VPS VIBRATIONS IN PHYSICAL SYSTEMS

DOI: 10.21008/j.0860-6897.2025.1.12
Vibrations in Physical Systems, 2025, 36(1), 2025112

# Acoustic properties of the absorption silencers with a micro-perforated channel in the air-flow

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**Abstract** Micro-perforated panels (MPPs) are known as thin sheets. There are perforated thickness-through hole with sized in the sub-millimetre range. With holes on such a small scale, the panels alone can provide high acoustic resistance and low acoustic reactance, conducive to effective sound absorption. Micro-perforated liners can be useful for attenuation in the low-frequency noise in ducted. The main objective of the paper is to compare the influence of testing facilities on the measured aeroacoustic performance of tested prototype silencers under an airflow between 4 and 12 m/s. This standard specifies the methods of ISO 7235 for determining the sound power level of the flow noise generated by silencers, the total pressure of silencers, and the insertion loss of silencers with and without airflow by using the substitute object. In this work, we focused on the correlation between the size of the hole in the studied silencers and its acoustic parameters, and also its relation to the insertion loss of silencers.

**Keywords:** silencer, insertion loss, experimental test, aeroacoustic.

## 1. Introduction

Noise pollution is defined as the presence of undesirable sounds generally regarded as bothersome by the majority of individuals. It poses a threat to human health and is a significant contributor to environmental pollution, impacting individuals not only in terms of their physical well-being but also their emotional state. Noise reduction is of utmost importance in societies, and the prevention of noise is an increasingly significant issue in both industry and the environment. Sound reduction in noise-producing sources can be classified as either active or passive. Passive noise reduction systems are preferred over active ones because they are more cost-effective, smaller in size, and may be employed with noise-generating devices in challenging environmental circumstances. Passive noise-control technologies include acoustic silencers, noise barriers, and noise-absorbing panels. Silencers are employed to attenuate the noise emitted by various sources, including internal combustion engines, fans, compressors, turbines, air conditioning systems, and blowers [1]. There are multiple categories of silencers, encompassing reactive, absorptive, and hybrid variants. Reactive silencers, operating on the impedance mismatch concept, redirect sound waves towards the noise source by rapidly expanding or altering the cross-sectional area. The noise reduction mechanism in absorptive silencers relies on the absorption of sound wave energy, which travels through the tube and is transformed into heat by sound-absorbing materials. Hybrid silencers incorporate both absorbent and reactive components to enhance their performance. The design of a silencer is an intricate process that impacts the acoustic and aerodynamic performance of noise-producing devices. Therefore, it is crucial to ensure that the silencer is designed effectively. The key factors considered in the design of the expansion chamber within a silencer include minimising sound reduction within the intended frequency range, minimising pressure loss, determining the optimal geometry, establishing the maximum permitted dimensions, ensuring structural strength, and considering economic concerns [2].

Micro-perforated panels (MPPs) are widely used as sound absorbers in many engineering applications, such as room acoustic absorbers [3–5], environmental noise abatement [6, 7], and noise reduction in flow ducts [8, 9]. MPPs generally consist of a slender metal sheet with evenly spaced perforation holes typically smaller than 1 mm in diameter. The acoustic impedance model proposed by Maa [10] regards the small perforation holes as patterns of short and thin tubes. The MPP can be characterised by specific impedance, which is normalised by $\rho_0 c$, the air characteristic acoustic impedance, and r, the panel porosity. An MPP's specific acoustic impedance ($Z_{MPP}$) is composed of a real part ($Z_{resistance}$) and an imaginary part ($Z_{reactance}$), as given by the equation:

$$Z_{MMP} = Z_{resistance} + Z_{reactance} = r + j\omega m\,, \tag{1}$$

where:

$$r = \frac{32\eta t}{\sigma\rho_0 c d^2}\left[\left(1+\frac{k^2}{32}\right)^{1/2} + \frac{\sqrt{2}}{32}k\frac{d}{t}\right], \tag{2}$$

$$\omega m = \frac{\omega t}{\sigma c}\left[1+\left(1+\frac{k^2}{2}\right)^{-1/2} + 0.85\frac{d}{t}\right], \tag{3}$$

