August 27-31, 2023
FLORENCE - ITALY
ICWE 16
16th International Conference on Wind Engineering

Unsteady aerodynamics of circular cylinder: a field observation compared with wind tunnel models

Pascal Hémon [1]

[1]*LadHyX, CNRS-Ecole polytechnique, IP Paris, France, pascal.hemon@ladhyx.polytechnique.fr*

SUMMARY:
This paper deals with the unsteady wall pressure distribution around circular structures in relation with the vortex shedding excitation. We compare the measurement results from three different experiments: a small cylinder in wind tunnel, a large cylinder in wind tunnel and a vertical chimney in natural wind. The small scale experiment is performed with rough cylinder in turbulent flow with Re < 70 000, while the other wind tunnel tests are performed on smooth structures, with Re < 2 200 000 and smooth flow. The chimney was observed in natural wind conditions, leading to Re ≈ 1 131 000. All structures are motionless. The synchronized wall pressure signals are processed using the bi-orthogonal decomposition in order to compare the structures of the pressure distribution which generate the lift by vortex shedding. Although the processing with the chimney in natural wind contains intrinsic difficulties, the analysis could be performed and provides for the first time an accurate description of the unsteady wall pressure. The upstream turbulence and the Reynolds number are found to be essential features in the phenomenon.

Keywords: Circular cylinder, vortex shedding, Reynolds number

1. INTRODUCTION

As pointed out in (Demartino & Ricciardelli 2017) the circular cylinder at various scales is very common in wind engineering problems, especially because of the vortex shedding excitation. In this paper we focus on the unsteady and synchronous wall pressure distribution measured during three experiments: two in wind tunnel on 2D cylinder and one on an experimental chimney in natural wind as shown Figure 1. Experimental details can be found in (Ellingsen *et al.* 2022a, 2022b) for the wind tunnels and in (Ellingsen *et al.* 2021; Manal & Hémon 2022) for the chimney. The main parameters of these setups are given in Table 1.

Figure 1. Views of the three experiments

In this paper, we analyse the measurements of the wall pressure around the circumference of the cylinder in motionless conditions of the models. The pressure is made non-dimensional by means of the usual pressure coefficient

$$Cp(\theta,t) = \frac{P(\theta,t) - P_{ref}}{\frac{1}{2}\rho \bar{U}^2} \quad (1)$$

which depends on time t and the azimuthal coordinate θ. Hereafter the $\theta = 0$ reference is set aligned with the wind direction.

For the chimney, the measurement altitude is 26 m, which is 9.5 m from the top and 10 m from the diameter restriction at the bottom. Therefore, the flow should be considered "almost" 2D with the possibility that 3D effects could occur. Few sequences were observed in relative stable wind; only one of 3 minutes is reported here which the results are similar to the other sequences: $\bar{U} = 8.49$ m/s and 15% of turbulence. One difficulty is to set the reference pressure for the pressure coefficient and the wind direction. Finally a "hand process" leads to an uncertainty of at least 10% on Cp and the position in θ. Indeed, the wind is measured by means of four anemometers mounted on a mast which is located at 50 m from the chimney, and there is no guarantee that the same wind at the same time is seen by the chimney (Manal & Hémon 2022).

Table 1. Main characteristics of the three experiments

	Diameter D (m)	Aspect ratio L/D	Re max	Inflow	Place
Rough cylinder	0.055	36	66 000	turbulent	Wind tunnel
Smooth cylinder	0.5	9.5	2 200 000	smooth	Wind tunnel
Chimney (≈ smooth)	2	10	1 130 000	atmospheric	Field

2. ANALYSIS OF WALL PRESSURE

2.1. The bi-orthogonal decomposition (BOD)

The principle of the BOD is to decompose the spatio-temporal signal $Cp(\theta,t)$ in a series of spatial functions $\phi_i(\theta)$ named further as "topos", coupled with a series of temporal functions $\psi_i(t)$ named "chronos". The BOD reads

$$Cp(\theta,t) = \sum_{i=1}^{N} \alpha_i \, \phi_i(\theta) \, \psi_i(t) \quad (2)$$

where α_i are the eigenvalues of the spatial or the temporal covariance matrix of the signal $Cp(\theta,t)$. N is the number of terms retained in the decomposition. The series converge rapidly so that N is possibly small compared to the original size of the problem (the smallest between the number of pressure taps and the number of time records). Chronos and topos are orthogonal between them. Mathematical details can be found in (Aubry & Lima 1991) and practical applications are presented in (Hémon & Santi 2003).

