ACOUSTICS 2025
JOONDALUP
SOUNDS OF THE SUNSET COAST

Room 45-205

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ABSTRACT
To most people, Room 45-205 is a small nondescript tutorial room located within the Mansergh Shaw Building at The University of Queensland. However, to anyone who completed the undergraduate third-year subject MECH3250 Engineering Acoustics between 1999 and 2023, Room 45-205 was known as the location of the room acoustics experiment. As a result, Room 45-205 is likely to be the most tested non-laboratory space in Australia, with measurements made of the reverberation time, critical distance and reverberation sound pressure levels. This paper presents some of the challenges faced by students as they measured the acoustic response of the space, prepared a Sabine room model and predicted the critical distance following directivity measurements of a source in an anechoic chamber. The experimental results for consecutive years, obstinately obtained under identical conditions, are compared to quantify the variances that occurred and how they might impact upon an acoustician completing in-situ testing of a furnished space.

1 INTRODUCTION
Room 45-205 is located on the second floor of the Mansergh Shaw Building at The University of Queensland's St Lucia Campus in Brisbane. It is normally utilised as a tutorial room or small lecture room capable of accommodating up to 25 students. Between 1999 and 2023, Room 45-205 was the location of the room acoustics experiment for MECH3250 Engineering Acoustics, with minimal changes occurring to the furnishings and finishes of the room over that period.

By analysing data from a large number of experimental groups obstinately obtained under identical conditions, insight can be obtained into the factors that are critical when measuring the acoustic characteristics of a space and preparing a room acoustics model to predict reverberation time and critical distance. This will be of use to acoustic consultants, who frequently base their room acoustic models on a single set of measurements and quickly made room dimension measurements and photographs.

2 MECH3250 COURSE EXPERIMENTS
MECH3250 Engineering Acoustics is a 3rd year elective undergraduate course offered by the Mechanical & Mining Engineering School at The University of Queensland. It is an on-campus course held over one semester at the University's St Lucia Campus in Brisbane.

Compared to most engineering undergraduate courses there is a large emphasis on empirical methods that culminates in Experiment 2 involving Room 45-205. The topics that are covered in the two experiments for the course are:

- Experiment 1: Use of a Sound Level Meter
    - Measurements of continuous noise, steady but varying noise and transient noise
    - Investigate distance attenuation, measurement duration, directivity, reverberant field v free-field and impact of background/extraneous noise
- Experiment 2: Room (45-205) Acoustics
    - Nodes and anti-nodes and extent of the reverberant field

- Background noise due to services
- Reverberation measurement
- Critical distance (where the direct sound level = reverberant sound level)
- Directivity of a source
- Application of the Sabine equation

Historically, sound reduction testing was part of Experiment 2 but due to time constraints (each experiment has to be completed within 3-hours) and changes to the adjoining laboratory to Room 45-205, it is no longer part of the experiment. To provide variation in the assessment, each year the students are given a task to do in addition to quantifying the acoustic characteristics of the room based upon tasks an acoustic consultant might be called upon to do. Examples include determining the sound power of the source, the sound power level of the source, implementing acoustic treatments to achieve a specified reverberation time or adapting the room for a different use (such as brass band practice). In 2018, calculation of the critical distance for comparison against the measured critical distance was added, involving the use of the University's anechoic chamber to measure directivity of the source.

3 ROOM 45-205 DESCRIPTION

Figure 1 shows the relationship between Room 45-205 and adjoining spaces. Room 45-204 is a lecture theatre, while Room 45-206 is a computer laboratory. Room 45-204A is a small mechanical plantroom that has ducts that exit the plantroom and pass through Room 45-205. The major dimensions of Room 45-205 are:

