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Efficacy of perforated liners with different porosity: Experimental analysis

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Abstract Perforated liners are one of the most commonly used acoustic dampers for reducing engine noise. This paper describes how different porosity (open area ratios) on a liner can affect the amount of sound reduction achieved. The investigation was conducted on a square channel using eight different porosity liners ranging from under 1% up to 9%. The results from the current setup showed that higher porosity liners performed better at reducing the acoustic signal.

Keywords: Experimental, Acoustic liner, Aeroacoustics

1 Introduction

Combustion engines typically generate significant noise signatures and are a source of noise pollution. One method of reducing such noise is by disrupting the acoustic waves using acoustic dampers - one example of such acoustic dampers are perforated plates known as liners. As air flows through the orifices of the liners (also known as bias flow), an unsteady jet flow is generated which interacts with the acoustic noise [1]. Through viscous dissipations, the acoustic fluctuations are then converted into non-radiating vorticial fluctuations [2]. Even though the fundamental mechanism is understood well enough, many other factors can affect how effective the liners are as acoustic dampers remains poorly understood. Early studies on factors such as multiple layers of liners [2], bias flow Mach number [2], thickness of liner walls [3] and length of pipe system [4] have shown improvement to acoustic damping of the liners.

This paper aims to experimentally study the effect of porosity (open area ratio) of perforated liners in the presence of grazing flow. For this experiment, only cold flow was used for both the grazing flow as well as the bias flow. The design and experimental setup are described in Section 2. The comparison between three different liner conditions, namely Sealed, Helmholtz and Bias flow were conducted and are described in Section 3

2 Experimental Setup

2.1 Electrical heater system

The schematic diagram of the experimental setup is shown in Figure 1. The experiments were conducted on a 5 cm by 5 cm square cross-section tube of length 2.5m, which consist of a 0.2m long liner section with 1m long upstream and downstream section.

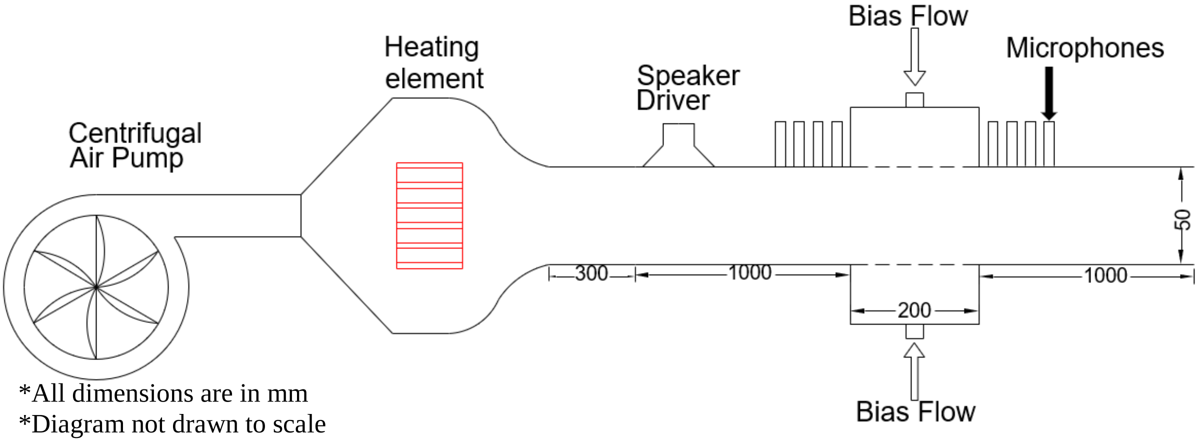

Figure 1:Schematic diagram of experimental setup.

