Acoustics Paper Preparation 2024 - Design and Verification of a High-Performance Acoustic Testing Laboratory

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Abstract - This paper describes the design, construction, and performance verification of a new acoustic testing laboratory built to meet multiple international standards. The facility consists of source and receiver rooms with 150 m^3 and 199 m^3 volumes, separated by a 10.9 m^2 test aperture. Key design features include non-parallel surfaces to optimize diffusion, vibration-isolated concrete floors, and high-mass walls to minimize flanking transmission.

Extensive testing was conducted to verify compliance with AS 1191, ISO 10140-5, and ASTM E90 standards. Diffusivity was assessed using the absorption coefficient method, demonstrating convergence. Reverberation times exceeded 5 seconds across most frequencies, with absorption coefficients below 0.03, meeting AS 1191 criteria but requiring some problems to be solved to comply with other standards. Flanking transmission testing achieved a maximum measurable sound reduction of Rw 75 allowing testing of samples up to Rw 65, limited by equipment rather than facility performance.

The results confirm the laboratory meets or exceeds all key standard requirements, enabling acoustic testing of materials and systems to all codes being considered. This paper details the critical design considerations, measurement techniques, and performance data for this NATA accredited acoustic testing facility.

1 INTRODUCTION

Accurate measurement of sound transmission and insulation properties of building elements are crucial for advancing noise control in architecture and engineering. This paper describes the design, construction, and performance verification of an acoustic testing laboratory, located in Loganlea, Queensland, Australia. The laboratory consists of a reverberation suite in compliance with AS 1191, ISO 10140-5, and ASTM E90 standards.

2 GOALS FOR THE LABORATORY

The client for the subject laboratory operates a NATA accredited facility for the testing of physical properties of aluminium and glass systems to various standards. Testing services include structural tests, Security screen doors and window grilles, weathering and other services. Their goal was to construct an acoustic testing laboratory for the measurement of airborne sound transmission insulation of building elements which was compliant with all the requirements of:

- AS 1191-2002 (R2016) – Acoustics - Method for laboratory measurement of airborne sound transmission insulation of building elements,
- ISO 10140-5:2010 – Acoustics - Measurement of sound insulation of building elements - Part 5 - Requirements for test facilities and equipment*, and
- ASTM E90-09 (2016) – Standard test method for laboratory measurement of airborne sound transmission loss of building partitions and elements.
- AS/NZS ISO 717.1 - Acoustics - Rating of sound insulation in buildings and of building elements, Part 1: Airborne sound insulation

** - This work was conducted prior to the release of the 2021 version of ISO 10140.*

The additional goals were:

- Suitable for NATA Accredited to AS 1191 and AS/NZS ISO 717.1
- Low construction cost using the least complex methods possible.
- Suitable for testing of airborne sound transmission insulation up to Rw 55.
- Provide good results in comparison to other Australian laboratories.
- Appropriate for testing of glazing systems, doors and wall systems both of lightweight and masonry construction.

3 COMPARISON OF STANDARDS

Our first step was to review of all requirements for the laboratory within the standards nominated by the client and make a list of requirements for the design of the laboratory. The requirements are provided in **Appendix A**.

4 LABORATORY DESIGN CONSIDERATIONS

4.1 Laboratory Location

The laboratory was to be located within a dedicated warehouse space with concrete tilt-panel walls, existing concrete floor and insulated metal roof. The building has relatively low levels of internal noise generated by transportation and building services. Therefore, the bounding walls of the laboratory did not require excessively high levels of noise reduction to exclude unwanted ambient noise.

4.2 Room Dimensions and Modes

The recommendations outlined by all relevant Standards generally apply to both source and receiving rooms where all walls are parallel. AS 1191 and ASTM E90-09 specify recommended room ratios (1:1.3:1.6 and 1:1.26:1.59, respectively) which aim to evenly distribute room modes / standing waves in rooms with parallel walls. Room modes are resonances and dips in sound pressure / intensity that occur at various frequencies and points throughout a room, primarily because of its dimensions.

It is therefore preferred to have all surfaces non-parallel (including floor and ceiling surfaces), thus minimising the number and strength of potential room modes (particularly axial modes). In any case, dimensions of all walls shall not be of equal length, nor ratios of small integers (e.g. 1:2). To minimise room mode influences on the vertical plane, the ceiling to both rooms shall also be angled in relation to floor plane (≥ 5° recommended).

4.3 Room Volumes

The volume of each room has significant influences on sound diffusion and room modes (discussed in Section 4.2). As with the physical dimensions of each space, the volume of both rooms shall not be identical to minimise the likelihood of coincident resonances in each space. Volume is also important to consider as rooms that have small volumes will create larger estimates of uncertainty in measurements, particularly at lower frequencies.

AS 1191 presents the most restrictive volume requirements suggesting that each room shall be in the order of 200 m^3. Alternatively, the minimum room volume should be ≥ 4λ3, where λ is the wavelength corresponding to the lowest centre frequency of interest. For 63 Hz and 125 Hz, this means that the minimum room volume shall be 651.2 m^3 and 83.4 m^3, respectively, in order to achieve an adequate distribution of room modes.

The large volume required to achieve even distribution of sound pressure at 63 Hz (651.2 m^3) may not be practical for the site. However, with room constructed with non-parallel walls resulting in a lesser strength of modes, accurate measurements ≤ 63 Hz are achievable. All Standards recommend ≥ 10 % variation of source and receiver room volumes. It was therefore recommended that the minimum volume of both source and receiver rooms was 150 to 225 m^3, with the receiver room being ≥ 10 % larger in volume than the source room.

