A Study of an Innovative Sound Absorbing Mechanism for Low-Frequency Sound

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Abstract - This paper presents the development and evaluation of an innovative mechanism for absorbing low-frequency sound, a challenge that stems from the long wavelengths associated with these frequencies. Traditional methods of sound absorption rely on thick materials to achieve effective attenuation, which can be impractical in environments with spatial limitations. This study aims to address the growing demand for materials that can absorb low-frequency sound while maintaining minimal thickness, offering solutions for various engineering and architectural acoustic applications. Two configurations of thin membrane systems were tested—one with high airflow resistivity and the other with low airflow resistivity—integrated into materials with thicknesses of 24mm and 12mm. The role of an air gap in enhancing the acoustic performance of these membrane systems was also investigated. The results of these tests are thoroughly reviewed and compared, with a focus on the membrane thickness, airflow resistivity, and the impact of the air gap on sound absorption efficiency. Potential applications of these systems in real-world acoustic scenarios are discussed, and directions for further research are recommended to optimize these thin, space-efficient mechanisms for broader use.

1 INTRODUCTION

Low-frequency sound presents a unique challenge in the field of acoustic insulation due to its long wavelength. Traditional homogenous sound-absorbing materials, such as acoustic foam, glass wool, and Rockwool, rely on factors like density, porosity, and airflow resistance to dampen sound (Attenborough, 2019). However, these materials become impractically thick when used to absorb low-frequency sounds (Heddle, 2016). For instance, in one project requiring sound absorption at frequencies as low as 31.5 Hz, insulation layers between 400 mm thick were specified. Such solutions are cumbersome and often unfeasible, underscoring the need for alternative, more practical approaches.

One potential solution lies in the use of thin membranes. It has been shown that impermeable membranes can exhibit resonant peaks, where sound absorption is maximized at a specific frequency. However, outside these resonant frequencies, their effectiveness is limited. With optimised airflow resistance, however, a thin membrane can be designed to extend sound absorption across a broader range of frequencies, making it a more versatile solution (USA Patent No. US 8,167,085 B2, 2012) (USA Patent No. US 8,573,358 B2, 2013).

This study explores the concept of utilising two thin membranes to enhance the sound absorption performance of homogenous materials, particularly at low frequencies, without increasing material thickness. A series of membranes with varying airflow resistances were selected, and different combinations of two membranes were tested. The results are summarised, and the study concludes with insights into the most effective combinations and recommendations for future research.

2 THE SOUND-ABSORBING MODELING

The schematic representation of the material build-up used for this investigation is illustrated in Figure 1.

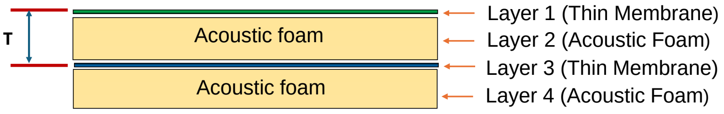


Figure 1 – Schematic drawing of the build-up of the two-membrane sound absorbing system

In this model, the build-up consists of four layers. Layer 1 is a thin membrane, also referred to as the facing material. Layer 2 is composed of acoustic foam designed to provide primary sound absorption. Layer 3 is a second layer of thin membrane, while Layer 4 is another layer of acoustic foam, reinforcing the overall sound absorption performance.

Four different types of thin membranes were selected for this investigation. Despite sharing the same density of 220 g/m^2 and a typical thickness of 0.22 mm, these thin membranes vary in their airflow resistance, as detailed in Table 1.

Table 1 – The four types of thin membranes based on Megasorber Soundmesh G8 Acoustic Fabric

Sample Name	MR2.5	MR5	MR15	MR45
Weight, *g/m2*	220	220	220	220
Thickness, *mm*	0.22	0.22	0.22	0.22
Airflow resistance, *mks Rayls*	200-400	800-1,000	2500-3000	6000 - 6500

The acoustic foam selected for this study is a thermoset foam with a density ranging from 8 kg/m^3 to 10 kg/m^3. The foam layers and membranes are bonded together using a hot-melt web adhesive, ensuring a stable and cohesive structure for testing.