where $r$ and $\omega m$ respectively represent the acoustic resistance and the acoustic reactance of the perforations [10], $\eta$ denotes the viscosity coefficient of the air, $\rho_0$ is the density of the air, $c$ is the speed of sound in air, $\omega$ is the angular frequency, $d$ is the orifice diameter, $\sigma$ is the porosity, and $t$ is the thickness of the panel. The perforation constant $k$ is defined as the ratio of the orifice diameter to the viscous boundary layer thickness of the air in the orifice, according to:

$$k = d\sqrt{\omega\rho_0/4\eta} \tag{4}$$

Currently, micro-perforated panels (MPPs) are employed in the development of silencers with the purpose of reducing duct noise. Wu [11] conducted early experiments using MPPs as liners in a duct and utilised a simplified analytical model to estimate the insertion loss of MPP duct silencers, concluding that the perforation ratio was the main factor influencing performance. Allam and Abom [12] proposed a new type of dissipative silencer based on MPPs. They studied the effects of axial flow on the acoustic impedance of MPP silencers using finite element methods (FEM) and the two-port microphone experimental method. In another study, the sound field inside a cylindrical silencer with MPP baffles was modelled as modal expansions using Bessel functions, also modelling the acoustic properties of the MPP silencer to calculate the transmission loss (TL) [13]. Researchers have been actively studying MPP silencers for fifteen years [14–16]. However, there are relatively few studies in the literature concerning the acoustic behaviour of MPPs in silencer applications. The main objectives of the present study are to capture the noise attenuation mechanism and analyse the possible influence of MPP characteristic parameters on this. We have studied the acoustic performance of selected micro-perforated cylindrical silencers under controlled laboratory conditions.

## 2. Test objects

The test objects comprise four circular absorption silencers, each featuring different hole diameters in the inner wall. Four distinct perforated sheets with round holes in a staggered pattern, having diameters of 0.4, 0.6, 0.8, and 1.0 mm, were utilised as the interior liner to separate the wool from the airflow within the silencers. The appearance of the perforations and the markings used in the article are depicted in Figure 1.

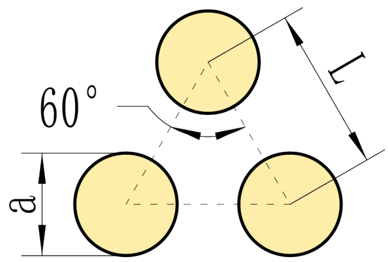


**Figure 1.** The appearance of the perforations with the markings.

Table 1 lists all the perforated sheets employed for constructing the silencer interiors, along with the dimensions of the holes, their spacing, the percentage of the area constituted by the holes, and the sheet thickness. All the silencers had an internal diameter of 200 mm. The length of the silencers without connections was 900 mm. Paroc HVAC Section AluCoat T covering, made of 100 mm thick rock wool and covered with reinforced aluminium foil, was used as the absorbing material. Figure 2 illustrates all the dimensions.

**Table 1.** Perforated sheets used for the construction of the silencer.

| type | a[mm] | L[mm] | open area [%] | sheet thickness [mm] |
|---|---|---|---|---|
| Rv0.4-1.5 | 0.4 | 1.5 | 6.4 | 0.4 |
| Rv0.6-1.5 | 0.6 | 1.5 | 14.5 | 0.6 |
| Rv0.8-1.5 | 0.8 | 1.5 | 25.8 | 0.6 |
| Rv1-2 | 1.0 | 2.0 | 22.7 | 1.0 |

Based on the research presented in the article [17], straight channels with the same connection diameter and length as the tested silencers were used as the substitution duct. This allows for a comparison of the insertion loss and pressure loss with the element that would be installed instead of the silencer, which is a straight ventilation duct.

