Proceedings of the Institute of Acoustics

DETERMINATION OF THE SCATTERING PARAMETERS OF FACTORY FITTINGS

H.A. Akil and D.J. Oldham

Acoustics Research Unit, University of Liverpool, P.O. Box 147, Liverpool L69 3BX.

1. INTRODUCTION

Computer based prediction models are generaly accepted as the best methods available for predicting noise levels in factory buildings. One computer model,RAYSCAT, based upon the ray-tracing technique and developed by Ondet-Barbry [1,2,3 and 4] has found considerable favour since it can be applied to a greater range of factory fields than many other existing models [4]. The model was designed to take into account almost all relevant factory parameters such as building geometry (dimensions and shape), surface properties (absorption coefficient), screens (location, dimensions and absorption coefficient), fitting parameters (density, scattering effect and absorption coefficient) and source properties (position and acoustic power).

Oldham and Akil [1,2] have investigated the RAYSCAT model by means of a number of computer simulations inputting systematically various values of model parameters. They have come to the conclusion that in order to make use this prediction model it is necessary to have very accurate values of the scattering cross section (*Sx*) and mean absorption coefficient (*αobst*) of factory fittings. At the present time there is no method available for determining these two parameters. In this paper we discuss how the required information might be obtained.

2. HYPOTHESIS

In earlier papers Oldham and Akil reported the results of investigations of the influence of various parameters on the Sound Propagation (*SP*) characteristics in two disproportionate rooms by applying RAYSCAT [1,2]. They concluded that it is the product of scattering cross section (*Sx*) and absorption coefficient (*αobst*) of fittings which determines the sound propagation characteristics in a room. *Sx* determines the value of the scattering frequency (*Q*). The parameter *Q* is defined by:

$$Q=nS_x \qquad (1)$$

where n is the number of scattering object per unit volume.

SCATTERING PARAMETERS

From an examinations of the effect of *Q* on *SP* obtained from a number of simulations, it was found that the difference in sound pressure level (*SPL*) in room with fittings and without fittings is almost constant and the *SP* characteristics are nearly identical if one parameter is halved and the other is doubled (see Figures 1 and 2). Figure 1 shows the difference in *SPL* between a room with fittings and without fittings at position of 30m from the source. Figure 2 shows *SP* characteristics as a function of the product of *Q(Sx)* and *αobst* both for the single zone case and a multi zone case.
From this comparison it can be seen that if the product of the scattering cross section (*Sx*) and absorption coefficient (*αobst*) of fittings can be determined in some way this is actually all the information required about the fittings for use in the model.

As the computer model needs the input of two distinct parameters, Oldham and Akil suggest that having measured the product, A, a way of solving this problem was to assume a value of absorption coefficient of an object *αobst* (based upon an intelligent guess) then the value of *Sx* can be estimated by:

$$S_x = \frac{A}{\alpha_{obst}} \qquad (2)$$

This approach was tested by means of the computer simulation assuming *αobst* = 0.1. In order to investigate the error of estimation, the difference between the sound pressure level obtained by inputting the correct value of *Sx* and *αobst* and that obtained by using an estimate of *Sx* obtained as described above was plotted for various values of the absorption coefficient of the wall (see Figure 3). It was found that the error of estimation was typically less than 1dB even in the most extreme cases of high wall absorption coefficient.

3. EXPERIMENTAL DETERMINATION OF A

The acoustic characteristics of a disproportionate space are usually characterised by the sound propagation which is the difference between the sound power level of an omnidirectional source and the sound pressure level resulting from its operation as a function of distance from the source. As the sound propagation characteristics are determined by the product of the scattering cross section and absorption coefficient of fittings then it follows that measurement of sound propagation in a disproportionate space could be used to determine the value of the product.

