Fluid-Structure-Acoustic Coupling Related to the Flow over Rigid and Flexible Plate Structures

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Introduction

In the present work, the interaction of a fluid flow with different plate structures and the resulting acoustic field was studied in detail. For this purpose, a test case was developed which represents a simplified model of a car side window.
Up to now there is very little work towards a comprehensive investigation of the fluid flow, the structural mechanics and the acoustics as well as the interaction of the different fields (see, e.g., Vergne et al. [1], Becker et al. [2]).

Model Setup

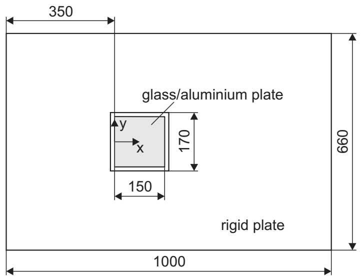

Figure 1: Schematic drawing of the setup, top view (units in mm)

The basic setup consists of a plate structure which is part of an otherwise rigid wall [see Figure 1]. One plate investigated in the following is made of sheet glass with a thickness of $h_\mathrm{g} = 3$ mm. The streamwise and spanwise extension of the glass plate amounts to 170 mm × 170 mm, respectively. Both the top and the bottom surface of the plate are freely accessible. In order to modify turbulence characteristics of the inflow, obstacles were mounted upstream of the plate structure.

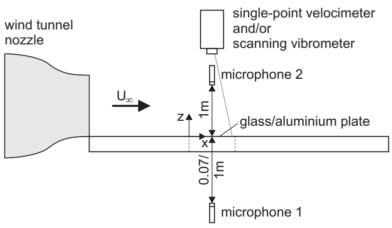

Figure 2: Sketch of the measurement setup, side view

In this paper, results corresponding to a configuration with a square cylinder obstacle orientated in spanwise direction in front of the plate (660 mm length) are presented. The edge length of the square cylinder is $D = 20$ mm. In the presented investigations, a free-stream velocity of $U_\infty = 40$ m/s was applied.
To generate a basis of comparison, additional investigations were carried out with an aluminium plate in place of the glass plate. The thickness of the aluminium plate amounts to $h_\mathrm{a} = 10$ mm.

Experimental Method

Figure 2 shows a sketch of the measurement setup with the equipment employed.
Two 1/2" free field condenser microphones (B&K 4189), each at a distance of 1 m and perpendicular to the overflown and the non-overflown side of the plate structure, are employed for the sound measurements. Additionally, the distance of the microphone averted from the turbulent flow is reduced to 0.07 m.

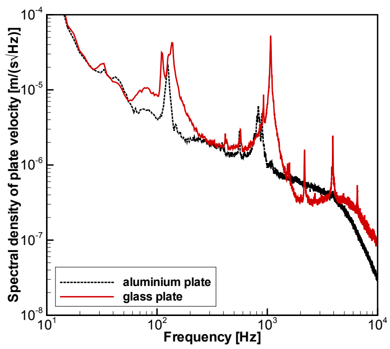

Figure 3: Frequency spectra of the measured vibration velocity in the centre point of the plates

To investigate the structure-acoustic interaction, correlation measurements of a single-point laser-Doppler velocimeter (OFV-303) and the microphones are carried out.
For the measurement of unsteady pressure fluctuations at high sample rates, a piezoresistive pressure transducer (Kulite XCQ-093-5SG) is applied.

Fluid-Structure-Acoustic Interaction

The frequency spectrum of the vibrational velocity in the centre point of the glass plate shows several peaks between 1 kHz and 6 kHz, which corresponds to the eigenfrequencies of the glass plate obtained by modal analysis.

In comparison to this, there are no peaks in the spectrum of the rigid aluminium plate, which is in accordance with expectation. But the spectrum of the glass plate differs from the spectrum of the aluminium plate between 50 Hz and 400 Hz as well as between 6 kHz and 10 kHz up to half an order of magnitude corresponding to a broadband excitation by the turbulent wall-bounded flow [see Figure 3].

