# IMPACT OF RIGID WALL BACK SHAPE ON THE SOUND ABSORPTION PERFORMANCE OF MICROPERFORATED PANELS

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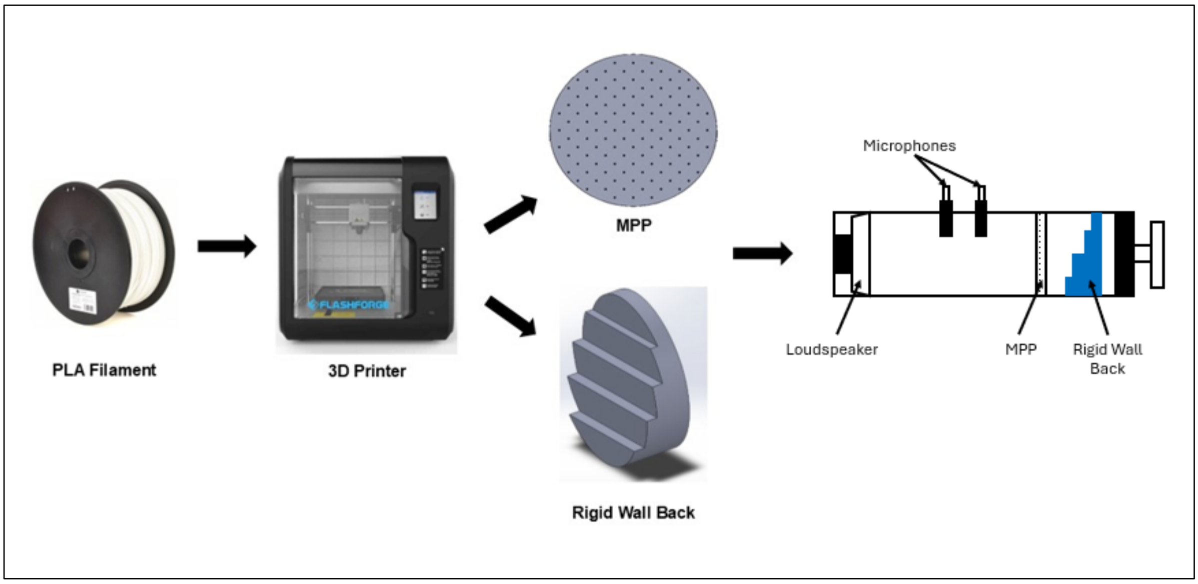
Muhammad Faizul Kamal Bin Norrifin [a], Muhammad Hadif Haiman Bin Madzian [a], Musli Nizam Bin Yahya [b*], Nazli Bin Che Din [c], Desmond Daniel Chin Vui Sheng [d], Vignesh Sekar [e]

[a]Faculty of Mechanical Engineering, Universiti Teknologi Malaysia, 81310 Johor Bahru, Johor, Malaysia
[b]Department of Transport Engineering Technology, Faculty of Engineering Technology, Universiti Tun Hussein Onn Malaysia, Pagoh Higher Education Hub, 86400 Pagoh, Johor, Malaysia
[c]Applied Mechanics Research and Consultancy Group (AMRCG), Faculty of Mechanical Engineering, Universiti Teknologi Malaysia, 81310 Johor Bahru, Johor, Malaysia
[d]The Centre for Building, Construction & Tropical Architecture (BuCTA), Faculty of Built Environment, Universiti Malaya, 50603 Kuala Lumpur, Malaysia
[e]Department of Mechanical Engineering, Saveetha Engineering College, Thandalam, 602105 Chennai, India

*Corresponding author
musli@uthm.edu.my

## GRAPHICAL ABSTRACT



## ABSTRACT

Microperforated panels (MPPs) are promising sound absorbers with significant potential for enhanced performance. Numerous studies have explored ways to improve MPPs by adjusting parameters such as perforation ratio, perforation diameter, panel thickness, air gap thickness, and material choice. Typically, MPPs are installed in front of rigid, flat surfaces; however, the effect of wall shape has been largely unexplored. This study investigates the impact of three different wall shapes—flat, stair-shaped, and concave—on MPP sound absorption. Both MPPs and models of the three wall shapes were 3D-printed, and their sound absorption was evaluated using an impedance tube. The results show that stair-shaped and concave walls provide superior sound absorption, particularly in the low-frequency range, compared to flat walls with the same air gap distance. These findings suggest that non-flat wall designs, such as stair-shaped and concave, can enhance sound absorption at lower frequencies. This study highlights the potential for MPPs to be effectively installed in front of rigid walls or surfaces of various shapes, expanding their applicability across a wide range of acoustic environments.

