

PRESSURE AND VELOCITY FLUCTUATIONS AFTER A ROW OF CYLINDERS IN FLOW WITH TURBULENCE INTENSITY VARIATION

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Abstract. *The present experimental study analyzes the velocity and pressure fluctuations in the wake of smooth cylinder row with diameter of 25.1 mm and spacing ratio of 1.26 submitted to a constant velocity air flow. Analysis is executed with signals obtained from flows with turbulence intensity equal to 1% and 11% and Reynolds number equal to 2.6×10^4 , based on the cylinder diameter and free flow velocity. The velocity signals are obtained using hot-wire anemometry technique and the pressure fluctuations using condenser microphones, positioned on the wall of the aerodynamic channel in two positions of the wake. Data are correlated and evaluated by continuous wavelets and Fourier analysis. Results show that the increase on the turbulence intensity impacts on the wake dispersion, which, due the momentum increase, reduces the downstream wake length, but does not changes the flow main characteristics.*

Keywords: *Row of cylinders, turbulence intensity, air flow, pressure fluctuations, velocity.*

1. INTRODUCTION

Cross flow over a row of cylinders present an asymmetric configuration with large and narrow wakes behind the cylinders, as presented in Fig. 1 (a) and (b) where a visualization with smoke and with dye are presented and show wakes with different sizes for each cylinder. These flow characteristics were described and confirmed by Zdravkovich (1997), where the author summarizes the relevant studies in this area and indicates the presence of an asymmetric characteristic of the flow over a cylinder row, this behavior was found on laminar and turbulent flows. The author presented studies for many pitch to diameter ratios, indicated as P/D , and observed that the non-uniformity is negligible for $P/D > 2$, but is significant in the range of $P/D = 1.2$ to $P/D = 2$. The author also observed that the non-uniform behavior can change-over intermittently, a common characteristic in cases with two cylinders, as presented by Alam et al. (2003), where the change-over was showed in P/D values lower than 2. The influence of the blockage ratio on the switching process is presented by Möller et al. (2015). Another study with cross flow over a row of cylinders was executed by de Paula et al. (2012) where the authors performed a flow visualization analysis increasing the number of rows and observing the resulting flow changes.

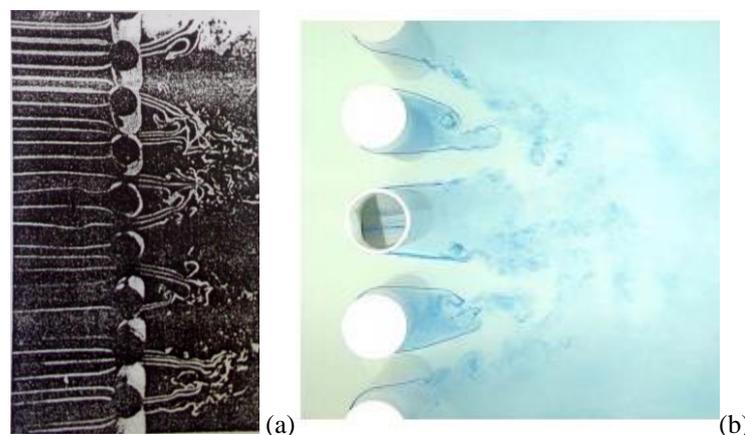


Figure 1 – Asymmetric wake characteristic a) visualization with smoke adapted from Zdravkovich, (1997) and b) visualization with dye from de Paula et al. (2012).

The change-over characteristics described by Zdravkovich (1997), where the author introduced disturbances on the flow and the intermittent metastable states happened, were not observed in the investigations performed by de Paula et al. (2012), where the authors observed the presence of the asymmetric characteristic, but not the switching process in the wakes.

Endres and Möller (2001) performed pressure and velocity fluctuations measurements in square and triangular tube arrays. No changes in the flow direction or presence of instabilities were found in their mean values and Fourier analysis, however, in a subsequent paper, Endres and Möller (2009) found that in square arrays, disturbances generated upstream the tube bank were amplified in the first rows then annihilated by the turbulence generated in the bank.

