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Objective Measurements in Model Auditoria

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There are four main problems associated with the realisation of the ultrasonic scale model technique : the selection of transducers, the selection of true-to-scale surface materials, the scaling of air-absorption and the examination of temporal behaviour at the reduced time-scale and increased frequencies.

Three main properties are required of the transducers, which are to some extent mutually exclusive. The output power of sources and sensitivity of microphones must be large enough to give adequate signal to noise ratio in subsequent processing ; this is made easier by large size or narrow bandwidth. The directional characteristics of sources and microphones must be under control ; omni-directionality is facilitated by small size and restriction to low frequencies. Thirdly, the frequency response of the transducers should be free of resonances and extend over the "scaled" audio range ; this is easier to achieve with large transducers of small sensitivity. It is thus necessary to compromise, but the nature of the compromise will depend on the relative importance of these factors in the particular application. This may be illustrated by the range of sources chosen for our objective measurements, which included a spark gap driven by an induction coil, a stub pipe coupled to a moving coil pressure unit and a dodecahedral assembly of electrostatic speakers.

Surfaces in the models should have the same impedance at scale frequencies as the surfaces they represent have at normal frequencies, particularly when the dimensions of the enclosure are of the order of a few wavelengths. This can be achieved in some simple cases, by straightforward dimensional scaling of the of the surface elements, but is more difficult if resistance depends upon air movement in a porous layer, since there is a change in flow regime in narrower pores (ref.1). In these cases we are forced back onto empirical selection of materials on the basis of their random incidence absorption coefficients, measured in model reverberant rooms. This seems a reasonable procedure for models of auditoria, though there is another major problem in the uncertainty about the variation of absorption coefficient with angle of incidence.

The absorption of sound in air is the result of a number of processes, the main one involving water molecules as a "catalyst" in a relaxation process. By removing water vapour from the air the relaxation time may be reduced and air-absorption controlled (see e.g.ref.2). It is necessary to choose a compromise value of humidity, since the size of the effect varies with frequency. This seems to lie at about 5 per.cent. R.H. at 20^{o}C, for tenth scale models. This can be achieved with chemical drying agents, but our own approach has been to use freeze-drying. Air extracted from the model, which is enclosed in a plastic tent, is cooled to -20^{o}C, then reheated before return to the model. Correct air absorption becomes more important as the reverberation time increases or the scale decreases ; no correction is possible for scales smaller than about $^{1}/12$ th.

Objective measurements may be made in real time, particularly those involving frequency-domain analysis, but for time-domain investigations it is often more convenient to record the room response on a multi-speed tape-recorder and subsequently replay this at lower speed to obtain time expansion. Some of the techniques used are given below.

<u>Reverberation time</u> The response of a model to bursts of third-octave bands of noise was recorded on one track of a multi-speed, multi-channel tape recorder, with the tape running at high speed. Other channels, operating in the F.M. mode were used to record switching pulses generated by a Bruel and Kjaer level recorder which was in control of the noise generating process. On replaying at one tenth of the recording speed these switching pulses, in conjunction with transistor switches and relays, were used to control filter selection and the level recorder so that decay curves

were obtained semi-automatically. These curves were then interpreted in the usual way.

Echograms For clear echograms it is necessary to excite the room with powerful; very short pulses. By using a spark gap driven directly by an induction coil single pulses with a width of 30 µsec were obtained, at a repetition rate of about 3 sec^{-1}. The response was displayed in real-time on an oscilloscope, using a pick-off from the induction coil as a trigger signal, and also recorded. The recording was later replayed with maximum time expansion into an ultra-violet trace recorder, the trace being analysed subsequently, according to a number of rating methods.

"Clarity" The clarity ratios(ratio of energy in first 50 msec to total energy in pulse response)were also obtained from the recordings of spark response. Replayed with time scale expanded by 10 the signal was passed through a squaring circuit and then to a gated integrator, the gate being opened by the trigger pulse picked off the induction coil, which had been recorded on another channel, and re-set to zero after the passage of the complete response. The voltage accumulating on the integrator was displayed on a storage oscilloscope with calibrated time base. The clarity and similar energy ratios were then read from the trace.

Early Decay Properties Examination of the early stages of the decay of reverberant sound in a room is made difficult by the need to use random noise excitation. This leads to random fluctuations in the detailed shape of the decay curve and hence a need to take ensemble averages over large numbers of decays. This may be avoided by application of Schroeder's integrated impulse response theorem (ref.3). A square pulse of optimum width was used to drive a third-octave filter. Its response was then amplified and used to excite a loudspeaker within the model. The room response at a particular point was then tape recorded, together with trigger signals from the pulse generator. This recording was then replayed in reverse with time expansion, through squaring and integrating circuits, the integrator again being gated by the recorded trigger signal. The output from the integrator was displayed on a level recorder, swithed to respond to direcr voltage ; the square root extraction required by the Schroeder theorem was carried out simply by interpreting the scale of the level recorder trace as being half that of the potentiometer used. Measurements were subsequently made on the traces.

Spacial Diffusion Measurement of loudness distribution throughout the model can be made more directly, in real time. Use of microphone trolleys and constant speed drives make measurements in models far more convenient than in the prototypes. Servo motors make it possible to relocate microphones within the model without breaking the vapour seal.

Frequency and Phase Response Frequency domain work was carried out in real time, a loudspeaker being driven by the signal from a slowly swept oscillator. In full size rooms the rate of sweep must be kept very small in order to maintain steady state conditions ; this condition is less stringent in models owing to the reduced time scale. Amplitude response was traced out directly with the microphone placed at various points in the models, the traces being analysed subsequently. The phase angle between the signal applied to the loudspeaker and the signal detected by the microphone was investigated by multiplying together the two signals in an analogue system. The product voltage consists of an alternating component with twice the drive frequency and a direct component proportional to the cosine of the phase angle between the two input signals and the product of the two amplitudes. By feeding the alternating component of the output to the compressor circuit of the oscillator it was possible to hold the amplitude product constant, so that a signal proportional to the cosine of phase alone was obtained. This was traced out on a graphic recorder for subsequent analysis.

All the above measurements were carried out at a number of positions in three models, which could be modified in some respects, giving a total of 41 separate measuring positions. "Subjective" recordings of music and speech were also made at these positions and work is now proceeding to correlate the measurements with the recordings. Some of the results will be presented.

Ref 1. R.D.Ford & M.A.McCormick, J.Sound Vib. v10 p411 (1969)

Ref. 2. R.G.Monk J.Acoust.Soc.Amer. v46 p560 (1969)

Ref.3.M.R.Schroeder J.Acoust.Soc.Amer. v37,p409 (1965)