Applied Innovative Research, ISSN 2581-8198, Vol. 4, Issue 2 - 4, Year 2023

An Experimental Study into Orifice Interaction Effects on Perforated Plates with Bias Flow

Amarjeet Gupta, Vikram, N. K. Jha, R. N. Hota*
Indian Institute of Technology (Indian School of Mines), Dhanbad, Jharkhand

Abstract

Bias flow perforated plates are applied as acoustic liners in gas turbine combustors to mitigate thermoacoustic instabilities. These constitute orifices of small diameters arranged in various patterns. The absorption of sound occurs due to the sound-flow interaction at the orifices of the perforated plate. The vortices created at the edge of the orifice by incident sound are swept away in the jet, and damping occurs by transfer of sound energy to the jet kinetic energy before being dissipated by viscosity into heat. The closely spaced orifices cause interactions between neighboring orifices, influencing the acoustic performance of perforated plates. In this work, perforated plates with bias flow considering the orifice interaction effect are studied regarding the acoustic absorption coefficient. The experimental evaluations are carried out for various orifice pitch with fixed plate porosity. The experimental measurements for orifice interaction effects have also been conducted without bias flow. The effects of the orifice interaction on the sound absorption coefficient are quantified in an in-duct arrangement facility using an impedance tube technique with the standard Two-Load method. The perforated plates of various geometric configurations are fabricated, keeping the fixed diameter of the orifice. The perforated plates having a fixed value of porosity correspond to the different orifice pitches for different configurations. The frequency range is considered 500 Hz to 2500 Hz, which satisfies the geometrical constraints of the impedance tube, as per ASTM standards. The orifice interaction is observed to have an effect on the sound absorption of the bias flow perforated plates.

Keywords : Sound Absorption; Acoustic Damping; Bias Flow

1. Introduction

Perforated plates have various applications under bias flow, mainly in gas turbine combustors, automobile exhaust mufflers, and flow ducts in combustion structures to mitigate thermoacoustic instabilities[1]. Sound absorption occurs due to the sound-flow interaction ateachorifice. Perforated plates consist of an array of orifices. The flow through the orifice and the interaction with the surrounding tube wall and other orifices significantly affect the acoustic properties of these plates. Most of the existing studies considered widely separated perforations to avoid interaction between orifices, while, in practice, the orifices are very often closely separated. Tayong et al.[2] worked out on the effect of orifices interaction and heterogeneity distribution effects (tortuosity) without mean flow. Howe[3] developed a theoretical formula for an infinite plate baffle with infinitesimally thin orifice under bias flow conditions to determine Rayleigh conductivity. Ingard[4] examined the effects on sound absorption considering the orifice interaction. Melling[5] suggested an impedance model by summarizing the

---

Corresponding authors: (rnhota@iitism.ac.in)

existing impedance models. Lee et.al[6] analyzed the acoustic impedance with bias flow of a circular tube having a circular orifice considering the interaction between orifices for various diameter ratios of orifice and tube. They substantiated this effect by measuring the transmission loss. Previous researchers assumed that the acoustic impedance of perforated plates could be obtained through the impedance of a single orifice, but, in practical applications, closely spaced orifices can influence the acoustic performance of the perforated plates greatly. Authors in the past addressed orifice interaction effects in the characterization of the acoustic properties of perforations. However, the acoustic parameter absorption coefficient was not considered. The present study presents the effects of orifice interaction in terms of the sound absorption coefficient. The present work is divided into the sections: experimental measurements, ASTM Two-Load method, and results. The last section mentions key conclusions of the present study.

