Investigation on aerodynamic noise generated by porous coated, staggered tandem cylinders

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Introduction

The aerodynamic noise generated by the landing gear of an aircraft, by overhead power lines or the protective guard grille of axial fans is often studied using a tandem cylinder configuration. This simplification can, for example, be used to model the interaction between main strut and hydraulic lines or drag-stay of an aircraft [1–3]. Even though many studies have been conducted on this configuration, only few consider the aerodynamic noise generated by the setup [4–8]. Previous investigations have shown that the angle between the upstream and downstream cylinder has a great effect on the tonal noise peaks [9, 10]. This angle of incidence replicates cross wind conditions for the noise of the landing gear of an aircraft or the curved construction of the guard grille of a fan due to safety and storage requirements. To mitigate the aerodynamic noise that is generated, the use of porous materials is one promising approach. Previous studies have shown that especially materials with low air flow resistivity should be applied [11] in order to achieve a proper noise reduction. In many studies, these materials were found to lead to a narrowing of the main spectral peak of the aeolian tone, but not to a complete suppression. In addition, a reduction in broadband noise especially at higher Reynolds numbers was observed in the aforementioned study.

The current study focuses on the use of porous coatings as a potential means to reduce aerodynamic noise from tandem cylinder configurations at an angle of incidence. A schematic of the configuration considered here is shown in Fig. 1

Experimental Setup

The experimental investigation was carried out in the aeroacoustic wind tunnel at the Brandenburg University of Technology Cottbus-Senftenberg. Two sideplates machined from acrylic glass were mounted to the rectangular nozzle of the wind tunnel with an exit area of 0.28 m × 0.23 m. The centre of the sideplates has a circular hole to hold two rotational discs which are used to fasten the cylinders, which allows to set the angle of incidence between the cylinders and the flow. A schematic of the sideplate and the disks is shown in Fig. 2. Both upstream and downstream cylinder used in the investigation have a diameter of $D = 30$ mm. When a porous coating is applied, a thinner core cylinder with $d = 15.6$ mm is used. The porous material consists of hollow pieces which can be slid over the core cylinder, resulting in the same total outer diameter of $D = 30$ mm (see Fig. 3). The cylinders are placed $4.7D$ apart, measured between the axes of the cylinders. To set this distance, holes were drilled in the circular receiving discs which also ensured that the spacing did not change when the angle of incidence was altered. For the reference measurement, both upstream and downstream cylinder were in the bare configuration without a porous coating applied.

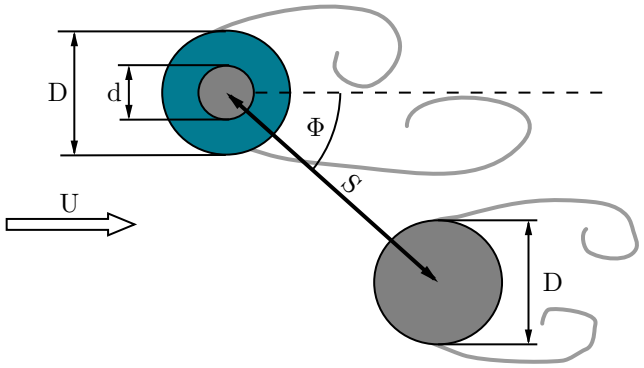

Figure 1: Schematic view of the experimental setup.

The inflow velocity was varied from $U = 15$ m/s to $U = 40$ m/s, which corresponds to Reynolds numbers between $Re = 30.000$ and $Re = 80.000$ based on D. The angle of incidence was varied from $\Phi = 0°$ to $\Phi = 60°$. The upper limit results from the fact that larger angles cannot be adjusted due to the limited size of the wind tunnel nozzle used in the measurements.

As shown in Fig. 2, two microphone arms with a total of 16 microphones were installed inside the wind tunnel for the acoustic measurements. The microphones were placed out of the flow in a radius of $R = 0.61$ m to the centre between the cylinders. The microphone used for the analyses in the present paper is marked with a red circle in Fig. 2. It is placed at 90° to the flow. The measurement data was recorded over a time period of 60 seconds with a sampling frequency of 51.2 kHz. All computations were done in Python using the open source software package *Acoular* [12].

