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PREDICTION AND EXPERIMENTAL VERIFICATION OF FAR-FIELD SOUND PROPAGATION OVER VARYING GROUND SURFACES

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INTRODUCTION

In recent years, the study of sound propagation outdoors has vastly improved knowledge of various physical factors which influence the degree to which sound waves travel from a source to a far-field receiver location. [1,2,3] Early investigations [4,5,6,7] have revealed that the characteristic ground surface impedance is an important factor affecting sound attenuation over flat terrain.

This paper deals with the effects on sound propagation over a flat ground surface sub-divided into a finite number of homogeneous segments, with finite impedance varying from one segment to the next. A known sound source, for the purpose of this study, is a high power outdoor warning siren. A substantial number of measurements were taken in the field to verify the computer-predicted results.

HOMOGENEOUS GROUND SURFACE

Before considering the case of a multi-segmented ground surface, it is worthwhile to examine the effects of an infinite planar (continuous) surface of finite impedance. Many experimenters have studied these effects, and the basis of all these studies is Equation 1, a form of the Weyl-van der Pol equation. [8]

$$\Phi = \frac{e^{ikr_1}}{r_1} + \left[R_p + \left(1 - R_p\right) F\left(P_e\right)\right] \frac{e^{ikr_2}}{r_2} \qquad (1)$$

Factors such as the interference between direct and reflected waves and phase shift differences may be incorporated in one measure of surface impedance, σ, the flow resistivity. Figure 1 illustrates the relationship between excess attenuation due to the ground surface and the flow resistivity of the ground beneath the source and the receiver.

EFFECTS OF ONE OR MORE DISCONTINUITIES

The ground surface between a source and a receiver may be represented by a finite number of segments. The presence of discontinuity, as shown in Figure 2, complicates the picture of sound waves propagating from source to receiver over the intervening ground surface. K.B. Rasmussen [9] used an equation developed by B.A. deJong for calculating the sound-field affected by a ground surface containing one impedance discontinuity.

From deJong's equation for a ground surface with a single impedance discontinuity, a similar equation was formulated for the analysis of sound propagating over a ground surface containing any finite number of impedance discontinuities:

$$\Phi = 1 + \frac{r_1}{r_2} Q_G e^{ik(r_2 - r_1)} + \sum_{j=1}^{n-1} \left\{ \left(Q_{j+1} - Q_j\right) e^{\frac{-i\pi}{4}} \frac{i}{\sqrt{\pi}} \frac{r_1}{s_j} \left[F(2)\left(\sqrt{k(s_j - r_1)}\right) + F(2)\left(\sqrt{k(s_j - r_2)}\right) \right\}_{-1}^{1} \left\{ e^{ik(r_2 - r_1)} \right] \right\} \quad (2)$$

An explanation of the terms used in this equation can be found in Rasmussen's paper [9]. This equation extends deJong's equation to account for all waves diffracted to the receiver by discontinuities.

VERIFICATION OF PREDICTION SCHEME

Based on equation [2], a computer-facilitated method was devised to predict the sound field in the region around a sound source. The computer model used in the prediction scheme also takes into account significant meteorological factors (such as air temperature and relative humidity) and ground surface conditions.

To verify the accuracy of the prediction scheme, field tests were conducted to measure the sound-field around a well-defined sound source. Narrow-band frequency analyses were conducted to determine the frequency and sound level of the significant tones making up the sirens' signals. The sound levels were recorded at various distances and directions from the siren and compared with the analytical results, as shown in Figure 3.

CONCLUSIONS

From this study it is clear that the prediction scheme produces results in excellent agreement with experimental data collected. As a reasonable first approximation in predicting sound pressure levels, the ground surface between the source and the receiver can be assumed to be continuous and homogeneous, with a finite impedance equal to that of the reflection point. However, a more accurate prediction scheme considers the effects due to the discontinuities in the ground surface impedance.

Practical applications can be made for this prediction scheme with respect to various environmental noise sources. For example, an analysis was performed on a hypothetical region surrounding a well-defined sound source, which emits a pure tone, such as a siren, power transformer, cooling tower, etc. The ground surface in the vicinity of this sound source was purposely taken to have highly varying ground surface cover and, therefore has disparate surface impedance values. For a selected arrangement of input variables, sound pressure contours (60 and 70 dBC) were predicted, as shown in Figure 4.

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SOURCE-RECEIVER CONFIGURATION
SURFACE WITH ONE
IMPEDANCE DISCONTINUITY
(TWO-SEGMENT CASE)

FIGURE 2

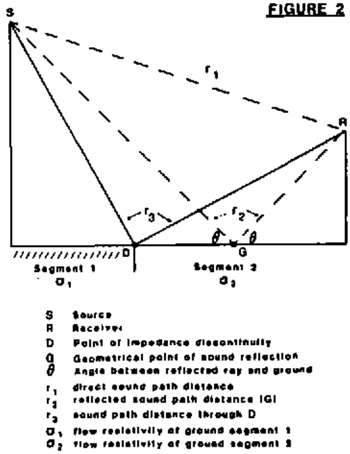


FIGURE 1:
SOUND ATTENUATION OVER A HOMOGENEOUS SURFACE FOR VARYING FLOW RESISTIVITY (4)

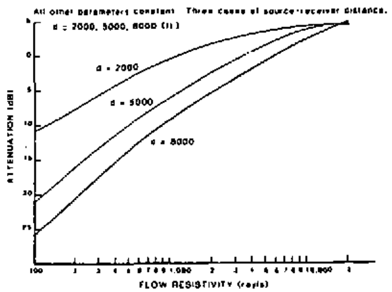


FIGURE 3:
COMPARISON OF PREDICTED AND MEASURED SOUND PRESSURE LEVELS AT VARIOUS MEASUREMENT SITES

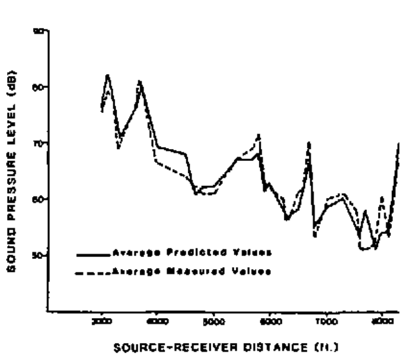
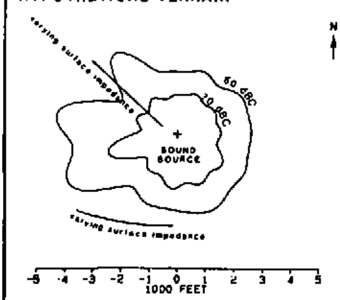


FIGURE 4:
SOUND LEVEL CONTOURS OVER HYPOTHETICAL TERRAIN



Source Height - 45 ft.
Receiver Height - 5 ft.
Source Rating - 108 dB
Source Tone Frequency - 500 Hz