Proceedings of the Institute of Acoustics

THE GROUND EFFECT AND DIRECTIONAL SOURCES

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1. INTRODUCTION

The outdoor propagation of sound from a source is strongly influenced by reflections from the ground surface, leading to an attenuation with distance that is different from that expected from simple spherical divergence of the sound energy and atmospheric absorption.

The majority of work on modelling this excess attenuation has been for simple point sources. For industrial noise problems it has not been shown that the planar elements of the envelope of a building can be replaced with point sources for prediction purposes, as used in several outdoor noise prediction methods. In this paper, an attempt is made to investigate the form of the excess attenuation for simple planar sources, and to see whether a planar source of pronounced directivity can be replaced (for prediction/modelling purposes) with a point source with the same directional characteristics. Other factors which affect the propagation of sound outdoors, such as air-absorption, turbulence and wind and temperature gradients, will not be dealt with here.

2. EXCESS ATTENUATION FOR A SIMPLE POINT SOURCE

Figure 1 shows a simple source-receiver geometry, where both are in the vicinity of the ground.- For single frequency radiation, the difference in lengths (r_1 and r_2) of the direct and reflected paths from the source to the receiver allow for destructive or constructive interference between the two rays, thereby giving rise to the aforementioned change in attenuation over that expected from the simple inverse square law. This "excess attenuation", EA is given by the following expression:

$$EA = 10\log_{10}\left(\frac{|p_t|^2}{|p_d|^2}\right) \quad (1)$$

where p_d represents the pressure that would exists at the receiver if the ground layer were not present, i.e. the free-field pressure, and p_t represents the total pressure at the receiver with the ground layer present.

The pressure produced by a point source in a free-field is given by:

$$p_d = A\frac{e^{jkr}}{4\pi r} \quad (2)$$

(ignoring the -ejωt term), where A is some complex source strength, so the problem is therefore reduced to finding the total pressure p_t produced by a source over a reflecting plane. Much effort has been put into the solution of this problem, both in the field of acoustics and the analogous problem in electromagnetic propagation theory.

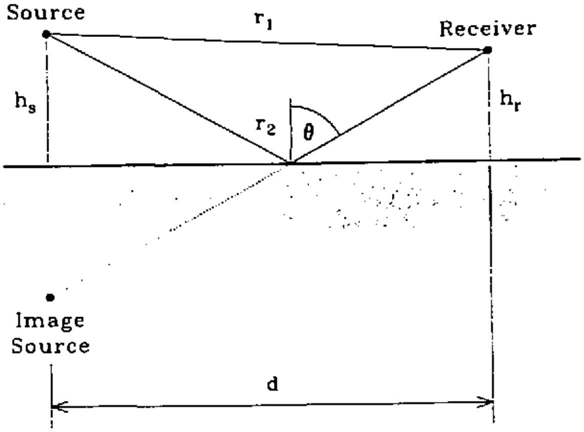

Figure 6.1: A simple source-receiver geometry

A popular approach to predicting the total field due a point source above a reflecting plane is to treat the reflected field as being due to an image of the source in the ground plane. The amplitude of this image source can be given in terms of the original source amplitude A, and the spherical wave reflection coefficient of the ground Q, so that the total pressure at the receiver is given by:

$$p_t = A\frac{e^{jkr_1}}{4\pi r_1} + QA\frac{e^{jkr_2}}{4\pi r_2} \qquad (3)$$

The majority of work on developing methods for predicting excess attenuation has been for simple omni-directional point sources, however,very few real sources will have omnidirectional characteristics. There has been a limited amount of work performed into the problem of predicting excess attenuation for sources with directivity, most notably by Moreland [1] and Sutherland [2].

3. DIRECTIONAL SOURCES

The directivity of a noise source is a function of its size and the wavelength of sound radiated by it. To investigate whether the use of a point source with directivity is a good model for a source of extent for predicting excess-attenuation, it was decided that a more complicated source than a simple array of point-sources should be modelled. Following Li et al [3], it was decided to model a simply-supported panel. The results for the excess-attenuation for the panel were compared to those for a point source with a similar far-field directivity to that of the panel, to ascertain the efficacy of the point source model in predicting the excess attenuation for a source of extent.