- Length: 7.3 m
- Width: 7.9 m
- Ceiling height: 3.1 m
- Volume: 179 m^3

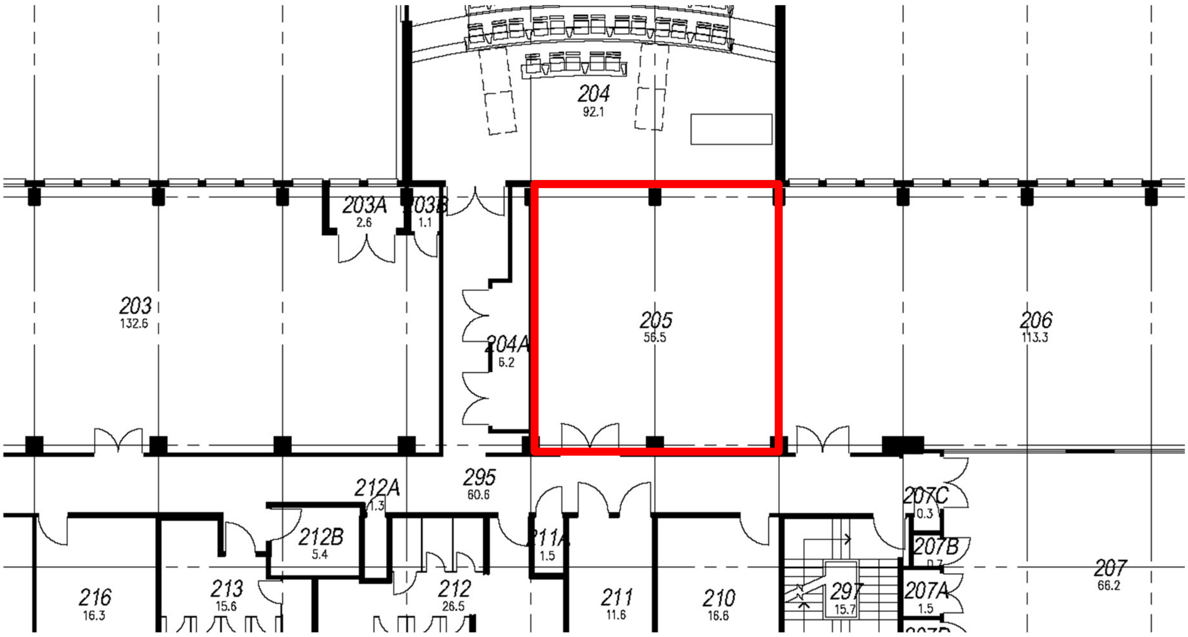


Figure 1: Part floorplan showing the relationship of Room 45-205 to adjoining spaces

Photographs showing the surface finishes and furnishings to the room are presented in Figure 2. The major materials and finishes within the room are:

- Ceiling: Sprayed Vermiculite, approximately 25 mm thick
- Floor: Carpet 5 mm thick, directly glued to concrete slab
- Walls: Brick, painted concrete, painted blockwork, plasterboard
- Glazing: Fixed 6 mm glass in doors and rear wall, 6 mm glass louvres above door
- Entry doors: Double timber and glass hinged doors, no seals
- Other: Sheet metal ductwork, blackboard, sectioned jet engine (Armstrong Siddeley Adder), model train, 25 x chairs, 14 x tables, cupboard, surface-mounted light fittings, projector and 2 x computers.

(a) View from front

(b) View from entry side wall

(c) View towards front

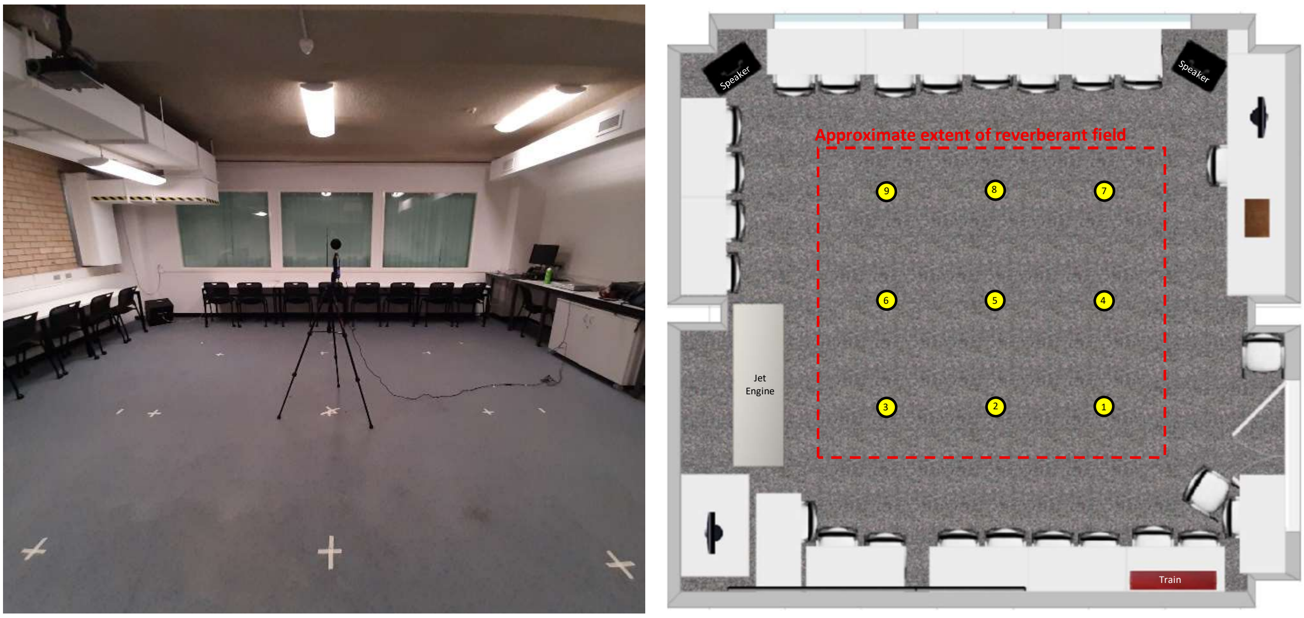
(d) View towards entry side wall

Figure 2: Photographs showing the layout, furnishings and finishes of Room 45-205

4 ROOM 45-205 EXPERIMENT SET-UP

The set-up of Room 45-205 for the room acoustics experiment is shown in Figure 3. The 11 desks and 22 chairs usually used by students are relocated to the perimeter of the room to create an open space in the centre of the room that encompasses the reverberant sound field. Speakers are located in the rear corners of the room, with one speaker facing the corner and the other facing into the room.