Grids have been used with the purpose to improve the flow quality, being also a simple and convenient method to generate turbulence, if the Reynolds number based on the grid characteristic length is high enough (Kurian e Fransson, 2009). The objective of the present study is to investigate the behavior of the wake after a row of cylinders in a cross flow with the change in the main flow turbulence intensity, caused by the use of a turbulent grid upstream the cylinders row.

2. METODOLOGY

The experimental study is executed in the aerodynamic channel at the Federal University of Rio Grande do Sul, which has a cross section of 146 x 193 mm. The tube row is composed of five cylinders with 25.1 mm of diameter each and the space ratio, P/D , is 1.26 with the details presented in Fig. 2. The mean velocity of the flow is 15.7 m/s, corresponding to a $Re = 2.6 \times 10^4$ based on the cylinder diameter. The turbulence intensity is increased from 1% to 11% using a horizontal grid composed by 8 cylinders with diameter of 6 mm each, equally spaced. The grid is positioned upstream of the tube row as shown in Fig. 3.

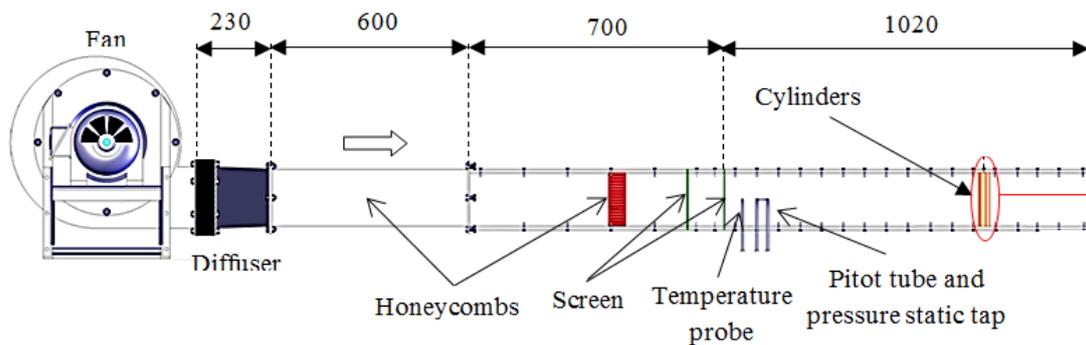


Figure 2 – Aerodynamic channel configuration.

The velocity values from the wake were obtained by hot wire anemometry technique applying a single wire probe (55P11), Streamline DANTEC, and in the same wake two microphone condensers were positioned on the channel wall to compare the characteristics observed. The probe and microphones positions are presented in Fig. 3. The acquisition was executed with an analogic/ digital 16 bits board and applying acquisition frequency of 3 kHz and low pass filter on the velocity signals of 1 kHz. For pressure fluctuations and velocity signals analysis, Fourier and Wavelet tools were applied, following the procedure adopted by Olinto et al. (2009). The uncertainties of the measurements are 3% in the velocity, 5% in the velocity fluctuations and 4% on the pressure fluctuations. The Fourier spectrum, used in the analysis, presents an error of 8.9%. The wavelet analysis is executed using Matlab[®] applying wavelet Db 20 (Daubechies 20) with the frequency range of 5 to 800 Hz and divisions of 4Hz.

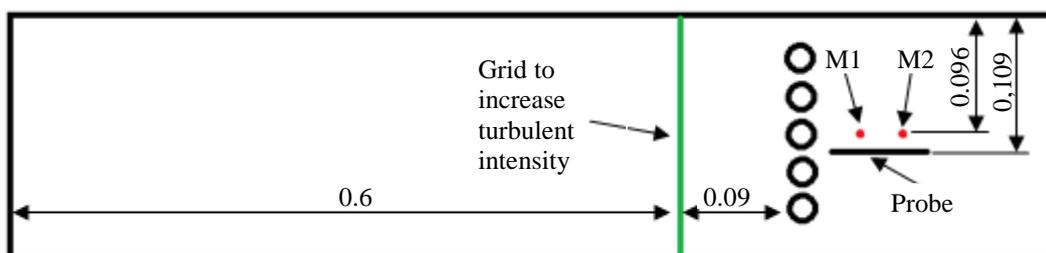


Figure 3 – Test section dimensions with the probe and microphones positions.