4.4 Aperture Size

To comply with all Standards, the minimum aperture size shall be ≈ 10 m^2, with the short edge dimension being ≥ 2.4 m^2. ASTM E90-09 suggests it as preferable that the aperture takes up the entire wall; however, this was not deemed a mandatory requirement.

4.5 Reverberation Time

Based on AS 1191 and the formulae outlined by ASTM E90-09 (assuming a room volume of 200 m^3), the average sound absorption coefficient of the receiver room shall not exceed α = 0.06 at all testing frequencies. To satisfy the requirements of ISO 10140-5 and assuming a room volume of 200 m^3, the maximum reverberation time of the receiver room shall not exceed ≈ 5.0 s. (This became an issue.) Therefore, the average sound absorption coefficient of the receiver room shall not be any less than α = 0.03. The requirements are generally satisfied by having a sealed concrete floor / ceiling and plastered concrete block walls, typical glazing and painted doors.

4.6 Diffusers

The diffusers need to be constructed of acoustically reflective material using sealed medium density fibreboard (MDF), painted compressed fibre cement (CFC) sheeting, glass or similar material. It was decided that the number, size and location of diffusers were to be determined post-construction of the acoustic laboratory based on the measurements of the reverberation properties in each room, when complete.

4.7 Ambient Noise Levels

AS 1191 recommends the test rooms should provide the necessary exclusion of external noise, however do not specify specific noise levels. Ambient noise levels shall be sufficiently low at all frequencies such that they do not contribute to any measurements, particularly in the receiver room. It was recommended that internal noise levels within each test laboratory do not exceed L_{Aeq} 35 dB(A) and L_{Amax} 40 dB(A). To determine the existing noise levels in the location of the laboratory and reductions required noise logging was conducted at the proposed location of the laboratory to determine levels associate with external traffic sources, as well as other noise from nearby warehouses.

4.8 Temperature and Humidity

AS 1191 and ISO 10140-5 do not specify temperature or humidity criteria; however, relevant laboratory test Standards including ISO 10140-2 do note that this information is to be recorded and stated in any test report.

ASTM E90-09 states that the average temperatures in each room during all acoustical measurements shall be in the range 22 ± 5°C (22 ± 2°C for glass) and the average relative humidity shall be at least 30%. Furthermore, variations in temperature and humidity in the receiving room shall not exceed 3°C and 3% relative humidity respectively.

The requirements outlined by ASTM E90-09 for glass were considered onerous and impractical to implement and would involve significant cost and 22 ± 5°C and ≥30% was adopted.

4.9 Vibration Isolation

Vibrations transmitted into the building structure can regenerate as noise when rigidly connected to the source which, in turn, can influence results measured in the receiving room. This may occur due to vibration transmission through the existing slab as a result of vehicle or machinery operations at the site, or as a result of structural vibration caused by the loudspeaker in the source room. To limit structural vibration between source and receiver rooms, it was considered essential that rooms were separated by provided a break in the floor slab, perimeter walls and ceilings. To limit structural vibration from external sources, it was adopted that each room was to have an independent floating concrete floor on isolation mounts.

5 CONSTRUCTION DETAILS

5.1 Overall

To meet all requirements of the Codes and client goals, we recommended that the laboratory was constructed of the following:

Floors	≥ 200 mm thick Independent 200 mm thick sealed concrete slabs on permanent formwork concrete floor supported by 76 mm thick elastomeric acoustic floor mounts with structural break between rooms.
Walls	≥ 190 mm thick core filled blockwork to the edge of each slab providing an independent double row of blocks for the common wall. Internal finish consists of multiple coats of an Acrylic block filler / undercoat with an Acrylic top coat / finish.
Ceilng	≥ 200 mm thick sealed concrete supported on block walls with structural break between rooms.
Room Volumes	The laboratory consists of two adjacent reverberant rooms: a source room and a receiver room. Both rooms were designed with non-parallel surfaces to optimize sound diffusion. The source room has a volume of 150.48 m³, while the receiver room is 32% larger at 198.97 m³. This design meets the recommendations of all relevant standards, which suggest ≥10% volume difference between rooms.
Test Aperture	The test aperture between the rooms measures 3.3 m x 3.3 m, providing a 10.9 m² area for specimen mounting. This exceeds the minimum 10 m² requirement specified by the standards. The aperture depth is 0.6 m, allowing for flexible positioning of test specimens.
Doors	The doors to the exterior of each room consist of a Suite-arrangement of 50 mm back-to-back metal clad solid core timber double doors with Fully grouted steel frames, absorptive finish to inner door, acoustic seals to top meeting stiles and sides of jambs, double acoustic seals to the thresholds.
Room Isolators	The properties of the mounting system of the independent Send and Receive rooms were required to be rubber with a natural supporting frequency less than 10 Hz with dead loads of the building with inclusion of Lateral restrained to meet seismic code obligations.
Diffusers	Multiple diffuser panels constructed of 17 mm form ply (hardwood with resin coating and painted edges – ≥ 9.5 kg/m²) mounted in groups of three (3) on steel poles located in the corners nearest the test aperture in both rooms. Panels are mounted on bracket system allow angling and random incidence of sound.
HVAC	As each individual test conducted for the Codes only take a few minutes, the decision was made to provide air-conditioning using wall mounted split units to maintain the nominated temperature and humidity requirements. These units could be turned off for the duration of the test and the internal temperature remain sufficiently constant.

A floor plan and sections of the laboratory design are shown in Figures 4 to 6.

