

Review

Structural and Geometric Enhancements of Microperforated Panel Absorbers: A Systematic Literature Review

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Abstract. This systematic review analyses sixty-one recent studies on structural and geometric enhancements of microperforated panel (MPP) absorbers, consolidating them into two primary categories: cavity structural strategies and panel modifications. Cavity-related approaches include multilayer, multi-depth, folded, and partitioned designs, while panel-related strategies address perforation geometry, distribution, and surface profiling. Hybrid designs that integrate both approaches are acknowledged but not the focus of this study. Comparative analysis indicates that cavity-related enhancements are particularly effective in extending sound absorption into low frequencies, whereas panel modifications provide greater flexibility for tuning absorption peaks and achieving compact broadband performance. Cross-category comparisons reveal performance trade-offs and clarify the structural solutions most suitable for engineering applications such as built environments, transportation systems, and enclosed technological spaces. The review establishes a structured overview of MPP absorber design strategies, highlighting current trends, limitations, and opportunities for future development. The synthesis not only provides design guidance for absorbers with improved low-frequency and broadband performance but also situates MPPs within the broader landscape of acoustic materials and engineering technologies.

Keywords: Microperforated panel (MPP), Sound absorption, Acoustic engineering, Cavity enhancement, Panel modification, Acoustic materials, Broadband absorption

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1. Introduction

Noise pollution, particularly from transportation and industrial sources, poses a significant environmental and public health concern. Long-term exposure to high noise levels has been linked to adverse effects such as stress, sleep disruption, and cardiovascular complications [1]. Among the various noise control strategies, sound absorption is widely used due to its effectiveness in attenuating acoustic energy by converting it into heat, typically through porous materials or acoustic resonators.

Among resonator-based absorbers, the microperforated panel (MPP) has attracted substantial attention due to its fibreless composition, simple structure, and mechanical robustness. An MPP absorber typically consists of a rigid panel with submillimeter perforations placed in front of a rigid backing, separated by an air cavity [2], [3]. Since its theoretical foundation was proposed by Maa in the 1970s, the MPP has been recognized for its simplicity, durability, and ease of fabrication.

However, a well-known limitation of the classic MPP structure is its narrowband absorption behaviour [4], [5]. Although Maa later proposed multilayer configurations to broaden the effective bandwidth, achieving efficient low-frequency absorption without significantly increasing the total absorber thickness remains a persistent challenge. This performance constraint is particularly critical in applications such as building acoustics, automotive panels, and HVAC systems, where space is limited and low-frequency noise is dominant.

To overcome these restrictions, researchers have explored a wide range of structural enhancement strategies that modify the panel body, the backing cavity, or both. These include multi-depth cavities, non-uniform hole distributions, contoured or corrugated panel profiles, folded and coiled cavities, and more recently, advanced meta-structure designs. Increasingly, hybrid absorbers that combine multiple strategies are being reported, although this trend complicates classification and comparison since many designs overlap across categories.

Broadly defined, structural and geometrical enhancement of MPP absorbers refers to the deliberate engineering of panel or cavity architecture to go beyond the absorption limits of conventional designs. Unlike porous or fibrous materials, where dissipation arises from bulk losses, MPP leverage carefully tuned structural features such as serial or partitioned cavities, inhomogeneous perforations, or embedded core structures. These manipulations directly affect the absorber's resonance conditions and viscous dissipation pathways, thereby extending usable bandwidth or shifting absorption toward lower frequencies.

The significance of these enhancements is not confined to acoustic performance alone. Structural strategies can simultaneously reduce thickness and weight, enhance mechanical integrity, or even integrate additional functionalities such as thermal insulation or structural stiffness. This multifunctionality makes MPP absorbers highly relevant to industries such as aerospace, automotive,

and architectural acoustics, where designs must satisfy both acoustic efficiency and practical robustness.

Despite substantial progress, the research landscape remains fragmented and highly diverse. While many studies propose novel configurations, there has not yet been a systematic consolidation of structural and geometrical enhancement approaches. Existing reviews have generally emphasized theoretical modelling or hybrid material systems, but not the structural design dimension itself.

These can be grouped into two major directions:

- **Cavity modifications**, including multi-depth cavities, folded or partitioned designs, and other geometric modifications aimed at broadening bandwidth or lowering resonance frequencies.
- **Panel modifications**, such as non-circular perforation shapes, variable hole distributions, or contoured panel profiles that alter viscous dissipation and resonance behaviour.

To the best of our knowledge, this review provides a comprehensive and timely systematic literature review dedicated specifically to structural and geometrical strategies for MPP absorbers. While various studies have discussed MPPs, this work uniquely classifies and analyses these strategies, evaluates emerging trends, identifies existing limitations, and highlights future research opportunities. Such a classification is necessary to guide both academic inquiry and practical engineering applications, where trade-offs between acoustic and non-acoustic requirements must be balanced.

2. Methodology

This study adopts a systematic literature review (SLR) approach to identify, analyse, and classify structural enhancement strategies used to improve the acoustic performance of MPP absorbers. The review was conducted with a clear protocol involving defined research questions, selection criteria, and a structured data extraction process to ensure relevance and quality [6], all summarized in Table 1.

The search was performed in two stages. First, a keyword-based search was carried out using the Scopus database, applying refined terms targeting studies related to MPP-based sound absorbers and their structural design enhancements. Second, a manual backward citation search was conducted to ensure coverage of foundational or cross-referenced studies that may not have appeared in the initial query. After removing duplicates, the screening process involved title and abstract filtering, followed by a full-text assessment of potentially relevant studies.

Table 1. Summary of Methodology.

Category	Criteria
Research Questions (RQ)	RQ1: What types of <i>structural modifications</i> , have been implemented to enhance MPP acoustic performance?
	RQ2: How do these modifications affect low-frequency absorption and/or bandwidth widening?
	RQ3: What hybrid strategies have emerged, and how are they structured?
	RQ4: How are these modifications validated, and what performance trends can be observed?
Data Extraction (DE)	DE1: Identify the primary design focus, with emphasis on cavity or panel enhancements.
	DE2: Summarize the structural configuration used.
	DE3: Record validation methods and hierarchy if multiple used.
	DE4: Note performance outcomes: target frequency range (low/mid/high), bandwidth improvement, or absorption level.
	DE5: Extract notable design features and place study within the appropriate result subsection.
Inclusion Criteria (IC)	IC1: Study must propose or analyse structural modification of MPP absorbers.
	IC2: Clearly addresses acoustic performance (absorption coefficient or related metrics).
	IC3: Peer-reviewed journal articles published in English.
	IC4: Publication year up to and including 2024.
	IC5: Includes validation method (numerical, theoretical, or experimental).
Exclusion Criteria (EC)	EC1: Focuses only on manufacturing, fabrication, or material characterization without structural focus.
	EC2: Non-MPP systems or non-airborne acoustics
	EC3: Conference papers, preprints, patents, or non-peer-reviewed sources.

3. Brief overview of MPP acoustic behaviour

The full description of MPP and its theoretical prediction of sound absorption can be found at [7], [8], so in this section, a brief of the context about the basic explanation of characteristics of MPP and its following prediction theories. A conventional MPP system consists of a rigid panel perforated with submillimeter holes, backed by a rigid wall and separated by an air cavity. Sound absorption occurs through viscous and thermal losses as

sound waves pass through the perforations and interact with the enclosed air volume behind the panel (Fig. 1).

The key geometric parameters of a single-layer MPP include:

- Perforation diameter, d
- Center-to-center hole spacing, b which defines the open area ratio or perforation ratio, σ
- Panel thickness, t
- Cavity depth, D representing the air gap between the panel and rigid backing

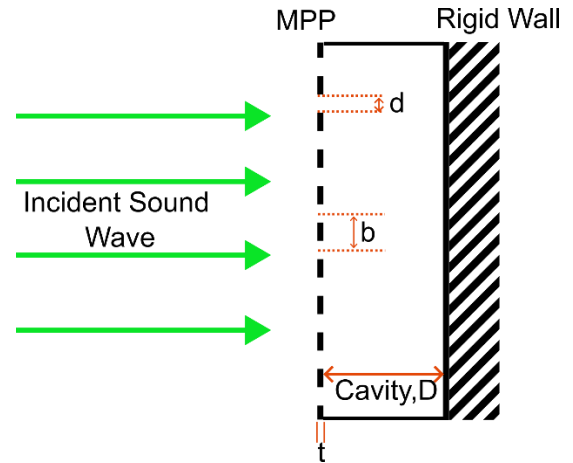


Fig. 1. Schematic of MPP configuration and geometric parameters.

The prediction model firstly introduced by Maa [2] that combines work from Rayleigh and solution from Crandal with some proposal of end correction, the equivalent surface impedance of MPP (Z_{MPP}) can be expressed as Eq. (1)-(3).

$$Z_{MPP} = R + jX \quad (1)$$

$$Z_{MPP} = \frac{32\eta}{\sigma\rho c} \frac{t}{d^2} \left(\sqrt{1 + \frac{x^2}{32}} + \frac{\sqrt{2}xd}{32t} \right) + \dots \quad (2)$$

$$\frac{t}{\sigma c} \left(1 + \frac{1}{\sqrt{9 + \frac{x^2}{2}}} + 0.85 \frac{d}{t} \right), \sigma = \frac{0.85b^2}{d^2} \text{ in \%}$$

$$\text{Perforation constant, } x = d \sqrt{\frac{\omega\rho}{4\eta}} \quad (3)$$

The cavity behind the panel also contributes to the system's total impedance. Assuming plane wave propagation at normal incidence, the impedance of the backing air cavity as Eq. (4).

$$Z_D = -j \left(\cot \frac{\omega D}{c} \right) \quad (4)$$

With c is speed of sound, The summation of the impedance is equal to total impedance for the MPP absorber (Z_{total}) and by assuming plane wave propagate at normal incident to the MPP, the Sound Absorption Coefficient (SAC) can be calculated as Eq. (5)-(6).

$$Z_{\text{total}} = Z_{\text{MPP}} + Z_{\text{D}} \quad (5)$$

$$\text{SAC}, \alpha = \frac{4\text{Re}[Z_{\text{total}}]}{(1 + \text{Im}[Z_{\text{total}}])^2 + \text{Im}[Z_{\text{total}}]^2} \quad (6)$$

This relationship enables the prediction of the absorber's frequency-dependent performance. A typical absorption curve displays a peak at a target frequency, with reduced effectiveness outside this range. However, it is important to note that Maa's model has inherent limitations. It assumes:

- Idealized, evenly distributed holes
- Normal incidence of sound waves
- Flat, rigid panels
- Linear acoustic behaviour

These assumptions reduce the model's applicability in scenarios involving complex or irregular configurations. To illustrate the limitations of conventional designs and the motivation for structural improvements, Fig. 2 presents a comparison of SAC curves between a conventional MPP absorber and representative examples of recent, structurally enhanced designs. While traditional systems typically show narrowband absorption centred at a particular frequency, enhanced MPP configurations demonstrate broader and more robust performance across wider frequency ranges.

