Aeroacoustics of Tandem cylinders in crossflow – application to fan guard grills

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Introduction

Protective grills are required components of fans to avoid risk of injury. The grill causes sound emission, as it is close to the fan downstream in the blade wake. The acoustic emissions produced by protective grills need to be reduced as much as possible as it is environmentally sound pollution. The guard grills contains a number of narrow rings mounted on a support structure. In this study we focus on grills mounted on the pressure side of the fan. The turbulent flow of the fan crosses the grill leading to aeroacoustic sound emission. Figure 1 shows a protective grill for an axial fan.

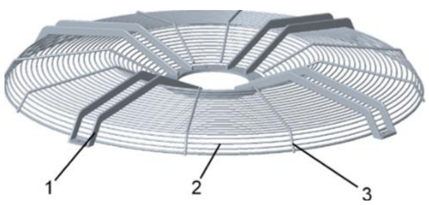

Figure 1: Protective grill downstream of an axial fan, 1 support structure, 2 protective ring, 3 stiffening rods

The turbulent flow of the fan crosses the protective grill leading to increased sound emission of the fan assembly. Figure 2 shows the sound power spectrum of fan with and without grill at maximum flow rate. The basic sound generation mechanism is the Kármán vortex shedding at the cylinders. This leads to a broad band hump at ~ 1500 Hz in the acoustic spectrum of the fan with grill. This hump is broader than typical aeolian tone of a single cylinder in crossflow. The reason is the spatial variation of flow velocity in the wake of the fan blade. Each cylinder faces another inflow velocity and thus sound emission spectrum. In addition, close cylinders interact with each other leading to increased force fluctuations [1]. There is a number of studies on flow phenomena and fluctuating forces on tandem cylinders [1-4], but to the authors knowledge no comprehensive study of sound emission with variation of geometric as well as turbulence parameters has been published.

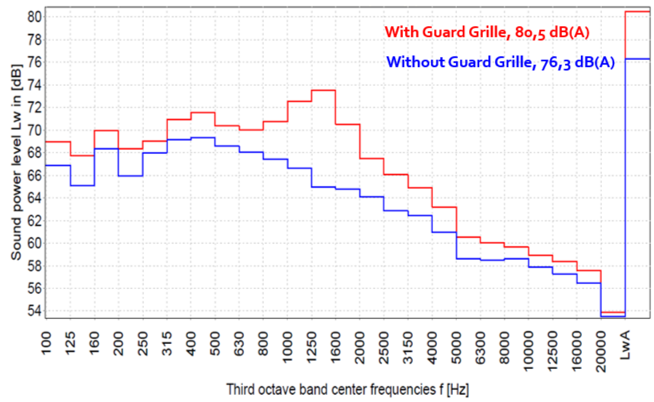

Figure 2: Sound power spectrum fan with and without protective grill.

Flow phenomena for tandem cylinders

Each configuration of the tandem cylinders is defined by two parameters: distance and angle. P^* is the dimensionless distance which is defined as ratio of center-to-center distance of the cylinders to their diameter. The angle between center-to-center line and the inflow freestream is mentioned as α. There are different flow classifications based on the variation of distance and angle of the tandem cylinders [1, 2]. At small angles the wake of the upstream cylinder interacts with the downstream cylinder leading to increased force fluctuations. For close distances both cylinders act as one big obstacle, whereas at larger distances two separate wakes are observed. It is also known, that not only lift fluctuations, but also St number changes depending on angle and distance.

The Reynolds number also has strong effect on the flow over the tandem cylinders[3], especially in the low Re regime. The Reynolds number for the target applications is low, depending on the fan operating point Re is in the range of 1000 to 3000. The changes o angle and distance of the two cylinders have strong effect on fluctuations of the lift coefficient [1]. At angles in the range of 25° and distances P* larger than 3 the fluctuation of lift is almost doubled compared to the no interaction regime. The distance itself also has strong effect. Especially for small distances < 3 lift fluctuations are strongly reduced. The Reynolds number in this investigation was 55000.

Experimental investigation on tandem cylinders

In this study, we investigated the sound emission of two cylinders in crossflow. The diameter of the cylinders was 3mm, which is typical for protective grill application. The cylinders were set up at P*= 2.6, 3.2, 3.8 and 4.4. The angle between the cylinders and freestream inflow varied from 0° to 90°. The cylinders were mounted horizontally between two vertical side plates made of Plexiglas. The distance between the plates was 280 mm corresponding to the spanwise length of the cylinders. All the measurements were performed in the free-jet acoustic wind tunnel at Brandenburg University of Technology Cottbus-Senftenberg (BTU). Figure 3 shows the measurement setup used in the wind tunnel.