3. RESULTS AND DISCUSSIONS

Figure 4 shows the velocity signals, from the two turbulence intensities flows, obtained on the wake of the tube row central cylinder, the behavior for the lower turbulence intensity condition is shown in Fig. 4 (a) and for the higher turbulence intensity condition in Fig. 4 (b). Despite the difference between the mean velocity value, which changes from 2.85 m/s in (a) to 3.39m/s in (b), the signals do not present large differences on the characteristics. There is the presence of some higher velocity peaks in the case with turbulence intensity 11%, which are a consequence of the higher diffusion caused by the grid upstream the cylinders row. All the acquisitions did not present changes on the wake modes behind the cylinders, agreeing with the results reported by de Paula et al. (2012). For the pressure fluctuations, similar results are observed in Fig. 5, and in this case the acquisitions were in two positions on the wake. The microphones read only the pressure fluctuations and the signals are indicated as P1 and P2, obtained respectively on the positions M1 and M2 indicated in Fig. 3. Comparing the results for P1 and P2, in lower turbulence intensity, Fig 5 (a) and (b), even for different position, do not show large differences in the signal, the region farthest from the cylinders show fluctuations less organized, presenting some peaks that are not visible in the position close to the cylinder. The increasing of turbulence intensity causes a reduction on the magnitude of the pressure fluctuations, observed on the signs of P1 and P2, in Fig. 5 (c) and (d), but maintain the fluctuation with higher peaks on the position farthest of the cylinder.

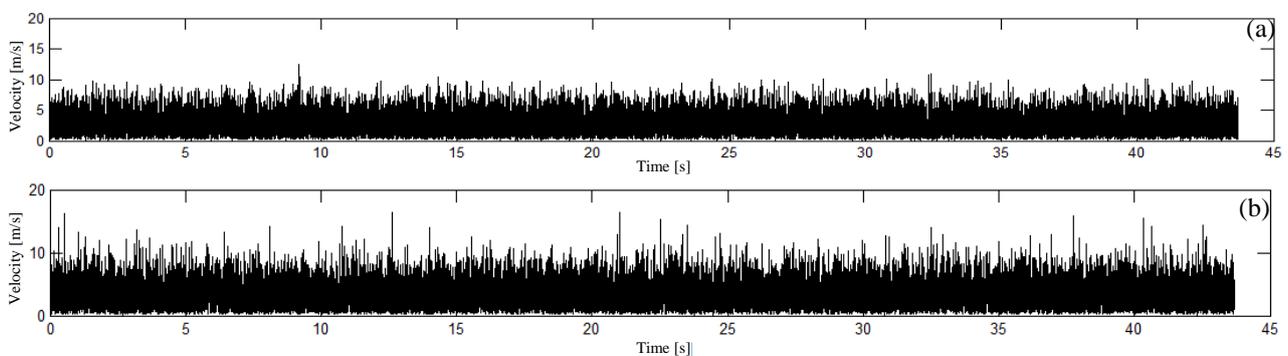


Figure 4 – Velocity signal from hot wires with a) turbulence intensity 1% and b) turbulence intensity 11%.