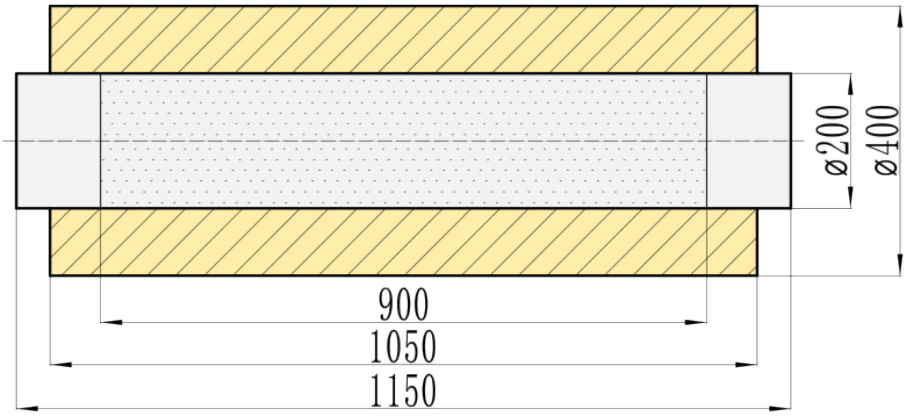


**Figure 2.** Dimensions of the silencers used in the experiment.

### 3. Experiment

The measurements were conducted on a test rig constructed in accordance with the ISO 7235 standard [18]. The reverberation chamber has a volume of 237.0 m$^3$ and an area of 231.5 m$^2$, comprising non-parallel reflecting walls. The test objects were connected to a centrifugal fan, behind which are three absorptions silencers and a sound source. The stand outlet is located inside the reverberation chamber. A schematic of the entire test rig is shown in Figure 3.

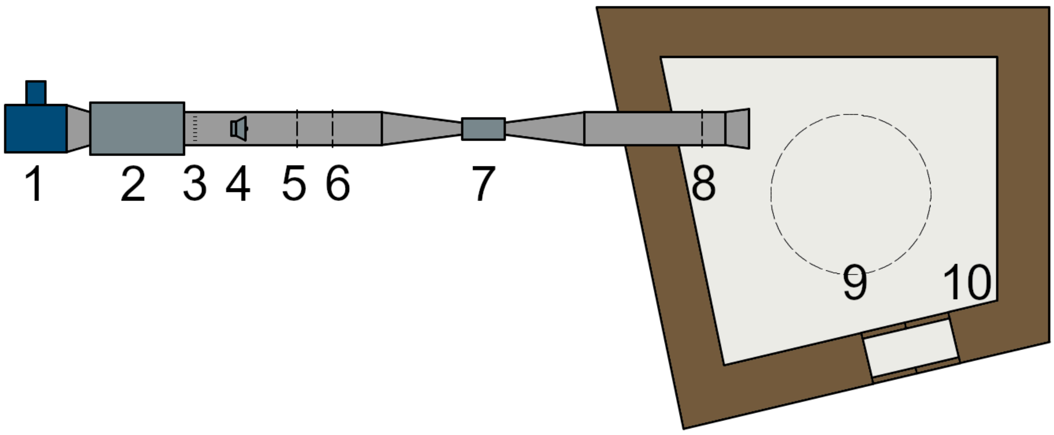


**Figure 3.** Test stand with reverberation room scheme.
1) fan, 2) set of three silencers, 3) flow straightener, 4) noise source, 5) pressure and temperature measurement, 6) flow velocity measurement, 7) test object, 8) pressure measurement, 9) microphone path, 10) reverberation room.

Tests were carried out with the pink noise source both switched off and on for three flow velocities of 4, 8, and 12 m/s at the inlet to the test silencers. The flow rate was adjusted by varying the speed frequency of the fan motor using a three-phase inverter. The flow velocity was measured using a Prandtl tube in accordance with the ISO 5221 standard [19]. The static pressure drop across the silencer under test was measured in the duct upstream and downstream of the silencer at four evenly spaced points around the duct. An electronic differential pressure transducer was utilised for this purpose.

The noise generated was determined by the sound power level measured and calculated according to ISO 3741 standard [20]. A Brüel&Kjær 2144 measuring set with a Brüel&Kjær 3923 rotary table was used for the measurements. The sound pressure was measured at nine points on a circle with a diameter of 3.4 m. It was measured at 1/3 octave in the range from 50 Hz to 10,000 Hz. The measurement time was 30 seconds. Background noise was measured for the stand without airflow to determine the background correction $K_1$. Reverberation was measured for four omnidirectional speaker positions with three microphone settings. All sound power level calculations were made using a calculation sheet. Before and after all measurements, the sound analyser was calibrated using a Brüel&Kjær 4231 calibrator. During the measurements, we recorded the temperature, relative humidity, and atmospheric pressure required for the sound power calculations.

