THE SCATTERING CROSS SECTION AND MEAN ABSORPTION COEFFICIENT OF FACTORY FITTINGS

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1. INTRODUCTION

Concern over the danger of noise induced hearing loss in industry has resulted in a considerable amount of research being undertaken with the objective of developing an accurate method of predicting noise levels in factory buildings. A method is urgently needed which will both enable the designer or acoustic consultant to assess the danger of noise induced hearing loss in a given situation and also the effect of any acoustic treatment applied to reduce that danger. The need for such a predictive method has become even more urgent in the UK following the introduction of the Noise at Work Regulations in January 1990 (1).

Conventional techniques for predicting noise levels in rooms based upon Sabine acoustics have been found not to work in most industrial spaces. This is largely because of the disproportionate shape of typical factory buildings (ie. one dimension being of a different order of magnitude to the other two).

Orlowski has recently investigated the efficiency of a number of factory noise prediction models and has concluded that ray tracing models based upon a Poisson distribution of point scatterers are the most promising (2). Similar conclusions have been drawn by Hodgson (3).

2. THE ONDET-BARBRY MODEL

The particular ray tracing model that Orlowski concluded had most promise was that developed at INRS, Vandoevre-les-Nancy by Ondet and Barbry (4,5) which drew on earlier work by Kuttruff (6) and Kurze(7). A particular feature of the Ondet Barbry model is the simple yet efficient way in which it treats fittings (eg. machinery) which absorb and scatter sound in such spaces. No attempt is made to accurately model a particular installation in terms of fitting size, shape or layout. Instead the distance between pairs of fittings is assumed to follow a Poisson distribution and the fittings are assumed to behave as point-like randomly scattering objects. The parameter which characterises the Poisson distribution is the scattering frequency, Q, which is given by:

$$Q = nS_s$$

where n is the number of scattering objects per unit volume
S_s is the mean scattering cross section of scattering objects. This is the acoustic scattering cross section averaged over all possible angles of incidence.

The model has been validated by a number of investigators. The validation has taken two forms. The first has involved measurements (either in real buildings (5) or scale models (8)) but employing unrealistic scattering objects - typically simple shapes for which the scattering cross section could be easily estimated. Nevertheless, these experiments have demonstrated the validity of the Ondet Barbry approach for simple scatterers.

The second form of validation is that typified by the work of Hodgson who has applied the Ondet Barbry model to the prediction of noise levels in a large workshop (3). His approach to the problem of determining the fitting scattering frequency was to assume a value and then to compare predicted sound propagation characteristics with measured values and to make appropriate adjustments to his assumed values until acceptable agreement was achieved. This procedure is only applicable to the limited case of an existing building in which it is required to apply the model to investigate the effect of possible noise control methods.

At the present time there is no method of determining the value of the mean scattering cross section for other than very simple objects. Ondet and Barbry suggest that the scatterer could be simulated by a sphere with the same external surface area and that the simple relationship that exists for a sphere between surface area and cross sectional area be applied in this case. (ie. the surface area of a sphere is four times its cross sectional area). The Ondet-Barbry suggestion is questionable on physical grounds since it is to be expected that a fitting with a higher ratio of surface area to volume (ie. "spindly") would scatter sound in a very different manner to a fitting with a lower ratio. Other suggestions have included simulating the scattering object by a sphere (or rectangular box) totally enclosing it or by a sphere (or rectangular box) embedded within its overall dimensions.

3. THE SIMULATION

The conventional method of defining the acoustical characteristics of a disproportionate space containing an arrangement of scattering objects is by means of a plot of the difference between the sound power level of a point source and the sound pressure level due to the operation of that source as a function of distance from the source. This is known as the sound propagation characteristics (SP) of the room. For a proportionate room the difference between sound power level and sound pressure level would tend to a constant value a short distance from the source. For the disproportionate room the difference continues to increase with distance and the rate of increase is determined by the room shape and the distribution and nature of the fittings.

In order to investigate the the effect of the various parameters in the Ondet-Barbry model on the SP characteristics of a factory space the program was run and the input parameters systematically varied. Two different types of disproportionate room (LONG and FLAT) were simulated representing two cases of typical industrial buildings. Sound propagation characteristics were obtained for a number of cases. A single zone space was assumed ie. the density of scatterers and hence the scattering frequency was uniform throughout the space.

