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ACOUSTIC SCALE MODELLING OF LARGE FACTORIES

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Introduction

This talk reports on the shift in emphasis by the Cambridge-Southampton acoustic modelling team from modelling exclusively auditoria to modelling industrial noise situations. Whereas, on the auditorium side we have been able to present the results of a detailed analysis of the Barbican Concert hall model, we can only discuss the inception and future of factory modelling.

The Factory Problem

The situation in factories is rather different from auditoria in that we are generally dealing with acoustically non-diffuse spaces and this is the principal reason for resorting to models. Sabine's theory of reverberant sound fields does not adequately describe sound propagation in typical industrial halls because their height is low compared to their length and width. The sound level drops continuously with increasing distance from a single sound source and does not approach a constant reverberant level. A further complication is that we are dealing with numerous complex sound sources distributed over the whole floor space.

Clearly, where the noise is excessive in industrial buildings it is desirable to control it at the source. However, this approach is very often not practical and consideration must be given to the treatment of walls and ceiling with absorbent material, the re-arrangement of machinery and the use of screens. The main problem involved with this solution is predicting and optimising the effectiveness of the noise control measures to be installed. We require, therefore, a technique which will enable us to evaluate the sound distribution in factory spaces under various conditions.

Mathematical Models

Simple mathematical models of sound propagation can be used where, for instance, the situation with a large number of identical machines can be represented by a two-dimensional array of point sources. This approach may have inadequacies but can nevertheless produce some interesting results. For example, let us consider an array of sources spaced 6m apart which is encompassed by a circle of 50m radius. Let us also assume that the reduction in sound level is 4dB for every doubling of distance from the source. The distance at which the sound level from a source is equal to the sound level from the remainder of the sources (a distance one might call "reverberation radius") is 0.6m. If we now increase the sound level reduction with doubling of distance to 5dB the so-called reverberation radius is 1m. For 6dB the value increases further to 1.5m. So these simple methods can give us an idea of what is going to happen in the real situation.

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More sophisticated mathematical models use computers to evaluate the noise distribution in factory buildings. One such model developed by Dr. Bschorr in Germany evaluates the intensity at a point by using a propagation model in which first order reflections are determined individually, and high order statistically. The computer can then automatically produce noise distributions in the form of contour or level maps. Although a high accuracy is claimed for this program (a mean deviation of 1.8 dBA between measurement and calculation for 140 comparisons) situations must arise where it is extremely complex to translate the absorption and scattering of machinery onto a computer program.

Acoustic Scale Models

It is considered, since acoustic modelling has proved feasible in the case of auditoria, that it will also prove feasible for factories. In the first instance the validity of factory modelling must be demonstrated. This problem is being tackled by constructing a model of a specific factory which is fairly typical of many other factories. This will enable results to be compared between the model and the real building and make adjustments to the model where necessary. If this exercise is successful then, clearly, factory modelling will be suitable as an aid for the acoustic consultant who will be able to evaluate the noise distribution in a particular factory design and calculate the cost benefit of various treatments. Moreover, the factory modelling technique will enable an investigation into the effectiveness of new types of noise control measures as well as checking on the established procedures.

The main factors which have to be considered in modelling industrial spaces are as follows:

1. The absorptive properties of the internal surfaces and the absorption by air have to be scaled.
2. The absorption and scattering provided by machinery and stock must be modelled.
3. The model source transducers must be designed so as to simulate the spectral and spatial characteristics of industrial noise sources.
4. Appropriate measurement techniques must be developed.

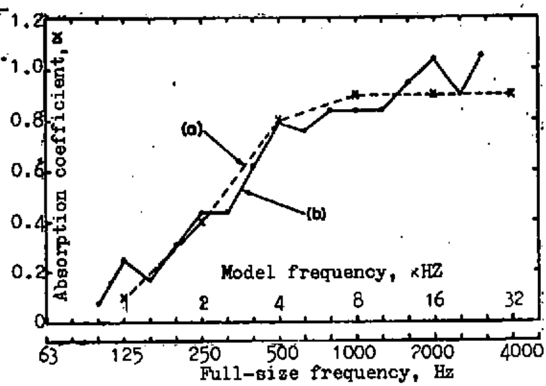

Figure 1. Absorption coefficient of mineral wool and its eighth scale equivalent.

(a) 30mm Rockwool against solid backing
(b) 4 mm Felt. Density 1.6 Kg/m^2.

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Model Materials
In auditoria, the acoustic character of surfaces is generally either absorptive such as porous absorbers or predominantly reflective such as concrete walls. Because of the different absorption characteristics of these two groups, different measurement techniques are employed to measure their absorption coefficients.