SCATTERING PARAMETERS

In their earlier work Oldham and Akil obtained numerous plots of sound propagation characteristics for two types of disproportionate space (FLAT and LONG) and for a range of scattering and room absorption characteristics. From this work some of the optimum characterisics of a disproportionate test chamber can be deduced. As the objective in designing such a chamber would be to obtain maximum divergence for a given change in scattering conditions it is apparent that a long room is to be preferred to a flat room.
The dimensions of the long room employed by Oldham and Akil were 80mx20mx10m. In constructing a practical test facility cost must be an important consideration and this will be determined by size. It will be necessary, therefore, to consider how the size of the test room might be reduced.
Oldham and Akil simulated the relatively simple case of a single zone space i.e fittings distributed throughout the entire volume. A more realistic experimental arrangement would be for the fittings to be concentrated in a zone close to the floor and for the height of this zone (determined by the maximum height of the fittings) to be much less than the 10m assumed in the original simulation. This has two potential consequences. The first relates to the positions selected for the measurement of sound propagation. These could be along a line situated in the zone populated by scatterers or above it in an zone devoid of scatterers. The latter alternative has advantages particlarly if anautomated traverse mechanism were to be employed as the fittings would not impede its operation. From a study of the effect of different measuring heights it was deduced that carrying out a measurement traverse above the zone containing the fittings will yield similar information to measurements in the fitting zone.
The second consequence resulting from all the fittings being situated in a zone close to the ground is the possibility of reducing the height of the test chamber since it might be supposed that the effect of scatterers on the sound propagation curve would be greater if the scatterers occupied a greater fraction of the total volume of the chamber. The effect of reducing the height of the test chamber from 10m to 5m whilst keeping the fittings in a zone of height 3m. was investigated. It was observed that for identical scattering conditions in the occupied zone, the greatest divergence in the sound propagation curves occured with the lower ceiling height.

As a result of the above analysis it can be concluded that a suitable test chamber might have the dimensions of 80mx 14mx5m with the absorption coefficient of all internal surfaces as low as possible.

Although systematic attention to the relevant parameters has reduced the dimensions the suggested facility is probably still too large to be constructed and it is necessary to examine alternatives.

4. THE SCALE MODEL APPROACH

An alternative to a full scale test facility could be a scale model version. At first sight this does not appear to be a particularly useful proposal since in order to model the scattering properties of a given fitting it would be necessary to know them in advance. However, Oldham and Akil have suggested that the product of the scattering cross section (*Sx*) and absorption coefficient (*αobst*) of fittings might be related to the absorption as measured in a conventional reverberation chamber. The form of this relationship could be expected to be a function of the geometry and absorption properies of the scatterer. It is possible, therefore to envisage employing a scale model to investigate this hypothesis and to seek relationships by means of a series of experiments on a variety of model fitting types. From these experiments it might be possible to establish a technique of determining the product of the scattering cross section and absorption coefficient from values of fitting absorption measured in a conventional reverberation chamber.

The use of acoustic scale modelling to investigate the properties of rooms is a widely accepted technique. In the physical scale model, the experimenter has greater flexibility particularly in controlling important parameters. In order to test the hypothesis two separate test rooms are needed (reverberation chamber and disproportionate chamber). Measurements of total absorption of fittings in a reverberation chamber should be carried out and also measurements of Sound Propagation (*SP*) characteristics in the disproportionate room from which the product of the scattering cross section and absorption coefficient can be determined.

5. DESIGN OF PHYSICAL SCALE MODELS

Although the construction of the scale model reverberation and disproportionate rooms is far simpler than that of an auditorium or theatre it is still necessary to consider any fundamental limitations to the scaling down of acoustic parameters such as air absorption and boundary absorption. It should also be remembered that scale modelling can be affected by the limitations of available instrumentation.

SCATTERING PARAMETERS

In order to model the behaviour of the full-scale sound field in miniature at scale 1:*K* (1/*K* is the scale-factor of the model), all dimensions must be scaled by 1/*K*. In order to maintain the correct wave effects, the model wavelength to dimension ratios must be the same as those at full scale. To obtain satisfactory data, investigations must be made up to a frequency of at least 2 kHz since noise components up to this frequency are commonly encountered in factories.

Reverberation and the propagation of sound will be affected by absorption due to either air in the room or to the surfaces of the room. The absorption of sound in air is the product of the classical absorption and the molecular absorption. The classical absorption is created by viscosity and heat conductivity effects, while the molecular absorption results from molecular relaxation processes associated with the water vapour present in air. These absorption components increase as the square of the frequency and therefore scaling frequency by a factor of *K* increases the air absorption by a factor of K^2.

Traditionally the excess air absorption can be minimised by the technique of reducing the relative humidity of the air inside a model chamber. This can be done by removing the water vapour (with circulating dry air) or by removing oxygen (by using nitrogen). The latter technique will affect the speed of sound.

