Archives of Computational Methods in Engineering (2021) 28:2817–2843
https://doi.org/10.1007/s11831-020-09482-6

ORIGINAL PAPER

A Review Approach for Sound Propagation Prediction of Plate Constructions

M. R. Zarastvand[1] · **M. Ghassabi**[1] · **R. Talebitooti**[1]

Received: 6 January 2020 / Accepted: 20 August 2020 / Published online: 30 August 2020

Abstract

In this contribution, a review study is established in order to gather, classify and organize all of the previous researches on the sound insulation characteristics of plate structures with span a period from 1967 to nowadays. Accordingly, more than 200 articles in the area of acoustic performance of these structures are rolled up and reviewed. To achieve this end, in the first step, all of the existence papers are categorized and classified based on the thematic correspondent. Herewith, not only some appropriate descriptions about the importance of the issue are given but also a series of basic equations and generalities in this field are developed. The paper is then conducted to focus on the various theories in order to present the reliable results according to thickness of structures. In this regard, different theories including classical, shear deformation and three-dimensional are highlighted. To extend the review, a comprehensive explanation is provided with emphasis on the type of materials such as composite, isotropic and functionally graded. It is useful to note that sandwich plate structures with their subdivisions are also set in this group. Consequently, the structures are organized according to their boundary conditions. Besides, the importance of type of incident field is inspected, too. Subsequently, in order to remark the methods employed by the researchers, the works are reviewed based on their solution techniques. Before concluding remarks, the remained papers are classified on the basis of various procedures such as optimization and control of sound transmission through plate structures.

1 Introduction

Unlike the curved shell structures which include one radius (cylindrical shell [1, 2]) or both radii (doubly curved shell [3–6]); plate structures can be known as shells wherein there is no effect of radii of curvature. Then, it can be deduced that all of plate structures are flat. Meanwhile, if little curvature exists, the plate structures can be referred to curved panels or shallow shells. In comparison with curved shells, these structures usually suffer from low stiffness (not to have radii of curvature) particularly at low frequency domain, in which the stiffness of structure has a key role. By increasing awareness from this subject, many authors have modeled their constructions based on the plate geometry due to various technical applications in aerospace design. Unlike the previous publication of the authors [7] wherein a review study was developed through acoustic performance of the various kinds of shell constructions, in this approach, a new review article is proposed to focus only on the noise insulation property of plate structures.

1.1 Generalities for Sound Transmission Loss of the Plate Structures

Sound transmission loss (STL) coefficient is investigated as an important parameter in the inspection of acoustic insulation characteristic of the plate structures. This coefficient is defined as the plate structure is vibrated by an acoustic wave. In fact, the noise and vibration is created due to wave propagation and interaction of sound wave through these structures. Then, when they are exposed in contact to mean flow, the manufacture of some unpleasant disturbances is inevitable. Typically, in modeling of the plate structures used in aerospace design, it is essential

✉ R. Talebitooti
rtalebi@iust.ac.ir

M. R. Zarastvand
m_zarastvand93@alumni.iust.ac.ir

M. Ghassabi
masood_ghassabi@mecheng.iust.ac.ir

[1] Noise and Vibration Control Research Laboratory, School of Mechanical Engineering, Iran University of Science and Technology, Tehran, Iran

that these structures to be acoustically analyzed in order to reduce the amount of transmitted noise into the cabin. In fact, these turbulences not only make annoyance to the passengers and crew but also cause the structural fatigue. Herewith, STL coefficient should be inspected for these structures before the flight. Nevertheless, as illustrated in Fig. 1, due to the collision of an acoustic wave, a part of sound wave is transmitted and remain one is reflected from the plate structure as below:

$$STL = 10\log\frac{1}{\tau} = 10\log\frac{W_i}{W_t} = 10\log\left(\frac{\left|P_i\right|^2}{\left|P_t\right|^2}\right) \tag{1}$$

In Eq. (1), τ presents the noise transmission coefficient. Besides, W_i and W_t denote the incident and transmitted sound powers by considering the following correspondent acoustic pressures $\left(P_i \text{ and } P_t\right)$ as:

$$\begin{aligned} P_i(x,y,z,t) &= P_0^I e^{i\left(\omega t - k_{1x}x - k_{1y}y - k_{1z}z\right)} \\ P_t(x,y,z,t) &= P_0^T e^{i\left(\omega t - k_{2x}x - k_{2y}y - k_{2z}z\right)} \end{aligned} \tag{2}$$

As depicted in Fig. 1, some of the incident waves are reflected in the following form:

$$P_R(x,y,z,t) = P_0^R e^{i\left(\omega t - k_{1x}x - k_{1y}y - k_{1z}z\right)} \tag{3}$$

In Eqs. (2) and (3), ω represents the angular frequency. Moreover, the following equations are investigated as the wavenumbers in three directions $\left(k_{1i(i=x,y,z)}\right)$ as a function of the wave number of incident wave $\left(k_1 = \frac{\omega}{c_1}\left(\frac{1}{1+M\sin(\gamma)}\right)\right)$ as below:

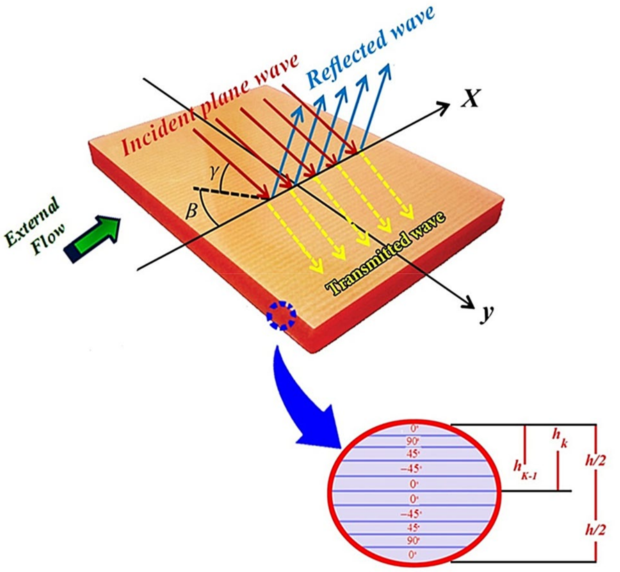

Fig. 1 Schematic of wave propagation through a laminated composite plate under excitation of an acoustic sound wave with two independent angles of γ and β [8]

$$k_{1x} = k_1 cos\gamma cos\beta, \quad k_{1y} = k_1 cos\gamma sin\beta, \quad k_{1z} = k_1 sin\gamma \tag{4}$$

Additionally, the below equations in the transmitted side are considered:

$$k_2 = \frac{\omega}{c_2}, \quad k_{2x} = k_{1x}, \quad k_{2y} = k_{1y}, \quad k_{2z} = \sqrt{k_2^2 - \left(k_{2x}^2 + k_{2y}^2\right)} \tag{5}$$

In above equations, M demonstrates the Mach number of external flow and $c_{i(i=1,2)}$ shows the sound speed in both sides. Note that although P_0^I has the specific value and it is considered as input acoustic amplitude of the incident wave, the two transmitted and reflected acoustic pressures involving P_0^T and P_0^R are investigated as the unknown constants which should be determined by solving the vibroacoustic problem. Herein, it is useful to note that since this review paper focuses on the transmitted noise into the plate structures, then the research works will be only reviewed wherein the acoustic solution procedure is followed in order to obtain the amount of transmitted pressure $\left(P_0^T\right)$. Meanwhile, the review of researches wherein the amount of reflected sound is of concern, is related to those papers under title of "scattering'' which is not set in order in this study. Subsequently, the below equations should be satisfied for relating between fluid particle and plate surface as:

$$\begin{aligned} \frac{\partial\left(P_i + P_R\right)}{\partial z} &= -\rho_1\left(\frac{\partial}{\partial t} + V\cdot\nabla\right)^2 W \\ \frac{\partial P_t}{\partial z} &= -\rho_2\frac{\partial^2 W}{\partial t^2} \end{aligned} \tag{6}$$

In Eq. (6), ∇ and V illustrate the gradient operator and velocity of the fluid. Furthermore, $\rho_{i(i=1,2)}$ presents the density of the incident and transmitted sides, respectively. Besides, the transverse displacement of an infinite plate is considered to be developed in the following harmonic form:

$$W = w_0 exp\left(j\left(\omega t - k_{1x}x - k_{1y}y\right)\right) \tag{7}$$

1.2 The Well-Known Dip Point of Plate Structures

As depicted in Figs. 2 and 3, a plate structure made of functionally graded (FG) materials is excited by an acoustic sound wave. In this configuration, h denotes the thickness of structure, $P_t$andP_b show the material characteristics at the top and bottom surfaces of structure as:

$$P(z) = P_b + \left(P_t - P_b\right)V(z) \tag{8}$$

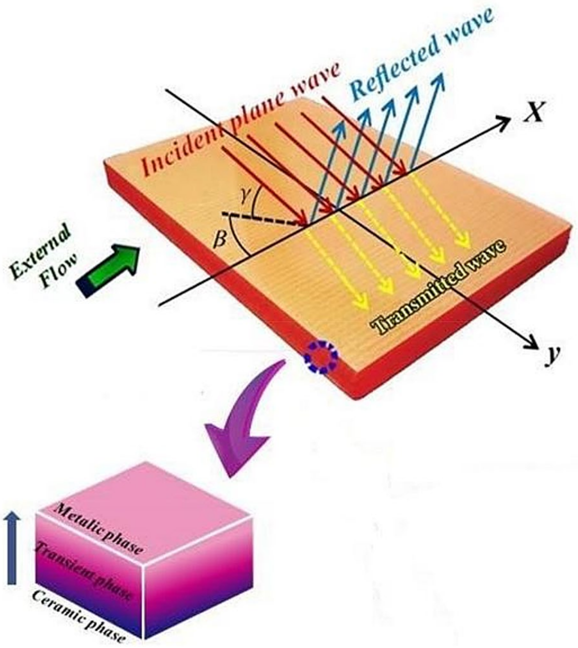

Fig. 2 Sound propagation through a FG plate structure in the mean flow [9]

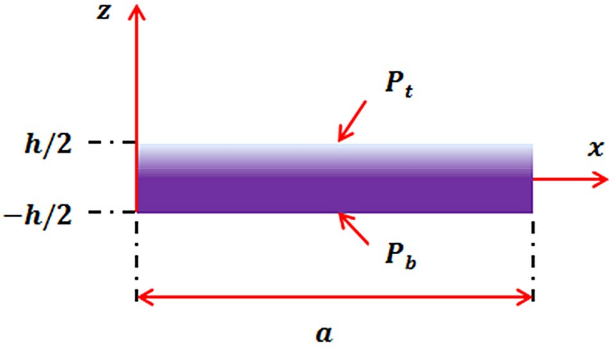

Fig. 3 Configuration of a plate made of FG materials [9]

In Eq. (8), $V(z) = (z/h + 1/2)^N$, in which $-h/2 \le z \le h/2$. It is noteworthy that in above equation, N shows the power-law exponent in the interval $[0, \infty]$, $P(z)$ is considered as one of characteristics of these materials (FG) containing Poisson's ratio, Young modulus and density which are continuously varied through thickness coordinate corresponding to power-law component. Since an acoustic wave is propagated on the FG plates, therefore, the STL curve related to these structures is presented and discussed in Fig. 4.

In Fig. 4, the vibroacoustic characteristic of a FG plate structure against the various azimuthal angles (β) is plotted. Also, the location of dip point nominated as coincidence frequency is demonstrated. This frequency (f_{coin}) is defined as the wavelength of an acoustic wave is equated with the wavelength of the forced bending wave of the plate structure as below [10]:

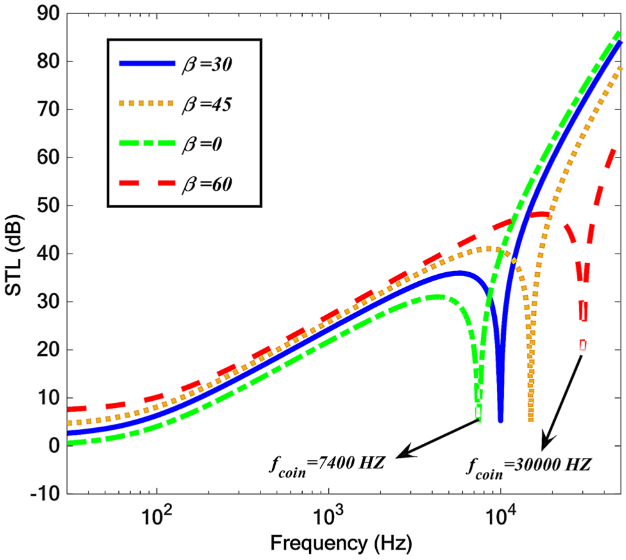

Fig. 4 STL curves for a plate made of FG materials with respect to various azimuthal angles β [9]

$$f_{coin} = \frac{c^2}{2\pi h \cos^2 \gamma} \sqrt{\frac{12\rho\left(1 - \nu^2\right)}{E}} \tag{9}$$

In Eq. (9), ρ, ν, and E respectively represent the density, Poisson's ratio and modulus of elasticity.

Unlike the curved shell structures involving cylindrical and doubly curved shells, wherein there are some dip points that splitting the STL curve into some domains, as depicted in Figs. 5 and 6, plate structures only include one dip point so that it separates the STL curve into the two regions, only. The first one which is located at low frequency domain is nominated as stiffness-control region, in which the stiffness of structure plays an important role whereas the second one is positioned at high frequency zone known as coincidence-control domain. It is noteworthy that although the both plate and doubly curved structures have the same definitions to introduce the coincidence frequency, curvature frequency is only related to the doubly curved shells which contain both radii of curvatures.

1.3 A Brief Look to the Organized Themes

The main goal of this study is to collect, classify and summarize all of the applicable researches carried out in the field of wave propagation on the plate structures. The present work is constructed as follows. Firstly, with giving some descriptions about the generalities and the basic main

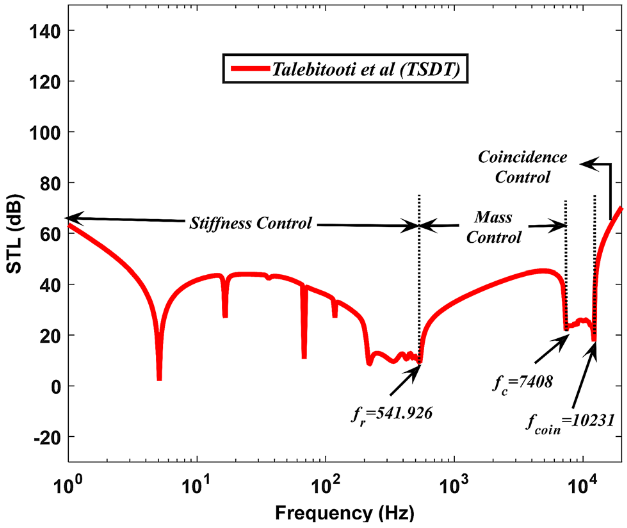

Fig. 5 STL curve of a cylindrical shell along with its regions and dip points [11]

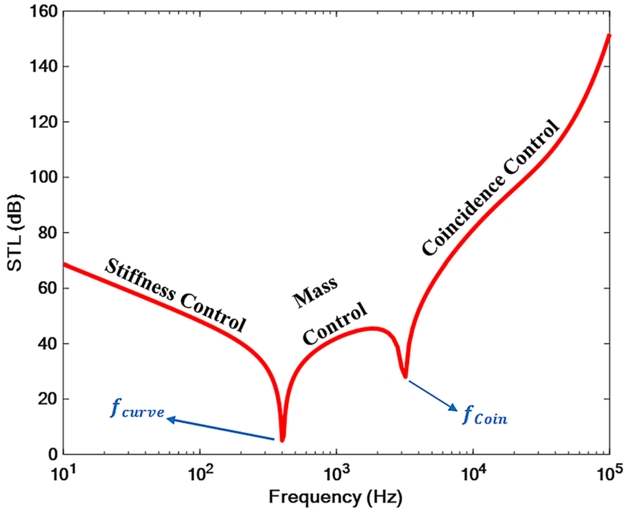

Fig. 6 STL curve of a doubly curved shell along with its regions and dip points [12, 13]

acoustic parameters related to wave propagation through plate structures, the importance of considering an appropriate theory corresponding with geometry and thickness of the plate is remarked. In this regard, some prevalent theories are discussed based on this issue that although for analyzing the thin structures when the effects of shear and deformation are neglected the classical plate theory is applicable; by thickening the plate, the usage of other theories including the three-dimensional theory along with the higher and first order shear deformation theories is remarked. The review is then developed to focus on the material characteristics to clarify the importance of some kinds of materials. Herewith, composite, isotropic and FG materials are classified in this group. Among them, sandwich plate structures with their subdivisions containing stiffener, porous, meta-material and smart ones should be considered.