2.2. Analysis of the chimney

The first 6 topos are plotted Figure 2 and their corresponding chronos are described Table 2. The atmospheric flow generates unusual structures, as topos #1 & 3. However, other topos can be linked with those found previously in wind tunnel, #2, 4 & 6. Topos #5 extracts an erroneous pressure taps at $\theta = -150°$.

Topos #2 represents the time-averaged value of the pressure. Topos #4 is the structure that generates the unsteady lift, having an anti-symmetric shape, while Topos #6 is quasi symmetric and responsible for an unsteady drag. As shown in Figure 3, the power spectrum of the chronos

4, although it is quite noisy, presents high peaks in the Strouhal number range [0.21-0.24], which confirms its contribution to the vortex shedding excitation.
Topos #1 & 3 are structures mainly located in the front of the chimney, and they might be due to the wind gust, but this has to be more deeply analysed.

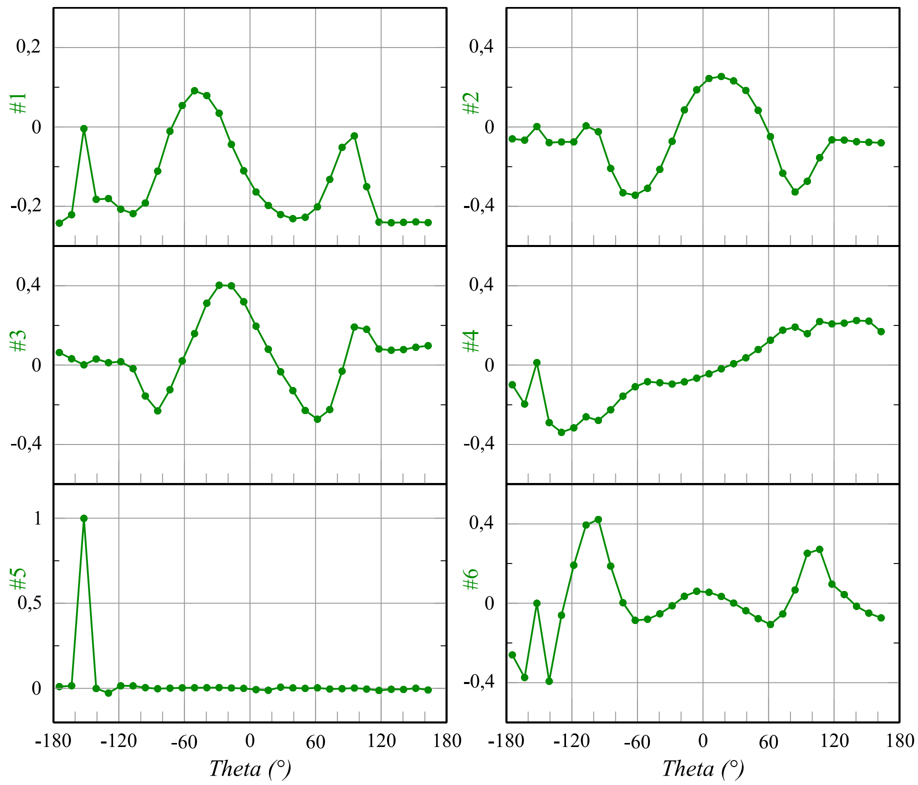

Figure 2. First 6 topos at 26 m of the chimney at $Re \approx 1\ 130\ 000$

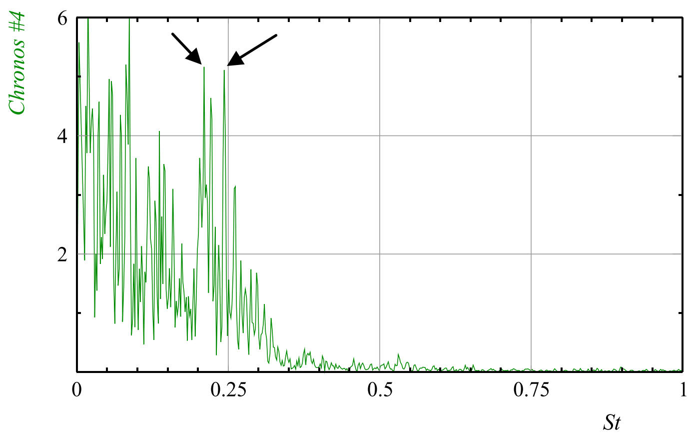

Figure 3. Power spectrum of the chronos #4 of the chimney at $Re \approx 1\ 130\ 000$