The directivity of a simply supported panel can be calculated using an expression due to Wallace (4). Figure 2 shows the directivity for a range of frequencies of a panels vibrating in the 1:3 mode shape. The importance of size and wavelength for determining the directional characteristics can be clearely seen

Using Rayleigh's equation for calculating the pressure due to a simply supported panel, gives the following two expressions for the mean-square direct and total pressures at the receiver position due to the panel:

$$|p_d|^2 = \left| \frac{A}{4\pi} \int_0^a dx \int_0^b \sin(m\pi x/a) \sin(n\pi y/b) \frac{e^{jkr_1}}{r_1} dy \right|^2 \quad (4)$$

$$|p_t|^2 = \left| \frac{A}{4\pi} \int_0^a dx \int_0^b \sin(m\pi x/a) \sin(n\pi y/b) \left\{ \frac{e^{jkr_1}}{r_1} + Q\frac{e^{jkr_2}}{r_2} \right\} dy \right|^2 \quad (5)$$

In this work,these integrals were modified to be compatible with the overall geometry used in the excess-attenuation calculations, i.e. the origin of the coordinate system used in the integrals was moved to be coincident with that used in the excess attenuation calculations.

. The expressions for the single frequency direct and total pressures for a point source with directivity function D are:

$$p_d = \sqrt{D(\theta_1)} A \frac{e^{jkr_1}}{4\pi r_1} \quad (6)$$

and

$$p_t = \frac{A}{4\pi} \left\{ \sqrt{D(\theta_1)} \frac{e^{jkr_1}}{r_1} + Q\sqrt{D(\theta_2)} \frac{e^{jkr_2}}{r_2} \right\} \quad (7)$$

where the square-root function is used because directivity functions (D) are usually provided in terms of a ratio of far-field intensity to acoustic power (i.e. a pressure squared ratio). Adapting equations (6) and (7) therefore gives the direct and total squared pressures in a frequency band for a directional point source as:

$$|p_d|^2 = \int_{k_l}^{k_u} D(\theta_1) \left| \frac{A}{4\pi} \frac{e^{jkr_1}}{r_1} \right|^2 dk \tag{8}$$

and

$$|p_t|^2 = \int_{k_l}^{k_u} \left| \frac{A}{4\pi} \left\{ \sqrt{D(\theta_1)} \frac{e^{jkr_1}}{r_1} + Q\sqrt{D(\theta_2)} \frac{e^{jkr_2}}{r_2} \right\} \right|^2 dk \tag{9}$$

The comparison were performed for several source and receiver height combinations at the octave band centre frequencies from 125 Hz to 4 kHz as a function of the horizontal separation between the source and receiver. The impedance model used in this work was the Attenborough 2-parameter variable-porosity model as it has been shown to give a good approximation to typical outdoor ground-surfaces. The values of the effective flow-resistivity and rate of change of porosity employed were 100000 MKS Units and 100 m^{-1} respectively, which represent typical values for outdoor ground surfaces.

The comparisons were first performed for single frequency excitation. For practical purposes, it will be the case that the prediction and calculations of excess attenuation will be performed in third and whole octave-bands, and not for single-frequencies. Third and whole octave band excitation were therefore examined, and compared to the single frequency results. For third and whole octave excitation, the squared direct and total pressures were calculated by integrating the single frequency squared pressure magnitudes.

4. RESULTS

Figure 3 shows the excess-attenuation as a function of horizontal range (this is opposed to calculating excess attenuation spectra as a function of frequency for a fixed geometry which is the more common approach), for a simply supported panel of side dimensions 1 m by 1 m vibrating in its (1,3) mode, with the centre of the panel at a height of h_s = 0.5 m, and the receiver at a height of h_r = 5 m.

As can be seen, for all frequencies from 125 Hz to 2 kHz, the point source model gives a very good approximation to the results for the panel. The point-source model overestimates the excess attenuation at the horizontal ranges where there are peaks in the excess-attenuation curves. For the 4 kHz curve, for $d < 30$ m, there is some additional discrepancy.

The calculations for Figure 3 were repeated with octave band excitation. The octave-band direct and total pressures were calculated by integrating equations (6.74) and (6.75) over the limits of the bands. Figure 4 shows the results for this octave band calculation. For octave band excitation the point source with directivity model gives a very good approximation to the excess attenuation for the planar source.

5. CONCLUSION

The directivity of a source of extent will have an effect on the propogation of sound over an impedance plane. When considering broadband sound radiation, the effect of source directivity can be modelled by treating the source as a point source with a directivity function similar to that of the real source.

