SMALL CHAMBER REVERBERANT ABSORPTION MEASUREMENT

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Abstract

The objective of the Small Chamber Reverberant Absorption Measurement Project was to investigate the feasibility of performing absorption measurements in a small specially built chamber. Absorption coefficients calculated from the small chamber measurements were compared to those taken in a full size reverberation room and an impedance tube. The SCRAM method was shown to give absorption coefficients close to those obtained from either the reverberation room testing or impedance tube tests over the frequency range of 200-4000Hz.

Introduction

Data about the sound absorption properties of materials is an essential tool of noise control specialists, whether choosing materials for the insulation of buildings and ductwork, designing theatres and concert halls, planning roadway noise barriers or controlling source noise.

There are currently two main methods of performing absorption type measurements - impedance tube testing using the standing wave ratio or two-microphone method [1], and reverberation room testing [2]. Both of these methods have limitations in terms of accessibility, ease of use and applicability of the data. The objective of the Small Chamber Reverberant Absorption Measurement Project was to investigate the feasibility of performing absorption measurements in a small specially built chamber.

Chamber Design

Design Principles

In order to achieve the required acoustical properties within the time and budgetary constraints, the following design requirements were set:

- Since most noise rating schemes use data from 250Hz up, the small chamber should be capable of reading from this frequency limit.
- Dispersion of the measured value should be equivalent to that of a reverberation room.
- The sound pressure level should be diffuse, with an absence of standing waves.
- The chamber should be compact and less than 2m wide x 2m deep x 2m high.
- The chamber should be cheap in construction materials and component parts, and easily constructed.
- The chamber should be able to be disassembled for transport, and easily accessible for setting up and experimentation.

Any room of cubic, rectangular or arbitrarily skewed geometry will have standing wave properties in three dimensions, resulting in spatial field inhomogeneities. At low frequencies, the modes are well separated and it is difficult to create a diffuse field. At higher frequencies (i.e. where the sound wavelength is much smaller than the room dimensions) the room modes are close and pure tones excite several modes at once. Random noise then gives a fairly uniform sound field that can be considered diffuse. In order to ensure a diffuse field the smallest dimension of the room should be an order of magnitude larger than the frequency wavelength. In a full size reverberation room the modal fields dominate below 100Hz. However a reasonably uniform field can be obtained in the region above the cut-off frequency, where the smallest dimension is more than half the wavelength of the frequency in question. A 250Hz signal has a wavelength of around 1.36m (200 Hz corresponds to 1.70m). Thus the smallest room dimension must be greater than 0.68m in order for the 250Hz field to be suitably diffuse. Since the measurements will be taken in one-third octave bands, it should also be ensured that the 200Hz measurement is reasonable, so the chamber will be designed to have the smallest dimension greater than half the 200Hz wavelength, or >0.850m.

In order to achieve a reasonably diffuse sound field inside the chamber and ensure an absence of standing waves, a number of geometric requirements must be met. Firstly, no two sides of the chamber can be parallel to prevent the formation of dominant standing waves. Similarly, no two sides of the chamber can be the same length or small whole number ratios of each other in order to promote a uniform distribution of modal frequencies, especially in the low frequency bands. The shape of the reverberation chamber should also be such that the chamber dimensions satisfy the equation $L_{max} \leq 1.9.V^{1/3}$, where L_{max} is the longest straight line that fits within the boundary of the room, and V is the volume of the chamber. This is in accordance with AS1045 [2] requirements for a full-size reverberation room.

The remaining design principles help ensure the easy construction and operation of the chamber. The chamber was designed to be less than 2m wide x 2m deep x 2m high so that it would be sufficiently compact to fit in a standard laboratory. The design also included a means of easy access to the chamber itself to facilitate set-up and testing procedures. The construction materials had to be relatively cheap, readily accessible and easy to work with so that the experiment could be undertaken within the budgetary and resource constraints of this project. The chamber was also designed to be disassembled if required so that it can be transported with relative ease.