Porous absorbers are measured by the normal reverberation chamber method using a model tank which has been scaled down from the ISO standard reverberation chamber. A typical material measured by this material is, for example, high density felt which can be used to model mineral wool (Figure 1).

Materials which are predominantly reflective are difficult to measure by the reverberation chamber method because their low absorption produces only a small change in reverberation time (R.T.). The easiest solution has been to build a box out of the test material and measure its R.T. thus yielding the absorption coefficient. 12mm plywood, for instance, when it has been sealed with 2 or 3 coats of gloss varnish has an absorption coefficient of about 0.05 at model frequencies and is therefore suitable for modelling concrete and brick walls. The acoustic character of surfaces in factories is not as straightforward as in auditoria. Modelling of the factory roof, for example, requires particular attention. The present trend in industrial building is to use corrugated sheet structures often with a trapezoidal type profile. These constructions have considerable absorption at low frequencies which falls off to a minimum of about 0.05 around 1 or 2 kHz. We are in the process of investigating materials to simulate this type of absorption characteristic.

Air Absorption
Again from our auditorium modelling work we have gained considerable experience in dealing with the modelling of air abosrption. For perfect acoustic modelling, $m' = \sigma m$, where m' is the air absorption coefficient at the model frequency, m is the absorption coefficient at the full-size frequency and σ is the scaling factor.

Two basic mechanisms are involved in air absorption: the so-called classical absorption and the molecular absorption. Classical absorption arises from viscosity and thermal conductivity effects in air and is unavoidable. Molecular absorption depends on the simultaneous presence of oxygen and water vapour and involves the conversion of vibrational energy in the oxygen molecules into translational energy, catalysed by the presence of the water vapour molecules.

The molecular component can be minimised by demuhidifying the model to a relative humidity of around 2%. In this condition we have near perfect scaling when modelling at eighth scale.

However, eighth scale models of factories can be very large and it may be necessary to reduce the scale to one-sixteenth. The modelling of air absorption will not be quite as good at this scale. At 4kHz equivalent the coefficient is half as big again as it ought to be which means that corrections will have to be applied. Below this frequency, however, the error is not very significant.

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Model Sources

Probably the most difficult obstacle to overcome when modelling factories is the design of the sources of industrial noise. These will have to simulate the diverse spectral and spatial characteristics that are encountered in practice. There are four types of sound generator available for modelling the sources: the electric spark, the loudspeaker, the air-jet and the mechanical transducer.

The electric spark is a useful impulsive source which radiates well into the ultrasonic region and is omni-directional. If a triggering electrode system is used adequate reproducibility can be obtained Its main drawback, however, is that in the region adjacent to the spark the propagation of sound in non-linear, it does not follow the inverse-square law. A spark with an energy of 2 joules, for instance, behaves non-linearly within a circle of radius 1m. This is not a serious problem in auditorium modelling where we are not too concerned about propagation in the vicinity of the source. In factory models, however, screens may be purposefully placed close to sources which would result in errors if a spark source were being used.

Several types of high frequency loudspeaker are available which radiate in the ultrasonic region. Broadband piezo-electric transducers, for example, operate up to 30kHz and have a high sound output. Small electrostatic loudspeakers are available which can radiate up to 100 kHz. Unfortunately these loudspeakers tend to be highly directional at ultrasonic frequencies. Another possibility is to control the directionality of a loudspeaker by feeding the sound down a tube. This technique has proved successful in the design of a speech source for auditorium work.

One source which could prove effective is the use of an air-jet. This has the advantage of being a broadband, omni-directional source which propagates linearly. It may also be possible to shape its noise spectrum by introducing various cavities and nozzles. One factor to be considered in the design of this source is that the air emanating from the jets must be dehumidified. It should be possible, however, to use a small compressor and reservoir somewhere in the dehumidifying circuit.

Measurement Techniques

Measurement of reverberation time in models will follow a fairly standard procedure. Recordings of noise bursts are played through the model whilst simultaneously recording the microphone signal. This recording is replayed, at slow speed, to a level recorder. However, it is not thought that much weight will be placed on the results of R.T. measurements since there appears to be no simple correlation between the reduction in R.T. in a factory and the resultant noise level reduction. A more useful measurement is the reduction in sound level with doubling of distance.

We hope to follow a measurement programme which will investigate the effect of the following parameters on sound propagation in factory buildings: different kinds and thicknesses of absorptive material; different methods of mounting; vertical noise absorbers of various types; and different groupings of machines and screening of machines. Finally, we hope to establish whether it is possible to model a small part of the total factory enclosure if the layout of machines is repetitive by modelling a representative element and surrounding it with reflective surfaces. If successful, this technique will provide an inexpensive and quick means of investigating alternative methods of noise control in a given situation.