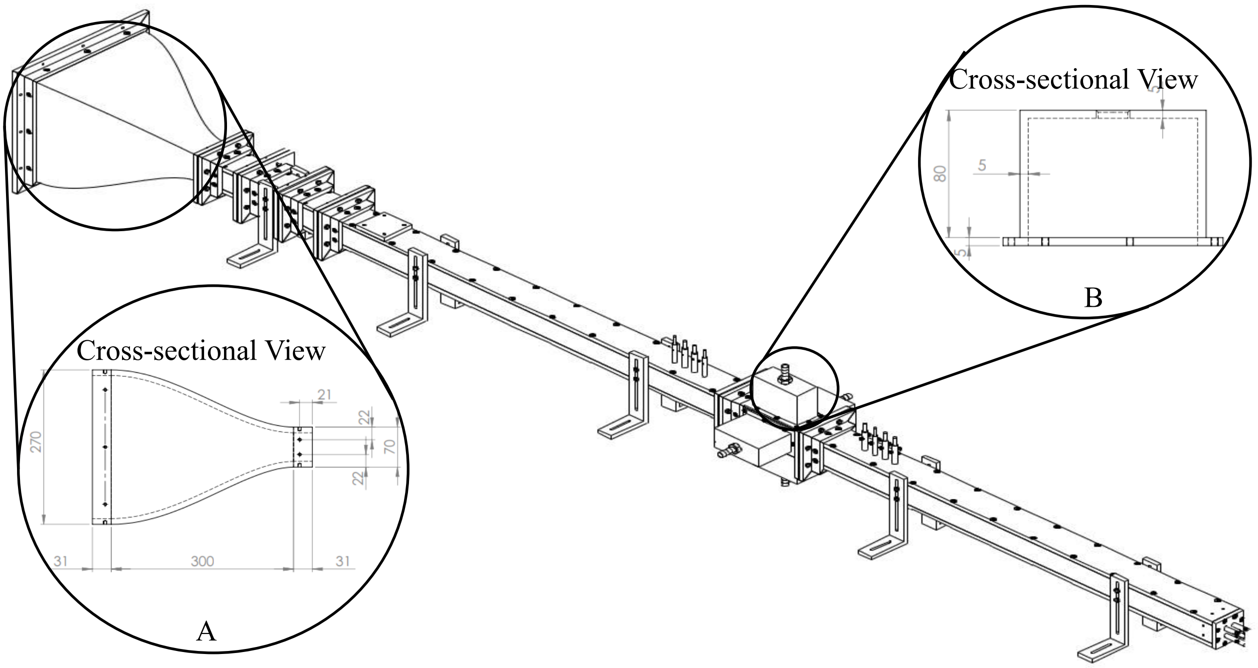

Figure 2: Detailed drawing of impedance tube
(A) Enlarged cross-sectional view of converging section
(B) Enlarged cross-sectional view of plenum chamber

A centrifugal air pump was used to provide the system with a driven mean air flow (also known as the grazing flow). The driven air flow passes through a section of heating elements which heats up the flow when required. The heating elements can heat the airflow up to approximately 70°C, measured at the end of the channel. The driven airflow then passes through the converging section which would accelerate the flow into the square tube (refer to Figure 2-A). Due to the volume flow rate limit of the centrifugal air pump, the maximum grazing flow speed within the channel is approximately 23 m/s.

A speaker driver, powered by a Yokogawa FG200 function generator, is located upstream of the liner section and provides a tonal 300Hz acoustic source with a magnitude of approximately 100 dB. Subsequently four B&K microphones, connected to a National Instrument PXIe-1062Q, are located at equal spacing (25 mm apart) downstream of the liner sections to capture the resulting acoustic signals.

2.2 Liner

Figure 3 shows actual liners used in the experiment. Each liner has 4 identical sides with each side having an even distribution of small circular orifices of diameter 2mm. A total of eight different liners were used for the experiment, with each subsequent liner having a higher porosity (refer to Table 1). Air is fed into the plenums which enclose the liners to produce bias flow through the liners. The plenum chamber provides an even distribution of air across each liner hole (refer to Figure 2-B).

Table 1: List of Liners used

Liner name	Holes Grid	Number of holes	Porosity	Type of holes
A	3 x 4	12	0.75%	Circular
B	3 x 6	18	1.13%	Circular
C	4 x 7	28	1.76%	Circular
D	4 x 10	40	2.51%	Circular
E	5 x 11	55	3.46%	Circular
F	5 x 13	65	4.08%	Circular
G	7 x 13	91	5.72%	Circular
H	9 x 16	144	9.05%	Circular