Figure 1 - Floor Plan

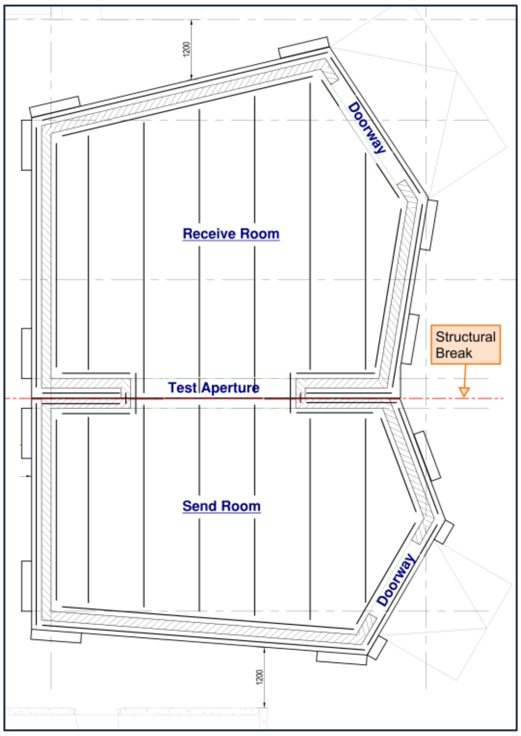


Figure 2 – Cross-section through test aperture

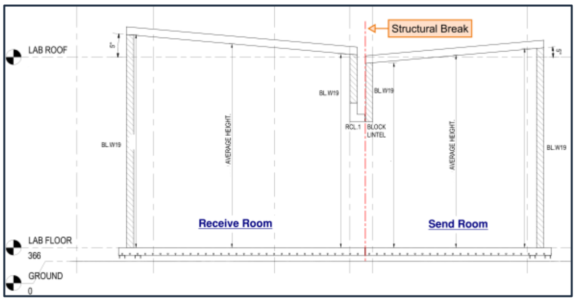
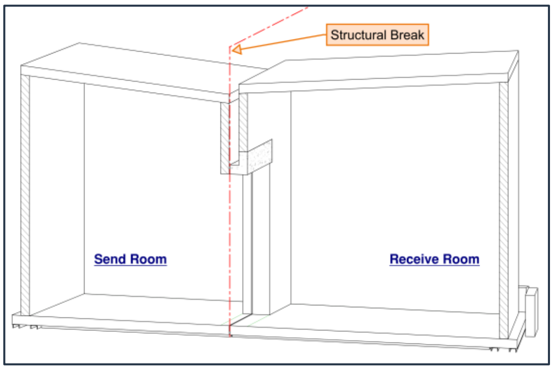


Figure 3 – 3D Cross-section through test aperture



6 PERFORMANCE VERIFICATION

Client and NATA Accreditation required demonstrating compliance with necessary attributes of the codes. Details and test outcomes are provided in this section.

6.1 Diffusivity of Sound Field

Test Methodology

With the filler wall in place, the diffusivity of both test rooms was conducted in accordance with the testing procedures and evaluation methods outlined in Appendix A of AS 1191. AS 1191 generally states that the optimum number (area) of diffusers is determined when the sound absorption performance of a test specimen installed within the test room remains constant (in the range 500 to 5000 Hz). This requirement is further reflected in Section 3.2.2 of ISO 10140-5 and Appendix X1.6.1 of ASTM E90.

Assessment of diffusivity was conducted by placing a homogeneous, porous absorbing material (test specimen) on the floor and in the centre of the test room and measuring the reverberation time several times with diffusers being added. Reverberation time measurements were conducted with test specimen present was conducted under the following conditions: without diffusers installed, with two diffusers added, with two additional diffusers added and with two more additional diffusers added.

The test specimen used was Knauf Insulation Earthwool R-2.0 1160 x 580 x 90 mm Thermal Wall Batts (6.22 m^2).

Measurement and Evaluation Methods

Test were conducted using the interrupted noise method using sound level meter with decay analysis software capabilities and inbuilt signal generator was used to deliver and analyse (in real-time) the excitation and decay rate of a steady-state broadband (pink) noise spectrum from a loudspeaker source located within the test room.

The equivalent sound absorption area of each test room containing a test specimen was calculated using the formula:

$$A_T = \frac{55.3V}{cT_1} - 4Vm$$	where	
	A_T	is the equivalent sound absorption area.
	V	is the volume, in cubic metres, of the empty reverberation room.
	c	is the propagation speed of sound in air, in metres per second.
	T_1	is the reverberation time, in seconds, of the reverberation room after the test specimen has been introduced.
	m	is the power attenuation coefficient, in reciprocal metres, calculated according to ISO 9613-1 using the climatic conditions that have been present in the empty reverberation room during the measurement. The value of m can be calculated from the attenuation coefficient, α, which is used in ISO 9613 according to the formula: $$A = \frac{\alpha}{10\lg(e)}$$

The sound absorption coefficient of the test room with the test specimen α_{r+s} installed has been calculated using the formula:

$$\alpha_{r+s} = \frac{A_T}{S}$$	where	
	α_{r+s}	sound absorption coefficient of the test room with the test specimen.
	S	is the area, in square metres, of the test room.

Diffusivity Test Results

The sound absorption coefficient α_{r+s} of each test room with the test specimen installed on the floor was calculated based on the number of diffusers. In accordance with Appendix A of AS 1191, for each set of measurements, the mean value of the sound absorption coefficients, in the range 500 to 5000 Hz has been calculated and plotted against the number (total area) of diffusers used in each scenario.

