Noise generation by tandem cylinders of different diameter in cross-flow

Thomas F. Geyer[1,2], Paul Abromeit[3], Maximilian Prügel[2]

[1] *Institute of Electrified Aero Engines, German Aerospace Center (DLR), 03046 Cottbus, Germany,*
Email: thomas.geyer@dlr.de

[2] *Technical Acoustics Group, Brandenburg University of Technology Cottbus - Senftenberg, 03046 Cottbus, Germany*

[3] *Chair of Electrified Aero Engines, Brandenburg University of Technology Cottbus - Senftenberg, 03046 Cottbus, Germany*

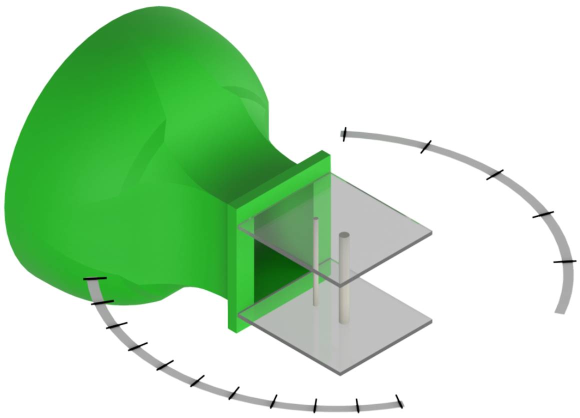
Introduction

The noise generation by two circular cylinders placed in a tandem configuration is of large interest for aeroacoustic research, as it constitutes a simple model for technical applications like the protective guard grille of axial fans or parts of the landing gear of aircraft [1]. For the latter problem, one such tandem cylinder configuration even constitutes an official AIAA benchmark problem [2, 3]. Thereby, the resulting tonal noise depends on parameters such as the diameter of the cylinders and their spacing, the angle between the cylinders with respect to the flow, the flow velocity, and inflow turbulence parameters. In addition, tandem cylinder configurations are used for the investigation of flow noise reduction strategies such as porous cylinder coatings [4–6].

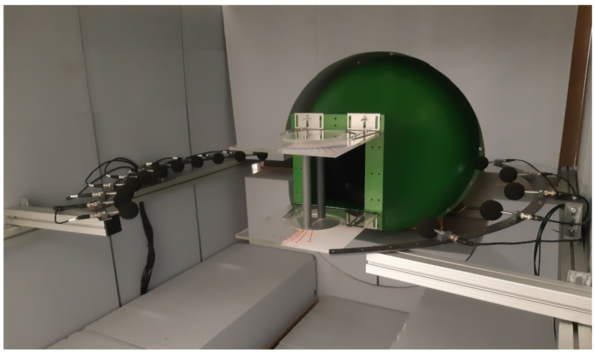
This paper presents results from a recent study in a small aeroacoustic wind tunnel facility on the far-field noise generated by parallel tandem cylinders with different diameters and for various cylinder spacings, with the main aim being the analysis of the effect that the wake impingement of the upstream cylinder on the downstream cylinder has on the tonal noise. Currently, there is only a small number of studies available that consider the influence of unequal cylinder diameters on the noise generation [7,8], but a detailed aeroacoustic investigation based on a comprehensive parameter variation is still missing. In the current paper, preliminary results from these experiments will be presented and discussed together with results from flow field measurements and qualitative two-dimensional flow simulations that enable a better understanding of the physical noise generation mechanisms. A more comprehensive analysis of the complete experimental database can be found in an upcoming paper by the authors [9].

Experimental Setup

The experiments took place in the small aeroacoustic open jet wind tunnel at the Brandenburg University of Technology in Cottbus [10]. The nozzle used in this study has a rectangular exit area of 0.28 m × 0.23 m. Side plates made of acrylic glass are attached to the nozzle on two sides. These plates hold the tandem cylinder configuration in a fixed distance from the nozzle exit. Although the setup allows for the adjustment of an angle of incidence [11], in the present study the cylinders were arranged in a classic tandem configuration, meaning at an angle of incidence of 0°. In addition, the setup allows for the generation of defined inflow turbulence by attaching passive turbulence grids to the nozzle exit. A



(a) Schematic.



(b) Photograph.

Figure 1: Experimental setup in the aeroacoustic wind tunnel.

schematic and a photograph of the setup are shown in Fig. 1. Acoustic measurements were performed using 16 1/4th inch free-field microphones located on two arcs on the side of the test section. One of the arcs contained eleven microphones with an angular spacing of 10°, the other five microphones and 20° spacing. The distance from the center between the two cylinders and each microphone was 0.61 m.