The sound absorption tests were conducted using the Alpha Cabin, depicted in Figure 2, which is a compact reverberation room specifically designed for precise sound absorption measurements. These tests complied with the AS ISO 354 standard (Australian-Standard, 2006), which requires the edges of the test samples to be covered to ensure consistent and reliable results.

Figure 2 – Alpha Cabin: a compact reverberation room for sound absorption measurement

Compared to a full-size reverberation room, the Alpha Cabin offers the advantages of faster measurement times and a smaller sample size of 1.2m^2. However, the trade-off is that its reduced size results in a cut-off frequency of 400Hz, limiting its ability to capture lower-frequency sound absorption data in this study.

3 THE EFFECT OF TWO MEMBRANES ON 24MM THICK FOAM

This section investigates the impact of two thin membranes introduced to a 24mm thick foam to assess the improvements in sound absorption, especially at mid to low frequencies.

A schematic representation of the test sample configuration is provided below:

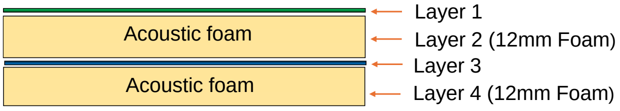


Figure 3 – A schematic drawing of 24mm test samples with two membrane system

The baseline reference for this study was established by testing two layers of 12mm thick acoustic foam, placed together and evaluated in the Alpha Cabin.

Next, two membranes were introduced into the system, as shown in Figure 3. Based on the computer model, the initial hypothesis was to utilise an open, porous membrane for Layer 1 to maintain sound absorption performance at mid to high frequencies. We anticipated that the second membrane layer would improve low-frequency absorption. To evaluate this, three initial samples were tested with Layer 1 consisting of MR2.5 and Layer 2 varied among MR5, MR15, and MR45.

However, the second foam layer's thickness of only 12mm limited its ability to significantly enhance low-frequency absorption, despite the higher airflow resistance of Layer 2. This prompted further investigation into the effect of increasing the airflow resistance of Layer 1. As a result, a total of 13 test samples were prepared for sound absorption testing. The combinations of membranes and foam layers for each sample are listed in Table 2.

Table 2 – Various combinations of the two membranes

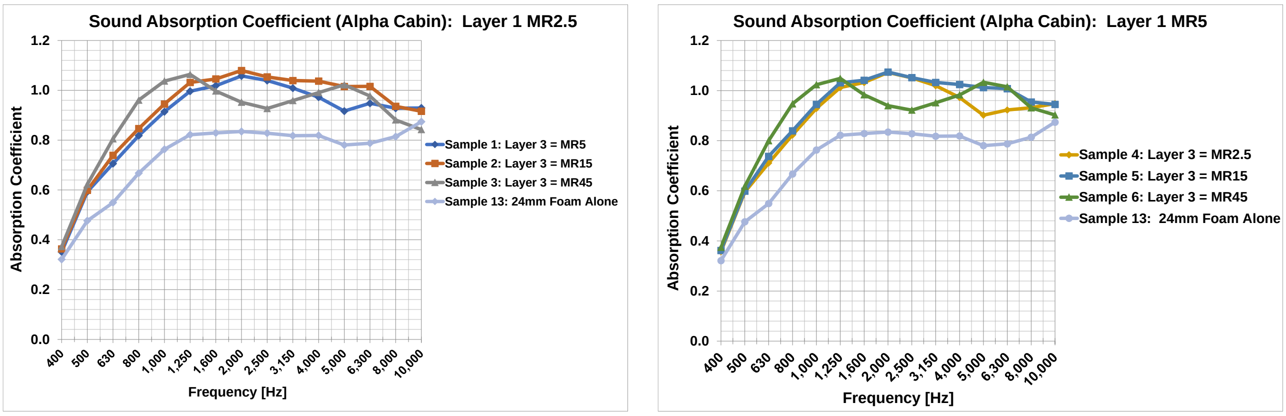
Sample Number	**Layer 1**	**Layer 2**	**Layer 3**	**Layer 4**
1	MR2.5	12*mm*	MR5	12*mm*
2	MR2.5	12*mm*	MR15	12*mm*
3	MR2.5	12*mm*	MR45	12*mm*
4	MR 5	12*mm*	MR2.5	12*mm*
5	MR 5	12*mm*	MR15	12*mm*
6	MR 5	12*mm*	MR45	12*mm*
7	MR15	12*mm*	MR2.5	12*mm*
8	MR15	12*mm*	MR5	12*mm*
9	MR15	12*mm*	MR45	12*mm*
10	MR45	12*mm*	MR2.5	12*mm*
11	MR45	12*mm*	MR5	12*mm*
12	MR45	12*mm*	MR15	12*mm*
13	24mm Acoustic Foam			