In the following, the geometrical properties of these structures in two states as finite and infinite are described. In this study, the plate structures are also reviewed in various acoustic environments involving fluid, thermal and cavity. Since the type of incident field impinges upon the structure can be important, therefore, not only the works are classified based on the plane wave incidence with its subdivisions containing random incident and diffuse acoustic field but also those researches performed using the point source are studied. Subsequently, the importance of numbering the solution methods including analytical, experimental and numerical is remarked. In fact, these solution techniques are convinced the authors to offer their outcomes based on the laboratory tests and then compare them with those of analytical and numerical ones. Before presenting the concluding remarks, the review is developed based on the other aspects containing acoustic control [14, 15] and optimization approach [16, 17] in order to highlight the works, wherein not only the sound insulation property of structure is controlled but also the vibroacoustic behavior of structure is improved.

2 Theory

In order to study the STL problems, it is common to consider an appropriate theory corresponding to geometry and characteristic of structure to analyze the amount of transmitted noise into the structure. In fact, the degree of accuracy and reliability of the results depends on the theory based on the thickness of the structure. Herewith, it can be deduced that this parameter is recognized as a key factor in this issue that should be identified. Nonetheless, although the most of the theories model the wave propagation on the structures in 2D state, three-dimensional elasticity theory is considered as particular one which presents the three-dimensional model of stress distribution.

2.1 Three-Dimensional Theory

It is essential to note that in each plate structure when its thickness is smaller than (1/10)th of the smallest of the wavelengths, it is nominated as thick construction. To inspect the sound insulation characteristic of a thick plate, higher order shear deformation theory (HSDT) and three-dimensional elasticity theory (3D) are employed. Although HSDT solves the STL problem in 2D state, 3D theory presents the three-dimensional model of stress and strain distributions by considering further effect of transverse strain in its equations. In this theory (3D) not only the displacements are extended in three-dimensional state but also the vibroacoustic problems are solved in three-dimensional direction. Therefore, it can present very reliable and accurate outcomes particularly at high frequency domain. Yang et al. [18] proposed a computation technique based on the state space solution to model the noise radiation from a FG plate by considering 3D theory. The FG structure was composed of metal and ceramic and its material specification was supposed to have smooth and continues variation in the thickness direction. Besides, some parametric studies were provided to inspect the noise radiation characteristic of FG structures. 3D theory was also used by Remillieux et al. [19] to model an elastic structure in the time domain according to the two numerical tools. Herewith, the image source technique along with an extension of the Biot–Tolstoy–Medwin method was used for the reflected and diffracted fields to compute the exterior sound propagation. Moreover, a truncated modal decomposition approach was employed to compute the fully coupled acoustic response of an interior fluid–structure system. The offered model has the advantage that can be used in the case of light exterior and arbitrary interior fluids.

2.2 Two Dimensional Theory

2.2.1 Classical Thin Plate Theory

Similar to those defined for shell structures, a plate is considered as a thin structure when its thickness is less than 1/20 of the wavelength of the deformation mode. Additionally, it is thin enough such that the ratio of the thickness to any of the plate's width or length is insignificant. According to the Kirchhoff's hypothesis, in these structures during the deformation, the normal to the middle surface stays straight and normal to the surface. Unlike the thin shell structures which are modeled by variety of theories, thin plates have only one theory known as classical plate theory (CPT), wherein the effects of shear and rotation are ignored in their kinematic equations. Bhattachary et al. [20] used CPT to describe the coincidence frequencies in a finite plate backed by a cavity. In this approach, also a short review of the other researches was presented to investigate the coincidence frequencies for infinite and finite plates. The results demonstrated that it was theoretically impossible to imagine the coincidence transmission in a finite plate by the condition of matching between flexural and acoustic waves unless the structure is backed by a cavity. In other researches worked by Craven and Gibbs [21, 22], the STL and the coupling mode at junctions of the thin plates were determined. Accordingly, in the first work [21], the CPT was applied to model the sound wave produced at a junction of a plate due to an acoustic wave incidence through any one of the structure. To prove the accuracy of the outcomes, the results were compared with those of previous literature for the case of bending wave at a cross junction and at a corner. Furthermore, an explanation was presented to involve the in-plane vibration incident at the same junctions. Subsequently, in another study [22], the parametric studies were discussed. The results showed that STL of the structure was more affected by varying bending rigidity and density rather than changing the other parameters involving thickness and loss factor of the plate. Clark and Frampton [23] presented the influence of external flow through an elastic plate via a full potential flow and a random pressure field considering CPT. For this purpose, they modeled their structure according to the convected fluid load. CPT was also applied by Lee and Ih [24] to study STL of the finite single partitions by considering some factors containing size, thickness and loss factor. In fact, by the aid of these factors, they could valid the range of ignoring the resonant sound transmission. To confirm the accuracy of their results, they investigated the differences between total and non-resonant sound transmission losses. Putra and Ismail [25] determined STL of a perforated panel using CPT. In their investigation, they also examined the influence of the hole diameter through acoustic characteristic of the structure. The dimension size of the hole diameters was investigated to be micro (submillimeter) and macro (millimeter). It was showed that STL was decreased as the perforation ratio was enhanced. Meanwhile, by keeping this ratio, the STL is increased as the hole diameter is decreased. Wójcik and Gambin [26] used the nonlinear equations of acoustic wave motion in a non-classical viscous medium to focus on the theoretical and numerical aspects of nonlinear reflection and transmission phenomena. They offered their numerical calculations for a simplified and one-dimensional wave traveling in an inviscid medium. As a result, the finite difference time domain procedure was applied to prove the accuracy of the theoretical prediction compared to numerical calculation. Xin et al. [27] proposed a theoretical model on the thermoacoustic response of a finite plate subjected to thermal and acoustic excitation effects investigating two types of thermal environments along with CPT. Firstly, the thermoacoustic equations were derived by synthesizing the thermal moments, membrane forces and acoustic loads into structural vibration equation and then solved by employing the modal decomposition technique. Moreover, a solution procedure was provided to solve the Fourier heat conduction equation for the graded temperature distribution in the structure. In this regard, the velocity continuity condition at the Fluid–plate interface was satisfied. Mana and Sonti [28] employed CPT to analyze the acoustic behavior of a fluid loaded finite perforated panel. The transmitted pressure because of an incident plane wave was achieved according to the fully coupled formulation in the two-dimensional wavenumber domain. It was shown that the absolute perforate impedance ascended at low frequencies by enhancing the resistive components of the hole impedance. In another study, a new plate-type acoustic metamaterial (AM) was designed by Wang et al. [29] with a high STL in the low frequency domain. They modeled a thin plate with large modulus based on the finite element (FE) method. In addition, an experiment was developed to inspect the influence of various structural parameters of plate. Finally, it was found that the considered AM could improve the behavior of STL in this frequency domain.

2.2.2 First Order Shear Deformation Theory (FSDT)

Although CPT is able to model the wave propagation through a thin plate and present the reliable outcomes at low frequencies, it shows the STL of the structure more than its real state particularly at high frequencies which leads to obtain inaccurate results. In this situation, it is needed to investigate first order shear deformation theory (FSDT) in order to apply the effects of shear deformation and rotary inertia in its equations for the special case of relatively thick plates. Yoon et al. [30] considered FSDT along with PVDF actuator to reduce the acoustic transmission of an elastic plate. The dynamic response of a composite plate and the sound fields on the plate were analyzed by considering the coupled FE and boundary element (BE) procedures. They also provided some numerical simulations across STL of an elastic structure. Renji [31] analyzed the acoustic behavior of the unbounded panels in bending vibration based on the transverse shear deformation according to the FSDT. In this work, the positive effect of loss factor on the STL was revealed so that by increasing this parameter, acoustic behavior was improved. It was also demonstrated that when the structure was under excitation of a diffuse field incidence, the loss factor was efficient even at higher frequencies. FSDT was also investigated in another research work [32] to study the sound insulation characteristic of an infinite stiffened plate. The structure was made of metallic or composite materials and it was excited by point excitation force under fluid loading. The generalized vibroacoustic equations of the model were developed via the periodic structure theory and the equivalent flexibility of the plate. In this research, the influences of location of the excitation and the spacing of the stiffeners were discussed, too. Xin [33] considered the two-dimensional plain strain elasticity theory to propagate an acoustic wave on the rib-stiffened plates surrounded by decoupling acoustic coating layers. To analyze the wave propagation in a solid medium, the Navier–Cauchy equations of the elastic plate and coating layer were taken into account. Furthermore, the procedure was followed by considering that the decoupling acoustic coating layer to be completely bonded to the rib-stiffened panel. As a result, the effects of various parameters involving coating layer thickness, periodical space of rib-stiffener and plate thickness were inspected.

2.2.3 Higher Order Shear Deformation Theory (HSDT)

As completely explained, in order to analyze the STL of a thick plate, higher order shear deformation theory (HSDT) is taken into account. Third order shear deformation theory (TSDT) is considered as one of drives of HSDT wherein although the displacements are developed in term of three order of thickness coordinate, no stretching is supposed in the z direction. Herewith, Chronopoulos et al. [34] employed this theory along with a wave FE approach to analyze the sound insulation property of a thick panel. A polynomial eigenvalue problem was formed by retouching the mass and stiffness matrices of the structure. They also used static energy analysis (SEA) to calculate the diffuse field power transmission of a panel. Finally, some results on the basis of the influence of the symmetric and the antisymmetric vibrational motion through STL of the structure were revealed. In this regard, Talebitooti et al. [8, 9] in two different approaches analyzed the acoustic behavior of the plate structures considering various derives of HSDT. In the first one [8], Two-variable Refined Plate Theory (RPT2) was considered to obtain the acoustic transmission of a plate in the subsonic flow. For this purpose, the lateral displacements were developed to three parts containing shear, bending and extension term without investigating any effect of shear coefficient factor. In another work [9], the hyperbolic shear deformation theory was employed to inspect the sound insulation specification of a FG thick plate. In their investigation, they extended the displacements of the problem as a combination of polynomial and hyperbolic tangent function without considering any effect of thickness stretching.

3 Material

In the inspection of vibroacoustic behavior of each structure, type of its material can be very impressive in decreasing the amount of transmitted sound through construction. Herewith, type of material is praised as a key parameter in this issue. Since in each STL problem the main aim is devoted to reduce the acoustic transmission through structure, it is impossible in some cases to achieve this end by varying other parameters in the geometry of structure. In this situation, by creating some changes in the material, STL of the structure is enhanced. Based on this issue, this section is classified to focus on this subject.

3.1 Composite Material

Composite materials are often applied in designing the aerospace structures because of the advantages offered by a high strength to weight ratio. These materials usually are constructed in two forms including laminate and orthotropic.

Although in the laminated structure a designer can reduce the amount of transmitted noise through structure by changing the stacking sequences, this issue is impossible when a composite structure is organized in the form of orthotropic. Herewith, in the following, the acoustic characteristic of the composite plates is set in order. Thomas et al. [35] actively controlled STL of a composite plate. A general formulation was proposed to model the vibration of the structure. Besides, the boundary conditions were considered as rotational and translational elastic limitations at the boundaries. To develop the equation of motion, the Rayleigh–Ritz procedure was used. In fact, they modeled a rigid panel and an elastic plate respectively with free and clamped edges. The results indicated that there was a single set of intricate secondary force strengths for a primary pressure field which minimized the radiated sound power. Pierre Jr et al. [36] also presented a procedure to minimize the transmitted wave through an array of composite panel. In their investigation, they employed an integrated control loudspeaker to minimize the volume velocity of the individual sections of array. It was shown at low frequencies; the applied methodology obtains the global sound power diminutions in the far-field. They also considered a digital controller to verify the STL, experimentally. In practical applications, the results of this paper can be used to control the broad band and low frequency transmitted sound to blockade spaces containing airplane or helicopter cabin. Kim and Song [37] used piezoelectric sensors and actuators to control the noise fields generated by vibrating a composite structure in flow. The FE and BE procedures were employed to analyze the dynamic behavior of a plate structure. On the basis of their outcomes, it was depicted that the global sound reduction could be explained via this technique. Since by expanding the countries, the importance of using the ferrocement panels is increased in different low cost housing construction, Kandaswamy and Ramachandraiah [38] conducted their attention through acoustic transmission of the cavity ferrocement composite panels containing double triangle ties. Ni et al. [39] proposed an innovative insulation sheet material with carbon and/or glass fabrics and Nano-silica hybrid PU resin. For this purpose, various sound performance parameters were applied. The outcomes indicated that these sheet materials were able to enhance the amount of STL more than 10 (dB) even though the structure thickness was only about 0.7 (mm). Furthermore, it was found that the influence of sound proof performance was various because of the variation of hybrid technique as well as size of silica particles. In addition, it was also proved that the time-domain finite wave analysis was impressive in designing of these materials. Kim and Kim [40] offered a procedure to control the transmitted sound within the aircraft trim composite panel employing a hybrid feed-forward/feed-back control method. Furthermore, a control technique was designed to minimize the deflection of structure. Experimental outcomes confirmed that by applying a hybrid controller, the vibroacoustic behavior of structure was improved. Lee and Kim [41] inspected the influences of structure through sound absorption and STL of a composite sheet. In order to consider the structural parameters, two various structures were provided employing flat and sine-wave sheets. The results indicated that the STL of a composite sheet was sensitive to variation of the surface density of polypropylene (pp) board. Park et al. [42] analyzed the acoustic behavior of a composite floating floor to obtain the factors that affect acoustic power transmission at low frequencies considering FE vibration model. The outcomes revealed that, in addition to isolation of the impact energy above the system's natural frequency, the aspect of coupled and decoupled waves of the structure affect the impact wave transmission. Zhang et al. [43] considered composite gratings because of their acoustic transmission characteristics induced by phase resonances by considering some rectangular and triangular notches in each periodic unit. The triangular notch demonstrated specific specifications in producing increased phase resonance and in holding acoustic transmission. The results of this paper can be applied in designing of acoustic filters to decrease the amount of transmitted sound. Kaijun et al. [44] inspected the sound insulation characteristic of a thin composite plate equipped with piezoelectric patches. These patches were bonded on the surfaces of the structure in a serialized style and interconnected by an analogical circuit network. They nominated the piezoelectric system as piezo-electromechanical (PEM) plate. In order to analyze the dynamic equations of a PEM plate, the Homogenization methods were considered. The results confirmed that at specified condition, the coincidence frequency of the structure was disappeared. In fact, they investigated this process to improve the behavior of STL. In this regard, Bhingare et al. [45] proposed a review paper to remark characteristics of the natural fibers and recyclable material composite as acoustic material. In their consideration, they showed the factors that affected acoustic efficiency. Following the last researches, now the focus is especially placed on the acoustic behavior of the orthotropic plates. Bosmans et al. [46] considered two models containing the finite and infinite composite structures to present wave transmission between composite plates connected by a rigid junction. In this work, also the outcomes for a junction of orthotropic plates were compared with those of equivalent isotropic ones. Tolokonnikov [47] focused on the reflection and transmission of an acoustic wave through an orthotropic plane inhomogeneous elastic layer. To reduce the ordinarily differential equations into the problem with initial conditions, the boundary-value problem was investigated. He also presented a numerical calculation to obtain the absorption coefficient. Lee and Kim [48] studied acoustic transmission of an orthotropic thin plate stiffened by equally spaced line stiffeners. Herewith, the structural and acoustic responses in terms of the space harmonic were developed to determine the vibroacoustic response of dynamic equations. Since the procedure fully modeled the structural and acoustic–structural coupling, an exact solution was provided based on the series solution. Christen et al. [49] considered the global sensitivity analysis (GSA) to inspect the noise transmission through the orthotropic plate structures. Accordingly, a method for GSA of acoustic transmission was offered to design parameters. Since one of the most promising classes of GSA technique was the analysis of variance, in the first step a metamodel of the system was built. Consequently, this metamodel was employed to provide a GSA along with the Fourier Amplitude Sensitivity Test (FAST) procedure. Wareing et al. [50] proposed a method to predict the vibroacoustic behavior of an orthotropic finite panel. This technique considered as an equation for the forced radiation impedance of structure. In order to perform an experimental test, plywood was employed. The results indicated that the Young's modulus of the plywood was dependent on the frequency of excitation. Besides, the effect of the frequency dependent Young's modulus was also inspected. Reynders et al. [51] studied the STL of an orthotropic finite rib-stiffened plate. In their consideration, they also found a physical description for the experimental observation on the basis that the narrow-band STL may fluctuate with frequency in the mid-frequency domain. For this purpose, the FE model of structure with different levels of detail were created and coupled to a reverberant model of the adjoining rooms by the hybrid of FE and SEA techniques. Zhang et al. [52] inspected the sound insulation characteristic of a thin composite structure resting on varying elastic Winkler and Pasternak foundations. They presented the admissible functions of an orthotropic plate and cavity according to the Fourier series method along with the CPT. Rayleigh–Ritz method was investigated to achieve all of the unknown series coefficients. In this work, not only the influences of different elastic foundations through structure were inspected but also some new discoveries were offered on the basis of varying orthotropic degree, boundary constraint and acoustic media.