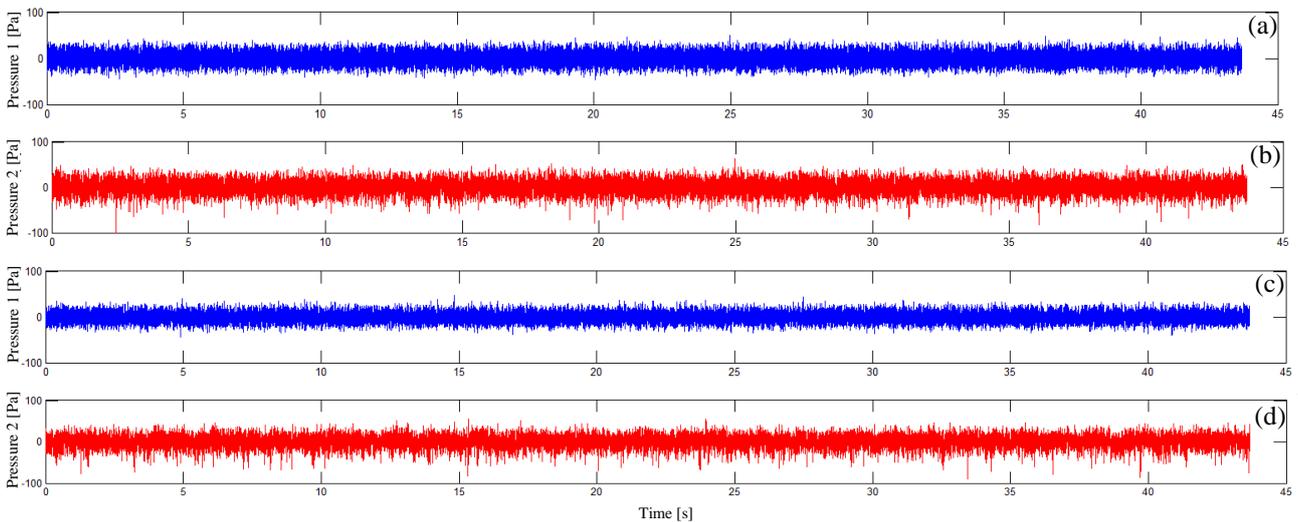


Figure 5 – Pressure fluctuation results from a) Microphone M1, P1, turbulence intensity 1%, b) Microphone M2, P2, turbulence intensity 1%, c) Microphone M1, P1, turbulence intensity 11% and d) Microphone M2, P2, turbulence intensity 11%.

In the temporal analysis, no changes were observed applying two different turbulence intensities on the flow. The Fourier transform is executed and the results are presented in Fig. 6, showing the power spectrum from the velocity and pressure fluctuation signals with turbulence intensity of 1% in Fig. 6 (a) and (c) and with 11% in Fig. 6 (b) and (d). In all cases no significant changes in the energy levels are observed. The higher energy levels are linked to the

measurements with the microphone M2, signal P2, visible in Fig. 6 (c) and (d), that is the farthest position measured and reads the wakes dispersion.

A visible difference happens on the frequency peaks from the comparing cases, while on the velocity results in Fig. 6 (a) a peak on 257.8 Hz is observed, in Fig. 6 (b) no indication of predominant frequency is visible. In the results from the pressure signals, Fig. 6 (c) and (d), both cases show frequency peaks on 76.2 Hz and 257.8 Hz. For the cases from the 11% turbulence intensity, Fig. 6 (d), the energy linked with the peak in 257.8Hz is lower, and reduces even more in the signal from the farthest acquisition position from the cylinder, what is expected due the reduced impact of the vortex shedding.

The Strouhal number, St , linked to 76.2 Hz is $St = 0.12$ and to 257.8 Hz is $St = 0.41$, this results are similar to the Strouhal number values presented by Ishigai and Nishikawa (1975) and Zdravkovich (1997), where the authors found values around $St = 0.15$ and $St = 0.42$ to $P/D = 1.26$ on flows with Reynolds Number varying between $Re = 4 \times 10^3$ and $Re = 3.3 \times 10^4$.

In Figure 7 the continuous wavelet spectrum is applied only in part of the velocity signals from Fig. 4, and for both tested cases, the frequencies with higher energy associated are below 200Hz in all the time period, in Fig. 7 (b) it is visible some peaks between 16 s and 17 s, probably caused by the higher disturbance on the flow caused by the additional grid. In both cases the behavior presented is similar, without alteration on the frequencies or on the energy due to the turbulence intensity increase.