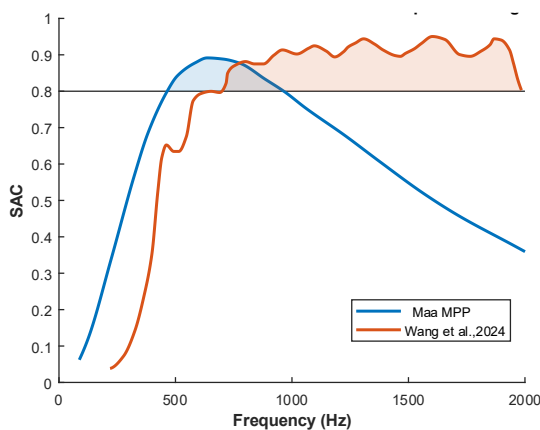


Fig. 2. A comparison between Conventional MPP and Complex MPP design. [3], [14]

4. Result

4.1. Structural and Geometric Enhancement

A total of sixty-one studies were identified under this category, representing the largest share of works in the present review. This reflects the central role of structural

modifications in enhancing the absorption capability of MPP absorbers.

The overall selection process is summarized in the Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) workflow (Fig. 3), which details the screening and exclusion steps. This systematic approach is consistent with established review methodologies previously published in the Engineering Journal [9], [10]. Following this process, the remaining studies were grouped into two major classes: cavity modifications (35 studies) and panel modifications (26 studies). The organization of these classes and their associated subgroups is presented in the classification hierarchy (Fig. 4).

This classification framework was developed after excluding studies that provided only theoretical predictions without structural innovation or that did not directly alter cavity or panel geometry. The retained works were then organized according to the absorber component being modified and refined based on the specific design strategy and geometric approach.

It should be noted that several studies employed multiple enhancement strategies simultaneously, for example combining multilayer arrangements with variable-depth cavities or pairing perforation shape variation with non-uniform porosity distribution. To avoid redundancy, each hybrid case was classified under the latest or most defining structural modification, while an asterisk symbol (*) is used in the tables to denote such hybrid designs. The explanation of some term used in this review were included in Appendix A1.

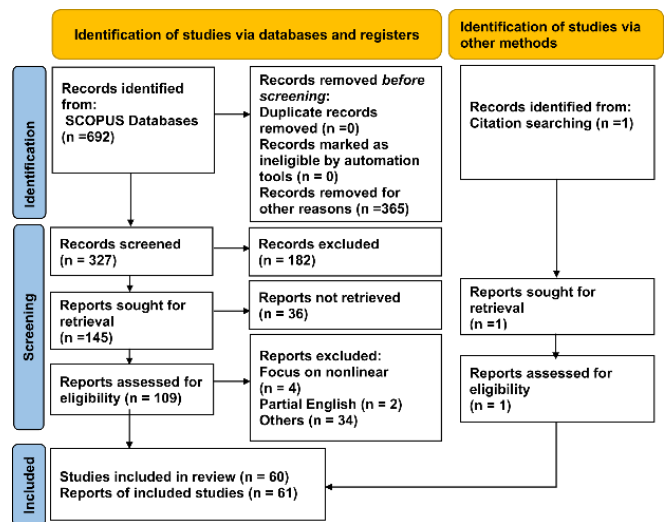


Fig. 3. PRISMA diagram with the number of records during each review step.

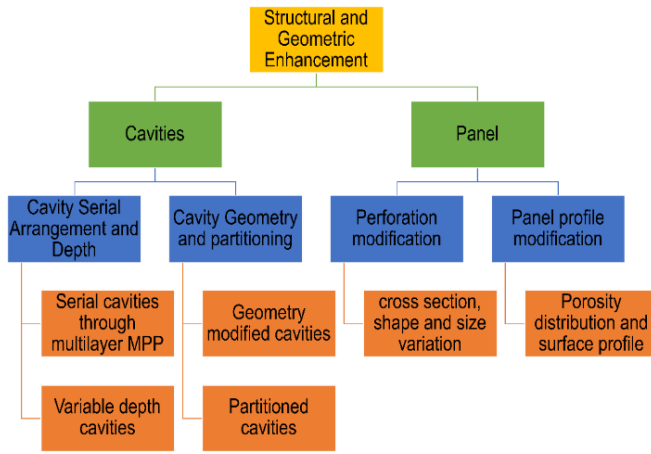


Fig. 4. Classification hierarchy of structural and geometric enhancement strategies for MPP absorbers. The framework divides the selected studies into cavity modifications and panel modifications, with further subcategories defined according to geometric design approach and intent.

4.2. Cavity Modification

4.2.1. Serial cavities through multilayer MPP

The use of multiple MPP layers to form serial cavities can be traced back to Maa's early theoretical work [2], which highlighted the potential of DL-MPP. Subsequent

studies, such as Sakagami et al. [11], advanced this understanding through the Helmholtz–Kirchhoff integral formulation, although discrepancies remained at mid-to-high frequencies. Follow-up work continuation [12], [13] proposed a multi-leaf MPP configuration, consisting entirely of MPP sheets without a rigid backing. This structure enhanced low-to-mid frequency absorption, though the average SAC remained around 0.6.

Moving beyond dual-layer arrangements, Cobo et al. [8] examined a TL-MPP and emphasized that balanced cavity depths across layers were crucial for achieving optimal broadband performance. More compact and extreme designs have also been reported. Yang et al. [15], [16] optimized an eight-layer MPP within a total depth of only 30 mm by employing a cuckoo search algorithm, demonstrating significant absorption coverage despite extreme space constraints. Similarly, Zhao et al. [17] introduced a dual-layer system for confined environments, where the sound incidence direction differed between layers. This design achieved performance comparable to conventional DL-MPP while addressing spatial limitations.

Overall, the trajectory of research in this category reflects a strong emphasis on achieving effective absorption within limited depth. A tabular summary of the reviewed studies is presented in Table 2, while comparative sketches of multilayer configurations are shown in Fig. 5, with Fig. 5(a) illustrating the single-layer baseline reference.

Table 2. Summary of studies on serial cavity configurations through multilayer MPP.

Authors and Year	Method Summary	Validation	Frequency target	Highlight
Sakagami et al., 2010 [11]	Improved prediction model for Dual Layer MPP	Analytical	250-2000 Hz	difference mainly appears in SAC peak frequencies between the first and the second peaks, and at high frequencies.
Sakagami et al., 2014 [29]	Tripple leaf MPP (open back air), a continuation from Dual leaf MPP	Analytical	10-2000 Hz	shows wider sound absorption frequency range due to the wider resonance peak with additional low frequency absorption.
Cobo et al., 2019 [8]	Triple Layer MPP	Experimental	1000-5000 Hz	The absorption bandwidth can be greatly increased by a proper design of multiple-layer structures
Yang et al., 2019 [15]	8 MPP with maximum total summation cavity depth 30mm	Experimental	1000-6000Hz	Improvement of average SAC from 69.79%(1MPP) to 84.30%(2MPP) and hover around 85-86%(3-8MPP)
Yang et al., 2019 [16]	8 iMPP with maximum total summation cavity depth 30mm	Experimental	1000-6000Hz	Improvement of average SAC from 69.79%(1MPP) to 79.40%(2MPP) and hover around 82.5-83.57%(3-8MPP)
Zhao et al., 2022 [17]	DL-MPP, with turned incident wave at second layer	Experimental	400-1400Hz	produce the same or very similar sound absorption coefficient to that of a series DL-MPP while substantially reducing the backing cavity depth in the direction of incident sound wave

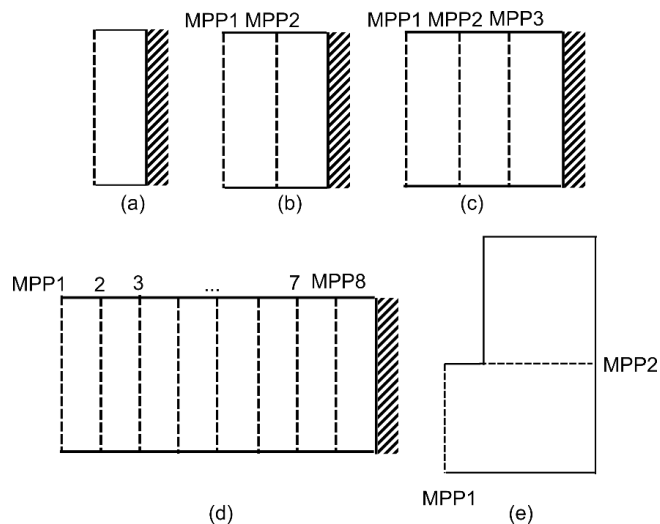


Fig. 5. Comparison of (a) SL-MPP, (b) DL-MPP, (c) TL-MPP, (d) ML-MPP and (e) Turned up DL-MPP configurations.

4.2.2. Multiple depth cavities

The use of multidepth cavities to broaden the absorption bandwidth was first demonstrated by Wang et al. [18], who introduced cavity partitioning with up to three sections of varying depths arranged in a modulated pattern as in Fig. 6(a). This approach achieved a wider effective bandwidth compared to uniform-depth designs, in which all cavity partitions shared the same depth. The concept was later expanded into a four-depth configuration [19] and tested under diffuse field conditions, confirming its potential for robust performance. Iman and Aboldreza [20] further introduced stepwise cavities inspired by stair-like geometries, investigating both two and four-depth designs. Their findings emphasized the importance of properly pairing cavity depths to maximize bandwidth enhancement. Yan et al. [21] subsequently optimized this approach with up to eight steps, achieving absorption as low as 400 Hz and extending up to 1600 Hz with a maximum sub-cavity depth of 60 mm. Min et al. [22] proposed a distinctive variation inspired by acoustic diffusers, employing a Quadratic Residue Sequence (QRS) arrangement with up to six distinct depths. Zhao et al. [4] later evaluated this configuration under diffuse sound field conditions and

confirmed its ability to maintain broad absorption coverage.

Qian et al. [23] investigated coupling effects by modifying the second layer of a DL-MPP into a multidepth arrangement, demonstrating wideband absorption within a total cavity depth of only 50 mm (see Fig. 6(b)). Mosa et al. [24] integrated multi-depth cavities into parallel MPP designs (Fig. 6(c)), and later expanded the concept into double-layer systems [25] (Fig. 6(d)). Rafique et al. [26] directly compared multi-depth and uniform cavity designs, reporting significant improvements in low-frequency absorption for the former.

Overall, recent studies highlight multi-depth cavities as one of the most effective and straightforward strategies for enhancing ML-MPP systems. Compared to hybrid configurations incorporating porous materials, this approach is simpler while offering more predictable performance. Although the complexity of arranging multiple cavities remains a challenge, the variation in depth between cavities has proven to exert the most dominant influence on absorption performance. A summary of these studies is provided in Table 3.