Pure tones are sequentially played through the speakers across the 1/1 octave bands between 31.5 Hz and 16 kHz and the students instructed to walk around the space to determine the positions of nodes and anti-nodes. A brief discussion is then given about the Schroeder frequency where the behaviour of sound within the space trans-



(a) (b)

Figure 3: (a) Photograph and (b) floor plan sketch showing experiment set-up

itions from being dominated by resonances (at low frequencies) to a more uniform sound field (at higher frequencies). Broadband pink noise is then played so the students can determine the extent of the reverberant field, which is marked out on the floor. A grid of nine discrete measurement points spaced equidistant apart are then marked out by the students.

5 UQ ANECHOIC CHAMBER

The University's anechoic chamber is located in Room 45-108, accessed off the Acoustics and Vibration Laboratory on the Ground Floor of the Mansergh Shaw Building. It is a full anechoic chamber, acoustically isolated from the building structure and accessed through three separate doors. The interior of the anechoic chamber consists of thousands of glasswool wedges with a base size of 100 mm x 100 mm and a length of 500 mm. The interior dimensions of the chamber (including wedges) are 4,400 mm long, 3,200 mm wide and 3,340 mm high.

The students take turns to manually conduct directivity measurements within the anechoic chamber. This enables the students to experience what it is like in a very quiet environment (the background noise level within the chamber is approximately 51 dB or 17 dB(A)) and understand the directivity of the sound emitted by the speaker.

6 EXPERIMENT RESULTS

6.1 Volume and Surface Area

The students are provided with tape measures and given approximately 45 minutes to measure the dimensions of the room and identify the different materials within the space. Figure 4 presents a summary of the volume and total surface area of the room and furnishings, rank ordered from smallest to largest.

Figure 4(a) shows that there is a 44 % difference between the smallest and largest volume. This difference is due to groups subtracting or not subtracting the volume of furnishings, people and other features from the overall volume of the space. Figure 4(b) shows there is a 175 % difference between the smallest and largest total surface area. The students are required to determine on their own what surface areas need to be accounted for in their room model. As such, some groups include the upper and lower surfaces of the tables and chairs, the table and chair legs, people, bags etc., while other groups decide to ignore some of all of those surfaces.

Figure 5 presents a scatter plot of the volume v total surface area for each group, showing that there does not appear to be a strong relationship between the volume and total surface area utilised by each group.

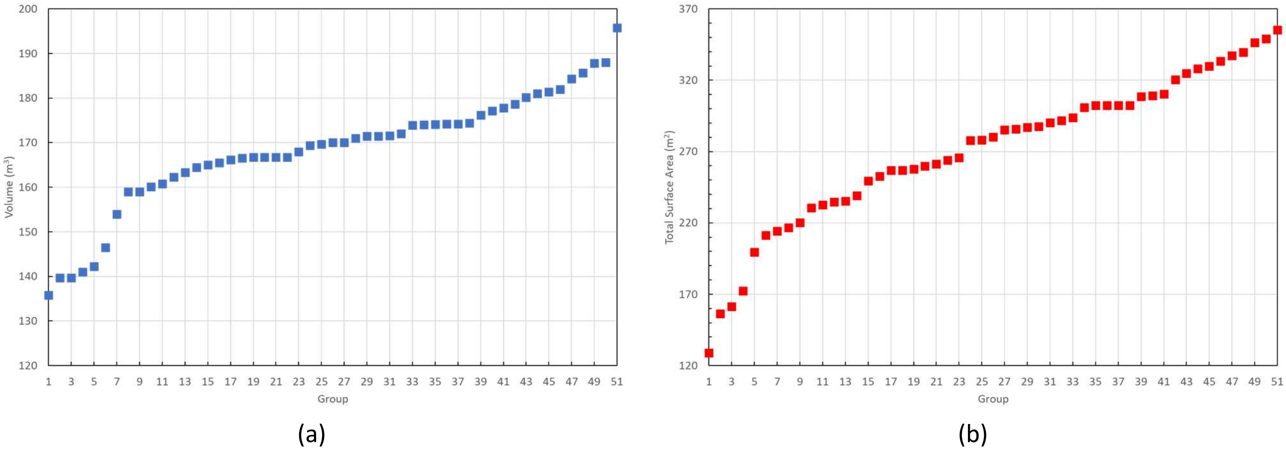


Figure 4: The (a) volume and (b) total surface area as determined by different student groups

