25th ABCM International Congress of Mechanical Engineering
October 20-25, 2019, Uberlândia, MG, Brazil

COB-2019-1564
AEROACOUSTIC EXPERIMENTS ON CIRCULAR CYLINDER NEAR PLANE WALL

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Abstract. *A concept of aeroacoustic noise is the sound generated by the flow when passing over a body regardless of the geometry. This work aims to study the noise of a cylinder and the influence of the proximity of a plane wall with laminar boundary layer. The study took place at the LANT wind tunnel at EESC-USP. Acoustic measurements and acoustic source maps were performed using a microphone array with conventional beamforming technique and DAMAS deconvolution method. A flat plate model and a wire were mounted in the test chamber and the distance between the wire and the model was varied by bringing it close to the plate in order to vary the Gap / Diameter. Measurements with Hot-wire anemometer at the flat plate show that in all cases the boundary layer was laminar. The results show that the sound generated by the cylinder presents tonal peaks arising in frequencies relative to number of Strouhal around 0.19. Maps of acoustic source finding the sources on the wire attached to the test chamber. It was shown that when the cylinder is closest to the plate, about G / D = 4 there is a suppression in the generated noise and a large drop in the intensity of the tones generated by the presence of the wire.*

Keywords: *Experimental aeroacoustics, Conventional beamforming, DAMAS, Cylinder noise.*

1. INTRODUCTION

The aeroacoustic noise can come from several sources, among them the flow around a body. To reduce the noise emission one of the first steps is to better understand the sound sources (Cox *et al.*, 1998). Together with some profiles, the cylinder is one of the geometries that receive most attention at the research community (Bearman and Zdravkovich, 1978). The phenomena of the noise generated by the passage of a flow over a cylinder has been studied since the work of Strouhal about the Aeolian tones (Blevins, 1984; Inoue and Hatakeyama, 2002). Near to a wall, this geometry receives even more attention, because of other applications as tubes of heat exchangers near wall, refrigeration of wires at electronic circuits and submarine cable and ducts (Bhattacharyya and Dhinakaran, 2008; Wang and Tan, 2008; Dipankar and Sengupta, 2005; Price *et al.*, 2002; Hutcheson and Brooks, 2012).

To study this kind of problem requires specialized facilities. The wind tunnel present at the Department of Aeronautical Engineering of the University of Sao Paulo was designed to has low background noise and low turbulence level, being a unique facility in Brazil. This work aims to study the noise generated by a cylinder and analyze the influence of the proximity of a wall with laminar boundary layer at the sound emission.

2. Metodology

For the present work the facility of the Low Acoustic Noise and Turbulence (LANT) wind tunnel, fig.1, present at the Department of Aeronautical Engineering of the University of São Paulo was used. This is a closed test section and closed circuit wind tunnel especially designed for aeroacoustics and flow instability experiments. The test section has cross-section of 1000mm x 1000mm with 3000mm length and achieve around 30 m/s of flow speed. Serrano Rico *et al.*

(2017) presents the wind tunnel design with further details. A flat plate with 2120mm chord, 1000mm width and 10mm thick was installed in the center of the test section 500mm away from the windows. This model has a 120mm leading edge in format of a super-ellipse to keep the stagnation point at the lower face of the model. A flap and tab are also present to allows the adjustment of the pressure gradient. At this study a cylindrical wire with $1,3$mm diameter was clamped to the test section floor and ceiling. The experiments were conducted in a position 120mm distant from the model leading edge with the wire positioned 250, 40, 13, 6, 3 and 1 mm away from the flat plate, as represented at the schematic in figure 2, for the flow speeds of 15, 20, 25 and 29 m/s.