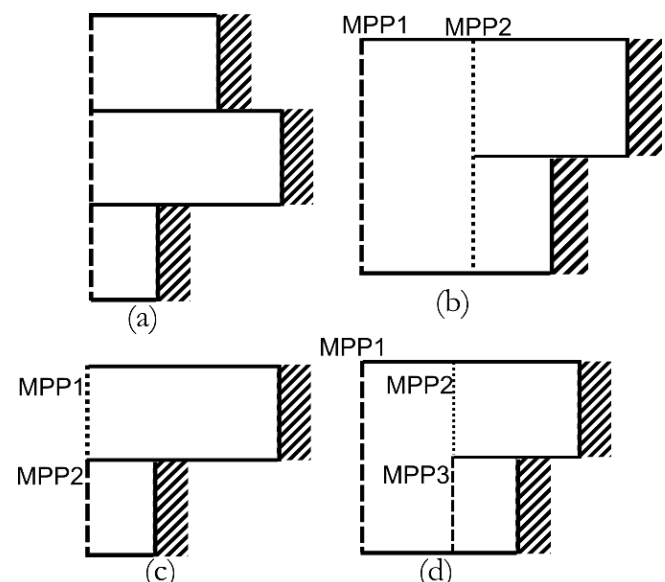


Fig. 6. Variations of multi-depth cavity configurations: (a) three multidepth cavities, (b) multi-depth DL-MPP, (c) multi-depth parallel MPP, and (d) multi-depth DL-iMPP.

Table 3. Summary of studies on multi-depth cavity designs for MPP absorbers.

Authors and Year	Method Summary	Validation	Frequency target	Highlight
Wang and Huang, 2011[43]	3 multi-depth cavities	Experimental	50-1700 Hz	Existence of near-field effect may affect the peak and dips in the SAC
Wang et al., 2014 [44]	4 multi-depth cavities	Experimental	300-2000 Hz	absorption break down at lower frequency at oblique incident
Qian et al., 2017* [23]	DL-iMPP, with (second layer) multi depth	Experimental	100-7000 Hz	The combination of serial-parallel MPP with very small holes significantly widening the SAC from mid to high bandwidth

Iman and Abdolreza, 2018 [20]	Multistep depth 2 and 4 cavity	Experimental	400-1600 Hz	There is trade-off between having a wide and high absorption, but a balance of it should be priority
Min et al., 2019 [22]	6 multi-depth cavities follow Quadratic Residue Sequence	Experimental	500-3500 Hz	depth ratio is more dominant than the arrangement
Mosa et al., 2019* [24]	Multi-depth cavity for parallel MPP	Experimental	200-1600 Hz	The absorption bandwidth can be improved by controlling the perforation ratio difference between the sub-MPPs.
Mosa et al., 2020* [25]	DL-iMPP, with second layer multi depth	Experimental	400-3500 Hz	increasing the back cavity depth on the sub-MPP with large hole diameter and small perforation ratio is effective low-mid SAC
Rafique et al., 2022 [26]	Comparison of iMPP with 4 partition multi-depth vs 4 uniform cavity vs single cavity	Experimental	195–455 Hz	Improve absorption at low frequency for 4 partition multi depth cavities
Yan et al., 2024 [21]	multistep depth up to 8 steps	Experimental	400-1600 Hz	The extension of more SAC peak potentially covers wider absorption
Zhao et al., 2024 [4]	6 multi-depth cavities follow Quadratic Residue Sequence (QRS) at diffuse field	Experimental	1000-3500 Hz	The modified QRS based multi depth cavities maintain nearly good absorption at desired frequency from 0 to 45 degree

4.2.3. Geometry modified cavities

Compared to conventional cavity design (Fig. 7(a)) Wang et al. [27] were among the first to investigate cavity shape modification, introducing a trapezoidal cavity (Fig. 7(b)) that produced multiple distinct absorption peaks. While less widely explored than depth partitioning, this work demonstrated the acoustic potential of non-rectangular cavity geometries. Tan et al. [28] extended this idea by varying cavity dimensions to form multiple-sized air gaps (Fig. 7(c)), achieving increased SAC peaks and enhanced low-frequency absorption.

Building on these concepts, later studies pursued hybrid or compact solutions. Lee et al. [30] combined trapezoidal shaping with multi-depth cavities (Fig. 7(d)), highlighting synergistic effects between geometry and depth modulation. Gai et al. [31] proposed an L-shaped cavity (Fig. 7(e)), which preserved absorption efficiency while reducing overall absorber thickness. Chu et al. [32] achieved deeper effective cavities by folding sub-cavities in constrained spaces (Fig. 7(f)), targeting low-frequency performance. Similarly, Wu et al. [33] drew inspiration from Fabry–Perot optical resonators, folding cavities into elongated channel-like structures (Fig. 7(g)), which improved low-frequency absorption without increasing absorber thickness.

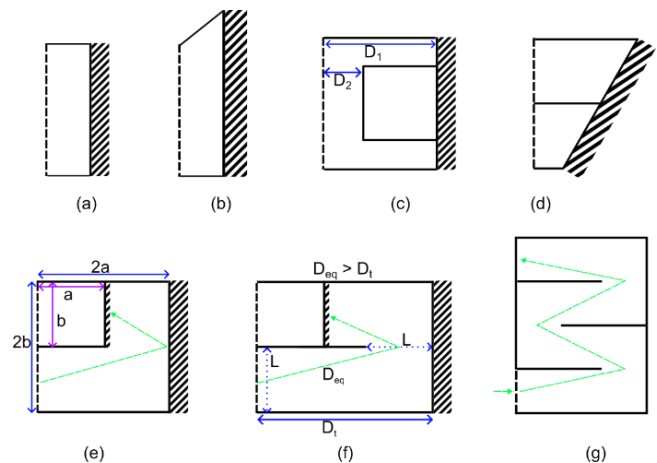


Fig. 7. Comparison of cavity geometries: (a) conventional cavity, (b) trapezoidal cavity, (c) multiple-size cavities, (d) Trapezoidal multi-depth cavities, (e) folding L-shaped cavity, (f) coiling cavities, and (g) coiling cavity following the Fabry–Perot principle.

More unconventional geometries have also been investigated. Rafique et al. [34] proposed a J-shaped cavity (Fig. 8(a)) that avoided the sharp turns common in coiled channels, further improving performance when combined with multi-depth designs. Singh et al. [35] introduced a fractal Hilbert-shaped cavity (Fig. 8(b)), which increased internal reflections and wave propagation paths, thereby enhancing absorption. Yang et al. [36] modified cavity channels into an Archimedean spiral (Fig. 8(c)), achieving wideband absorption with absorber thicknesses of only 20–30 mm. Rafique et al. [37] extended cavity modification toward metamaterial-inspired forms by combining spiderweb cavities with inhomogeneous MPP (Fig. 8(d)).

Overall, geometry-modified cavities provide creative pathways to improve absorption performance and enable compact designs. Although fewer in number compared to multi-depth studies, they demonstrate significant potential

for future integration with metamaterial concepts. A summary of these works is provided in Table 4.

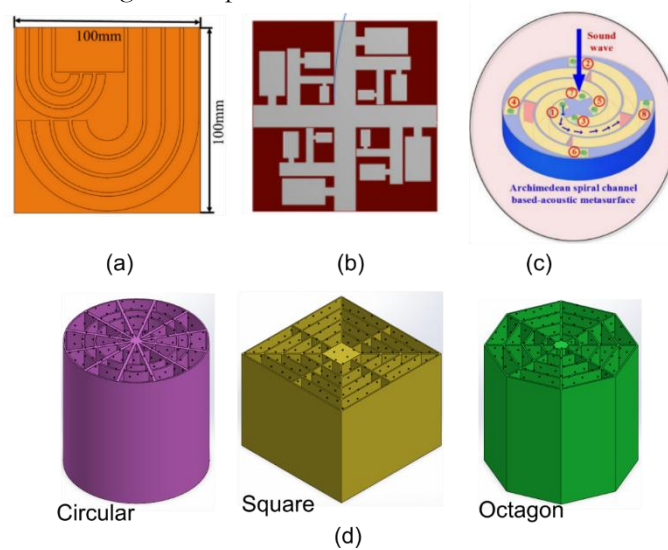


Fig. 8. Complex geometry-modified cavities approaching metamaterial concepts: (a) multiple cavities in J-shape [34] with permission (b) cavities based on Hilbert fractal design [35] with permission (c) Archimedean spiral cavity [36] (d) cavities with a spiderweb design, illustration adapted from Rafique et al. 2022 study [37].

Table 4. Summary of studies on geometrically modified cavity designs in MPP absorbers.

Authors and Year	Method Summary	Validation	Frequency target	Highlight
Wang et al.,2010 [45]	Trapezoidal shape cavity	Experimental	300-2500 Hz	Proposed design can produce more spectral SAC peak after the first resonance
Tan et al.,2015 [28]	Multiple volume cavity	Experimental	100-1600 Hz	Adding a depth into any sub cavity shift the peak absorption to lower bandwidth
Gai et al.,2017* [46]	Multiple depth cavities with longest cavity following L shape division	Experimental	200-1600 Hz	This structure enables wideband sound absorption even when the available cavity space is restricted
Lee et al.,2019* [30]	3 multi depth cavity with trapezoidal cross section with layer integration	Experimental	500-3500 Hz	Partitioning the trapezoidal boost the SAC peak, the peak occurrences follow on the partition number
Wu et al.,2019 [47]	Long cavity follows Fabry–Perot (FB) channels	Experimental	300-600 Hz	The folded cavity performance like long cavity, reduce the total absorber thickness
Rafique et al.,2022* [34]	Multi depth with long cavity folded following J-shape	Experimental	300-480 Hz	Shift and slightly wider the absorption to low-mid range compared to L shape and still wider than uniform shape(straight)
Singh et al.,2022 [35]	Cavity that follows Fractal geometry	Experimental	600-1000Hz	Near perfect absorption at 20 mm cavity depth
Chu J. et al.,2023* [32]	Multi depth cavity with Folded Long cavity	Experimental	400-5000 Hz	Good absorption at mid frequency
Rafique et al.,2023 [37]	Meta structure inhomogeneous MPP with spiderweb cavities	Experimental	230-470 Hz	Near perfect absorption at low frequency, with thickness 100mm

Yang et al., 2024 [36]	The long cavity of each channel was coiled following Archimedean spiral	Experimental	350-500Hz	Absorber with thickness around 20-30mm can achieve low and wide absorption
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4.2.4. Partitioning in cavities

Many earlier studies employed fully partitioned cavities as in Fig. 9(a), where rigid walls acoustically isolate each section, creating distinct air volumes. Huang et al. [38] proposed an incompletely partitioned configuration (Fig. 9(b)) that allows airflow between adjacent cavities, showing modest absorption improvements in the mid-to-high frequency range. Liu et al. [39] expanded this idea by exploring Helmholtz-resonator-like arrangements (Fig. 9(c)) and tapered partitions (Fig. 9(d)), providing valuable comparative insights into the resulting acoustic responses. Carbajo et al. [40] and Agarwalla et al. [41] advanced the concept further by replacing rigid partitions with MPP membranes as in Fig. 9(e). Their results revealed that, when designed carefully, MPP partitions can reproduce absorption characteristics like multi-depth or multilayer MPP systems. Recognizing the strong role of acoustic coupling, Yang et al. [42] developed an improved theoretical model to better capture interactions between adjacent cavities. Their findings underscored the importance of effective partitioning in suppressing unwanted grazing and oblique modes that reduce absorption performance.