The graphs presented for the source (**Figure 4**) and receiver (**Figure 5**) rooms demonstrate the sound absorption of each room with the test sample installed based on the number of diffusers. The repeatability of measured reverberation times for each test within each room have also been provided in **Table 1** and **Table 2**, respectively. It is evident that the sound absorption performance converges to a maximum value with four (4) diffusers installed. Therefore, based on guidance provided by AS 1191, both test rooms fulfil the diffusivity requirements of the Standard when four (4) or more diffusers are present.

Figure 4: Sound absorption coefficients of source room with test specimen installed

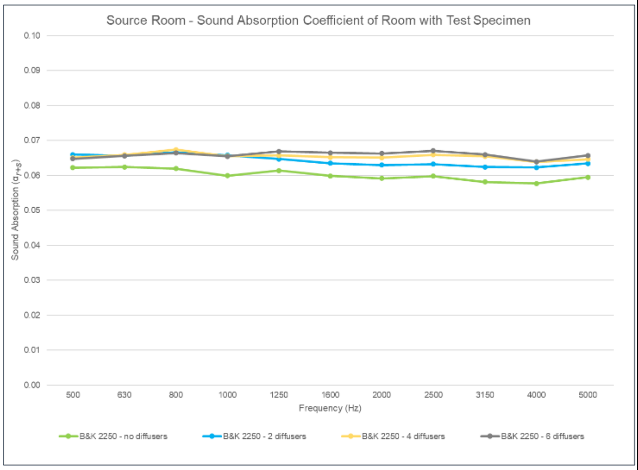


Figure 5: Sound absorption coefficients of receiver room with test specimen installed

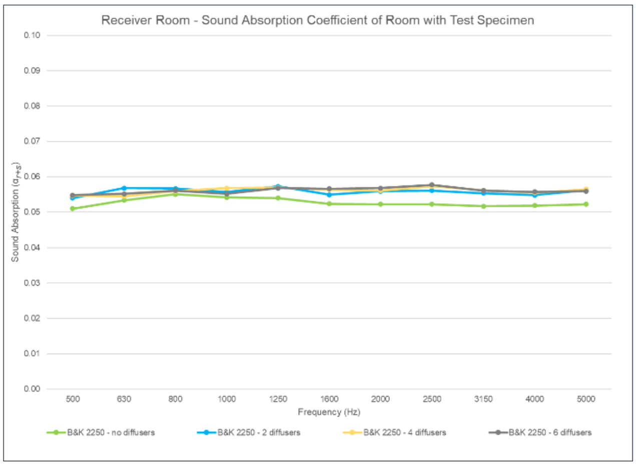


Table 1: Source Room -Repeatability of measured reverberation times for source room with test specimen installed[1]

Test	Repeatability of measured reverberation times in one-third octave bands, s [1)]										
	500 Hz	630 Hz	800 Hz	1 kHz	1.25 kHz	1.6 kHz	2 kHz	2.5 kHz	3.15 kHz	4 kHz	5 kHz
B&K 2250 - no diffusers	0.11	0.10	0.09	0.08	0.07	0.06	0.05	0.05	0.04	0.03	0.03
B&K 2250 - 2 diffusers	0.11	0.09	0.08	0.07	0.07	0.06	0.05	0.05	0.04	0.03	0.03
B&K 2250 - 4 diffusers	0.11	0.09	0.08	0.07	0.07	0.06	0.05	0.04	0.04	0.03	0.03
B&K 2250 - 6 diffusers	0.11	0.09	0.08	0.07	0.07	0.06	0.05	0.04	0.04	0.03	0.03

Table 2: Receiver Room -Repeatability of measured reverberation times for receiver room with test specimen installed[1]

Test	Relative standard deviation of measurement in one-third octave bands, s [1)]										
	500 Hz	630 Hz	800 Hz	1 kHz	1.25 kHz	1.6 kHz	2 kHz	2.5 kHz	3.15 kHz	4 kHz	5 kHz
B&K 2250 - no diffusers	0.12	0.11	0.09	0.08	0.07	0.07	0.06	0.05	0.04	0.04	0.03
B&K 2250 - 2 diffusers	0.12	0.10	0.09	0.08	0.07	0.06	0.06	0.05	0.04	0.04	0.03
B&K 2250 - 4 diffusers	0.12	0.11	0.09	0.08	0.07	0.06	0.06	0.05	0.04	0.04	0.03
B&K 2250 - 6 diffusers	0.12	0.11	0.09	0.08	0.07	0.06	0.06	0.05	0.04	0.04	0.03

6.2 Reverberation Time / Sound Absorption (Empty Room)

General

The reverberation time and sound absorption of both test rooms when empty was conducted and compared against the requirements outlined by AS 1191. Section 5.2.4 of AS 1191 suggests that the average sound absorption coefficients of the interior surfaces of each room and of the surfaces of the diffusing elements should be less than 0.06 at each test frequency. Prior to conducting the tests, diffusing elements (described in Section 6.1), and the filler wall were installed.

Measurement and Evaluation Methods

For comparative purposes, test measurements conducted in the receiving room used two different Class 1 Sound Level Meters. Results from both instruments have been provided.

Reverberation Time / Sound Absorption (Empty Room) Test Results

1 Relative standard deviation calculated in accordance with Section 8.2.2 of AS ISO 354 – 2006 (R2016) *Acoustics—Measurement of sound absorption in a reverberation room.*

The sound absorption coefficient α_r and average reverberation time (T_{30}) were calculated for each of the empty test rooms. These have been presented in **Figure 6** and **Table 3** for the source room, and **Figure 7** and **Table** 4 for the receiver room.