Chamber Design

The chamber design went through a number of iterations before a design was found that fulfilled the design criteria. It was decided that the chamber should have a flat floor and perpendicular sides, rising to an angled roof. The floor would be shaped to have two right angles at opposite corners, with no two sides parallel or the same length as per the geometric requirements. The sides were designed to be able to be cut from a standard piece of plywood (2.4x1.2m) to make the construction stage easier. With floor dimensions of 1.80m, 1.50m, 1.70m and 1.61m, this meant that the maximum height of the chamber was 1.20m, with other dimensions measuring 1.10m, 1.00m and 0.91m, determined through an angle analysis. The inner dimensions of the chamber are shown in Figure 1.

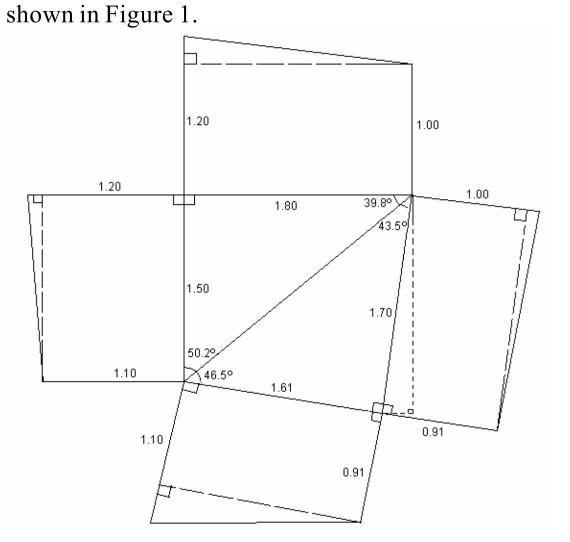

Figure 1: Chamber Dimensions

This design resulted in a total volume when unlined of 2.86m^3, and a fully lined volume of 2.29m^3. The total surface area was 12.4m^2 when unlined, and 10.8m^2 when fully lined (assuming 50mm thickness). The smallest dimension is 0.91m, which is larger than the 0.85m required for 200Hz measurements. At 1.80m the largest dimension allows the chamber to be sufficiently compact. No two sides have the same length or are whole number ratios of each other. There are no parallel sides, ensuring a sufficiently diffuse field and a uniformity of sound. When unlined, the largest straight line that would fit within the boundaries was 2.62m long. This fulfils the criteria $L_{\max} \leq 1.9V^{1/3}$, with 1.9V$^{1/3}$ equal to 2.70m.

The chamber designed from these principles was built from 12mm plywood joined with 24mm self-tapping screws to simplify construction, with a partly hinged roof to provide access to the inside of the chamber for setting up test equipment. Two materials were tested, Tontine AcoustiSorb3 Polyester and Bradford Ultratel Glasswool, both having a density of 48kg/m^3 and 50mm thicknesses. These tests were then compared to those taken in a full size reverberation room and an impedance tube.

Software

Excitation and analysis was carried out using MLSSA hardware and software. MLSSA employs a special signal called a maximum length sequence as an alternative to white noise stimulus. The sequence is deterministic (so can be precomputed) and periodic yet retains many of the desirable characteristics of white noise. The smaller time-bandwidth product resulting from the single channel system allows extended wide-band impulse measurements of up to 63 535 points. MLSSA also includes all post-processing algorithms needed to extract information like reverberation time from the measured impulse response. It also provides a fully programmable digital band-pass filter that allows calculation of reverberant decay curves and reverberation time for any designated octave or one-third octave band.

Comparison of Methods

One-third octave results

One measure of success for the performance of the chamber comes from comparing the results obtained from the small chamber method with those from the reverberation room and impedance tube tests.

The comparison between the different methods is shown in Figure 2 and Figure 3. The absorption coefficients obtained from the various methods are shown, including those obtained from the small chamber using both the Sabine equation and the Eyring equation. The 'alpha statistical' impedance tube result is displayed.