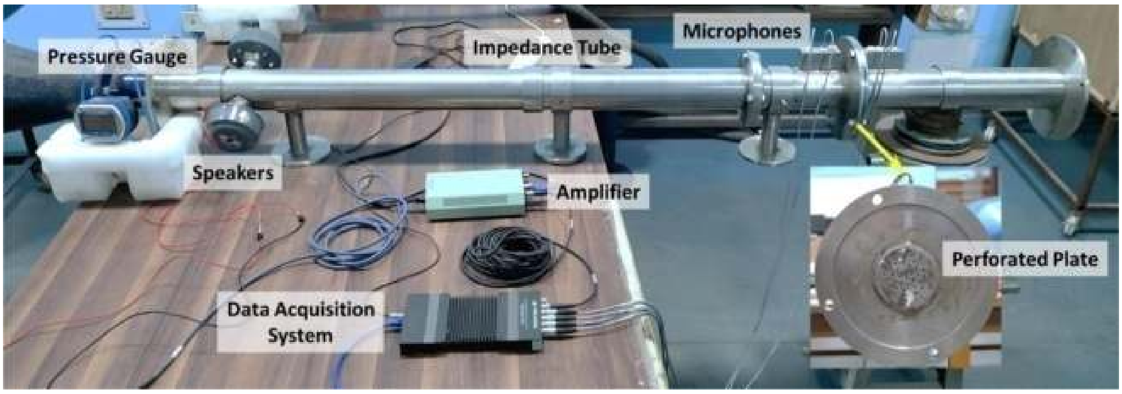


Fig. 1 *Experiment setup*

2. Experimental Measurements

In this section, the experimental work carried out is described. The facility constitutes flow discharge devices, flow control valves, and flow measuring devices. The methodology of acquiring and processing measured data to get the desired acoustic properties is presented.

Figure 1 shows the test facility developed to examine the perforated plates experimentally. The test facility constitutes the following components; Flow discharge devices, settling and plenum chambers, flow measuring devices, sound sources, impedance tubes, bypass ducts, microphones, and data acquisition system.

Figure 2 shows the measurement layout. It consists of an impedance tube with a downstream section, an upstream section, and a perforated plate between them. At one end this setup has a sound source and at the other end there are acoustic loads. Microphones are mounted before and after the perforated element.

3. ASTM Two-Load Method

The "Two Load Method," along with the wavenumber constituting convective terms, is used to characterize the perforated plates in an impedance tube. In the formulation of traveling wave numbers for upstream and downstream portions, mean flow terms of both upstream and downstream are included. The impedance tube configuration is schematically shown in Figure 3 with microphones, a sound source, and present bias flow for two distinguish acousticloads. Four microphones, two on both sides of the test section, are flush-mounted to the circumference of the tube. Sound sources are mounted at specific locations upstream to get plane waves in the impedance tube.

The propagation of these plane waves results in a standing wave pattern, which is measured at four locations simultaneously with the help of microphones and discretized into forward and backward traveling wave components[7]. The transfermatrix elements are then obtained using these decomposed waves in order to characterize the perforated plates. The transfer matrix (four-pole parameter representation) relates acoustic pressure and particle velocities on either side of the test specimen. For the estimation of the absorption coefficient, various loads were employed which are shown in Fig. 4.