As evident for both rooms, the sound absorption coefficients are below 0.06 at each one-third-octave band test frequency from 125 Hz to 4 kHz, and thus, both test rooms comply with the performance recommendations nominated by AS 1191. However, reverberation times exceeded 5 seconds in most frequency bands in the receiver room. While this meets requirements of AS 1191 and ASTM E90 criteria, it exceeded ISO 10140-5 recommendations.

Figure 6: Sound absorption coefficients of empty source room

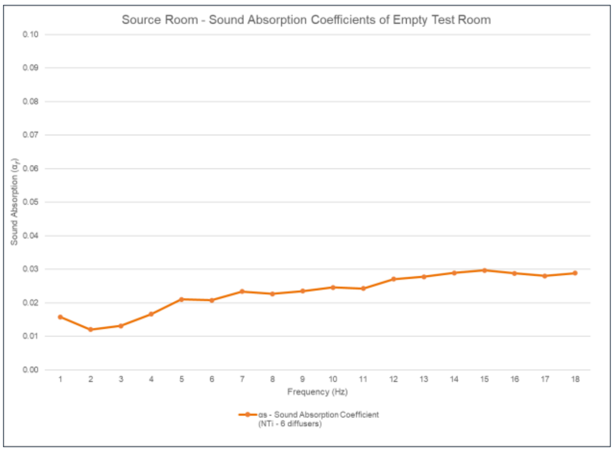


Figure 7: Sound absorption coefficients of empty receiver room

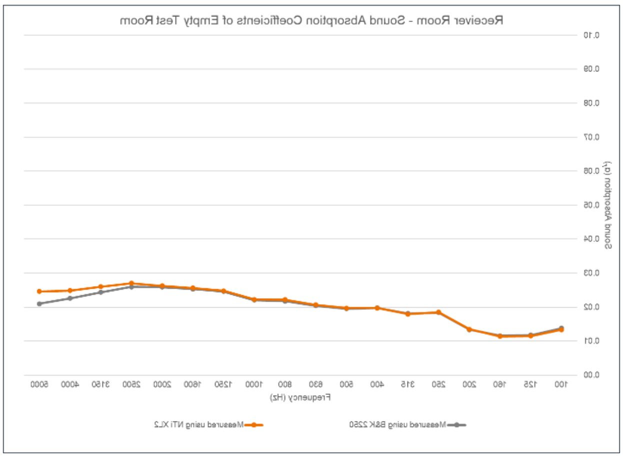


Table 3: Measured reverberation time within source room

Test	Reverberation Time, T_{30}, s																	
	100 Hz	**125 Hz**	**160 Hz**	**200 Hz**	**250 Hz**	**315 Hz**	**400 Hz**	**500 Hz**	**630 Hz**	**800 Hz**	**1 kHz**	**1.25 kHz**	**1.6 kHz**	**2 kHz**	**2.5 kHz**	**3.15 kHz**	**4 kHz**	**5 kHz**
NTi Audio	8.8	11.5	10.4	8.2	6.4	6.4	5.6	5.6	5.3	5.0	4.9	4.4	4.1	3.8	3.5	3.3	2.9	2.4

Table 4: Measured reverberation time within receiver room

Test	Measured reverberation Time, T_{30}, s																	
	100 Hz	**125 Hz**	**160 Hz**	**200 Hz**	**250 Hz**	**315 Hz**	**400 Hz**	**500 Hz**	**630 Hz**	**800 Hz**	**1 kHz**	**1.25 kHz**	**1.6 kHz**	**2 kHz**	**2.5 kHz**	**3.15 kHz**	**4 kHz**	**5 kHz**
B&K 2250	11.2	13.0	13.0	11.1	8.1	8.0	7.1	7.0	6.6	6.0	5.8	5.1	4.8	4.5	4.2	3.9	3.4	2.9
NTi Audio	11.6	13.3	13.2	11.0	8.0	8.0	7.2	7.0	6.5	5.9	5.8	5.1	4.8	4.4	4.0	3.7	3.3	2.7

6.3 Flanking Limits

General

Assessment to identify noise flanking limits and maximum sound reduction index achievable in the test lab was conducted in accordance with Appendix C of AS 1191. A filler wall (described below) was installed in the aperture between both test rooms. The filler wall installed in the aperture was constructed of the following configuration:

- Three (3) layers of 13 mm USG Boral Soundstop plasterboard;
- Two (2) 90 mm x 45 mm timber studs (600 mm centres) of discontinuous construction creating a ≈ 522 mm cavity;
- Two (2) 90 mm Knauf Insulation Earthwool R-2.0 Thermal Wall Batts (one (1) layer to each stud set); and
- Three (3) layers of 13 mm USG Boral Soundstop plasterboard.

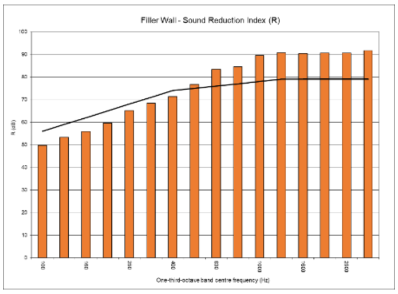
The partition was installed with one side located on the source room side and the other side located on the receiver room side of the aperture such that the two rooms were not “bridged” at any point (including at all peripheries). All edges of the partition were sealed with a flexible sealant (gap filler).

Flanking Limit Results

The highest weighted sound reduction performance achieved between the source and receiver room was R_w 75; however, it shall be noted that the performance has been limited due to insufficient noise levels in the source room (i.e. resultant noise levels in the receiver room were ≤ 10 dB above the ambient noise levels at frequencies ≥ 630 Hz).