## 4. Results

### 4.1. Insertion loss

Insertion loss was utilised to represent the effectiveness of silencers. Insertion loss $D_i$ is the reduction in the level of the sound power in the duct behind the test object due to the insertion of the test object into the duct in place of a substitution duct, as given by equation:

$$D_i = L_{WII} - L_{WI} \tag{5}$$

where:

- $L_{WI}$ — the level of the sound power in the frequency band considered, propagating along the test duct or radiating into the connected reverberation room when the test object is installed;
- $L_{WII}$ — the level of the sound power in the frequency band considered, propagating along the test duct or radiating into the connected reverberation room when the substitution duct replaces the test object.

Since, in this case, the sound power level did not depend on the set air velocity, average values were used in the calculations.

Table 2 shows the results of the insertion loss calculations in octave bands for silencers with different hole diameters in the metal sheet shielding the wool inside.

**Table 2.** Insertion loss results in octave bands for silencers with different internal perforations.

| | $D_i$ [dB] | | | |
|---|---|---|---|---|
| f [Hz] | 0.4 mm | 0.6 mm | 0.8 mm | 1.0 mm |
| 63 | 11.2 | 11.0 | 12.4 | 13.2 |
| 125 | 12.7 | 13.7 | 13.0 | 14.9 |
| 250 | 15.6 | 14.6 | 14.8 | 14.4 |
| 500 | 21.6 | 20.6 | 21.5 | 20.2 |
| 1000 | 28.0 | 27.9 | 26.9 | 27.9 |
| 2000 | 34.7 | 35.1 | 34.1 | 36.6 |
| 4000 | 20.6 | 19.1 | 24.9 | 22.5 |
| 8000 | 16.2 | 18.4 | 17.7 | 14.7 |

A graph of the insertion loss spectrum in one-third octave bands for each tested silencer is presented in Figure 4.

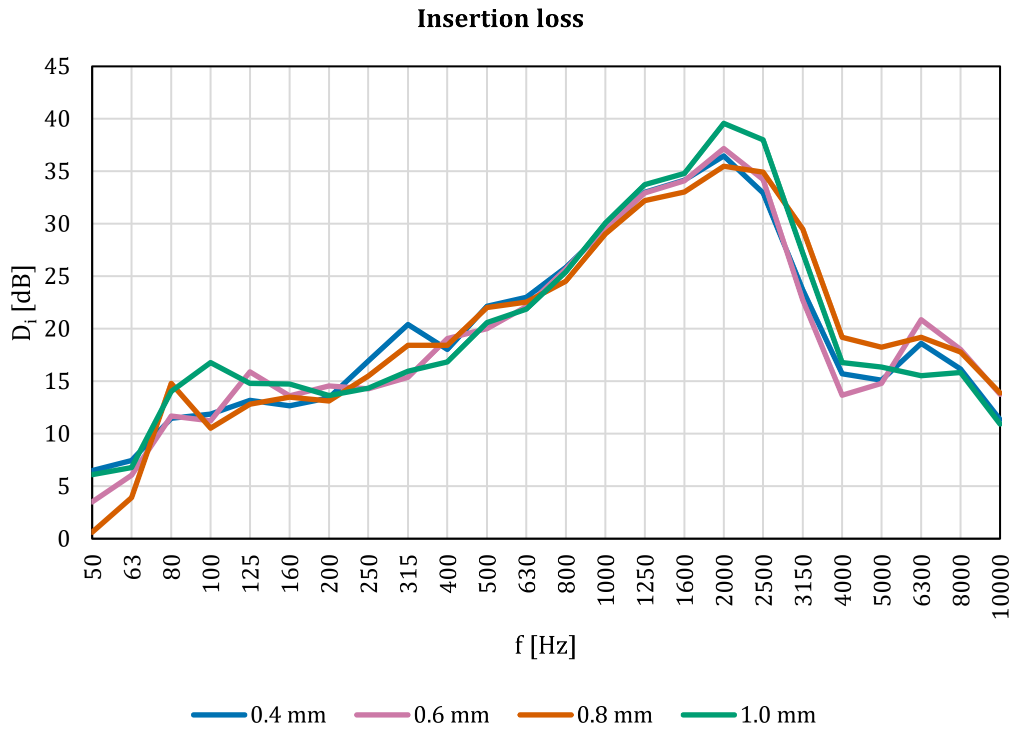


**Figure 4.** Insertion loss spectrum of silencers constructed with different perforated sheets inside.

The 1.0 mm hole silencer demonstrated the greatest efficacy below 125 Hz, as well as at approximately 2000 Hz and 2500 Hz. The 0.8 mm variant exhibited superior performance around 4000 Hz and 5000 Hz, while the 0.6 mm model displayed the highest efficacy at 6300 Hz and above. The model with 0.4 mm apertures achieved the best insertion loss at approximately 315 Hz.

