Proceedings of the Institute of Acoustics

THE MEASUREMENT AND ANALYSIS OF A CONTROL ROOM ACOUSTIC TREATMENT DURING CONSTRUCTION

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1. INTRODUCTION

As part of an investigation being undertaken at the Institute of Sound and Vibration Research (ISVR) into the effectiveness of various forms of low-frequency absorption systems, advantage was taken of the opportunity to measure the progressive effects of the acoustic control treatments in a ground up studio during its construction. The sound control room was the first part of the studio to be completed, in an overall shell of 20m x 12m x 8m high. During the construction of the control room, a series of 44 measurements were taken (11 at each of 4 different places) during the different phases of the work, beginning with a bare shell, and ending with a finished control room.

Of particular interest to the investigations was to what degree each stage of the acoustic control work took effect and over which frequency range, and also to look for redundancy in the design. Also of interest was the degree to which any beneficial effect of any given part of the absorption systems may be masked by the subsequent layers of control materials. It is hoped that in the future we may be able to model more of these things, but this will only be possible after correlating the results between models and the real thing, so the gathering of the real data was an essential part of the current investigations.

Displayed in this paper are a series of response plots, all laid out in the same manner, corresponding to a set of photographs (shown in Figure 3) depicting the state of work at the time of each measurement, along with a brief description of the construction work carried out between the measurements. Measurement #1, the bare shell, has been omitted due to excessive reverberation rendering it all but irrelevant. There are thus 10 plots displayed on each page of figures, consisting of waterfall plots, reverberation time plots, energy-time curves, Schroeder integration plots, and pressure amplitude curves. Each of of quantities plotted are derived from the frequency response function measured at the intended listening position; excitation of the room was via a single 15-inch woofer mounted at the left monitor position.

2. PURPOSE

The general aim of the work was to create a monitoring environment with a decay time of around 0·2s in a working space of about 200m^3. If anything could be gleaned from the results which could reduce the proportion of overall volume consumed by the acoustic control system, then that would be useful. Indeed that was one of the prime objectives of the ISVR investigations – higher degrees of control in small rooms – because the great majority of recordings are currently being made using inadequately controlled small rooms.

3. ROOM PHILOSOPHY

The room to be measured was of the hard front-wall / highly absorbent rear-wall design concept, now in widespread use. Some variants are referred to by some designers as "Non-Environment" rooms, where the room decay time is source-position dependent, with the lowest decay time being for sources mounted in the hard front wall; the normal location for the loudspeakers. The rooms become progressively more live as the source moves towards the centre of the room, hence the rooms are not oppressive for the personnel working in them, and the small loudspeakers close to the mixing desk are in a rather more lively environment than the main monitors, which are located in positions which result in the greatest overall response flatness at the listening position.

The principal reflective surfaces are the front wall and the floor, and these are typically opposed by a highly absorbent rear wall and ceiling, respectively. As each side wall is reasonably absorbent, the opposing wall need not be as heavily treated as the rear wall and ceiling. Of obvious importance (if a maximally flat frequency response is to be achieved at the listening position, and in a designated listening area around and behind it) is to have a relatively uniform and rather short decay time versus frequency. The means of achieving this in many such rooms have been somewhat empirically designed over many years. In fact, they have been developed to a standard which is generally considered to be excellent, and the wideband absorption is very effective. However, without a greater understanding of the complex interdependence of the absorption systems and their component materials, the prediction of their effectiveness in other circumstances, or the reduction of their size whilst maintaining their efficacy, has been something of a lottery, and very time consuming.

4. SYSTEMS OF ABSORPTION

In the room whose results will be presented here, the outer shell is of concrete, with an inner structure based on the old Camden partitioning principle. The 10cm timber stud frame is covered on the outside with a double layer of 13mm plasterboard, but the sandwiched material between the two layers is a 3·5kg/m^2 plasticised deadsheet instead of the insulation board used in the old designs. Between the studs, the cavities are filled with 10cm of 40kg/m^3 mineral wool. The studs are then faced with deadsheet, followed by 2cm of a 40kg/m^3 cotton waste felt. The ceiling structure is essentially similar to the wall structure, except for having a 22cm depth, due to the dimensions of the ceiling timbers. The floor is a 10cm floated, reinforced concrete slab, and the front wall consists of a stud frame with multiple board layers, faced with 10cm of irregular-faced granite and cement, to provide a massive baffle extension for the loudspeakers. The remaining treatment consists of an arrangement of plywood and chipboard panels, covered on one side with a damping layer of deadsheet, and on both sides with a 4cm layer of cotton waste felt. These are hung from chains, both parallel to the wall surfaces and also at various angles, mounted in a manner which can easily be seen in the photographs of Figure 1.

