RESULTS OF THE NPL STUDY INTO COMPARATIVE ROOM ACOUSTIC MEASUREMENT TECHNIQUES PART 1, REVERBERATION TIME IN LARGE ROOMS

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1. INTRODUCTION

In October 2000 Adrian James Acoustics were appointed by the National Physical Laboratory (NPL) to undertake a Deep Study into standards for Architectural, Room and Building Acoustics. This was a scoping study for the National Measurement System Acoustics Metrology programme, for which NPL act as programme formulators to the Department of Trade and Industry. The aims of the study were;

- to review recent technological developments in measurement techniques and instrumentation used in this area of applied acoustics;
- to review recent activity, developments and expected trends , in standards relevant to this area, including the adequacy of ISO 3382;
- to review and assess the economic and trade implications of the current state of standardisation in this area;
- to assess the implications of these developments for the UK National Measurement System, links with existing activity on acoustical standards at NPL (e.g. free field calibration of microphones), and the subsequent requirements for additional research and measurement services;
- to report and identify priority areas for action.

Our report was published in December 2001 [1] and summarised in a paper to the Institute of Acoustics in November 2001 [2]. We identified a number of problems with ISO 3382 [3] which was the only ISO or BS standard for room acoustics measurement. There were also inconsistencies between ISO 3382 and widely used ITU standards for acoustic measurement of small rooms [4, 5]. ISO 3382 was due for review but there had been limited research into the effects on results of sound source types and locations, microphone types and locations, and signal processing methodology.

We suggested that a useful exercise would be to take measurements in real rooms under controlled conditions, using different types of instrumentation and different set-ups with each item of instrumentation, analysing the results and investigating the reasons for differences in these. The results would be of considerable value in any review of ISO 3382, although we postulated that they might demonstrate that a proscriptive standard for all room acoustics measurements was simply not appropriate or practicable, and that a set of guidelines or code or practice for different types of acoustic measurement in different types of room might be more appropriate.

A technology transfer meeting specific to this subject was proposed, to include leading researchers, consultants and instrumentation manufacturers. In the event a one-day “Workshop” on acoustic measurements was organised to fulfil, within the limitations of a one-day event, the roles both of a comparative measurement exercise and a technology transfer meeting. This report summarises the results for reverberation times in large room. Results for the small room and for other parameters will be published at a later date.

2. THE WORKSHOP

The workshop took place at the Institute of Sound Recording, University of Surrey, Guildford on 22 July 2002, immediately after the IoA 2002 conference on Auditorium Acoustics. This enabled the attendance of a number of leading acousticians from outside the UK who would were already in London for the IoA conference. There were 41 delegates comprising researchers and consultants from the UK, USA, Italy, Portugal, Netherlands, Norway, Japan and South Korea.

The IoSR provided a large theatre and a small control room for acoustic measurements, with delegates encouraged to bring their measurement equipment and take measurements in controlled conditions, so that results and methodologies could be compared. In parallel with the measurements, we ran a workshop comprising seminal papers, demonstrations and on specific aspects of measurements including :

- The application of ISO 3382 to different types of rooms
- Measurement parameters
- Measurement systems and signal processing
- Sound sources for measurement – Omni-directional loudspeakers, directional loudspeakers, impulsive sources etc)
- Receivers – Microphones, head-torso simulators
- Measurement locations, spatial and time averaging
- Verification and calibration
- Application of ISO 3382

A summary of these discussions and the conclusions reached was included in the IoA's publication "Acoustics Bulletin" [6].

3. METHODOLOGY

A large recording studio "live room" and a small control room were made available for delegates to take measurements or such room acoustics as they wished. Delegates were given the option of using their own measurement systems or those supplied by ourselves. Systems used included MLSSA, WinMLS, Matlab, Dirac, and sound level meter based systems.

To keep the number of variables manageable, the source and receiver locations were fixed although source and receiver types were variable. Sources included dodecahedron and directional loudspeakers, balloons and rocket launchers, and receivers included dummy heads, omni-directional, Soundfield and binaural microphones.

Because of the limited time available, all delegates were asked to process the results outside the measurement rooms after their measurements were completed. This also eliminated the possibility of repeating measurements where the results were not as expected.

All participants took measurements in the frequency range 125–4000 Hz, and for the present exercise we have limited our analysis to this range. A few participants measured at other frequencies, and in general we found that the variations below 125 Hz were so large as to make analysis difficult.