A similar comparison with continuous wavelet applied on pressure fluctuation signals is presented in Fig. 8 where for the sign P1, the closest to the cylinder, it is visible two frequency regions of high energy along all analyzed signal. For the signal with turbulence intensity of 1%, Fig. 8 (a), the first frequency range is between 30 and 130 Hz, that is linked to the peak of 76.2 Hz on the Fourier analysis presented in Fig. 6 (c) and the second range stays between 190 e 380 Hz related to the peak 257.8 Hz also visible in Fig. 6 (c). In the signal from the flow with turbulence intensity of 11%, Fig. 8 (b), the ranges are not so defined but still visible in the same ranges, 30 to 130 Hz and 190 to 380 Hz.

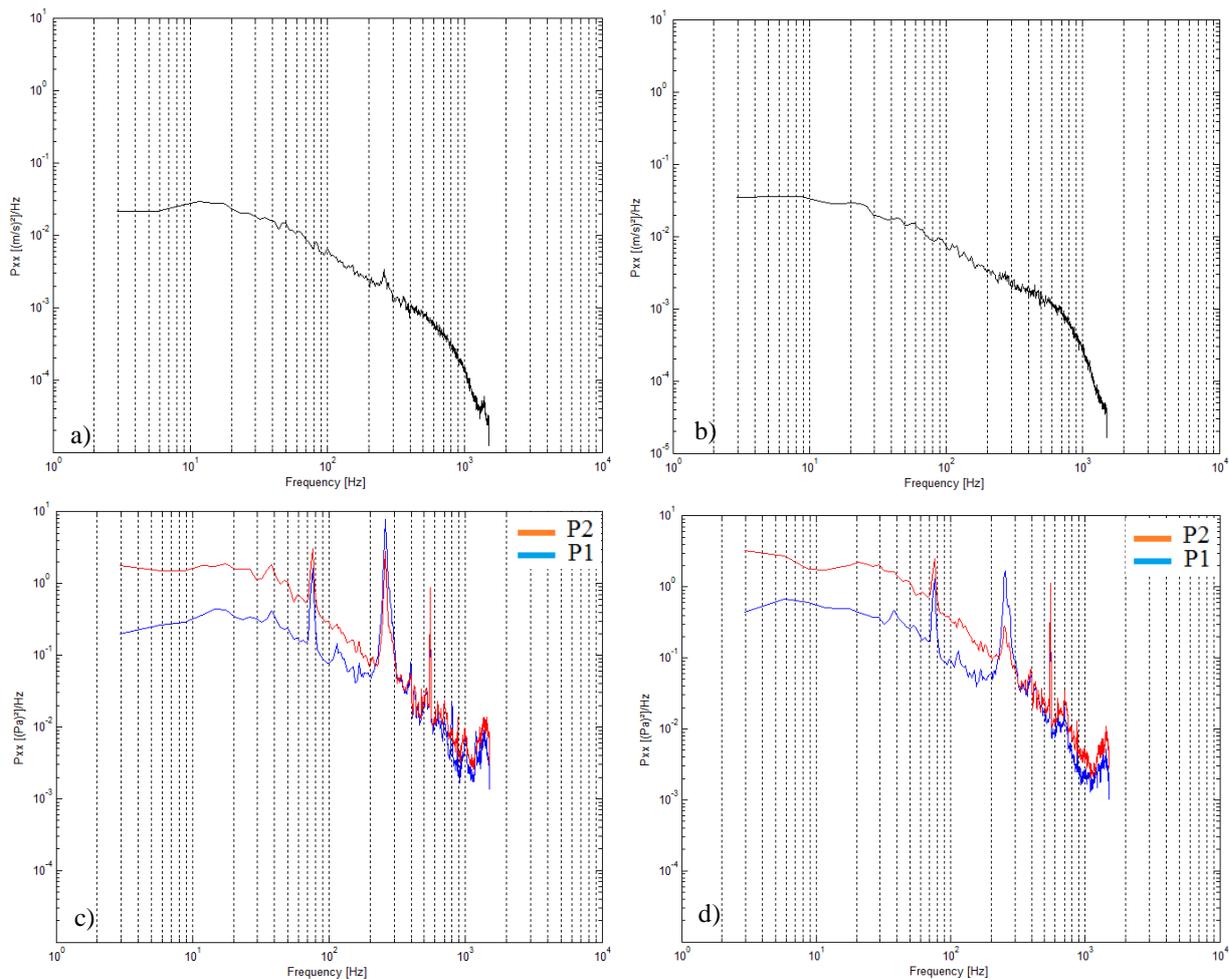


Figure 6 – Power Spectrum results from a) Velocity signal with turbulence intensity 1%, b) Velocity signal with turbulence intensity 11%, c) Pressure fluctuation signals with turbulence intensity 1% and d) Pressure fluctuation signals with turbulence intensity 11%.

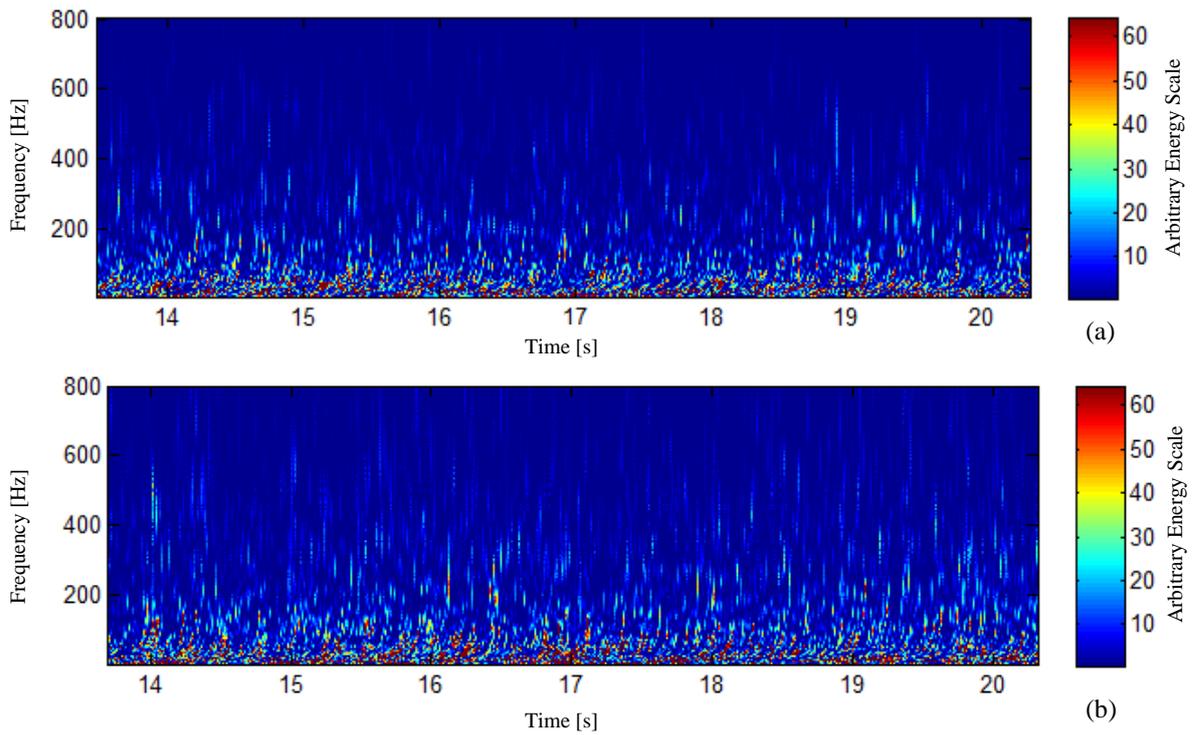


Figure 7 –Continuous Wavelet Spectrum of the velocity signal with a) turbulence intensity 1% and b) turbulence intensity 11%.