Experimental Results

In a first step, the resulting spectra of a single cylinder, the tandem cylinder configuration without an angle of incidence and the background noise is analysed (see Fig. 4). For the single cylinder configuration, three distinct peaks can be identified: the first and highest maximum is located at 247 Hz, which is near the theoretical vortex shedding frequency of 267 Hz when assuming a Strouhal num-

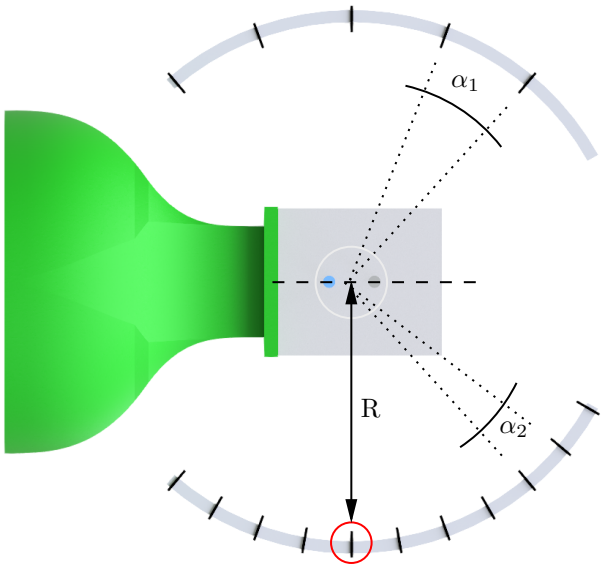

Figure 2: Top view of the experimental setup at $\Phi = 0°$ (upstream cylinder, blue, fitted with a porous coating; angles between microphones are $\alpha_1 = 20°$ and $\alpha_2 = 10°$).

Figure 3: Photograph of the bare and porous coated cylinders. The porous material was water jet cut into hollow cylinders that can be slid over the smaller diameter cylinder.

ber fD/U of 0.2. This peak is caused by the fluctuating lift forces acting upon the single cylinder. Since the aerodynamic noise of a cylinder can be classified as a dipole noise source, this fluctuating lift causes noise especially perpendicular to the direction of the flow. The noise generated due to the fluctuating drag forces acting on the cylinder is located at twice the shedding frequency. Consequently, a second peak in the spectrum can be found at 494 Hz. In the spectrum, this second maximum has a lower sound pressure level than the first, which is expected since the microphone used for the analysis is located perpendicular to the flow and the noise radiated due to the fluctuating drag is in the direction of the flow. The third main peak in the spectrum is a harmonic of the first peak generated by the fluctuating lift, located at three times the frequency at 725 Hz, about 20 Hz below the expected value. These results confirm that the measurement is valid and matches known effects from literature. Now, adding a second cylinder downstream of the first cylinder slightly shifts the first main peak towards lower

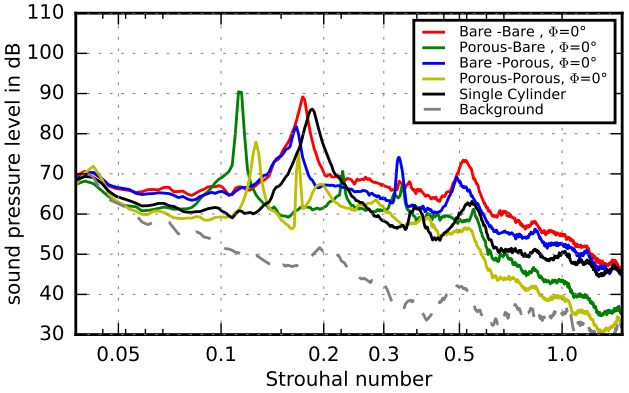

Figure 4: Spectra of the different configurations with a porous cover at $\Phi = 0°$. The inflow velocity is set to $U = 40$ m/s, corresponding to $Re = 80.000$.

frequencies while increasing the sound pressure level of the second and third peaks.