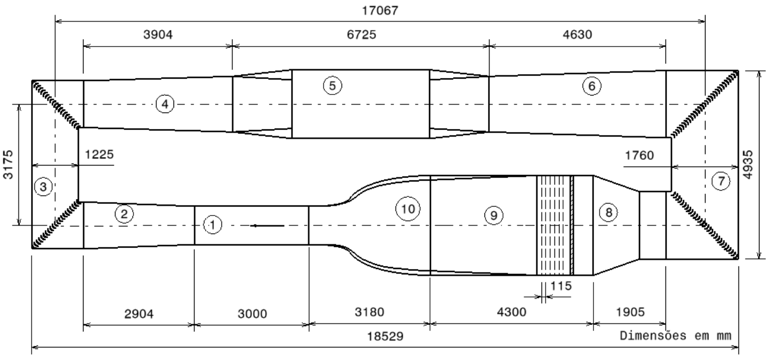


Figure 1: LANT wind tunnel aerodynamic circuit.

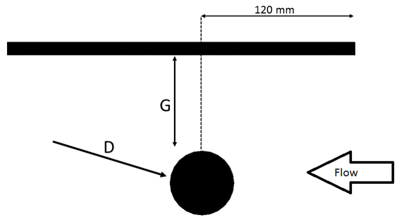


Figure 2: Schematic of the experimental setup.

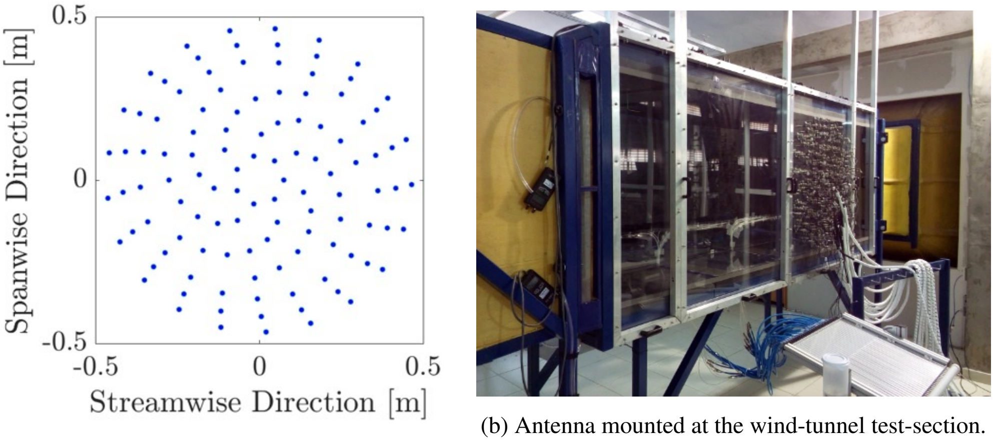
For the aeroacoustic measurements, an phased array containing 112 microphones was specially designed for closed test-section aeroacoustic measurements, Fig. 3, (Amaral *et al.*, 2018). The G.R.A.S. Sound and Vibration 1/4 in 40PH microphones used reach frequencies up to 20 kHz and have a large dynamic range, topping at around 135 dB. The data acquisition employed a National Instruments hardware, including seven PXI-4496 boards of 24-bit and 16 analogical inputs each, arranged into a PXI-1042Q chassis. Data transfer is accomplished at 132 MB/s by the PXI-PCI 8336 modulus, which connects the PXI-1042Q chassis and the PXI-8351 computer. In-house beamforming codes were employed to post-process the microphone array data, deconvolution technique DAMAS was also used (Pagani Jr, 2014; Amaral, 2015).

Hot-wire anemometer (HWA) measurements were used to characterize the flat plate boundary layer. A constant temperature anemometer DISA model 55D05 together with a probe Dantec 55P05 were employed for the realization of the experiments. The AC component of the signal were acquired with the PXI-4496 boards and the DC component were acquired with a National Instruments cDAQ 9184 with NI 9234 board. As HWA measurements are punctual, a traverse system was designed to allow the movement of the probe at great part of the test section.

3. Boundary layer measurement

The boundary layer measurement was realized with the flat plate installed at the wind tunnel but without the presence of the cylinder. The probe was placed 0.5 mm from the wall and then moved away 20 points $0.15mm$ distant from each other. This measure was realized for the flow speeds of 15 m/s e 25 m/s. Figure 4 shows the comparison between the experimental points with the theoretical profile of Blasius for a laminar boundary Layer at 25 m/s, η was calculated according to equation

$$\eta = y\sqrt{\frac{U}{\nu x}}. \tag{1}$$



(b) Antenna mounted at the wind-tunnel test-section.