An alternative to reducing Relative Humidity has been suggested by Polack et al [5]. In this method air attenuation is compensated using a computer technique (numerical compensation).
The selection of a sound source must be on the basis of the technique used for compensating for air attenuation. The sound source which can employed with the Polack technique is an impulse source. Furthermore, impulse sources have better omnidirectional characteristics at all frequencies. This will facilitate comparison with the sound propagation predicted in the computer model.

As far as the sound processes in the models are concerned, any sound transmitted through the walls of the model chamber is absorbed. In practice, an increase of transmitted sound can be avoided by increasing the wall thickness. The absorption due to thermal and viscous losses in the boundary layer of air at the walls would still exist even if the walls were perfectly rigid and smooth. This is known as "unavoidable" absorption coefficient. It is proportional to the square root of the frequency and given by

SCATTERING PARAMETERS

$$\alpha_{unv}=1.8x10^{-4}f^{1/2} \quad (3)$$

5.1 Model Reverberation Chamber

The measurement of total absorption of an object should follow the method specified in British Standard 3638:1987 [7]. Therefore, the specifications (volume and reverberation time) of the model chamber must be determined by scaling down the standard requirements for a full-scale chamber as given in BS 3638. In 1971, Spring of the British Broadcasting Corporation (BBC) [8], first, developed such model chamber with the scale factor one-eight. About ten years later, Orlowski [9] developed model reverberation chamber which was similar in design to the one-eight scale model chamber developed by BBC and used it for one-sixteenth scale measurements.

The model chamber consists of a rectangular tank constructed of 13mm steel plate. The interior volume of the model is 0.39m³ and the surface area 3.22m². To maintain the recommended relationship between the size of sample object and the volume of chamber, the area of a sample in this model must be 0.156m².

5.2 Model Disproportionate Room

A compromise between several conflicting requirements must be made when deciding upon the model scale. There are two practical choices of model scale factors considered here: one-tenth scale and one-twentieth scale. At a scale factor of 10, the highest frequency of interest is 20kHz. This would enable the use of standard equipment but would require a very large model. The dimensions of a model room may be limited by the size of the available space for housing it. A scale factor of 20 has the advantage of resulting in models which are small and, hence, economical to build, easy to house and easy to modify. However, this scale factor has disadvantages associated with the need to work at very high test frequencies (the highest frequency of interest = 40kHz) with the resultant high air absorption.
In order to determine optimum dimensions of a model and to investigate the effect of the various parameters in the RAYSCAT program on the *SP* characteristics of a model disproportionate room, a number of simulations were made for several cases of the model dimensions with the input values of parameters similar to those employed in the previous work [1,2].

SCATTERING PARAMETERS

For a one-tenth scale factor, simulations were made in a single-zone space for models with equivalent full-scale dimensions of:
(1) L80mxW20mxH10m
(2) L80mxW15mxH7m
(3) L60mxW15mxH7m
(4) L50mxW15mxH7m
(5) L50mxW15mxH4m
(6) identical to (4) but with one end wall very absorptive

Then simulations were also carried out for a double-zone space for the same arrangement as Case(6) above with receiver positions close to the roof and with close to the floor. For a one-twentieth scale model, simulations were made only in a single zone space and only for a model which had equivalent full-scale dimensions to the original LONG room.

In order to examine and to show the influence of scaling, all necessary parameters (model dimensions and air absorption) on the *SP* characteristics of the model, *SP* curves obtained for each case were plotted together. Examples of comparisons are shown in Figures 4, 5 and 6. Figure 4 shows *SP* characteristics of the models for Case(1) - Case(5), Figure 5 shows *SP* characteristics of the model for Case(6) whilst Figure 6 shows *SP* characteristics of full-scale room, one-tenth scale model and one-twentieth scale model.

6. DISCUSSION

The curve obtained from Case(1) as shown in Figure 4 where the dimensions were obtained by scaling down the original dimensions of the LONG room is much steeper than the curve obtained from any other case. This suggest that the bigger the model is the better. The reduction of the length of the model dimensions has little effect on the shape of the *SP* curves. By contrast, the reduction of the height of the model dimensions can greatly affect the *SP* curves. This can be illustrated by referring to the *SP* curves obtained from Case(1), Case(2) and Case(4), Case(5), as shown in Figure 4, the greater the height of the model then the steeper the *SP* curve obtained from the model.