## KEYWORDS

Microperforated Panel (MPP), Sound Absorption, Polylactic Acid (PLA), Biodegradable Polymer, Impedance Tube, Indoor Environment

## INTRODUCTION

In today’s era of urbanization, pollution continues to worsen. While air and water pollution are often highlighted in news and publications, noise pollution is frequently overlooked. Numerous studies show that prolonged noise exposure can negatively affect individuals, leading to issues such as insomnia, elevated stress levels, and in severe cases, permanent hearing loss [1,2,3]. To improve quality of life, especially in urban settings, addressing noise pollution is essential. There are various methods to reduce environmental noise, with sound absorbers being a popular choice due to their effectiveness and economic advantage, as installation of sound absorbers requires no major modifications or renovations to existing spaces [4].

There are three main types of sound absorbers: porous, membrane, and panel sound absorbers. Porous sound absorbers are made from materials with small openings, which can be either natural or synthetic. Synthetic materials are often preferred due to their customizability during production, optimizing sound absorption [5]. However, prolonged exposure to certain synthetic materials, like fiberglass or rock wool, poses serious health risks. These materials can release fine particles into the environment, which may enter the lungs and cause conditions such as pulmonary fibrosis and lung tissue scarring [6]. Due to these health concerns, recent research has focused on using natural fibers to replace synthetic ones for sound absorption. Porous absorbers are particularly effective at attenuating higher frequencies (above 2000 Hz) [7].

Membrane sound absorbers work well at low to mid frequencies [8]. These absorbers feature a flexible, often thin surface that vibrates in response to sound waves, converting sound energy into mechanical energy and dissipating it as heat, which reduces sound reflection. However, membrane absorbers are usually tuned to specific low frequencies, performing best around their resonant frequency [9]. This narrow range limits their effectiveness at other frequencies, and effective low-frequency absorption may require a large membrane or a substantial air gap behind it. This can make them bulky and space-intensive, limiting their practicality in smaller spaces where depth is restricted. Membrane sound absorbers are ineffective at higher frequencies. For applications requiring broad-spectrum absorption, membrane absorbers alone are insufficient and need to be paired with materials like porous absorbers to handle mid to high frequencies [10].

A panel sound absorber is a type of sound-absorbing material that utilizes the principles of the Helmholtz resonator to attenuate sound [8,11]. Among these, the microperforated panel (MPP) is recognized as an advanced form of panel sound absorber with unique acoustic properties. Professor Dah You Maa is widely credited as the pioneering researcher who introduced the MPP concept for sound absorption applications, bringing a transformative approach to acoustic engineering. The MPP evolved from the traditional perforated panel, which has larger perforations and was initially designed to absorb sound. However, the larger perforation diameter in conventional perforated panels limited their sound absorption capabilities, especially across a wide frequency range. As a result, these panels were primarily used as protective covers for porous sound absorbers, serving more as a structural component than as a primary sound absorber [12,13]. Maa proposed reducing the diameter of these perforations to the microscale, which significantly enhanced the sound absorption performance of the panels. The shift to micro-perforations allowed the MPP to absorb sound more efficiently across a broader frequency range, achieving an impressive improvement over traditional perforated panels. With this micro-scale adjustment, the MPP demonstrated not only a higher sound absorption coefficient but also a wider frequency absorption range, making it highly effective in various soundproofing applications.