Table 2. First 6 chronos mean value and their standard deviation

Number	#1	#2	#3	#4	#5	#6
Mean value	68.7	188.6	59.5	52.4	-45.3	0.0
Standard deviation	42.3	44.3	35.6	19.6	4.20	16.6

3. CONCLUSION

The topos #4 mentioned above can be compared to its equivalent found in wind tunnel, which is done in Figure 4. It appears that the topos of the small rough cylinder in turbulent flow is close, while the topos of the large and smooth cylinder in smooth flow at the same Reynolds number range is quite different. However the Strouhal number found with the chimney, *ie* the range [0.21-0.24], agrees well with the one of the large cylinder at high Reynolds number (Ellingsen *et al.* 2022a).

The upstream turbulence and the Reynolds number appear to be some essential parameters in the vortex shedding excitation of circular structures in natural wind.

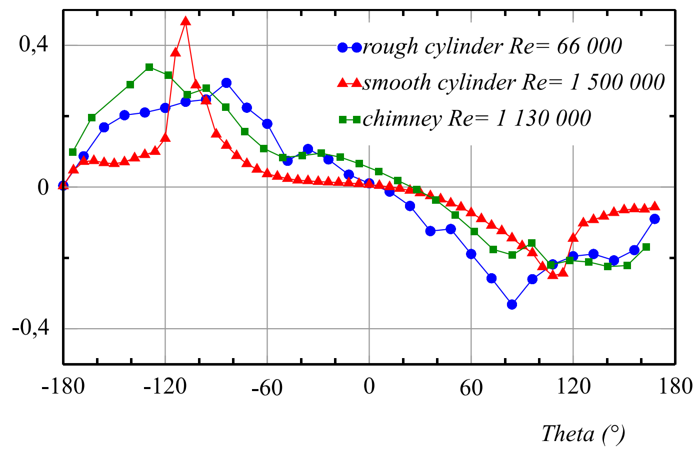

Figure 4. Comparison of the topos generating the lift force around Strouhal frequency

ACKNOWLEDGEMENTS

This work is part of a partnership co-funded by Beirens (Poujoulat Group), Centre Scientifique et Technique du Bâtiment (CSTB), Centre National d'Etudes Spatiales (CNES) and LadHyX, CNRS-Ecole polytechnique. Special acknowledgement is extended to Olivier Flamand from CSTB for the measuring systems and to Aurélien Jeanneton from Beirens for the chimney design. A part of the data analysis from the chimney was performed by Yacine Manal during his master thesis in LadHyX.

REFERENCES

Aubry, N., Guyonnet, R., Lima, R., 1991. Spatiotemporal analysis of complex signals: Theory and applications. Journal of Statistical Physics, 64.3, 683–739.

Demartino, C. & Ricciardelli, F., 2017. Aerodynamics of nominally circular cylinders: A review of experimental results for Civil Engineering applications. Engineering Structures 137, 76–114.

Ellingsen, Ø. M., Flamand, O., Amandolese, X., Coiffet, F. and Hémon, P., 2021. Field tests on a full-scale steel chimney subjected to vortex-induced vibrations. Structual Engineering International 32, 55-61.

Ellingsen, Ø. M., Amandolese, X., Flamand, O. and Hémon, P., 2022a. Twin Strouhal numbers in pressure loading of circular cylinder at high Reynolds numbers. Journal of Fluids & Structures 115, 103782.

Ellingsen, Ø. M., Amandolese, X. and Hémon, P., 2022b. In wind tunnel the reproduction of vortex shedding behind circular cylinder at high Reynolds number is incomplete. Proceedings of the 12th International Conference on Flow-Induced Vibration, FIV2022, Paris-Saclay, 5-8 July 2022, 509-515.

European Committee for Standardization, 2005. Eurocode 1: Actions on structures - Part 1-4: General actions - Wind actions. Ref. n° EN 1991-1-4:2005 F.

Hémon, P., Santi, F., 2003. Applications of biorthogonal decompositions in fluid-structure interactions. Journal of Fluids & Structures 17.8, 1123–1143

Manal, Y. and Hémon, P. 2022. Unsteady wall pressure measurements on a full scale flexible chimney subject to natural wind. Proceedings of the 12th International Conference on Flow-Induced Vibration, FIV2022, Paris-Saclay, 5-8 July 2022, 79-86.