The purpose of the simulations was to examine how small the dimensions of the model disproportionate room could be made whilst still giving rise to a measurable effect. Simulations were therefore made for the case of a small model with one of the end walls very absorptive (see Case(6)). The direction of the *SP* measurements is towards the absorptive wall. From Figure 5 it can be seen that the *SP* curves obtained are generally steeper than the *SP* curves obtained from Case(4). However, the effect of varied values of *Q(Sx)* on *SP* characteristics cannot be distinguished when the absorption coefficient of a fitting is low (0.05). Similar results were also found for the case of the double-zone space. Therefore, the use of an absorptive material on one end wall is not beneficial since a measurable difference in levels due to different values of scattering parameters is what is required.

As regards the *SP* curves obtained from the full scale rooms and the corresponding models as shown in Figure 6, similar propagation characteristics can be observed. The differences between the full scale room and a 1:20 scale model are larger than those between the full scale room and a 1:10 scale model. The highest difference (about 3 dB) is obtained when the position of the receiver from the position of the source is greatest (75m). When comparing the simulated effect of air attenuation on the *SP* curves using a 1:10 scale model with the simulated effect of that on the *SP* curves using a 1:20 scale model, the difference in results between two models is not too considerable. This suggests that a 1:20 scale model can be employed for validating the hypothesis regarding the determination of the scattering parameters of factory fittings.

7. CONCLUSIONS

It is suggested that measurement of total absorption of a scattering object in a conventional reverberation chamber can be used for determining scattering parameters of factory fittings. However, the hypothesis needs to be confirmed experimentally by means of measurements in a model reverberation chamber and a model disproportionate room.
From a study of *SP* curves obtained from a number of simulation it is suggested that a 1:20 scale model of a disproportionate room which has an equivalent full-scale dimensions of 80mx14mx5m would be an appropriate size for use in this experiment.
The measurement of reverberation time as an alternative to the measurement of sound propagation for the determination of the product of the scattering cross section and absorption coefficient can also be investigated using the model .

8. REFERENCES

[1] D.J. Oldham and H.A. Akil, "The accuracy of measurement of the scattering cross section of obstructions in industrial spaces", Proceedings Inter Noise '92 Vol. II, Toronto 1992, pp.731-734.

[2] D.J. Oldham and H.A. Akil, "The scattering cross section and mean absorption coefficient of factory fittings", Proceedings Euro-Noise'92, London 1992, pp.865-871.

[3] S.M. Dance and B.M. Shield, "Factory noise computer prediction using a complete image-source method", Proceedings Euro-noise'92, London 1992, pp.485-

[4] A.M. Ondet and J.L. Barbry, "Sound propagation in fitted rooms-comparison of different models", Journal of Sound and Vibration (1988) 125(1), pp.137-149.

[5] J.D. Polack, A.H. Marshall and G. Dodd, "Digital evaluation of the acoustics of small models: The MIDAS package", Journal Acoustical Society of America 85 (1), January 1989, pp.185-193.

[6] H.E. Bass, L.C. Sutherland, J. Piercy and L. Evans, "Absorption of Sound by Atmosphere", in Physical Acoustics, edited by W.P. Masson and R.N. Thurson (Academic Press), Vol. XVII, pp.145-232.

[7] British Standard 3638:1987, "Measurement of sound absorption in a reverberation room", British Standards Institution.

[8] N.F. Spring, "Acoustic scaling: A one-eighth scale model reverberation room. Report no 1971/3", Research Department, The British Broadcasting Corporation.

[9] R.J. Orlowski, "The arrangement of sound absorbers for noise reduction-Results of model experiments at 1:16 scale", Noise Control Engineering Journal, March-April 1984, pp.54-60.