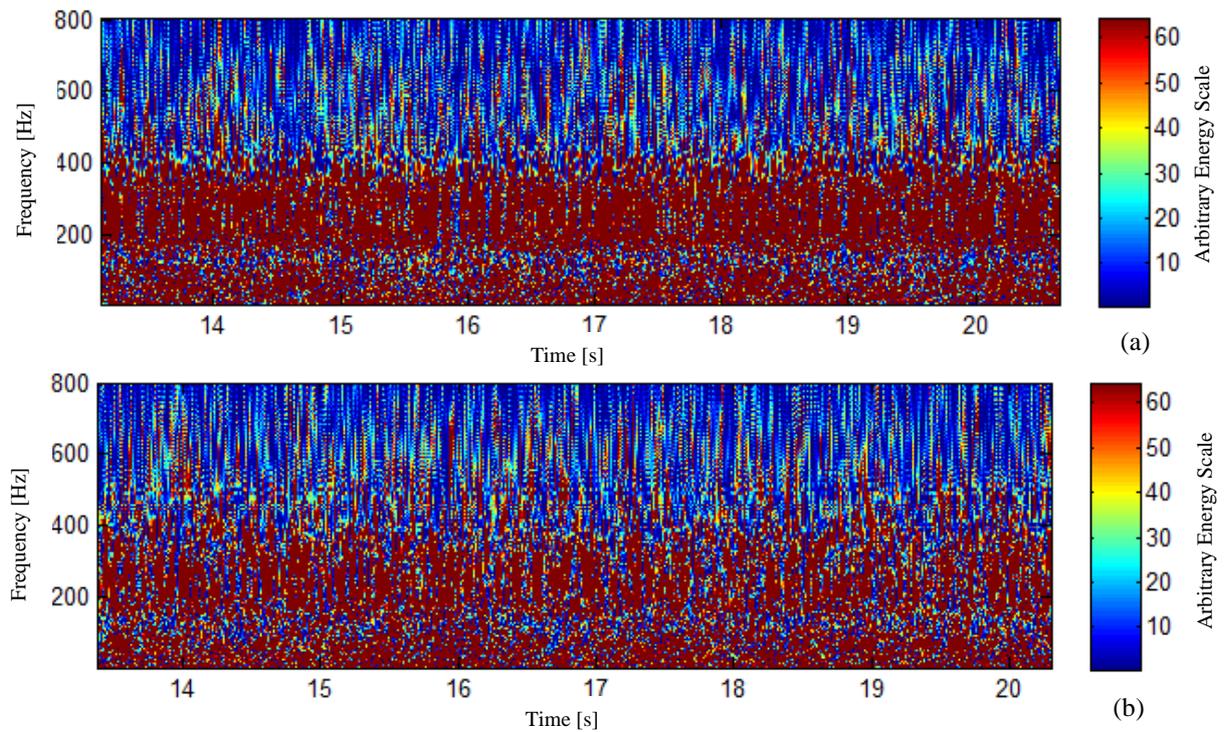


Figure 8 –Continuous Wavelet Spectrum of the pressure fluctuation P1: a) turbulence intensity 1% and b) turbulence intensity 11%.

In the case of pressure P2, the continuous wavelet was also applied on the signals and is presented in Fig. 9. In this case, the signal with lower turbulence intensity, Fig. 9 (a), indicate the same frequency ranges, but with less energy linked and a reduced visual demarcation of the ranges. While the signal with turbulence intensity 11%, Fig. 9 (b), indicates higher energy on low frequencies that can be linked to the range 30 to 130Hz, but without the second range around 200Hz. This behavior indicates that the increase on the turbulence intensity changes the wake dispersion, reducing the impact of the wake downstream the cylinder.