4. DATA ANALYSIS

There were four principal variables in the analysis :

- Measurement system / technique (MLS, sine sweep etc)
- Source Type (Omni speaker, cabinet, etc)
- Receiver type (Omni Microphone, dummy head)
- Receiver location

Some of the participants took measurements with several different types of system, source and / or receiver. While this added to the interest and range of the exercise it also added enormously to the complexity of the data analysis, not least because they did not always measure all combinations of the system, source and receiver. This made it difficult to use a standardised system of comparing results from different participants. For example, one participant measured using three different measurement systems, five different sources and two different receiver types. Ideally all possible combinations of these would have been tried and although this would have generated a great deal of data (30 data sets at each of the three positions) a formal statistical analysis of the data would have been possible. In fact, for reasons of time, only 9 of the 30 possible combinations were tested and to allow us to compare the data we have therefore had to undertake a preliminary analysis of the data to determine which variables were significant.

As another example, one participant took four sets of measurements at each location. The only difference between the datasets was the type of source used. We have therefore analysed these four datasets to determine the effect of the different source types. This is more valid than including these four data sets in a much larger comparison of the effect of source type over all of the data, because in the latter case we could not necessarily eliminate the effects of other variables.

When these variables within the data from each participant have been analysed, we have generally used a mean of that participant’s data in the remaining analysis. We have therefore considered the effect of receivers first, then of sources, then of receiver locations. Having eliminated (as far as possible) variations arising from these effects, we have finally analysed the effects of measurement technique. As our analysis is not formally complete at the time of writing of this paper, these results should be regarded as preliminary and, to an extent, informal and participants are not identified.

In this paper, we present only a very simplified analysis of the effects of different variables on reverberation time (RT) measured at the locations in the large room. It should be noted that all of the following analysis is on the basis of numerical results only. We have not requested or received source data files, impulse responses or decay curves from any of the participants. This immediately raises the question of the portion of the decay over which the RT should be calculated. Many participants provided both T_{20} (calculated from the decay from –5 to –25 dB) and T_{30} (calculated from the decay from –5 to –35 dB). T_{30} decays were generally not available at 125 Hz, because the signal-to-noise ratio was less than 35 dB at that frequency. This is a common problem with many sources. However, comparison at T_{30} and T_{20} data at other frequencies showed that there was no significant systematic difference between T_{20} and T_{30} at any frequency so T_{20} data was used.

4.1 Effect of receiver microphone type

Two participants carried out single-variable tests where the only variable was the receiver. Figure 1 shows the results for one of these participants using electret microphones on a Cortex Dummy Head (Bin 1, Bin 2 and Bin 3) and a single Crown CM-150 omnidirectional microphone, (Omni 1, Omni 2 and Omni 3) at each of the three microphone locations. There is no significant systematic difference as a function of either receiver type or measurement location.

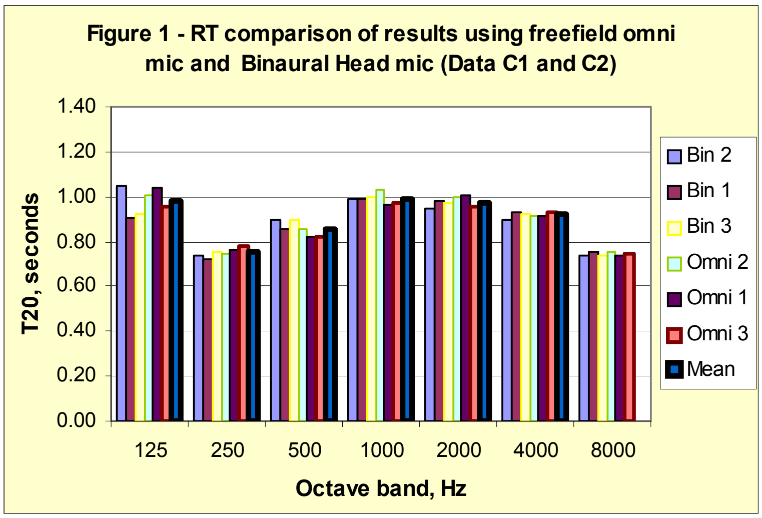
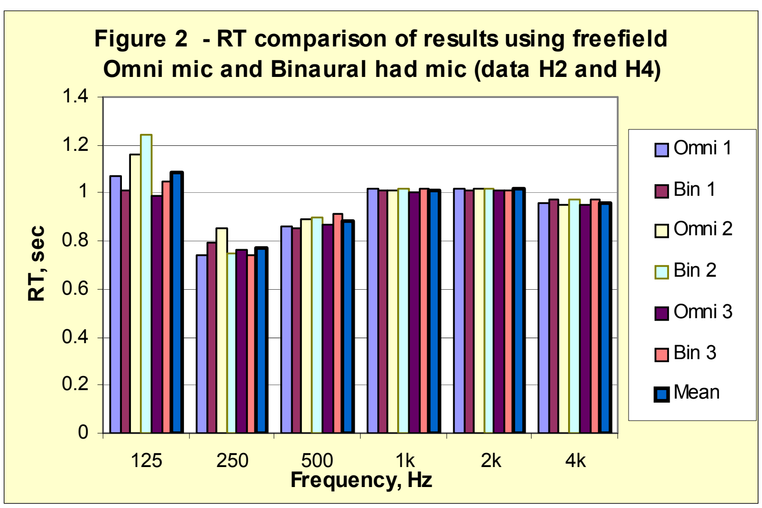