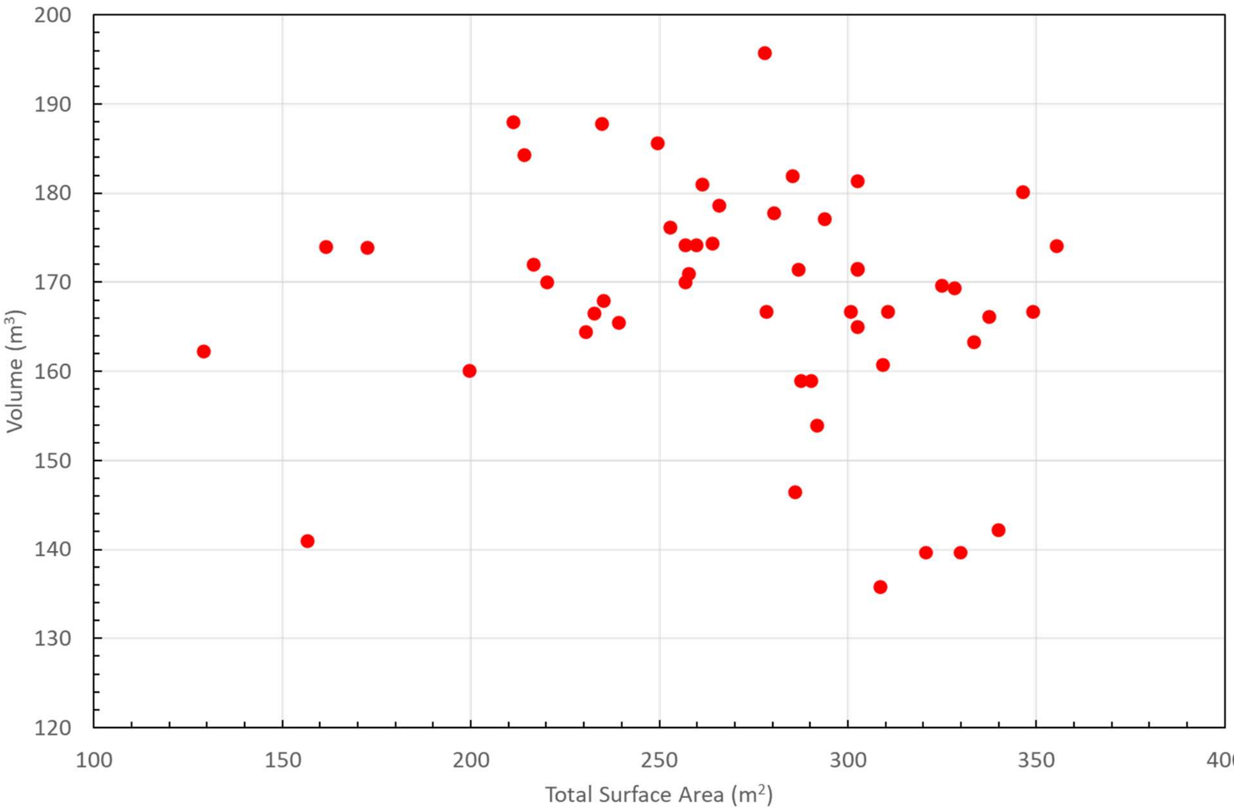


Figure 5: Scatter plot of volume v total surface area for each group

6.2 Background Noise Level

The background noise level provides the students with an opportunity to learn how to conduct time and space measurements within a reverberant field. Three separate measurements are made by students walking randomly within the reverberant field while moving the sound level meter (Larson Davis 831) at arm's length in a figure-8 pattern. The background noise level is set by ductborne noise and noise breaking out of the adjacent plantroom. The students are tasked with subjectively evaluating the noise to decide on how long the measurement duration should be. As the noise is continuous and non-varying, the measurement duration is typically between 30 and 60 seconds as chosen by the experimental group.

While a student is conducting the measurements the other students are instructed to observe and evaluate whether the measurement is influenced by extraneous noise or not. The general consensus from the students is that it is not that easy to manually complete a time and space averaged sound level measurement due to factors such as extraneous noise from clothes rustling, feet scuffing on carpet and knees and ankles clicking, the sound level meter wandering outside of the reverberant field and forgetting to hold SLM away from the body and move it in a random pattern.

The measured background noise levels for different experimental groups are presented in Figure 6. From the results it is clear that the air-conditioning system operates in at least two different modes, resulting in two very different noise profiles with different levels of scatter between the measurements. The average overall levels vary by 5.5 dB between the two modes. The air-conditioning system operates automatically and hence there is no opportunity to ensure identical operating conditions.