6. REFERENCES

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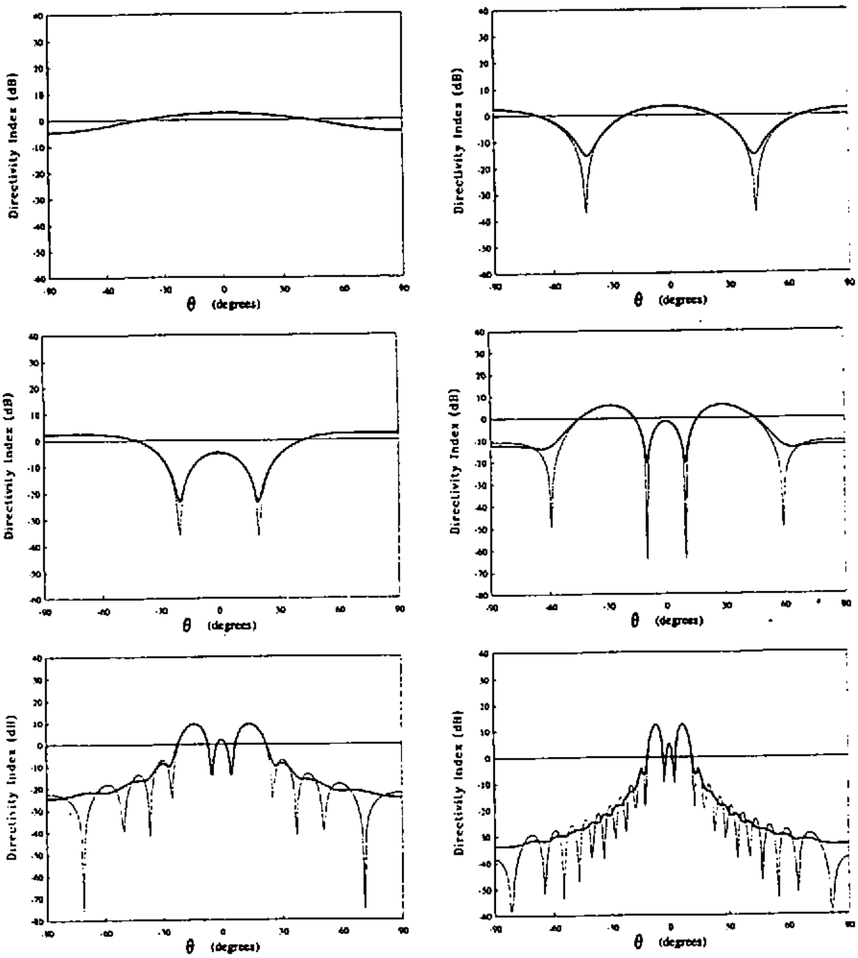

Figure 2: The directivity index for a simply supported panel, a = b = 1m, (m,n) = (3,1), ——— single frequency, ▬▬▬ third octave and .... whole octave