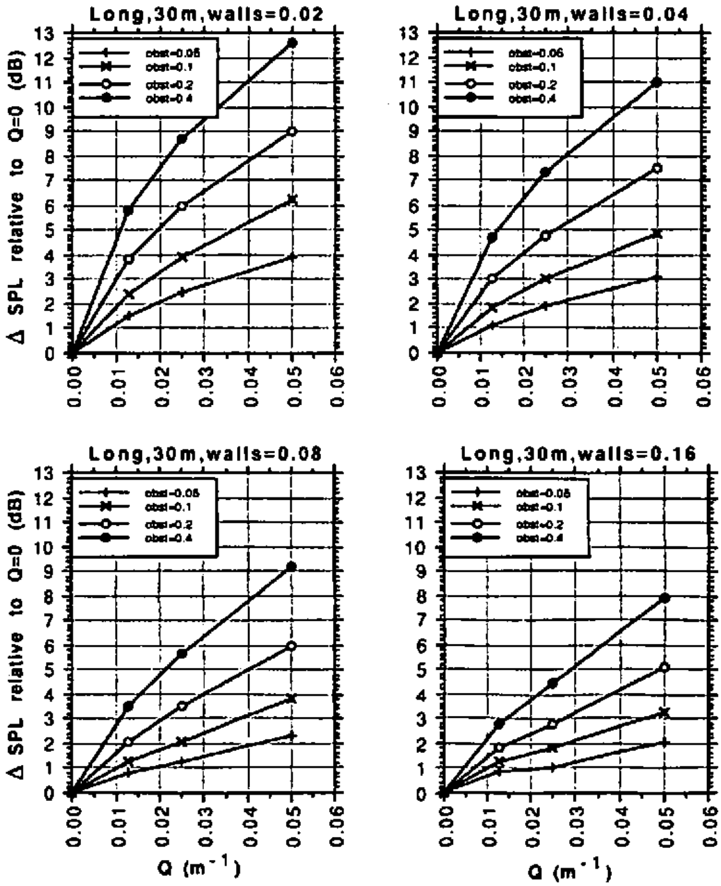

Figure 1. Effect of *Q* at position 30m from source

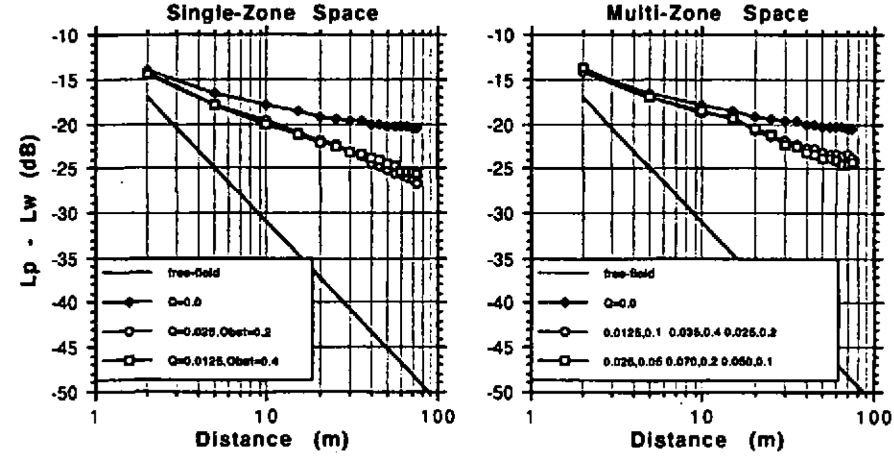

Figure 2. Sound Propagation in Single-Zone and Multi-Zone Spaces by the product of *Q(Sx)* and *αobst*.

