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OUTDOOR SOUND PROPAGATION
INTRODUCTION AND REVIEW OF RELATED RESEARCH PROBLEMS

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APPLICATIONS AND PHENOMENA

Outdoor sound propagation is of interest to the prediction and the reduction of noise nuisance from surface and non-surface transportation and from industrial sources. In the U.K. the interest in the accuracy of predictions is enhanced by the various legislation (Noise Insulation Regulations, Noise Certification Procedures, Noise Abatement Zones). The subject is of interest for military personnel concerned with the detection, ranging and classification of acoustic sources. Finally, the subject finds applications in problems of outdoor communication and ecology [1]. Sound propagating outdoors is subject to absorption during its passage through the atmosphere, reflection by the ground surface, diffraction by barriers (topographical, artificial or purpose-built) and by impedance discontinuities, scattering by vegetation and by surface roughness, turbulence associated with convection and surface roughness and refraction associated with wind- or temperature-gradients. Measurements outdoors that permit the isolation of one or several of these mechanisms are notoriously difficult and scarce. Since the last review of the topic in Institute proceedings [2], there has been progress in understanding and measuring all of these phenomena. However, this review concentrates on research problems related to the effects of ground reflection, impedance discontinuities and vegetation. Recent advances in the study of air absorption turbulence and refraction phenomena have been reviewed elsewhere [3, 4]. It should be noted that the main influence of refraction is to increase or decrease the effects of ground reflection. Furthermore, turbulence will affect the extent to which patterns due to interference between direct and ground-reflected can occur.

GROUND EFFECT

Theoretically, the sound received from a point source above a plane absorbent ground can be expressed as the sum of three terms; the direct field, a contribution from the mirror-image source and a correction resulting from the sphericity of the wave fronts and the acoustic properties of the ground. The predicted effect of the presence of an absorbing ground plane is to produce an attenuation in excess of that due to spherical wave-front spreading. Theoretical analysis, based upon contour integration, shows that, at grazing incidence, the correction term has the form of a surface wave which propagates with less attenuation than the spherical wave front from the source. The existence of the surface wave is critically dependent upon the acoustical properties of the ground and upon the grazing angle. When the surface is supposed to be locally-reacting and the source and receiver are on the boundary, the condition for the existence of the surface wave simplifies to the requirement that the imaginary part of the (complex) normal surface impedance should be greater than the real part.

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Calculation of the excess attenuation from an incoherent line source of cars or trucks, over various ground surfaces of known or estimated normal impedance, and assuming all these surfaces to be locally-reacting, shows significant variation of the rate of attenuation with source-receiver separation, mean propagation height and type of surface [6]. There is considerable evidence that flat grass-covered ground can be regarded as locally reacting and, in the absence of climatic effects, theory is able to give accurate predictions of measurements [3, 7, 8]. However, more measurements are needed to check the validity of this assumption about non-grass surfaces and to investigate the effects of layering and thus to substantiate the predicted ground effect [6]. A different approach to prediction of the field above an absorbent plane even when there are layered inhomogeneities, utilises the Fast Fourier Transform algorithm as part of a numerical method [15]. However, comparison with the analytical approach based upon Contour Integration needs to be made on a fairer basis. In [9], the asymptotic solution resulting from analysis is taken only as far as the terms in 1/r before comparison. Moreover, the numerical method does not lead to physical understanding of the phenomenon of ground effect.

BARRIERS

According to the theoretical description of the total sound field above plane absorbing ground, the presence of purpose-built barriers will have two contrary effects. If the top of the barrier may be regarded as a secondary sound source, then the mean propagation height from source to receiver is raised compared with the unobstructed situation. Thus excess attenuation due to the presence of an absorbing ground plane is likely to be reduced. On the other hand, since the possibility of near-grazing incidence is reduced, there is less likely to be a surface wave and, consequently, the presence of the barrier increases excess attenuation due to the ground in addition to diffraction effects due to the barrier. Whatever the effects of the barrier, however, its erection on plane absorbent ground requires some consideration of ground reflection in relevant theory [5, 10]. Furthermore, this consideration suggests that insertion loss is a better measure of barrier effect than attenuation measured after erection. Interaction between barrier effect and ground effect is the basis for a suggested method of reducing highway noise by a series of parallel regularly-spaced low walls [11].

IMPEDANCE DISCONTINUITIES

So far, few predictions of ground effect for highway noise have not considered the fact that the source is radiating from above a hard (road) surface even though a substantial part of the propagation may be above absorbing ground. A similar problem arises with the presence of parking areas or service roads. Indeed, the general problem of the presence of impedance discontinuities is likely to be relevant to many situations of outdoor sound propagation. Three relatively ad hoc methods for dealing with this problem have been proposed [10, 12, 13]. Further careful measurements are needed to show whether more sophisticated analyses should be applied [14].

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VEGETATION

To some extent, the influence of vegetation can be taken into account theoretically by assuming that it merely modifies the normal surface impedance of the underlying soil which remains otherwise locally-reacting [6]. However, the presence of vegetation, apart from introducing uncertainty in the location of the ground surface introduces mechanisms of dissipation, other than those associated with viscous effects in pores. This is true particularly when considering propagation through or over forests [5]. At present, it would be possible to compute attenuation through forests by a simple arithmetic sum of the various attenuations involved. However, the total sound field within and above the forest is likely to be the result of interaction between attenuation mechanisms related to the various components and this needs further investigation.

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See ~~Do~~ Daigle 1980 ~~Sect~~ Turbulence effects

> Changes coherence: wavefront changes - beam spreading of a narrow beam. Effects probably 1200 → 2K

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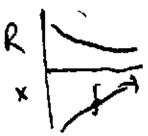
Some evidence ground can be treated as locally reacting



Canada (inclined tube) + (imp tube)

→ same results ∴ locally reacting

Delany & Bazley - theory & expt of ?? porous absorbers

Rasmussen ?