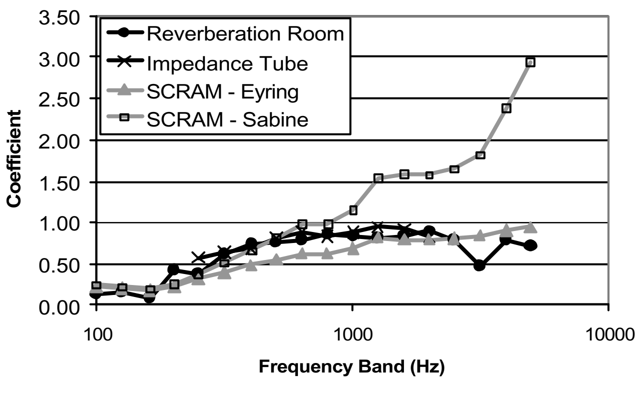

Figure 2: Comparison of methods: Glasswool

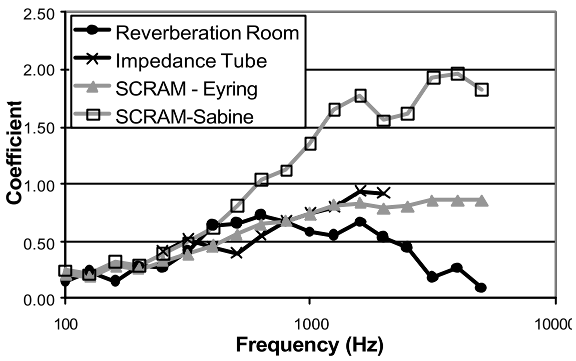

Figure 3: Comparison of methods: Polyester.

It is clear from these graphs that the Eyring equation provides a much better estimate for the absorption coefficient than the Sabine equation, with results much closer to those obtained from the accepted methods. Despite the 200Hz cut-off frequency for the small chamber , and the influence of modal frequencies in the region below 800Hz, the results from the chamber appeared to give a reasonable estimate for the absorption coefficient over the entire frequency range covered in the full size reverberation room tests (from 100 to 4000Hz).

There were some problems comparing the data to the results obtained from the reverberation room testing. The reverberation time measurements for the empty room were quite different to results obtained at an earlier date. Whether this was due to changes in the room since the earlier measurements, or indicated some problems with the measuring equipment is unclear. The resulting reverberation room results were unusual, especially at high frequencies. This made comparisons with the small chamber results difficult. However the combination of the reverberation room results and the impedance tube results indicate that the small chamber results obtained using the Eyring equation are sufficiently accurate, i.e. the small chamber absorption coefficient for glasswool is within 0.3 of the average of the reverberation room and impedance tube results between 100Hz and 2.5 kHz. This variation was less than 0.1 for the polyester material.

Octave Band Comparisons

Comparisons can be made between the various measurements on an octave band basis, by calculating the practical sound absorption coefficient, α_p, defined as

$$\alpha_p = \frac{\alpha_1 + \alpha_2 + \alpha_3}{3}. \quad (1)$$

Graphical representations of the octave band results are shown in Figure 4 and Figure 5.