Based on this, the noise flanking limit of the acoustic test lab has not yet been identified; however, it is a fair assumption that testing of partition elements rated to at least R_w 65 can be accurately measured in the facility without any influences caused by noise flanking. A summary of the measurements and calculations has been provided in **Table 5**.

Table 5: Calculation of weighted sound reduction index (R_w) for filler wall partition

Freq. (Hz)	Source Room Level (L_{ps}), dB	Receiver Room Level (L_{pr}), dB	Background Noise Level (L_{br}), dB	Reverberation Time (T_{20}), s	Sound Reduction Index (R), dB	Def.	Estimation of Precision (95 % Confidence), dB
100	108.1	63.9	45.8	10.9	49.8	6.2	1.0
125	109.4	62.3	42.9	12.5	53.2	5.8	0.8
160	108.8	59.2	40.3	12.4	55.8	6.2	0.5
200	104.1	50.0	33.4	10.8	59.6	5.4	0.4
250	103.9	42.9	27.7	7.8	65.1	2.9	0.3
315	104.2	39.9	23.6	7.9	68.5	2.5	0.3
400	104.5	36.9	19.9	7.1	71.3	2.7	0.2
500	104.4	31.4	17.3	7.0	76.7	0	0.2
630	103.9	23.9	*14.4*	6.5	83.4	0	0.1
800	102.3	20.8	*13.3*	6.0	84.5	0	0.2
1000	100.9	14.2	*11.7*	5.8	89.5	0	0.3
1250	99.7	11.3	*9.9*	5.2	90.7	0	0.7
1600	98.1	9.8	*6.4*	4.8	90.3	0	0.7
2000	98.3	9.4	*6.8*	4.5	90.6	0	0.7
2500	98.3	9.1	*6.9*	4.2	90.6	0	0.7
3150	98.2	7.6	*6.4*	3.9	91.7	0	0.4
4000	96.6	8.2	*7.5*	3.4	89.0	0	0.2
5000	96.1	9.0	*8.7*	2.9	86.9	0	0.1
Weighted sound reduction index (R_w)			75				
Spectrum adaptation terms (C ; C_{tr})			-3 ; -9				
Sum of deficiencies			31.7				

7 SUMMARY OF FINDINGS

7.1 Diffusivity of Sound Field

Tested results showed that sound absorption converged to a maximum value with four diffuser panels installed in both rooms. This demonstrated compliance with diffusivity requirements of the relevant standards.

7.2 Reverberation Time and Absorption

Empty room reverberation times were measured using the interrupted noise method in accordance with ISO 354. Measurements were conducted in both rooms across one-third octave bands from 100 Hz to 5kHz. The average absorption coefficients for both rooms were ≤ 0.03 across all tested frequencies, well below the AS 1191 limit of 0.06. Reverberation times exceeded 5 seconds in most frequency bands in the receiver room, which meets AS 1191 and ASTM E90 criteria but exceeds ISO 10140-5 recommendations.

7.3 Flanking Transmission Limits

A high-performance filler wall was installed in the test aperture to assess maximum achievable sound reduction. Measurements followed the procedures in AS 1191 Appendix C. The highest measured weighted sound reduction index was Rw 75. However, this was limited by insufficient source room levels rather than facility performance. The results indicate that the laboratory can accurately measure partitions rated up to at least Rw 65 without flanking influences.

7.4 Performance Summary / Comparison with International Standards

The acoustic performance of the test facility has been compared against the relevant Australian and International Standards. Comparisons to the requirements and recommendations of all Standards is provided in **Appendix B.**

8 REVERBERATION TIME CORRECTION FOR ISO 10140-5

To gain compliance with the maximum reverberation time requirement of <5.0 seconds in test frequency bands in the receiver room, required by ISO 10140-5, additional works were performed. To address the above performance requirements, irrespective of whether the sound reduction index of a test specimen installed in the test aperture is influenced by reverberation time, removable acoustic bass traps were designed and positioned in both reverberation chambers (see images in Appendix C).

Measurements of reverberation time in both reverberation chambers were conducted in accordance with the requirements specified by ISO 10140-4. The partition installed within the test aperture generally consisted of plasterboard and glazing which had negligible sound absorption. Since the upper reverberation time at frequencies ≥ 100 Hz is volume dependent, the following criteria were applied:

Source Room: $1 \leq T \leq 4.2$ s and Receiver Room: $1 \leq T \leq 5.0$ s

A summary of the measured reverberation times in the source and receiver rooms are presented in **Table 6** and **Table 7**, respectively.

Table 6: Measured reverberation time in the source room with acoustic bass traps installed

Source Room – Measured reverberation time, *T*, s								
100 Hz	**125 Hz**	**160 Hz**	**200 Hz**	**250 Hz**	**315 Hz**	**400 Hz**	**500 Hz**	**630 Hz**
3.95	3.39	3.78	3.64	3.05	3.45	3.33	3.72	3.62
800 Hz	**1 kHz**	**1.25 kHz**	**1.6 kHz**	**2 kHz**	**2.5 kHz**	**3.15 kHz**	**4 kHz**	**5 kHz**
3.5	3.53	3.5	3.57	3.42	3.22	3.03	2.65	2.34

Table 7: Measured reverberation time in the receiver room with acoustic bass traps installed

Receiver Room – Measured reverberation time, *T*, s								
100 Hz	**125 Hz**	**160 Hz**	**200 Hz**	**250 Hz**	**315 Hz**	**400 Hz**	**500 Hz**	**630 Hz**
3.48	3.23	3.07	3.57	3.07	3.29	3.51	3.61	3.74
800 Hz	**1 kHz**	**1.25 kHz**	**1.6 kHz**	**2 kHz**	**2.5 kHz**	**3.15 kHz**	**4 kHz**	**5 kHz**
3.79	3.86	3.82	3.88	3.78	3.56	3.35	2.94	2.56

Based on the above, the reverberation time measured within both reverberation chambers satisfy the requirements specified by Section 3.2.3 of ISO 10140-5 with bass traps installed.

