BRITISH ACOUSTICAL SOCIETY

70/113

"MODEL STUDIES IN ACOUSTICS"

12th November, 1970.

SMALL SCALE MODELS AND COMPUTER TECHNIQUES AS DESIGN AIDS FOR AUDITORIA.

A. H. Marshall. The University of Western Australia.

1. INTRODUCTION :

For at least 40 years scale models have been commonplace in the study of Auditorium acoustics, and for about 10 years the possibility of mathematical modeling by digital computer has been recognised. (1)

Since 1967, both techniques have been used in the acoustics laboratory in the University of Western Australia as design aids for the production of real buildings as well as for student designs in the School of Architecture. This paper deals with some aspects of this experience.

1.1 Blocks of equipment at the University of Western Australia.

There are three major blocks of equipment in the acoustics laboratory which are used for the design and analysis of auditoria. These comprise equipment for :

(a) Model measurements of spark generated reflection sequences.
(b) Analogue simulation of reflection sequences in an anechoic room, using direct sound, three independantly variable delays and six dependent variable delays, and an EMT reverberation plate. A PDP-11 computer is at present being interfaced to this simulator to control the presentation of the sound fields.
(c) Digital analytical processes.

2. SCALE MODELS :

Scale models of auditoria range extensively in size, elaboration, and in the claims made for them by their constructors. At their simplest they may be used, as we have used them, to measure the time spacing of reflections at a particular seat in an auditorium, or to trace rays optically. At their most complex, with the use of time-scaling tape recorders it is claimed that they may be used to predict reliably reverberation time, early decay time, and even to permit the accurate simulation of room conditions so that music recorded with scaled time in the model is recognisably the same as that recorded in the real room. (2) Apart from the considerable technical difficulties involved (suitable air conditions, accurate scaling of boundary and audience absorption) such sophisticated models have one major disadvantage in a design process. To function at all they must be large (1/10 to 1/15 full size). Their construction then becomes a significant percentage of the total building cost and is not possible at all until the building designs are substantially complete. Having constructed such a model, the designers' choice of further designs is prejudiced by its very existence. In other words the construction of an elaborate model implies that the acoustical and other design problems are already solved or at least decided and if that is the case it is difficult to see the point of the model.

3. SCALE MODELS FOR MEASUREMENT OF REFLECTION ARRIVAL TIMES :

By comparison, the cost of a model suitable to measure reflection arrival times is trivial, the time scaling is easily performed on an oscilloscope, and the model can be easily altered and adapted to make corrections. We normally use models of ⅛" or ¼" = 1'0" scale - these being the scales customarily used on architects drawings and close to their metric equivalents 1:100 and 1:50.

3.1 Equipment.

The sound source is a spark discharging between electrodes and controlled by a generator with a variable spark rate. The sound is detected by condensor microphones, either those made in the laboratory to a design developed at Goettingen, (3) or ¼" or ⅛" Bruel & Kjaer microphones. A simple high pass filter is used to combat traffic noise from a nearby highway. It is found that a low frequency cut-off about 9 dB per octave below 10 kHz is adequate for this purpose. The impulse response of the Bruel & Kjaer 1/3 octave filters in the spectrometer itself is found to obscure details of the reflection sequence. The reflection sequences are displayed on a dual trace storage oscilloscope triggering on the stray E.M. radiation from the spark. By storing an initial sequence on the upper half of the screen and then viewing it dynamically on the lower, the effect of alterations to the model may be observed directly. Individual components of the trace are identified by absorption with a cottonwool probe.

4. ANALYSIS :

The objective of the measurements is the determination of the audibility of various components of the reflection sequence. One must take into account both the probable attenuation in transit from the source, and the psychophysical data which are available.

4.1 Echoes.

Late reflections are easily detected on the trace and may be considered in terms of the various criteria for acceptibility for echoes of speech or music.

4.2 Masking.

A basis for the acoustical design of halls has been described (4)

A procedure has been evolved for plotting the reflections on a log time scale and for applying the data of Watters & Schultz (5) and Schubert (6) to the resulting sequence. This procedure will be reported in detail elsewhere. The process is tedious and time consuming and one is limited by the number of microphone positions which are accessible in the model. It is not easy to locate both source and receiver position accurately in a small scale model which is complex in shape. The main limitation however is the difficulty of including in the analysis the Schubert data on the effect of angle of incidence.(azimuth) upon the threshold of audibility. The oscilloscope trace does not, of course, include this information, and it is very difficult to measure it in a model with the equipment we have. Directional miniature microphones would possibly be the answer to this problem, but manipulation within the model, which is not easy with the simple microphones we use, would then be even more difficult. No particular account is taken of diffraction effects in the model, though in its design and construction and in the auditorium itself the sizes of elements are in part determined by these considerations.