In hybrid approaches, Mosa et al. [48] integrated partitions within a DL-iMPP (Fig. 10(a)), achieving superior absorption compared to DL-MPP designs. Li et al. [49] introduced a partitioned DL-MPP resembling a Helmholtz resonator (Fig. 10(b)), producing three unequal cavity volumes with enhanced broadband absorption. Jiang et al. [50] investigated an N-core MPP partition system, reporting notable absorption improvements while maintaining structural lightness. More recently, Wang et al. [51] proposed a hybrid configuration combining partitions with multi-depth cavities (Fig. 10(c)), where partition elements directly contributed to overall absorption.

Overall, partial partitions or MPP-based partitions form additional cavities that remain connected through a shared air volume. The key mechanism lies in how sound waves propagate through these interconnected volumes, which can be exploited to enhance absorption. In contrast, rigid partitions without modifications to cavity depth or panel parameters may have negligible influence, effectively becoming acoustically “invisible.” For this reason, partitions are most effective when paired with other strategies, such as multi-depth cavities or the use of MPP membranes. The studies reviewed in this subsection are summarized in Table 5.

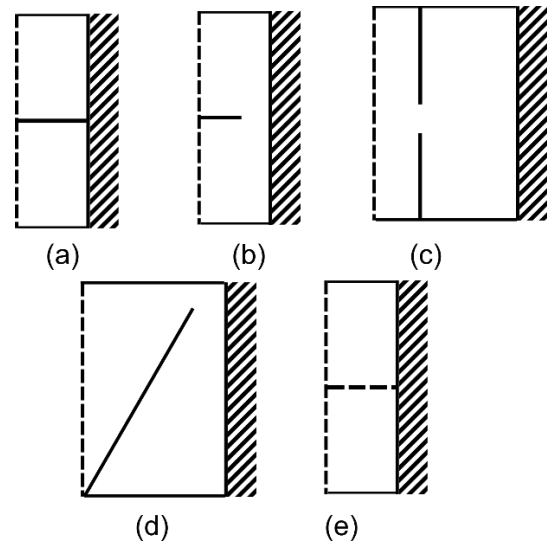


Fig. 9. A comparison of partitioning strategies: (a) rigid partition, (b) incomplete partition, (c) Helmholtz resonator shape, (d) tapered partition cavities and (e) porous/MPP partition.

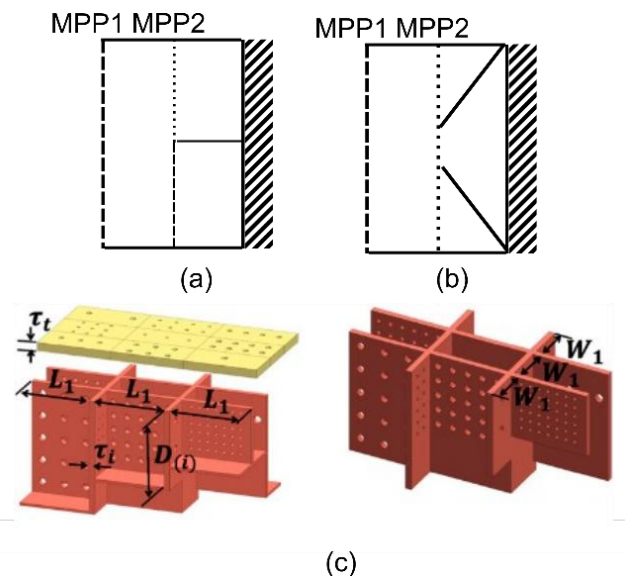


Fig. 10. Hybrid integration of partitioning strategies: (a) DL-iMPP, (b) partitioned DL-MPP resembling Helmholtz resonator, and (c) partitions combined with multi-depth cavities [51].

4.3. Panel Modification

While cavity-related strategies focus on the backing volume, Panel modifications (26 studies) directly target the microperforated sheet itself. These works are categorized into perforation modifications (14 studies) and panel profile modifications (12 studies). Panel-focused works tend to emphasize precision microfabrication techniques and the possibility of tailoring impedance profiles with relatively small material changes.

Table 5. Summary of studies on cavity partitioning strategies in MPP absorbers.

Authors and Year	Method Summary	Validation	Frequency target	Highlight
Huang et al., 2017 [61]	Incomplete partitioning	Experimental	200-5000 Hz	Modest performance in the mid-to-high frequency range.
Liu et al., 2017 [39]	Comparison of multiple cavity design	Experimental	200-10000 Hz	Adding resonator boost absorption at low region and channel wider the absorption
Carbajo et al., 2019 [40]	MPP as partition instead of rigid wall	Experimental	500-2000Hz	Has similar performance like multi depth cavity or multilayer MPP
Mosa et al., 2020* [48]	DL-iMPP, each layer is iMPP with second layer partition	Experimental	300-2500Hz	Depth between first and second layer effecting the mid-high and second layer and wall effecting the mid frequency SAC
Yang et al., 2020 [42]	Cavity partitioned into smaller section	Numerical	200-2000hz	Author suggesting partitioning the cavity to avoid grazing and oblique mode
Jiang et al., 2023 [50]	integration of MPP partition into NH core	Experimental	500-1600Hz	The usage of NH core partition is a direction for lightweight yet durable absorber
Li et al., 2023* [49]	partitioning resembles of HR in second layer of DL-MPP	Experimental	632-1954Hz	low and wide band absorption with 53 mm thickness
Agarwalla et al., 2024 [41]	Partitioning MPP into Parallel MPP	Experimental	800-1800Hz	claimed as an alternative for low frequency absorption without sacrifice longer cavity depth
Wang et al., 2024* [51]	Meta structure with MPP partition	Experimental	300-4000Hz	with absorber thickness at 47mm, good SAC at around 300 -2000Hz

4.3.1. Perforation modification

One of the primary ways to enhance an MPP absorber is by altering the perforations themselves. The cross-sectional profile of a hole has a direct influence on impedance and overall sound absorption. Herdtel et al. [52] highlighted that the classical Maa model tends to oversimplify end corrections, particularly at low frequencies where hole tapering and shape strongly affect performance, the standard perforation condition shown as Fig. 11(a). Using Computational Fluid Dynamics (CFD), they showed that tapered perforations (Fig. 11(b)) can be more accurately modelled to predict acoustic behaviour. Qian et al. [53] further demonstrated that both inlet and outlet diameters are equally critical, while Li et al. [54] extended this idea by replacing perforations with microtubes to increase acoustic path length and improve low-frequency absorption.

Additional design variations include countersunk profiles (Fig. 11(c)), which resemble screw-like openings [55]. These introduce additional viscous losses and acoustic resistance. Sailesh et al. [56] applied additive

manufacturing to create multi-step cross-sections which consist of divergence(D), convergence–divergence(CD) and divergence–convergence(DC) similar to Fig. 11(d) 11(e) and 11(f), respectively, offering greater control over hole geometry. Liu et al. [57] demonstrated that rough, oblique holes (Fig. 11(g)) can enhance low-frequency absorption and He et al. [56] confirmed that tapered holes (Fig. 11(h)) can still achieve accurate mid-frequency performance when properly modelled. A summary of these cross-sectional variations is presented in Table 6.

Beyond cross-sectional design, perforation size and shape variation represent another important avenue for tuning acoustic performance. Smaller perforations increase surface resistance and shift absorption characteristics. For instance, Qian et al. [58] implemented holes as small as 0.028 mm in diameter, while Gai et al. [59] achieved 0.23 mm using a hybrid manufacturing process. More recently, Zheng et al. [60] used 0.07 mm holes in a multi-cavity system, achieving strong performance with only 71 mm of total thickness.

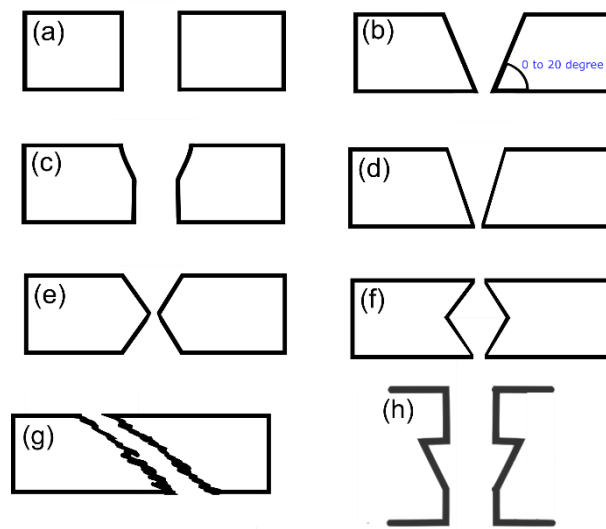


Fig. 11. Sketch of cross-sections of perforation profiles: (a) standard perforation, (b) tapered perforation with angles varying from 0° to 20° , (c) countersunk profile, (d) divergence, (e) convergence–divergence, (f) divergence–convergence, (g) rough oblique holes and (h) Tapered divergence holes.

Table 6. Summary of perforation cross-section variations and their acoustic effects.

Authors and Year	Method Summary	Validation	Frequency Target	Highlight
Herdte et al., 2013 [52]	New modelling of tapered holes at 0-20 degree	Numerical	300-4000 Hz	The proposed CFD model for this problem accurate capture the dynamic flow resistance at low frequency
Qian et al., 2014 [53]	Tapered holes with different inlet and outlet diameter	Experimental	300-1000 Hz	MPPs with tapered holes demonstrate improved sound absorption, especially for thick panels, compared to conventional cylindrical holes.
Li et al., 2016* [54]	Holes extended over the panel	Statistical	150-440 Hz	The use of extended tube has good performance at low frequency range compared to conventional MPP absorber
Yuvaraj et al., 2020* [55]	MPP with countersunk holes profile, backed with porous cavity	Experimental	300-1500 Hz	a greater viscous loss of sound due to convergent effect of countersunk profile
Sailesh et al., 2021 [56]	comparison of Thick MPP with multiple holes cross section (Constant, D, DC, C and CD)	Experimental	500-2000Hz	DC perforation registered better performance compared to the constant 1 mm diameter perforation pertaining to both peak absorption coefficient and bandwidth
He et al., 2021 [71]	MPP with tapered holes	Numerical	400-1400Hz	Increasing the bottom radius of tapered holes tend to shift the absorption into high frequency range
Liu et al., 2024 [57]	Holes with rough condition	Experimental	230 - 260Hz	A rough surface is designed for low frequency sound absorption

Ning et al. [62] compared circular, triangular, square, and slit perforations, finding that triangular holes yielded the most favourable results across configurations. Ren et al. [63] developed a model for panels with tuneable hole

shapes and sizes, enabling spatial variation of hole morphology. In hybrid designs, Arjunan et al. [64] tested maze, hexagon, and star shapes, while Reddy et al. [65] used the concept of equivalent hydraulic diameter to

compare different shapes under equal perforation ratios. Their results showed that rectangular perforations could outperform square and circular ones under the same conditions. Figure 12 from Ren et al. [63] illustrates the variety of hole geometries achieved through parameter tuning.