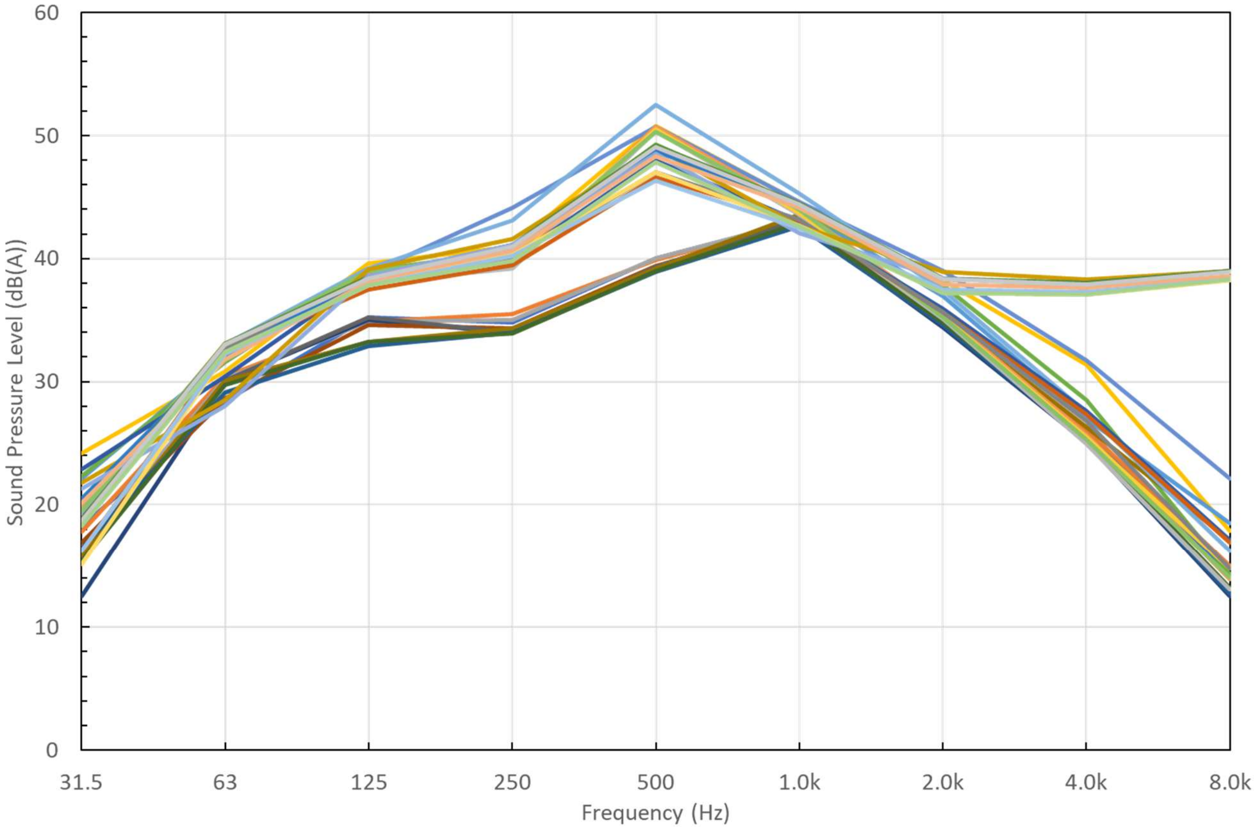


Figure 6: Measured background noise levels

6.3 Reverberation Time

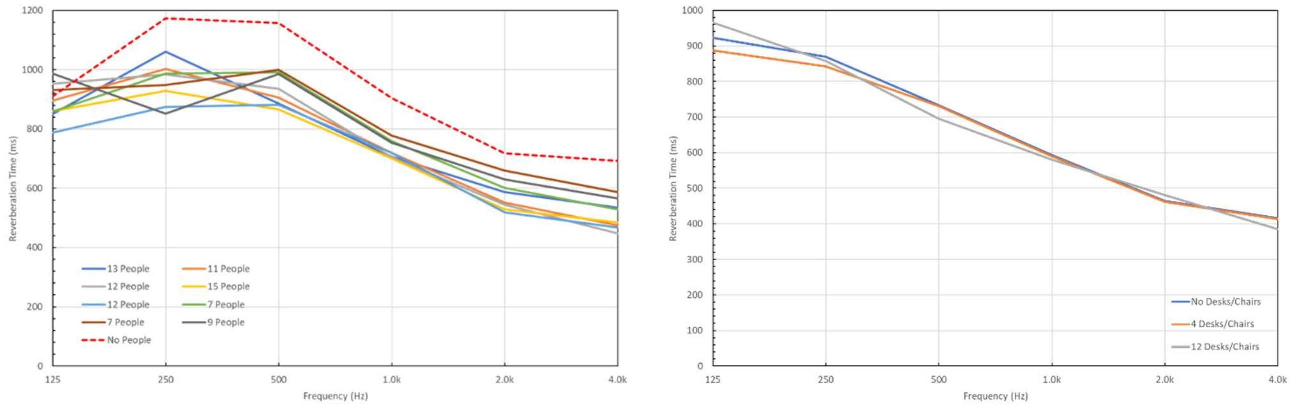
The reverberation module in the Larson Davis 831 is used to excite the room, record the decays and calculate the reverberation times using the interrupted method. Every experimental group has to do reverberation measurements at Location 5 as indicated in Figure 3(b), with two other locations randomly chosen from the remaining eight points. At each point a minimum of three reverberation measurements are conducted.

In 2019 the experiment considered the effect of people within the space by having each experimental group conduct reverberation measurements with people in and out of the room. The results are presented in Figure 7(a). Based upon those results, the average sound absorption per person was determined as presented in Table 1.

Table 1: Measured sound absorption for a person

Frequency (Hz)	125	250	500	1.0 k	2.0 k	4.0 k
Metric Sabins per person (m^2)	0.09	0.32	0.53	0.62	0.89	1.33

In 2020 a thesis project report examined the applicability of the Sabine equation to the room and the effect of furniture on the reverberation time (Hansen, 2020). Autex Quietspace panels 50mm thick were installed to cover the rear wall of the room to void the Sabine equation assumption of equally distributed sound absorption. As shown in Figure 7(b), the effect of furniture was found to be negligible on the reverberation time. Additionally, analysis completed by Hansen (2020) determined that the Sabine equation provided better agreement against the measured reverberation times than the Fitzroy and Eyring equations.



