Micro-perforated panels in interaction with boundary layers in zero pressure gradient flow

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Introduction

In recent studies [1, 3, 2], a circular micro-perforated panel (MPP) arrangement using the principle of $\lambda/4$ reflection damping, has been applied adjacent to a low-pressure axial fan. The MPP in combination with an airtight back volume of length L_c forms a micro-perforated absorber (MPA). It can be tuned to absorb noise caused by the fan at large orders of magnitude. It has been established that the MPA effectiveness can be diminished in certain frequency regions by the self-noise emitted by the overflown MPA. Also, the fan's efficiency depends strongly on the character of the inflow towards the fan which can be changed by rough surfaces, like the MPPs used.

The following investigations,therefore, have the goals of clarifying:

- the influence of the MPA on the flow character after the MPP surface
- the influence of the grazing flow on the MPA's effectiveness and what determines the scale of the MPP self-noise.

Measurement Setup

The setup has been designed to allow velocity measurements before and after the MPA and the measurements of the emitted sound pressure. The configuration can be seen in Fig. 1 and is comparable to that of Nelson [4]. The MPP is placed in the outflow of the nozzle and is fully embedded in the flow. The microphones are placed 0.5 m above the MPP surface, and the velocity is measured 2 cm in front (green) and after (red) the MPP. The enlarged view (cf. Fig. 2) of the MPA section shows the in-cavity microphone and hydraulic pressure sensor in front of the MPP. The investigated MPPs are shown in Fig.3. They show four different plates varying in porosity ϕ, slit length $l_{\text{pore,LSE2}} = 350\,\mu\text{m}$, $l_{\text{pore,LSE3}} = 120\,\mu\text{m}$ and $l_{\text{pore,LSE4LSE7}} = 70\,\mu\text{m}$ and slit width w_{pore}, with the indicated change of slit orientation relative to the flow with speed U_0. As the figure indicates, if the slits are aligned 90° with the flow, the relative (to the flow direction) separation becomes much higher than in the case of the 0° orientation.

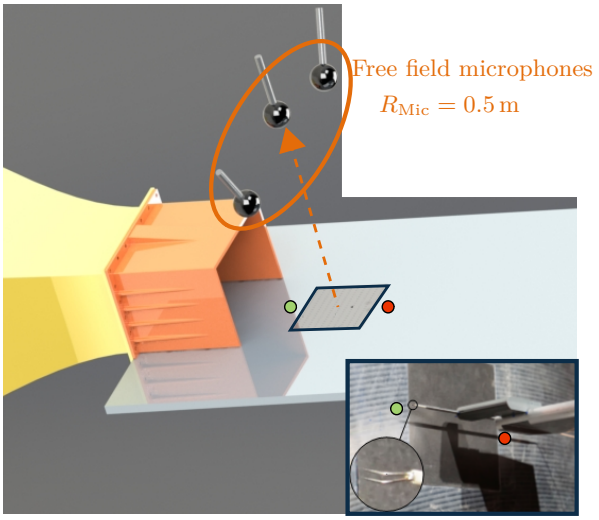

Figure 1: Rendered view of the measurement rig with indicated free field microphones and velocity probing positions.

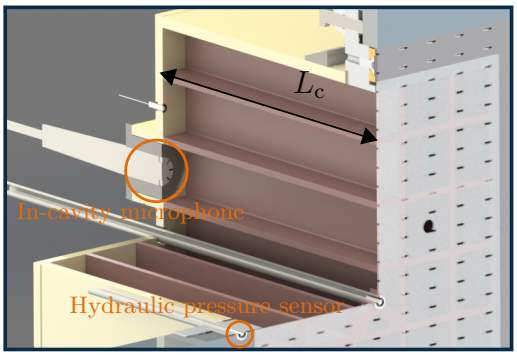

Figure 2: Enlarged view of the segmented MPA with positions of the cavity microphone (orange) and hydraulic pressure sensor (orange) in front of the MPP.