Figure 2 shows the results of the second of these two participants, using both a customised dummy head and a B&K 4007 omnidirectional microphone at each of the three microphone locations. Again, there is no systematic difference as a function of receiver type or measurement location.

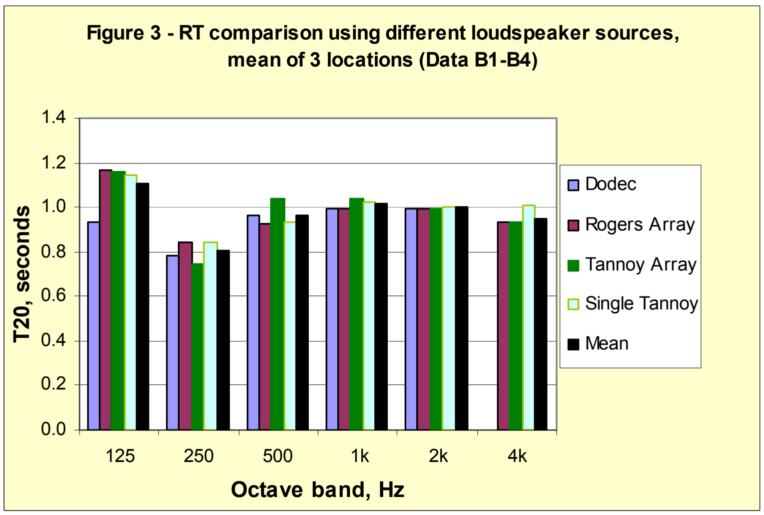


From these two sets of tests, it therefore seems that measured reverberation time in the large room was not affected by changing between omnidirectional microphone and directional microphones in a dummy head.

4.2 Effect of source

Three participants independently carried out single-variable tests where the variable was the source type. Figure 3 shows the T20 results for one of these participants, averaged across the three measurement locations, using the following source types :

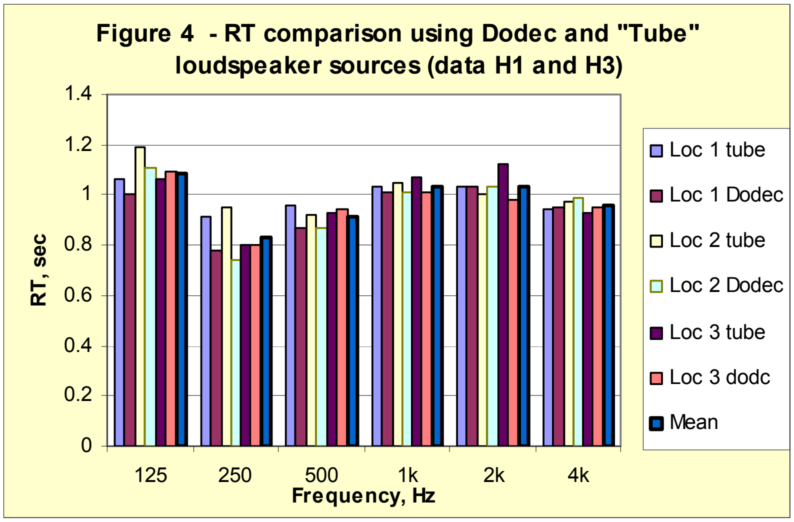
- A Dodecahedron loudspeaker Type B&K 4296
- A square array of Rogers LS 3/5 loudspeakers
- A square array of Tannoy System 600A loudspeakers
- A single Tannoy System 600A cabinet loudspeaker