3.2 Functionally Graded (FG) Material

In material science, a FG material is a new type of inhomogeneous materials whose compound is designed to alter continuously within the solid. These materials are well-known due to their resistance in high temperature environment. The implication is to construct a composite material by modifying the microstructure from one to another using particular gradient. In fact, this enables the material to have appropriate characteristics of both materials. In this regard, Chandra et al. [53] modeled the wave propagation through a FG plate. Subsequently, this work was extended in another work [54] on the simply supported FG plates by considering the simplified FSDT. The procedure was followed based on the Mori–Tanaka homogenization technique along with the far field sound radiation according to the Raleigh integral. George et al. [55] employed a combination of FE and Rayleigh integral to study the STL of the functionally graded carbon nanotube (FG-CNT) reinforced nanocomposite plates. The results indicated that although the natural frequencies were remarkably affected by the nature of functional grading, the mode shapes remain unchanged. It was illustrated that the vibroacoustic response of structure was considerably affected by the nature of various functional grading.

3.3 Sandwich Structure

During the last years, the importance of using double-walled structures has been increased because of their sound insulation specifications. Sandwich plates are considered as one of derives of them which are well-known due to their superior sound performance in comparison with single plate in decreasing the amount of transmitted noise into structure. These structures are usually modeled by entering a further layer of porous and smart materials as well as stiffeners and metamaterials as an intermediate layer. Hence, in the following, the review is focused on the research papers related to the vibroacoustic behavior of sandwich plates.

3.3.1 Stiffener

Generally, in STL problem, the reduction of noise transmission at low frequencies is of particular importance particularly in engineering science. Since the stiffness of structure is recognized as a key parameter in this range of frequency, by modeling the plate structures with further layer of stiffener, this end is implemented. Herewith, Elmallawany [56] considered SEA to analyze the acoustic characteristics of the single and double partitions. In this work, the STL of the ribbed panels which are extensively used in superficial structure of ships was determined. In another work [57], the dynamic vibration absorber was used to improve the STL of a panel integrated with stiffener. Since an experiment was performed, an admissible agreement with those of prediction one was observed. Ng and Zheng [58] inspected the acoustic characteristic of the double leaf corrugated panel structures. They determined the STL coefficient of some single and double leaf corrugated structures based on the laboratory experiments to propose the important effects on the acoustic performance of the constructions. Yuan et al. [59] considered a hybrid control procedure to active control the transmitted noise into the stiffened panel. In addition, in order to simulate aircraft fuselage and cabin system, a stiffened panel was modeled installed on the metallic box. To provide an acoustic excitation, a loudspeaker set outside of the box was investigated. Consequently, a hybrid control technique was proposed using a combination of feedback and feedforward controls. In their consideration, they inspected the efficiency of their hybrid control method on the amount of sound pressure level (SPL) below the first resonance frequency and the acoustic transmission in entire range of frequency. In this regard, another study was presented by Xin and Lu [60] to analyze the noise radiation of the stiffened plates under convected harmonic pressure excitation. Zheng and Wei [61] also obtained the STL of a stiffened thin plate with nonuniform discrete edge restrains based on the energy approach. The Rayleigh–Ritz convergence criteria and the edge boundary conditions were employed to discretize the equations. In their work, some numerical approaches were provided and outcomes were discussed in detail to analyze the sound insulation of structure with various edge elastic restrains. Jin et al. [62] presented a theoretical approach to obtain STL of an infinite lightweight panel subjected to equally spaced stiffeners. Fourier Transform technique was considered to obtain the vibroacoustic equation of structure and then the influence of varying different parameters containing the plate thickness and the stiffener spacing was inspected. In another research work [63], the sound insulation characteristic of a stiffened window was searched based on the FE and BE methods. The procedure was followed by considering that the window had optional elastic boundary conditions and the stiffeners had located at ideal positions inside the window. Accordingly, it is confirmed that when the aim is to improve the STL, the stiffeners are able to enhance sound insulation. Zhou et al. [64] studied the acoustic performance and the sound absorption property of the two types of periodically stiffened micro-perforated panels (MPP). They developed a semi-analytical model of the vibrating stiffened plates according to the fundamental acoustic formulas. To consider both types of the stiffened plates, the FE and Fourier transforms techniques were taken into account. They also inspected the influence of various parameters involving perforation ratio and periodical distance. Moreover, it was illustrated that although the flexural vibration of the structure had a remarkable influence through sound absorption in the water, a little effect in the air can be seen. Subsequently, Chen et al. [65] proposed an acoustic metamaterial adopting side structures, loops and labyrinths, arranged along a main tube. In the following, Ou et al. [66] considered a combination of FE and BE procedures to analyze the STL of a stiffened building structure. Accordingly, the influences of boundary condition and stiffener for an effectual computation of a plate structure were studied based on the arbitrary boundary conditions as well as arbitrary located stiffeners. Furthermore, an experimental validation was provided for a stiffened plate system. Finally, the parametric studies were examined to show the influence of stiffener through STL of the structure.

3.3.2 Porous Material

Although the stiffeners are able to decrease the amount of transmitted sound into the plate structures at low frequency domain, the positive performance of the porous material is only remarked at high frequency domain, wherein the wavelength are short enough. Besides, there are other factors containing great sound absorption capability, light weight and low cost that they increase the importance of employing these materials. By increasing awareness of this issue, Ford et al. [67] inspected the effect of absorbent linings through acoustic property of double-leaf partitions. In their investigation, they improved the noise performance of structure at least 7 (dB). Cumming [68] extended his pervious publication on the acoustic analysis of the walls of rectangular ducts to inspect the effect of external layer of porous material. For this purpose, a simple theoretical model was designed to present the accurate results in comparison with measurements. As a result, it was demonstrated that the employed technique was not efficient on the improvement of STL. In this regard, another work [69] was presented wherein the acoustic behavior of a porous disk was described. Hasheminejad and Avazmohammadi [70] offered a theoretical model to suggest the interaction of a plane compressional sound wave with a cluster of two fluid-saturated porous elastic cylinders submerged in a boundless acoustic medium. Dupont et al. [71] examined the acoustic specifications of materials with complex micro-geometry involving partially open or dead-end (DE) porosity. Firstly, a simple model was proposed on the basis of considering two acoustic transfer matrices including one for non-symmetric and one for symmetric dead-end porous elements. Secondly, some simplified samples were presented and tested with a three-microphone impedance tube in order to validate the model. Following the last works, Hung et al. [72] employed a combination of 70% metakaolin as well as 30% blast furnace slag powders to generate the inorganic polymeric foams (IPF) with different densities and thicknesses. To assess the influences of density and thickness, the above parameters containing STL, sound absorption coefficient and water absorption for the specimens were measured. The outcomes demonstrated that the alternation of water absorption versus to density was the same as the noise reduction coefficient. Moreover, STL of the sandwich structures with various thicknesses and densities was measured. In their investigation, they also evaluated the possibility of employing inorganic polymeric foam. Huq et al. [73] also determined the STL of a polyvinyl acetate polymer combined with various porous carbons. It was found that the porous carbon plays an important role in assigning the soundproof efficiency of polyvinyl acetate based coating. In another study, Fang et al. [74] inspected the acoustic behavior of a metasurface fabricated by porous materials in some procedures containing analytical, numerical and experimental. The structure was composed of four elements with varying characteristics, which was aligned in a periodic manner. The results of this paper proved that the propagation directions and the number of refracted waves were only affected by period lengths at a definite frequency. Wang and Zhang [75] considered the waste agricultural plastic film to offer a novel sound absorption material. Unlike the porous core and the perforated plate which can be efficient only at high frequency domain, this new material which has a complex structure with perforations, cavities and an air layer improves the behavior of STL at low and high frequencies. Furthermore, its lightweight is considered as an important major in comparison with other sound absorption materials. As a result, it is concluded that this material can be effective for employing on bridges and inside tunnels during high-speed road construction as well as sections of vehicles and roofs. Fang et al. [76] experimentally analyzed the reflection and transmission of the sound wave through composite structures made by a metal-based porous material. The structure was composed of four slits filled with the porous samples with various thicknesses in one period. To valid the outcomes, the offered results based on the diffraction theory were compared with those of laboratory tests. As a result, they showed that the proposed composite structure can be efficient for noise isolation. Hernandez et al. [77] presented a new tool for acoustic analysis of poroelastic structures in order to propose efficient and precise simulations outcomes considering diffuse field. For this purpose, they firstly developed the fundamental equations on the basis of tensors and then transfer matrix method (TMM) was used. Then, STL of a multilayered material containing one panel as well as two various foam layers was determined in comparison with laboratory test.

3.3.3 Metamaterial

A metamaterial is investigated as a material managed to have a characteristic that is not found in naturally happening materials which are made of many elements formed from composite materials including metals or plastics. Based on the different studies, these materials present tunable anti-resonances with STL values much higher than the corresponding mass-law. Besides, it is useful to note that these materials conclude their properties from their recently designed structures not from the properties of the foundation materials. Ma et al. [78] considered the resonant theory to study STL of the combination of membrane-type and thin plate structures. Li et al. [79] presented a type of sound insulation metamaterial with the ability of energy harvesting from sound waves by taking account a flexible piezoelectric patch. In their verification made between the dual functionality of metamaterial device and that of experimental one, the novel characteristic of metamaterial device in noise controlling was revealed. Guild et al. [80] theoretically and experimentally examined the application of silica aerogel as a section of a compact soft AM structure. They achieved their experimental data on the density and sound speed considering an air-filled acoustic impedance tube. Herewith, the results were offered for silica aerogel ordered in parallel with either one or two acoustic ports. Afterwards, Ma et al. [81] presented a two-dimensional multiple cells lumped ultrathin lightweight plate-type AMs, in which broadband great noise attenuation ability was realized at low frequencies via a lumped element coupling resonant influence. In this regard, another work was presented by Jung et al. [82] to theoretically examine the sound insulation characteristics of AM panels. The retrieval procedure was employed to extract the impressive bulk modulus for AM panel. The outcomes confirmed that the frequency domain of the negative efficient bulk modulus coincides with the stop band of AM panel. The obtained results from this study can be efficient in the design of a holey soundproof panel. Zhang et al. [83] focused on the AMs involving Helmholtz resonators (HRs) and built-in decorated membranes which are well known as sound insulation and energy harvesting. Herewith, it can be deduced that when the aim is respectively to control and harvest the transmitted noise and sound energy, the presented material can be impressive. In another research, Liao et al. [84] obtained STL of an adaptive metamaterial with respect to both frequency and angular spectrum. They also prepared the negative spring stiffness via the piezoelectric stack to suppress the resonance-induced high acoustic transmission. Herewith, it is possible to say that these lightweight adaptive metamaterials can be used when the aim is to broadband noise isolation. Moreover, Chen et al. [85] presented a review paper to remark some recent developments on the tunable AMs according to the different modulation procedures. Since the locally resonant acoustic metamaterials (LRAM) with their structural stop band characteristic are able to considerably increase the behavior of STL in a targeted frequency range, Belle et al. [86] considered the effect of damping on the STL of a LRAM plate using infinite periodic and finite structure modeling. Based on the outcomes, it was found that by involving damping in an infinite periodic structure, the acoustic performance with improved precision was achieved. The inspection of the vibroacoustic performance of the LRAM was also followed by Edwards et al. [87]. In practical applications, the presented results of this study are beneficial because of preparing materials for acousticians with an impressive methodology for enhancing the efficiency of these membrane-kind acoustic metamaterial

(MAM) constructions. It is worth emphasizing that they proposed an analytical tool that could be applied for sample fabrication as well as testing. Accordingly, it is possible to prove and convince favorable interaction between membrane and array-scale dynamics during the design process.

3.4 Smart Material

During the last decades, the importance of using structures with low weight has been increased in various technical applications including aerospace and automotive design. Besides, the inspection sensibility of these structures in noise and vibration is recognized as an important major. In order to actively suppress the vibration and the radiated sound in low frequency domain, smart materials such as piezoelectric transducers and patches are being widespread. Piezoelectric patches are extensively employed as actuators and sensors in these sandwich structures. Akishita et al. [88] actively controlled the transmitted sound into a clamped plate by employing piezoelectric ceramics as actuators and sensors. Based on employing direct velocity feedback control via five pieces of actuators, the outcomes demonstrated a significant decrease on the peak level at eigenmodes frequency below 1500 (Hz). In the following, Tan and Hird [89] developed an experimental study to actively control the sound power of a constrained panel using electromagnetic actuator. It was shown that the applied control method along with the usage of a single point force input of an electromagnetic actuator had an excellent potential to be utilized in controlling the low frequency panel vibration. Green and Leo [90] also build a damped vibroacoustic absorber based on the piezoceramic material. The absorber was composed of a conic piston, attached to a system of flexures along with surface-bonded piezoceramic material. To create coupling between the mechanical motion of the acoustic piston and the resonant dynamic of a closed acoustic cavity, an absorber was designed. Moreover, the Lagrangian procedure was developed to locate the model of the absorber. Chen et al. [91] employed an active vibration control system to decrease the transmitted sound through a square plate acted on via a reverberant field. In this work, also the following remarks involving the prediction of resonant frequencies of structure, the derivations of both the feedback adaptive control algorithm and the experiment results of the active vibration control through STL were discussed. The results also depicted that by applying this control technique, the behavior of STL was improved. Next, FE method was used by Nguyen and Pietrzko [92] to simulate the piezo-shunting of a PZT actuated vibrating plate for damping the plate vibration. The process was developed to illustrate the piezoelectric–vibrational–acoustic frequency response and the free sound radiation of the plate into air. In this regard, another work was presented by Yu et al. [93] wherein the acoustic characteristic of a panel was actively controlled based on the experimental outcomes. In this approach, they also described the restrictions and possibilities of the applied method. Herewith, the non-uniform cancellation of noise through panel at high frequencies, harmonic nonlinear behavior at very low frequencies and actuator saturation at high sound levels were highlighted as limitations. In their consideration, they offered some procedures to overcome the restrictions. Larbi et al. [94] used a combination of FE and BE techniques to control the noise radiation and the acoustic transmission of vibrating structure based on the passive piezoelectric procedure. The system was composed of an elastic structure equipped with external and internal acoustic regions. To reduce the vibration at low frequency domain, the passive shunt damping technique was used. Additionally, Sanada et al. [95] used an active controller to reduce the transmitted sound on the panel according to the single input and single output feedforward dynamic control investigating point-force actuators and piezoelectric film sensors. As a result, it was found that by combining the presented actuation technique and the sensing procedure could obtain a practical control effect at low frequencies. Kaizuka et al. [96] actively controlled the transmitted sound through a panel integrated with sensor and actuator layers. The strategies were to independently measure and control the structural modes. This end was fulfilled by employing modal noise transmission coefficients before controlling as the criteria. As a result, it was deduced that by controlling a small number of structural modes, the STL will be improved in a broad frequency band. In another work, Zhang et al. [97] offered an intelligent acoustic metasurface containing an ultra-thin isotropic foil subjected to piezoelectric resonators. It was confirmed from experimental and numerical outcomes that the metasurface could break the popular mass law of acoustic transmission approximately 30 (dB) in the low frequency domain (< 1000 (Hz)). The results also indicated that the tremendous sound insulation characteristic could be straightly tuned by simply regulating the external circuits instead of reclaiming the structure of the metasurface. Recently, Langfeldt and Gleine [98] analyzed the vibroacoustic performance of membrane and plate-type AMs with a non-rigid grid. To achieve this end, an impressive theoretical model was proposed in order to determine the STL and eigenmodes of such metamaterials. It was found that even as a non-rigid grid and a diffuse incident field are investigated, STL of this material presented anti-resonances with considerably high sound decrease values. The results of this study can be efficient in the application of these metamaterials in practical acoustic control.