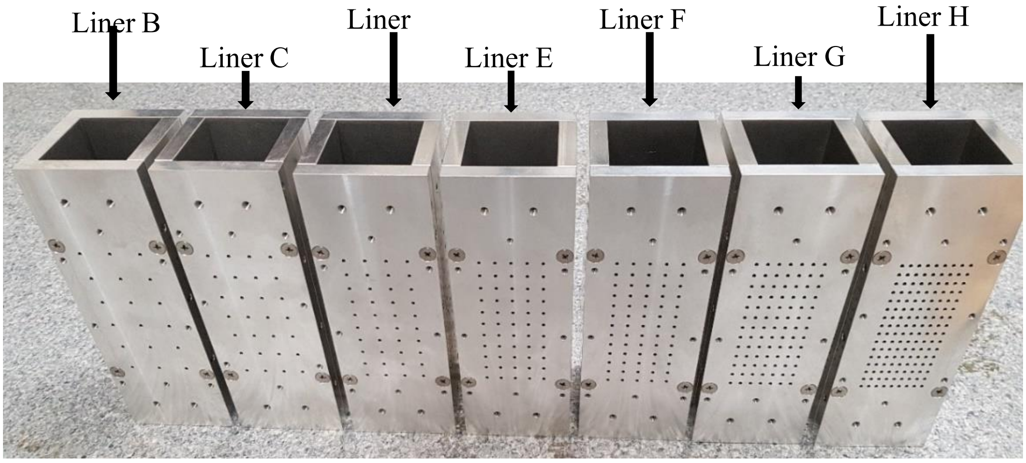

Figure 3: Actual photo of the different liners with increasing open area ratio from left to right

2.2.1 Different bias conditions

The compressed air used for bias flow is supplied by a compressed air tank or a compressor unit. The bias flow rate is controlled using a Dwyer variable area flowmeter (RMC-122-SSV) rated in standard cubic feet per minute [scfm]. The bias flow from the flowmeter is split into 4 equal length tube before entering the plenum chamber. Table 2 shows the bias flow rates used in the experiment, as well as the corresponding bias flow Mach number range from liner A (lowest porosity) to liner H (highest porosity).

2.3 Velocity profiling and Turbulence intensity

Velocity measurements were taken near the start of the upstream section and at the end of the channel to characterize the flow within the channel. Velocity measurement in the horizontal and vertical directions were taken at the end of the channel to obtain the velocity profile within the channel as shown in Figure 4.While velocity measurements at the center of the channel were taken at the speaker port location to obtain the mean velocity (20.9 m/s) and turbulence intensity (0.37221%) of the flow entering the channel shown in Figure 5.

Table 2: Bias flow rate used

Total bias volume flowrate [m^3/s]	Percentage of main flow	Across a single orifice for			
		Liner A		Liner H	
		Velocity [m/s]	Mach number	Velocity [m/s]	Mach number
0.0	0.0%	-	-	-	-
0.00118	2.5%	24.58	0.071	2.05	0.006