Work by Alistair Walter, at ISVR in 1988, showed the powerful waveguide effect of these panels, which has been thought for some time to be an important component part of the overall effectiveness of the absorption systems. In three investigations, however, the solid panels themselves have been shown *not* to be responsible for any significant absorption [1, 2, 3], though the absorbent materials alone, suspended without the panels, have not been found to be as effective as with the panels inserted.

5. DESCRIPTION OF CONSTRUCTION WORK PRIOR TO EACH MEASUREMENT

Measurement #2
The empty shell with only the framework for vocal and machine rooms. No absorbent.

Measurement #3
Stud frames of the control room walls and ceiling erected and covered on the outside with plasterboard / deadsheet / plasterboard sandwiches.

Measurement #4
Construction of concrete isolation wall around control room (see photograph of concrete block).

Measurement #5
All wall frames filled with mineral wool and covered on inside with deadsheet and felt. Front-wall boarded and loudspeaker flush-mounted. Vocal and machine rooms lined with deadsheet and mineral wool.

Measurement #6
Large (6·5m × 4m) absorbent-covered chipboard panel hung in front of back-wall.

Measurement #7
Ceiling lined with deadsheet and felt.

Measurement #8
Absobent-covered suspended panels installed in both side-walls.

Measurement #9
Ten waveguide panels mounted in front of back-wall.

Measurement #10
Twenty waveguide panels mounted in front of back-wall.

Measurement #11
Absobent-covered suspended panels installed in ceiling.

Figure 1 Photographs Corresponding to Measurement Numbers

6. DISCUSSION OF RESULTS

6.1 Waterfall Plots

Figure 2 shows waterfall plots derived from the frequency response function measured at the intended listening position. Comparing Measurements #2 and #3 of Figure 2 shows that the introduction of the stud frames of the walls and ceiling, covered on the outside with plasterboard / deadsheet / plasterboard sandwiches, greatly reduces the decay time in the sub-100Hz frequency range. The frequencies above 100Hz remain broadly unaffected though. The introduction of the outer, concrete isolation shell between Measurements #3 and #4 can be seen to increase the low-frequency energy in the room, and not until Measurement #11 does this fall back to that shown for Measurement #3. Measurement #5 was taken after all the wall frames had been filled with mineral wool, and covered with deadsheet and felt. The front wall had also been boarded, resulting in an increase in low-frequency energy (compared to Measurements #2 to #4) due to the flush mounting of the loudspeaker. Despite the ceiling still being hard-surfaced, the effect of the treatment on the frequencies above 100Hz is drastic, having the same order of effect as the plasterboard sandwiches had on the low frequencies. At this point in the construction, a floor-to-ceiling 'chatter' was quite subjectively pronounced on speech within the room, as all the other reflexions had been very much reduced. However, it is interesting to note that very little of this significant subjective effect is evident on the plots, presumably because of the position of the source in the hard front-wall.

Measurement #6 was taken after a large (6·5m x 4m) absorbent-covered chipboard panel was hung in front of the back-wall. This produced an unexpected result – little except a small increase in decay time in the 100Hz region. Experience over many years has shown that rooms that have these large panels have sounded considerably more controlled in their low-frequency responses than rooms without the panels. It seems rather odd that such a large item could be introduced into a room with little effect on the response (the slight rise in decay time at 100Hz is presumably due to its masking effect on the deadsheet-covered back wall).

Measurement #7 was taken after the lining of the ceiling with absorbent material. All trace of any low-level activity, evident in the earlier measurements, has been removed from the plot. The floor-to-ceiling 'chatter', previously heard on speech in the room disappeared, but a low-level resonance was still audible. Prior to Measurement #8, the suspended panels were installed in the side-walls, and the waterfall plot shows little effect except for a decrease in decay time in the 100-500Hz range.

Measurement #9 was taken after the mounting of 10 of the angled 'waveguide' panels in front of the large, parallel panel at the rear wall. The waterfall plot shows that installing these panels (each 1·2m x 4m) reduced the decay time in the 200-1500Hz range by a significant amount. It is strongly suspected, though not yet proved, that the effect of the large panel parallel to the back-wall is augmented in its ability to absorb sound after the introduction of the waveguide panels. Measurement #10 is as Measurement #9, but with 20 panels occupying the same space as the previous 10. The increase in the number of panels appears, from the waterfall plots, to have had almost no effect at the listening position. The spacing of these panels, together with their optimum angle, is another subject of current research at ISVR.