Extensive research has been conducted to enhance the overall sound absorption of microperforated panels (MPP) by modifying parameters such as perforation ratio, perforation diameter, panel thickness, air gap thickness, and the materials used in MPP fabrication. For instance, Chin et al. found that the choice of material significantly influences the sound absorption performance of MPPs due to the superposition effect of microperforated holes and the material's structure in absorbing sound [14,15,16]. Mosa et al. studied the effect of inhomogeneous MPPs and discovered that they exhibit higher sound absorption performance and a wider bandwidth compared to standard MPPs [17,18]. Ideally, microperforated holes are assumed to be perfectly circular; however, this is often not the case in practice due to manufacturing and fabrication processes. Ning et al. examined the sound absorption of MPPs with different cross-sectional hole shapes and found that varying the cross-sectional shape moderately influences the sound absorption performance [19]. This is attributed to the distinctive roughness of differently shaped perforated holes, which affects the movement of air in and out of the air cavity. Villamil investigated the impact of different hole arrangements on the sound absorption of MPPs and concluded that hole arrangement does not significantly affect the overall sound absorption performance [20]. Additionally, Li et al. introduced an MPP design with parallel-arranged extended tubes for the microperforated holes [21]. This method was found to enhance the sound absorption performance of MPPs at lower frequency ranges, although it resulted in a narrower absorption bandwidth.

Most research has focused on modifying the perforation characteristics of MPP; however, to the best of current knowledge, limited work has explored the impact of altering the shape of the rigid wall on MPP sound absorption. The primary objective of this study is to examine how different wall shapes affect the sound absorption performance of MPP. This research aims to provide valuable insights into the potential of MPP for enhancing acoustic conditions in a range of indoor environments, including applications in aerospace and automotive vehicles.

## METHODOLOGY

### Material

In this study, polylactic acid (PLA) filament, made from a biodegradable polymer, was chosen as the material for fabricating both the microperforated panel (MPP) and the rigid wall backs of different shapes: flat, stair-shaped, and concave. A 3D printing process was used to fabricate both the MPP and the rigid wall backs. The PLA filament had a density of 1.24 g/cm$^3$ (ISO 1183) and a melting temperature of 160°C (ISO 11357). The tensile strength of the PLA filament was 39 ± 2 MPa (ISO 527), and its melt flow index, according to ISO 1133-A (210°C, 2.16 kg), was 42.4 ± 3.5 g/10 min.

### Methods

Prior to printing, the MPP and the rigid wall backs were designed using SOLIDWORKS software. **Figure 1** shows the design of the MPP used in this study. The MPP has a diameter of 100 mm, which matches the inner dimension of the impedance tube. It features a panel thickness of 1 mm, a perforation ratio of 2%, and perforation diameters of 1.5 mm. **Figure 2** shows the flat wall back design used in this study. The diameter of the flat rigid wall back is 100 mm, corresponding to the inner dimension of the impedance tube. The thickness of the flat rigid wall back is 30 mm, with no special specifications, as it follows a standard flat back design. **Figure 3** shows the stair-shaped rigid wall back design used in this study. The diameter of the stair-shaped rigid wall back is also 100 mm, matching the inner dimension of the impedance tube. The maximum thickness of the stair-shaped rigid wall back is 30 mm, with five stair cuts, each having a horizontal length of 6 mm and a vertical length of 20 mm. **Figure 4** shows the concave rigid wall back design used in this study. The diameter of the concave rigid wall back is 100 mm, in accordance with the inner dimension of the impedance tube. The maximum thickness of the concave rigid wall back is 30 mm, with two symmetrical curved cuts, the deepest of which is 10 mm.