Even allowing for the fact that this is a comparison of the mean of three measurement results, there is remarkably little variation in results at high frequencies. At lower frequencies there are larger variations but all still within the standard deviation of all of the measurements of all participants except at 125 Hz, where the mean of the measurements is reduced due to an unexpectedly low value of 0.75 seconds at one location Even excluding this result, however, the mean of the remaining two results with the dodec loudspeaker at 125 Hz remains some 15% lower than the mean of the measurements using other source types. Although the sample size is small, this is a consistent trend and also occurs in the T30 results, which generally accord very closely to the T20 results although this is to be expected as for any one measurement as all parameters are calculated from the same measurement of impulse response . It is, however, unexpected as we would expect any differences due to loudspeaker directivity to occur at high frequencies rather than at lower ones.

We would need to analyse the measured impulse response to determine the reason for this but previous experience suggests that it could be due to the measurement system attempting to compensate for a lack of signal-noise ratio at 125 Hz, which is a common problem in large rooms with some types of dodecahedral loudspeakers.

Figure 4 shows the T20 results for another participant, averaged across the three measurement locations, using a proprietary Dodecahedron loudspeaker and a proprietary “Point source” or “Tube” loudspeaker. Although the variations between measurements are greater than for those shown in Figure 3, there is no clear systematic difference or trend as a function of loudspeaker type. The same participant also took measurements using custom-made dodecahedral and point sources. In general the differences between individual measurements using the proprietary and custom variants of the same loudspeaker type were generally slightly larger than the differences between different types of loudspeaker.



Another participant carried out measurements at all three microphone positions using both a dodecahedron loudspeaker and a custom-made directional cabinet loudspeaker. The results for microphone position 1 are shown in Figure 5. Measurements “1 Omni 1” to “1 Omni 4” are four identical measurements, with the microphone at Location 1 and using the omnidirectional loudspeaker. These show the intrinsic variation in results of the T20 measurements using this system. Measurements “1 Dir 1” and “1 Dir 2” are two identical measurements with the microphone at Location 1 and the cabinet loudspeaker. Although due to time constraints it was not possible to take further measurements it seems clear that any difference due to the change of loudspeaker type is smaller than the intrinsic uncertainty of the measurements.

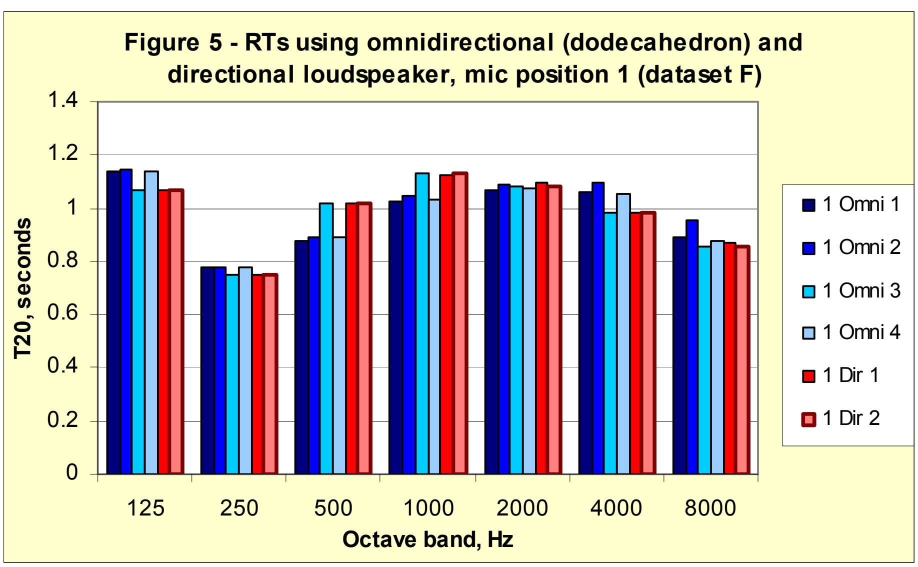
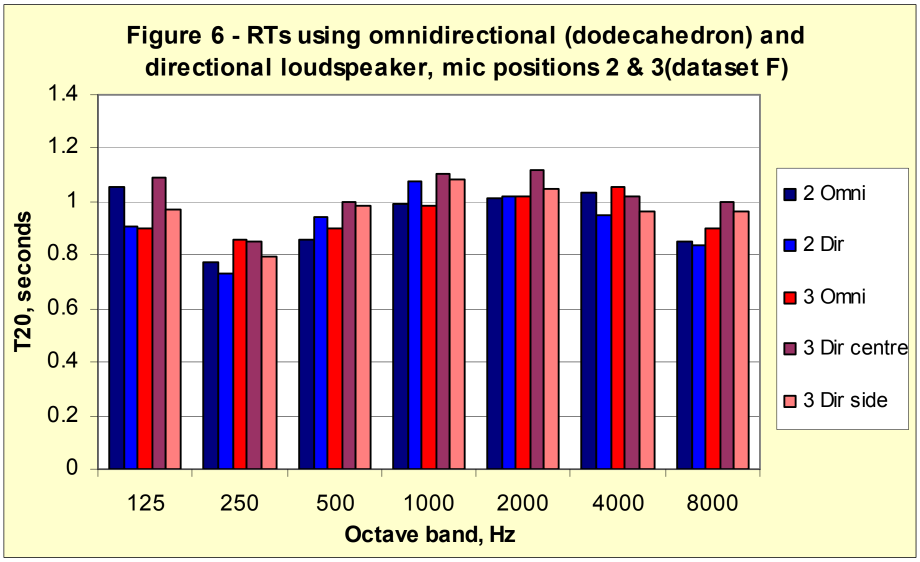