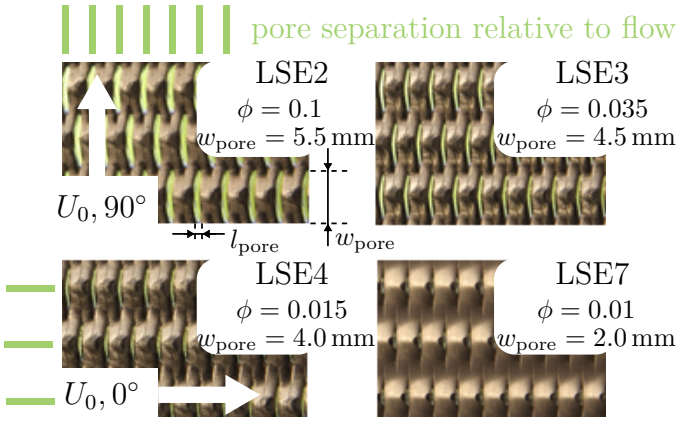

Figure 3: MPP type and orientation to flow with characteristic slit lengths.

Results

The results of the velocity measurements and emitted noise spectrum are presented here. First, the velocity data can indicate whether the MPP has an influence on the turbulence character of the grazing flow. Then, the emitted sound spectrum dependent on varying MPA and flow parameters are shown.

Velocity measurements

The character of the flow can be estimated by the form factor $H = \delta^*/\Theta$, where δ^* is the displacement thickness and Θ is the momentum thickness. One can see from the form factors in Figs.4, 5 and 6 that if the inflow

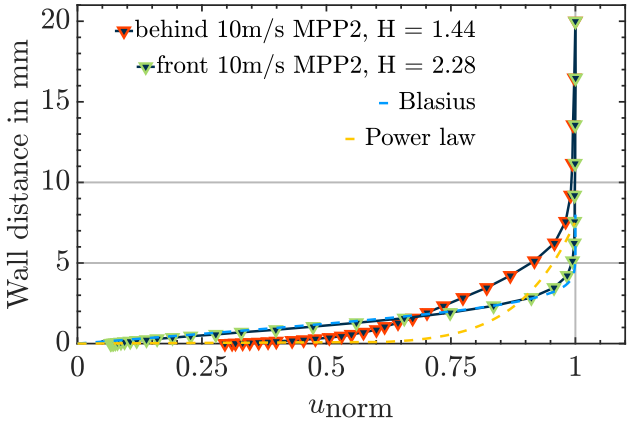

Figure 4: MPP type LSE2 at $U_0 = 10\,\mathrm{m\,s^{-1}}$.

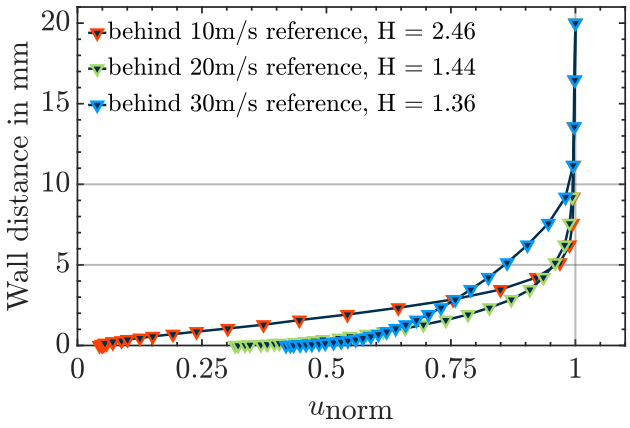

Figure 5: Reference plate at $U_0 = 10, 20, 30\,\mathrm{m\,s^{-1}}$.

is undisturbed and laminar ($U_0 = 10\,\mathrm{m\,s^{-1}}$) MPP LSE2 with a large porosity, induces a more turbulent flow profile, comparable more to the power law than the Blasius profile. Usually, a value of $H > 2.0$ indicates a laminar near-wall flow and values in the vicinity of $H = 1.4$ indicate a turbulent profile or a profiles in transition from laminar to turbulent. However, if the boundary layer is already turbulent-like due to higher flow speeds, the MPP does not make it more turbulent (cf. Fig. 5 and 6). If the slits are small, and the porosity is small (MPP LSE7 in Fig. 6), the boundary layer profile stays laminar-like. Again, the turbulent profile at higher flow speeds is unaffected by the MPP.