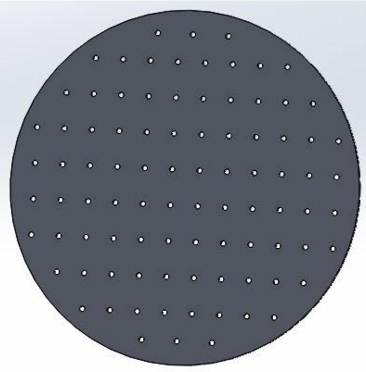


**Figure 1:** MPP design

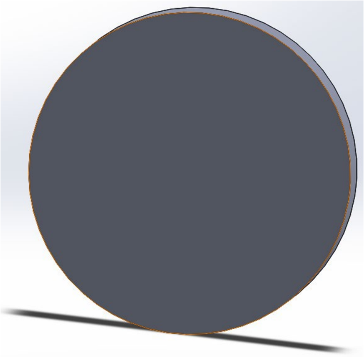


**Figure 2:** Flat rigid wall back design

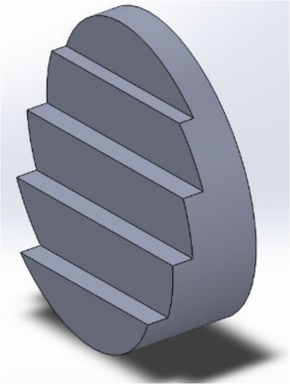


**Figure 3:** Stair-shaped rigid wall back

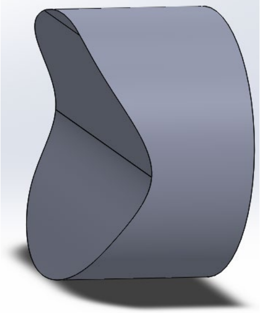


**Figure 4:** Concave rigid wall back design

All the SOLIDWORKS files were converted to STL format, and a 3D printer (Flashforge Adventurer 3 Version 2) was used to fabricate both the MPP and the rigid wall backs. The printing layer thickness was set to 0.18 mm with two (2) shell layers. The infill density and printing speed were set to 15% and 60 mm/s, respectively. The travel speed was set to 80 mm/s, and the platform temperature was set to 50°C. The infill pattern was set to hexagonal, and the extruder temperature was set to 210°C.

The sound absorption performance of the MPP backed by different rigid wall shapes was determined using an impedance tube (S.C.S Controlli e Sistemi – SCS9020B model), according to the ASTM E1050-12 standard (equivalent to ISO 10534-2). Calibration of the two microphones in the impedance tube was performed to ensure the reliability and accuracy of the results. Channel calibration was also carried out to confirm that the measurement system was functioning correctly and aligned with the expected sound levels. After calibration, the samples were inserted into the tube for measurement. First, the rigid wall back was placed in the tube. **Figure 5** shows the flat rigid wall back inserted into the tube. Next, the MPP sample was positioned in front of the flat rigid wall. The distance between the MPP sample and the rigid wall back is referred to as the air gap thickness. **Figure 6** shows the measurement procedure for the distance between the flat rigid wall back and the MPP sample positioned in front of it. The same procedure was followed for the other rigid wall back shapes. The air gap between the MPP and three different rigid wall back shapes was 5 mm. **Figure 7** shows the MPP installed in front of the flat rigid wall back while **Figure 8** shows the illustration of MPP and fabricated rigid wall back positioned within the impedance tube.

This study focused on assessing the sound absorption coefficient of MPP in the frequency range of 400–1,600 Hz. In this method, a random sound signal was generated by a loudspeaker at one end of the impedance tube. The complex acoustic transfer function $H_{12}$ for the two microphones was applied in the impedance tube to calculate the sound reflection coefficient ($R$) for all samples. The sound absorption coefficient ($\alpha$) was subsequently determined using the formula $\alpha = 1 - |R|^2$. Each experiment was repeated three times to obtain average results for all samples.

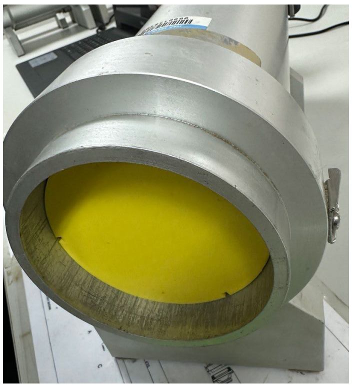


**Figure 5:** Flat rigid wall back inserted into the tube

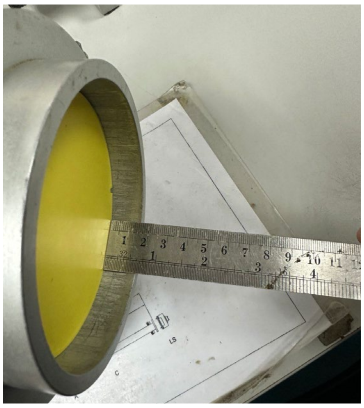


**Figure 6:** Measurement procedure for the distance between the flat rigid wall back and the MPP sample positioned in front of it