(a) (b)

Figure 7: Reverberation results showing the effect of (a) people and (b) furniture

6.4 Sabine Room Model

The students are required to prepare a Sabine room model and calibrate it against their measured reverberation ties to within 0.1 seconds across each octave band between 125 Hz and 4 kHz. The Sabine equation is (Bies and Hansen, 2009):

$$T_{60} = \frac{55.25V}{ac} \quad (1)$$

Where T_{60} is the reverberant time in seconds, V is the volume in m^3, c is the speed of sound and a is the total absorption, given by $a = \sum_{i=1}^{n} S_i \alpha_i$ where S_i is the surface area and α_i is the Sabine sound absorption coefficient of each element i.

The large variances in the room volume and total surface area as shown in Figure 4 require that there must also be large variances in the areas and sound absorption coefficients for the different materials within the space to match the measured reverberation time. Figure 8 presents a scatter plot of the number of materials versus the number of elements used in each experimental group's Sabine model. Where a high number of elements have been used in the Sabine model, groups have considered elements such as plastic power points, the clock face, computer monitor back and front, paper recycling box, air-conditioning supply and return air vents, the speaker front and back and paper recycling box. Given that groups using a far lower number of elements were able to successfully calibrate their Sabine model against the measurements, the results indicate that for small rooms like Room 45-205, elements that provide insignificant levels of sound absorption can be ignored.

Before 2019, the students sourced all of the Sabine sound absorption coefficients from widely available textbooks such as Bies and Hansen (2009) and Cox and D'Antonio (2009), and product supplier websites. The sound absorption coefficients for all of the materials are well known with the exception of the sprayed Vermiculite ceiling. Using published Sabine sound absorption coefficients such as those presented in Table 2, the calculated reverberation times are lower than the measured reverberation times, even when all other surfaces except the Vermiculite ceiling are assumed to provide no sound absorption. The thesis project completed by Hansen (2020) measured the reverberation time and worked backwards to determine the appropriate sound absorption coefficients for the ceiling as presented in Table 2. The big difference in sound absorption coefficients is attributed to the ceiling being painted in the past, which impacted on the porosity of the sprayed Vermiculite.

Table 2: Comparison between measured and published sprayed Vermiculite sound absorption coefficients

Source	Sound Absorption Coefficient α at Frequency Hz					
	125	250	500	1.0 k	2.0 k	4.0 k
Room 45-205 Measured (Hansen, 2020)	0.13	0.12	0.14	0.20	0.12	0.08
Vermitex Acustico (LAF Group, 2025)	0.10	0.20	0.50	0.80	0.90	0.80
Pyrok Acoustement 40 (Pyrok, 2025)	0.18	0.35	0.64	0.73	0.73	0.77