3.1 Layer 1 with MR2.5

The test results, as shown in Figure 4(a), indicate that when Layer 1 is MR2.5, the introduction of two membranes enhances sound absorption across all frequencies compared to the 24mm thick foam without membranes.

The results reveal that as the airflow resistance of Layer 3 increases from MR5 to MR15, there are small improvements in sound absorption across all frequencies. When the airflow resistance of Layer 3 further increases to MR45, there is a significant increase in sound absorption in the range of 630Hz to 1,250Hz. However, the absorption dips around 2,500Hz and again at 8,000Hz.

These results align with the hypothesis that Layer 1 with MR2.5 allows sound to enter the system with minimal obstruction, resulting in no substantial loss of high-frequency sound absorption. The higher airflow resistance of the second membrane enhances sound absorption in the lower frequency range. However, when the airflow resistance of Layer 3 increases from MR15 to MR45, a resonant peak effect becomes apparent, with maximum absorption around 1,250Hz and notable dips at 2,500Hz and 8,000Hz.



(a) Layer 1 MR2.5 *(b) Layer 1 MR5*

Figure 4 – Sound absorption of various samples with Layer 1 MR2.5 and Layer 1 MR5

3.2 Layer 1 with MR5

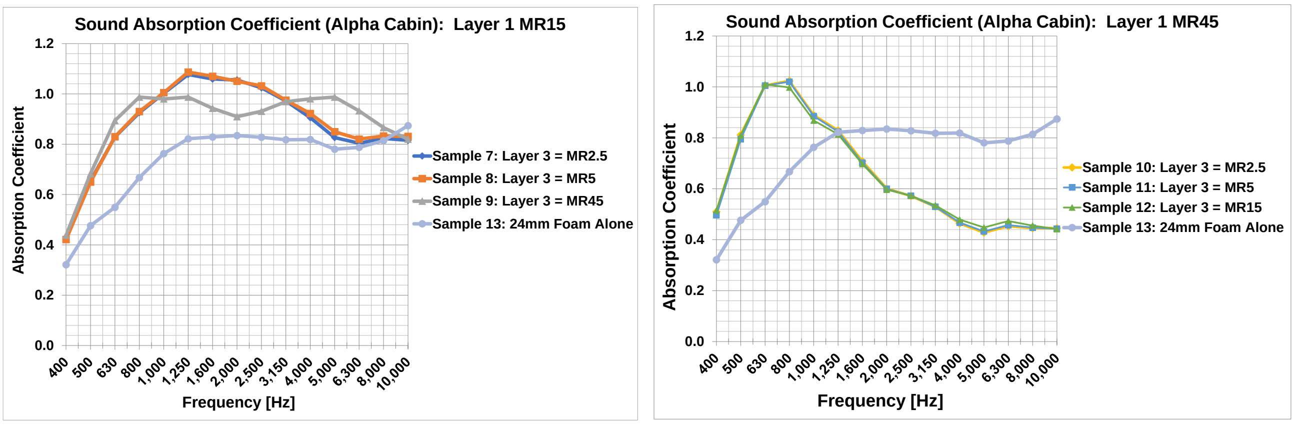
The test results, as shown in Figure 4(b), demonstrate that when Layer 1 is MR5, the addition of two membranes enhances sound absorption across all frequencies compared to the 24mm thick foam without membranes.