**Figure 7:** MPP installed in front of the flat rigid wall back

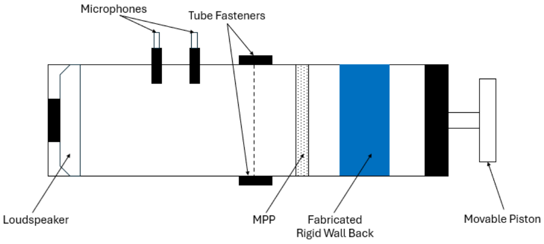


**Figure 8:** Illustration of MPP and fabricated rigid wall back positioned inside the impedance tube

## RESULTS AND DISCUSSION

**Figure 9** illustrates the sound absorption performance of the MPP when paired with different rigid wall back shapes, each having a 5 mm air gap. The results show that the flat rigid wall back exhibited the lowest sound absorption coefficient, 0.711 at 1,342 Hz. In contrast, the stair-shaped rigid wall back demonstrated the highest sound absorption coefficient, 0.967 at 1,044 Hz. The concave rigid wall back displayed performance comparable to the stair-shaped design, with a peak absorption coefficient of 0.964 at 1,137 Hz. These findings suggest that a 5 mm air gap thickness is suitable for both the stair-shaped and concave rigid wall backs. However, the 5 mm air gap in the flat rigid wall back configuration appears to limit the MPP's ability to interact with and dissipate sound waves effectively. The reduced gap may restrict sound wave absorption, resulting in a lower absorption coefficient. Specifically, the flat wall back may function more like a reflective surface, particularly at certain frequencies, preventing the MPP from fully engaging with the sound waves. The simple, smooth geometry of the flat wall back does not introduce the complexity needed to enhance absorption, causing the air gap to be less effectively utilized. Consequently, less energy is absorbed, which accounts for the lower absorption coefficient observed in the flat wall back configuration. In contrast, the stair-shaped and concave rigid wall backs feature geometrical complexities that increase the effective surface area, thereby enhancing sound wave diffusion and scattering. The perforated holes and air gap thickness can be modeled as a mass-spring system, where the holes act as masses and the air gap as the spring, influencing the sound absorption mechanism. The varying geometries of the stair-shaped and concave backs likely allow sound waves to react more effectively with the air gap, where the sound energy can be dissipated more efficiently. Additionally, the stair-shaped and concave rigid wall back shapes demonstrated improved performance at lower frequencies compared to the flat rigid wall back shape. This is likely due to differences in their geometric configurations, which influence the acoustic stiffness of the air gap. As a result, the resonance frequency shifts to a lower frequency range.

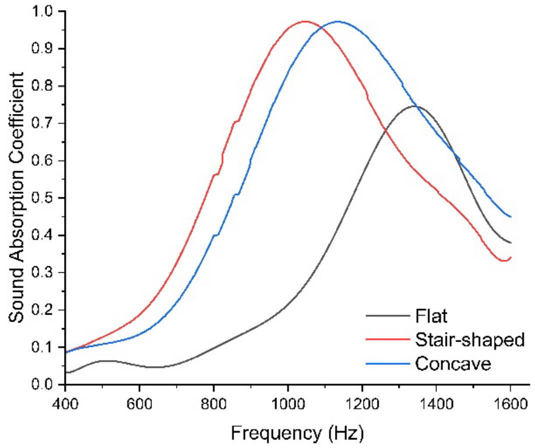


**Figure 9:** Sound absorption performance of the MPP paired with different rigid wall back shapes

## CONCLUSION

This study investigated the sound absorption performance of MPP in combination with different rigid wall back shapes. The results indicate that the MPP paired with the flat rigid wall back exhibited the lowest sound absorption performance, likely due to the simplicity of its geometry. The smooth, flat surface lacks the complexity necessary to promote effective sound wave interaction and absorption. In contrast, the MPP paired with the stair-shaped and concave rigid wall backs demonstrated comparable and superior sound absorption performance. This improvement can be attributed to the geometrical complexity of these designs, which increases the effective surface area, thereby enhancing sound wave diffusion and scattering. The findings underscore the significant influence of rigid wall back shape on the overall sound absorption performance of MPP absorbers. This study highlights the importance of considering geometric design when optimizing for sound absorption. These insights are valuable for future research, as the design of rigid wall backs can be tailored to meet specific acoustic requirements, providing a more effective solution for sound absorption in various applications. Further investigation into the optimization of geometric parameters and air gap dimensions may lead to even more efficient absorber designs, improving sound absorption across a broader frequency range.

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