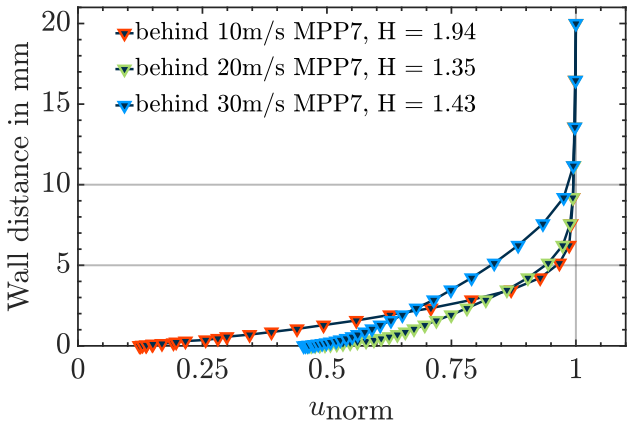

Figure 6: MPP type LSE7 at $U_0 = 10, 20, 30\,\mathrm{m\,s^{-1}}$.

Thus, one should conclude that the MPP can make the grazing flow more turbulent if the inflow is laminar-like or undisturbed but does not make an already turbulent near-wall profile more turbulent.

Sound emissions from the MPP

The effectiveness of the MPA in a grazing flow field depends on whether or how much sound is produced by the MPA configuration; here, it is called "self-noise". The first consideration is the flow speed level, depicted in Fig. 7 for MPP LSE3 and at $L_c = 143$ mm. One can see that the intensity of the sound emissions $\overline{L_p}$ is strongly correlated to the flow speed level. Also, the sound emission peaks correspond to the $\lambda/4$ resonance peaks (vertical dashed grey lines) the MPA is tuned to by the length L_c. In Fig. 7, also the sound emissions of the reference plate are shown. It is obvious that below 1000 Hz the emitted sound is due to the flow itself and only beyond 3000 Hz the sound emission peaks are due to the MPA configuration. The thinner lines in Fig. 7 indicate the emitted sound if the inflow is disturbed and turbulent. The turbulent only causes higher sound levels at low flow speeds and if the reference plate is used. The turbulent flow causes a broadband noise level in the higher frequency range. At these frequencies these noise levels are augmented by the self-noise of the MPA. Figure 8 shows the

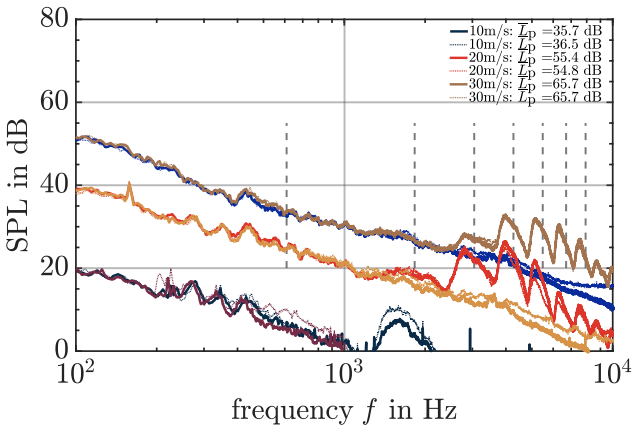

Figure 7: SPL of reference plate (blue and light brown) compared MPP LSE3 at different flow speeds.