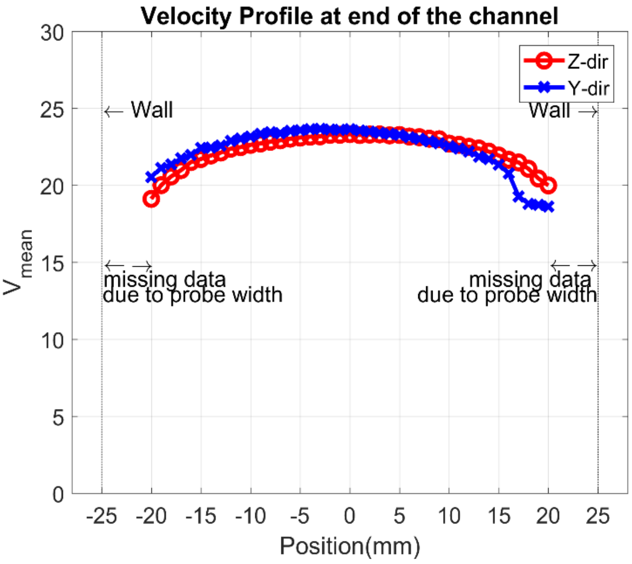

Figure 4: Channel exit velocity profile

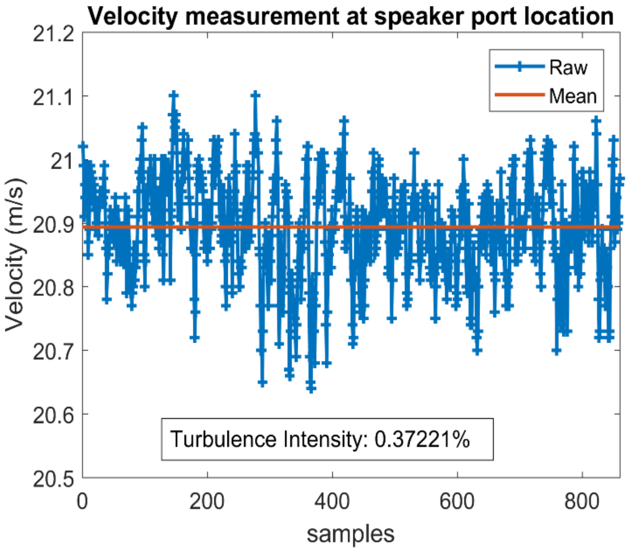

Figure 5: Turbulence intensity measurement

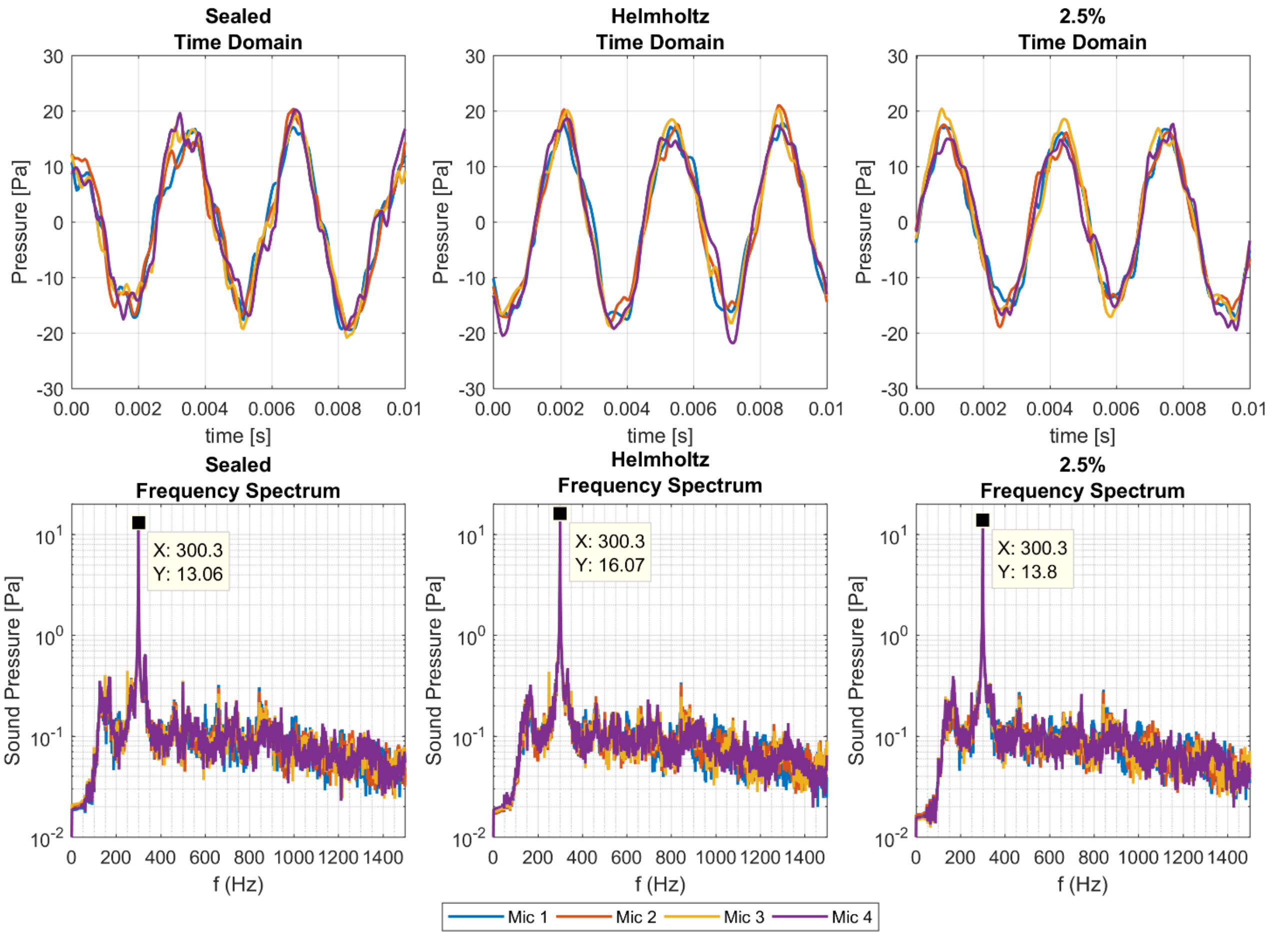

Figure 6: Liner A comparison

3 Results and discussion

Fast Fourier Transform (FFT) was used to analyze the microphone data. Three different cases were used to analyze each liner used, namely Sealed, Helmholtz and 2.5% bias flow. Out of the three cases, two do not involve bias flow which are the Sealed and Helmholtz case. The liner holes are sealed using a firm tape for the Sealed case while for the Helmholtz case the firm tape is remove and replaced with plenum chamber as shown in Figure 2-B. The last case involves pushing air through the liner at 2.5% of main flow volume rate.

3.1 Liner A (lowest Porosity)

Figure 6 shows the comparison of the acoustic pressure from the 3 different cases for liner A. The top row of plots displays the acoustic pressure signal in time domain while the bottom row displays the acoustic pressure in frequency domain. The Sealed case which will be used as the reference, obtained 13.06 Pascal. The Helmholtz cavity amplified the acoustic pressure by approximately 23%. Finally using 2.5% of main flow volume rate, the acoustic pressure decreased by approximately 5%. Despite being a higher amplitude as compared to the Sealed case, it proves that bias flow does help to improve the acoustic damping capability of the liner.

