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ON THE USE OF A LOCAL REACTION BOUNDARY CONDITION IN THEORIES OF SOUND PROPAGATION OUTDOORS

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Introduction

A situation commonly encountered in environmental noise problems is that of near-grazing sound propagation (an angle of incidence $\theta_i > 85^0$, say) above plane outdoor surfaces such as grassland. At these angles the ground surface plays an important role in determining the level and spectrum of transmitted sound, giving rise to the so-called ground effect (see for example the measurements of Parkin and Scholes [1]). To accurately model near-grazing propagation, we must be able to assign a boundary condition which adequately accounts for the behaviour of real ground surfaces. Our purpose here is to examine existing measurements of ground surface properties, and to infer from them the validity of the commonly used local reaction assumption.

True surfaces of local reaction do not allow sound to propagate parallel to the surface. Surfaces of extended reaction on the other hand, do allow lateral propagation but under some conditions may act as though they were locally reacting. By considering reflection at a plane interface, it may be shown that an extended reaction surface may be approximated as a surface of local reaction if

$$\left| \left(\frac{c_1}{c_0}\right)^2 \right| \ll 1$$

where c_1 is the effective speed of sound in the reflecting medium (defined here as $c_1 = \omega/k_1$).

There is no reason to assume <u>a priori</u> that grassland or ploughed fields are inherently locally reacting; thus a local reaction boundary condition may only be used safely in theories of outdoor sound propagation if it can be shown that the above condition is satisfied for a particular surface. This would be of only academic interest if there were not significant advantages of simplicity in the use of the local reaction boundary condition. Reflection from such a surface may be calculated knowing only the surface normal specific impedance, ζ_n, while for a surface of extended reaction both the specific characteristic impedance ζ and the velocity of sound in the reflecting medium c_1 must be known in addition to a knowledge of its geometry, e.g., layer depth.

Interpretation of Surface Normal Impedance Measurements

Measurements of the surface normal impedance of typical ground surfaces [2] often show a real component which is nearly constant, and smaller in magnitude than the imaginary component. This is a feature characteristic of thin porous layers [3] and so it has been postulated that the ground surface may be modelled as such. The two models which have been considered are: (i) a homogeneous porous layer over a hard backing, and (ii) a layer of linearly decreasing porosity. The layer of linearly decreasing porosity has been approximated as a sequence of thin homogeneous layers with a discrete reduction of porosity from one to the next with increasing depth. A model in which the porosity decreases exponentially with depth has recently been considered by Donato [4].

The porous material theory used is essentially that of Morse and Ingard [5], slightly modified to allow more realistic interpretation [6]. In this theory, the four real parameters that determine the acoustical behaviour of a porous material are, (i) the steady-state flow resistance Φ[kg/(sec - m^3)], which accounts for viscous dissipation [7], (ii) the porosity, Ω, which is the ratio of the volume of air contained within a porous medium to the total volume of the material, and indicates the fraction of the volume in which sound may propagate, (iii) a term (γ_e/γ_s) which accounts for thermal effects, where γ_e is the 'effective' ratio of specific heats of the air within the pores, and γ_s the adiabatic ratio of specific heat, and (iv) the structure factor, m, which accounts for the effective increase of inertia of the fluid in the pores due to sudden expansions, contractions and the non-uniform orientation of the pores. The flow resistance and porosity are the most significant of these factors since they vary over wide ranges ($0 < \Omega < 1.0$, $10^3 < \Phi < 10^6$ approx.) while (γ_e/γ_s) varies from a low frequency limit of .7 to a high frequency limit of 1.0, and for the model used here, m lies between 1 and 3.0.

Using this theory, expressions for the characteristic specific impedance and the effective speed of sound of the porous material may be deduced and then combined with one or the other of the two models described above to predict the surface normal impedance. By matching measurements of surface normal impedance with theoretical predictions in a trial and error process, the acoustical parameters of the ground are deduced and used to estimate c_1, and thus $|(c_1/c_0)^2|$. As an example, two of Dickinson's [2] measurements of surface normal impedance have been matched. Figure 1 shows results for an uncut grass meadow (grass about 5 cm tall). The solid lines are an approximate fit achieved using the single homogeneous layer model (m is assumed equal to 1.3 throughout and values of (γ_e/γ_s) are those suggested by Delaney and Bazley [7]. Figure 2 shows similar results for a surface of small stones over hard rock; here the linear gradient model was used. Note that the effect of an apparent layer resonance (the sharp dip in the reactive part of the impedance at 800 Hz) is reproduced by the model. While the fits between experiment and theory are reasonable, one has considerable scope for adjustment using a four parameter model (Φ, Ω, m and ℓ the layer depth) and similar curves may result from different combinations of parameters. Thus while it cannot be claimed that the matching process produces results which are unique, they may at least be claimed to be representative if the choice of parameters is guided by the physical nature of the surface involved.

The surface parameters deduced from the above matching process have been used to calculate the ratio $|(c_1/c_0)^2|$ as a function of frequency for these two ground surfaces. The results are shown in Figure 3 where 0.1 has been chosen arbitrarily as the limit of the validity of the local reaction assumption. It can be seen that this particular grassland may be considered locally reacting up to approximately 1000 Hz which covers most situations of environmental interest. The second surface however ceases to be locally reacting at much lower frequencies

Conclusions

It has been shown that measurements of ground surface normal impedance can be interpreted by assuming that the ground may be modelled as a thin porous layer. Parameters deduced from matching theory with experiment have in turn been used to test the validity of the local reaction boundary condition for two types of ground. It appears that the assumption that all outdoor surfaces are locally reacting is not justified, and in particular precision predictions of near-grazing sound propagation over surfaces like the second type can only be made using an extended reaction boundary condition and a reflection theory that accounts more or less accurately for the real structure of the surface.

References

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Figure 1: Grassland (Dickinson test 6.1)

o Measured Resistance
x Measured Reactance
— Theory (homogeneous layer model)

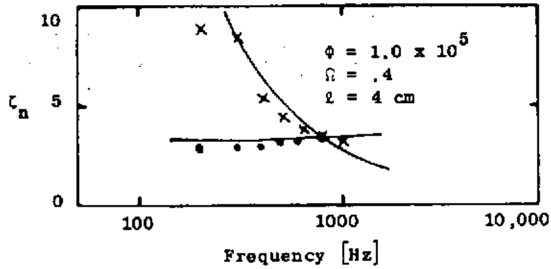

Figure 2: Small Stones (Dickinson test 6.7)

o Measured Resistance
x Measured Reactance
— Theory (linear gradient model - 100 layers used in calculation)

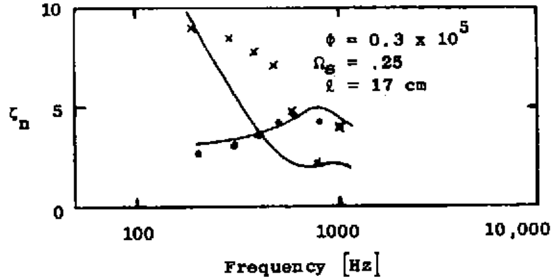

Figure 3: $\left|\frac{c_1}{c_o}\right|^2$ vs. Frequency