### 4.2. Flow noise

The flow sound power levels (self-noise) of the silencers, measured in the reverberation chamber for flow velocities of 4, 8, and 12 m/s, are presented in Table 3 in octave bands and as A-weighted single number values.

**Table 3.** Silencer self-noise in octave bands and as a single number for different perforations and flow velocities.

| f [Hz] | Lw [dB] | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 4 m/s | | | | 8 m/s | | | | 12 m/s | | | |
| | 0.4 mm | 0.6 mm | 0.8 mm | 1.0 mm | 0.4 mm | 0.6 mm | 0.8 mm | 1.0 mm | 0.4 mm | 0.6 mm | 0.8 mm | 1.0 mm |
| 63 | 36.3 | 33.0 | 34.6 | 34.6 | 38.1 | 38.9 | 35.4 | 39.0 | 41.6 | 46.9 | 39.6 | 46.3 |
| 125 | 31.6 | 30.6 | 32.6 | 30.6 | 42.9 | 40.1 | 35.7 | 41.8 | 50.0 | 47.5 | 45.2 | 51.0 |
| 250 | 31.9 | 34.4 | 32.2 | 34.3 | 42.4 | 42.3 | 39.9 | 42.7 | 50.9 | 48.8 | 45.1 | 52.1 |
| 500 | 22.8 | 22.8 | 23.3 | 24.1 | 33.6 | 32.1 | 33.3 | 35.0 | 42.1 | 40.5 | 40.8 | 43.9 |
| 1000 | 14.5 | 16.8 | 15.1 | 15.5 | 24.1 | 22.9 | 27.0 | 25.9 | 35.2 | 34.8 | 37.1 | 37.7 |
| 2000 | 13.7 | 15.0 | 13.8 | 14.5 | 16.9 | 15.7 | 19.9 | 18.2 | 30.2 | 28.7 | 33.7 | 33.0 |
| 4000 | 16.3 | 16.6 | 16.3 | 16.4 | 17.2 | 17.5 | 17.6 | 18.0 | 22.9 | 21.6 | 24.9 | 25.2 |
| 8000 | 19.2 | 19.8 | 19.4 | 19.0 | 19.6 | 20.2 | 19.8 | 19.5 | 20.6 | 21.2 | 20.6 | 20.5 |
| A | 26.9 | 28.5 | 27.5 | 28.3 | 36.2 | 35.7 | 34.9 | 36.8 | 44.8 | 43.2 | 42.9 | 46.4 |

The graph in Figure 5 illustrates the flow sound power levels for a flow velocity of 4 m/s at the inlet to the silencers.