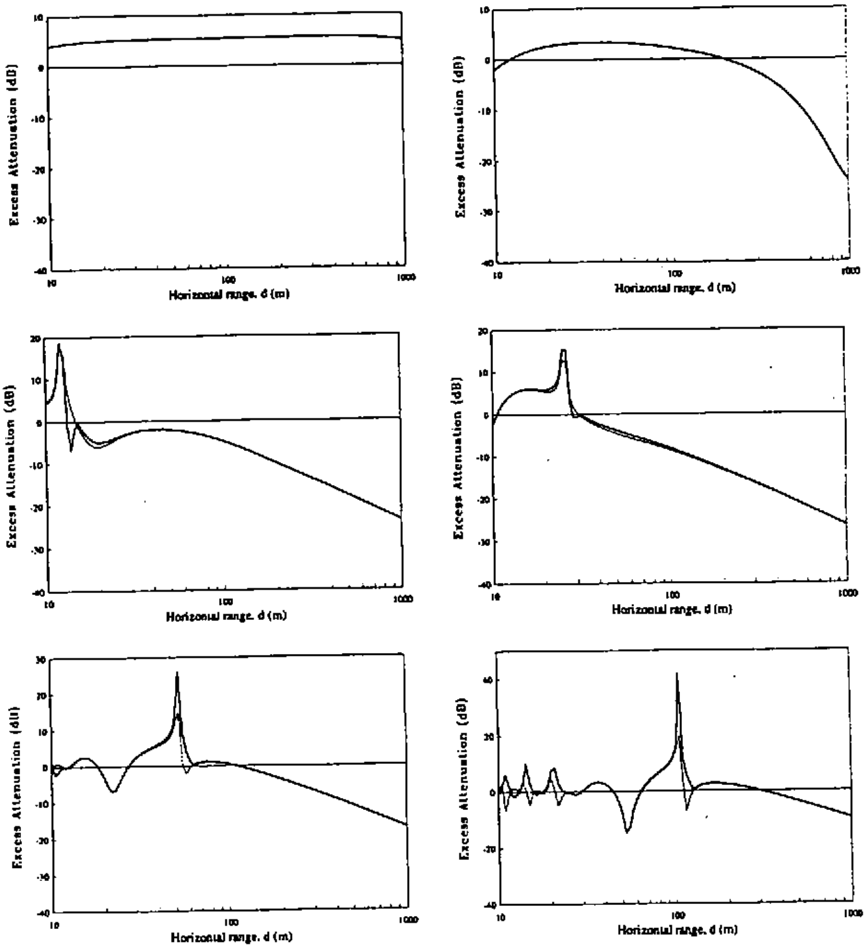

Figure 3: A comparison of the single frequency excess attenuation for a simply supported panel (——) with a = b = 1m, (m,n) = (3,1), and a point source with similar far field directivity (▬▬), $h_s = 0.5$m and $h_r = 5$m.

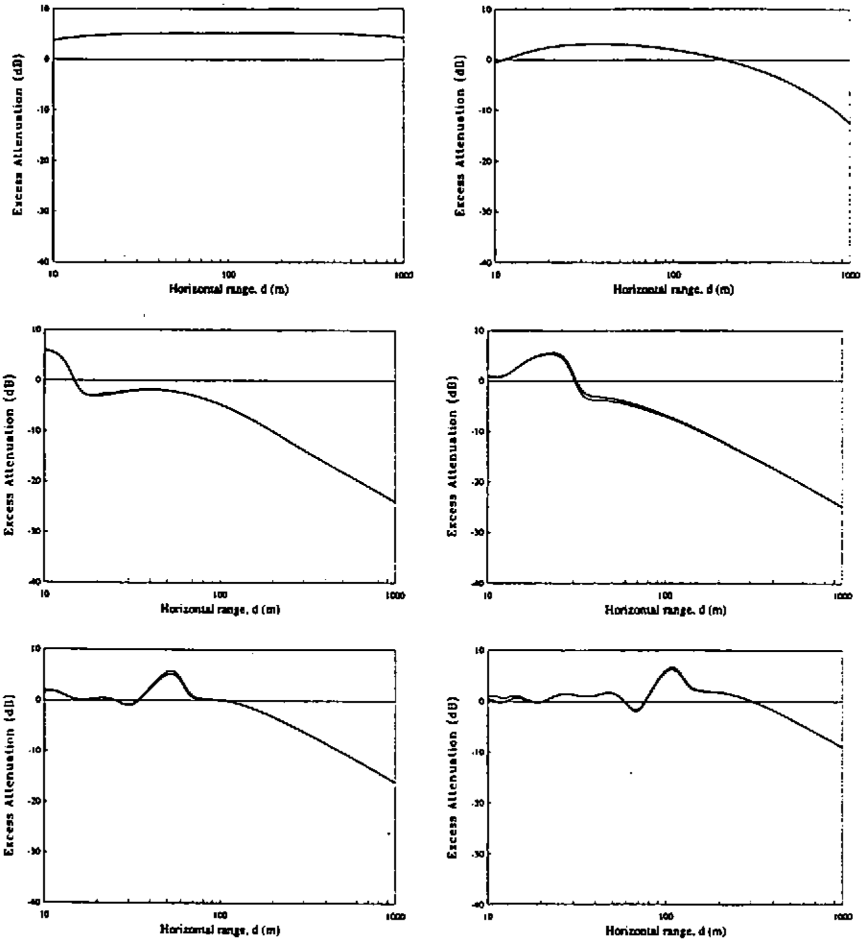

Figure 4: A comparison of the octave band excess attenuation for a simply supported panel (——) with a = b = 1m, (m,n) = (3,1), and a point source with similar far field directivity (▬▬), h_s = 0.5m and h_r = 5m.