Figure 6 shows the corresponding results with the microphone at Locations 2 and 3. Again, there is no apparent correlation between loudspeaker type or orientation and the measurement results.



We therefore have three separate and independent sets of data which show that variations in RT measurement between Dodecahedron, point source, single cabinet loudspeakers and arrays of cabinet loudspeakers are smaller than the intrinsic variations in the measurements and do not show any systematic trend under statistical analysis. It seems reasonable to conclude that measured reverberation time in the large room was not affected by the type or directivity of the loudspeaker.

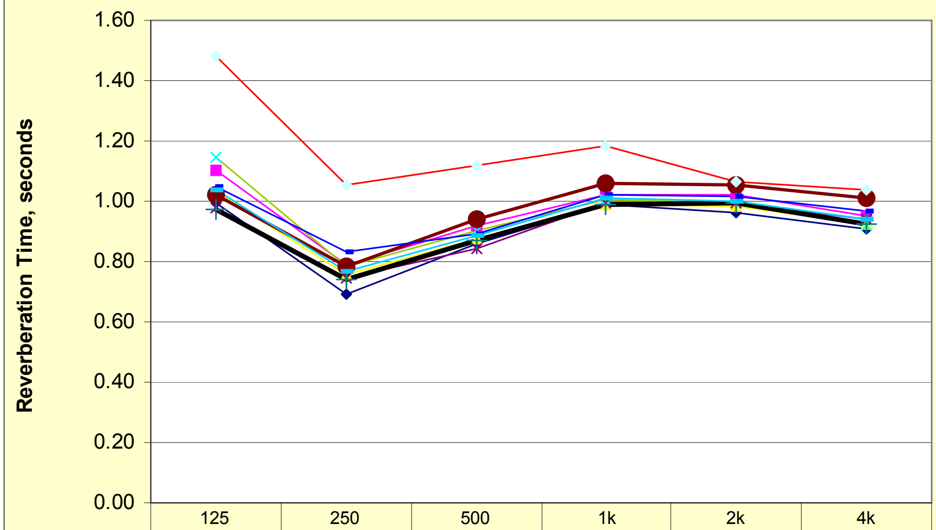
4.3 Effect of Measurement Systems

Figure 7 shows the arithmetic mean of all measurements taken by all participants, averaged across the three microphone positions. One dataset shows values consistently and significantly above all of the other values. In fact, looking at the results at the three separate microphone positions, the individual RTs in this dataset are invariably higher than all of the other results at all frequencies, and are anywhere from 5% to 73% above the mean of all other datasets, the differences being greatest at 125 and 250 Hz.

These results were obtained using a sound level meter connected to a laptop computer running proprietary software, with the source being a gun firing blank cartridges. The form of the source is unlikely in itself to be the cause of these anomalous results as elsewhere in the study results very close to the mean of all other results have been obtained using other impulsive sources such as balloon bursts. Another participant also used the same make of sound level meter to measure and calculate the reverberation time, and returned results well within the expected range. It is therefore likely that in this dataset, either the software was either at fault or being used incorrectly, with a possible cause being a failure to integrate the decay curve as recommended in ISO 3382.

