Proceedings of The Institute of Acoustics

DIFFUSION IN AUDITORIA AND AUDITORIUM MODELS

M BARRON

DEPARTMENT OF ARCHITECTURE, CAMBRIDGE UNIVERSITY

INTRODUCTION:

One of the characteristics associated with good auditorium acoustics is a diffuse reverberant sound field in which sound energy is uniformly distributed and with equal probability in all directions. However although there is general agreement about the desirability of diffusion there are no recognised means for measuring it and published design requirements to achieve adequate duffusion are vague. Moreover if we consider the simple auditorium we do not expect a diffuse field at all.

THE SIMPLE CASE:

The simplest model for an auditorium is a rectangular reflective enclosure with a highly absorbant floor. It is easy to appreciate that sound travelling in a horizontal plane above the audience/floor will be subjected to minimal attenuation on reflection and will have a long reverberation time associated with it. As will be discussed below, this horizontal sound field will dominate the later part of the decay; clearly the situation is far from diffuse. For the same situation, the image model also predicts non-diffuse conditions (1): the images of the source lie in two horizontal planes, one contains the source, the other is the mirror image of the source plane in the ceiling. From a spatial point-of-view this is clearly not diffuse and the predicted decay is curved i.e. non-linear.

In these conditions more diffuse conditions would exist for a vertical line source, which leads to the unhelpful suggestion that members of each orchestral group of instruments might be better arranged one above the other!

To create diffuse conditions in such unpromising circumstances, diffusing elements are added to the ceiling and walls. Scattering by a diffusing element is an irreversible process, so that in general the randomness of the sound field will increase with time. One of the difficult problems facing the designer is to know the required amount of such diffusing elements.

WHY DIFFUSION?

There are many possible reasons for diffusion; but some of these are now known to be spurious. There was a school of thought which considered that diffuse reflections were subjectively preferred to discrete ones. The most extreme manifestation of this school is the Beethovenhalle in Bonn, Germany, completed in 1959 with a ceiling of pyramids and hemispheres as well as diffusing side walls concealed by an acoustically transparent screen. It is now known that in most cases the ear cannot distinguish between a discrete and diffuse reflection and from the work of Damaske (2) that only a few widely spaced incoherent signals are needed to produce the subjective sensation of being surrounded by sound. The particular effect associated with early lateral reflections, known as 'spatial impression', depends on the proportion of lateral energy and not on any particular distribution of reflection direction (3). (For early reflections, the case for a diffuse reflection is limited to strong overhead reflections which have a tendency to create tone colouration).

The need for diffusion and diffusing surfaces is thus limited to the later sound, for the desirable characteristics of a diffuse reverberant field rather than a subjective preference for diffuse reflections as such. A diffuse reverberant field decays "linearly" (i.e. exponentially) and is spatially uniform. Though there is evidence that linear decays and spatial diffusion are not essential from a subjective point of view, diffuse conditions guarantee several desirable characteristics. A linear decay is likely to be subjectively preferable to a seriously non-linear one. Diffuse conditions are a condition for reverberation time (R.T.) formula to predict accurately. They are also a reasonable guarantee for uniformity throughout the seating area. From a spatial point-of-view receiving sound from behind appears important (4), a condition satisfied in a diffuse field. Diffuse conditions are probably a characteristic of the world's most respected concert halls.

The best documented example of a hall with a non-diffuse sound field is the Stadthalle in Göttingen, Germany (5). Longer reverberation times were measured in the hall than had been predicted. It was found that the upper region of the hall above the balcony served as a reservoir for sound energy which was gradually radiated downwards. The ceiling is highly articulated with pyramid shapes, but the upper wall surfaces are plane and allow a horizontal reverberation field with a small decay rate. The balcony front is critical in the coupling between the upper and lower sound fields and placing absorbent on this surface drastically reduces the R.T.. The importance of this example lies not only in the detail of the objective evidence about it, but also in the favourable subjective evidence concerning the general acoustics. In spite of the non-diffuse conditions, this extended reverberation time is preferred and overall the hall is well liked by both audience and performers.

This example demonstrates that in certain circumstances lack of diffusion can be desirable. However with the present state of the art it would be rash to use this experience to influence design in general. Aiming for diffuse conditions remains conventional wisdom and with good reason.

MEASUREMENT OF THE STATE OF DIFFUSION IN MODELS.

Many sophisticated methods have been proposed for measuring diffusion, but none appears to be completely satisfactory or widely accepted. There is nothing particularly novel about the following method, but it does appear to reveal important divergences from diffuse conditions unambigiously. In our experience lack of diffusion influences the measured reverberation time before affecting the linearity (or rather perceived shape) of the decay curve. The measured R.T. has the additional advantage that it can be treated statistically and compared with predictions.

It is normal practice when conducting a modelling project to measure the reverberation time in the model prior to installation of the seating. In general it is reasonable to assume diffuse conditions in this case since the only absorption is incidental and uniform. The absorption of the model seating can be measured accurately in a model reverberation chamber and the R.T in the model with seating can be predicted . If the measured reverberation time in the model with seating deviates significantly from the predicted value it is probable that there is inadequate diffusion. The requirements in terms of necessary diffusing treatment can readily be established; diffusing elements are added to the model until the predicted and measured reverberation times agree. This procedure has been found to work equally satisfactorily in models with scales of 1:8 and 1:50 (6). Three experiences of poor diffusion will be related.