(a) Microphone array design.

Figure 3: Microphone phased array used at aeroacoustics experiments.

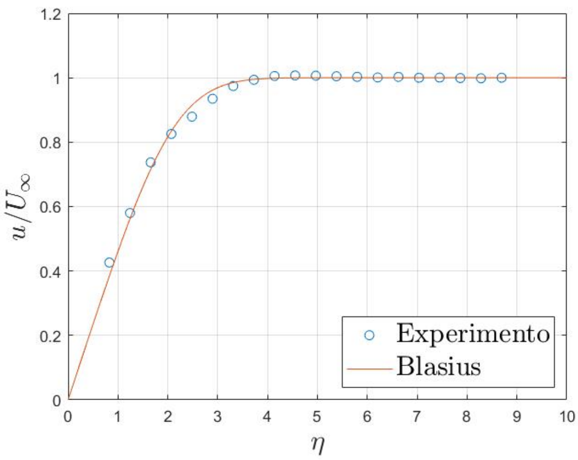


Figure 4: Comparison between experimental points and Blasius boundary layer profile.

As the results present good agreement between the experimental points and the theory, equations 2 and 3 were used to calculate the boundary layer thickness and displacement thickness at all flow speeds used during the experiment. Results are shown at table 1.

$$\frac{\delta}{x} = \frac{5}{\sqrt{Re_x}}. \tag{2}$$

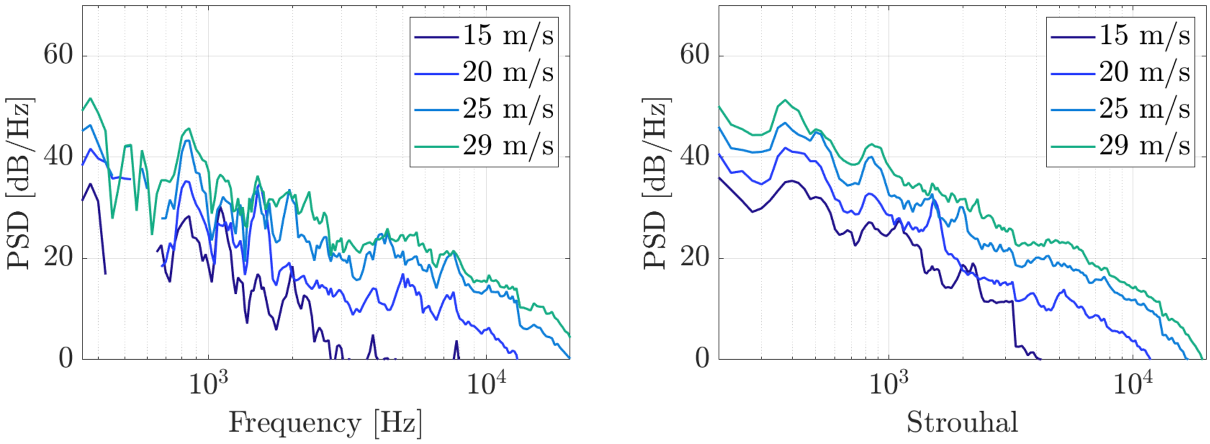
$$\frac{\delta^*}{x} = \frac{1,72}{\sqrt{Re_x}}. \tag{3}$$

Table 1: δ and δ^* for x = 120 mm from leading edge at all freestream speeds.

	Boundary Layer Thickness (δ) (mm)	Displacment thickness (δ^*) (mm)
15 m/s	1.66	0.554
20 m/s	1.55	0.515
25 m/s	1.30	0.434
29 m/s	1.28	0.428

4. Cylinder noise measurements

For comparison reasons the noise spectrum of flat plate without the presence of the cylinder is presented first at figure. 5. The Spectrum are plotted for all flow speeds used at the experiment and for booth methods of post-processing, DAMAS and conventional Beamforming (CBF).