The test data reveal that as the airflow resistance of Layer 3 increases from MR2.5 to MR15, there is only a minimal improvement in sound absorption across all frequencies, indicating that the MR5 layer largely governs the system's performance. However, when the airflow resistance of Layer 3 increases further to MR45, sound absorption significantly improves in the (a) range from 630Hz to 1,250Hz. Similar to previous results, a dip in absorption is observed at approximately 2,500Hz and again at 8,000Hz.

These results support the prediction that Layer 1 MR5, while slightly less open than MR2.5, still allows sound to enter the system with minimal obstruction, preserving high-frequency absorption. The second membrane’s increased airflow resistance enhances sound absorption in the lower frequency range. However, as with the MR2.5 configuration, when Layer 3's airflow resistance increases from MR15 to MR45, a resonant peak effect emerges, with maximum sound absorption at around 1,250Hz and dips at 2,500Hz and 8,000Hz.

3.3 Layer 1 with MR15

The test results, shown in Figure 5(a), demonstrate that when Layer 1 is MR15, the addition of two membranes improves sound absorption for frequencies up to 6,300Hz. However, beyond 6,300Hz, the sound absorption remains the same or decreases compared to the 24mm thick foam without membranes.



(a) Layer 1 MR15 *(b) Layer 1 MR45*

Figure 5 – Sound absorption of various samples with Layer 1 MR15 and Layer 1 MR45

The results indicate that Layer 1 MR15 dominates the acoustic performance. Varying the airflow resistance of Layer 3 from MR2.5 to MR5 has little to no effect on overall sound absorption. A significant increase in sound absorption occurs between 400Hz and 6,300Hz, with a peak at 1,250Hz. Increasing the airflow resistance of Layer 3 to MR45 causes a small improvement in absorption in the 500Hz to 800Hz range, but a significant dip at 2,000Hz.

Layer 1 MR15 allows sound to enter the system without substantial loss of high-frequency absorption. The second membrane's increased airflow resistance enhances low-frequency absorption, but when the airflow resistance rises from MR15 to MR45, a resonant peak effect emerges, with maximum absorption at around 1,250Hz and dips at 2,500Hz.

3.4 Layer 1 with MR45

The test results, shown in Figure 5(b), reveal that when Layer 1 is MR45, the membranes enhance sound absorption between 400Hz and 1,250Hz compared to the 24mm homogeneous foam. However, above 1,250Hz, the sound absorption is significantly lower than that of the homogeneous foam.

The results show that Layer 1 MR45 controls the acoustic performance. Sound absorption increases significantly between 400Hz and 1,250Hz, nearly doubling around 600Hz. Changes in the airflow resistance of Layer 3—whether MR2.5, MR5, or MR15—have little to no impact on the overall absorption.

Layer 1 MR45 allows sound to enter the system but causes a significant loss of sound absorption at higher frequencies. However, there is a notable increase in absorption within the 600Hz to 800Hz range. This performance is particularly relevant for projects where high-frequency sound absorption is not desired, but specific low-frequency sound must be addressed.

4 THE EFFECT OF THE TWO THIN MEMBRANES ON 12MM ACOUSTIC FOAM WITH AN AIR GAP

Based on the previous test results, introducing an air gap in place of Layer 4 could amplify the performance of the two-membrane system. A schematic representation of this material configuration is illustrated in Figure 6.

In this model, the build-up consists of three layers. Layer 1 is a thin membrane, often referred to as the facing material. Layer 2 consists of acoustic foam, which provides the primary sound absorption. Layer 3 is a second thin membrane, referred to as the acoustic backing, with a plenum behind it.

This section will also explore the differences between a single-layer and a two-layer membrane system, as well as the impact of the membrane position—whether as a facing or backing material—in the one-layer configuration.

For this study, a 12mm thick acoustic foam was selected. For comparison, a 19mm commercial ceiling tile was also tested. The sample configurations are listed in Table 3.