The second step of the investigation introduces an angle of incidence between the flow and the tandem cylinders, shown in Fig. 5. The first main peak of the spectrum stays at an approximately constant frequency, and thus Strouhal number, over the range of angles of incidence investigated. The second and third peaks also change only slightly in frequency. The sound pressure level of the first peak decreases until an angle of $\Phi = 25°$ is reached, and then increases again. For the second and third peak, the levels are strongly dependent on the incidence angle. At small angles the amplitude increases compared to a single cylinder arrangement. With increasing angle to the flow, the sound pressure level decreases, approaching the reference case of a single cylinder. Another effect can be observed at an incidence angle of $\Phi = 60°$: The main peak seems to split into two "sub-peaks" with lower amplitude. This is shown in Fig. 5 and was also observed in past studies [13]. Especially at low angles of incidence, the second and third peak are up to 20 dB higher in amplitude than at higher angles, indicating a strong interaction between the cylinders in this range. A similar effect was observed by Miyata et al. [14] with cylinders of unequal diameter in a similar range of incidence angles.

In the third step, a porous coating is added to the cylinders. The material chosen for this investigation is Panacell 45 ppi, a soft polyurethane foam with a very low air flow resistivity of σ =700 Pa s/m^2 and a porosity of ϕ =0.98.

In the spectra shown in Fig. 4 the main effects of the porous coating around the cylinders can be seen. Adding a porous coating to the upstream cylinder shifts the main tonal peak to a lower frequency while the amplitude is similar to the non-coated tandem cylinder case. The second and third peak as well as high frequency components decrease in sound pressure level. Also, the peaks get narrower when the coating is applied. The changes are way more subtle when adding a porous coating to the downstream cylinder. These findings correspond to prior studies by Liu et al. [15] and Geyer [16]. Interestin-

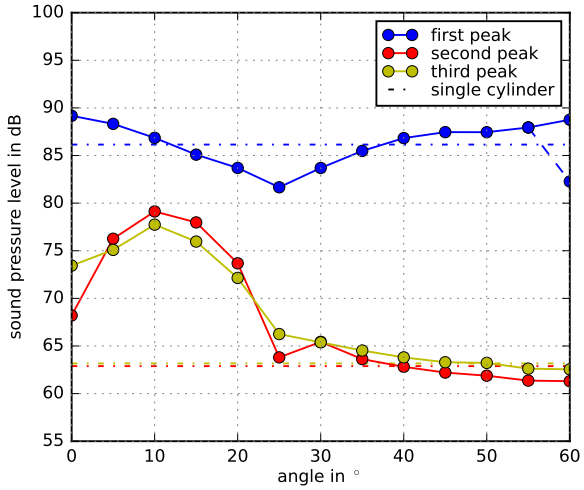

Figure 5: Sound pressure level of the main peaks in the spectrum over the angle of incidence (dashed line indicates bifurcation of the main peak and dash-dotted line denotes single cylinder case, inflow velocity $U = 40$ m/s, $Re = 80.000$).

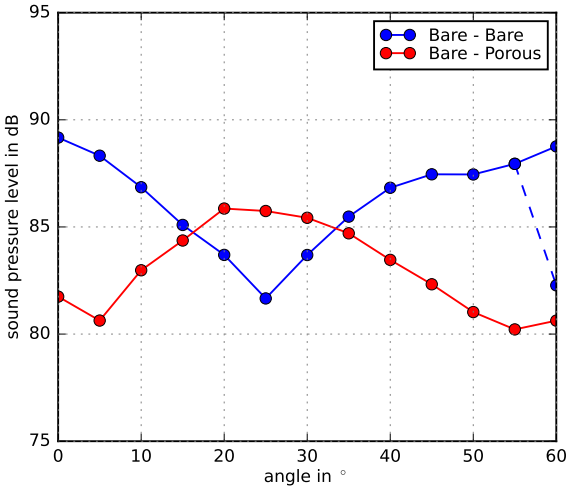

Figure 6: Sound pressure level of the first main peak in the spectrum over the angle of incidence for the reference case and the bare - porous configuration (inflow velocity $U = 40$ m/s, $Re = 80.000$).

gly, adding a porous coating to the downstream cylinder also has an effect on the peak sound pressure level. The sound pressure level of the main peak is reduced by almost 10 dB with reference to the bare setup even though the frequency is reduced only slightly. The configuration with both cylinders being coated also decreases the amplitude of the tone significantly.