Data were recorded with a duration of 60 s and a sampling frequency of 51.2 kHz. In post-processing, which was performed using the open-source software package *Acoular* [12], the time data were converted to the frequency domain using a Fast Fourier Transform with a block size of 16384 samples, the Hanning window function and 50 % overlap.

Measurements were performed at flow velocities ranging

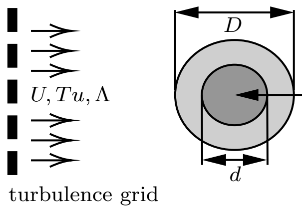


Figure 2: Schematic of the configuration analyzed exemplarily in the present paper (top view).

from 10 m/s to 40 m/s. For brevity, only results for two different cylinder diameters at a single flow velocity of 40 m/s are chosen to illustrate fundamental findings. The thicker cylinder has a diameter D of 30 mm, and the tandem cylinder configuration with two thick cylinders serves as a baseline throughout the study. The thinner cylinder has a diameter d of 18 mm. Furthermore, the current paper focuses on a single tandem cylinder spacing of 3.7 D only, which corresponds to the spacing used in the AIAA benchmark [2]. To further try to give an overview on basic trends, additional results are presented for the case of a turbulent inflow as well as for a porous coating of the upstream cylinder. A schematic of the configuration used here is shown in Fig. 2.

Flow field measurements were performed in the wake of the two cylinders, but not in tandem configuration, using Constant Temperature Anemometry with a single wire miniature probe at a single flow velocity. Flow profiles were measured at the location corresponding to the axis of the downstream cylinder, but without the cylinder in place.

In addition to the measurements, two-dimensional Computational Fluid Dynamics simulations were performed for selected configurations to allow for qualitative conclusions that help understanding the acoustic results. These simulations were done assuming non-reactive incompressible flows using the open-source software *Flowsquare* [13].

Results

Figure 3 shows spectra for five different configurations as well as for the wind tunnel background noise, measured at a flow velocity of 40 m/s (corresponding to a Reynolds number of approximately 80,000 based on the thicker cylinder diameter) with the microphone located at 90° to the flow on the left microphone arc.

With respect to the baseline configuration (30 mm - 30 mm) and the single 30 mm cylinder, it can be seen that the single cylinder leads to a clear peak due to periodic Kármán vortex shedding, which is shifted towards lower Strouhal numbers when a second cylinder of equal diameter is added. This agrees well with existing literature (e.g. [3]). In addition, the broadband noise increases for the tandem cylinder configuration compared to the single cylinder.

For the configurations with unequal cylinder diameters it can be noted that the case with the smaller cylinder downstream (30 mm - 18 mm) only leads to a slight increase in the vortex shedding frequency, while the case

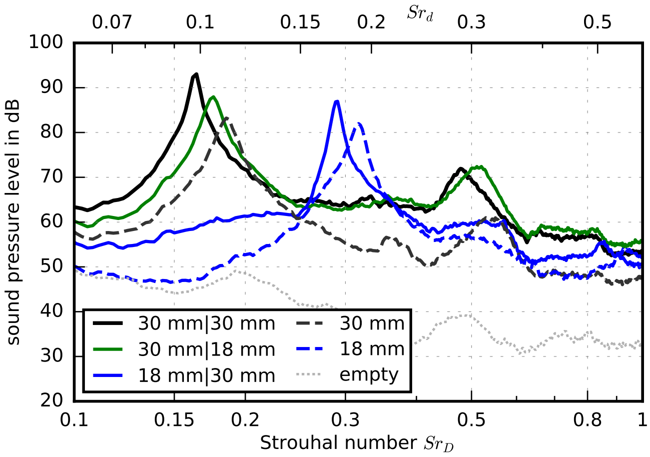
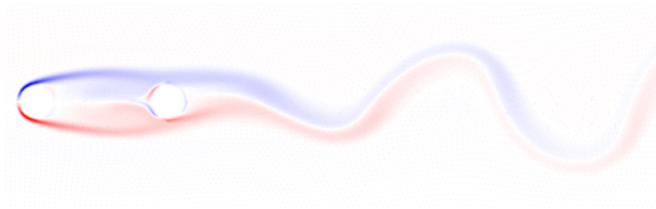
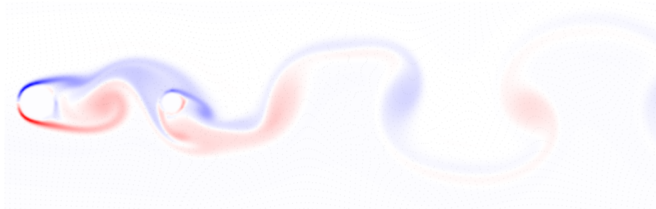