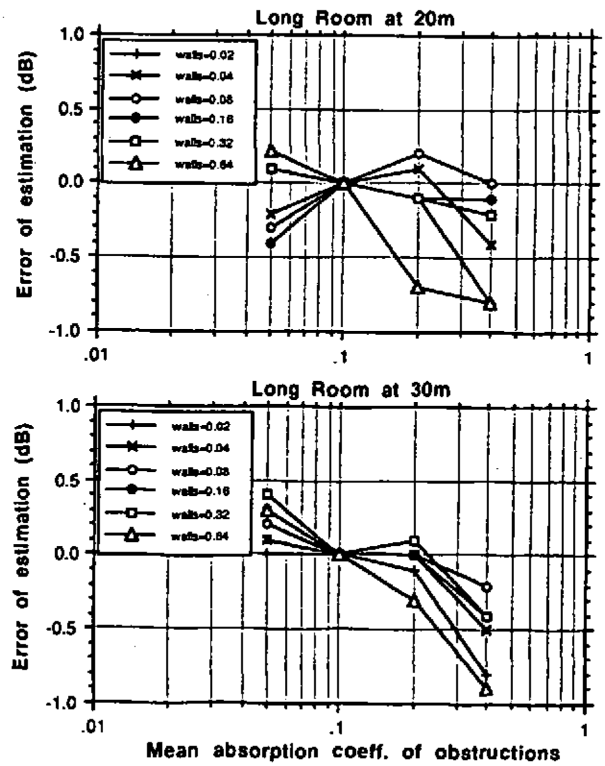

Figure 3. Errors of Estimation at positions of 20m and 30m.

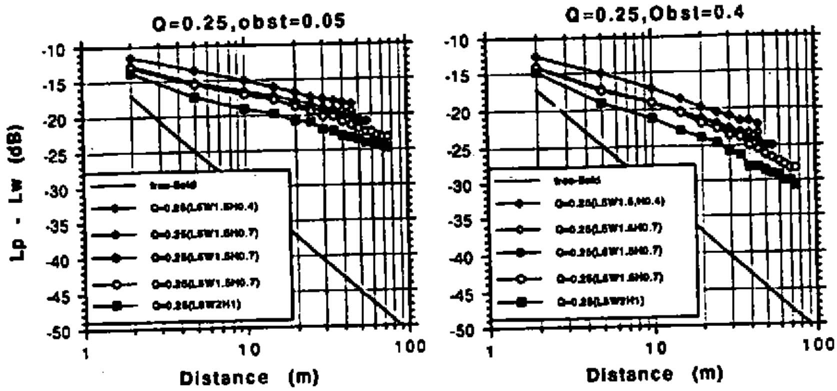

Figure 4. Sound Propagation in Several Models with different dimensions.

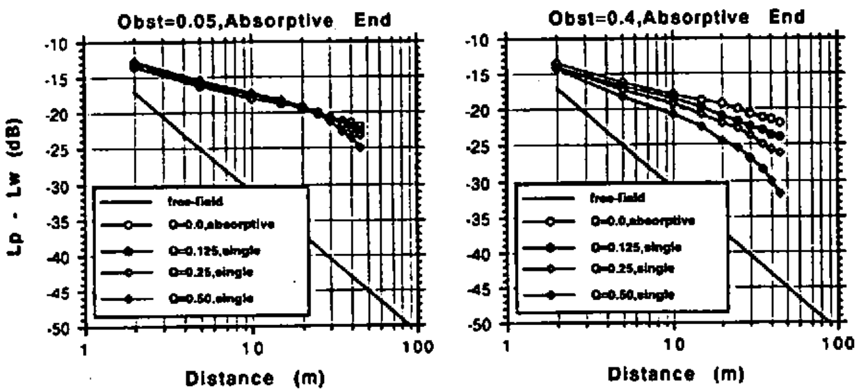

Figure 5. Sound Propagation in Model with one of walls is absorptive.

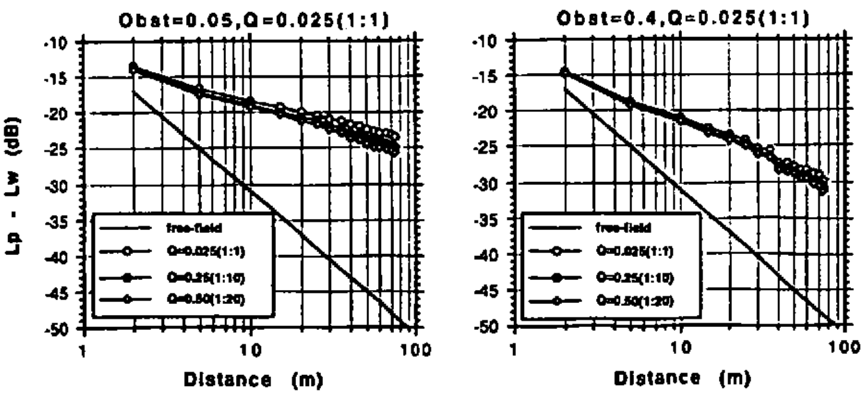

Figure 6. Sound Propagation in Full-Scale Room, 1:10 Scale Model and 1:20 Scale Model.