4.3 Conclusions.

In spite of these difficulties the technique has much to commend it. It promotes comprehension of the distribution of reflections in space and time in a form which is particularly useful to the designer of the room. One can examine the conditions for good speech intelligibility at sight (one or more strong reflections prior to 35 MS after the direct), and one can easily determine the surfaces which must be made absorbent to avoid unwanted late reflections. In Concert Halls, subject to the limitations noted in the previous paragraph one can study the reflection sequences sufficiently accurately to set up the principal components of the sound field on the simulator, and to experience planned changes in these principal components, corresponding to changes in room surfaces. These techniques have been used with success in the design of an 800 seat School Hall and are being used in the design of both the Christchurch (N.Z.) Town Hall - a 2500 seat auditorium and the Perth Concert Hall - a symphony hall for 2000.

The usefulness of the equipment in the lectures and laboratories of the acoustics courses offered at the University is of course considerable.

5. DIGITAL METHODS :

It will be apparent that apart from the qualitative and conceptual benefits of a model study, all the above process could be modeled mathematically and are amenable to a computer approach. A recent study (7), which will be reported in detail elsewhere, permits any hall to be modeled in this way.

The programme computes :

- direct and reflection transit times to every seat from any chosen source position.
- Indicates obstruction of the direct sound and so the adequacy of sight-lines.
- Tests each reflection for obstructions.
- Orders the reflections temporally.
- Computes their sound pressure level relative to the direct sound and angle of arrival relative to the median plane of the observer's head.
- Applies the masking data we have (from Schubert) for lateral reflections relative to the frontal sound which precedes them.

: Displays plans of the seating blocks with a plot of seats which do not fulfil the criteria, together with the computed reflection sequence and masking for any selected seat.

The length of the computation and the speed of the PDP-6, 48K computer in this University limit the degree to which direct design interaction is possible here, but it is obviously a small step on a larger machine to use this programme to design a hall directly. The programme has recently been further generalised to include comparison of late reflections with the echo criteria mentioned earlier. It is far easier to modify a hall design by changing data on the coordinates of a plane than it is to change even a simple model. Scale models are however still useful.

The associated print out enables one to set up reflection sequences on the simulator and associated model studies permit both an easy check of the computation, and rapid visulation of the modifications one might wish to make to the room. Present use of the programme indicates that it is usually unnecessary to consider every seat in a large auditorium as faulty sequences usually occur in blocks.

As further psychophysical data becomes available it will be incorporated in the programme. The dependance of masking upon motif,(6) and the uncertainties which will always surround the placing of particular instruments on the podium, however, indicate that greater precision in the technique itself is unlikely to be useful.

REFERENCES :

1. An excellent list of references relating to Model Studies is to be found in Technical Aspects of Sound, Vol iii - Chap.5. by Richardson & Meyer, pubs. Elsevier 1962.

2. F. SPANDÖCH 1965 Proc. 5th I.C.A. Liège . Die Vorausbestimmung der Akustik eines Raumes mit Hilfe van Modellversuchen.

3. W. BURGTORF. Personal communication.

4. A. H. MARSHALL. 1968 Proc. 6th I.C.A. Tokyo. Concert Hall Shapes for minimum masking of lateral reflections.

5. B.C.WATTERS and T.SCHULZ 1964 J.Acoust.Soc.Am.36,885. Propagation of sound across audience seating.

6. P. SCHUBERT 1966 Techn.Mitt.RFZ Heft 3, 124. Untersuchungen über die Wahrnehmbarkeit von Einzelruckwurfen bei Musik.

7. T.B.ARDAGH. 1970. submitted M.Building Science Thesis. University of W.A. A digital Study of Reflection Masking in Auditoria.

ACKNOWLEDGEMENTS:

The work reported in this paper has been supported by grants from the Australian Research Grants Committee and the Research Grants Committee of the University of Western Australia. Mr.Ardagh's fundamental work on the programme has been extended by Miss Helen Nicol.