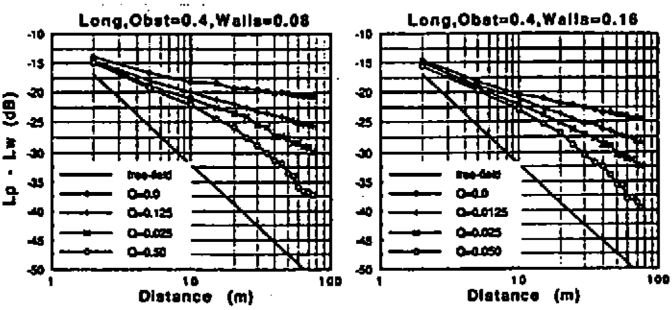

Figure 1 Examples of Sound Propagation Characteristics

Some examples of the sound propagation characteristics of the LONG room are shown in Figure 1. In order to show the influence of the various parameters on sound propagation, four SP curves, each corresponding to a given value of Q and the free field curve are shown. The curves show the characteristics of SP in large disproportionate rooms ie. levels decrease continually with distance.

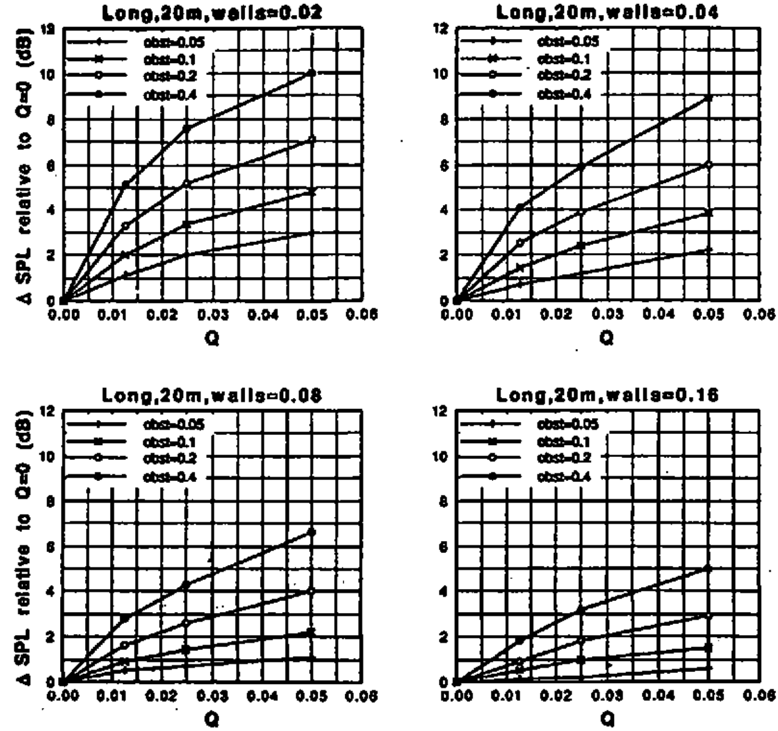

Figure 2 Effect of Q

In order to further clarify the effect of Q, the sound levels obtained at a number of set distances from the source for particular values of Q relative to the sound pressure levels at the same point in an empty room (Q=0) were plotted (Figure 2). These curves could be used to estimate the degree of accuracy required in the measurement of the scattering cross section and absorption coefficient. As the objective of employing ray tracing programs to predict factory noise levels is to establish the risk of noise induced hearing loss, the accuracy of prediction of sound pressure level should be similar to that required in a measurement survey aimed at establishing the L_{eq}. From an examination of Figure 2 this means that for an accuracy of 1 dB it is necessary to know the scattering cross section and absorption coefficient of fittings to an accuracy of 20%.

A further conclusion can be drawn from an examination of Figure 2 and that is that it is *the product of scattering cross section and absorption coefficient* that determines the difference between the sound pressure level in a room with fittings and the empty room. It can be seen that, starting with a given value of scattering frequency and absorption coefficient, the same difference in sound pressure level is obtained if one parameter is halved and the other is doubled.