In summary, custom perforation designs can offer unique acoustic advantages, but they require thicker panels and often reduce absorption bandwidth. Such approaches may be justified in cases where structural strength is a priority. Similarly, ultra-small perforations provide enhanced resistance but demand advanced microfabrication technologies such as Digital Light Processing (DLP) 3D printing. Even with these methods, consistent hole precision remains challenging, often leading to imperfect holes. Non-circular shapes are likewise limited by conventional drilling, yet they can exploit shape-dependent effects, where specific geometries alter flow behaviour within the holes, potentially benefiting targeted frequency absorption. All

studies reviewed in this section about size and shape of perforation are summarized in Tables 7 and 8, respectively.

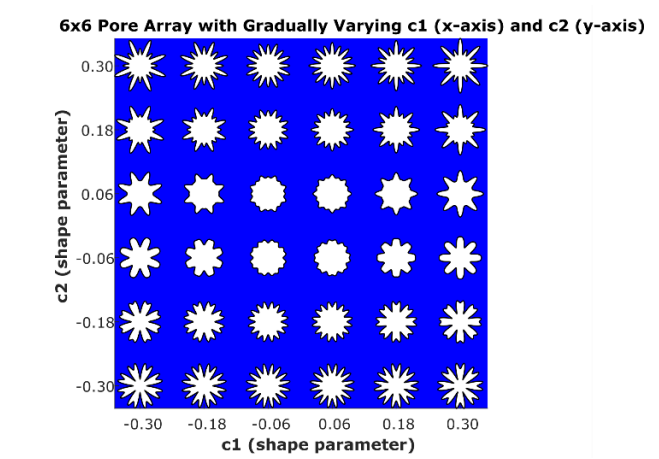


Fig. 12. Illustration of hole morphology variations adapted from study by Ren et al. (2017) [63].

Table 7. Studies employing ultra-small perforation sizes.

Authors and Year	Method Summary	Validation	Frequency Target	Highlight
Qian et al., 2013 [58]	MPP with holes diameter at 0.02 mm	Experimental	1000-7000 Hz	a single MPP absorber can satisfy high absorption in wide frequency range by using an ultra-micro perforation
Gai et al., 2019 [59]	ultra micro holes at 0.23mm using heat shrinkable sheet	Experimental	350-2100 Hz	The shrinkable sheet will make MPP fabrication with smaller holes than traditional technology
Zheng et al., 2024* [60]	MPP with holes diameter around 0.07 mm, integrated with multi depth	Numerical	500-3480 Hz	A potential usage in aerospace noise engineering

Table 8. Studies on perforation shape variations.

Authors and Year	Method Summary	Validation	Frequency Target	Highlight
Ning et al., 2016 [62]	holes with arbitrary shape (circle, slit, triangle and square)	Experimental	100-2200 Hz	Sound absorption coefficient of the MPP absorber with the triangle cross section is the largest in all cases in the range of frequencies
Ren et al., 2017 [63]	MPP with varying holes shape, varying morphology	Experimental	200-1600 Hz	Meso-scale circular pores with micro-scale bulges along the boundaries lead to near-perfect sound absorption
Arjunan et al., 2021 [64]	comparison of Thin MPP with 3 holes design (Maze, Hexagon and Star), backed with porous cavity	Experimental	500-1600 Hz	The star perforation shows the performance followed by maze and hexagon
Reddy et al., 2022 [65]	Comparison of DL-MPP with different holes shape (circle, square and rectangular) at equivalent hydraulic diameter	Analytical	10-1500 Hz	Rectangular perforations have higher absorptivity than square and circular perforations with the same surface criteria

4.3.2. Perforation distribution and panel profile

Beyond the geometry of individual perforations, the arrangement of holes and the overall panel profile also play a significant role in shaping the acoustic response of MPP-based absorbers. Perforation distribution strategies, such as parallel or cross arrangements, can alter the coupling between the panel and the backing cavity. Qian et al. [66] compared parallel and cross-hole layouts in triple-sized MPPs, using a Multi-Population Genetic Algorithm (MPGA) to identify configurations that maximise bandwidth. Prasetyo et al. [67] reported that thick parallel MPPs enhanced low-to-mid-frequency bandwidth, nearly doubling performance compared to conventional thick panels. Conversely, Kusaka et al. [68] examined unit cells containing multiple hole sizes, which allowed for tailored absorption over a broader frequency range. Deacon et al. [69] investigated thick MPPs with high porosity (8.73%), comparing multiple prediction models including Maa, Beranek, Transfer Matrix Method (TMM), and a Distance-Based Linearized Navier–Stokes–Fourier (DBLNSF) approach. While DBLNSF offered the highest accuracy in the mid–high range, it also required greater computational effort. Li et al. [70] proposed a four-panel parallel MPP arrangement as an alternative to the traditional long-cavity approach for improving low-frequency absorption. Similarly, Mosa et al. [24] demonstrated that parallel MPPs with varied perforation ratios in separate cavities can fine-tune target frequencies by adjusting their spatial arrangement.

Panel profile modifications represent another design route, has focused on non-flat panel geometries. Ren et al. [72] designed an ultrathin flexible MPP (Fig. 13(a)) that would normally suffer from panel–cavity coupling losses,

but by integrating local resonators, the design preserved low and mid-frequency absorption. Wang et al. [73] tested corrugated MPP (Fig. 13(b)) and found that corrugation depth, more than pitch, was the dominant factor influencing absorption, with effective performance spanning low to mid–high frequencies. Yang et al. [74] proposed a sinusoidal “Z-shaped” MPP (Figure 13(c)), which outperformed flat MPPs under oblique plane-wave incidence, particularly in the mid to mid–high range.

In summary, perforation distribution strategies provide a fine-grained means to control frequency response, while panel profile modifications broaden design flexibility by mitigating coupling issues and enhancing robustness under varying acoustic conditions. Together, these approaches highlight how both micro-level distribution and macro-level shaping of the panel can be leveraged to advance MPP absorber performance. All studies reviewed in this section about perforation distribution and profile of panel are summarized in Tables 9 and 10, respectively.

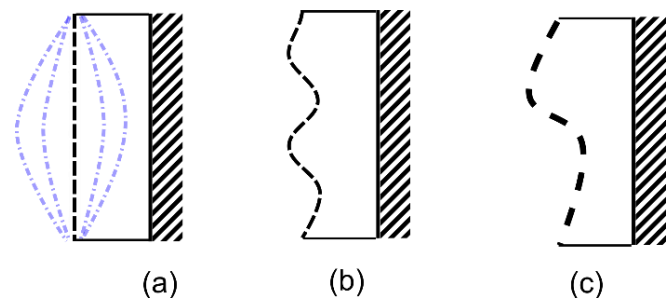


Fig. 13. Comparison of panel profile strategies: (a) ultrathin flexible MPP, (b) corrugated MPP, and (c) sinusoidal “Z-shaped” MPP

Table 9. Summary of perforation distribution strategies in MPP absorbers.

Authors and Year	Method Summary	Validation	Frequency Target	Highlight
Qian et al., 2014 [66]	3 holes size selected through MPGA	Experimental	200-2000 Hz	3 combinations of parallel MPP that work best at low and mid frequency Parallel MPP doubles the absorption bandwidth of thick MPP, overcoming the typical bandwidth reduction seen in thicker panels.
Prasetyo et al., 2016 [67]	Thick Parallel MPP	Experimental	400-800 Hz	Distance-Based Linearized Navier-Stokes-Fourier (DBSLF) for numerical method proved to be accurate but consume processing time
Deacon et al., 2018 [69]	MPP with very high porosity (8.73%)	Numerical	500-5500 Hz	Proposed method was suitable for Low Frequency Absorption without having multi depth cavities
Li et al., 2019 [70]	4 Parallel MPP	Experimental	150-400 Hz	The design was claimed to be used in complex noise environment
Zhang et al., 2020 [75]	A panel attached with baffle to freely adjust the count of holes	Experimental	2500-3200 Hz	the combination of multiple holes diameter has a similar result of single mean diameter
Xie et al., 2020 [76]	Changing the single holes diameter	Experimental	700-1800 Hz	

Kusaka et al., 2021 [68]	based on pattern of honeycomb core Holes distributes at different layout that compare to parallel profile	Experimental	300-800 Hz	The proposed method is relatively good except for some cases where the air cavity is deep, or the specimen has relatively large heterogeneity
Dorra et al., 2021 [77]	heterogeneity MPP with holes distribute on varying pattern (square, triangle and random)	Experimental	200-1000 Hz	SAC improvement 11-12% using holes from circle to square and rectangular, but the arrangement has negligible effect

Table 10. Summary of panel profile modifications for enhanced absorption.

Authors and Year	Method Summary	Validation	Frequency Target	Highlight
Ren et al., 2019* [72]	Flexible MPP at 0.5mm supported with local resonator(mass- spring-damping)	Numerical	400-800 Hz	suffering from panel-cavity coupling absorption dips can be enhance with local resonator
Wang et al., 2020 [73]	MPP with corrugated profile	Experimental	200-1600 Hz	corrugation depth is found to be more influential than the corrugation pitch on the sound absorption
Shafeer et al., 2023 [78]	A graded perforation and thickness in single MPP	Experimental	500-800 Hz	Graded thickness provides a good mechanical strength without compromising absorption performance
Yang et al., 2023 [74]	MPP with wavy profile (Z)	Experimental	700-1800 Hz	the proposed structure is superior to Flat MPP under oblique plane-wave incidence, especially at large incident angles

5. Comparative Insights, Trends, and Emerging Directions

5.1. Cross-categories comparison of structural enhancements

A clearer understanding of relative performance can be obtained by comparing strategies that share overlapping objectives but differ in structural implementation.

- Multidepth vs. Multilayer cavities.
Both strategies aim to extend absorption over a wide frequency range also preferred for low frequency absorption, yet they do so with different emphases. Multidepth cavities introduce variation in resonance frequencies within compact structure, resulting in high absorption coefficients over targeted frequency bands (e.g., 400–1600 Hz). This a coiling depth integration approach also particularly effective when targeting shallow-band coverage with reduced overall thickness. In contrast, multilayer cavities create distinct sequential resonances, cover wider range (e.g., 1000-5000Hz) but often resulting good low-frequency absorption at the cost of increased structural depth. While multidepth cavities

are advantageous for compact installations and targeted low-frequency control. ML-MPP typically provide superior broadband and low-frequency absorption, especially when space is not a primary constraint. The optimal choice depends on the specific acoustic and spatial requirements.

- Multidepth vs. Parallel configurations.
Multidepth and Parallel MPP are similar on how they still create multiple resonance in each cavity. The different is how they exploit multiple cavities, multidepth more into depth ratio between sub cavities while parallel MPP into MPP parameter (by assuming no depth variation). The trade-off lies in fabrication: parallel systems require precise spatial control refer to the MPP parameter and increased material use, but they excel when selective frequency absorption (e.g., noise band control) is needed. Multidepth systems remain preferable for broad, more uniform coverage where exact tunability is less critical as the homogenous MPP can be used for all cavities.
- Panel profile vs. Geometric cavity modifications.
Panel profile modifications, such as corrugated or sinusoidal MPP, primarily influence coupling efficiency and structural robustness. They perform well in high-

broadband absorption scenarios and under non-ideal conditions like oblique incidence. But at low frequency it will behave like flat MPP. Geometric cavity modifications, on the other hand, enhance absorption by manipulating the effective acoustic path. These excel in low-frequency extension without excessive absorber thickness but often require more complex fabrication. Thus, panel profiles are suitable for reverberation control where both structural rigidity and broadband absorption are desired, while geometric cavities are more suited for specialized low-frequency treatments where space constraints are critical.