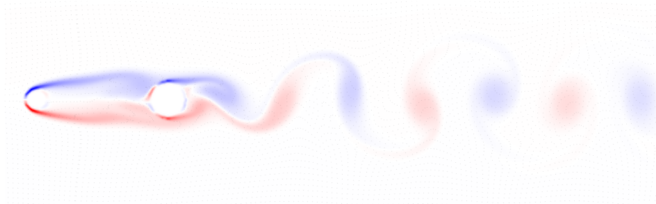
Figure 3: Sound pressure level spectra obtained for various cases at a flow speed of 40 m/s.



(a) 30 mm - 30 mm



(b) 30 mm - 18 mm

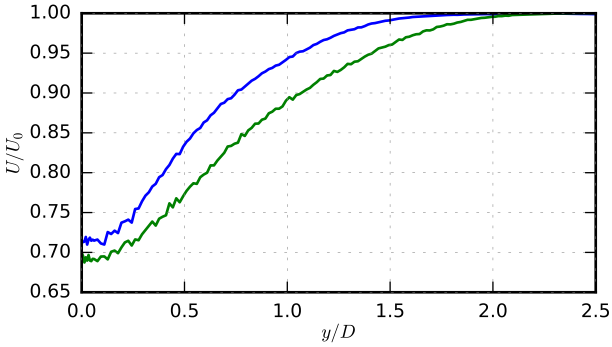


(c) 18 mm - 30 mm

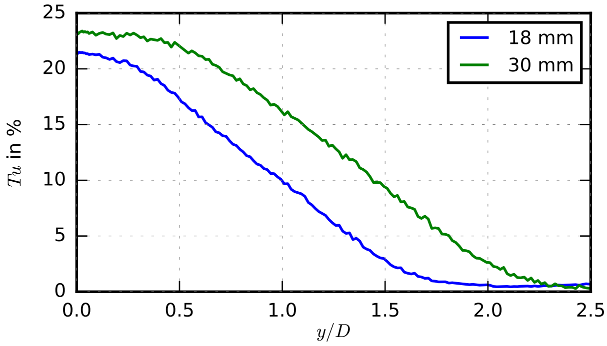
Figure 4: Numerical simulation of the flow around different tandem cylinder configurations in clean inflow.

with the smaller cylinder upstream (18 mm - 30 mm) leads to a quite notable increase of the shedding frequency. A comparison with the corresponding single cylinder cases (30 mm and 18 mm) shows that the resulting tones are similar to the tandem cylinder configurations with the same upstream cylinder diameter. These observations indicate that for the selected cylinder spacing of 3.7D, the vortex shedding is apparently governed by the upstream cylinder. This is also confirmed by the fact that the cases with the thicker cylinder diameter scale with the Strouhal number Sr_D, which is based on D, whereas the other cases rather scale with Sr_d.

This finding is further corroborated qualitatively by the



(a) Mean flow velocity.



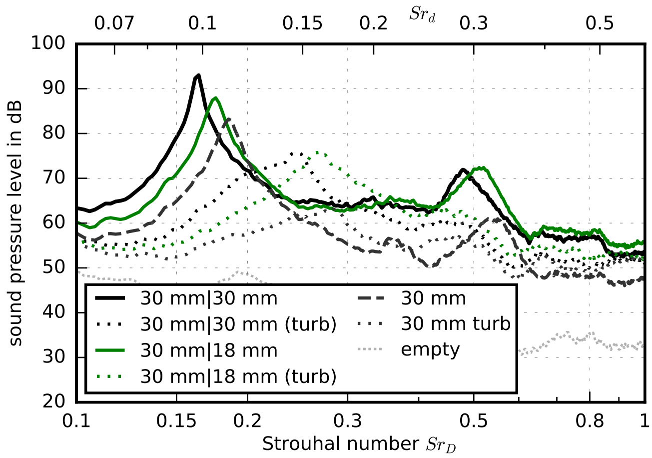
(b) Turbulence intensity.

Figure 5: (Half) wake profiles measured downstream of a single cylinder at a distance of $3D$.