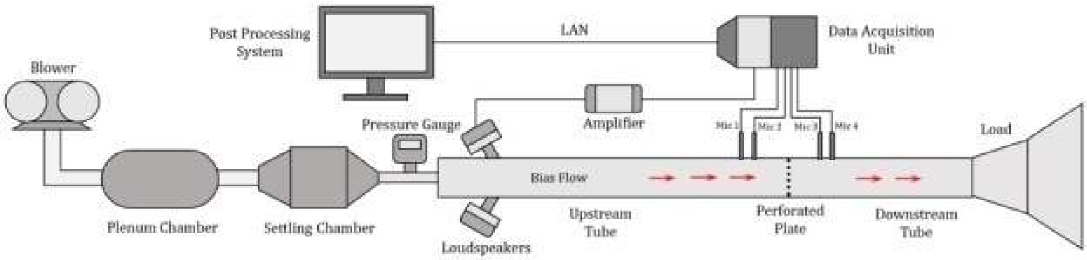


Fig. 2*Measurement setup layout*

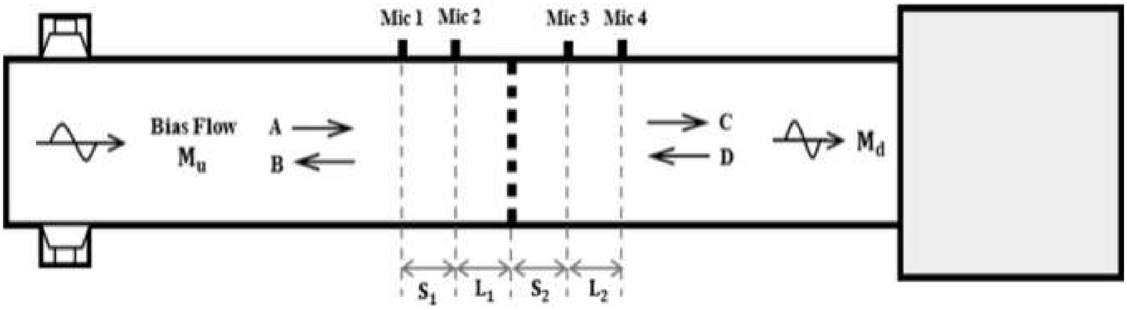


Fig. 3 Schematic of the Two-Load method

Absorption coefficient is the ratio of net energy absorbed by the perforated element to the energy introduced to the test section.With the use of aeroacoustic parameters[8] A_c, B_c, C_c, and D_c with respect to the amplitudes of waves$A$, B, C, and D in the formulation of sound absorption coefficient (α) results in the development of the following equation:

$$\alpha = 1 - \frac{|B_c|^2 + |C_c|^2}{|A_c|^2 + |D_c|^2}$$

The fabricated perforated plates (Fig.5), 80 mm in diameter each in size, 1mm in plate thickness, with 3.2 mm as orifice diameter, was used in all tests and experiments, with 4.96% constant porosity having various pitches between orifices. The details of plate configurations are mentioned in Table 1.

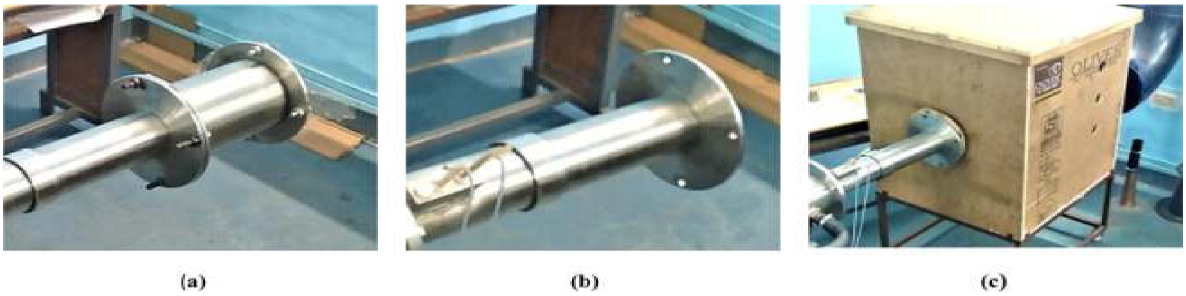
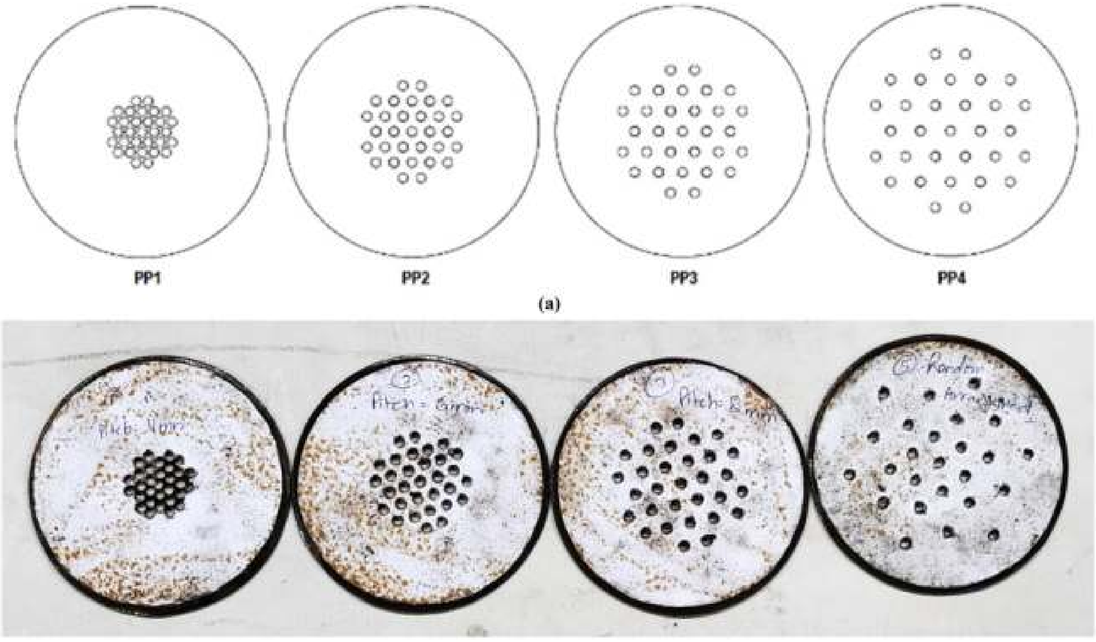