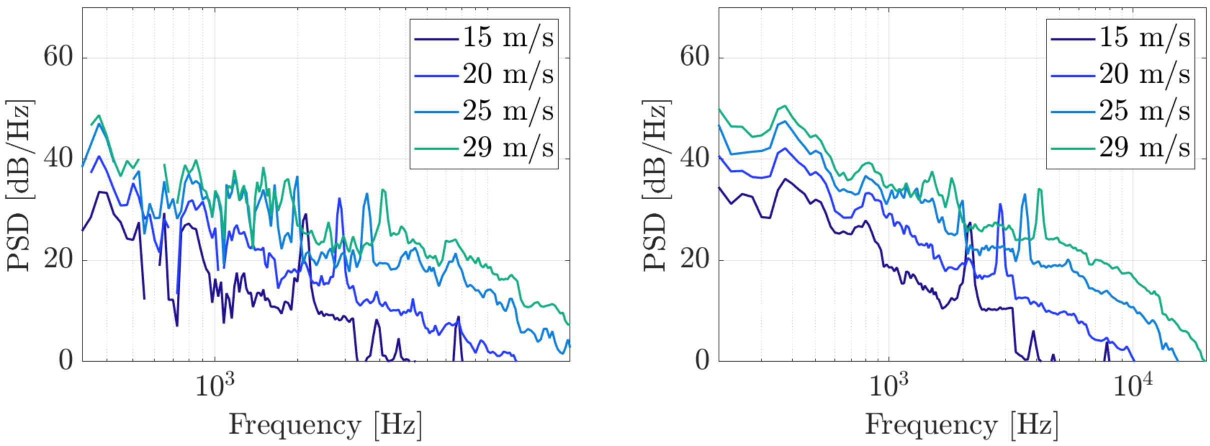


(a) (DAMAS) (b) (CBF)

Figure 5: Noise spectrum of the Flat plate without the cylinder.

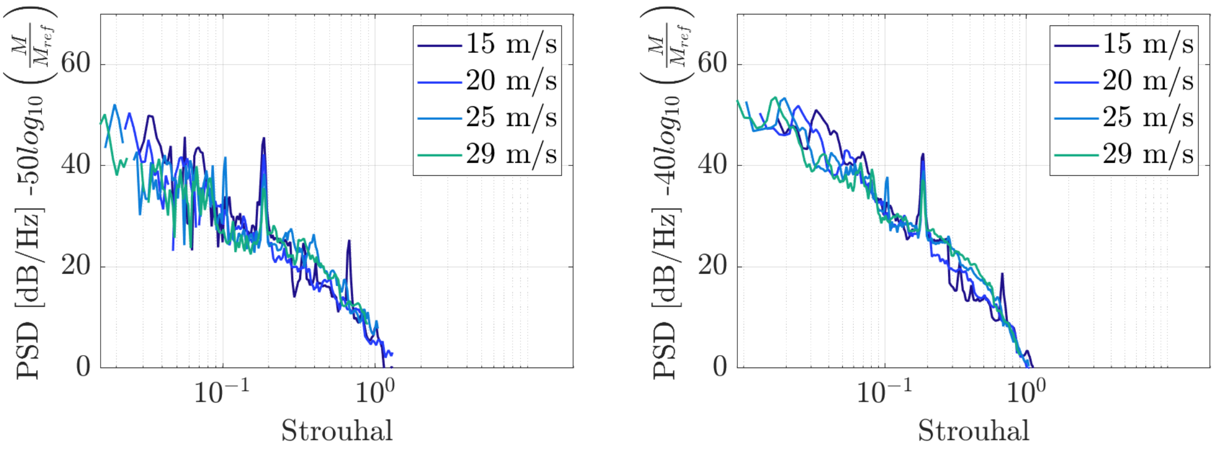
Figure 7 presents the noise spectrum of the cylinder plotted by Conventional Beamforming(CBF) and DAMAS deconvolution method for the case with the wire distant 40 mm from the flat plate. As shown, for 15, 20, 25 and 29 m/s a tonal peak arise at the frequencies of 2150, 2900, 3600 and 4200 Hz respectively and this peaks collapse at a number of Strouhal by the wire diameter of 0.19, as presented at 6. Figure 6 also shows a Mach collapse for this case which has good agreement for $Mach^5$ for DAMAS and $Mach^4$ for CBF. The acoustic source maps are presented at figures 8 and 9 for both methods of post-processing, it shows that sound source is located over a big part of the wire length. This plot was made for the free stream speed of 25 m/s at 3600 Hz. Comparing the two methods it can be seeing that the deconvolution Method DAMAS presents a more linear source over the wire in better agreement with a bi-dimensional phenomena as presented in the literature.