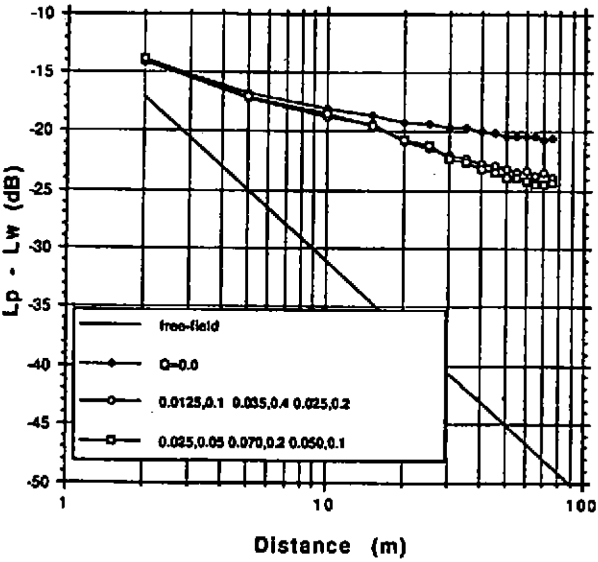

Figure 3 Sound Propagation in Multi-Zone Space

This hypothesis was tested by running the program for a series of cases where the values of scattering cross section and absorption coefficient were varied whilst their product remained constant. It was found that the SP characteristics were generally almost identical. Simulations were carried out for both single zone and multi-zone spaces. Figure 3 shows results obtained for a three zone space. The product of scattering cross section and absorption coefficient differed from zone to zone whilst in a particular zone different values of each parameter were employed but the product was kept constant.

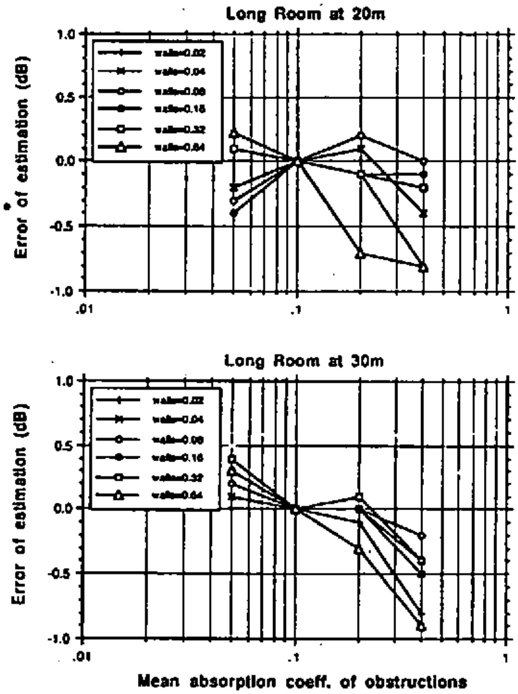

Figure 4 Errors of Estimation

4. DISCUSSION

It could be argued that the total absorption of an object as measured in a conventional reverberation chamber is equivalent to the product of scattering cross section and absorption coefficient and this is the data required for the Ondet-Barbry model. The computer model, however, requires the input of two distinct parameters. A possible approach might be to measure the absorption of the scattering object, A, to assume a value of the absorption coefficient, a, based upon an intelligent guess and to obtain a value of S_x as:

$$S_x = A/a$$

A value of 0.1 would seem to be appropriate for a.

Figure 4 shows a plot of the error of estimation resulting from the above approach. The error is the difference between the sound pressure level obtained by inputting the correct value of S_x and *a* and that obtained by using an estimate of S_x as suggested above. For all but the most extreme cases of high wall absorption coefficient it can be seen that the error is typically less than 1 dB.

5. CONCLUSIONS

It has been shown that in order to make use of the Ondet-Barbry model it is essential that a method of determining the value of the scattering cross section and absorption coefficient of fittings be devised. From an examination of SP characteristics obtained from a number of simulations it is suggested that it might be possible to use a simple measure of the absorption of a fitting as determined by measurements in a conventional reverberation chamber. This hypothesis will be tested as part of an on-going research programme at the Acoustics Research Unit at the University of Liverpool.

7. REFERENCES

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