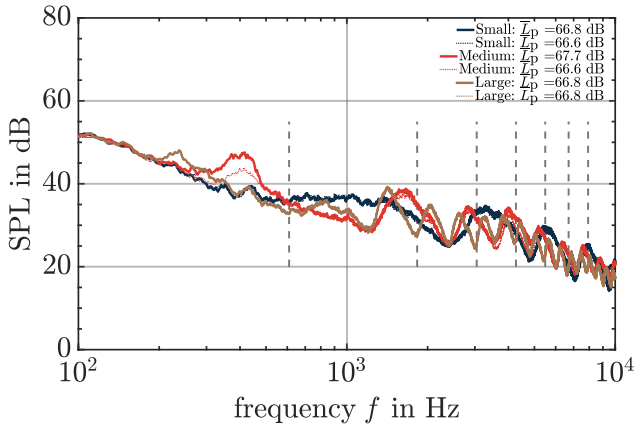

Figure 8: SPL of MPP LSE2 depending on L_c at 90° at $U_0 = 30\,\mathrm{m\,s^{-1}}$.

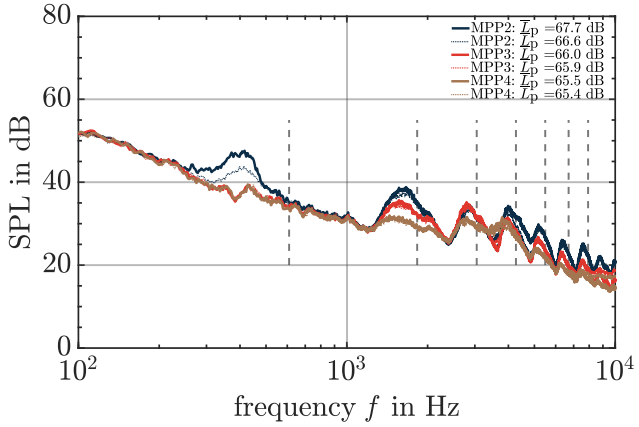

Figure 9: SPL depending on ϕ and w_{pore} at 90° at $U_0 = 30\,\mathrm{m\,s^{-1}}$.

effects of varying the cavity length L_c and aligning the MPP slits parallel to the flow (90°). One can observe that the alignment with the flow and thus the effective separation augmentation within the flow, induces a much more lower-frequency self-noise. Also, it is clear that the smaller the cavity length, the more broadband the emission spectra become.

One important conclusion is, therefore that at those frequencies where the MPA absorbs the most sound power the MPA also emits the most sound power. However, the intensity at the investigated flow speeds is lower than the flow-induced low-frequency sound emission. Last but not least, the MPP parameters influence on the self-noise is shown in Fig. 9. It is revealed that the overall sound emissions $\overline{L_p}$ are highest for MPP LSE2 at $U_0 = 30\,\mathrm{m\,s^{-1}}$. MPP LSE2 having the highest porosity and slit lengths. MPP LSE4 has the lowest emissions, and the trend seems to be that smaller perforations also induce lower sound intensities. It has to be added that MPP LSE 4 proofed to be the material with the highest sound absorption capability. It also produces the lowest sound emission and could therefore represent an optimal choice for the application in a grazing flow field.

Conclusion

The investigations presented above lead to the following recommendations for the usage of MPAs embedded in a grazing flow field:

- If the inflow is undisturbed and laminar, the MPP induces turbulence,
- the MPA effectiveness is determined by the frequency range and intensity of its self-noise,
- this self-noise is governed by the MPP parameters, flow speed level, MPP orientation relative to the flow and the cavity length,
- at its absorption peaks, the MPA also emits sound at higher levels,
- these levels, however, are still lower than the low-frequency emission sound by the flow itself.

We conclude therefore that the application of MPPs in flow is possible with the proper considerations taken into account. Following these findings, it could be interesting to investigate flow speeds towards higher Mach numbers and to find models that can predict the MPA's self-noise.

References

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