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SOUND PROPAGATION OVER SURFACES CONSISTING OF HARD & SOFT AREAS

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THEORY

Consider a point source of sound in air, producing spherical waves situated above an absorbing plane (i.e. the ground). The sound field above the plane can be derived as the sum of a direct contribution from the source and a second contribution from waves which have interacted with the surface. In figure 1, S and R are the source and receiver positions and S' is the geometrical image of the source. The field potential at R, at near grazing incidence, can be written as:

$$\phi = \frac{\exp(ikr)}{4\pi r} + \frac{\exp(ikr_1)}{4\pi r_1} \cdot R_p + \frac{\exp(ikr_1)}{4\pi r_1} \left(\left[1 - R_p\right] F\right) \qquad \ldots(1)$$

where k is the wave number of the sound in air, the time dependence $\exp(i\omega t)$ is assumed and separation of source and receiver is in excess of one wavelength. $R_p(\theta)$ is the plane wave reflection coefficient.

The first term in equation (1) is a result of the direct contribution from the source. The second term is a component related to a wave geometrically reflected from the surface. The third term represents the ground or surface wave which is effectively a correction to the second term and arises because the wavefronts incident on the ground are curved rather than plane.

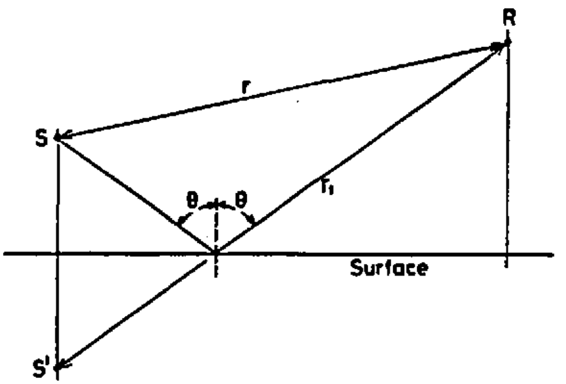

Figure 1

If the surface is hard then equation (1) reduces to:

$$\phi = \phi_D + \phi_R + \frac{\exp(ikr)}{4\pi r} + \frac{\exp(ikr_1)}{4\pi r_1} \qquad \ldots(2)$$

The second, geometrical reflection term in this equation may be given in the form:

$$\phi_R = \frac{a}{2\lambda}\iint_{-\infty}^{\infty}\left[\mathrm{Cos}\theta_2\left(1+\frac{i}{kr_2}\right)+\mathrm{Cos}\theta_3\left(1+\frac{i}{kr_3}\right)\right]\frac{\exp i(k(r_2+r_3)-\pi/2)}{r_2 r_3}\,ds \qquad \ldots(3)$$

where a is an amplitude constant and λ is the wavelength. This formulation is based on the Fresnel-Kirchoff diffraction theory. The reflected wave is derived by considering the surface of infinite extent, in figure 2, to be divided into elemental areas ds. Each of the areas behaves as a monopole source, radiating into the half-space above the plane at a relative phase defined by the path r_2. The integration, over all the plane, of the contribution from each of the monopole sources with suitable obliquity and attenuation factors produces equation (3).

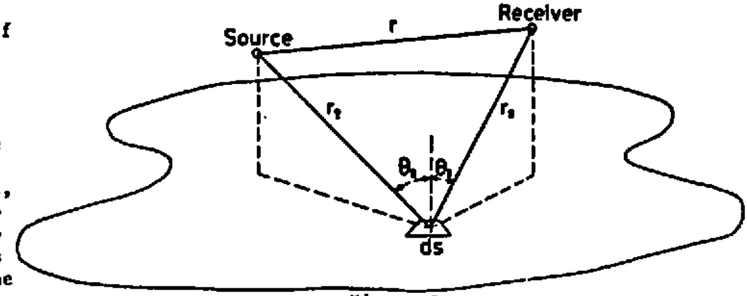

Figure 2

Consider an absorbing surface with a plane wave incident, then the field potential of the reflected wave can be simply defined as $R_p \frac{e^{ikr_1}}{4\pi r_1}$. It can also be derived by dividing the surface into elemental areas which act as monopole sources. The relative phase and amplitude of these sources depends on the function $R_p(\theta)$, where θ is the angle of incidence of the wave and the combination of wavelets from these sources produces the reflected wavefront.

Returning to the point source problem each elemental area will have a small section of wavefront incident upon it which, in the limit, approximates to a plane wave. Hence, it is reasonable to extend equation (3) to describe the reflected wave from a surface of finite normal surface impedance in the following way:

$$\phi_R = \frac{a}{2\lambda}\iint_{-\infty}^{\infty}\frac{R_p(\theta_2)}{r_2 r_3}\left[\mathrm{Cos}\theta_2\left(1+\frac{i}{kr_2}\right)+\mathrm{Cos}\theta_3\left(1+\frac{i}{kr_3}\right)\right]\exp i(k(r_2+r_3)-\pi/2)\,ds \qquad \ldots(4)$$

In this expression the angle at which the wavefront is incident, θ_2, changes for each element and allowance for the curved surface of the wavefront, which is the source of the ground wave, appears naturally in the theory.

NUMERICAL SOLUTION AND DISCUSSION

Equation (4) can be evaluated numerically if a finite area of surface is considered, divided into small areas ΔS, for which r_2, r_3, θ_2 and θ_3 can be determined. The pressure amplitude at the receiver is obtained when

$a = (W\rho c/4\pi)^{\frac{1}{2}}$ where W is the source power.