9 CONCLUSION

The designed acoustic testing laboratory meets or exceeds all the key requirements of AS 1191, ISO 10140-5, and ASTM E90 standards. The facility's performance in terms of diffusivity, reverberation characteristics, and flanking control enables high-accuracy acoustic testing across a wide frequency range. The laboratory's high flanking limit ensures its suitability for testing high-performance acoustic materials and systems.

At the time of publication, we are pleased to know that our client holds NATA accreditation for the facility for testing of codes: AS 1191 and AS/NZS ISO 717.1.

This paper has detailed the critical design considerations, measurement techniques, and performance data for this state-of-the-art acoustic testing facility. The methods and results presented here can serve as a valuable reference for the design and verification of similar laboratories in the future.

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10 APPENDIX A: COMPARISON OF APPLICABLE STANDARDS

Parameter	Requirements of Standard		
	AS 1191-2002 (R2016)	**ISO 10140-5**	**ASTM E90-09 (2016)**
Room Dimensions	No two dimensions equal or in ratio of small integers. Ratio of smallest to largest dimension of either room shall be less than 2 parallelepiped ratios: 1:1.3:1.6	Such that eigenmode frequencies in the low frequency bands are uniformly space	No two dimensions equal or in ratio of small integers. Ratio of smallest to largest dimension of either room shall be less than 2 Parallelepiped ratios: 1:1.26:1.59
Source and Receiver Room Volume	≥ 100 m^3 (desired) ≥ 200 m^3 (preferred) 4λ3 lowest centre frequency of interest	≥ 50 m3	≥ 80 m^3 For new construction, room volumes of at least 200m^3 are recommended to allow more reliable measurements at low frequencies.
Minimum Variance of Room Volumes	≥ 10% variance in room volumes	≥ 10% variance in room volumes	≥ 10% variance in room volumes
Aperture Size	≈ 10 m^2 Smallest dimension other than thickness shall not be less than 2.4 m	≈ 10 m^2 Smallest dimension other than thickness shall not be less than 2.3 m	Preferably forms a whole room surface. Alternatively, the depth from the principal surface of each room to the specimen surface should be small compared to the lateral dimensions of the specimen, about 0.5 m or less.
Diffusion	Adequately diffuse sound field. For diffusers to be effective, their width should be at least one-quarter wavelength at the lowest test band (about 1 m for bands centred on 100 Hz or 125 Hz). Diffusers of different sizes, ranging from approximately 0.8 m^2 to 3 m^2 in area (for one side) are recommended, though it is appreciated that the choice of size will be influenced by the volume of each room. The sheets may be slightly curved and should be oriented and positioned throughout the room. A check for adequate diffusivity shall be conducted in accordance with Appendix A2.	Diffusing elements to be installed to reduce standing waves. Positioning and number of elements arranged in such a way that sound reduction index is not influenced when additional elements are added. NOTE: For some kinds of test element, as for elements with one surface significantly more absorbent than the other (see ISO 10140-2), the installation of diffusing elements is mandatory.	Stationary diffusing panels: set of 3-6 panels suspended in random orientations. Number, distribution and orientation to be experimented with by checking spatial variances of sound pressure level or decay rate are reduced. Lateral panel dimensions - 0.5-1 wavelength of lowest test band. Panel to be ≥ 5 kg/m^3.Rotating or moving diffusers: one or more rotating panels set at oblique angles to the room surface. Dimensions and weight as above. Total single-sided area of panels ≥ 10-15% of total room surface area
Reverberation Time / Room Absorption	The average sound absorption coefficients of the interior surfaces of each room and of the surfaces of the diffusing elements should be less than 0.06 at each test frequency.	$1 \leq T \leq 2(V/50)^{2/3}$ s	In the frequency range that extends from $f = 2000 / V^{1/3}$ to 2000 Hz, the absorption in the receiving room (as furnished with diffusers) should be no greater than: $A=V^{2/3}/3$
Background Noise	Not specified. Signal in the receiving room shall exceed the background noise by at least 10 dB. Corrections to be applied to receiver room measurements (in accordance with Section 8.4) where receiver room measurements are ≤ 10 dB above background noise levels.	Sufficiently low to permit measurements of the sound transmitted from the source room. Corrections to be applied to receiver room measurements (in accordance with ISO 10140-4, Section 4.3) where the receiver room ≤ 15 dB above background noise levels.	Not specified. Corrections to be applied to receiver room measurements (in accordance with Section 10.2) where receiver room measurements are ≤ 10 dB above background noise levels.
Temperature / Humidity	Not specified	No specified	Unless otherwise specified, the average temperatures in each room during all acoustical measurements shall be in the range 22 ± 5°C (22 ± 2°C for glass) and the average relative humidity shall be at least 30%. Variations in temperature and humidity in the receiving room shall not exceed 3°C and 3% relative humidity respectively.

Flanking Transmission Control	The test rooms shall be constructed so that the sound transmitted by any path other than through the test specimen shall be negligible compared with the sound transmitted through the test specimen.	Provide sufficient structural isolation between source and receiving rooms Refer to Annex A	Supporting one or both rooms on vibration isolators (resilient materials or springs) is a common method of reducing flanking transmission. Structural discontinuities are recommended between the source-room and the test specimen and between the receiving room and the test specimen to minimize flanking transmission between them.