Finally, the ceiling 'trap' system, consisting of five panels, up to 1·2m deep and 6m long, were installed prior to Measurement #11. The panels are set at angles such that they all point their lower edges towards the centres of the monitor loudspeakers. In the past, much importance has been attached to these panels, and it has been noticeable that rooms with insufficient ceiling space for them have been subjectively inferior to rooms with adequate ceiling traps. Measurement #11 clearly shows a very significant reduction in the decay time of the lowest octave, 20-40Hz. This bears out the subjectively 'tighter' bass attributed to the rooms with adequate ceiling traps. The word 'trap' is perhaps a good choice here, because, being angled edge-on to the expanding wavefront, the panels offer little obstruction to the entry of the sound waves, but the exit route via the heavily-lined ducts which they form is extremely difficult to negotiate. The arrangement of these panels also serves to interrupt the parallel surfaces of the floor and ceiling, removing all traces of any remaining 'chatter'.

6.2 Reverberation Time Plots

The reverberation time (RT) plots shown in Figure 3 are actually point-to-point diagrams with each point determined by one-third octave Schroeder integration. As well as the usual –60dB decay times, the figures also include the decay time to –30dB as these can prove a useful guide to many subjective effects. One limitation of these plots is demonstrated in Figure 8, which shows the equivalent RT for the set of filters combined with a theoretical model of the loudspeaker. This 'additional' reverberation, which is not a property of the room, is present in all of the plots and cannot, in general, be corrected for. In order to minimise the decay in the loudspeaker response, the sound source was a 15-inch low resonance (20Hz) drive-unit in a 500 litre sealed cabinet, which is capable of giving a useful output down to 10Hz. A comparison between the RTs for the later measurements in Figure 3 and those in Figure 8 reveals that much of the apparent reverberation at very low frequencies is due to the third-octave filters and the loudspeaker as well as the room. The waterfall plots in Figure 2 suggest that much low-frequency absorption has taken place by the time of Measurement #5; this is less apparent in the RT plots of Figure 3. Nevertheless, the trend of the RT plots is generally downwards from Measurement #3 onwards (Measurement #3 was taken after the studwork shell introduced six relatively hard and plane surfaces around the microphone).

Two points worth observing from Figure 3 are the reduction in RT due to the construction of the two remaining concrete outer isolation walls before Measurement #4, and the very noticeable effect that the ceiling panels have at low frequencies (#10 to #11). The completion of the concrete isolation wall, tightly fitted round the rear and left wall of the control room, with fibrous material in the gap, actually appears to reduce the RT of the room. This may be due to a damping effect on the stud-framed walls. As previously mentioned, the addition of the large rear suspended panel also caused a small increase in RT to be apparent in Measurement #6, though its effect is not obvious in the pressure amplitude response.

6.3 Energy / Time Curves

Not surprisingly, the energy / time curves (ETC) in Figure 4 show details which are not apparent in the waterfall or RT plots, such as discrete reflexions. One such reflexion is that due to the floor. This reflexion appears about 10dB below the direct signal, and about 5 milliseconds later and is present in all the measurements. In the finished room, its specular nature would be broken up by the presence of the mixing console. Measurement #3 shows a rise in the level of reflected energy due to the completion of the smaller, inner case of the control room bringing the reflective surfaces nearer to the microphone. However, from then on, the trend of the plots is downwards (except for the previously mentioned effect on Measurement #6, and some minor effects due to the concrete outer isolation shell before Measurement #4).

Table 1 shows the decay times to –20, –30, –40 and –50dB for the last five plots. 10ms has been deducted from the time scales to allow for the arrival of the direct signal at 10ms.

Meas.	-20dB	-30dB	-40dB	-50dB
#7	33	72	129	190
#8	18	73	127	185
#9	9	58	105	161
#10	18	55	106	149
#11	17	50	90	139

Table 1 Decay Times (milliseconds) for Measurements #7 to #11

Only three reversals take place in the downward trend. Two are of only 1ms, but the third is after the strangely low figure for Measurement #9 crossing the -20dB line. This is only due to the spike around the 28ms mark on the plot being on the threshold of the line. If it were 1dB higher, then the anomaly would not exist.

If a diagonal line is drawn from the peak of the direct signal to the -60dB / 200ms point, it becomes apparent that the reflected energy has been reduced in Measurement #10 from that in #9. This suggests that the closer panel spacing is absorbing more energy. This fact is not apparent from the waterfall or RT plots. The most clear indication of the effectiveness of the ceiling panels is shown by the plot of Measurement #11, with significantly reduced energy in the 100–200ms region.

6.4 Schroeder Integration Plots

Figure 5 shows a sequence of Schroeder plots which again clearly show a significant downward overall trend in the decay times as the construction progresses, resulting in a final figure in Measurement #11 of about 250ms. An increase in early reverberant energy is apparent in Measurements #3 and #4, after the progressive enclosure of the control room space, and an increase in decay time can be seen in Measurement #6, after the installation of the large, rear suspended panel.