3.5 Isotropic

In this section, the research works are reviewed, wherein the wave propagation is carried out through plate structures made of isotropic materials. Guyader et al. [99] proposed a new formulation for obtaining STL of the coupled structures with specific usage to flanking transmission. In fact, the usage of this procedure is for the case of acoustic transmission in buildings. The proportions of the energy transmitted by the dividing and flanking walls were determined to diagnose the situation and then improve the behavior of STL between the rooms. In another study, Craik et al. [100] used SEA to present the structure-borne acoustic transmission at low frequencies. It was found that the modal characteristics of the taking subsystem affect the coupling between two subsystems. Afterwards, a full potential flow and a random pressure field was investigated by Clark and Frampton [23, 101] to present the influence of external flow on an isotropic elastic plate. It is noteworthy that they modeled this problem based on the convected fluid load. Sakuma and Oshima [102] presented a three-dimensional numerical model to analyze the acoustic behavior of the wall members. The results proved the accuracy and precision of the outcomes in some aspects including mass law, resonance and coincidence effect. Besides, the application of the method in analyzing the acoustic property of the structure in the low and middle frequencies was revealed. In addition, the effect of boundaries was also inspected. Chen and Kao [103] also analyzed the vibroacoustic behavior of the thin membranes with square frame-shaped masses. It was found that the multiple STL peaks could be produced by adding more frame mass inclusions. The results demonstrated that near the STL peak frequencies, the dynamic impressive mass density changed from positive to negative. In their investigation, they used two kinds of cell adjustments involving cells in series and cells in array. It was also shown that either the stack or the array configuration could generate better sound attenuation than single-celled structures.

4 Geometrical Boundary Condition

In the last section, the importance of using stiffeners in the improvement of the vibroacoustic performance of a sandwich plate was cleared particularly at low frequency domain. Since this region of frequency is of particular importance, it is possible to reduce the amount of transmitted noise through structure in this region via considering an appropriate geometrical boundary condition. Nonetheless, a plate structure is modeled in finite extend when the ratio of length to thickness is small.

4.1 Finite Plate

Chen et al. [104] improved the acoustic behavior of a finite duct based on the HRs. They also compared the STL of a duct with that of measurement one at frequency region above 200 (Hz). It was found that as some appropriate HRs were added to the structure, STL was enhanced approximately 28 (dB). However, Hosseini-Toudeshky et al. [105] focused on the parameters which may considerably affect the STL of a finite partition between two contiguous enclosures based on the FE method. The achieved outcomes according to the Perspex party walls with various width and boundary conditions were compared with those of double-layered ones subjected to air layer. It was indicated that the noise transmission between room with an asymmetric arrangement was less than that of symmetric one. Lee et al. [106] considered the nonlinear vibration effects through sound absorption of a finite panel absorber and STL of a finite panel subjected to cavity based on the harmonic balance technique. To formulate the equations, the two-coupled partial differential equations involving Karman's plate and wave equations were taken into account. The results demonstrated that by enhancing the number of harmonic terms as well as acoustic and structural modes, the displacement components were converged. In their investigation, they also inspected the influence of other parameters including excitation level, cavity depth and boundary condition. Subsequently, Koju et al. [107] analyzed the acoustic behavior of a finite rigid barrier subjected to HRs. The resonators were limited within a waveguide and oriented such that one neck egresses onto each side of the barrier. It was found that the maximum transmission happened at resonant frequency of the HR. The results also illustrated that the transmitted sound examined continuous phase transmission of π radian as a function of frequency on the resonance. They also proved that it was possible to create an acoustic lens by developing the simulation to a linear array of tuned HRs. In another research work presented by Chen et al. [108], the acoustic behavior of a finite plate was analyzed to study the sound energy absorption mechanism within MAM. According to the considered model along with the point matching technique, the in-plane strain energy can be precisely obtained because of the resonant and anti-resonant motion of the appended masses by investigating a solution procedure on the basis of the coupled acoustic integro-differential equations. Langfeldt et al. [109] proposed a new MAM with tunable acoustic transmission characteristics. For this purpose, some numerical and analytical models were provided to present the two important mechanisms involving shifting of the eigenfrequencies and modal residuals because of the pressurization. As a result, they proved the accuracy of their results by comparing them with those of test sample measurements inside an impedance tube. Ma et al. [110] focused on the general concept of acoustic metamaterials. In their computational and experimental investigations, they showed that the offered contributory design concept could effectively bring up a design for metamaterials that present a new degree of freedom for broadband sound attenuations.

Chen et al. [111] analyzed the vibroacoustic performance of an arbitrary restrained finite plate backed by an irregular cavity. The procedure was followed based on the sub-structure method to model the structure and the sound space. Furthermore, the Rayleigh–Ritz method was applied to obtain the vibration and sound pressure solutions. They proved the accuracy of their results by comparing them with those of FE ones. The outcomes revealed that the current formulation was appropriate for a structure subjected to an irregular cavity and an elastically restrained plate. Liu and Du [112] studied the boundary restraint non-uniformity influence through sound insulation of a silencing finite plate. To present the acoustic response of three-dimensional panel–cavity–duct silencing system, the energy principle was formulated. In order to obtain the optimal sound attenuation, the relationship for translational restrains at both of duct entrance and outlet was achieved on the characteristic inverse proportional functions. Next, the two and three polynomial Chebyshev series method along with the FE method was applied by Chin and Ji [113] in order to consider I-junction within the structural acoustic model of a cascaded rectangular finite plate–cavity system. In this work, also the effects of boundary conditions and plate properties through the transmitted sound were discussed.

4.2 Infinite Plate

In the following of the acoustic analysis of the finite plate structures, now it is interesting to review the articles wherein their dimensions are extended to infinite. This issue was considered by Wöhle et al. [114] to propose a generally valid technique for the calculation of coupling losses at a slab junction for incident bending, longitudinal and transverse waves according to SEA. They [115] also extended their last work to present the structure-borne acoustic transmission induced by forced bending waves and discussed that how this form of STL should be investigated. It is noteworthy that they proposed their outcomes based on the experimental and theoretical approaches. In another research, Chen and Jan [116] determined the acoustic response of an infinite perforated panel using analytical and experimental outcomes based on the sound intensity. Although, the analytical results were validated with those of measurement ones in frequency region over 630 (Hz), some discrepancies about 2 (dB) could be observed below this region. As a result, it was found that by perforating the thick panel, the coincident effect at the critical frequency was decreased. In this regard, Villot et al. [117] proposed a new procedure based on a spatial windowing of plane waves to consider the finite size of a plane structure in order to determine STL. Xiao et al. [118] calculated STL of a metamaterial thin plate involving multiple sub-wavelength arrays of spring-mass resonators connected to an unbounded homogenous plate. In order to obtain diffuse field sound transmission, two analytical wave approaches were developed. Based on the outcomes, it was found that the metamaterial-based plates presented higher level of STL in comparison with bare plates at frequencies within the mass-law region and the coincidence region. Then, it can be deduced that a metamaterial is considered as a potential sound insulation material with an admissible performance at low frequencies. Oudich et al. [119] calculated STL of an infinite thick plate-type AM built of spring-mass resonators joined to the surface of a homogeneous elastic plate based on the theoretical and numerical approaches. In order to analyze the STL of a metamaterial plate and its band structure, two procedures according to the plane wave expansion were taken into account. In their investigation, they proved the importance of a plate-type AM in improving the vibroacoustic performance at low frequency domain. They [120] also theoretically focused on the sub-wavelength acoustic energy harvesting (AEH) employing a thin AM built of spring-mass resonators connected to the surface of a homogeneous elastic thin plate. Furthermore, some kinds of sub-wavelength cavities were taken into account to optimize of AEH. Form the results, it is concluded that such system can be useful in the design of effectual tunable sub-wavelength acoustic energy harvesters according to the AM. Robin and Berry [121] used vibration measurements to estimate diffuse field acoustic transmission of the homogeneous, isotropic and thin infinite panels. They also determined the radiated acoustic power by employing the radiation resistance matrix method. Although the obtained results were validated, large discrepancies on the resonance and close to resonance because of ill conditioning of the virtual field method were observed.

5 Environment

Acoustic–structure interaction is remarked when a plate is placed in the external flow. This Phenomenon is known as the main reason of producing noise and vibration through these structures. According to this issue, in the last years, many authors have inspected the impact of external environment as fluid, cavity and thermal on the vibroacoustic characteristic of plate structures. Therefore, in the following, the importance of this matter is highlighted.

5.1 Fluid

Bechert et al. [122] presented an experimental outcome through superposition of a turbulent jet inside the nozzle in the mean flow. It was found that since the transmitted sound power from the nozzle in comparison with the radiated sound power in the far field provides a considerable attenuation at low frequencies, a jet can be investigated as a low frequency muffler. Note that this behavior is independent of the broadband jet noise reinforcement. Dimitriadis and Fuller [123] used some piezoelectric actuators to actively control the transmitted sound into the elastic plates. For this purpose, the excitation of the plate was performed by a plane acoustic wave by considering that the transmitted sound into structure was a noise field. The results confirmed that the piezoelectric elements had numerous potential in controlling the transmitted sound through structure. Afterwards, the acoustic analysis and the dynamic response of a finite baffled plate based on considering turbulent boundary layer were determined [124]. Dokumaci [125] considered a Riccati equation to obtain the impedance or the reflection coefficients of an acoustic wave in an inhomogeneous duct. The results indicated that the duct impedance matrix could be related to the solutions of the mentioned equation for duct impedance. To present the results, two duct acoustic problems were taken into account. Although various studies through sound transmission of the narrow pipe in a mean flow media have been presented based on solving the convected acoustic equations, Dokumaci [126] also focused on this issue by assuming the form of the axial mean flow velocity profile. In fact, the pipes with circular and rectangular cross-sections were compared. Besides, a new approach was proposed to solve the equations of the rectangular pipe for the first time. The outcomes illustrated that the idea of a uniform mean profile nearly predicted the result of parabolic profile. It is noteworthy that in this work a new configuration for honeycomb structures with rectangular pores was considered, too [127]. Next, Naify et al. [128] used a measurement procedure to determine the acoustic transmission of the LRAM. In fact, FE method was utilized to present the acoustic performance of some ring configurations in order to validate the STL. Furthermore, for enhancing the expanse of STL peak, by changing the mass and membrane characteristics, STL peak frequency in membrane-kind LRAM was tuned. Wang [129] presented a modal behavior in acoustic transmission. Herewith, it was illustrated that the reciprocal modal radiation impedances in modal noise transmission coefficients may not be neglected even for a panel immersed in a light fluid. He presented a theoretical phrase for the modal acoustic transmission according to the equivalent modal impedance. The results indicated that the famous mass law efficiency was attributed to all the supersonic modes. Wang et al. [130] focused on the sound insulation characteristic of a metamaterial plate subjected to lateral local resonators (LLR) in the mean flow. The results confirmed that the structure integrated with vigorously oscillating LLR presented the higher level of STL in comparison with bare plate. Mach number was praised as a parameter that enhanced/reduced STL below/above the coincidence frequency. Although elevation angle improved the acoustic specification of structure, no considerable changes on the STL were revealed by variation of the azimuth angle. Yamamoto [131] offered a new AM plate. The structure combined the HRs, periodically embedded at intervals shorter than acoustic wavelengths. In comparison with flat plate, these structures presented supernatural STL at resonance frequency. To show the sound insulation of these structures, numerical experiments were provided, too. Finally, it was found that the decadence of STL made by the coincidence influence was approximately eliminated for waves, incident at random angles.

5.2 Cavity

Literature clearly shows that during the last decades, many authors modeled their plate structures according to the cavity. Therefore, these articles are reviewed in this section. Bravo et al. [132] inspected the acoustic characteristic of MPP backed by an air cavity and a thin plate. A fully coupled modal technique was employed to determine the absorption coefficient and STL of a finite structure along with the conservative boundary conditions. From the outcomes, it was depicted that the absorption mechanisms at the resonances were ruled by a large air-frame relative velocity over the MPP surface along with either in-plane or out-of-phase relationships. Low [133] presented an equation to determine STL of the concrete structures using SEA. It was confirmed that in a practical situation the most of the frequency range related to these structures was devoted to the above and near to the critical frequency wherein the response of the vibrating structure is frequently prevailed by resonant modes. Afterwards, Osipov and Vermeir [134] inspected the effect of elastic layers (EL) at connections between walls and floor slabs through acoustic transmission of the airborne and structure-borne in buildings. In their consideration, they also theoretically modeled the acoustic transmission of the junctions between elastically coupled plates. It was proved that the advantage of employing EL depends on the particular condition. Hopkins [135] proposed the measured data to verify the SEA for the flanking transmission paths. In his experimental test on the masonry cavity wall structure, the structural coupling because of splitting wall foundations was revealed to be a prevailing route for transmission on splitting cavity wall. Unlike the last works, wherein the influence of boundary conditions through STL of a plate-like structure was theoretically determined, Ou and Mak [136] experimentally validated the STL of a baffled plate under elastic boundary condition. Accordingly, not only a procedure was developed to achieve the boundary conditions of the system but also the accuracy of the offered outcomes was confirmed via this comparison. Reynders et al. [137] considered a hybrid of FE and SEA procedures to model a partitioning wall subjected to cavity. They developed a hybrid technique in order to compute the mean and variance of STL. Consequently, the results were compared with those of measurement ones and both were found to agree within the prediction uncertainty in the investigated frequency domain. Since the popular numerical techniques including FE and SEA often have some restriction to predict STL in mid-frequency domain, Wu et al. [138] offered a novel hybrid edge-based smooth FE coupled with SEA (ES–FE–SEA) to further improve the precision of mid-frequency of STL curve. In their work, they also compared their obtained outcomes by ES–FE–SEA with those of different numerical instances. It is noteworthy that the technique was appropriate for modeling of the complicated engineering problems in acoustic fields through both sides of front windscreen in a passenger car. Xie et al. [139] considered a variational formulation to analyze the vibroacoustic response of a panel backed by an irregularly-bounded cavity. To achieve this end, the structural and acoustical models were formulated via the modified variational procedure along with the multi-segment partitioning strategy. The outcomes demonstrated that by considering this method, the precise and efficacious predictions could be achieved for different kinds of coupled panel–cavity problems. Additionally, a formulation based on the FE method was presented by Dammak et al. [140] to analyze the acoustic behavior of a vehicle to determine the SPL inside the cabin. This study was also mixed with a stochastic analysis to account for variability of parameters. It was found that the uncertainty in the input data could lead to large variability in the obtained interior SPL. Hoshi et al. [141] proposed the absorption performance of honeycomb-backed MPP absorbers. These structures are required to progress the acoustics of an existing 91 (m^3) small meeting room taking account that the reverberation time is over 2 s from 250 (Hz) to 2 (kHz). At the first step, the absorption properties of the MPP absorber were designed to decrease reverberation times at mid-frequency considering an electroacoustical equivalent theory. In the next step, a wave-based FE procedure was employed to obtain the absorber placement. Based on the results, it was found that not only the reverberation time was decreased under 1.5 (s) in all frequencies but also the primary rottenness time value was reduced from 2.7 to 1 (s) at 1 (kHz). Furthermore, The STL value was enhanced from 0.55 to 0.67.

5.3 Thermal

In this section, the study of works is remarked, in which the thermal effect on the sound insulation characteristic of the plate structures is investigated. Parrott and Zorumski [142] inspected the wave propagation on a tube with intense thermal gradients along its axis to measure fluctuating pressures in high temperature environments. Herewith, the measured transfer function through a centralized heated region in the structure was compared to a computed transfer function according to theoretical analysis. Yu et al. [143] examined the influence of internal resistance of a HR through the reduction of acoustic energy in an enclosure. It was found that the model served as an impressive design procedure to obtain the internal opposition of the resonator for reducing the sound in the frequency band enclosing acoustic resonances. Rocha and Dias [144] employed a series of piezoelectric patches and dissipative shunt circuits to analyze the vibroacoustic of different automotive components involving dashboard, panel, door and roof. To support the selection of the electrical component amounts and the correct location of the piezoelectric patches, FE method was applied. They also compared their outcomes with that of baseline experiment embedding the popular viscoelastic material. Geng and Li [145] analyzed the vibroacoustic behavior of a clamped thin plate in thermal environments. Therefore, a general formulation was proposed by considering further effect of thermal loads. In their study, they also inspected the effect of identical temperature variation through response characters, in detail. It was shown that by increasing the temperature of a plate, the natural frequencies are reduced. It was also proved although the thermal loads decrease the radiation proficiency of the structure below the critical frequency, the maximum value almost remains constant.