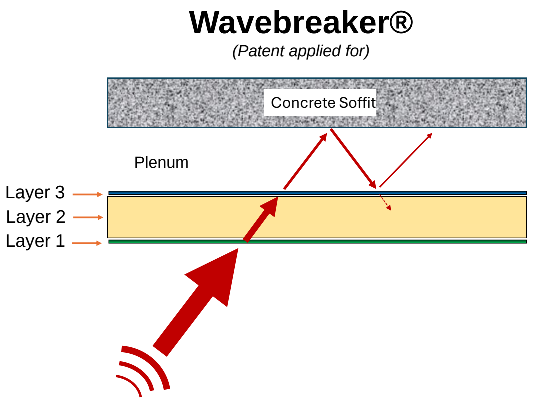


Figure 6 – Schematic drawing of the sound-absorbing build-up with an air gap

Table 3 – Various combinations of the two membranes

Sample	Layer 1	Layer 2	Layer 3	Plenum
1	MR5	12mm	MR15	250mm Air Gap
2	MR15	12mm	MR5	250mm Air Gap
3	MR2.5	12mm	MR45	250mm Air Gap
4	MR5	12mm	None	250mm Air Gap
5	MR15	12mm	None	250mm Air Gap
6	None	12mm	MR5	250mm Air Gap
7	None	12mm	MR15	250mm Air Gap
8	Commercial ceiling tile (USG Boral, 19mm)			250mm Air Gap
9	12mm Foam			250mm Air Gap

4.1 Test Results: The effect of two membranes with an air gap

The test results are presented in Figure 7, which includes both the 12mm homogeneous foam and the 19mm commercial ceiling tile for comparison.

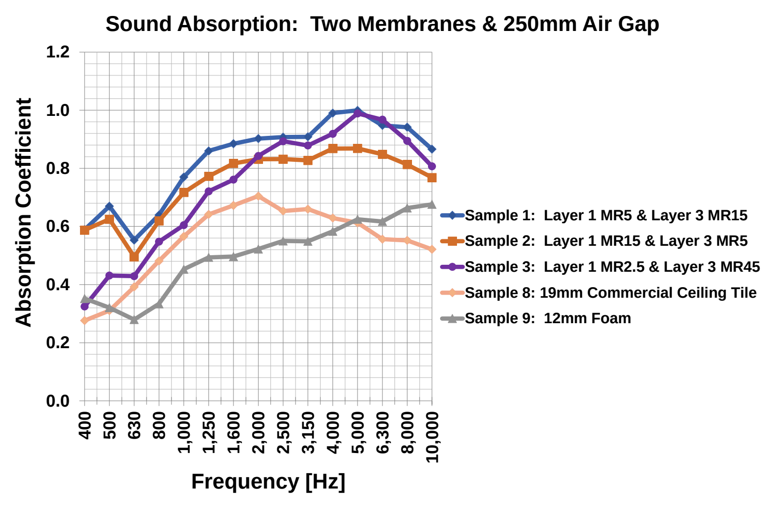


Figure 7 – Sound absorption of various samples with a two-membrane sound absorbing system and 250mm air gap