In view of the very large difference between this data set and all other results, we therefore considered it reasonable exclude to these results from all further analysis.

Figure 7 - Comparison of RT (T30) measurements averaged over 3 microphone positions (all data)



	125	250	500	1k	2k	4k
A	0.99	0.69	0.86	0.99	0.96	0.91
B	1.10	0.79	0.92	1.02	1.02	0.95
C	1.04	0.76	0.88	0.99	0.98	0.93
D	1.15	0.78	0.90	1.00	0.99	0.92
E	0.98	0.75	0.84	1.00	0.99	0.94
F	1.02	0.78	0.94	1.06	1.05	1.01
G	0.97	0.74	0.87	0.99	0.99	0.93
H	1.05	0.83	0.89	1.02	1.02	0.97
Mean	1.04	0.77	0.89	1.01	1.00	0.94
I	1.48	1.05	1.12	1.18	1.07	1.04

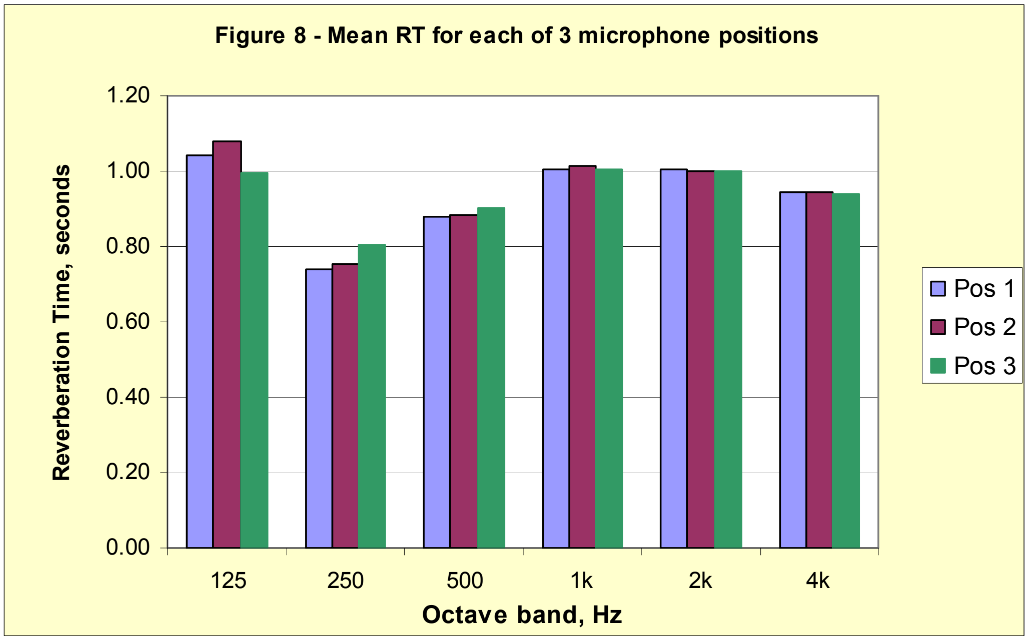
Octave band, Hz

4.4 Effect of measurement location

Figure 8 shows the mean of all of the RTs measured at each of the three microphone positions. The agreement is generally good and the normalised standard deviation for each of the three positions is as follows :

	Octave Band Frequency, Hz					
Location	**125**	**250**	**500**	**1k**	**2k**	**4k**
1	8.5%	7.9%	5.0%	3.6%	3.6%	4.4%
2	9.3%	7.8%	3.3%	1.6%	2.2%	2.9%
3	3.8%	4.8%	3.7%	2.4%	3.5%	3.7%

Overall, the values at locations 1 and 2 are much as expected, with variations being greater at low frequencies, due largely to non-systematic variations in individual results. At microphone position 3 however, these variations are much smaller and in fact the spread of results at 125 Hz is remarkably small. Location 3 was relatively close to a corner of the room, among the relatively absorbent and diffusing seats and this may have some bearing on this unexpected result. Further measurements across a larger number of microphone positions would be required to investigate this further.



The analysis continues and it is hoped that the complete results will be published in the near future.

Acknowledgements

This paper draws on work carried out by Adrian James Acoustics for the National Physical Laboratory under the National Measurement System Acoustics Metrology Programme. The author would like to thank Sue Dowson of NPL, staff of Surrey University IoSR, and all those who participated in the workshop and measurements.

5. REFERENCES

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