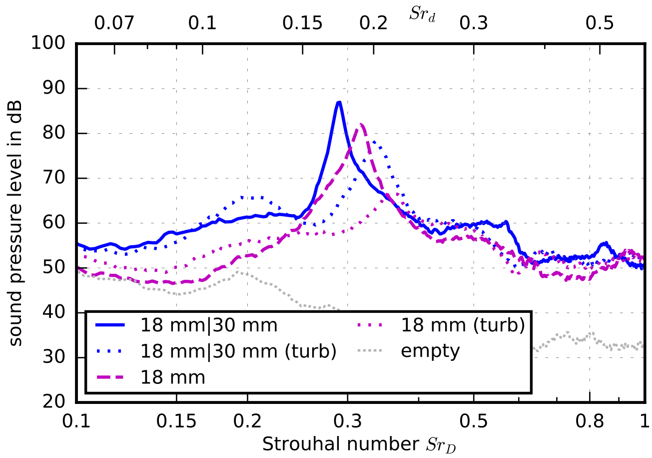
results from the numerical simulations shown in Fig. 4. For the configuration with the thinner cylinder located downstream (30 mm - 18 mm, Fig. 4(b)), the flow visualization shows a slight shortening of the distance between subsequent vortices shed from the downstream cylinder, and hence a slight increase of periodicity, compared to the baseline case (30 mm - 30 mm, Fig. 4(a)). Interestingly, this configuration also features notable vortex structures being shed from the upstream cylinder and impinging on the downstream cylinder. This may be the cause for the increase in broadband noise at Strouhal numbers above the vortex shedding peak compared to the single cylinder case that can be seen in Fig. 3, although additional research is necessary to confirm this hypothesis. For the case with the thinner cylinder upstream, the flow simulation confirms a strong increase in the vortex shedding periodicity (Fig. 4(c)).

Figure 5 shows wake profiles measured downstream of the first cylinder at the streamwise location of the downstream cylinder axis (but without the cylinder in place). It can basically be observed that the smaller cylinder leads to a narrower wake profile, an increased mean flow velocity and a reduced turbulence turbulence intensity compared to the thicker cylinder.

In a next step, the effect of a turbulent inflow on the tonal noise generated by the different tandem cylinder configurations will be analyzed. To this end, turbulence with an intensity of approximately 9 % and an integral length scale of 9 mm was generated using a passive turbulence grid with a mesh width of 15 mm and a bar



(a) Thick cylinder (D = 30 mm) upstream.



(b) Thin cylinder (d = 18 mm) upstream.

Figure 6: Sound pressure level spectra obtained for various cases at a flow speed of 40 m/s in turbulent inflow.

width of 5 mm (see [14]). Figure 6 shows example results, split into two cases: Results for the configurations with the thicker cylinder upstream (30 mm - 30 mm, 30 mm - 18 mm and the single 30 mm cylinder) are given in Fig. 6(a), revealing that the turbulent inflow leads to a notable reduction and broadening of the vortex shedding peak as well as to a shift of this peak towards higher Strouhal numbers. For the configurations with the thinner cylinder upstream (18 mm - 30 mm and the single 18 mm cylinder), the results shown in Fig. 6(b) are less distinct. For the single cylinder, a notable shift of the tonal peak to higher Strouhal numbers as well as a reduction and broadening is visible. The tandem cylinder case, on the other hand, shows only small reduction and broadening of the spectral peak, especially when compared with the trend seen for the thicker cylinder upstream (Fig. 6(a)). However, a notable shift of the peak towards higher Strouhal numbers can still be observed.

Finally, the effect of adding a porous coating to the upstream cylinder will briefly be discussed as a means to reduce the noise radiated from tandem cylinder configurations. However, this will be done only for the case with the thinner cylinder located upstream (18 mm - 30 mm) as well as for the single 18 mm cylinder. To this end, a

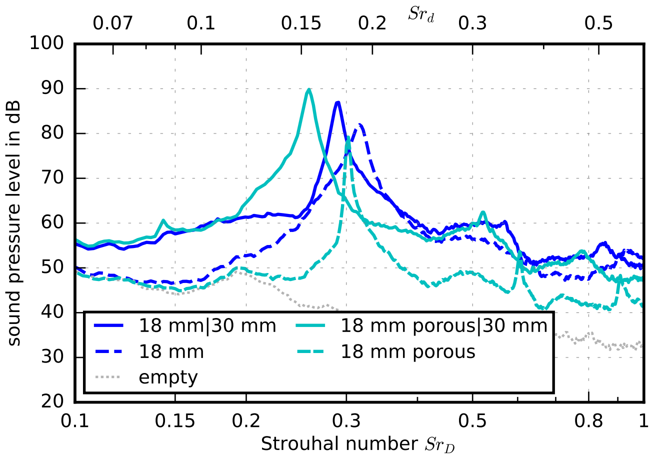


Figure 7: Sound pressure level spectra obtained for various cases at a flow speed of 40 m/s.