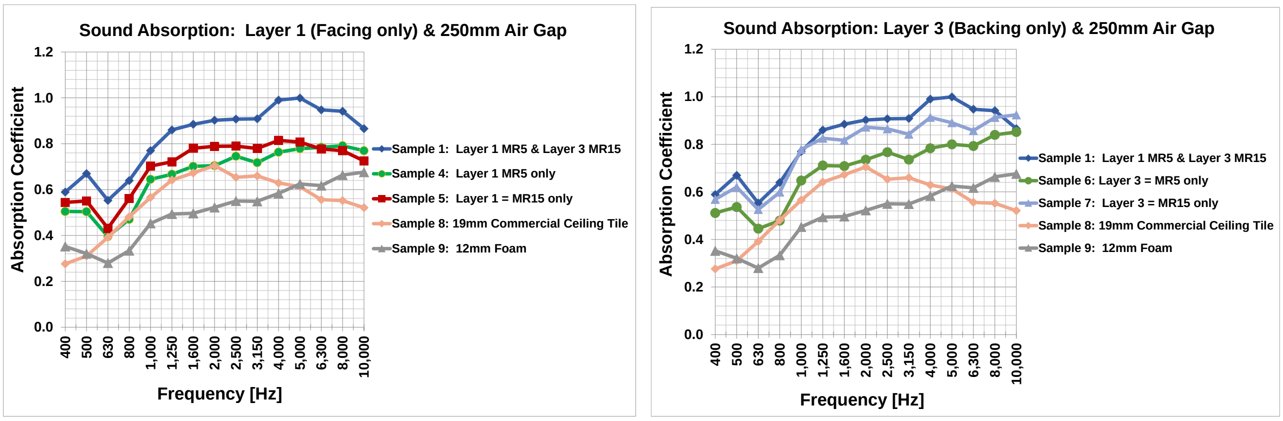
Compared to the 12mm thick acoustic foam, the two-membrane systems show a dramatic improvement in acoustic performance.

Computer modelling predicted that Sample 3, with an MR2.5 facing and MR45 backing, would provide a substantial increase in low-frequency absorption. However, the test results did not confirm this hypothesis.

In contrast, Sample 1, featuring an MR5 facing and MR15 backing, exhibited a significant increase in sound absorption at both low and high frequencies. These results suggest that the two-membrane system performs optimally when the airflow resistance is balanced between the layers.

4.2 The effect of one layer only with an air gap

The test results shown in Figure 8(a) illustrate the performance with Layer 1 (facing only) when Layer 3 (the acoustic backing) is removed. The single-layer system still delivers a significant increase in acoustic performance compared to both the 12mm homogeneous foam and the commercial ceiling tile. Sample 5, which uses the MR15 layer, outperformed Sample 4, which uses the MR5 layer.



(a) *Layer 1 (Facing only)*

(b) Layer 3 (Backing only)

Figure 8 – Sound absorption of various samples with one membrane on the facing or backing only

However, Sample 1, the two-membrane system, provided much higher sound absorption across all frequencies compared to the single-layer system (Sample 4 and Sample 5)

The test results shown in Figure 10(b) depict the performance with Layer 3 (backing only) when Layer 1 (the acoustic facing) is removed. Even with only one membrane, the system provides a considerable improvement in sound absorption compared to the 12mm homogeneous foam and the commercial ceiling tile. Sample 7, which features the MR15 layer, outperforms Sample 6, which uses the MR5 layer. Furthermore, Sample 7 demonstrates acoustic performance comparable to the two-membrane system, specifically Sample 1.

5 APPLICATIONS

For the acoustic design of the London Theatre project, achieving effective sound absorption at low frequencies, specifically between 50Hz and 125Hz, was critical. The design utilised 100mm thick acoustic foam with two membranes: MR5 on the facing side and MR15 on the backing side. The product used was identified by the code Wavebreaker FM100-DS. Acoustic modelling was conducted to analyse the effectiveness of various air gaps, as shown in Figure 9. The results demonstrated a significant enhancement in low-frequency absorption with air gaps of 400mm and 800mm. In comparison, the absorption performance of the same product without an air gap (solid absorption) was also evaluated. The Wavebreaker FM100-DS with a 400mm air gap was ultimately selected for the project. This approach proved highly effective, and the project was a resounding success.

For the acoustic design of a project with a project name “Cutaway”, the specification called for a sound absorption coefficient of 0.76 at 31.5Hz**.** The complete specification can be seen in Figure 10**.** After conducting acoustic modelling, Wavebreaker FM100-DS with a 390mm air gap was chosen as the optimal solution. This replaced the previously considered 400mm to 500mm bulk insulation material. Figure 9(b) illustrates how Wavebreaker FM100-DS replaced the 400mm thick bulk insulation.