Fig. 4*Acoustic loads (a) expanded (b) open (c) partially anechoic*



(a)

(b)

***Fig. 5.** Perforated plates (a) Schematic (b) Photograph*

4. Results

This section presents the sound absorption coefficient (SAC) of perforated plates fabricated for different pitches. Figure 6 shows the comparison of SAC among the plates without flow. The plate with the lowest pitch value (PP1) has the least absorption in comparison to all the plates with a higher pitch. In the lower frequency range below 700 Hz, absorption is the same for all the plates. With the increased pitch, the curve of absorption coefficient corresponding to the plate with a pitch of 6mm (PP2) shifted upwards appreciably and exhibited maximum value in the entire range of frequency, except below the frequency of 700 Hz. With the further increase in pitch, SAC decreased in the entire range of frequency, and the difference between the SAC of plates PP3 and PP4 is insignificant. The reason behind the least pitch plate having the least amount of absorption could be linked to the interaction effect between orifices[9].

Table 1: Perforated plate configurations

S. No.	Porosity (%)	Pitch (mm)
PP1	4.96	4
PP2	4.96	6
PP3	4.96	8
PP4	4.96	10
PP5	4.96	Random

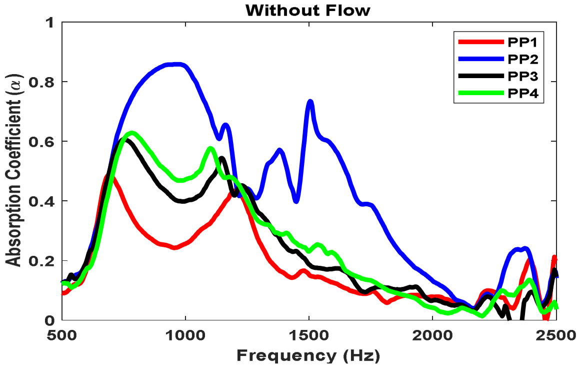
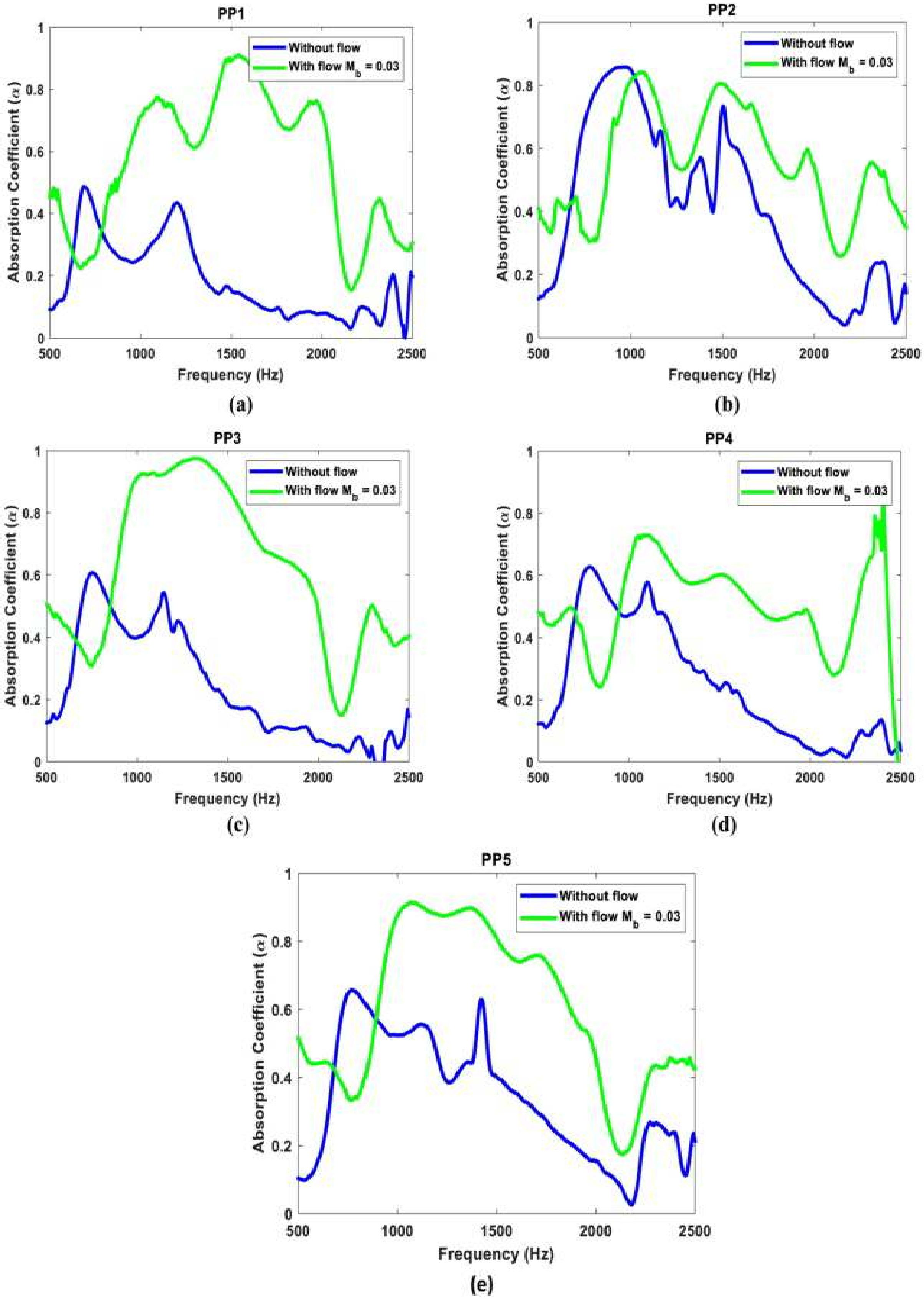