- Geometric cavities vs. Perforation design.

Perforation-focused strategies offer micro-level tuning of acoustic impedance, making them highly effective for shifting absorption peaks and tailoring bandwidths. In contrast, geometric cavity modifications manipulate absorption at the macro-structural scale, often enabling dramatic low-frequency enhancement. Perforation strategies are lightweight, flexible, and computationally optimizable, but limited in shifting the fundamental frequency bound by cavity depth. Geometric modifications overcome this limitation, though they introduce fabrication and integration challenges. Therefore, perforation design is ideal for precision control and lightweight structures, while geometric cavities provide robust solutions for deep, low-frequency absorption.

5.2. Trend of Structural Enhancements Over Times

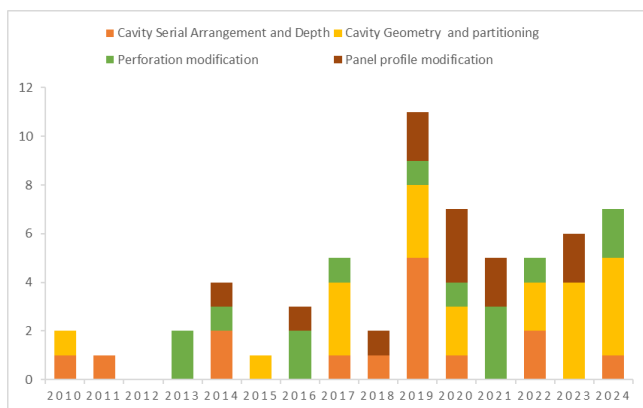


Fig. 14. Annual distribution of studies by for cavities and panel modification (2010–2024).

Figure 14 illustrates the distribution of published studies on different structural enhancement strategies for MPP absorbers between 2010 and 2024. The earliest works were relatively sparse, with isolated explorations of cavity geometry and perforation modification. From 2014 onward, research activity became more consistent, showing a gradual diversification of approaches.

A noticeable peak occurred around 2019–2020, when cavity-based enhancements particularly serial arrangements, multi-depth configurations, and geometric partitioning are dominated the literature. This reflects a strong research emphasis on addressing low-frequency

absorption, often at the expense of increasing system complexity. Panel-related strategies, such as profile modification, gained momentum around the same period, indicating growing interest in compact or application-driven solutions.

In more recent years (2021–2024), the trend has shifted toward a more balanced distribution across all strategies. Perforation modifications have gained renewed attention, reflecting advances in precision fabrication methods, while cavity geometry remains a consistent area of study. Overall, the data suggest an evolution from early reliance on cavity enhancements to a broader portfolio of design strategies, with increasing integration of multiple approaches. This indicates that the field is moving toward more flexible, application-specific absorber designs rather than depending on a single dominant enhancement technique.

5.3. Limitations And Future Directions

Various structural innovations, particularly in cavity and panel design, have significantly improved the performance of MPP absorbers. However, several key limitations remain, particularly in terms of bandwidth extension, manufacturability, predictive accuracy, and applicability in real-world environments.

Cavity modifications such as multilayer, multi-depth, and partitioned designs consistently improve absorption performance. Yet, they often require increased overall thickness for low-frequency targets or complex assemblies when aiming for broadband coverage. This can make them impractical in space-limited applications [30]. Geometrically modified cavities, such as folded or coiled paths, show promising results for compact low-frequency absorbers but introduce challenges in manufacturing precision, installation, and alignment. Future studies could compare manufacturing approaches in terms of cost, durability, and acoustic trade-offs to provide clearer guidance for large-scale deployment.

Perforation condition remains a direct and powerful way to manipulate absorption, as it governs the resistive component of the panel impedance. Ultra-small perforations can achieve near-perfect absorption across wide frequency ranges but are difficult to reproduce with conventional methods. Advanced techniques such as MEMS or laser drilling offer precision but increase cost and limit scalability [79]. Imperfect perforations, whether due to tolerance errors, surface roughness, or non-uniformity, can cause peak shifting and unstable low-frequency performance. Research is needed both to develop more accessible, high-precision, and cost-effective manufacturing methods, and to refine analytical models so they better capture real-world deviations.

The existent of hybrid configurations, combining multiple design modifications, offer the potential for multi-mechanism enhancement. However, interaction effects between design elements remain poorly understood. As complexity increases, performance prediction becomes less reliable, and mismatched

combinations can lead to suboptimal or unexpected results. Future work should focus on isolating and quantifying the contribution of each element within hybrid absorbers, supported by detailed parametric and sensitivity studies.

While many of these modifications have been experimentally validated, testing is still predominantly conducted at small scales using impedance tubes under normal incidence and controlled conditions. This leaves uncertainty about absorber performance in practical settings with random incidence, oblique waves, and environmental variations such as temperature, humidity, and contamination. Long-term durability studies, environmental resilience tests, and field-scale trials are essential for bridging the gap between laboratory results and real-world application.

Addressing these challenges will require not only incremental improvements in individual design strategies but also an integrated research approach that combines advanced modelling, scalable manufacturing, and practical deployment testing. This review has outlined the breadth of current strategies; the next step is to unify these advances into adaptable, manufacturable, and reliable solutions for diverse acoustic environments.

While this review provides a comprehensive synthesis of MPP absorber design strategies, it is limited by its reliance on published literature, which may underrepresent unpublished or industrial studies. In addition, the categorization framework although designed to minimize overlap still faces challenges when classifying hybrid designs that combine multiple approaches. The quantitative comparisons presented are constrained by the variability in experimental conditions, measurement setups, and reporting practices across studies. As a result, some trends may be influenced by differences in methodology rather than inherent design performance. Nonetheless, by presenting the current state of the art alongside clearly identified research gaps, this review aims to offer a balanced and constructive perspective that can guide future work rather than overstate current achievements.

6. Conclusion

This review has examined structural enhancement strategies for microperforated panel absorbers, focusing on cavity modifications and panel modifications as the two primary pathways of improvement.

Cavity modifications such as multilayer, multi-depth, folded, or partitioned designs have shown consistent potential to broaden absorption bandwidth and improve low-frequency performance. Each approach, however, introduces trade-offs between acoustic gain and structural complexity. Geometric modifications like coiling and folding allow significant space savings for low-frequency absorption but pose fabrication and installation challenges. Partitioning and multi-depth designs deliver broadband effects but often require thicker or more intricate assemblies.

Panel modifications ranging from alternative perforation geometries to non-uniform hole distributions and profiled surfaces remain a direct method of tailoring impedance. They allow finer control over peak placement and bandwidth with minimal changes to cavity design. Yet, the benefits are tightly coupled to manufacturing feasibility, as ultra-small or irregular perforations remain challenging to realise at scale.

When translated to real-world applications, these findings highlight both promise and caution. For architectural acoustics, cavity-based modifications are effective for tailoring wall or ceiling treatments, but their thickness and installation tolerance must meet practical building requirements. In compact environments such as vehicles or aircraft cabins, panel-focused modifications may be more realistic, since they offer performance gains without requiring large depths.

Future research should also reflect on whether every proposed enhancement is genuinely necessary. Does an added geometric folding always justify its complexity, or would a simpler multi-depth approach suffice? If ultra-broadband absorption is achieved in theory, is the additional frequency coverage truly needed for applications where dominant noise bands are already well targeted? For example, in automotive applications, the priority is often mid- to low-frequency suppression (e.g., 100–800 Hz), while in building acoustics, controlling reverberation in the speech range may matter more than extreme bandwidth.

Such questions challenge the assumption that “wider and lower is always better.” A coiled cavity might be acoustically impressive but excessive if wall construction already allows sufficient space. Similarly, claims of wideband improvement must be considered against actual user needs: what bandwidth is practically necessary for classrooms, offices, concert halls, or vehicle interiors?

In conclusion, both cavity and panel strategies have advanced MPP absorber performance, yet their ultimate value lies in context-sensitive application rather than theoretical optimisation alone. Moving forward, the field must balance acoustic performance with manufacturability, practicality, and true user requirements ensuring that structural innovations not only demonstrate laboratory excellence but also deliver meaningful impact in the environments they are intended to serve.

Appendix

Table A1. Terminology Used in This Review

Term	Definition
Single-layer MPP (SL-MPP)	An absorber consisting of one perforated panel backed by a single cavity.
Double-layer MPP (DL-MPP)	Two or more MPP layers arranged sequentially, with cavities in between. Sound passes through each layer consecutively.
Tripple-Layer MPP (TL-MPP)	
Multi-layer MPP (ML-MPP)	
Multi-leaf MPP	A stack of multiple MPP layers without a rigid backing.
Parallel MPP	Multiple MPP panels arranged side by side, each backed by its own cavity, exposed to the same incident wave.
Serial-Parallel MPP	Hybrid arrangement where each parallel branch contains multiple serial layers before combining.
Homogenous MPP	MPP specifications are uniform across the entire surface/multilayer system
Inhomogeneous MPP (iMPP)	A panel with varying hole parameters (diameter, spacing, porosity) across its surface.
Heterogeneous MPP	A broader category where both perforation and material properties vary.
Folding / Coiling	Cavities designed in folded or coiled geometries to increase effective acoustic path length.
Sub-MPP	A smaller MPP element within a larger composite structure, often used as a unit cell in periodic arrays.
Hybrid MPP	Any MPP system combining two or more strategies (e.g., multilayer + porous).
Sound Absorption Coefficient (SAC)	The ratio of absorbed sound energy to incident sound energy at a given frequency. Values range from 0 to 1.

Data Availability Statement

No new data were generated or analysed in this study. All data supporting this work are available from the published literature cited in the Reference list.

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Compliance with Ethical Standards

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Conflict Of Interest The authors declare that they have no conflict of interest.

