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SCALE MODELLING OF SOUND PROPAGATION OVER FLAT UNOBSTRUCTED ABSORBING TERRAIN

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Introduction

Scale models are now recognised as having a useful role to play in both the design and problem solving areas of acoustics. Although originally developed as an aid to the design of auditoria, they now find extensive use in the fields of outdoor sound propagation and industrial noise control.

In the context of outdoor sound propagation, the main advantage of a scale model is that it enables experiments to be conducted within a controlled environment free from the vagaries of wind and temperature gradients and other climatic effects.

The simplest scale model consists of a source, a receiver and a horizontal surface, with variables source and receiver heights, separation distance and surface. Such models have been used extensively to test the theoretical predictions for point source propagation above a finite impedance surface.

Models have also been used to evaluate the effects of surface impedance variations. Of particular interest are those which locate the source over a rigid strip, as in the case of a road vehicle, and those which include an infinite rigid strip normal to the propagation path.

This contribution reviews some of the work currently being conducted at the Open University, and in particular looks at some of the recent proposals for measuring the impedance of scale modelling materials.

Modelling the Propagation Path

Propagation between source and receiver imposes strict scaling requirements upon the experimental method. Unless measurements are made outdoors, reflections from the laboratory walls and ceiling intermingle with those from the model surface and introduce errors. Two techniques exist to minimise the effect of such reflections, absorption and time gating.

Absorption is essential if continuous sources, such as air jets, are to be used. However, it is not necessary to cover all surfaces with absorbent, only those likely to contribute significant reflected energy. Time gating can be used with transient sources, such as tone-bursts or sparks, to limit the measurement period.

A further consideration when modelling the propagation path is the choice of scale factor. Early experiments were limited to values based upon powers of 2 or powers of 10; since these are compatible with octave and 1/3 octave filter sets. The availability of digital spectrum analysers has removed this limitation and the experimenter is free to choose a scale factor based upon modelled path length and available room size.

Modelling the Source and Receiver

The essential characteristics of the source that need to be modelled are bandwidth, directivity and size, but in practice the only one that presents any problem is directivity. Possible solutions involve using several distributed sources to produce the appropriate characteristic.

A major problem with all model sources is that of power output. Insufficient power can result in errors due to an inadequate signal to noise ratio, especially when the received field is dominated by interference effects. For scale factors less than 1/10, the two main model sources are air jets (continuous) and sparks (transient). Both these devices have fixed output spectra and omni-directional characteristics.

The model receiver is usually a commerically available capacitor microphone, either 1/4" or 1/8" in diameter. Although these devices have an acceptable frequency response, their sensitivity and directionality at high frequencies are far from ideal. Some improvement in directivity can be obtained by fitting a nose cone or by using an open diaphragm.

Modelling the Group Surface

The greatest problem to scale modelling outdoor sound propagation is the modelling of the ground surface itself. The choice of material to simulate ground effects is very difficult because one must scale the impedance at the model frequencies.

The local-reaction ground surface can be adequately described by a normal incidence impedance. However, measuring this over the frequency range of interest (1-100 kHz) poses many problems. The impedance tube can be used up to several kilohertz, provided that the tube diameter is sufficiently small to inhibit cross-modes propagating within the tube. Commercial tubes can be used up to 6 kHz, but above this free-field methods must be used.

Free-Field Impedance Measurements

Several free-field impedance measurement techniques have been proposed in recent years, but most are of limited use because they assume the incident waves are plane, whereas outdoor measurements have shown single vehicles are best modelled as point sources. Theoretical solutions for point source propagation indicate that the received field is dominated by a 'surface-wave' like term at low frequencies and grazing angles of incidence. Hence the plane approximation can introduce significant errors into the impedance measurement.

Recently two measurement procedures have been outlined which should overcome the plane-wave problem (1,2). The first method measures the transfer function between to vertically separated microphones and A and B, compares the result to that obtained from a theoretical prediction. The technique has the advantage that the frequency response of the microphones can be eliminated by performing two measurements, the second with the microphone positions reversed. The actual transfer function is the geometric mean of the two results.

The theoretical solution chosen is that most appropriate to the ground surface to be modelled, local reaction, extended reaction or layered. The impedance is determined by minimising the function

$$H_{AB}(\omega) - \frac{\Psi_{B}(\omega,z)}{\Psi_{A}(\omega,z)}$$

where $H_{AB}(\omega)$ is the mean of the measured transfer functions. $\Psi_B(\omega,z)$ is the predicted field at the higher microphone and $\Psi_A(\omega,z)$ is the predicted field at the lower microphone.

The major criticism of the technique is that there is no justification for the assumption that the resulting impedance value is unique. However, results obtained for real ground surfaces do show good agreement with those obtained from other measurement techniques.

The second technique utilises the concept of homomorphic deconvolution as outlined by Bolton and Gold. A single microphone is used to measure combined direct and reflected pressure, and the complex cepstrum calculated from the single sided complex spectrum. If the direct and reflected components do not overlap significantly, it is possible to separate them by 'comb-filtering' in the cepstral domain, and hence determine the reflection coefficient and the impedance.

The first advantage of this method is that a single microphone can be used to measure the direct and reflected waves, therefore no errors are introduced by a non-uniform frequency response. However, it may be necessary to correct for directivity. The second advantage is that no assumptions need be made regarding the incident wavefront.

Conclusions

Scale models have proved a reliable method for testing recent developments in the theoretical prediction of point to point sound propagation over absorbing terrain. Furthermore, they enable one to examine site configurations for which no theoretical solution exists. Future developments will examine the possibility of using scale models to measure the field transmitted into the ground surface with a view to predicting the transfer function.

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References

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