6 Type of Incident Wave

Type of incident wave can impressively effect on the vibroacoustic performance of the structures. To clear this issue, it is noteworthy that although a plane wave incident can be applied to present an analytical solution, a diffuse field incidence which is the summation of plane waves for various incident angles can be also used to present the much more accurate and reliable outcomes. Since in the factual states, the structures are under excitation of a number of acoustic waves as random incident field, then the offered results of this incident filed are much recommended. In this regard, another sound field as point source is recognized, too. Therefore, in the following, the previous researches are classified based on these subjects.

6.1 Plane Wave

As it is obvious, all types of acoustic waves have point source. Among them, a plane wave can be employed when the structure is further than center of the wave. Craik [146] is considered as the researcher who used this acoustic field to present the transmitted noise into a path. The procedure was followed based on the SEA, recognized as the most common technique in assigning the performance of a system as well as solving a series of simultaneous equations. It is noteworthy that this method is also included many benefits in inspecting the performance on a path by bath basis.

Wu and Dandapani [147] focused on the STL of the thin plates on the basis of boundary element solution. Since the problem included two acoustic domains, therefore Helmholtz integral equation was utilized. To couple the equations of these acoustic domains, two interface conditions were taken into account. Besides, some comparisons were also made between the present formulation and that of uncoupled one. Consequently, Bretagne et al. [148] proposed a class of sonic meta-screens to retouch air-borne acoustic waves at ultrasonic or audible frequencies. In their investigation, they considered that the screens composed of periodic adjustments of air bubbles in water or possibly embedded in a soft elastic matrix. Zhang et al. [149] proposed analytical and experimental studies through MAM embedded with various masses at adjoining cells to improve the behavior of STL at low frequency. To validate the results, FE method was used. Song et al. [150] proposed a novel kind of waveform-preserved unidirectional acoustic transmission (UAT) device consists of an impedance-matched acoustic metasurface (AMS) and a phononic crystal (PC) structure. To present the acoustic pressure field distribution and transmittance, FE procedure was taken into account. Finally, according to the obtained transmission spectra, it was confirmed that the UAT device was reliable within a moderately broad frequency domain. The results of this paper are praised as an appropriate reference for designing waveform-preserved UAT devices. Moreover, it has potential usages in other fields involving sound insulation, acoustic rectifier and medical ultrasound. Wang et al. [151] also designed membrane-type acoustic metamaterial muffler (MAMM). In order to better realizing of MAMM, not only the resonance frequency of the membrane was determined but also a simulation was employed to analyze the STL of a MAMM. It was shown that the MAMM decreased the structural size of muffler in comparison with the customary Helmholtz and expand mufflers, which can find usage for MAMs in noise absorption. Gao and Hou [152] presented a honeycomb-silicone rubber AM to defeat and achieve, respectively, the effect of mass law through traditional acoustic materials and a lightweight thin-layer structure which can effectively isolate the low frequency noises. They proved that the STL in this approach was remarkably higher than that of monolayer silicone rubber metamaterial via their experimental outcomes. It is concluded that the offered results can be counted as a new approach for controlling the transmitted noise into structures. Furthermore, Li et al. [153] presented an analytical model through acoustic micro-membranes (AMMs). It was shown that how a membrane could improve the acoustic property of structure in mid-low frequency domain. In this work, also the importance of using AMMs in noise control engineering was revealed. Liu et al. [154] analyzed the acoustic performance of a duct-membrane system subjected to strip masses. Accordingly, the energy formulation along with the Rayleigh–Ritz method was applied to fully couple structural acoustic interactions between membrane-mass dynamics and duct noise propagation. Consequently, in order to confirm the precision and effectiveness of the presented model, the outcomes were compared with those obtained by FE method. In their investigation, they also identified the peak frequency for STL curve by the variation of mass position and weight. Based on this issue, it was revealed that although the first peak was mostly dependent on the mass characteristics, the second one was more sensitive to the mass location. The results presented a considerable increment of duct silencing performance for the first time by using strip mass attachment. Boulvert et al. [155] used normal incidence field to offer a numerical optimization technique of continuous porous layer specifications in order to obtain full absorption. In comparison with uniform ones, the offered results of this study presented a changing of the full absorption peak to lower frequencies or a enlarging of the full absorption frequency domain for graded materials.

6.2 Random Incident Filed (Diffuse)

As explained in the first part of this section, the importance of a diffuse field incidence was cleared. In order to complete the last descriptions, it is worth to note that when the aim is to find the simplest way to inspect the acoustic environment, the importance of using this incident field is remarked. According to this fact, this incident field was considered by Gerretsen [156] to determine the STL between dwellings by partitions and by flanking structures using CPT. Furthermore, the effects of boundary conditions by means of the structural reverberation time in situ were inspected. Besides, the vibration level differences were achieved for various junctions based on the situ measurements. Based on a series of reasonable limitations, this model presented the results similar to those offered by SEA. Vaicaitis et al. [157] developed theoretical and experimental approaches through acoustic property of an aircraft panel in a diffuse field. The modal decomposition and the Galerkin-type technique were employed to develop the acoustic-structural equations. As a result, it was confirmed that stiffening aircraft panel with honeycomb add-on treatment prepared additional sound attenuation. Steel [158] focused on the diffuse field acoustic transmission between plates in framed structures, in which the rooms as well as corridors were designed by setting partitions between structural columns. This process generated connections between plates that had a column running along the joint. The obtained results from transmitting the sound through a joint showed that the joint column was important when the transmission properties are determined. Herewith, the STL is enhanced at high frequencies. Osipov et al. [159] obtained the low frequency airborne acoustic transmission of single partitions in a diffuse field. For this purpose, the structure was modeled in various models involving a baffled plate, an infinite plate and a room-plate-room. It was shown that the low frequency domain depends on the characteristics of the test wall and the geometry as well as the dimension of the system. Chiello et al. [160] determined the diffuse acoustic response of an elastically-supported baffled plate based on different boundary stiffnesses considering free-interface component mode synthesis method. In another work [161], STL of a finite panel at different incident angles was obtained under excitation of the plane sound wave. The results illustrated that the highest level of excitation was happened at the normal incidence. Meanwhile, by increasing the incident angle, the level of excitation of the panel is reduced. It was also shown that since a plane wave excited the structure, then the excitation of the panel was nearly independent of the incident angle. In another work [162], the mechanism of the niche effect was inspected through airborne acoustic transmission of a specimen installed an aperture in the wall between the source and receiving reverberation rooms. To decrease the low frequency STL, the equivalent resonant phenomena were known for symmetric triple windows or solid walls with the same air gaps and lightweight boards on both sides. As a result, in STL comparison which was made between acoustical and experimental models, a good validity was revealed. Crocker et al. [163] used SEA to examine the vibroacoustic behavior of panels and tie beams. The experimental results in the case of single panel indicated the well predicted by the theory. It is noteworthy that this issue was also verified in the independent double panel and coupled double panel cases. Dijckmans [164] used a wave based model to evaluate the flanking acoustic transmission between two contiguous rooms on the plenum of hovering roofs. The plenum could either be empty or somewhat filled with an absorbent layer. The outcomes were compared with a classical three-room model that supposed diffuse acoustic fields in both rooms and the plenum. Recently, Ang et al. [165] presented a large-scale meta-panel adopting modularity for customizable acoustical performance considering resonator or without one. From the results, it was found that the acoustical performance of each specimen could be scaled and modularly mixed.

6.3 Point Source Incidence

Point force actuators were used by Sanada and Tanaka [166] to present analytical and experimental approaches in order to actively control acoustic transmission of a simply supported panel. For this purpose, an active transmission control technique was applied to achieve a large control effect at low frequencies. Based on the simulation outcomes, it was proved that the (1, 3) modal actuation was globally impressive for decreasing the acoustic transmission by more than 10 (dB) in the low frequency range. Then, the results were compared with those of experimental ones and the accuracy of them was confirmed. Poblet-Puig and Rodríguez-Ferran [167] focused on the acoustic transmission of the slits and opening between cuboid-shaped rooms. In their investigation, they proposed an effective formulation to split the original domain into some sections containing slit, receiving and sending rooms. Besides, an element-based numerical method likes FE technique was applied to model the geometry and boundary condition of the problem. In this work, also some new results involving the effects of slit dimensions, opening position and room characteristics (dimensions and absorption) were presented. Yu et al. [168] presented a virtual panel treatment to model thin apertures. After proving the accuracy of the outcomes, the impressive thickness range was achieved to impose the virtual panel treatment. In this regard, some numerical examples were presented to show the capability and the flexibility of the formulation. Yairi et al. [169] calculated the power transmission of a single-leaf wall under the excitation of spherical wave. To determine the displacement of a plate and the transmitted sound pressure in the far-field, respectively, Hankel transform in wavenumber space and Rayleigh's formula were taken into account. The results indicated that the mass law for a spherical wave incidence was not the same with that of normal plane one. Afterwards, a combination of BE and FE acoustic structural couplings was used by Djojodihardjo [170] to analyze acoustic performance of the flexible structures. In fact, the aim was to serve as a baseline in the acoustic analysis of lightweight structures. Yuan et al. [171] considered theoretical and experimental approaches to control the transmitted sound into an isotropic panel integrated with some piezoelectric patches as actuators and a series of collocated accelerometers as sensors. Furthermore, a hybrid decentralized control law was derived. The results indicated that by applying this control mechanism, not only the deflection was suppressed amount 16.7 (dB) but also the SPL was lowered by more than 7 (dB). In another research, Liu et al. [172] inspected the effect of considering a spherical sound wave in comparison with an incident plane wave through acoustic transmission characteristics of a finite plate based on the modal expansion method. In this work, also the influences of the dimension of structure, the distance between the source and the plate were considered. Shi et al. [173] presented a solution procedure to determine the vibroacoustic behavior of a plate subjected to partially opened cavity. Therefore, firstly, the vibration response of the three-dimensional acoustic coupled system was obtained. Besides, the influence of opening was investigated, too. In the next step, the acoustic coupling between finite cavity and exterior field along with the structural acoustic coupling between flexible plate and interior acoustic field was taken into account. In this work, also the effects of the opening and the cavity volume through acoustic behavior of the structure were discussed. Wang et al. [174] inspected the possibility of boundary control for acoustic transmission on an opening, which only installs the secondary sources through its frame. Herewith, firstly, the modal expansion technique was applied to present a theoretical model in order to determine the sound field transmitted into a cavity subjected to baffled opening. Afterwards, the performance of the boundary control systems was checked for various early and secondary sources configurations. Toyoda and Ishikawa [175] formulated a locally reactive boundary based on the mechanical mass–damper–spring (MDS) system to analyze the noise absorption and transmission using finite-difference time-domain (FDTD). In their consideration, they studied the stability conditions of the MDS boundary, too.

7 Solution Process

Literature clearly shows that there are a series of prevalent procedures containing analytical, experimental and numerical which can be applied by the authors to study the acoustic characteristic of the plate structures. Although in the past, the focus was put on using the analytical and numerical techniques, nowadays by developing the technology it is attempted to perform some empirical tests in the laboratory and analyzing the sound insulation property of these structures based on the experimental set up. By increasing awareness about this subject, not only the authors are able to close their results into real state but also they can compare their outcomes with those of predicted ones. Nevertheless, in this section, the works are reviewed based on their applied methods.

7.1 Analytical Approach

Meidinger and Legrain [176] considered piezoelectric film technology to compare the computational and experimental results for controlling the acoustic behavior of a thin plate based on the optimal control theory. Gardonio et al. [177–179] considered an intelligent panel with multiple decentralized units to control the transmitted noise in some papers using analytical approach. The construction was composed of a thin isotropic panel equipped with 16 closely spaced accelerometer sensor and piezoceramic actuator pairs joined by single-channel velocity feedback controllers. In the first paper [177], a general theoretical study was proposed to evaluate the behavior of an intelligent structure. It was indicated that for both acoustic and force sources, an admissible decrease of the averaged kinetic energy or whole sound power radiation can be obtained about 0–2 (kHz). In another one [178], the design and implementation of the 16 decentralized control units was discussed. In order to produce the active damping, it was considered that each control unit involved a collocated accelerometer sensor and piezoceramic patch actuator along with a single channel velocity feedback controller. As a result, the control effectiveness of an intelligent structure was experimentally determined [179]. Wang [180] presented a theoretical study through acoustic analysis of the apertures, including the patterns of notches or holes periodically pored on the one or two-dimensional rigid panels. They investigated the acoustical impedance to explain the influence of noise diffraction by both surfaces of a perforated leaf through aperture resonance. As a result, they concluded that tuning the resonant transmission became actually possible in usage of the resonant transmission phenomenon. Then, a theoretical approach was proposed by Jin et al. [181] on the active control of STL through vibroacoustic enclosure containing two flexible plates considering two kinds of actuators. In order to describe the excitation and interaction in the coupled acoustic transmission system, the modal acoustic transfer impedance mobility matrices were taken into account. In their investigation, they confirmed the benefit and performance of the used control strategy. The results indicated that the incident plate actuator was impressive in controlling the cavity prevailed modes and the structural modes. Following the last work, another analytical model through vibroacoustic performance of MAM was proposed, in which the structure was modeled as a membrane [182] considering FE method. The structure was composed of a prestretched elastic membrane with joined rigid masses. The results of this paper can be considered as an impressive tool in designing of such MAM. Sharma et al. [183] analytically modeled wave propagation on a periodically voided soft elastic medium submerged in water considering the homogenisation theory along with the FE approach. In this work, not only the influences of strong and weak coupling of void resonances through transmission specifications were inspected but also the benefits and limitations of each technique were discussed. Tian et al. [184] developed the last works by presenting a new approach on a square membrane-ring structure of MAM. In their investigation, they inspected the geometrical influences of ring mass through STL peak and dip frequencies of MAM. In an impressive analytical model presented by Langfeldt et al. [185], acoustic characteristic of the baffled and multi-celled MAM panels was studied. The model considered a novel technique by the concept of an efficient surface mass density. In fact, it approximated the unit cell vibrations in the form of piston like displacements. In comparison which was made between their results and those of numerical ones, the importance of their formulation due to surfing lower time was revealed. Furthermore, the influence of flexible MAM unit cell edges compared to the fixed edges was inspected. Their study also prepared a complete realizing of the acoustic performance of MAM under more pragmatic conditions. Lee et al. [186] used acoustic analysis model to compare STL of the HRs with those of quarter and half- wave and conical half-wave resonators. The aim was to check the efficiency of each resonator before beginning laboratory tests.

7.2 Experimental Technique

Now it is useful to highlight the works wherein acoustic performance of the plate structures is analyzed according to measured data. Crocker and Price [187] used SEA to present the radiation resistance, vibration amplitude and STL of a partition. They also showed the effect of resonant modes on the vibration amplitude. Minten et al. [188] used the sound intensity and the conventional procedure to calculate STL of a single metal panel and then compared with the result of SEA. The comparison indicated a small systematic departure between the outcomes of both experimental approaches. In fact, the precision of the intensity measurement was confirmed by the discrepancy between the so-called residual reactivity level and the measured reactivity. Howard [189] studied the sound insulation characteristic of a panel subjected to an array of tuned vibration absorbers. Herewith, STL of the proposed structure was compared with those of attached equivalent blocking masses and bare panel. They also compared their prediction results with experiment measurement ones. Estrada et al. [190] analyzed the acoustic behavior of the plates made of isotropic material perforated with periodically distributed subwavelength holes, immersed in water. The results demonstrated that the number of the transmission peaks depends on thickness of the structure. Yang et al. [191] focused on the problem of sound absorption from a landscape goaled at deriving upper bounds under various scenarios involving whether the sound is incident from one side or both sides and whether there is a reflecting surface through back side of the membrane. They also compared their results with those of experimental ones. Based on the outcomes, it was concluded that when the developed landscape is applied with the Green function's formalism, it can be impressive in obtaining insights into constrains through what are accessible in absorption as well as scattering. Wareing et al. [192] considered the effect of sample size through measured STL of various sample constructions. The procedure was followed by evaluating the STL of the two various sized samples with respect to various materials and constructions. Furthermore, a qualitative analysis was carried out to determine the effect of different factors on the STL. Shen et al. [193] proposed a design of acoustic metasurface producing asymmetric transmission within a specified frequency band. The design was composed of a layer of gradient-index metasurface and a layer of low refractive index metasurface. It was indicated that the results prepared the high transmission conflict between the two incident directions within the designed frequency band. As a result, they declared that their outcomes could be impressive in different scenarios involving acoustic control and therapeutic ultrasound. Zhang et al. [194] actively controlled the transmitted noise into a small opening in a wall formed by two infinite baffles. They developed an analytical approach along with the modal expansion procedure to inspect the influences of various secondary source and error sensor techniques applying various kinds of primary acoustic fields. They offered their results based on an experimental set up with an opening of 6 (cm) by 6 (cm) on a 31.8 (cm) thick wall, which indicated an agreement with those of numerical ones. From the results, it was confirmed that employing active control in small openings could considerably develop the frequency domain of control. It is worth to note that the active control systems may be used to improve the sound control scenarios that involve both sound reduction and ventilation requirements in the middle to high frequency zone. Li et al. [195] developed experimental and numerical approaches and considered tantamount acoustic source model to improve the precision of acoustic field determination under an oblique incident condition based on Khokhlov–Zabolotskaya–Kuznetsov (KZK) equation. In order to decrease the transmitted noise into the plenum windows, Du et al. [196] experimentally examined the effect of some factors involving the opening size, the panel thickness and air-gap spacing between two glass panes through STL. It was shown that as the half wavelength of encroach noise was great, these three parameters have less influence on acoustic characteristic. Wrona et al. [197] also performed laboratory tests to further extend the frequency response shaping procedure and use it to a device casing panel. Accordingly, they considered the effective objective function and mathematical model to optimize the position of a passive mass mounted to the structure with the aim of increasing the noise performance of system.

