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

Flow structures around a square cylinder

Diego Iglesia [1,2], Mikel Ogueta-Gutiérrez [1,3], Sergio Marín-Coca [1,4], Omar Gómez-Ortega [1,5], Raúl Manzanares-Bercial [1,6]

[1]*Instituto Universitario de Microgravedad Ignacio da Riva, Universidad Politécnica de Madrid, Madrid, Spain,*
[2]*diego.iglesia.garcia@alumnos.upm.es*
[3]*mikel.ogueta@upm.es*
[4]*sergio.marin.coca@upm.es*
[5]*omar.gomez@upm.es*
[6]*raul.manzanares@upm.es*

SUMMARY: (10 pt)
Particle Image Velocimetry (PIV from now on) has been used to determine the flow around a square cylinder. The tests have been done with a Reynolds number of 25000 and a turbulence intensity of the upcoming flow of 0.1%. The measurements have been processed with Proper Orthogonal Decomposition (POD from now on) in order to understand better the flow in the wake. With this technique, relative variations of the velocity field can be studied. Several angles of incidence have been tested. POD shapes in the wake in both the longitudinal and vertical component of the velocity have been obtained and studied. It has been observed that first two modes of both components are in geometrical quadrature. This shows the transportation of the vortexes in the wake of the square cylinder. Results show very good agreement with other literature on the wake of bluff bodies (for a circular cylinder and a square cylinder).

Keywords: Particle Image Velocimetry, Proper Orthogonal Decomposition, Wind tunnel

1. INTRODUCTION

Flow around bluff bodies is inherently complex. The detachment and reattachment of boundary layers and the wake make it difficult to study these flows. One of the simplest bluff bodies is the square. Comprehensive analyses of the flow in these bodies are still needed. For example, the BARC initiative, sponsored by the Associazione Nacional per l'Ingengneria del Vento, generated a lot of information on a 5:1 aspect ratio rectangular cylinder (Bruno et al., 2014). Some authors of this paper have also contributed to it studying the pressure field around it (Cárdenas et al., 2022).

Bluff bodies under wind conditions and specifically two-dimensional bodies are very common (buildings, elements of structures, photovoltaic solar trackers), so it is interesting to research further into the topic.

1.1. Particle Image Velocimetry (PIV)

PIV technique is very extended in wind engineering. It is based in the statistical correlation of the movement of particles between two very close pictures (in time) to measure velocity. The particles are shed in the flow and then illuminated with a laser. Compared to other techniques such as hot wire, Laser Doppler Anemometry or multihole probes, its main advantage is the capability of measuring simultaneously in different points of the area of interest. The principles and some applications of the PIV can be read elsewhere (Raffel et al., 2018).

1.1. Proper Orthogonal Decomposition (POD)

POD is a numerical tool that helps decompose complex phenomena in simpler ones. It is used in many areas to understand complex processes. In fluid mechanics, it has been used since the late sixties (Lumley 19677). A lot of research on the application of the tool has been done in wind engineering, both in pressure and velocity fields (Solari et al., 2007). The mathematical process can be consulted elsewhere (Flores, 2011).

2. EXPERIMENTAL SETUP

The size of the square cylinder (7 cm each side has been selected so as not to block the flow in the wind tunnel. The wind tunnel used for these experiments has a square test section being each side 1 m. The angle of attack of the cylinder has been varied from 0º to 75º with steps of 15º. The maximum blockage during the experiments is therefore 9.9%. The flow with an empty test chamber has a very low turbulence of approximately 0.1%. Different Reynolds number have been tested (between 5000 and 65000), but in this case, results for Re=25000 are presented.

The cylinder has been placed in the middle of the test section. The two-dimensional planar PIV system has been placed in the central section of the cylinder, so that the wall boundary layers do not affect the flow in the measurement area. Figure 1 shows the setup of the experiment in the wind tunnel.