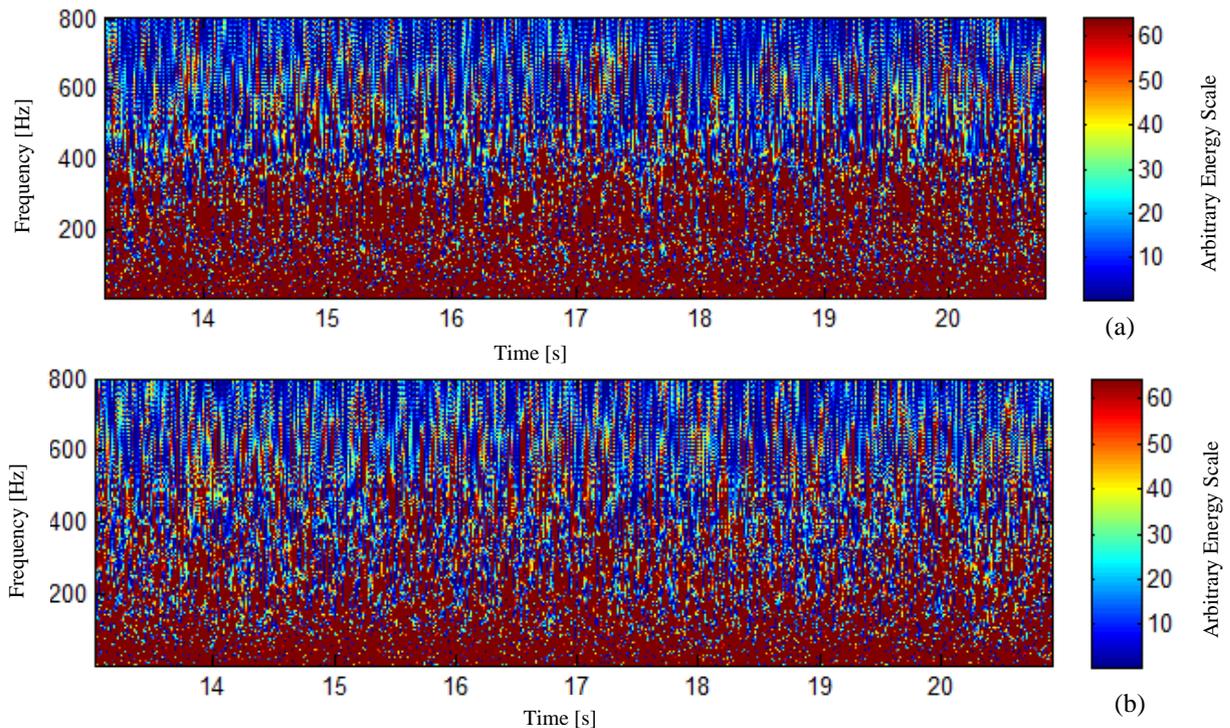


Figure 9 –Continuous Wavelet Spectrum of the pressure fluctuation P2: a) turbulence intensity 1% and b) turbulence intensity 11%.

4. CONCLUSIONS

The present experimental study was executed with cross flow over a row of cylinders, positioned on an aerodynamic channel with cross section of 146 x 193mm. The flow had $Re = 2.6 \times 10^4$ and the turbulence intensity was changed from 1% to 11% using an additional grid upstream the cylinder row. The impact on the flow behavior, increasing the turbulence intensity, was executed comparing velocity and pressure fluctuation signals. The results were treated with Fourier transform and continuous wavelet transform.

In all the analysis with velocity signals, no relevant alterations were observed but in the cases of the pressure fluctuations, differences on the predominant frequencies ranges were visible. In the position closest to the cylinder, P1, a higher quantity of energy is linked with the signals, indicating clear frequencies ranges on the both turbulence intensity cases, but with higher contrast in the results with 1% of turbulence intensity, indicating the vortices shedding.

In the results from the pressure fluctuations signals, obtained on the position farthest of the cylinders, P2, two frequency ranges are visible in the signal with turbulence intensity 1%, but with the increase on the turbulence intensity the level with higher value was not evident. This behavior indicates that the increase on the turbulence intensity impacts on the wake dispersion, which, due the momentum increase, reduces the downstream wake length, but does not changes the flow main characteristics.

The velocity and pressure fluctuation data signals presented alteration on the mean value and peaks magnitudes, but showed similar characteristics for the cases with turbulence intensity 1% and 11%. The signals did not show changes on the wake modes behind the cylinders and no indications of changeover were observed in the wavelet analysis, maintaining the same energy levels during all the acquired time.

5. ACKNOWLEDGEMENTS

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5. RESPONSIBILITY NOTICE

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