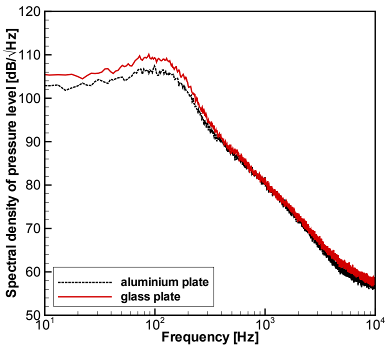

Figure 4: Frequency spectra of the wall-pressure fluctuations at x = 92 mm and y = 0 mm

Figure 4 shows the spectra of the unsteady wall-pressure measurements 92 mm downstream to the leading edge of the plates at the centreline of the spanwise direction. One can observe higher amplitudes between 50 Hz and 400 Hz and 6 kHz and 10 kHz, respectively, for the case with the glass plate, which is in good agreement with the results of the vibration velocity measurements. Contrary to Figure 3, there are no prominent peaks as a result of the natural vibrations of the glass plate.
For glass and aluminium as plate material, the spectra of the sound pressure level at a 0.07 m distance perpendicular to the back side of the plates are very similar. The main differences are the tonal components for the glass plate [Figure 5].

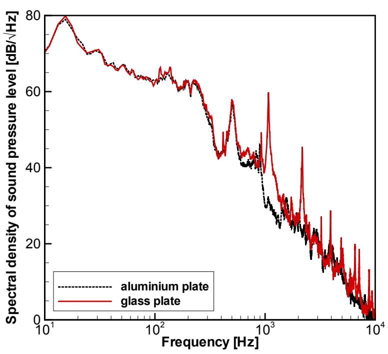

Figure 5: Sound pressure level at a 0.07 m distance perpendicular to the back side of the plates

To sum up, one can say that the flow over a glass plate is influenced by the flow-induced broadband vibrations of the flexible plate structure but there is no effect of the natural vibrations. Contrary, the modified wall-bounded turbulent flow causes no difference in the sound radiation up to 1 kHz and only the eigenfrequencies distinguish the examined spectra from the spectra of the cases with aluminium plate.

Separation of Vibrational and Flow-Induced Sound

To separate vibrational sound from flow-induced sound in the near field and the far field, measurements of the correlation between the acoustic pressure at the microphone position and the velocity in the centre point of the vibrating plate were conducted. The corresponding coherence spectra are provided in Figure 6 for microphone distances of 0.07 m at the back side of the glass plate and 1 m at the front side of the glass plate.

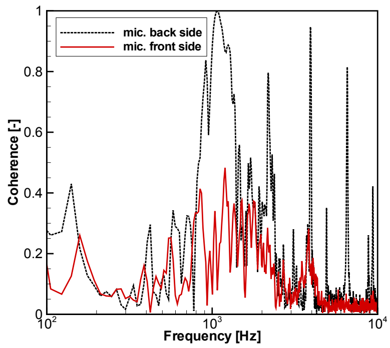

Figure 6: Spectra of the coherence between sound pressure signal (back side: 0.07 m distance, front side: 1 m distance) and plate velocity signal (centre point)

In the near field a strong correlation is found at the frequencies of the tonal vibrational noise of the glass plate. In between the tonal components, at lower frequencies and in the far field there is a small coherence between the sound pressure signal and the plate velocity, but this is due to the flow-induced vibration of the plate. At these frequencies the flow-induced noise is generated by the turbulent fluctuations.

Conclusion

The flow over a glass plate is influenced by the flow-induced broadband vibrations of the flexible glass plate but there is no effect on the radiated sound. Both in the acoustic near field and in the far field the tonal noise is generated by structural vibrations and the broadband noise is flow-induced due to turbulent fluctuations in the flow field.

References

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