***Fig 6.** Absorption coefficient of perforated plates at* $M_b = 0$



(a) (b) (c) (d) (e)

Fig 7. *Comparison of absorption coefficient for $M_b = 0, 0.03$ at pitch (a) 4mm (b) 6mm (c) 8mm (d) 10mm, and (e) random*

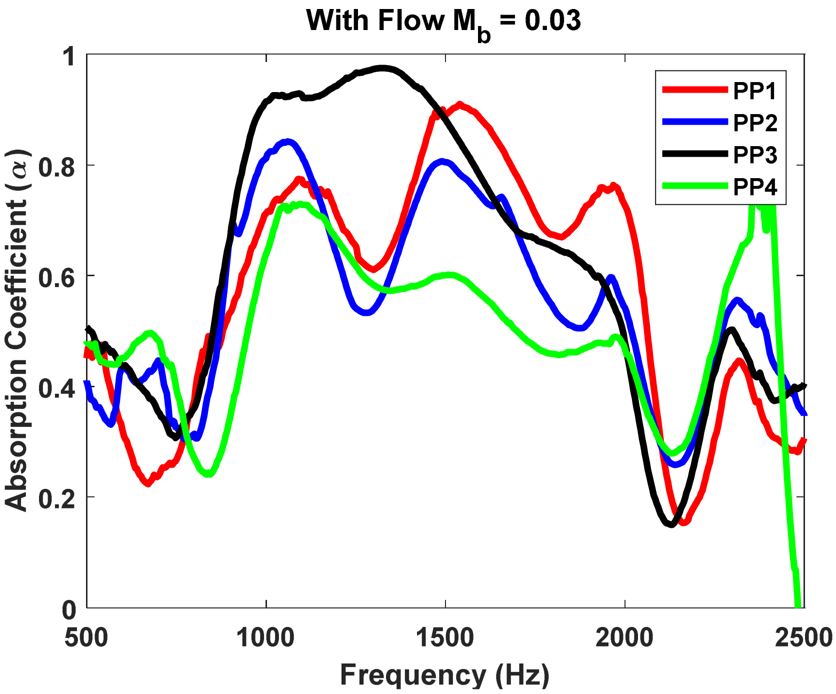


Fig 8. *Comparison of absorption coefficient of perforated plates at M_b = 0.03*

The effects of the introduction of bias flow on the sound absorption for individual plates have been assessed. For all the plates, in comparison to the case without flow, absorption increased throughout the range of frequency investigated, except in the lower frequency range. The absorption coefficient curves for all the plates have a trough at about 700 Hz, which can be attributed to the standing wave formation in the impedance tube[10].

Figure 8 compares all the perforated plates in the presence of bias flow Mach number M_b = 0.03. In comparison to without flow case, all the plates have a higher amount of absorption. However, there are differences among them. The frequency range of dominant absorption is different for all the plates. The mechanism of sound absorption in the presence of flow is due to vortex shedding at the orifices. The nature of vortex shedding is supposed to be different for all the plates in the presence of flow, which is the reason behind different sound absorption ranges.

5. Conclusions

The present study qualifies the sound absorption capabilities of perforated plates of different orifice pitches. Perforated plates were fabricated for various pitch keeping porosity fixed. The Impedance Tube Technique, along with the ASTM Two-Load method was used to get the sound absorption coefficient experimentally. The sound absorption abilities of perforated plates were observed to be sensitive to the pitch distance in both the cases i.e., with and without flow. The absorption coefficient of sound first increases and then decreased with the increase in pitch. The findings of this study can be used to design acoustic liners of fixed porosity with appropriate pitch. Further study could be conducted to establish the mechanism behind dependence of sound absorption on orifice pitch.

Acknowledgment

The authors gratefully acknowledge that the current work (SPR/2020/000086) has been supported by the Department of Science and Technology (Scientific and Useful Profound Research Advancement (DST (SUPRA)), Government of India

References

[1] Eldredge JD, Dowling AP. The absorption of axial acoustic waves by a perforated liner with bias flow. J Fluid Mech. 2003;(485):307-335. doi:10.1017/S0022112003004518

[2] Tayong R. On the holes interaction and heterogeneity distribution effects on the acoustic properties of air-cavity backed perforated plates. Applied Acoustics. 2013;74(12):1492-1498. doi:https://doi.org/10.1016/j.apacoust.2013.05.016

[3] Howe MS. On the theory of unsteady high Reynolds number flow through a circular aperture. Proceedings of the Royal Society A: Mathematical, Physical and Engineering Sciences. 1979;366(1725):205-223. doi:10.1098/rspa.1979.0048

[4] Ingard U. On the Theory and Design of Acoustic Resonators. J Acoust Soc Am. 1953;25(6):1037-1061. doi:10.1121/1.1907235

[5] Melling TH. The acoustic impedance of perforates at medium and high sound pressure levels. J Sound Vib. 1973;29(1):1-65. doi:https://doi.org/10.1016/S0022-460X(73)80125-7

[6] Lee SH, Ih JG, Peat KS. A model of acoustic impedance of perforated plates with bias flow considering the interaction effect. J Sound Vib. 2007;303(3):741-752. doi:https://doi.org/10.1016/j.jsv.2007.02.001

[7] ASTM International. ASTM E2611-17: Standard Test Method for Normal Incidence Determination of Porous Material Acoustical Properties Based on the Transfer Matrix Method. ASTM International. 2017;i:1-14. doi:10.1520/E2611-17

[8] M. L. Munjal. Acoustics of Ducts and Mufflers. 2nd Edition. John Wiley & Sons Ltd.; 2014.

[9] Lahiri C. Acoustic performance of bias flow liners in gas turbine combustors. DLR Deutsches Zentrum furLuft- und Raumfahrt eV - Forschungsberichte. 2014;(39):1-364. doi:10.14279/depositonce-4270

[10] Jha N K, Das D, Tripathi A, Hota RN. Acoustic damping: Analytical prediction with experimental validation of mixed porosity liners and analytical investigation of conical liners. Applied Acoustics. 2019;150. doi:10.1016/ j.apacoust. 2019.02.006