References

- [1] M. Zaman, M. Muslim, and A. Jehangir, "Environmental noise-induced cardiovascular, metabolic and mental health disorders: a brief review," *Environ. Sci. Pollut. Res.*, vol. 29, no. 51, pp. 76485–76500, 2022, doi: 10.1007/s11356-022-22351-y.
- [2] D.-Y. Maa, "Microperforated-panel wideband absorbers," *Noise Control Eng. J.*, vol. 29, no. 3, pp. 77–84, 1987, doi: 10.3397/1.2827694.
- [3] D.-Y. Maa, "Potential of microperforated panel absorber," *J. Acoust. Soc. Am.*, vol. 104, no. 5, pp. 2861–2866, 1998, doi: 10.1121/1.423870.
- [4] Y. Zhao, H. Min, and N. Rong, "Random incidence sound absorption of micro-perforated panel absorbers backed with parallel-arranged cavities of different depths," *Appl. Acoust.*, vol. 222, p. 110064, 2024, doi: 10.1016/j.apacoust.2024.110064.
- [5] C. Rui Liu, J. Hui Wu, Z. Yang, and F. Ma, "Ultra-broadband acoustic absorption of a thin microperforated panel metamaterial with multi-order resonance," *Compos. Struct.*, vol. 246, p. 112366, 2020, doi: 10.1016/j.compstruct.2020.112366.
- [6] P. V. Torres-Carrion, C. S. Gonzalez-Gonzalez, S. Aciar, and G. Rodriguez-Morales, "Methodology for systematic literature review applied to engineering and education," in *2018 IEEE Global Engineering Education Conference (EDUCON)*, Tenerife: IEEE, 2018, pp. 1370–1379. doi: 10.1109/EDUCON.2018.8363388.
- [7] R. B. Tayong, "On the Use of Micro-Perforated Panels for Sound Absorption," in *Acoustical Engineering - The Intricate World of Sound Technology*, IntechOpen, 2024. doi: 10.5772/intechopen.1008283.
- [8] P. Cobo, C. De La Colina, E. Roibás-Millán, M. Chimeno, and F. Simón, "A wideband triple-layer microperforated panel sound absorber," *Compos. Struct.*, vol. 226, p. 111226, 2019, doi: 10.1016/j.compstruct.2019.111226.
- [9] M. Khalid, C. Pluempitiwiriawej, S. Wangsiripitak, G. Murtaza, and A. A. Abdulkadhem, "The Applications of Deep Learning in ECG Classification for Disease Diagnosis: A Systematic Review and Meta-Data Analysis," *Eng. J.*, vol. 28, no. 8, pp. 45–77, 2024, doi: 10.4186/ej.2024.28.8.45.
- [10] A. Thongprasert and A. Jiamsanguanwong, "New Product Development Processes for IOT-Enabled

- Home Use Medical Devices: A Systematic Review,” *Eng. J.*, vol. 25, no. 2, pp. 15–48, 2021, doi: 10.4186/ej.2021.25.2.15.
- [11] K. Sakagami, K. Matsutani, and M. Morimoto, “Sound absorption of a double-leaf micro-perforated panel with an air-back cavity and a rigid-back wall: Detailed analysis with a Helmholtz-Kirchhoff integral formulation,” *Appl. Acoust.*, vol. 71, no. 5, pp. 411–417, 2010, doi: 10.1016/j.apacoust.2009.11.014.
- [12] K. Sakagami, T. Nakamori, M. Morimoto, and M. Yairi, “Double-leaf microperforated panel space absorbers: A revised theory and detailed analysis,” *Appl. Acoust.*, vol. 70, no. 5, pp. 703–709, 2009, doi: 10.1016/j.apacoust.2008.09.004.
- [13] K. Sakagami, T. Nakamori, and M. Morimoto, “A theoretical study on triple-leaf microperforated panel absorbers,” *Acoust. Sci. Technol.*, vol. 35, no. 2, pp. 122–124, 2014, doi: 10.1250/ast.35.122.
- [14] J. Wang and G. J. Bennett, “Ultra-broadband sound absorption in a compact multi-chamber micro-perforated panel absorber with varying depths,” *AIP Adv.*, vol. 14, no. 1, 2024, doi: 10.1063/5.0187328.
- [15] X. Yang *et al.*, “Optimal design and experimental validation of sound absorbing multilayer microperforated panel with constraint conditions,” *Appl. Acoust.*, vol. 146, pp. 334–344, 2019, doi: 10.1016/j.apacoust.2018.11.032.
- [16] X. Yang *et al.*, “Optimization of geometric parameters of the standardized multilayer microperforated panel with finite dimension,” *Noise Control Eng. J.*, vol. 67, no. 3, pp. 197–209, 2019, doi: 10.3397/1/376718.
- [17] L. Zhao and T. R. Lin, “A turned double-layer microperforated panel for low frequency sound absorption in enclosures with limited cavity space,” *Appl. Acoust.*, vol. 188, p. 108594, 2022, doi: 10.1016/j.apacoust.2021.108594.
- [18] C. Wang and L. Huang, “On the acoustic properties of parallel arrangement of multiple micro-perforated panel absorbers with different cavity depths,” *J. Acoust. Soc. Am.*, vol. 130, no. 1, pp. 208–218, 2011, doi: 10.1121/1.3596459.
- [19] C. Wang, L. Huang, and Y. Zhang, “Oblique incidence sound absorption of parallel arrangement of multiple micro-perforated panel absorbers in a periodic pattern,” *J. Sound Vib.*, vol. 333, no. 25, pp. 6828–6842, 2014, doi: 10.1016/j.jsv.2014.08.009.
- [20] F. Iman and O. Abdolreza, “Optimisation of multistep cavity configuration to extend absorption bandwidth of micro perforated panel absorber,” *Archives of Acoustics*, vol. 43, no. 2, pp. 187–195, 2018.
- [21] H. Yan, S. Xie, Z. Li, Z. Feng, K. Jing, and F. Zhang, “Enhanced sound absorption performance of stepped-type multi-cavity acoustic absorbers using a hybrid particle swarm algorithm,” *J. Vib. Control*, vol. 30, no. 13–14, pp. 3233–3246, 2023, doi: 10.1177/10775463231192749.
- [22] H. Min and W. Guo, “Sound absorbers with a micro-perforated panel backed by an array of parallel-arranged sub-cavities at different depths,” *Appl. Acoust.*, vol. 149, pp. 123–128, 2019, doi: 10.1016/j.apacoust.2019.01.013.
- [23] Y. J. Qian, J. Zhang, N. Sun, D. Y. Kong, and X. X. Zhang, “Pilot study on wideband sound absorber obtained by adopting a serial-parallel coupling manner,” *Appl. Acoust.*, vol. 124, pp. 48–51, 2017, doi: 10.1016/j.apacoust.2017.03.021.
- [24] A. I. Mosa, A. Putra, R. Ramlan, I. Prasetyo, and A.-A. Esraa, “Theoretical model of absorption coefficient of an inhomogeneous MPP absorber with multi-cavity depths,” *Appl. Acoust.*, vol. 146, pp. 409–419, 2019, doi: 10.1016/j.apacoust.2018.11.002.
- [25] A. I. Mosa, A. Putra, R. Ramlan, and A.-A. Esraa, “Absorption Coefficient of a Double-Layer Inhomogeneous Micro-perforated Panel Backed with Multiple Cavity Depths,” *Acoust. Aust.*, vol. 48, no. 1, 2020, doi: 10.1007/s40857-020-00176-4.
- [26] Faisal Rafique, Jiu Hui Wu, Syed Murawat Abbas Naqvi, and Fuyin Ma, “Enhanced wideband low-frequency sound absorption of a single-layer multiple parallel-arranged inhomogeneous microperforated panel absorber,” *Acoust. Aust.*, vol. 50, no. 1, 2021, doi: 10.1007/s40857-021-00252-3.
- [27] C. Wang, L. Cheng, J. Pan, and G. Yu, “Sound absorption of a micro-perforated panel backed by an irregular-shaped cavity,” *J. Acoust. Soc. Am.*, vol. 127, no. 1, pp. 238–246, 2010, doi: 10.1121/1.3257590.
- [28] W.-H. Tan, M. Afendi, R. Ahmad, R. Daud, M. Shukry, and E. M. Cheng, “Sound absorption analysis on micro-perforated panel sound absorber with multiple size air cavities,” *Int. J. Mech. Mechatron. Eng.*, vol. 15, no. 5, 2015.
- [29] K. Sakagami, Y. Fukutani, M. Yairi, and M. Morimoto, “A theoretical study on the effect of a permeable membrane in the air cavity of a double-leaf microperforated panel space sound absorber,” *Appl. Acoust.*, vol. 79, pp. 104–109, 2014, doi: 10.1016/j.apacoust.2013.12.015.
- [30] W.-Y. Lee and J.-C. Kim, “A Study on Micro-Perforated Panel Absorber with Multi-Layered and Parallel-Arranged Structure to Enhance Sound Absorption Performance,” *Int. J. Precis. Eng. Manuf.*, vol. 20, no. 6, pp. 937–947, 2019, doi: 10.1007/s12541-019-00072-6.
- [31] X.-L. Gai *et al.*, “Sound absorption of microperforated panel with L shape division cavity structure,” *Appl. Acoust.*, vol. 122, pp. 41–50, 2017, doi: 10.1016/j.apacoust.2017.02.004.
- [32] J. Chu *et al.*, “A Multi-Layer Micro-Perforated Panel Structure Based on Curled Space for Broadband Sound Absorption at Low Frequencies,” *Arch. Acoust.*, vol. 48, no. 4, 2023.
- [33] F. Wu, Y. Xiao, D. Yu, H. Zhao, Y. Wang, and J. Wen, “Low-frequency sound absorption of hybrid absorber based on micro-perforated panel and coiled-up channels,” *Appl. Phys. Lett.*, vol. 114, no. 15, p. 151901, 2019, doi: 10.1063/1.5090355.