6.5 Pressure Amplitude Response Plots

Once again, a clear trend is apparent in the pressure amplitude plots of Figure 6; a progressive flattening of the response as the room treatment is added. The severe peak and dip in the sub-100Hz region can be seen to change frequency during the early measurements, especially due to the additions to the structure before Measurements #3, #4 and #6, but beyond Measurement #7 there is a stabilisation of their frequencies which is accompanied by a reduction in their amplitudes. The addition of the ceiling panels, as shown in Measurement #11, deals most effectively with them, and significantly flattens the low-frequency response.

Figure 7 shows the pressure amplitude plot for Measurement #11, but this time in one-third octave bands after having been corrected for the low-frequency roll-off of the loudspeaker using a suitable theoretical model. The response is seen to lie within ±4dB from 10Hz to 2kHz; a demonstration of the effectiveness of the acoustic treatment.

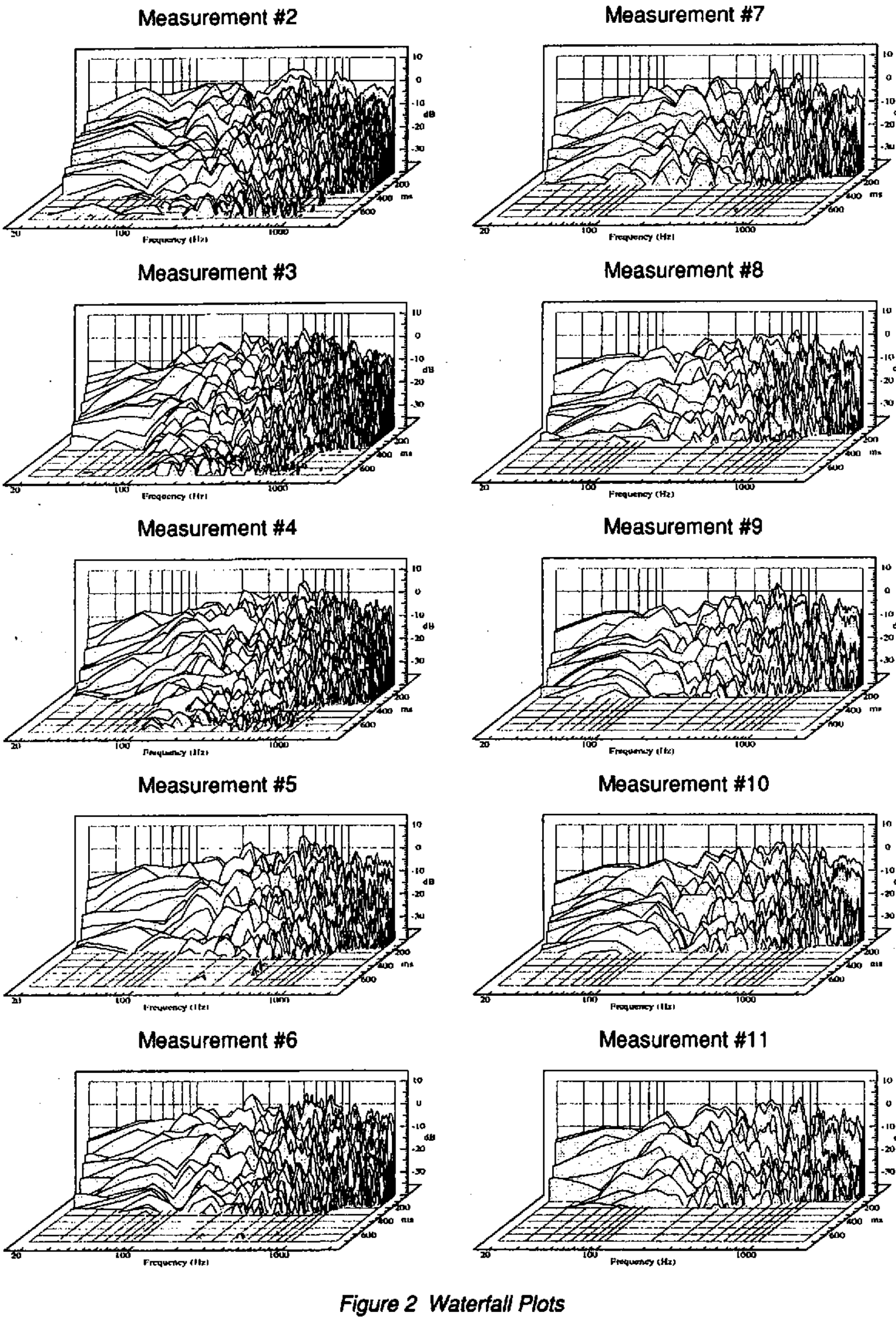

Figure 2 Waterfall Plots

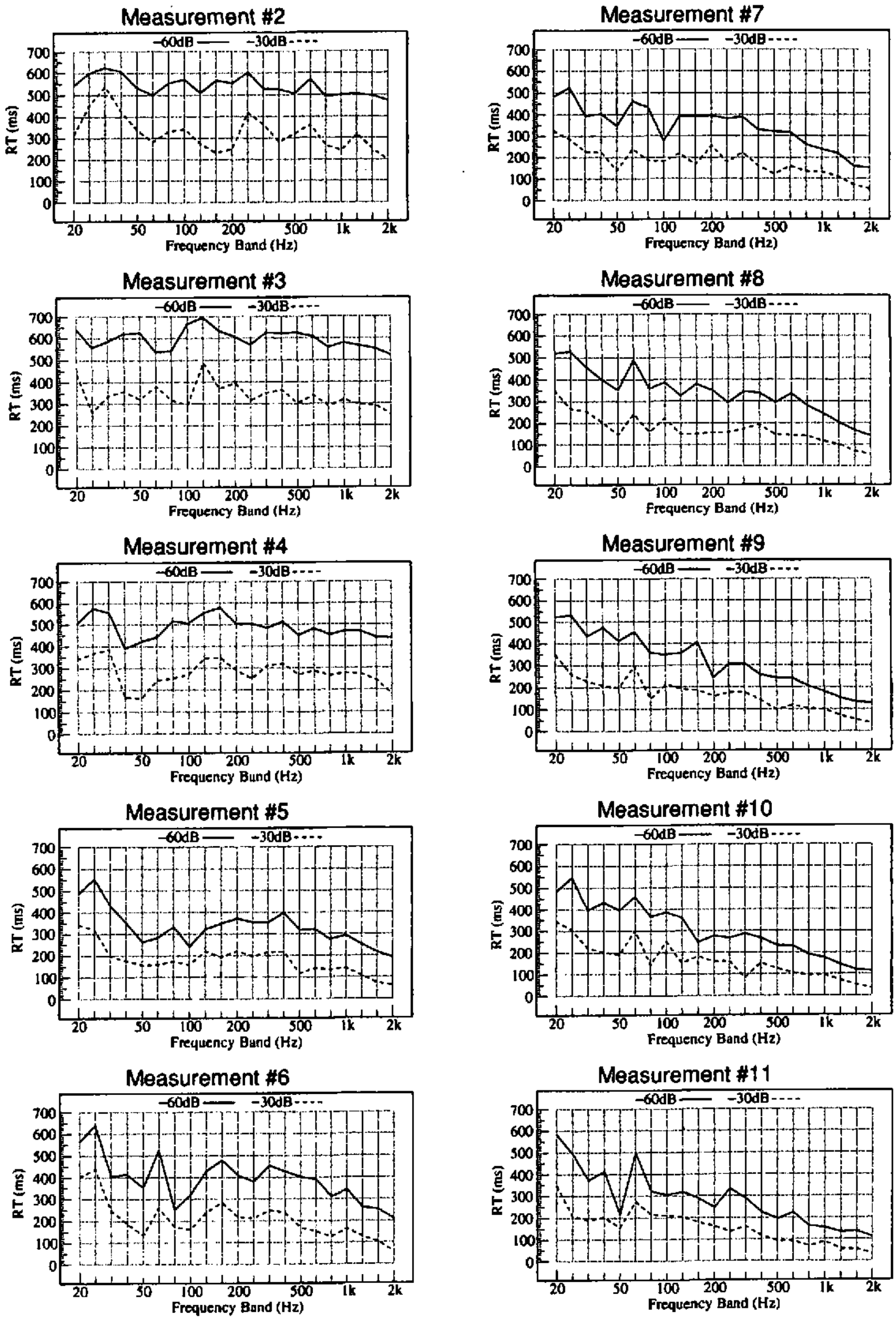

Figure 3 Reverberation Time Plots

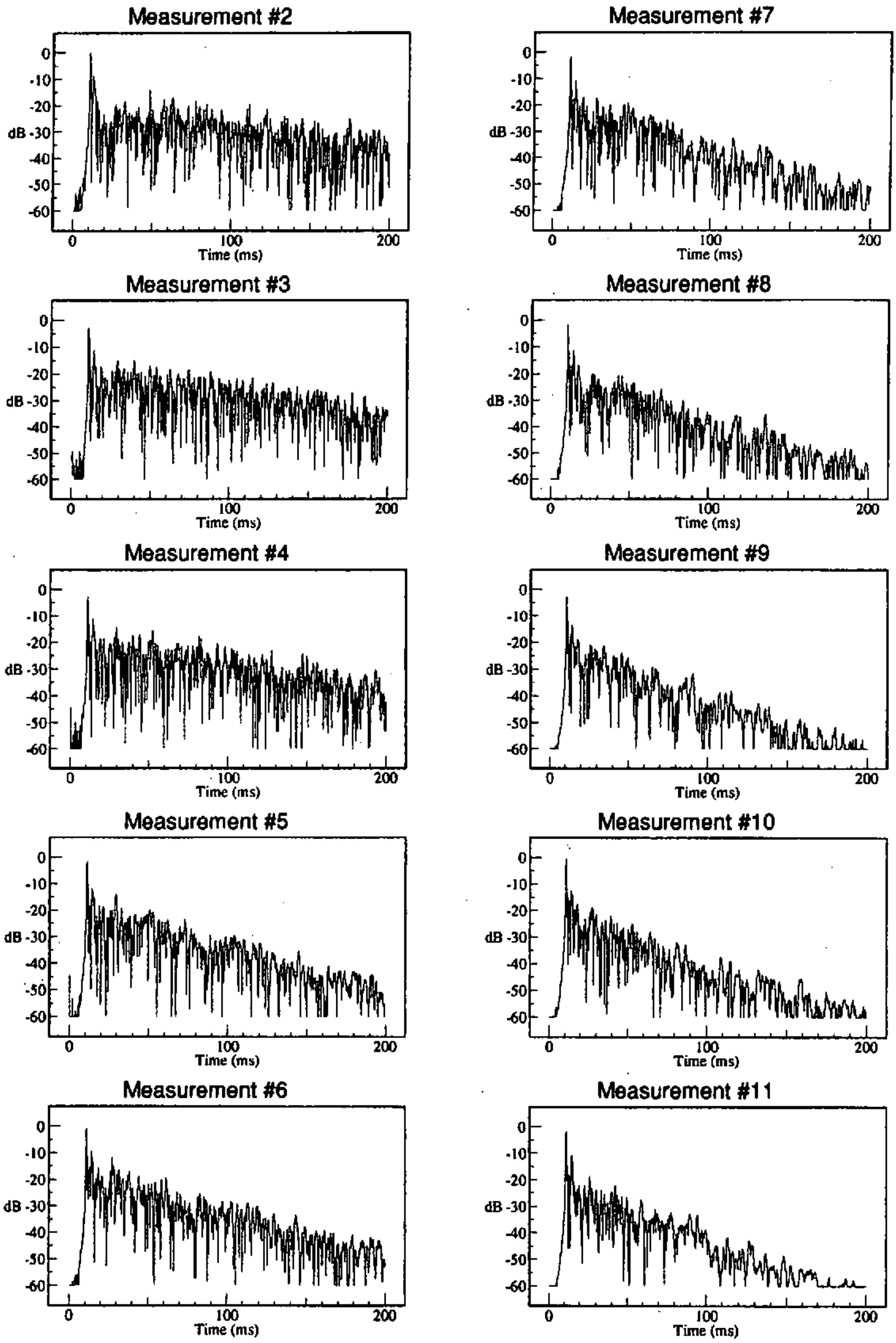

Figure 4 Energy / Time Curves

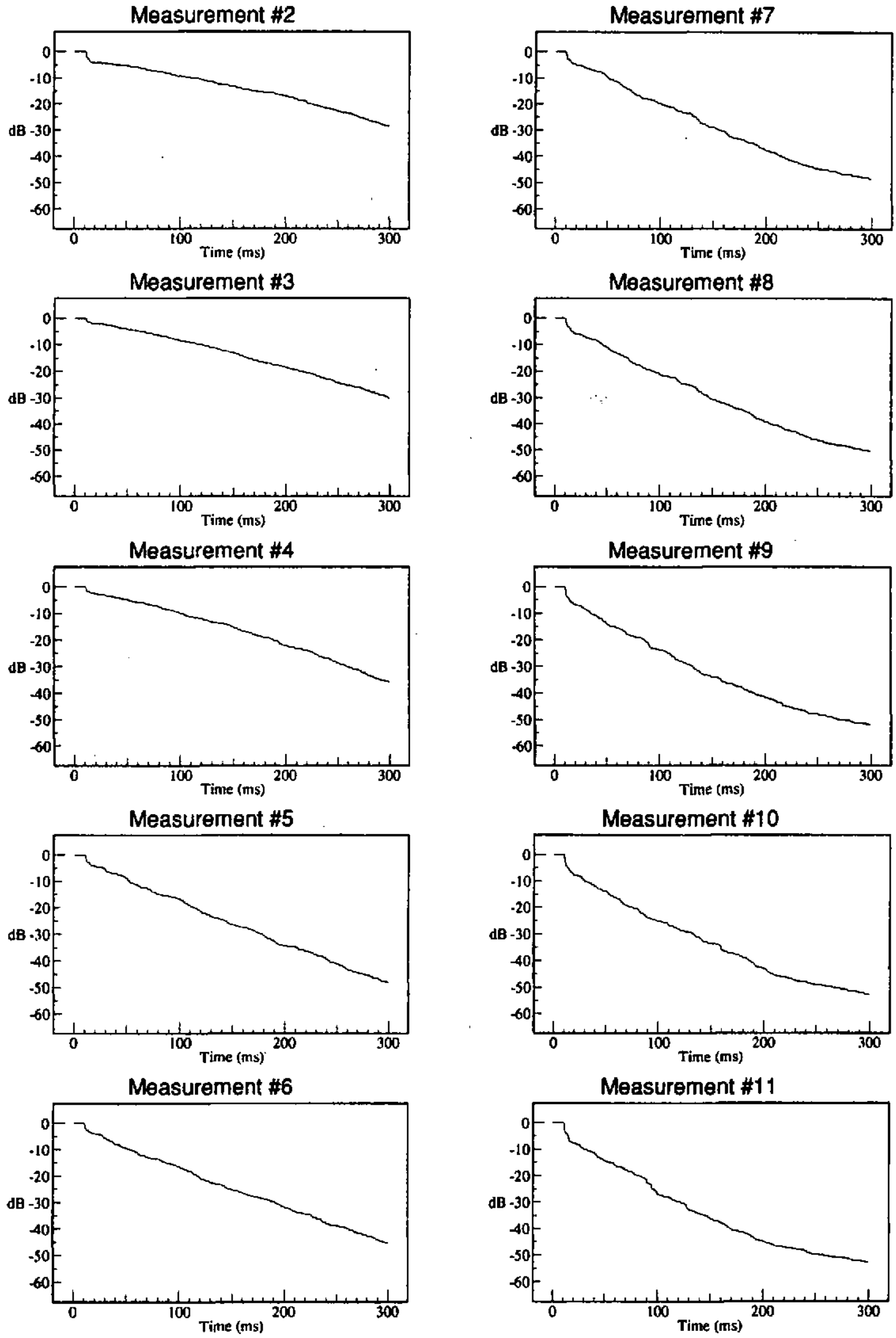

Figure 5 Schroeder Integration Plots

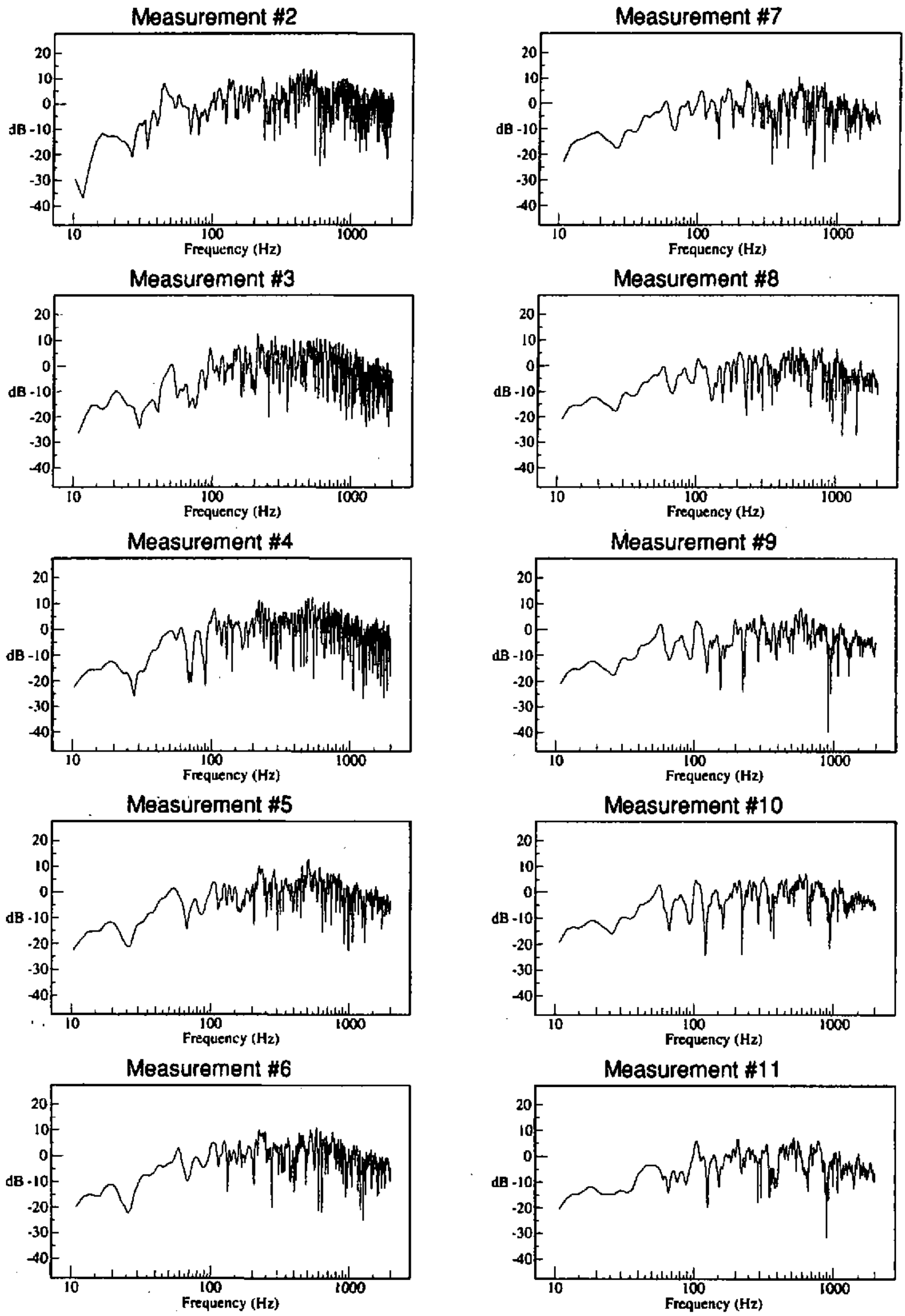

Figure 6 Pressure Amplitude Plots