Introducing an angle of incidence to the Bare - Porous configuration yields the following results: Compared to the case without the porous coating, the general behaviour is basically "inverted", meaning that the sound pressure level of the first main peak is increased by up to 4 dB at angles between $\Phi = 15°$ and $\Phi = 35°$. This can be seen in Fig. 6. At these angles of incidence there seems to be a stronger interaction with the flow, resulting in an increase in sound pressure level. A more detailed overview with an additional S/D ratio will be presented in an upcoming paper [17]. At low and high angles of incidence the noise reduction effect of the porous coating is highest when it is applied to the downstream cylinder.

To further compare the effect of the porous coating added to the cylinder, the difference in sound pressure level with respect to the reference configuration, where no coating is applied, is shown in Fig. 7. It can be seen that in a straight configuration without an angle of incidence, the porous material reduces the overall sound pressure level by 2 to 4 dB. This effect is valid for angles up to $\Phi = 10°$ and for angles larger than $\Phi = 35°$. For angles between 10° and 35°, the porous coated downstream cylinder does not have an effect on the overall sound pressure level. But more interestingly, the coated upstream cylinder even slightly increases the overall sound pressure level by up to 4 dB. This range of incidence angles has also been observed in prior studies to feature a strong aerodynamic interaction between the cylinders, especially with large fluctuations in lift forces acting upon the cylinders [18]. For the spacing of $S = 4.7D$ chosen for this study, this range of angles apparently results in flow phenomena that lead to an increase in overall sound pressure level. Further research is necessary to explore this phenomenon.

Acknowledgements

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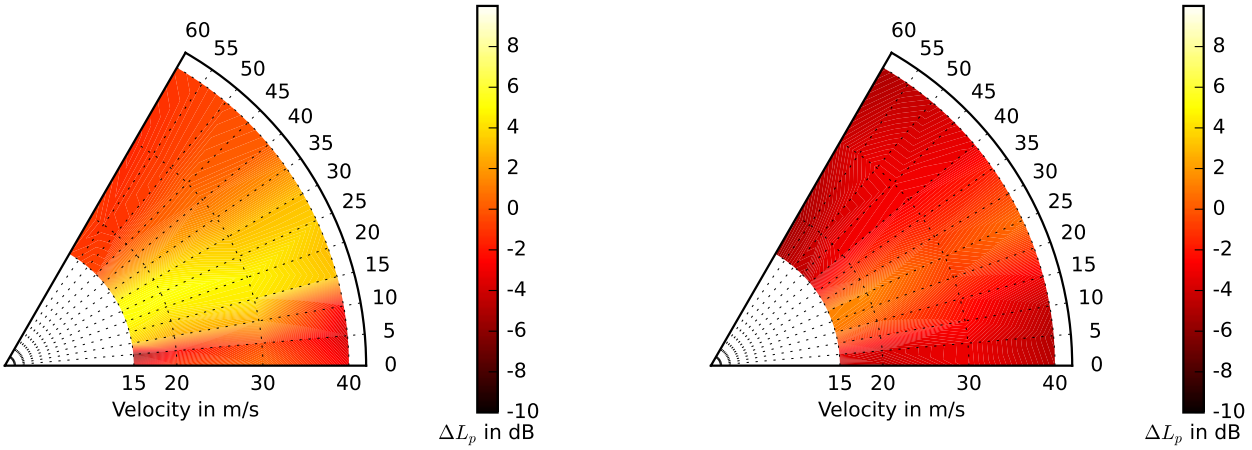

(a) Porous coated cylinder upstream

(b) Porous coated cylinder downstream

Figure 7: Difference in sound pressure level of the porous coated configurations to the reference bare configuration (interpolated between data points located at intersections of the grid).

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