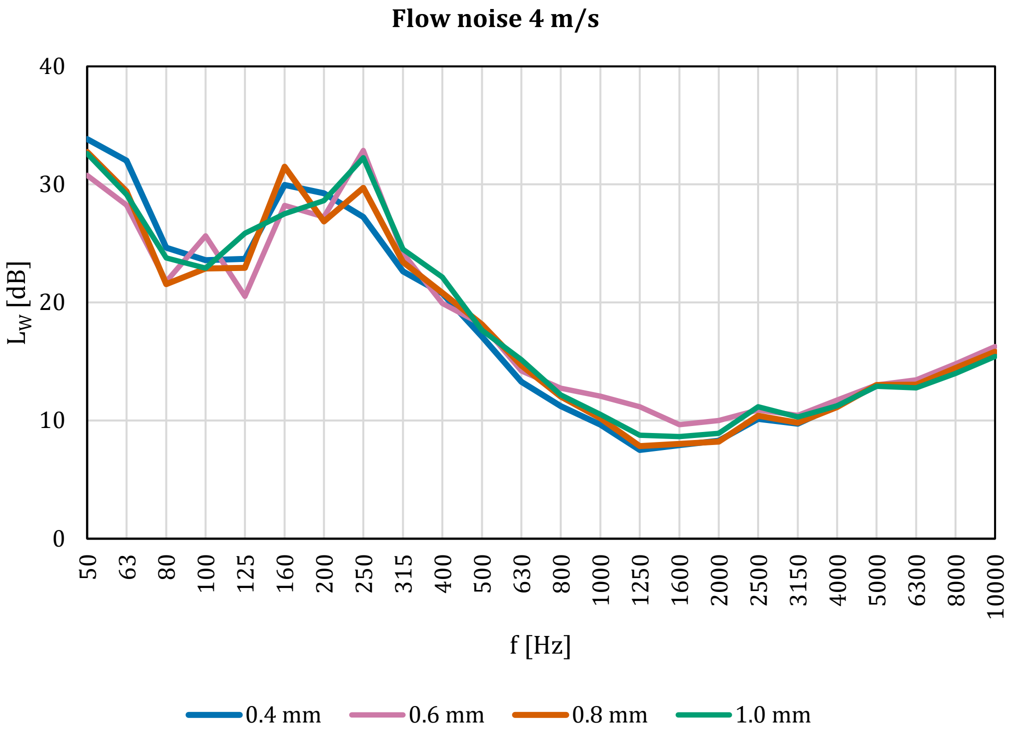


**Figure 5.** Self-noise spectrum of silencers at 4 m/s flow velocity.

The self-noise spectrum of the silencers that were evaluated at an 8 m/s flow velocity is displayed in Figure 6.

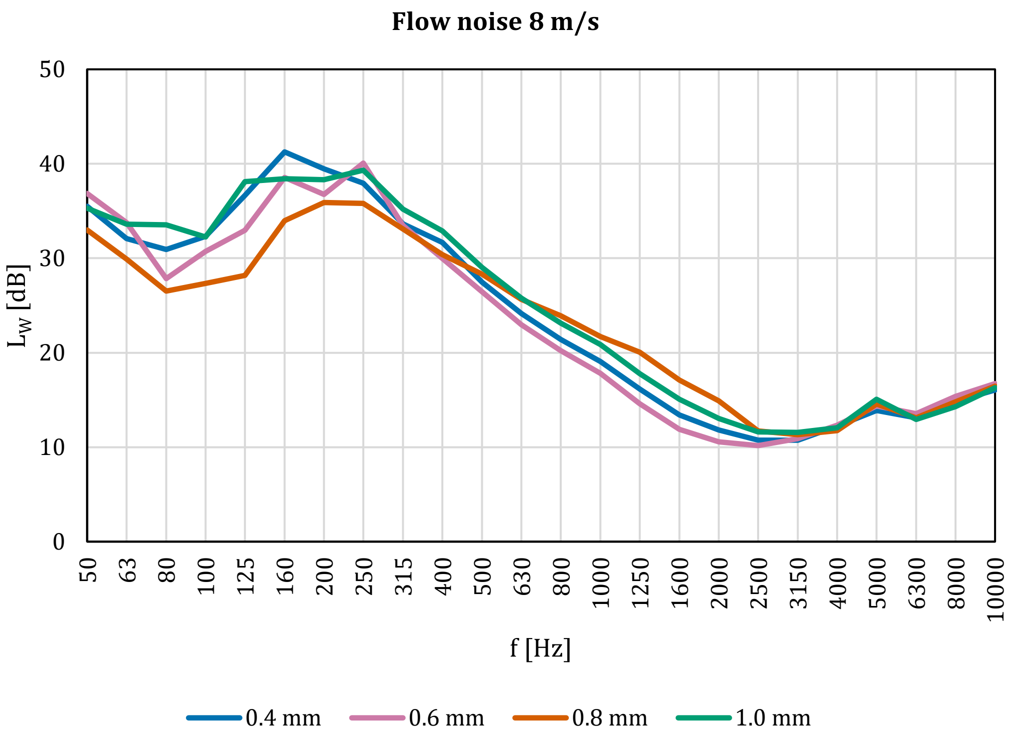


**Figure 6.** Self-noise spectrum of silencers at 8 m/s flow velocity.

The graph in Figure 7 depicts the spectrum of flow noise sound power levels for the silencers at a 12 m/s air velocity.