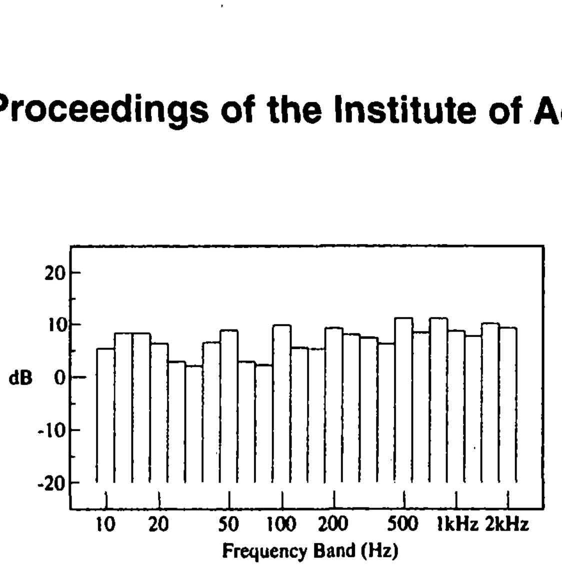

Figure 7 1/3rd Octave Response of Completed Room (Measurement #11) with Correction for Loudspeaker Roll-Off

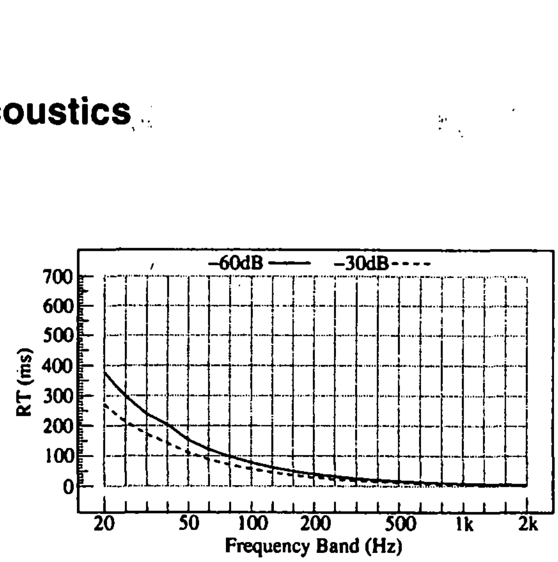

Figure 8 Equivalent Reverberation Time of 1/3rd Octave Filters and Loudspeaker Combined

7. CONCLUSIONS

The measurements presented here have outlined the room acoustic control available from a system of membranes, deadsheets, waveguides and fibrous absorbers. It has been shown how a short and well controlled decay time can be created in a concrete isolation 'bunker'. The effect of each group of elements has been discussed stage-by-stage. The techniques used are simple, require no special skills to install, and are flexible in their application. The major purpose of the exercise described in this paper has been to provide real data for use in future modelling procedures.

It has been gratifying to see that in all of the series of measurements, each element of the acoustic control system, as it has been installed, has had a worthwhile effect on the overall room response (or rather the suppression of it). Despite the fact that no single display of the results has been capable of indicating all of the beneficial effects, the cumulative evidence from the whole presentation leaves little doubt that the somewhat under-researched method of room control is highly effective. The only exception which might apply is the effect of the large, rear, suspended panel, when installed without the waveguide panels in front of it, but its effect with the waveguides installed is a subject of current research, the outcome of which will be reported when available.

8. REFERENCES

[1] Soares, L. E. B., "An Experimental Study of the Responses of a Recording Studio Control Room at Low Frequencies Using a 1:10 Scale Model", MSc Thesis, ISVR, University of Southampton, 1991.

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[3] Colam, S., Holland, K. R., "An Investigation into the Performance of a Chipboard Panel as a Low Frequency Sound Absorber", Proceedings of the Institute of Acoustics, 21(8), 105–112, 1999.