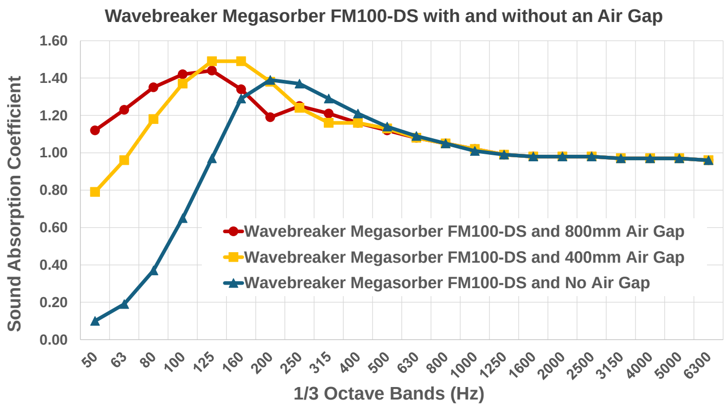


Figure 9 – Sound absorption 100mm thick foam with MR5 facing and MR15 backing with and without an air gap

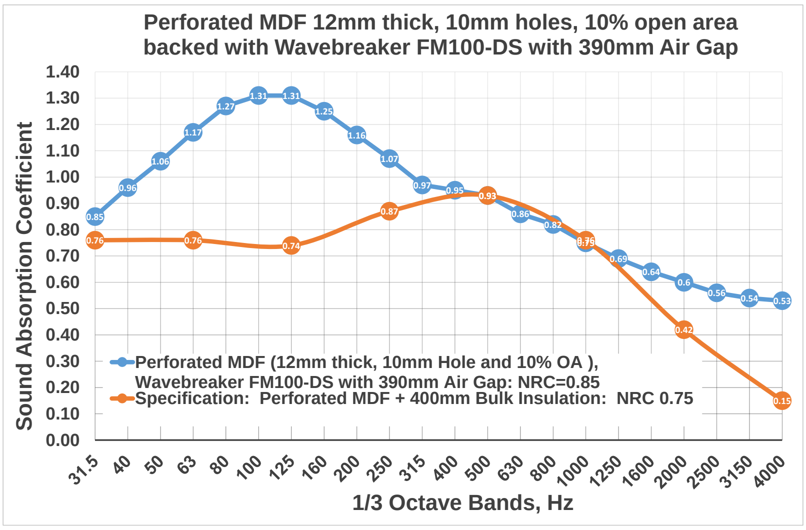


Figure 10 – Sound absorption 100mm thick foam with MR5 facing and MR15 backing 390mm air gap and perforated MDF

6 CONCLUSIONS

The two-membrane systems show great promise in enhancing sound absorption in homogeneous materials, particularly at low frequencies. Additionally, these systems demonstrate strong potential for improving acoustic performance when used with a plenum or air gap (patent applied for).

7 FURTHER STUDY

This study illustrates the significant potential of two-membrane systems to enhance sound absorption in relatively thin materials. The Alpha Cabin proved to be an excellent tool for this investigation, providing quick results with only 1.2m² of sample material required. However, it has a cut-off frequency of 400Hz. For lower frequencies below 400Hz, further investigation is recommended. Future studies should also explore the impact of thicker products and larger air gaps on sound absorption performance.

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REFERENCES

Standards Australia. (2006). *AS ISO 354-2006: Acoustics—Measurement of sound absorption in a reverberation room.*

Attenborough, Keith (2019). *Macro- and micro-structure designs for porous sound absorbers, Applied Acoustics 145 (2019), 349 – 357.*

Law, Harvey Hui-Xiong (2012). *Non-combustible Sound Absorbing Facing, US Patent No.: US 8,167,085 B2, May 1 2012.*

Nonogi et al. (2013). *Multilayer Sound Absorbing Structure Comprising Mesh Layer, US Patent No.: US 8,573,358 B2, Nov. 5, 2013.*

James, Heddle (2016). *Room Acoustics for Listening, Proceedings of ACOUSTICS 2016, 9-11 November 2016, Brisbane, Australia.*