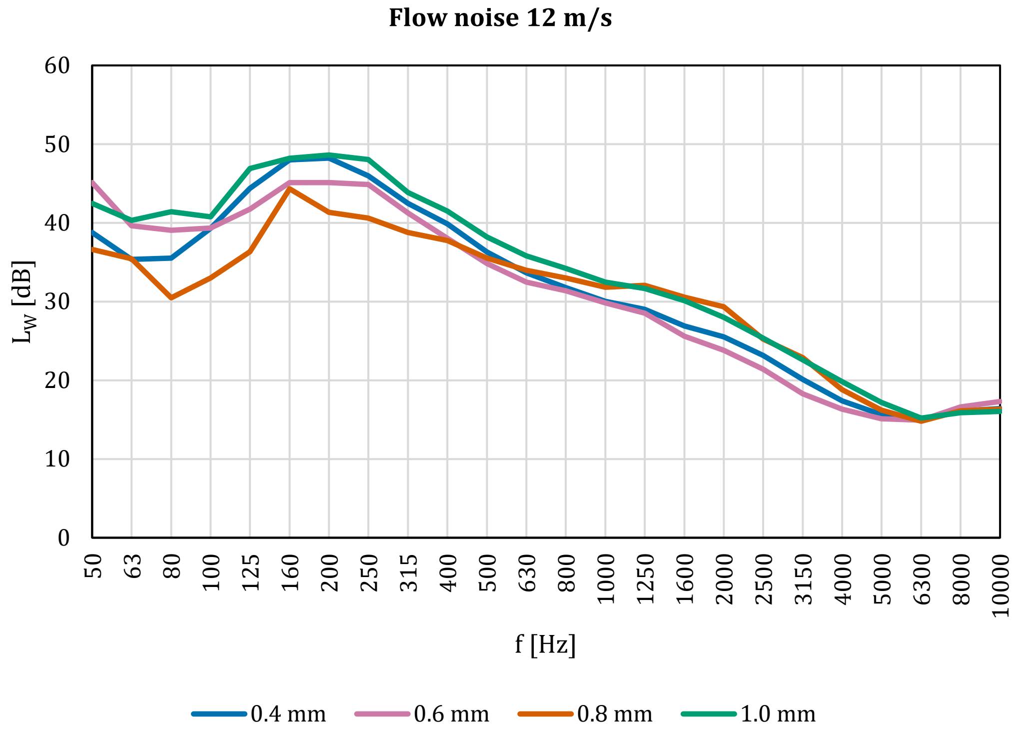


**Figure 7.** Self-noise spectrum of silencers at 12 m/s flow velocity.

At a flow rate of 4 m/s, the self-noise levels of the silencers were found to be comparable. At a flow rate of 8 m/s, the 0.8 mm silencer exhibited the lowest noise levels at lower frequencies, whereas the 0.6 mm silencer demonstrated the lowest noise levels at medium frequencies. At a flow rate of 12 m/s, the same pattern was observed, albeit with minor shifts in the frequency bands.

### 4.3. Pressure loss

The pressure loss of the micro-perforated silencer prototypes was compared to a smooth duct of the same internal diameter and length as the silencers tested. Table 4 presents the additional pressure loss introduced by each silencer for the three velocities tested.

**Table 4.** Pressure loss of silencers for different perforations and flow rates.

| v [m/s] | Δp [Pa] | | | |
|---|---|---|---|---|
| | 0.4 mm | 0.6 mm | 0.8 mm | 1.0 mm |
| 4 | 0.7 | 0.7 | 0.6 | 0.7 |
| 8 | 2.7 | 2.8 | 2.6 | 2.6 |
| 12 | 6.0 | 6.2 | 5.8 | 5.9 |

As the values are similar for the same flow velocities, a single curve is plotted in Figure 8 using the average values from all silencers.

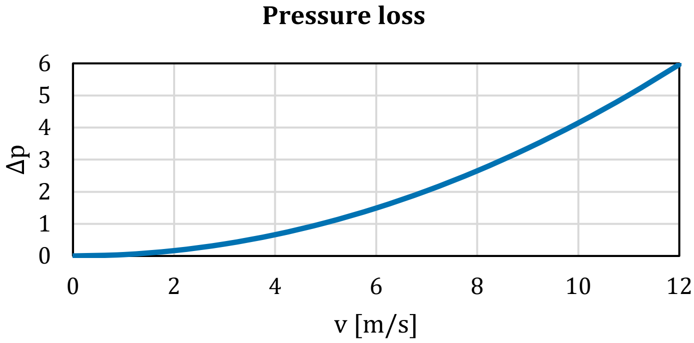


**Figure 8.** Average additional pressure loss due to duct change to silencer as a function of flow velocity.

The pressure losses exhibited by the silencers were found to be consistent, irrespective of their micro-perforation sizes, across a range of airflow speeds.