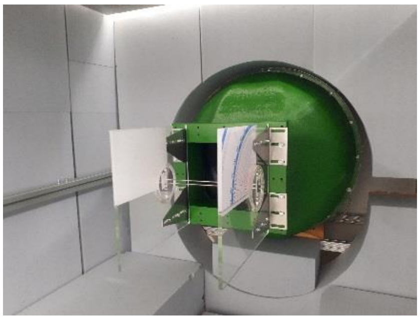

Figure 3: Tandem cylinders in wind tunnel

The noise measurements were conducted at five inflow velocities namely 10, 15, 20, 25 and 30 m/s which are corresponding to Reynolds number range of 2000 to 5500. Two different turbulence grids were used named G1 and G2 to produce turbulence in the freestream inflow. The turbulence intensities of G1 and G2 are approximately [5.3%...5.7%] and [7.2%...7.9%] respectively depending on flow velocity. In addition, the undisturbed inflow without grid was also measured. The flow field downstream the fan blades is always turbulent, thus only turbulent cases are discussed in this study.

The acoustic measurements were performed with 56 microphones mounted on a plate above the cylinders. This arrangement can be used to perform beamforming for sound source localization. In the present study, the vortex shedding occurred at frequencies below 1 kHz for the low velocities. As beamforming is generally very challenging at low frequencies, it was decided to use sound pressure level spectra obtained from single array microphones instead. For this reason, five microphones close to the midplane between the two plates were chosen as reference. All spectra shown are averages of these five single microphone spectra. The frequency resolution is 11.7 Hz.

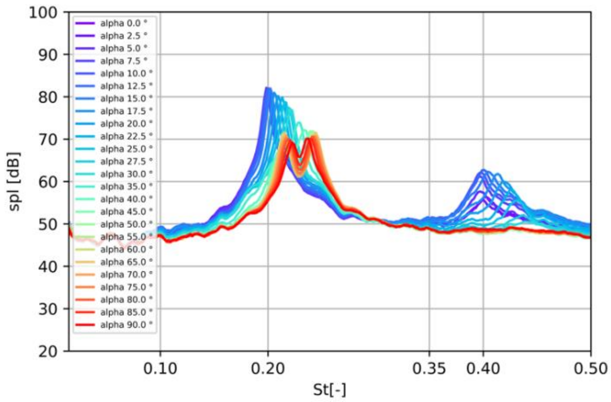

Figure 4: Dependency of sound spectra on angle, P* =3.8, u0=20 m/s, turbulence G2

Figure 4 shows the averaged sound spectra for different angles. The distance P* is 3.8, velocity 20 m/s, turbulence grid is G2 with higher turbulence intensity. The results show strong influence of angle on peak level as well peak Strouhal number. At high angles > 65° two separate peaks with almost the same peak levels are observed with St > 0.2. Peak levels are ~ 10 dB smaller compared to the highest peaks. For small angles in the range up to 30° one single peak is observed. The Strouhal number increases from 0.2 to 0.23 with increasing angle. Peak level decreases with angle. Starting from 40° two separate peaks with different levels appear. Both peaks reach the same level at angles > 65°. Results are exemplary discussed for one configuration and differ slightly at other conditions. For better general understanding overall levels in St range [0.15 … 0.35] are calculated. This range was chosen to avoid higher harmonics in the given spectral range. Harmonics are observed at low angles < 25° only.

Figure 5 shows a contour plot of the overall levels in the given St range. Highest sound pressure levels are observed at small angles less than 30° and distances 3.2 to 3.8. SPL is ~ 8 dB higher compared to small interference configurations at high alpha 80° - 90° and P* 4.4. Most interesting is the strong decrease of SPL with small distances. Here the tandem cylinder interaction leads to 15 dB less SPL compared to max. levels. It is interesting to note, that the cylinder interference decreases levels ~ 7dB below the small interaction regime, where the two cylinders can be regarded as two single independent sound sources.

These finding offers potential for reducing sound emission on protective grills. Small angles between flow and ring alignment should be avoided. In addition smaller distances P* < 3 should be applied if possible. Increasing the distance to P* 4.4 also leads to reduction of sound emission, but max. distance is usually fixed to ensure the protective function.