cylinder consisting of a bare core cylinder with a diameter of 10 mm and a porous coating made of a 4 mm thick melamine resin foam was used [15]. It has an air flow resistivity σ of approximately 10.000 Pa s/m^2 and a porosity ϕ of approximately 0.99. As can be seen from Fig. 7, a porous coating applied to the single cylinder leads to a notable narrowing of the vortex shedding peak as well as to a slight shift of this peak towards lower Strouhal numbers. The narrowing of the peak is assumed to be due to an increased spanwise coherence of the vortex shedding and a regularization of the wake, leading to a more synchronized vortex shedding [16]. For the tandem cylinder case, a porous coating of the upstream cylinder leads to a notable shift of the vortex shedding peak towards lower Strouhal numbers, an effect caused by the notable reduction of the mean velocity downstream of the porous coated upstream cylinder as well as the stabilizing effect of the porous coating on the wake [6]. In addition, the porous coating leads to a slight increase in peak magnitude.

Summary

As part of an ongoing study of the noise generated by tandem cylinder configurations, the present paper contains an overview of results obtained experimentally for the case of cylinders with an unequal diameter at a fixed spacing of $3.7D$ (referring to the diameter of the thicker cylinder) in an open jet wind tunnel. One main finding is that, at this spacing, the vortex shedding is governed by the upstream cylinder, meaning that the relevant vortex shedding Strouhal number needs to be calculated using the diameter of the upstream cylinder. In addition, the effect of a turbulent inflow as well as of a porous coating applied to the upstream cylinder are briefly discussed.

Results for a number of additional cylinder spacings as well as additional cylinder diameters will be presented in an upcoming paper [9].

References

[1] Zdravkovich, M.: Flow induced oscillations of two interfering circular cylinders. Journal of Sound and Vibration 101(4), 1985, 511-521

[2] Lockard, D., et al.: Tandem cylinder noise predictions. In: 13th AIAA/CEAS Aeroacoustics Conference (AIAA paper 2007-3450), 2007

[3] Khorrami, M. R., et al.: Unsteady flowfield around tandem cylinders as prototype component interaction in airframe noise. AIAA Journal 45(8), 2007, 1930-1941

[4] Liu, H., et al.: Tandem cylinder aerodynamic sound control using porous coating. Journal of Sound and Vibration 334, 2015, 190-201

[5] Liu, H., et al.: The importance of controlling the upstream body wake in tandem cylinders system for noise reduction. Proceedings of the Institution of Mechanical Engineers, Part G: Journal of Aerospace Engineering 232(3), 2018, 517-531

[6] Geyer, T. F.: Experimental investigation of flow and noise control by porous coated tandem cylinder configurations. AIAA Journal 60(7), 2022, 4091-4102

[7] Hutcheson, F. V., Brooks, T. F.: Noise radiation from single and multiple rod configurations. International Journal of Aeroacoustics 11(3-4), 2012, 291-333

[8] Mg, A., Jothi, T. J. S.: Aerodynamic noise characteristics of tandem cylinders in a subcritical flow regime. Proceedings of the Institution of Mechanical Engineers, Part G: Journal of Aerospace Engineering 238(15), 2024, 1564-1582

[9] Geyer, T. F., et al.: Experimental Investigation of the Tonal Noise Generation from Tandem Cylinders with Different Diameter. In: 13th AIAA AVIATION Forum (upcoming), 2025

[10] Sarradj, E., et al.: Acoustic and aerodynamic design and characterization of a small-scale aeroacoustic wind tunnel. Applied Acoustics 70(8), 2009, 1073-1080

[11] Geyer, T. F., Enghardt, L.: Noise generation by two staggered circular cylinders of equal diameter in cross-flow. In: 28th AIAA/CEAS Aeroacoustics 2022 Conference (AIAA paper 2022-3093), 2022

[12] Sarradj, E., Herold, G.: A Python framework for microphone array data processing. Applied Acoustics 116, 2017, 50-58

[13] Minamoto, Y.: Flowsquare 4.0: Theory and Computation, http://flowsquare.com, 2013

[14] Ocker, C., et al.: Permeable structures for leading edge noise reduction. In: AIAA Aviation 2021 Forum (AIAA paper 2021-2192), 2021

[15] Geyer, T. F.: Effect of a porous coating on the vortex shedding noise of a cylinder in turbulent flow. Applied Acoustics 195, 2022

[16] Sharma, S., et al.: On the influence of porous coating thickness and permeability on passive flow and noise control of cylinders. Journal of Sound and Vibration 549, 2023