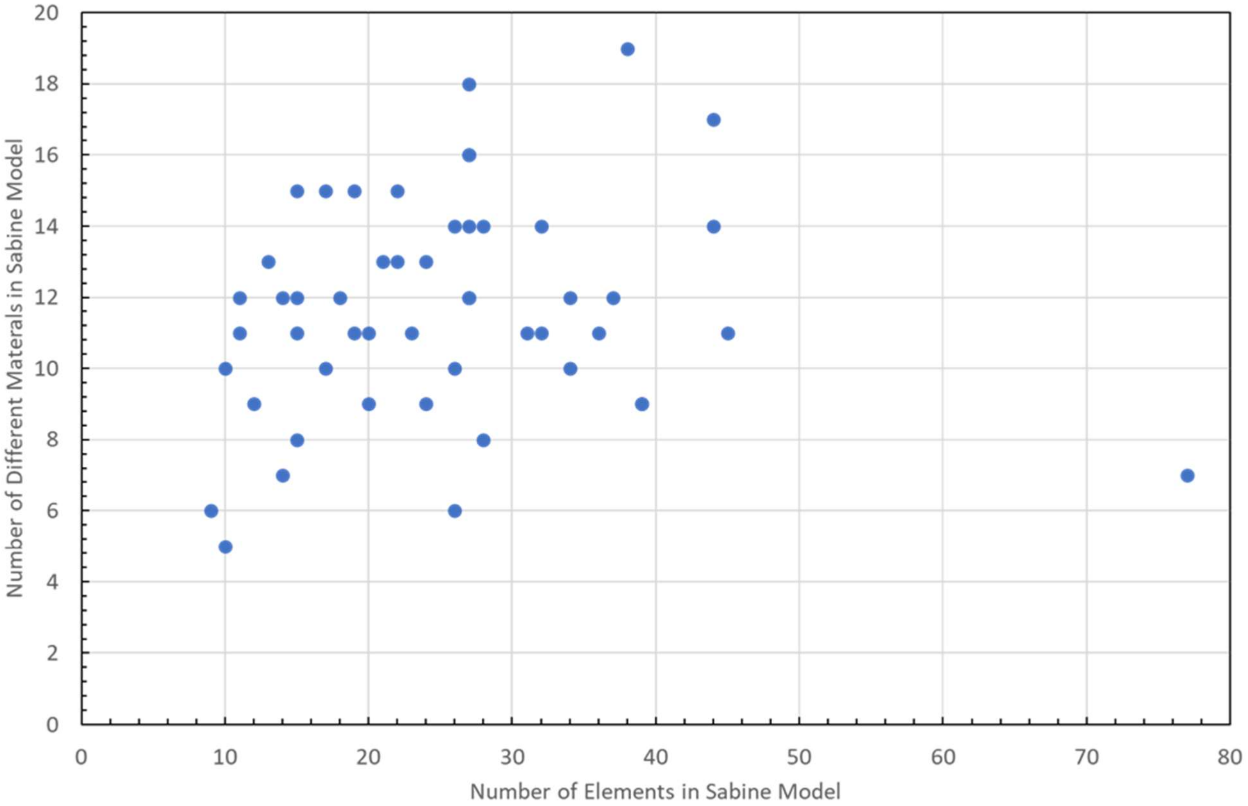
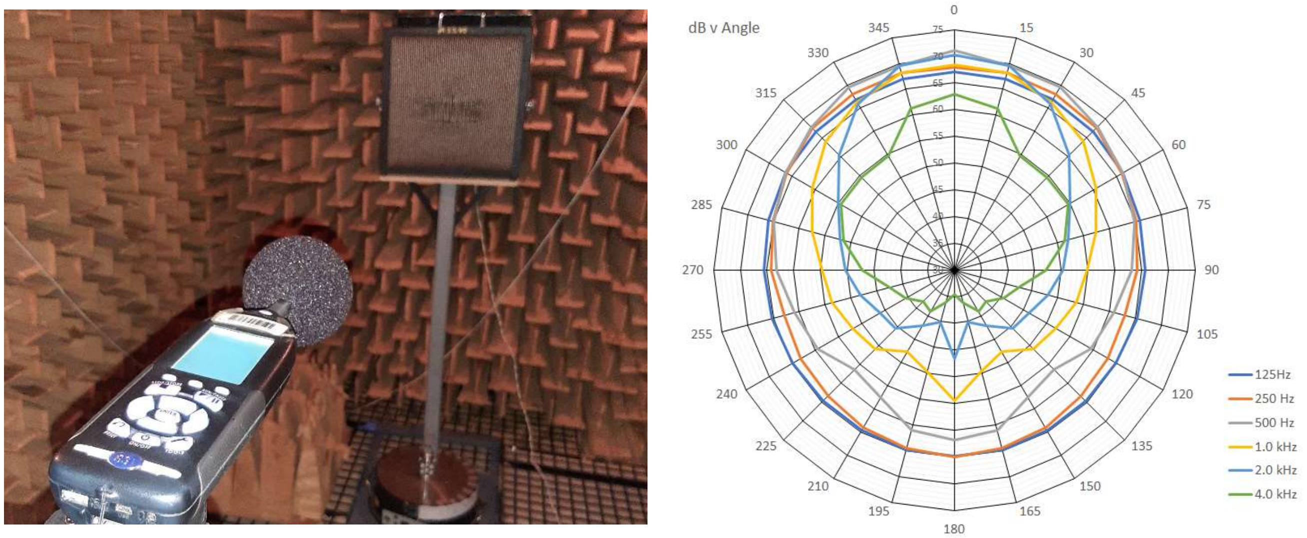


Figure 8: Scatter plot of the number of materials and number of elements used in the Sabine models

6.5 Directivity of Speaker

To measure directivity, the speaker is placed on a turntable as shown in Figure 9(a) and the sound level meter positioned along the centreline of the speaker in the far field 1.5 m from source. Measurements are made at 15^{o} increments between 0^{o} and 180^{o} with the speaker emitting pink noise at an overall level of 75 dB. As the speaker is symmetrical, those measurements results are mirrored to provide 360^{o} of data as shown in Figure 9(b).



(a) (b)

Figure 9: (a) Directivity measurement set-up and (b) polar plot showing the directivity of the speaker

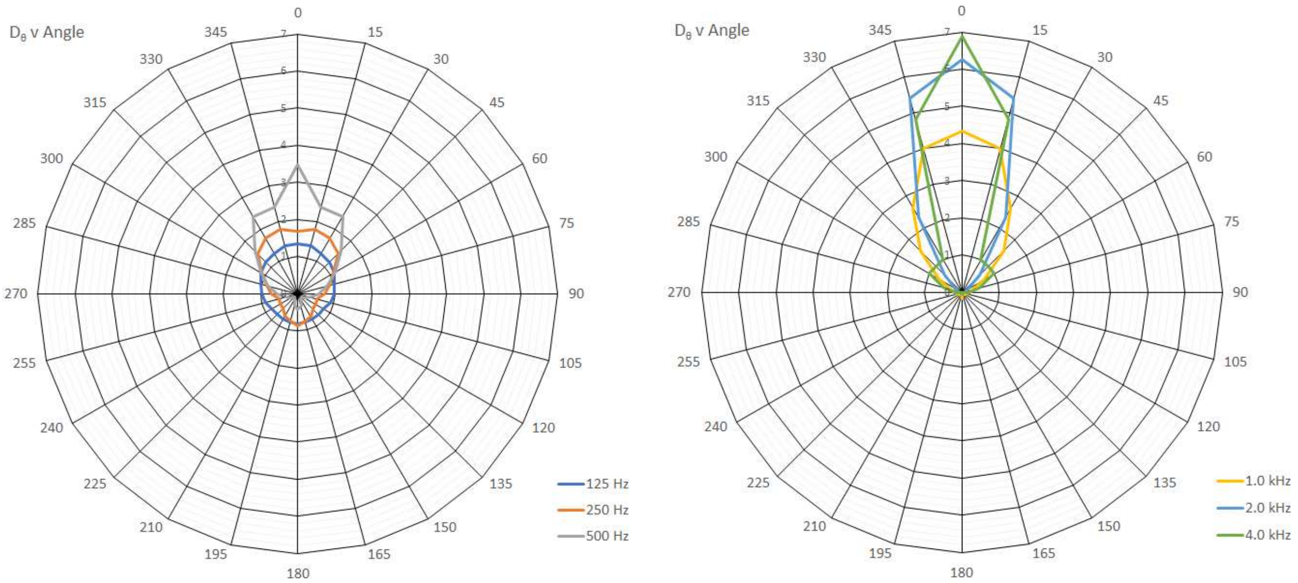
The directivity factor D_θ of the source is calculated using (Vér and Beranek, 2006):