- [34] F. Rafique, J. H. Wu, C. R. Liu, and F. Ma, "Low-Frequency Sound Absorption of an Inhomogeneous Micro-Perforated Panel with J-Shaped Cavities of Different Depths," *Acoust. Aust.*, vol. 50, no. 2, pp. 203–214, 2022, doi: 10.1007/s40857-021-00261-2.
- [35] S. K. Singh, O. Prakash, and S. Bhattacharya, "Hybrid fractal acoustic metamaterials for low-frequency sound absorber based on cross mixed micro-perforated panel mounted over the fractals structure cavity," *Sci. Rep.*, vol. 12, no. 1, p. 20444, 2022, doi: 10.1038/s41598-022-24621-8.
- [36] X. Yang *et al.*, "Archimedean spiral channel-based acoustic metasurfaces suppressing wide-band low-frequency noise at a deep subwavelength," *Mater. Des.*, vol. 238, p. 112703, 2024, doi: 10.1016/j.matdes.2024.112703.
- [37] F. Rafique, J. Hui Wu, S. M. A. Naqvi, M. Waqas, and C. R. Liu, "Extremely effective broadband low-frequency sound absorption with inhomogeneous micro-perforated panel (iMPP) backed with spider-web designed cavities," *Proc. Inst. Mech. Eng. Part J. Mater. Des. Appl.*, vol. 237, no. 4, 2023, doi: 10.1177/14644207221126810.
- [38] S. Huang, S. Li, X. Wang, and D. Mao, "Micro-perforated absorbers with incompletely partitioned cavities," *Appl. Acoust.*, vol. 126, pp. 114–119, 2017, doi: 10.1016/j.apacoust.2017.05.016.
- [39] W. Liu, D. W. Herrin, and E. Bianchini, "Diffuse Field Sound Absorption of Microperforated Panels with Special Backings," *SAE Int. J. Veh. Dyn. Stab. NVH*, vol. 1, no. 2, 2017, doi: 10.4271/2017-01-1876.
- [40] J. Carbajo, J. Ramis, L. Godinho, and P. Amado-Mendes, "Perforated panel absorbers with micro-perforated partitions," *Appl. Acoust.*, vol. 149, pp. 108–113, 2019, doi: 10.1016/j.apacoust.2019.01.023.
- [41] D. K. Agarwalla and A. R. Mohanty, "Broadband Sound Absorption Technique Using Micro-perforated Panel Absorber with Perforated Extended Panel," *J. Vib. Eng. Technol.*, vol. 12, no. 1, pp. 495–511, 2024, doi: 10.1007/s42417-023-00855-2.
- [42] C. Yang and H. Xu, "Effects of the backing cavity on the acoustic absorption of a microperforated panel absorber," *Appl. Acoust.*, vol. 166, p. 107361, 2020, doi: 10.1016/j.apacoust.2020.107361.
- [43] C. Wang and L. Huang, "On the acoustic properties of parallel arrangement of multiple micro-perforated panel absorbers with different cavity depths," *J. Acoust. Soc. Am.*, vol. 130, no. 1, 2011, doi: 10.1121/1.3596459.
- [44] C. Wang, L. Huang, and Y. Zhang, "Oblique incidence sound absorption of parallel arrangement of multiple micro-perforated panel absorbers in a periodic pattern," *J. Sound Vib.*, vol. 333, no. 25, 2014, doi: 10.1016/j.jsv.2014.08.009.
- [45] Chunqi. Wang, L. Cheng, J. Pan, and G. Yu, "Sound absorption of a micro-perforated panel backed by an irregular-shaped cavity," *J. Acoust. Soc. Am.*, vol. 127, no. 1, 2010, doi: 10.1121/1.3257590.
- [46] X.-L. Gai *et al.*, "Sound absorption of microperforated panel with L shape division cavity structure," *Appl. Acoust.*, vol. 122, pp. 41–50, 2017, doi: 10.1016/j.apacoust.2017.02.004.
- [47] F. Wu, Y. Xiao, D. Yu, H. Zhao, Y. Wang, and J. Wen, "Low-frequency sound absorption of hybrid absorber based on micro-perforated panel and coiled-up channels," *Appl. Phys. Lett.*, vol. 114, no. 15, 2019, doi: 10.1063/1.5090355.
- [48] A. I. Mosa, A. Putra, R. Ramlan, and A.-A. Esraa, "Wideband sound absorption of a double-layer microperforated panel with inhomogeneous perforation," *Appl. Acoust.*, vol. 161, p. 107167, 2020, doi: 10.1016/j.apacoust.2019.107167.
- [49] H. Li, J. Wu, S. Yan, and Q. Mao, "Design and study of broadband sound absorbers with partition based on micro-perforated panel and Helmholtz resonator," *Appl. Acoust.*, vol. 205, p. 109262, 2023, doi: 10.1016/j.apacoust.2023.109262.
- [50] Y. Jiang, C. Shen, H. Meng, W. He, and T. Lu, "Design and optimization of micro-perforated ultralight sandwich structure with N-type hybrid core for broadband sound absorption," *Appl. Acoust.*, vol. 202, p. 109184, 2023, doi: 10.1016/j.apacoust.2022.109184.
- [51] J. Wang and G. J. Bennett, "Ultra-broadband sound absorption in a compact multi-chamber micro-perforated panel absorber with varying depths," *AIP Adv.*, vol. 14, no. 1, 2024, doi: 10.1063/5.0187328.
- [52] T. Herdtle, J. Stuart Bolton, N. N. Kim, J. H. Alexander, and R. W. Gerdes, "Transfer impedance of microperforated materials with tapered holes," *J. Acoust. Soc. Am.*, vol. 134, no. 6, pp. 4752–4762, 2013, doi: 10.1121/1.4824968.
- [53] Y. J. Qian, K. Cui, S. M. Liu, Z. B. Li, D. Y. Kong, and S. M. Sun, "Numerical study of the acoustic properties of micro-perforated panels with tapered hole," *Noise Control Eng. J.*, vol. 62, no. 3, pp. 152–159, 2014, doi: 10.3397/1/376216.
- [54] D. Li, D. Chang, and B. Liu, "Enhancing the low frequency sound absorption of a perforated panel by parallel-arranged extended tubes," *Appl. Acoust.*, vol. 102, pp. 126–132, 2016, doi: 10.1016/j.apacoust.2015.10.001.
- [55] L. Yuvaraj and S. Jeyanthi, "Acoustic performance of countersunk micro-perforated panel in multilayer porous material," *Build. Acoust.*, vol. 27, no. 1, pp. 3–20, 2020, doi: 10.1177/1351010X19886588.
- [56] R. Sailesh, L. Yuvaraj, J. Pitchaimani, M. Doddamani, and L. B. Mailan Chinnapandi, "Acoustic behaviour of 3D printed bio-degradable micro-perforated panels with varying perforation cross-sections," *Appl. Acoust.*, vol. 174, 2021, doi: 10.1016/j.apacoust.2020.107769.
- [57] M. Liu, X. Wang, and F. Xin, "Sound absorption of acoustic resonant absorbers with rough oblique perforations," *Appl. Acoust.*, vol. 217, 2024, doi: 10.1016/j.apacoust.2023.109828.

- [58] Y. J. Qian, D. Y. Kong, S. M. Liu, S. M. Sun, and Z. Zhao, "Investigation on micro-perforated panel absorber with ultra-micro perforations," *Appl. Acoust.*, vol. 74, no. 7, pp. 931–935, 2013, doi: 10.1016/j.apacoust.2013.01.009.
- [59] X.-L. Gai *et al.*, "Developing a microperforated panel with ultra-micro holes by heat shrinkable materials," *Appl. Acoust.*, vol. 152, pp. 47–53, 2019, doi: 10.1016/j.apacoust.2019.03.021.
- [60] M. Zheng, C. Chen, and X. Li, "Ultra-broadband and nonlinear robust sound absorption based on ultra-microperforated panel," *J. Sound Vib.*, vol. 575, p. 118262, 2024, doi: 10.1016/j.jsv.2024.118262.
- [61] S. Huang, S. Li, X. Wang, and D. Mao, "Micro-perforated absorbers with incompletely partitioned cavities," *Appl. Acoust.*, vol. 126, pp. 114–119, 2017, doi: 10.1016/j.apacoust.2017.05.016.
- [62] J. F. Ning, S. W. Ren, and G. P. Zhao, "Acoustic properties of micro-perforated panel absorber having arbitrary cross-sectional perforations," *Appl. Acoust.*, vol. 111, pp. 135–142, 2016, doi: 10.1016/j.apacoust.2016.04.012.
- [63] S. Ren *et al.*, "Tunable acoustic absorbers with periodical micro-perforations having varying pore shapes," *Europhys. Lett.*, vol. 120, no. 4, p. 44001, 2017, doi: 10.1209/0295-5075/120/44001.
- [64] A. Arjunan, A. Baroutaji, and A. Latif, "Acoustic behaviour of 3D printed titanium perforated panels," *Results Eng.*, vol. 11, 2021, doi: 10.1016/j.rineng.2021.100252.
- [65] M. B. S. S. Reddy and R. K. K. Reddy, "Sound absorption characteristics of DL-MPP with non-circular perforations using electro-acoustical model," *Mater. Today Proc.*, vol. 56, pp. 3612–3616, 2022, doi: 10.1016/j.matpr.2021.12.069.
- [66] Y. J. Qian *et al.*, "Optimization of multi-size micro-perforated panel absorbers using multi-population genetic algorithm," *Noise Control Eng. J.*, vol. 62, no. 1, pp. 37–46, 2014, doi: 10.3397/1/376204.
- [67] I. Prasetyo, J. Sarwono, and I. Sihar, "Study on inhomogeneous perforation thick micro-perforated panel sound absorbers," *J. Mech. Eng. Sci.*, vol. 10, no. 3, 2016, doi: 10.15282/jmes.10.3.2016.12.0218.
- [68] M. Kusaka, K. Sakagami, and T. Okuzono, "A Basic Study on the Absorption Properties and Their Prediction of Heterogeneous Micro-Perforated Panels: A Case Study of Micro-Perforated Panels with Heterogeneous Hole Size and Perforation Ratio," *Acoustics*, vol. 3, no. 3, pp. 473–484, 2021, doi: 10.3390/acoustics3030031.
- [69] M. Deacon, G. Cican, L. Cristea, and L. Dragasanu, "Analysis of high porosity micro perforated panel using different methods," *UPB Sci. Bull. Ser. Mech. Eng.*, vol. 80, no. 3, 2018.
- [70] X. Li, Q. Wu, L. Kang, and B. Liu, "Design of Multiple Parallel-Arranged Perforated Panel Absorbers for Low Frequency Sound Absorption," *Materials*, vol. 12, no. 13, 2019, doi: 10.3390/ma12132099.
- [71] L. He, C. Li, Y. Hu, H. Wang, Q. Ran, and H. Wu, "Sound absorption of a thick micro-perforated panel with tapered sections," *Noise Control Eng. J.*, vol. 69, no. 4, pp. 331–340, 2021, doi: 10.3397/1/376930.
- [72] S. W. Ren *et al.*, "Improvement of the sound absorption of flexible micro-perforated panels by local resonances," *Mech. Syst. Signal Process.*, vol. 117, pp. 138–156, 2019, doi: 10.1016/j.ymssp.2018.07.046.
- [73] C. Wang and X. Liu, "Investigation of the acoustic properties of corrugated micro-perforated panel backed by a rigid wall," *Mech. Syst. Signal Process.*, vol. 140, p. 106699, 2020, doi: 10.1016/j.ymssp.2020.106699.
- [74] W. Yang, Y. Choy, and Y. Li, "Acoustical performance of a wavy micro-perforated panel absorber," *Mech. Syst. Signal Process.*, vol. 185, 2023, doi: 10.1016/j.ymssp.2022.109766.
- [75] X. Zhang, J. Wu, Q. Mao, W. Zhou, and Y. Xiong, "Design of a honeycomb-microperforated panel with an adjustable sound absorption frequency," *Appl. Acoust.*, vol. 164, p. 107246, 2020, doi: 10.1016/j.apacoust.2020.107246.
- [76] S. Xie, D. Wang, Z. Feng, and S. Yang, "Sound absorption performance of microperforated honeycomb metasurface panels with a combination of multiple orifice diameters," *Appl. Acoust.*, vol. 158, p. 107046, 2020, doi: 10.1016/j.apacoust.2019.107046.
- [77] H. M. A. Dorra, M. Abd-Elbasseer, A. E. A. Mahmoud, and H. Kh. Mohamed, "Influence of different distribution patterns of holes on single micro-perforated panel sound absorption behaviour," *Can. Acoust. - Acoust. Can.*, vol. 49, no. 2, pp. 11–20, 2021.
- [78] M. Shafeer P.P, J. Pitchaimani, and M. Doddamani, "3D Printed Thick Micro-Perforated Panel with Graded Perforation for Practical Wall Sound Absorption Applications," *Acoust. Aust.*, vol. 52, no. 1, pp. 25–40, 2023, doi: 10.1007/s40857-023-00303-x.
- [79] Y. Qian, Z. Gao, J. Zhang, and Y. Wei, "Investigation on the band narrowing and shifting effects of micro-perforated panel absorbers," *J. Acoust. Soc. Am.*, vol. 155, no. 3, pp. 1950–1968, 2024, doi: 10.1121/10.0025277.



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