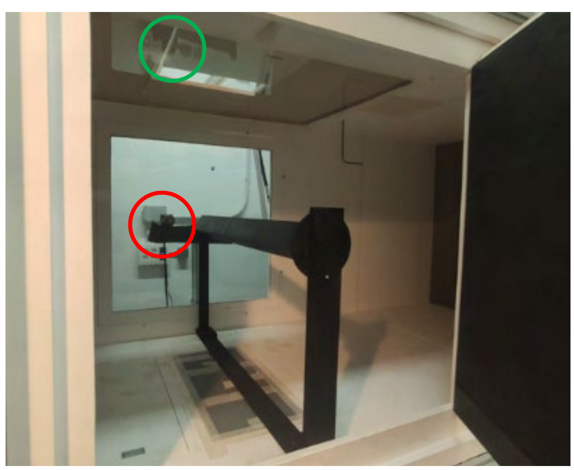

Figure 1. Cylinder in the wind tunnel. Camera is highlighted in red; laser is highlighted in green.

In that section, due to the limitations of the system, the camera and the laser have been moved to study the flow in the surroundings of the windward side, the top side and the leeward side of the cylinder. For each configuration, 200 pairs of images have been taken and processed. The processing has done with Insight4G software. A 64x64 pixel window has been used and the preprocess of the images consisted in the background subtraction and an application of a mask.

3. RESULTS

Figure 2 shows the two first modes of the u component (longitudinal) of the velocity field in the wake. In this case, the angle of attack of the cylinder is 0º (the wind is impinging perpendicular to a face of the cylinder). The leeward part of the cylinder can be seen in grey in the left part of the images. Both modes have an asymmetrical behaviour around the horizontal axis. For the first mode, two main regions of changes in the velocity appear (when the velocity increases in the upper part, it decreases in the lower part). In the second mode, four areas of change appear in a quadrant.

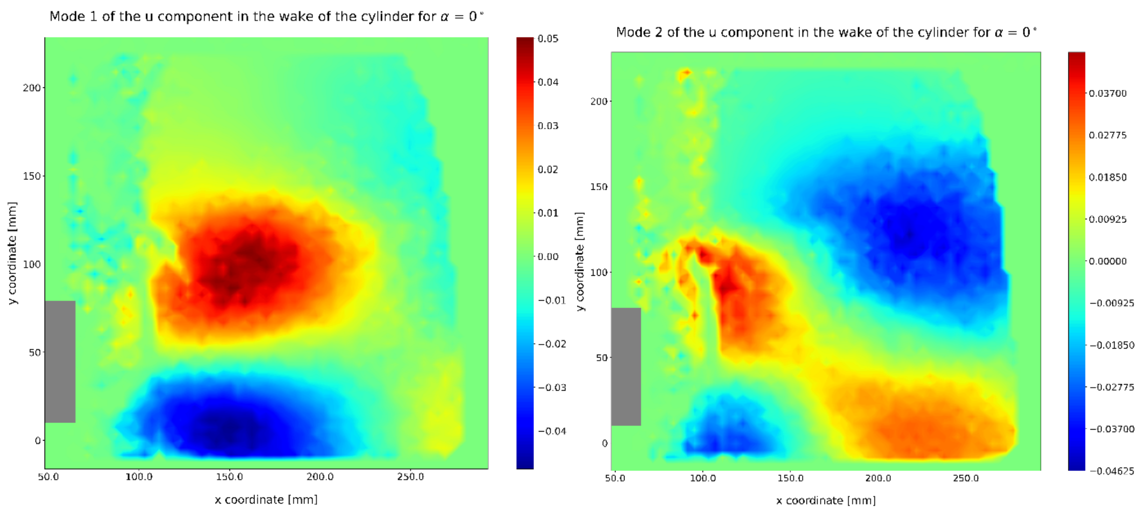

Figure 2. First (left) and second (right) modes of the u component in the wake of the square.

Figure 3 shows the same first two modes, but in this case, of the v component (vertical) of the velocity field. First two modes have been found to be in geometrical quadrature (an extreme value of one mode corresponds geometrically to a zero value of the other one).