By putting the wire closer to the wall, the results shown that between the position of 13 mm and 6 mm the peak present at the noise spectrum decreases significantly, being even lower closer to the wall, for the case 1 mm distant from the wall the peak is almost imperceptible, Fig.10. The acoustic source maps plotted by DAMAS and conventional beamforming for the case 1 mm distant from the wall, figures12 and 11, show only a small noise source over the wire, located on the center of the span. This source has less intensity than the one founded at figures 8 and 9.



(a) (DAMAS) (b) (CBF)

Figure 6: Noise spectrum of the cylinder 40 mm distant from the Flat plate.



(a) (DAMAS) (b) (CBF)

Figure 7: Mach and Strouhal collapse for the cylinder 40 mm distant from the Flat plate.

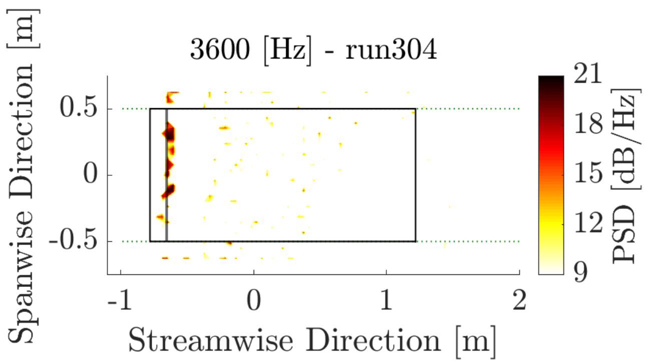


Figure 8: Acoustic source map for the wire 40 mm distant from the plate ate 25 m/s at 3600 Hz plotted by DAMAS.

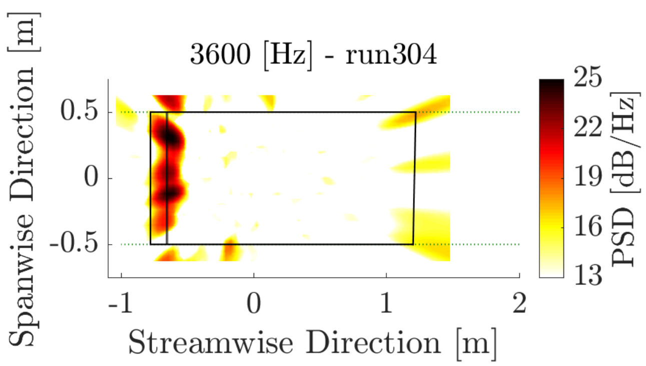
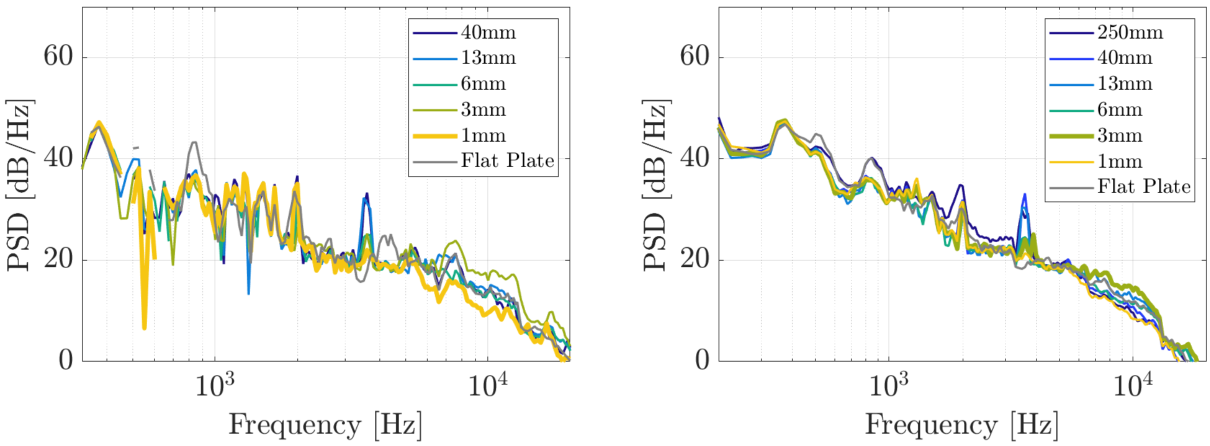