7.3 Numerical Procedure

Szechenyi [198] used a numerical technique to achieve diffuse field resonant and non-resonant wave transmission through a plate structure. Although for resonant STL, the previous publication of the authors on the basis of statistical solutions was taken into account, the theory of plates based on the statistical method was employed for non-resonant one. Since in the calculation of STL by SEA, there is a significant discrepancy between theoretical and measured amount at low frequencies which is known as one of disadvantage of this solution technique, Elmallawany [199] improved these differences at this region by introducing a correction factor. Santos and Tadeu [200] obtained the acoustic transmission of a single simple wall separating two joined tunnels. To analyze acoustic behavior of the structure, one of the tunnels was excited by a harmonic line load pressure so that for formulating the acoustic pressure, BE method was considered. The offered model was also appropriate to show the effect of various parameters including dimension of the rooms along with rigidity and thickness of the wall through acoustic insulation. Desmet et al. [201] analyzed acoustic behavior of the agricultural machinery cabins based on two-microphone sound intensity probe. Herewith, they offered their numerical approaches by employing FE and BE methods in terms of practical use for air-bone sound insulation predictions. In this work, also all numerical and experimental methods were considered for showing the reliability of the different analysis procedures. In another approach [202], the hybrid method as well as the reciprocity relation were developed. For instance, the authors showed that it was possible to couple a statistical model of a plate structure to a FE model of an acoustical cavity, or to a statistical acoustical cavity. Afterwards, the acoustic analysis of the single-inlet/double-outlet as well as double-inlet/single-outlet rigid walled expansion chamber mufflers was offered by Wu et al. [203]. Ruber et al. [204] determined STL of a panel backed by a small enclosure. They searched in detail the effect of air cavity on the panel. It was shown that although the influence of the sealed air was to enhance the stiffness of the plate which results in increasing the frequency in its first natural mode, STL of the structure was not sensitive to it in this frequency domain. Wang [205] extended his last work on the STL of a single leaf panel to study the behaviors of acoustic transmission coefficients in some generic frequency domains. Herewith, asymptotic solutions were proposed for the panels with moderately low bending stiffnesses. As a result, they compared their outcomes with those of numerical analysis and the popular mass law theories. Huang et al. [206] focused on the combination of membrane and plate-type AMs. In fact, the purpose was to present an overview through recent advancement of the metamaterials. In this work, the limitations, challenges and opportunities of them were brought up, too. Hartmann et al. [207] modeled the sound-born waves through the built-up structures based on the dynamical energy analysis (DEA). This method offered the detailed information of the vibrational energy distribution within a complex structure in the mid-to-high frequencies. Moreover, SPL and vibration of the structure were studied. In this regard, another work was presented by Takahashi et al. [208] on the finite elastic plates to highlight the relationship between airborne acoustic transmission and structure-borne sound radiation according to the numerical procedures. In another research [209], TMM and FE procedure were used to examine the acoustic specification of an expansion chamber before and after the introduction of MPP. Although the offered results of both techniques were the same at low frequencies, the first pass frequency vanished and acoustic insulation bandwidth becomes broad band with introducing the MPP. The outcomes demonstrated that making impressive hole led to convinced noise insulation. Meanwhile, by adding double-layer MPP, this improvement was more enhanced.

8 Noise Transmission Reduction

As obviously defined, in this contribution up to here, all of the research works of the authors through acoustic performance of a plate structure were reviewed. The study of these researches illustrates that not only the structures were molded based on the various materials but also different solution procedures were used for inspection of sound insulation characteristic of these structures. Herewith, it can be deduced that in the most of the works, the intention of the researchers is to study the sound insulation property of the plate structures. Therefore, in the following, the inspection of the works is highlighted wherein other techniques containing control and optimization approaches are used. By applying these methods not only the amount of transmitted noise into the structure is reduced but also the vibroacoustic characteristic of structure is improved.

8.1 Sound Control

Fuller [210] and Metcalf et al. [211] respectively investigated theoretical and experimental approaches to actively control the noise radiation from the vibrating plates. The structure was composed of a plane acoustic wave incident through clamped elastic circular thin plate. The quadratic optimization was applied to determine the optimal control gains to minimize the objective function proportional to the radiated acoustic power. They also showed the performance of the proposed control procedure. Afterwards, in experimental consideration [211], the outcomes of the both procedures were compared and then the influences of employing a point or global minimization scheme were inspected. Zhang et al. [212] employed an effective medium method to analyze acoustic behavior of the metamaterial thin plate composed of periodic subwavelength arrays of shunted piezoelectric patches. The results indicated that the structure equipped with shunted piezoelectric patches presented higher level of STL in comparison with unshunted one. Gu et al. [213] controlled the acoustic transmission of the two-dimensional density-near-core (DNZ) membrane structure. Herewith, the structure was modeled as a network of inductors and capacitors and the resume efficient mass density was considered to be zero at resonance frequency. In fact, this procedure was presented as an appropriate model to build the unit cell for obtaining DNZ at the designed frequency. The offered outcomes can be efficient in controlling the acoustic transmission of an acoustic cloak which reveals high transmission on the sharp corners and high-impressive wave splitting. Xiao et al. [214] demonstrated that the MAMs could be simply tuned by using an external voltage. It was also shown that based on considering phase-matched AC voltage, the vibration of the MAM might be considerably increased or suppressed. Kaizuka and Nakano [215] employed the structural modal filters to actively control the wave transmission through enclosure considering actuators and sensors. In fact, they developed a formulation for expressing the contribution from each structural mode to clear which mode should be measured and controlled. To prove the accuracy of the applied theory, a numerical simulation was considered.

8.2 Acoustic Transmission Optimization

Zhang et al. [216] considered a numerical procedure on the basis of smart PSO–CGA algorithm to analyze acoustic behavior of the panels. In their investigation, they also validated their computational model with that of experimental test. Furthermore, the effectiveness of the applied algorithm was checked by comparing it with the common CGA and PSO algorithms. Based on the optimized outcomes, it was confirmed that the PSO–CGA model had a high clustering degree. It is worth to note that the results of this study cause to reduce the amount of transmitted noise in the cabin, considerably. Recently, Roca et al. [217] employed various computational procedures involving a multiscale homogenization framework, modal order reduction techniques and topological optimization methods to consider the so-called LRAM for the design of specifically engineered devices in order to inspect the acoustic insulation. The results of this study can be remarked as a computational mechanism along with huge potential for analyzing the acoustic property of the metamaterial-based structures. Wang et al. [218] considered an artificial neural network (ANN) procedure to present the vibroacoustic behavior of ultrafine glass wool mats. Based on the comparison which was made between present results and those of measured data, the accuracy of the results was confirmed. Dammak et al. [219] presented a technique to carry out the multi-objective design optimization for a coupled acoustic–structural system employing a hybrid method with the genetic algorithm. The structure was composed of two flexible plates coupled with an acoustic rectangular cavity. Accordingly, they proposed a formulation to consider the acoustic pressure inside the cavity and the displacements of the plates. It was illustrated that the applied optimization procedure coupled with hybrid technique was able to present the admissible Pareto solutions.

9 Concluding Remarks

The inspection of the acoustic analysis of the plate structures is recognized as one of the main matters in aerospace engineering. Literature obviously illustrates that the numbers of researches in this field are very huge about 200 papers. Gathering them by decades, it is confirmed that there is an enhancing consideration on this issue, and it is continuing. Accordingly, it is possible to deduce that the number of interesting contributions linearly enhances with span a period due to the development of the technology as well as extensive applications of plate structures in aerospace design. Therefore, it was attempted in this review study to collect all of works in the area of wave propagation through the plate structures based on the various categories. Firstly, some explanations were given such as the importance of the subject and the basic equations of the problem. Afterwards, the thickness of structure was recognized as a parameter which specifies the theory should be applied for various geometries including thin, relatively thick and thick structures. After remarking the type of materials in the inspection of sound insolation characteristic of a plate, the works were reviewed according to their geometrical boundary conditions including finite and infinite structures. It is not worthless to note that by developing the science and computational methods, it is attempted to model the structure in finite extend in order to approach the outcomes into the real state. The study of the last researches clearly indicates that the acoustic environment is important in the noise analysis of plate structures. Herewith, some papers were reviewed wherein the effect of various environments such as fluid, cavity and thermal was inspected. Additionally, it is noteworthy that since in each actual acoustic environment the existence of airflow is unavoidable, however the researchers tend to close their outcomes to factual state, investigating the effect of these acoustic environments as well as modeling the structures in these situations definitely enhances the degree of reliability and accuracy of the outcomes. In this regard, the type of incident field can be very effective. Some common incident fields were investigated including point source, plane wave and diffuse field. In fact, this issue is completely related to the distance of acoustic wave source as far or close. From the results, it was found that as the distance between plate structure and center of acoustic wave was high, a plane wave incidence could be employed. In addition, a diffuse field incidence is impressive in genuine states wherein the structure goes under excitation of a sound wave with random incident angles. Moreover, it was shown that in order to create this incident field, a vast number of sound waves should be summed. Then, much more accurate and precise outcomes can be achieved from this incident field. To emphasis this issue, in the following, the researches were classified by their solution procedures. The review of the results recommended that although numerical and analytical techniques were able to predict the noise performance of the plate structures, the measured data could present much better outcomes. This issue convinced the authors to perform some experimental tests in laboratory and present their results based on the experimental set up. In this study, the topic was also highlighted by reviewing the other researches wherein by applying other methods including optimization and control, not only the amount of transmitted noise is controlled but also the acoustic response of the structure is improved. At the end, it is worth emphasizing that the following goal is considered as an important issue that convinces the authors to work on the sound insulation characteristic of the plate constructions:

- Enhancement of the sound transmission loss (STL) of these structures on the basis of developing various vibroacoustic control and optimization methodologies as well as proposing different extended materials.

Compliance with Ethical Standards

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

References

1. Darvish Gohari H, Zarastvand M, Talebitooti R (2019) Acoustic performance prediction of a multilayered finite cylinder equipped with porous foam media. J Vib Control. https://doi.org/10.1177/1077546319890025
2. Talebitooti R, Choudari Khameneh A, Zarastvand M, Kornokar M (2018) Investigation of three-dimensional theory on sound transmission through compressed poroelastic sandwich cylindrical shell in various boundary configurations. J Sandwich Struct Mater. https://doi.org/10.1177/1099636217751562
3. Talebitooti R, Zarastvand M (2018) Vibroacoustic behavior of orthotropic aerospace composite structure in the subsonic flow considering the third order shear deformation theory. Aerosp Sci Technol 75:227–236
4. Talebitooti R, Zarastvand M (2018) The effect of nature of porous material on diffuse field acoustic transmission of the sandwich aerospace composite doubly curved shell. Aerosp Sci Technol 78:157–170
5. Talebitooti R, Zarastvand M, Gohari H (2017) Investigation of power transmission across laminated composite doubly curved shell in the presence of external flow considering shear deformation shallow shell theory. J Vib Control. https://doi.org/10.1177/1077546317727655
6. Talebitooti R, Zarastvand M, Gohari H (2018) The influence of boundaries on sound insulation of the multilayered aerospace poroelastic composite structure. Aerosp Sci Technol 80:452–471
7. Zarastvand M, Ghassabi M, Talebitooti R (2019) Acoustic insulation characteristics of shell structures: a review. Arch Comput Methods Eng. https://doi.org/10.1007/s11831-019-09387-z
8. Talebitooti R, Johari V, Zarastvand M (2018) Wave transmission across laminated composite plate in the subsonic flow investigating two-variable refined plate theory. Latin Am J Solids Struct 15:e39
9. Talebitooti R, Zarastvand M, Rouhani A (2019) Investigating hyperbolic shear deformation theory on vibroacoustic behavior of the infinite functionally graded thick plate. Latin Am J Solids Struct 16:e139
10. Zhou J, Bhaskar A, Zhang X (2013) Sound transmission through a double-panel construction lined with poroelastic material in the presence of mean flow. J Sound Vib 332:3724–3734
11. Talebitooti R, Zarastvand M, Gheibi M (2016) Acoustic transmission through laminated composite cylindrical shell employing third order shear deformation theory in the presence of subsonic flow. Compos Struct 157:95–110
12. Ghassabi M, Talebitooti R, Zarastvand M (2019) State vector computational technique for three-dimensional acoustic sound propagation through doubly curved thick structure. Comput Methods Appl Mech Eng 352:324–344
13. Ghassabi M, Zarastvand M, Talebitooti R (2019) Investigation of state vector computational solution on modeling of wave propagation through functionally graded nanocomposite doubly curved thick structures. Eng Comput. https://doi.org/10.1007/s00366-019-00773-6
14. Darvishgohari H, Zarastvand M, Talebitooti R, Shahbazi R (2019) Hybrid control technique for vibroacoustic performance analysis of a smart doubly curved sandwich structure considering sensor and actuator layers. J Sandwich Struct Mater. https://doi.org/10.1177/1099636219896251
15. Talebitooti R, Darvish Gohari H, Zarastvand M, Loghmani A (2019) A robust optimum controller for suppressing radiated sound from an intelligent cylinder based on sliding mode method considering piezoelectric uncertainties. J Intell Mater Syst Struct 30:3066–3079
16. Talebitooti R, Gohari H, Zarastvand M (2017) Multi objective optimization of sound transmission across laminated composite cylindrical shell lined with porous core investigating Non-dominated Sorting Genetic Algorithm. Aerosp Sci Technol 69:269–280
17. Talebitooti R, Zarastvand M, Darvishgohari H (2019) Multi-objective optimization approach on diffuse sound transmission through poroelastic composite sandwich structure. J Sandwich Struct Mater. https://doi.org/10.1177/1099636219854748
18. Yang T, Huang Q, Li S (2016) Three-dimensional elasticity solutions for sound radiation of functionally graded materials plates considering state space method. Shock Vib. https://doi.org/10.1155/2016/1403856
19. Remillieux MC, Pasareanu SM, Svensson UP (2013) Numerical modeling of the exterior-to-interior transmission of impulsive sound through three-dimensional, thin-walled elastic structures. J Sound Vib 332:6725–6742
20. Bhattacharya M, Guy R, Crocker M (1971) Coincidence effect with sound waves in a finite plate. J Sound Vib 18:157–169
21. Craven P, Gibbs B (1981) Sound transmission and mode coupling at junctions of thin plates, part I: representation of the problem. J Sound Vib 77:417–427
22. Gibbs B, Craven P (1981) Sound transmission and mode coupling at junctions of thin plates, part II: parametric survey. J Sound Vib 77:429–435
23. Clark RL, Frampton KD (1996) Sound transmission through an aeroelastic plate into an acoustic cavity. J Acoust Soc Am 99:2586–2603
24. Lee J-H, Ih J-G (2004) Significance of resonant sound transmission in finite single partitions. J Sound Vib 277:881–893
25. Putra A, Ismail A (2014) Normal incidence of sound transmission loss from perforated plates with micro and macro size holes. Adv Acoust Vib 2014:1–4
26. Wójcik J, Gambin B (2017) Theoretical and numerical aspects of nonlinear reflection–transmission phenomena in acoustics. Appl Math Model 46:771–784