PRACTICAL EXPERIENCES OF POOR DIFFUSION

1) To gain experience in 1:50 modelling a rectangular box was built with dimensions approximately equivalent to the Royal Festival Hall. The equivalent volume was 21,000 m^3; a plane and a coffered ceiling were constructed. Prior to model seating being developed absorbent velvet was placed on the floor and the reverberation time was found not to behave as expected in spite of the coffered ceiling. Diagonal strip diffusing elements were placed on the walls but this failed to modify the R.T.. To achieve diffuse conditions it was found necessary to distribute the absorbent velvet with 25% placed on the wall surfaces. Figure 1 shows R.T. values in the model empty, with velvet on the floor and distributed as well as the predicted values.

When subsequently model seating was developed, the experiment was repeated with model seating on the floor of the model and in this case predicted and measured R.T.'s agreed implying satisfactory diffusion. The results show that the physical height of the seats contributes to diffusion.. It is apparent that diffusion is not a trivial condition to achieve and that computer models etc. are unable to predict this sort of behaviour.

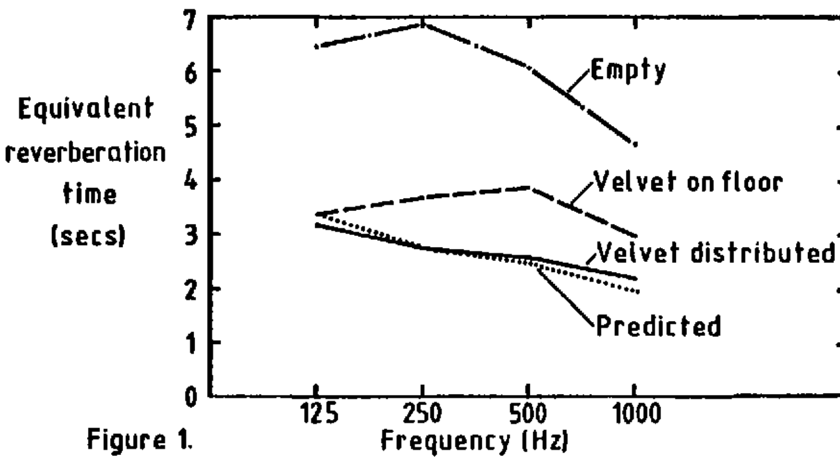

Figure 1.

2) A 1:8 scale model of the Barbican concert hall has been the subject of an extensive test programme. The halls most unusual feature is the 3.7 m deep beams dividing up the ceiling area. The reverberation time was measured in the empty model, then with half and finally all the seating installed. With half the seating all appeared well but with the total seating higher R.T.'s were measured than had been predicted. The largest discrepancy occured at 125 Hz where the measured absorption by the seating was only half the predicted.

About 2000 plastic spheres had been proposed which were then suspended at roof level. The measured total absorption increased dramatically at125 Hz giving a much better agreement for the total absorption on a percentage basis. It was obvious that the spheres were performing a useful diffusing role.

3) The third example comes from a 1:50 scale model of a theatre under construction. Again the reverberation time in the model with seating was found to be higher than expected. If the absorption coefficient of the model seating as measured in a model reverberation chamber is compared with the value measured in the model, the model value at 250,500 and 1000 Hz is only about 83% of the expected one. This difference was found to be significant at the 5% level. The reason for this discrepancy has not been investigated in detail but it is assumed to be due to shielding of some areas of seating by balconies.

CONCLUSIONS;

Though it is dangerous to generalise about something as fickle as the state of diffusion, our experiences suggest that inadequate diffusion may be a more common characteristic in auditoria than one is generally lead to suspect. Acoustic models are the only means at present of guaranteeing suitably diffuse conditions. Models at scales of 1:50 or larger are suitable for this purpose.

REFERENCES:

1. M. BARRON 1973 Journal of Sound and Vibration 27, 183-196. Growth and decay of sound intensity in rooms according to some formulae of geometric acoustics theory.

2. P.DAMASKE 1967 Acustica 19, 199-213. Subjektive Untersuchung von Schallfeldern.

3. M. BARRON 1974 Proceedings of the 8th ICA London. 2, 602. Early lateral reflections and cross-section ratio in concert halls.

4. P.H. PARKIN and K. MORGAN 1970 Journal of the Acoustical Society of America 48, 1025-1035. "Assisted Resonance" in the Royal Festival Hall, London 1965-1969.

5. E. MEYER, H. KUTTRUFF and N.ROY 1967 Acustica 19, 132-142. Raumakustische Untersuchungen an einem Modell der Stadthalle in Göttingen.

6. M. BARRON and C.B. CHINOY 1979 Applied Acoustics 12, 361-375. 1:50 scale acoustic models for objective testing of auditoria.