## 5. Conclusions

This paper investigates the insertion loss, self-noise, and pressure loss of silencers equipped with micro-perforated sheet metal. Perforated sheets with hole diameters of 0.4, 0.6, 0.8, and 1.0 mm were utilised. The tests adhered to the ISO 7235 standard and were conducted in a reverberation chamber, revealing differences in insertion loss and self-noise levels among the tested silencers.

The silencer with 1.0 mm holes demonstrated the highest insertion loss at frequencies of 100, 160, 2000, and 2500 Hz. The 0.8 mm hole silencer performed best between 3150 and 5000 Hz. The 0.6 mm hole silencer showed peak attenuation at 125 and 6300 Hz, while the 0.4 mm hole silencer excelled between 250 and 315 Hz.

Under an air velocity of 4 m/s, the self-noise levels were similar across all silencers. At an air velocity of 8 m/s, the 0.8 mm hole silencer had the lowest noise levels from 50 to 315 Hz, and the 0.6 mm hole silencer was quietest from 400 to 3150 Hz. At the highest tested airflow of 12 m/s, the 0.8 mm hole silencer remained the most effective from 50 to 400 Hz, and the 0.6 mm hole silencer from 500 to 5000 Hz.

The pressure losses were relatively consistent among all silencers with micro-perforations ranging from 0.4 to 1.0 mm at all measured flow velocities.

Figure 9 illustrates the insertion loss of the tested absorption silencers with a micro-perforated channel in octave bands, compared to the attenuation range of various standard absorption silencers of the same size and wool thickness (indicated by the grey area in the plot). At the lowest frequency of 63 Hz, the proprietary micro-perforated silencers achieved significantly better insertion loss. For 125 Hz and 4000 Hz, some of the silencers examined demonstrated superior attenuation. However, at frequencies from 250 Hz to 1000 Hz, they exhibited lower insertion loss.

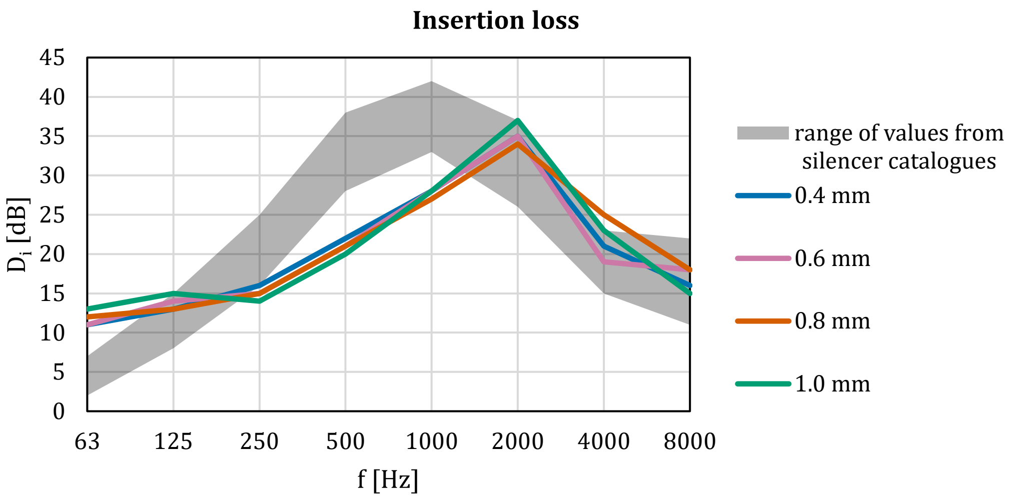


**Figure 9.** Comparison of the insertion loss of the micro-perforated silencers studied with the ranges of insertion loss values given in catalogues of standard absorption silencers.

**Additional information**

The author(s) declare: no competing financial interests and that all material taken from other sources (including their own published works) is clearly cited and that appropriate permits are obtained.

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