27. Xin F, Gong J, Ren S, Huang L, Lu T (2017) Thermoacoustic response of a simply supported isotropic rectangular plate in graded thermal environments. Appl Math Model 44:456–469
28. Mana AA, Sonti VR (2018) Sound transmission through a finite perforated panel set in a rigid baffle: a fully coupled analysis. J Sound Vib 414:126–156
29. Wang X, Guo X, Chen T, Yao G (2018) Plate-type metamaterials for extremely broadband low-frequency sound insulation. Int J Mod Phys B 32:1850019
30. Yoon K, Kim S, Kim W, Yoon K, Kim S, Kim W (1997) Active control of sound fields in plate–cavity system by anisotropic piezoelectric polymers. In: 38th Structures, structural dynamics, and materials conference. pp 1313
31. Renji K (2005) Sound transmission loss of unbounded panels in bending vibration considering transverse shear deformation. J Sound Vib 283:478–486
32. Jin Y-Q, Pang F-Z, Yang F, Li G-M (2014) A general model for analysis of sound radiation from orthogonally stiffened laminated composite plates. China Ocean Eng 28:457–470
33. Xin F (2015) An exact elasticity model for rib-stiffened plates covered by decoupling acoustic coating layers. Compos Struct 119:559–567
34. Chronopoulos D, Ichchou M, Troclet B, Bareille O (2014) Computing the broadband vibroacoustic response of arbitrarily thick layered panels by a wave finite element approach. Appl Acoust 77:89–98
35. Thomas D, Nelson P, Pinnington R, Elliott S (1995) An analytical investigation of the active control of the transmission of sound through plates. J Sound Vib 181:515–539
36. Pierre RS Jr, Koopmann G, Chen W (1998) Volume velocity control of sound transmission through composite panels. J Sound Vib 210:441–460
37. Kim SJ, Song KY (1999) Active control of sound fields from plates in flow by piezoelectric sensor/actuator. AIAA J 37:1180–1186
38. Kandaswamy S, Ramachandraiah A (2003) experimental investigations of sound transmission in cavity ferrocement panels with ties. Archit Sci Rev 46:55–60
39. Ni Q-Q, Lu E, Kurahashi N, Kurashiki K, Kimura T (2008) Development of insulation sheet materials and their sound characterization. Adv Compos Mater 17:25–40
40. Kim I, Kim Y-S (2009) Active vibration control of trim panel using a hybrid controller to regulate sound transmission. Int J Precis Eng Manuf 10:41–47
41. Lee B, Kim S (2014) Effect of structure on sound absorption and sound transmission loss of composite sheet. Adv Compos Mater 23:319–325
42. Park HS, Oh BK, Kim Y, Cho T (2015) Low-frequency impact sound transmission of floating floor: case study of mortar bed on concrete slab with continuous interlayer. Build Environ 94:793–801
43. Zhang H, Fan L, Qu J, Zhang S (2016) Sound transmission properties assisted by the phase resonances of composite acoustic gratings. J Appl Phys 119:084902
44. Kaijun Y, Lin L, Ichchou M, Collet M (2017) Sound insulation performance of plates with interconnected distributed piezoelectric patches. Chin J Aeronaut 30:99–108
45. Bhingare NH, Prakash S, Jatti VS (2019) A review on natural and waste material composite as acoustic material. Polym Test 80:106142
46. Bosmans I, Mees P, Vermeir G (1996) Structure-borne sound transmission between thin orthotropic plates: analytical solutions. J Sound Vib 191:75–90
47. Tolokonnikov L (1998) The transmission of sound through an inhomogeneous anisotropic layer adjoining viscous liquids. J Appl Math Mech 62:953–958
48. Lee J-H, Kim J (2002) Analysis of sound transmission through periodically stiffened panels by space-harmonic expansion method. J Sound Vib 251:349–366
49. Christen J, Ichchou M, Troclet B, Ouisse M (2014) Global sensitivity analysis of acoustic transmission models through infinite plates. In: Proceedings of ISMA. pp 4177–4188
50. Wareing RR, Davy JL, Pearse JR (2016) The sound insulation of single leaf finite size rectangular plywood panels with orthotropic frequency dependent bending stiffness. J Acoust Soc Am 139:520–528
51. Reynders E, Van Hoorickx C, Dijckmans A (2016) Sound transmission through finite rib-stiffened and orthotropic plates. Acta Acust United Acust 102:999–1010
52. Zhang H, Shi D, Zha S, Wang Q (2018) Sound-vibration behaviors of the thin orthotropic rectangular fluid–structure coupled system resting on varying elastic Winkler and Pasternak foundations. Results Phys 11:188–200
53. Chandra N, Raja S, Gopal KN (2014) Vibro-acoustic response and sound transmission loss analysis of functionally graded plates. J Sound Vib 333:5786–5802
54. Chandra N, Raja S, Gopal K (2015) A comprehensive vibroacoustic parametric analysis and ranking of functionally graded materials. Int J Appl Mech 7:1550072
55. George N, Pitchaimani J, Murigendrappa S, Lenin Babu M (2018) Vibro-acoustic behavior of functionally graded carbon nanotube reinforced polymer nanocomposite plates. Proc Inst Mech Eng Part L J Mater Des Appl 232:566–581
56. Elmallawany A (1985) Calculation of sound insulation of ribbed panels using statistical energy analysis. Appl Acoust 18:271–281
57. Sun Z, Sun J, Wang C, Dai Y (1996) Dynamic vibration absorbers used for increasing the noise transmission loss of aircraft panels. Appl Acoust 48:311–321
58. Ng C, Zheng H (1998) Sound transmission through double-leaf corrugated panel constructions. Appl Acoust 53:15–34
59. Yuan M, Ji H, Qiu J, Ma T (2012) Active control of sound transmission through a stiffened panel using a hybrid control strategy. J Intell Mater Syst Struct 23:791–803
60. Xin F, Lu T (2012) Sound radiation of parallelly stiffened plates under convected harmonic pressure excitation. Sci China Technol Sci 55:496–500
61. Zheng H, Wei Z (2013) Vibroacoustic analysis of stiffened plates with nonuniform boundary conditions. Int J Appl Mech 5:1350046
62. Jin YQ, Pang FZ, Tang D, Xie XZ (2013) Sound transmission through lightweight metallic plate by Fourier transform method. Adv Mater Res 676:325–329
63. Ou D, Mak C, Deng S (2013) Prediction of the sound transmission loss of a stiffened window. Build Serv Eng Res Technol 34:359–368
64. Zhou H-A, Wang X-M, Mei Y-L (2014) Theoretical analysis of the sound absorption characteristics of periodically stiffened micro-perforated plates. Acta Mech Sin 30:714–726
65. Chen Z, Fan L, Zhang S-Y, Zhang H, Li X-J, Ding J (2015) An open-structure sound insulator against low-frequency and wideband acoustic waves. Appl Phys Express 8:107301
66. Ou D (2015) Low frequency sound insulation analysis and evaluation of stiffened building structures. Build Environ 94:802–809
67. Ford R, Lord P, Williams P (1967) The influence of absorbent linings on the transmission loss of double-leaf partitions. J Sound Vib 5:22–28
68. Cummings A (1979) The effects of external lagging on low frequency sound transmission through the walls of rectangular ducts. J Sound Vib 67:187–201
69. Hovem JM (1981) Transmission of sound through a porous disk. Appl Phys Lett 39:590–591

70. Hasheminejad SM, Avazmohammadi R (2006) Acoustic diffraction by a pair of poroelastic cylinders. ZAMM J Appl Math Mech Z Angew Math Mech Appl Math Mech 86:589–605
71. Dupont T, Leclaire P, Sicot O, Gong XL, Panneton R (2011) Acoustic properties of air-saturated porous materials containing dead-end porosity. J Appl Phys 110:094903
72. Hung T-C, Huang J-S, Wang Y-W, Lin K-Y (2014) Inorganic polymeric foam as a sound absorbing and insulating material. Constr Build Mater 50:328–334
73. Huq MM, Chen P-Q, Hsieh C-T, Yang H-C, Tasi T-P (2016) Sound transmission loss from polyvinyl acetate polymer mixed with different porous carbons. Microporous Mesoporous Mater 232:184–188
74. Fang Y, Zhang X, Zhou J (2017) Sound transmission through an acoustic porous metasurface with periodic structures. Appl Phys Lett 110:171904
75. Wang L, Zhang F-S (2017) Characterization of a novel sound absorption material derived from waste agricultural film. Constr Build Mater 157:237–243
76. Fang Y, Zhang X, Zhou J (2018) Experiments on reflection and transmission of acoustic porous metasurface with composite structure. Compos Struct 185:508–514
77. Teagle-Hernandez A, Ohtmer O, Nguyen D (2019) Mathematical modeling of porous medium for sound absorption simulations II: wave propagation and interface conditions. J Appl Math Phys 7:2780–2795
78. Ma F, Wu JH, Huang M (2015) Resonant modal group theory of membrane-type acoustical metamaterials for low-frequency sound attenuation. Eur Phys J Appl Phys 71:30504
79. Li J, Zhou X, Huang G, Hu G (2016) Acoustic metamaterials capable of both sound insulation and energy harvesting. Smart Mater Struct 25:045013
80. Guild MD, García-Chocano VM, Sánchez-Dehesa J, Martin TP, Calvo DC, Orris GJ (2016) Aerogel as a soft acoustic metamaterial for airborne sound. Phys Rev Appl 5:034012
81. Ma F, Huang M, Wu JH (2017) Ultrathin lightweight plate-type acoustic metamaterials with positive lumped coupling resonant. J Appl Phys 121:015102
82. Jung JW, Kim JE, Lee JW (2018) Acoustic metamaterial panel for both fluid passage and broadband soundproofing in the audible frequency range. Appl Phys Lett 112:041903
83. Zhang X, Zhang H, Chen Z, Wang G (2018) Simultaneous realization of large sound insulation and efficient energy harvesting with acoustic metamaterial. Smart Mater Struct 27:105018
84. Liao Y, Chen Y, Huang G, Zhou X (2018) Broadband low-frequency sound isolation by lightweight adaptive metamaterials. J Appl Phys 123:091705
85. Chen S, Fan Y, Fu Q, Wu H, Jin Y, Zheng J, Zhang F (2018) A review of tunable acoustic metamaterials. Appl Sci 8:1480
86. Van Belle L, Claeys C, Deckers E, Desmet W (2019) The impact of damping on the sound transmission loss of locally resonant metamaterial plates. J Sound Vib 461:114909
87. Edwards WT, Chang CM, McKnight G, Sorensen A, Nutt SR (2020) Transmission loss and dynamic response of hierarchical membrane-type acoustic metamaterials. J Vib Acoust. https://doi.org/10.1115/1.4045789
88. Akishita S, Mitani Y-I, Miyaguchi H (1994) Sound transmission control through rectangular plate by using piezoelectric ceramics as actuators and sensors. J Intell Mater Syst Struct 5:371–378
89. Tan C, Hird C (1997) Active control of the sound field of a constrained panel by an electromagnetic actuator—an experimental study. Appl Acoust 52:31–51
90. Green K, Leo DJ (2000) Piezoelectric-actuated vibroacoustic absorbers for interior noise control. J Intell Mater Syst Struct 11:910–920
91. Chen K-T, Chiang K-T, Huang S-M, Tsai B-C (2002) Active vibration control for the improvement of sound transmission loss through a square plate. Build Acoust 9:289–301
92. Nguyen C, Pietrzko S (2007) Vibroacoustic FE analysis of an adaptive plate with PZT actuator/sensor pairs connected to a multiple-mode, electric shunt system. Finite Elem Anal Des 43:1120–1134
93. Yu X, Zhu H, Rajamani R, Stelson KA (2007) Acoustic transmission control using active panels: an experimental study of its limitations and possibilities. Smart Mater Struct 16:2006
94. Larbi W, Deü J-F, Ohayon R, Sampaio R (2014) Coupled FEM/BEM for control of noise radiation and sound transmission using piezoelectric shunt damping. Appl Acoust 86:146–153
95. Sanada A, Higashiyama K, Tanaka N (2015) Active control of sound transmission through a rectangular panel using point-force actuators and piezoelectric film sensors. J Acoust Soc Am 137:458–469
96. Kaizuka T, Tanaka N, Nakano K (2016) Active control of sound transmission using structural modal filters. J Sound Vib 381:14–29
97. Zhang H, Xiao Y, Wen J, Yu D, Wen X (2016) Ultra-thin smart acoustic metasurface for low-frequency sound insulation. Appl Phys Lett 108:141902
98. Langfeldt F, Gleine W (2019) Membrane-and plate-type acoustic metamaterials with elastic unit cell edges. J Sound Vib 453:65–86
99. Guyader J, Boisson C, Lesueur C, Millot P (1986) Sound transmission by coupled structures: application to flanking transmission in buildings. J Sound Vib 106:289–310
100. Craik R, Steel J, Evans D (1991) Statistical energy analysis of structure-borne sound transmission at low frequencies. J Sound Vib 144:95–107
101. Frampton K, Clark R (1996) Transmission of stochastic pressures through an aeroelastic plate into a cavity. In: 37th Structure, structural dynamics and materials conference. pp 1445
102. Sakuma T, Oshima T (2001) Numerical vibro-acoustic analysis of sound insulation performance of wall members based on a 3-D transmission model with a membrane/plate. Acoust Sci Technol 22:367–369
103. Chen J, Kao D (2016) Sound attenuation of membranes loaded with square frame-shaped masses. Math Probl Eng. https://doi.org/10.1155/2016/1740236
104. Chen K, Chen Y, Lin K, Weng C (1998) The improvement on the transmission loss of a duct by adding Helmholtz resonators. Appl Acoust 54:71–82
105. Hosseini-Toudeshky H, Mofakhami M, Yarmohammadi R (2009) Sound transmission between partitioned contiguous enclosures. Proc Inst Mech Eng Part C J Mech Eng Sci 223:1091–1101
106. Lee Y, Li Q, Leung A, Su R (2012) The jump phenomenon effect on the sound absorption of a nonlinear panel absorber and sound transmission loss of a nonlinear panel backed by a cavity. Nonlinear Dyn 69:99–116
107. Koju V, Rowe E, Robertson WM (2014) Extraordinary acoustic transmission mediated by Helmholtz resonators. AIP Adv 4:077132
108. Chen Y, Huang G, Zhou X, Hu G, Sun C-T (2014) Analytical coupled vibroacoustic modeling of membrane-type acoustic metamaterials: plate model. J Acoust Soc Am 136:2926–2934
109. Langfeldt F, Riecken J, Gleine W, Von Estorff O (2016) A membrane-type acoustic metamaterial with adjustable acoustic properties. J Sound Vib 373:1–18
110. Ma F, Huang M, Wu JH (2017) Acoustic metamaterials with synergetic coupling. J Appl Phys 122:215102
111. Chen Y, Jin G, Feng Z, Liu Z (2017) Modeling and vibro-acoustic analysis of elastically restrained panel backed by irregular sound space. J Sound Vib 409:201–216