The appropriate direct field component was added to enable the total sound field at a reception point to be calculated. The reflected component of the sound field due to a point source above a hard surface can be simply determined analytically. This provided results which could be compared with solutions for hard ground derived using equation (4).

Equation (4) can be solved to an acceptable degree of accuracy for most normally encountered configurations if the element area is $(\lambda/4)^2$ and the surface area is $(2r)^2$. The second condition assumes that r is significantly greater than the source and receiver height, which is usually the case.

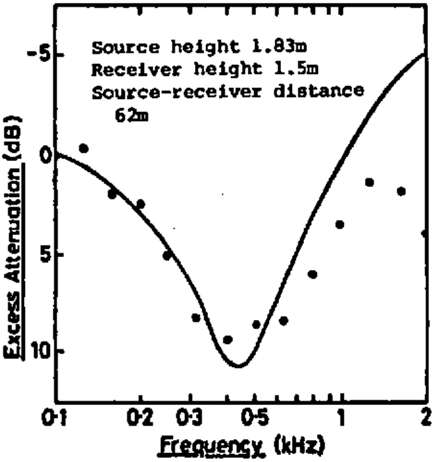

Figure 3

To test the theory for propagation over ground of finite impedance calculations were compared with experimental results for propagation of noise from aircraft over grassland (1). Figure 3 shows the excess attenuation calculated using equation (4) with values of R_p derived from reference (2). The fit between the experimental points and the calculated curves is good, but is dependent on the data chosen for the ground impedance.

The usefulness of the method lies in the fact that it allows discrimination of areas of the surface which is unavailable in all other solutions, which may be more sophisticated and accurate. The simplest case consists of a flat surface with a hard (concrete or asphalt) area and a soft (grassland) area, separated by a straight boundary which lies perpendicular to the direction from source to receiver. The excess attenuation calculated as a function of frequency using the impedance values of Sutherland (2) in equation (4) are shown in figure 4. H denotes a hard surface and S a soft. The first letter defines the surface beneath the source and the figure the proportion of the distance from source to receiver at which the ground cover changes. As the proportion of soft ground between source and receiver decreases the first minimum becomes less intense, as expected. Above about 300Hz the shape of the curve is strongly dependant on the proportion of soft to hard ground but much less so on the distribution over the propagation path. Below this figure the distribution becomes important, in particular the ground type below the receiver, as at 100Hz the curves related to hard ground beneath the receiver have excess attenuation in the region 5 - 6dB while for soft ground beneath the receiver the region is 1 - 3dB. All the curves should be asymptotic to the 6dB level in the low frequency limit.

The results so far discussed have only limited application in any environmental noise propagation problem. In most cases the sources are broad band and extended, with imperfect coherance. The ground surface will usually be uneven and local impedance changes will occur in areas of soft cover. Any other surface

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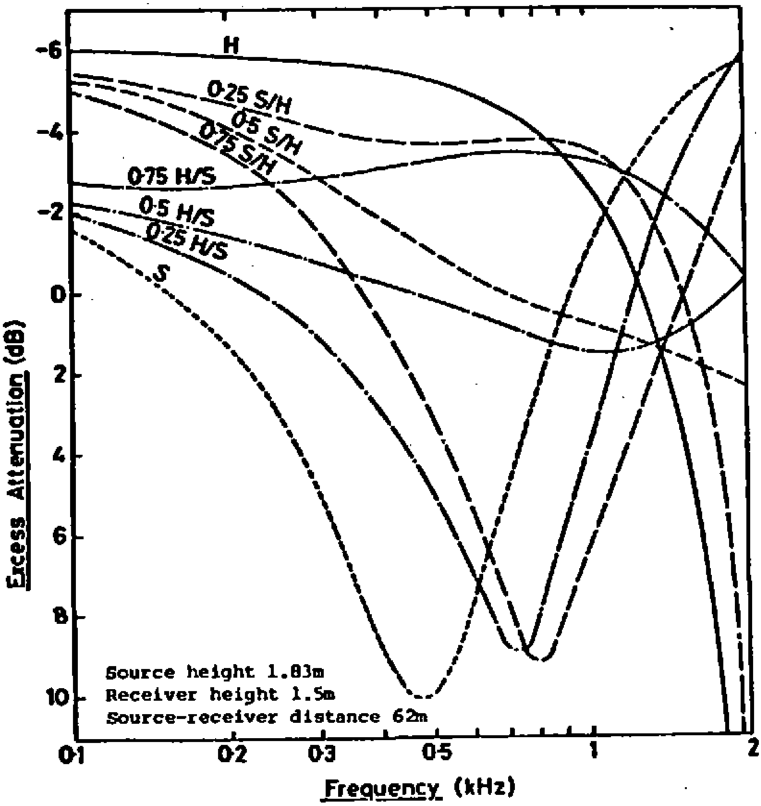

Figure 4

will also contribute to the interference effects. The higher frequencies will be particularly affected. However the theory provides the basis for a practical calculation. Good agreement has been gound between the results of the theory and a simple analysis of propagation over hard ground. Similarly, over soft ground cover (grassland) good agreement of the theory with experimental results has been obtained. It has been shown that, as the proportion of soft ground cover reduces over the propagation path, there is an apparently linear reduction in the magnitude of the first minimum of the excess attenuation vs frequency.

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(2) L.C. Sutherland, "Sound Propagation over open Terrain from a Source Near the Ground." Paper at 84th Meeting Acoust. Soc. Am., (Nov. 1972).