3.2 Comparison between all liners

Figure 7 shows how the porosity effects the sound pressure generated by the acoustic source. For lower porosity, amplification of acoustic pressure is observed. Dampening of acoustic pressure was observed only when the porosity exceeded 1.5%. Upon applying a bias flow of 2.5%, the sound reduction is only slightly improved within a narrow range of porosity between 1.5% to 4%. Beyond 4%, the Helmholtz and 2.5 Bias cases are comparable.

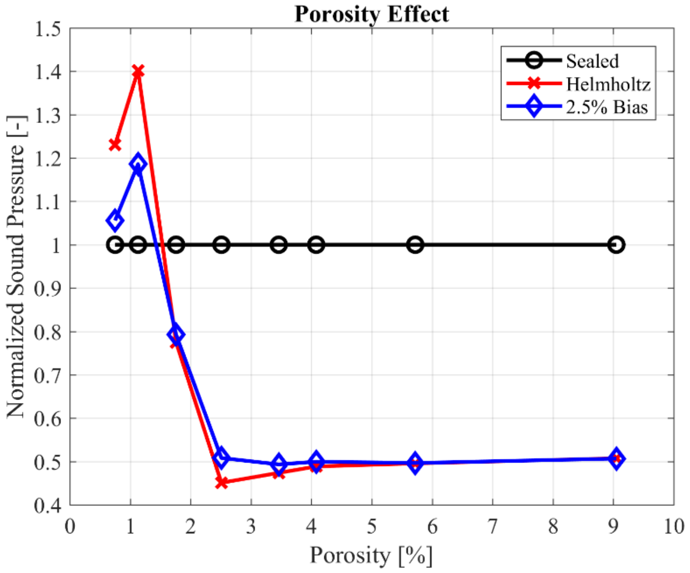

Figure 7: Normalized sound pressure for three different cases across 8 different liners.

4 Conclusion

Results from this study shows that at very low porosity, acoustic amplification occurs instead of damping. Increasing the porosity of the liners improves the acoustic damping capability of the liners. However, there is an optimum porosity that provides the best acoustic, beyond which the performance will level out. The results also show that applying a bias flow seem to improve the acoustic damping of the lower porosity liners, especially between porosity of 1.5% to 4%. The bias flow seems to become ineffective at higher porosity. Further investigations will be conducted to include the effects of the bias flow Mach number, as well as the effectiveness across different acoustic frequencies.

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