$$D_\theta = 10^{\left(\frac{L_{p\theta} - \overline{L_p}}{10}\right)} \tag{2}$$

where $L_{p\theta}$ is the sound pressure level measured at a distance *r* and angle *θ* from a source radiating power W into an anechoic space and $\overline{L_p}$ is the average sound pressure level measured at a distance *r* from a source radiating power W into an anechoic space*,* given by:

$$\overline{L_p} = 10\log_{10}\left(\frac{\sum_{i=1}^{n} 10^{\frac{L_{p_i}}{10}}}{n}\right) \tag{3}$$

where L_{p_i} is the measurement made at position i in the anechoic chamber and n is the total number of measurements. Using Equation (2), the directivity factors for the speaker can be calculated as presented in Figure 10.



(a) (b)

Figure 10: Directivity factors D_θ for the speaker

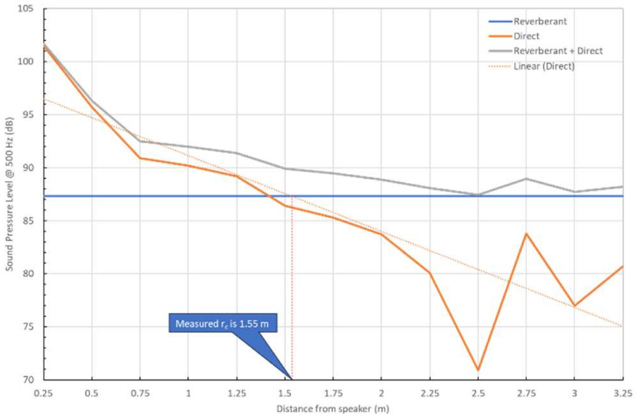
6.6 Critical Distance

At a given distance, termed the critical distance, r_c, the direct-field equals the reverberant-field level. The critical distance is calculated by rearranging the relevant parts of Equation 7.43 in Bies and Hansen, 2009:

$$r_c = \sqrt{\frac{D_\theta R}{16\pi}} \tag{4}$$

where D_θ is determined from Equation (2) and R is the room constant, defined by $R = \frac{S\bar{\alpha}}{1-\bar{\alpha}}$.

To measure the critical distance in the experiment, the reverberant sound field is measured at the nine points shown in Figure 3(b) at a height of 1.5 m above the floor and averaged. With the speakers emitting the same sound power level, measurements (comprising the direct + reverberant components) are made along the centreline of the speaker pointing into the room at 0.5 m increments. The average reverberant sound level is subtracted from those measurements to calculate the direct component and the results interpolated to determine where the direct component level intersects the reverberant component level. An example showing the agreement between the measured and calculated critical distances at 500 Hz is presented in Figure 11. Note that there is some unevenness in the measured levels due to measurement points being located at or near-to a node or anti-node.



At 500 Hz:

- Figure 10(a) gives D_θ= 3.5 along centreline of speaker
- Room constant R = 35.343 m^2
- Calculated critical distance using Equation (4) is r_c = 1.57 m

This value agrees well with the measured r_c of 1.55 m.

Figure 11: Example measurement and calculation of critical distance

7 SUMMARY

Analysis of the experimental data and calculations for Room 45-205 has revealed that it is possible to calibrate a Sabine room acoustics model using a large range of different values for the volume, surface areas and Sabine sound absorption coefficients. Determining whether those values are appropriate or not can be difficult, especially in the situation where the acoustic consultant has limited time to complete dimensional measurements and note the different surface materials.

When calibrating a room acoustics model, priority should be given to ensuring that the total absorption provided by the highest sound absorbing elements is correct. It is not necessary to include small sound reflective surfaces in the model, as their contribution is negligible. If people are to be present within the space, their contribution in reducing the reverberation time should be considered. Whether furniture increases the sound absorption within a space is also questionable, as test data obtained in Room 45-205 does not support that assertion.

When conducting sound level measurements, proper technique is important. It is easy to forget about self-generated noise from items such as clothing and proper positioning of the sound level meter to ensure it remains within the reverberant field and there is adequate separation from the acoustician's body.

Measuring background noise levels due to mechanical services can be problematic when the air-conditioning system is set up to automatically operate according to the cooling/heating requirements of the building.

If directivity data is available for a source and the room acoustics model is accurate, it is possible to achieve good agreement between the measured and predicted critical distance, noting that the locations of the nodes and anti-nodes will potentially influence any measurements.

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