112. Liu Y, Du J (2018) Structural-acoustic interaction of a three-dimensional panel–cavity–duct system with non-uniform boundary restraints. J Fluids Struct 79:94–114
113. Chin CS, Ji X (2019) Analytical modelling of structure-borne sound transmission through I-junction using Chebyshev–Ritz method on cascaded rectangular plate–cavity system. Appl Acoust 143:171–182
114. Wöhle W, Beckmann T, Schreckenbach H (1981) Coupling loss factors for statistical energy analysis of sound transmission at rectangular structural slab joints, part I. J Sound Vib 77:323–334
115. Wöhle W, Beckmann T, Schreckenbach H (1981) Coupling loss factors for statistical energy analysis of sound transmission at rectangular structural slab joints, part II. J Sound Vib 77:335–344
116. Chen K, Jan S (2001) Sound transmission loss of thick perforated panels. Build Acoust 8:41–56
117. Villot M, Guigou C, Gagliardini L (2001) Predicting the acoustical radiation of finite size multi-layered structures by applying spatial windowing on infinite structures. J Sound Vib 245:433–455
118. Xiao Y, Wen J, Wen X (2012) Sound transmission loss of metamaterial-based thin plates with multiple subwavelength arrays of attached resonators. J Sound Vib 331:5408–5423
119. Oudich M, Zhou X, Badreddine Assouar M (2014) General analytical approach for sound transmission loss analysis through a thick metamaterial plate. J Appl Phys 116:193509
120. Oudich M, Li Y (2017) Tunable sub-wavelength acoustic energy harvesting with a metamaterial plate. J Phys D Appl Phys 50:315104
121. Robin O, Berry A (2018) Estimating the sound transmission loss of a single partition using vibration measurements. Appl Acoust 141:301–306
122. Bechert DW, Michel U, Pfizenmaier E (1978) Experiments on the transmission of sound through jets. AIAA J 16:873–874
123. Dimitriadis EK, Fuller C (1991) Active control of sound transmission through elastic plates using piezoelectric actuators. AIAA J 29:1771–1777
124. Wu SF, Maestrello L (1995) Responses of finite baffled plate to turbulent flow excitations. AIAA J 33:13–19
125. Dockumaci E (1998) An exact transfer matrix formulation of plane sound wave transmission in inhomogeneous ducts. J Sound Vib 217:869–882
126. Dokumaci E (1998) On transmission of sound in circular and rectangular narrow pipes with superimposed mean flow. J Sound Vib 210:375–389
127. Xin F, Lu T (2010) Analytical modeling of sound transmission across finite aeroelastic panels in convected fluids. J Acoust Soc Am 128:1097–1107
128. Naify CJ, Chang C-M, McKnight G, Nutt S (2011) Transmission loss of membrane-type acoustic metamaterials with coaxial ring masses. J Appl Phys 110:124903
129. Wang C (2015) Modal sound transmission loss of a single leaf panel: effects of inter-modal coupling. J Acoust Soc Am 137:3514–3522
130. Wang T, Sheng M, Qin Q (2017) Sound transmission loss through metamaterial plate with lateral local resonators in the presence of external mean flow. J Acoust Soc Am 141:1161–1169
131. Yamamoto T (2018) Acoustic metamaterial plate embedded with Helmholtz resonators for extraordinary sound transmission loss. J Appl Phys 123:215110
132. Bravo T, Maury C, Pinhède C (2012) Sound absorption and transmission through flexible micro-perforated panels backed by an air layer and a thin plate. J Acoust Soc Am 131:3853–3863
133. Low HK (1974) Prediction and measurements of airborne sound transmission through concrete structures. Archit Sci Rev 17:5–9
134. Osipov A, Vermeir G (1996) Sound transmission in buildings with elastic layers at joints. Appl Acoust 49:141–162
135. Hopkins C (1997) Sound transmission across a separating and flanking cavity wall construction. Appl Acoust 52:259–272
136. Ou D, Mak CM (2011) Experimental validation of the sound transmission of rectangular baffled plates with general elastic boundary conditions. J Acoust Soc Am 129:EL274–EL279
137. Reynders E, Langley RS, Dijckmans A, Vermeir G (2014) A hybrid finite element–statistical energy analysis approach to robust sound transmission modeling. J Sound Vib 333:4621–4636
138. Wu F, He Z, Liu G, Li G, Cheng A (2016) A novel hybrid ES-FE-SEA for mid-frequency prediction of transmission losses in complex acoustic systems. Appl Acoust 111:198–204
139. Xie X, Zheng H, Qu Y (2016) A variational formulation for vibro-acoustic analysis of a panel backed by an irregularly-bounded cavity. J Sound Vib 373:147–163
140. Dammak K, Koubaa S, El Hami A, Walha L, Haddar M (2019) Numerical modelling of vibro-acoustic problem in presence of uncertainty: application to a vehicle cabin. Appl Acoust 144:113–123
141. Hoshi K, Hanyu T, Okuzono T, Sakagami K, Yairi M, Harada S, Takahashi S, Ueda Y (2020) Implementation experiment of a honeycomb-backed MPP sound absorber in a meeting room. Appl Acoust 157:107000
142. Parrott TL, Zorumski WE (1992) Sound transmission through a high-temperature acoustic probe tube. AIAA J 30:318–323
143. Yu G, Li D, Cheng L (2008) Effect of internal resistance of a Helmholtz resonator on acoustic energy reduction in enclosures. J Acoust Soc Am 124:3534–3543
144. Rocha TL, Dias M (2015) Improved sound transmission loss in an automotive component using piezoceramic patches and dissipative shunt circuits. J Intell Mater Syst Struct 26:476–786
145. Geng Q, Li Y (2016) Solutions of dynamic and acoustic responses of a clamped rectangular plate in thermal environments. J Vib Control 22:1593–1603
146. Craik RJ (1990) Sound transmission paths through a statistical energy analysis model. Appl Acoust 30:45–55
147. Wu T, Dandapani A (1994) A boundary element solution for sound transmission through thin panels. J Sound Vib 171:145–157
148. Bretagne A, Tourin A, Leroy V (2011) Enhanced and reduced transmission of acoustic waves with bubble meta-screens. Appl Phys Lett 99:221906
149. Zhang Y, Wen J, Zhao H, Yu D, Cai L, Wen X (2013) Sound insulation property of membrane-type acoustic metamaterials carrying different masses at adjacent cells. J Appl Phys 114:063515
150. Song A-L, Chen T-N, Wang X-P, Wan L-L (2016) Waveform-preserved unidirectional acoustic transmission based on impedance-matched acoustic metasurface and phononic crystal. J Appl Phys 120:085106
151. Wang F, Chen T, Wang X, Bao K, Wan L (2017) A membrane-type acoustic metamaterial muffler. Int J Mod Phys B 31:1750049
152. Gao N, Hou H (2017) Low frequency acoustic properties of a honeycomb-silicone rubber acoustic metamaterial. Mod Phys Lett B 31:1750118
153. Li S, Mao D, Huang S, Wang X (2018) Enhanced transmission loss in acoustic materials with micro-membranes. Appl Acoust 130:92–98
154. Liu Y, Du J (2019) Vibroacoustic characteristics and sound attenuation analyses of a duct–membrane system coupled with strip masses. J Vib Control. https://doi.org/10.1177/1077546319873459
155. Boulvert J, Cavalieri T, Costa-Baptista J, Schwan L, Romero-García V, Gabard G, Fotsing ER, Ross A, Mardjono J, Groby J-P

(2019) Optimally graded porous material for broadband perfect absorption of sound. J Appl Phys 126:175101
156. Gerretsen E (1979) Calculation of the sound transmission between dwellings by partitions and flanking structures. Appl Acoust 12:413–433
157. Vaicaitis R, Grosveld F, Mixson J (1985) Noise transmission through aircraft panels. J Aircr 22:303–310
158. Steel J (1994) Sound transmission between plates in framed structures. J Sound Vib 178:379–394
159. Osipov A, Mees P, Vermeir G (1997) Low-frequency airborne sound transmission through single partitions in buildings. Appl Acoust 52:273–288
160. Chiello O, Sgard F, Atalla N (2003) On the use of a component mode synthesis technique to investigate the effects of elastic boundary conditions on the transmission loss of baffled plates. Comput Struct 81:2645–2658
161. Trevathan JW, Pearse JR (2005) The significance of the incident sound field on the sound transmission loss of a finite panel. Build Acoust 12:225–235
162. Vinokur R (2006) Mechanism and calculation of the niche effect in airborne sound transmission. J Acoust Soc Am 119:2211–2219
163. Crocker MJ, Battacharya M, Price A (1971) Sound and vibration transmission through panels and tie beams using statistical energy analysis. J Eng Ind 93:775–781
164. Dijckmans A (2016) Wave based modeling of airborne flanking transmission across suspended ceilings. Dimensions 1:1
165. Ang LYL, Koh YK, Lee HP (2019) Plate-type acoustic metamaterials: evaluation of a large-scale design adopting modularity for customizable acoustical performance. Appl Acoust 149:156–170
166. Sanada A, Tanaka N (2012) Theoretical and experimental study on active sound transmission control based on single structural mode actuation using point force actuators. J Acoust Soc Am 132:767–778
167. Poblet-Puig J, Rodríguez-Ferran A (2013) Modal-based prediction of sound transmission through slits and openings between rooms. J Sound Vib 332:1265–1287
168. Yu X, Cheng L, Guyader J-L (2014) On the modeling of sound transmission through a mixed separation of flexible structure with an aperture. J Acoust Soc Am 135:2785–2796
169. Yairi M, Koga T, Takebayashi K, Sakagami K (2014) Transmission of a spherical sound wave through a single-leaf wall: mass law for spherical wave incidence. Appl Acoust 75:67–71
170. Djojodihardjo H (2015) Vibro-acoustic analysis of the acoustic–structure interaction of flexible structure due to acoustic excitation. Acta Astronaut 108:129–145
171. Yuan M, Qiu J, Ji H, Zhou W, Ohayon R (2015) Active control of sound transmission using a hybrid/blind decentralized control approach. J Vib Control 21:2661–2684
172. Liu B, Jiang Y, Chang D (2017) Sound transmission of a spherical sound wave through a finite plate. J Sound Vib 410:209–216
173. Shi S, Su Z, Jin G, Liu Z (2018) Vibro-acoustic modeling and analysis of a coupled acoustic system comprising a partially opened cavity coupled with a flexible plate. Mech Syst Signal Process 98:324–343
174. Wang K, Tao J, Qiu X (2018) Boundary control of sound transmission into a cavity through its opening. J Sound Vib. https://doi.org/10.1016/j.jsv.2018.11.006
175. Toyoda M, Ishikawa S (2019) Frequency-dependent absorption and transmission boundary for the finite-difference time-domain method. Appl Acoust 145:159–166
176. Meidinger N, Legrain I (1997) Comparison of computational and experimental results in vibroacoustic active control using piezoelectric film technology. Aerosp Sci Technol 1:573–580
177. Gardonio P, Bianchi E, Elliott S (2004) Smart panel with multiple decentralized units for the control of sound transmission. Part I: theoretical predictions. J Sound Vib 274:163–192
178. Gardonio P, Bianchi E, Elliott S (2004) Smart panel with multiple decentralized units for the control of sound transmission. Part II: design of the decentralized control units. J Sound Vib 274:193–213
179. Bianchi E, Gardonio P, Elliott S (2004) Smart panel with multiple decentralized units for the control of sound transmission. Part III: control system implementation. J Sound Vib 274:215–232
180. Wang X (2010) Theory of resonant sound transmission through small apertures on periodically perforated slabs. J Appl Phys 108:064903
181. Jin G, Feng N, Yang T (2011) Control strategies and mechanisms for active control of sound transmission into a vibroacoustic enclosure. J Mar Sci Appl 10:206–214
182. Chen Y, Huang G, Zhou X, Hu G, Sun C-T (2014) Analytical coupled vibroacoustic modeling of membrane-type acoustic metamaterials: membrane model. J Acoust Soc Am 136:969–979
183. Sharma GS, Skvortsov A, MacGillivray I, Kessissoglou N (2017) Sound transmission through a periodically voided soft elastic medium submerged in water. Wave Motion 70:101–112
184. Tian H, Tong D, Tao Y (2018) Analytical approach of membrane-type acoustic metamaterial with ring masses. Multidiscip Model Mater Struct 14:828–836
185. Langfeldt F, Gleine W, von Estorff O (2018) An efficient analytical model for baffled, multi-celled membrane-type acoustic metamaterial panels. J Sound Vib 417:359–375
186. Lee CH, Han MJ, Park TW, Kim YS, Shin KD (2020) A comparative study on the transmission loss of helmholtz resonator and quarter, half, conical half-wave resonator using acoustic analysis model. Int J Mech Eng Robot Res 9:153–157
187. Crocker M, Price A (1969) Sound transmission using statistical energy analysis. J Sound Vib 9:469–486
188. Minten M, Cops A, Wijnants F (1987) The sound transmission loss of a single panel measured with the two-microphone and the conventional method-comparison with the statistical energy analysis model. Appl Acoust 22:281–295
189. Howard CQ (2008) Transmission loss of a panel with an array of tuned vibration absorbers. Acoust Aust 36:98–103
190. Estrada H, Candelas P, Uris A, Belmar F, Meseguer F, de Abajo FJG (2011) Sound transmission through perforated plates with subwavelength hole arrays: a rigid-solid model. Wave Motion 48:235–242
191. Yang M, Li Y, Meng C, Fu C, Mei J, Yang Z, Sheng P (2015) Sound absorption by subwavelength membrane structures: a geometric perspective. C R Méc 343:635–644
192. Wareing RR, Davy JL, Pearse JR (2015) Variations in measured sound transmission loss due to sample size and construction parameters. Appl Acoust 89:166–177
193. Shen C, Xie Y, Li J, Cummer SA, Jing Y (2016) Asymmetric acoustic transmission through near-zero-index and gradient-index metasurfaces. Appl Phys Lett 108:223502
194. Zhang C, Qin M, Zou H, Qiu X (2019) Secondary source and error sensing strategies for the active control of sound transmission through a small opening. J Sound Vib 464:114973
195. Li H, Ma J, Zhu J, Chen B (2019) Numerical and experimental studies on inclined incidence parametric sound propagation. Shock Vib. https://doi.org/10.1155/2019/2984191
196. Du L, Lau S-K, Lee SE (2019) Experimental study on sound transmission loss of plenum windows. J Acoust Soc Am 146:EL489–EL495
197. Wrona S, Mazur K, Rzepecki J, Chrapońska A, Pawełczyk M (2019) Sound transmission through a thin plate with shaped frequency response. Arch Acoust 44:731–738
198. Szechenyi E (1971) Sound transmission through cylinder walls using statistical considerations. J Sound Vib 19:83–94

199. Elmallawany A (1982) Improvement of the method of statistical energy analysis for the calculation of sound insulation at low frequencies. Appl Acoust 15:341–345
200. Santos P, Tadeu A (2002) Acoustic insulation provided by a single wall separating two contiguous tunnels via BEM. J Sound Vib 257:945–965
201. Desmet W, Pluymers B, Sas P (2003) Vibro-acoustic analysis procedures for the evaluation of the sound insulation characteristics of agricultural machinery cabins. J Sound Vib 266:407–441
202. Langley RS, Cordioli JA (2009) Hybrid deterministic-statistical analysis of vibro-acoustic systems with domain couplings on statistical components. J Sound Vib 321:893–912
203. Wu C, Wang X, Tang H (2007) Transmission loss prediction on SIDO and DISO expansion-chamber mufflers with rectangular section by using the collocation approach. Int J Mech Sci 49:872–877
204. Ruber K, Kanapathipillai S, Randall R (2015) Sound transmission loss of a panel backed by a small enclosure. J Low Freq Noise Vib Act Control 34:549–567
205. Wang C (2015) Modal sound transmission loss of a single leaf panel: asymptotic solutions. J Acoust Soc Am 138:3964–3975
206. Huang T-Y, Shen C, Jing Y (2016) Membrane-and plate-type acoustic metamaterials. J Acoust Soc Am 139:3240–3250
207. Hartmann T, Morita S, Tanner G, Chappell DJ (2018) High-frequency structure-and air-borne sound transmission for a tractor model using dynamical energy analysis. Wave Motion 87:132–150
208. Takahashi K, Yairi M, Okuzono T, Sakagami K, Toyoda M (2019) Basic study on relationship between airborne sound transmission and structure-borne sound radiation of a finite elastic plate. Acoust Sci Technol 40:52–55
209. Gai X-L, Xing T, Kang Z-X, Li X-H, Zhang B, Cai Z-N, Wang F, Guan X-W (2020) Study on sound insulation performance of the periodic arrangement expansion chambers structure with built-in micro-perforated panel. Appl Acoust 161:107187
210. Fuller CR (1990) Active control of sound transmission/radiation from elastic plates by vibration inputs: i. Analysis. J Sound Vib 136:1–15
211. Metcalf V, Fuller CR, Silcox R, Brown D (1992) Active control of sound transmission/radiation from elastic plates by vibration inputs, II: experiments. J Sound Vib 153:387–402
212. Zhang H, Wen J, Xiao Y, Wang G, Wen X (2015) Sound transmission loss of metamaterial thin plates with periodic subwavelength arrays of shunted piezoelectric patches. J Sound Vib 343:104–120
213. Gu Y, Cheng Y, Wang J, Liu X (2015) Controlling sound transmission with density-near-zero acoustic membrane network. J Appl Phys 118:024505
214. Xiao S, Ma G, Li Y, Yang Z, Sheng P (2015) Active control of membrane-type acoustic metamaterial by electric field. Appl Phys Lett 106:091904
215. Kaizuka T, Nakano K (2018) Active control of sound transmission into an enclosure using structural modal filters. J Sound Vib 431:328–345
216. Zhang H, Xu G-L, Yin W, Wang H-B, Ge P (2018) Numerical investigation on the transmission loss of skin panels based on the intelligent PSO-CGA algorithm. IEEE Access, DOI
217. Roca D, Yago D, Cante J, Lloberas-Valls O, Oliver J (2018) Computational design of locally resonant acoustic metamaterials. Comput Methods Appl Mech Eng 345:161–182
218. Wang F, Chen Z, Wu C, Yang Y (2019) Prediction on sound insulation properties of ultrafine glass wool mats with artificial neural networks. Appl Acoust 146:164–171
219. Dammak K, El Hami A (2019) Multi-objective reliability based design optimization of coupled acoustic-structural system. Eng Struct 197:109389