Figure 9: Acoustic source map for the wire 40 mm distant from the plate ate 25 m/s at 3600 Hz plotted by CBF.



(a) (DAMAS) (b) (CBF)

Figure 10: Noise spectrum of the cylinder by the distance from the Flat plate at 25 m/s.

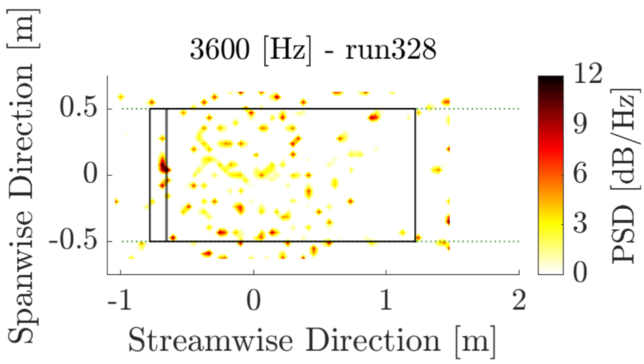


Figure 11: Acoustic source map for the wire 1 mm distant from the plate ate 25 m/s at 3600 Hz plotted by DAMAS.

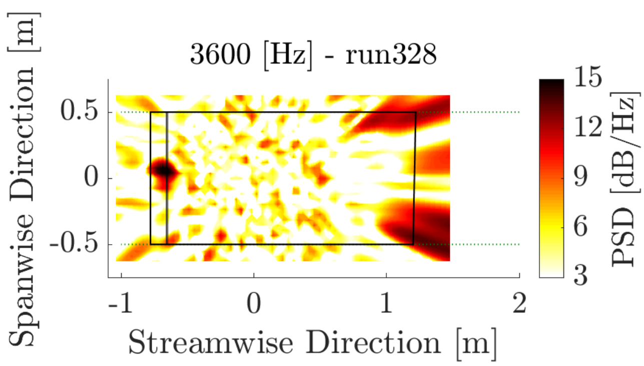


Figure 12: Acoustic source map for the wire 1 mm distant from the plate ate 25 m/s at 3600 Hz plotted by CBF.

5. Conclusion

The experiments show that the noise from the cylinder is due to the vortex shedding and that the tonal peaks collapse for a Strouhal number by the cylinder diameter of 0.19 wich is close to the St of 0.2 present at the literature. Also when the cylinder is placed closer to the wall a fall at the tonal peak intensity is noted at the position 6 mm distant from the flat plate. When the cylinder is 1 mm distant from the plate, which is inside the boundary layer, the peak is imperceptive. Acoustic maps sources show the noise source over the wire placed in the test section, confirming that the sound comes from it. However when the wire is placed near to the wall the source intensity is reduced.

6. ACKNOWLEDGEMENTS

M.M.B received funding from Coordination for the Improvement of Higher Education Personnel (CAPES/Brazil).

C.S.B received funding from Coordination for the Improvement of Higher Education Personnel (CAPES/Brazil).

J.C.S.R. received support from from National Council for Scientific and Technological Development (CNPq/Brazil), grant #140211/2014-4.

F.R.A. received funding from Coordination for the Improvement of Higher Education Personnel (CAPES/Brazil), grant #DS00011/07-0.

M.A.F.M. received support from CNPq/Brazil, grant #304859/2016-8.

The Wind tunnel financial support was provided by FINEP/Brazil, grant #01.09.0334.04.

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