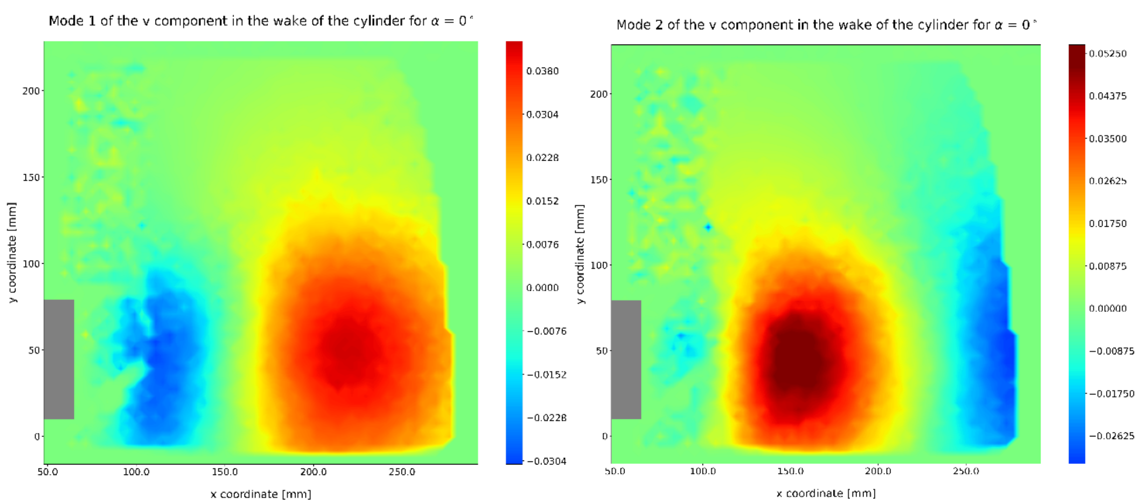

Figure 3. First (left) and second (right) modes of the v component in the wake of the square.

These results match those shown by other authors. Some research has been done in the wake of circular cylinders (Michálek et al., 2022). They tested the effect of the roughness in the flow structures around the circular cylinder and found very little difference in the modes analysed in the wake.

The wake on the square cylinder studied in (van Oudheusden et al., 2005) is very similar to the one found here. They also found extracted first and second modes of both components. In both cases, they also obtained modes displaced one quarter of the phases (modes in quadrature). For the sake of shortness, no other results are displayed. However, it is remarkable that the modal shapes of the configurations with different angles of attack are very similar to the ones displayed here for an angle of attack of 0º. This also matches the results observed in (van Oudheusden et al., 2005).

7. CONCLUSIONS AND FUTURE WORK

The flow around a square cylinder has been studied with a PIV system. Main modes of the velocity field have been obtained. The results are similar to those in the literature.

Future work associated with this research includes the extension to other shapes (different aspect-ratio rectangular cylinders, triangles, circular cylinder) and the use of a time-resolved PIV system to study the evolution of vortexes in the wake.

ACKNOWLEDGEMENTS
The authors acknowledge the contribution of Manuel Ortega, Carlos Pascual and Javier Pascual in the construction of the model.

REFERENCES

Bruno, L., Salvetti, M. V., Ricciardelli, F., 2014. Benchmark on the Aerodynamics of a rectangular 5:1 cylinder: An overview after the first four years of activity. Journal of Wind Engineering and Industrial Aerodynamics, 126 87-106.

Cardenas-Rondón, J. A., Ogueta-Gutiérrez, M., Franchini, S., Gómez-Ortega, O., 2022. Experimental analysis of the aerodynamic characteristics of a rectangular 5:1 cylinder using POD. Wind and Structures, An International Journal 34(1), 29-42.

Flores, R., 2011. The Use of Proper Orthogonal Decomposition for the Characterization of the Dynamic Response of Structures Due to Wind Loading. Ph.D. Dissertation, University of Ottawa, Ottawa, Canada.

Lumley, J. L., 1967. The structure of inhomogeneous turbulence. Atmospheric turbulence wave propagation, 166-178.

Michálek, P., Procházka, P., Uruba, V., Pospíšil, S., 2022. Proper ortogonal decomposition analysis of cylinder wake. Proceedings of "8th European-African Conference on Wind Engineering", 20-23 Sept. 2022, Bucharest, Romania

Raffel, M., Willert, C. E., Scarano, F., Kähler, C. J., Wereley, S. T., Kompenahns, J., 2018. Particle Image Velocimetry. A Practical Guide. 3rd ed. Springer International Publishing, Switzerland.

Solari, G., Carassale, L., Tubino, F., 2007. Proper Orthogonal Decomposition in wind engineering-Part 1: A state-of-the-art and some prospects. Wind and Structures, An International Journal 10(2), 153-176.

Van Oudheusden, B. W., Scarano, F., van Hinsberg, N. P., Watt, D. W., 2005. Phase-resolved characterization of vortex shedding in the near wake of a square-section cylinder at incidence. Experiments in Fluids 39, 86-98.