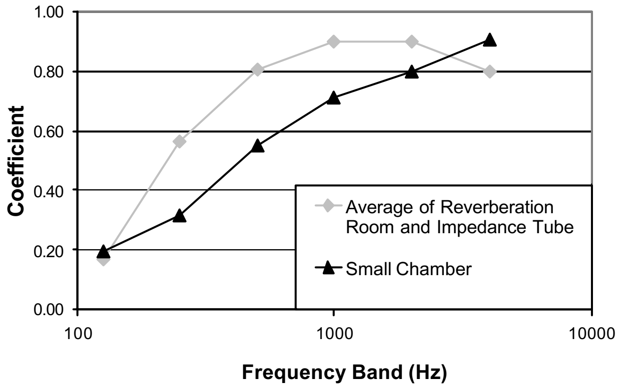

Figure 4: Octave Band Results - Glasswool

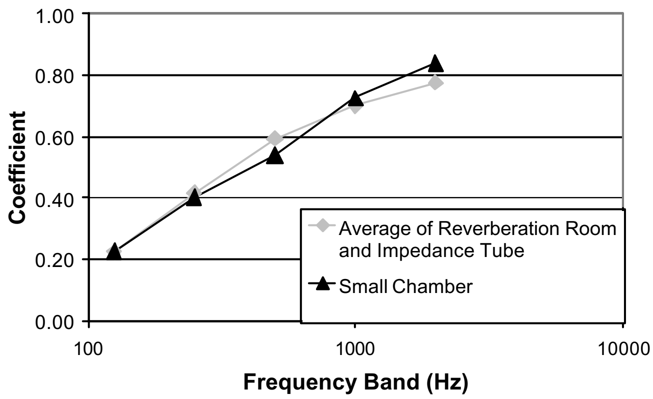

Figure 5: Octave Band Results – Polyester

The octave band results smooth out some of the perturbations found in the one-third octave results, giving an indication of the absorption trends over the frequency range.

Comparative Methods

Another method of comparing the methods of obtaining sound absorption coefficients is to determine the rating of the material, either through the Noise Rating Criteria or the Weighted Sound Absorption Coefficient [3]. The ratings found through these methods are shown in Table 10 overleaf.

These criteria give an indication of the absorption properties of the materials with a single number. The ratings obtained from the small chamber testing are within 5-10% of the ratings obtained from the other two methods. This gives a further indication that the small chamber is a viable method of obtaining reverberant absorption measurements.

Table 1: Rating Criteria for various methods

	Bradford Glasswool			Polyester		
	Reverberation Room	Impedance Tube	Small Chamber	Reverberation Room	Impedance Tube	Small Chamber
NRC	0.70	0.64	0.56 0.64	0.56	0.53	0.58
α_W	0.72	0.70	0.59 0.67	0.59	0.58	0.59

Conclusions

The Small Chamber Reverberant Absorption Measurement method was shown to give absorption coefficient measurements suitably close to those obtained from either the reverberation room testing or impedance tube tests.

Full lining of the chamber created a measuring environment like that of an anechoic chamber, so the Eyring equation for reverberation time measurements was generally more suitable. The resulting data were close to those obtained from either impedance tube measurements or reverberation room testing. The Noise Rating Criteria and Weighted Sound Absorption Coefficient obtained from the small chamber test were within 5-10% of the accepted test methods. This seems to indicate that the small chamber testing is a valid method of obtaining absorption information about materials and systems.

There are some limitations associated with testing in a small chamber. The cut-off frequency in the chamber was quite high, at 200Hz, and modal frequencies dominated up to 800Hz. At very high frequencies (4000-5000Hz) the rate of decay of the sound field was close to the sampling rate of the microphone. Though the results obtained from the small chamber compared well with those obtained from the other test methods over the frequency range from 100-5000Hz, the data can only be said to be reliable between 200-4000Hz. Whether this constitutes an unacceptable limitation depends on the intended application for the measurements.

The full lining of the chamber removed the time and error associated with empty room testing. As a result, quick 1/1 octave-band measurements of the material could be taken within half an hour or full one-third octave measurements can be taken in around one hour. This is a significant improvement on other measurement methods and makes the Small Chamber Reverberant Absorption Measurement method a quicker, more accessible method of obtaining absorption information.

The nature of the small chamber lends itself to possible extensions if more time and resources are available. The chamber could be built to be adjustable, so that it can be adapted for different uses and frequencies easily. The chamber could also possibly be connected to a similar chamber for transmission loss measurements. If a more reflecting material was used to construct the chamber it could be used to test the absorption properties of small structures with a pronounced shape, in the same manner that structures are tested in a full-size reverberation room. The success of the small chamber testing indicates the potential for many other applications.

Acknowledgments

The work discussed in this paper is based on a thesis completed with the support and facilities of the University of Queensland, with materials donated by Tontine and Bradford. The author acknowledges these arrangements and expresses her appreciation to these organizations. Any opinions expressed are those of the author.

References

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[2] Acoustics – Measurement of Sound Absorption in a Reverberation Room Standards Association of Australia, AS 1045: 1988

[3] *Acoustics – Rating of Sound Absorption – Materials and Systems* International Standards Organization, ISO 11654:1997, Amended 2002