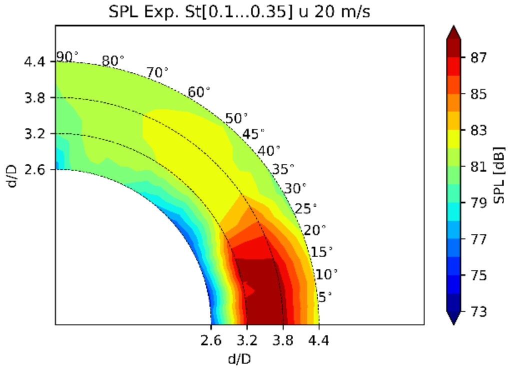

Figure 5: Measured overall sound pressure St [0.15… 0.35], velocity 20 m/s, turbulence G2.

Sound emission model

For optimization of the geometry of a protective grill, a simple model for the sound emission is required. From the experimental results we have seen, that the spectrum is dominated by one or two peaks in the given St range. We suggest to model the spectrum by two simple parabolas following equation (1)

$$SPL\_model = a\,(St - St\_peak)^2 + SPL\_peak \qquad [\text{dB}] \qquad (1)$$

Where *St_peak*, and *SPL_peak* are peak parameters of the measured spectrum for each configuration. The parabola width *a* is obtained from fitting a parabola to the measured spectrum. The fitting was done for a small part of the spectrum around the peak with 5 points from the peak in each direction. Figure 6 shows the model spectrum for one exemplary configuration.

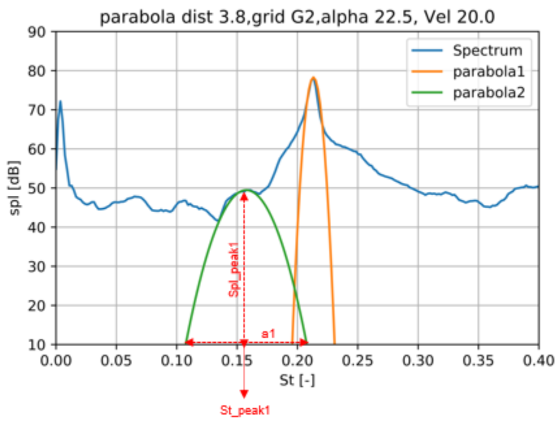

Figure 6: Approximation of detected peaks with parabolas.

The total model spectrum is now derived as logarithmic sum of both parabolas. This approach works well in cases, were the overall level is dominated by the peaks. This is true for most configurations. What is neglected in the model is the broad band sound emission due to turbulent inflow. We evaluated the model error by comparing the overall levels in the given St range for experiments as well as the model. Figure 7 shows the linear difference of SPL between model and experiments.

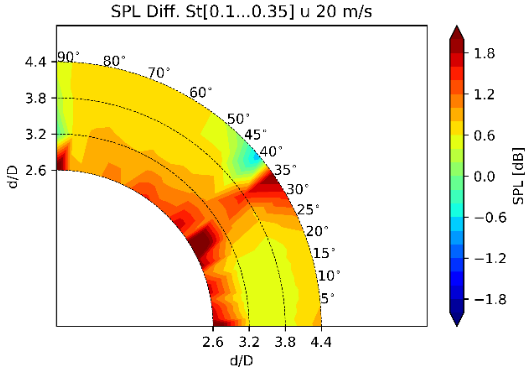

Figure 7: Model error *SPL_Meas – SPL_model*, velocity 20 m/s, turbulence G2.

The accuracy of the model is high, the model error is less than +/- 2 dB. For most configuration a slight underprediction is observed. This is attributed to the neglection of broad band contribution in the model. Largest deviations are found at small distances P* 2.6 and α ~ 35°.

Summary

The sound emission of tandem cylinders in turbulent flow was investigated in a wind tunnel. Strong dependency on angle as well as distance was found. Results correspond to published studies showing fluctuating forces. A simple model spectrum covering two parabolas is suggested. The evaluation of the error showed only small differences in terms of overall levels. The measured results show potential improvements for protective grill arrangements. The suggested model can be applied to estimate the sound emission of the protective grill. Required flow velocities and angles for any operating condition and ring position can be provided by steady state CFD of the fan.

References

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