*AS/NZS ISO 717.1 only refers to the other standards.

Appendix B: Performance Summary / Comparison with International Standards

Test Parameter	General Requirements and Recommendations of Relevant Standards			Comments
	AS 1191	ISO 10140-5	ASTM E90	
Room Dimensions	*Section 5.2.3* No two dimensions equal or in ratio of small integers. Ratio of smallest to largest dimension of either room shall be less than 2. Parallelepiped ratios: 1 : 1.3 : 1.6	*Section 3.2.1* Corresponding dimensions of the two test rooms should not be the same.	*Section X1.4* No two dimensions equal or in ratio of small integers. Ratio of smallest to largest dimension of either room shall be less than 2. Parallelepiped ratios: 1 : 1.26 : 1.59	The room is an irregular pentagonal prism. With the exception of wall height surrounding the test aperture in both the source and receiver rooms, no two dimensions equal or in ratio of small integers (NOTE: heights of the source and receiver rooms around the aperture are not equal).
Volume	*Section 5.2.2* Source room: ≥ 100 m^3 preferred. Receiver room: ≥ 200 m^3 preferred. *V* = 4λ^3 lowest centre frequency of interest. ≥ 10% variance in room volumes.	*Section 3.2.1* Source room: ≥ 50 m^3. Receiver room: ≥ 50 m^3. ≥ 10% variance in room volumes.	*Section X1.2* Source room: ≥ 80 m^3. Receiver room: ≥ 80 m^3. ≥ 10% variance in room volumes.	Source room volume: 150.48 m^3 Receiver room volume: 198.97 m^3 The receiver room volume is 32 % larger than the source room. The lowest frequency of interest for the test facility is 100 Hz. The receiver room satisfies the minimum recommended volume formula outlined by AS 1191.
Test Aperture	*Section 6.1* The minimum area of the test specimen shall be 10 m^2 and the smallest dimension, other than thickness, shall not be less than 2.4 m.	*Section 3.3.1* The area of the full-sized test opening shall be approximately 10 m^2 for walls	*Section X1.5* For new test suites, test specimens should preferably form a whole room surface (wall or floor). Alternatively, the depth from the principal surface of each room to the specimen surface should be small compared to the lateral dimensions of the specimen, about 0.5 m or less.	The dimensions of the test aperture are 3.3 m x 3.3 m (10.9 m^2). The total depth of the test aperture is 0.6 m; however, it is possible to situate the test specimen at a position on the receiver room side of the opening such that the alternative method recommended by ASTM E90 is met.
Diffusers	*Section 5.2.1* Adequately diffuse sound field. *Appendix A* Diffusers: Low sound absorption and ≥ 5 kg/m^2	*Section 3.2.2* Diffusing elements to be installed to reduce standing waves. Positioning and number of elements arranged in such a way that sound reduction index is not	*Section X1.6* Stationary diffusing panels: set of 3-6 panels suspended in random orientations. Number, distribution, and orientation to be experimented with by checking spatial variances of sound pressure level or decay rate are reduced. Lateral panel dimensions - 0.5-1 wavelength of lowest test band. Panel to be ≥ 5 kg/m^2.	Diffusivity of both rooms has been described in **Section 6.1** of this document. Six (6) diffuser panels constructed of 17 mm formply (hardwood with resin coating) are mounted in groups of three (3) on steel poles located in the corners located nearest the test aperture. The diffuser material has a surface mass of 9.5 kg/m^2. The minimum width of the

	Width: ≥ one-quarter wavelength at the lowest test band.	influenced when additional elements are added.		panels is 0.5x the wavelength of the lowest frequency of interest (i.e. 100 Hz).
Reverberation Time / Room Absorption	*Section 5.2.4* The average sound absorption coefficients of the interior surfaces of each room and of the surfaces of the diffusing elements should be less than 0.06 at each test frequency.	*Section 3.2.3* $1 \leq T \leq 2(V/50)^2$ s recommended where measured sound reduction index of a partition is dependent on the reverberation time.	*Section 6.4* In the frequency range that extends from $f = 2000/V^{1/3}$ to 2000 Hz, the absorption in the receiving room (as furnished with diffusers) should be no greater than: $A=(V^{2/3})/3$	The average absorption coefficient for both rooms in all one-third octave bands ranging from 100 – 5000 Hz is ≤ 0.03. The sound absorption of both rooms meets the criteria set out by AS 1191 and ASTM E90; however, results in exceedances to the upper reverberation time limit outlined by ISO 10140-5 (i.e. receiver room ≈ 5.0 s) See correction in Section 8.
Flanking Transmission Control	*Section 5.3* The test rooms shall be constructed so that the sound transmitted by any path other than through the test specimen shall be negligible compared with the sound transmitted through the test specimen.	*Section 3.2.5* Provide sufficient structural isolation between source and receiving rooms. Refer to Annex A	*Section A5.1* Supporting one or both rooms on vibration isolators (resilient materials or springs) is a common method of reducing flanking transmission. Structural discontinuities are recommended between the source-room and the test specimen and between the receiving room and the test specimen to minimize flanking transmission between them.	The highest sound isolation performance measured between the source and receiver room was R_w 75; however, it shall be noted that the performance has been limited due to insufficient noise levels in the source room (i.e. resultant noise levels in the receiver room were ≤ 10 dB above the ambient noise levels at frequencies ≥ 630 Hz (refer to **Section 6.3** of this report).