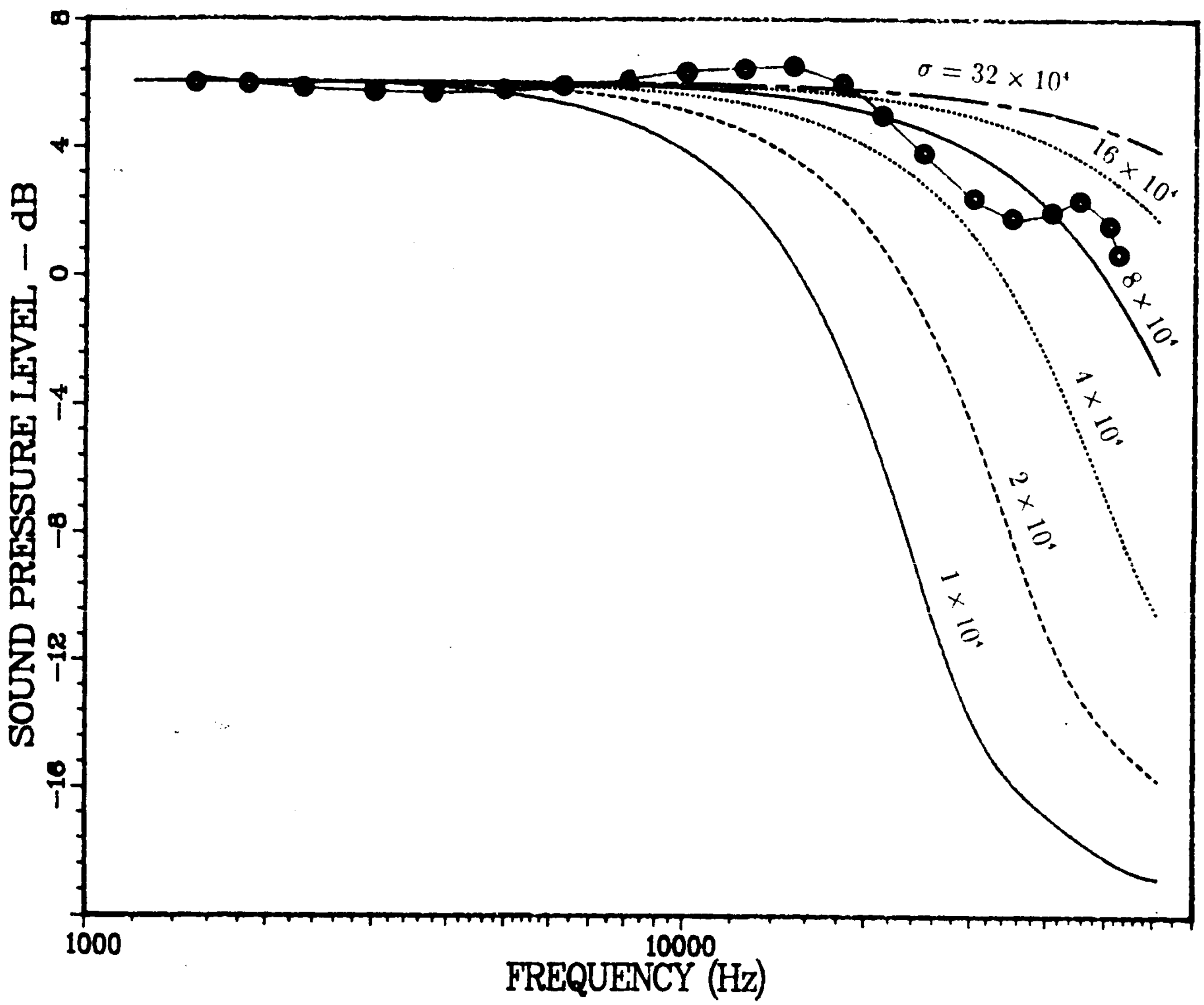

Figure 2. Typical results for determination of flow resistivity σ of plywood. Shown are predicted and the measured SPL-versus-f curves for sound propagating over carpet; the source height is two centimeters and the receiver height is 0.3 cm; the horizontal separation distance between source and receiver is 100 cm. From the data shown it is inferred that σ is approximatey 80,000 Rayls cgs.

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DEVELOPMENT OF COMPUTATIONAL ALGORITHMS

The following pages reprint a paper written and published by Allan Piere and Geoffrey Main during the subject reporting period. The proper citation for this paper is as follows:

Allan D. Pierce and Geoffrey L. Main, "Computational algorithms for the matched asymptotic expansion solution of high frequency acoustic wave diffraction by curved surfaces of finite impedance," in ***Advances in Computer Methods for Partial Differential Equations • VI*** (R. Vichnevetsky amd R. S. Stepleman, editors), International Association for Mathematics and Computers in Simulation (IMACS), Rutgers University, Department of Computer Science, New Brunswick, New Jersey 08903, 1987, pp. 187–194.