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PIV measurements on the flow past a cylinders with various shapes

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SUMMARY:
The flow field past a cylinder with different shapes is investigated using TR-PIV technique. Two configurations were studied, the first one includes square cylinder with the side length D = 0.02 m and the second one includes triangle cylinder. The experiment was performed for three different Reynolds numbers. To have an insight into the fluid flow, the particle image velocimetry (PIV) method was used. Particular attention was paid to examining the effect of the cylinder shape on the flow field around the body. The airflow around cylinders is creating a number of characteristic zones in the surrounding region which is manifested by vortices formation and local acceleration. Presentation of the results obtain the qualitative assessment of the streamwise (U_x) velocity fields and the contour maps of TKE distributions for both cases. The effect of Re (for the considered range of change in Re in this study on the velocity field was found to be marginal for each configuration.

Keywords: square cylinder, triangle cylinder, particle image velocimetry (PIV), wind tunnel experiment

1. INSTRODUCTION

The flow around bluff bodies is increasingly becoming the subject of many studies. Flow control, enhancement of mixing processes, cooling of electronic components, thin wire probes, or wind flows in urban areas are only a few examples of their applications (Blocken, 2015, Zhao et al., 2020, Jafari and Alipour, 2021).

Very often, even laminar, incompressible two-dimensional flows are distinguished by a variety of coherent structures, as well as different vortex shedding frequencies. The vortices are alternately shed and the cylinder is followed by the well-known Karman vortex street, which can cause structural damage as a result of regular and irregular surface loading. Yagmur et al. 2015 in their work conducted numerical and experimental studies of bluff bodies with a circular, square, and triangular cross-section, which were placed perpendicular to the direction of flow, for Reynolds numbers 5 000 and 10 000. Experimental studies were carried out in a water channel using the particle image velocimetry method (PIV), and numerical studies using the ANSYS Fluent with LES model. The results showed that the trace length of the triangular cylinder was the shortest,

while the square one was the longest. In the flow around bluff bodies, two symmetrical vortices occurred, one was positive and the other in the opposite direction. In contrast, at high Reynolds numbers, the length of the vortex was greater for all cylinders, large values of the vorticity contours covered an increased area, and the flow was more chaotic. The drag coefficient for the triangular cylinder was greater at Re = 5000. When all geometries were compared, the square cylinder had the highest drag coefficient values, and the circular cylinder had the lowest value. The flow around a square cylinder depends on the Reynolds number. At a low number, the flow is steady and laminar, while at higher Reynolds numbers, the flow transitions to time-dependent flow and later to three-dimensional flow before finally becoming turbulent. Three-dimensional flow around square cylinders leads to abrupt changes in vortex shedding frequency and drag coefficient, as demonstrated by articles in numerical studies (Sheard, 2011, Nidhul et al., 2015). On the other hand, for a triangular cylinder as the Reynolds number increases, the wide trace decreases and the stagnation points approach the back side of the triangular cylinder, as was demonstrated by Yagmur et al. (2017) in their experimental and numerical studies. Strouhal numbers are close to St = 0.22 for PIV and LES for all Reynolds numbers, therefore these values are independent of it. The drag coefficient is determined numerically and after $Re=5.8\times10^3$ the drag coefficient decreases (Yagmur et al. 2017).
In this paper, after the analysis of previous research and their results, the square cylinder and the triangular cylinder will be examined for three Reynolds numbers. The dependencies arising in the flow around the objects resulting from the nature of the flow around various shapes will be analysed.

2. THE EXPERIMENT DESCRIPTION

The time-resolved PIV measurements were conducted in wind tunnel in the Department of thermal Machinery Czestochowa University of Technology.
The experiment was conducted in an open-circuit wind tunnel with 2 m long test section with square cross-section (0.3 x 0.3 m). Two configurations were studied, namely, the first one includes square cylinder with the side length D = 0.02 m) and the second one includes triangle cylinder with dimensions presented in Figure 1. The height of each cylinder was the same as the channel height (0.3 m) so taking into account that both investigated objects were in tandem the value of the blockage ratio parameter was less than 7% which is satisfactory for such measurements. Three different Reynolds numbers ($Re = U_\infty D/\nu$, where U_∞ is the free stream velocity and ν the kinematic viscosity) were investigated for each configuration and the details about each investigated test case can be found in Table 1.

Table 1. The investigated configurations.

case	cylinder shape	*Re*
S-Re1	square	5000
S-Re2	square	10000
S-Re3	square	15000
T-Re1	triangle	5000
T-Re2	triangle	10000
T-Re3	triangle	15000

The measurement apparatus consisted of a laser and a CMOS camera. PIV illumination was provided by a double cavity Nd:YAG laser adjusted on the second harmonic (wavelength of 532 nm) emitting a pair of pulses with energy of 2x25 mJ each and with a frequency rate of 4000 Hz.

Droplets (~1 μm in diameter) of Di-Ethyl-Hexyl-Sebacate are used as a seeding to obtained 2-dimmensional velocity fields. The camera and the laser were placed on a traverse system. They can faithfully follow the flow as the mean diameter size is 1 μm. The data were acquired with frequency of 400 Hz for longer (10 second) recording time to precise evaluate the statistical quantities. On the other hand, we used acquisition frequency of 1,4 kHz for shorter time (2 second) to study dynamics of the flow mainly using Proper Orthogonal Decomposition (POD). The camera is Phantom V611. It has resolution 1280 x 800 pixels, 8GB internal memory and it enables to acquire 3000 double-images per second. The camera and the laser were simultaneously traverse using ISEL traverser. The hardware and software used for data acquisition and evaluation were produced and distributed by the Dantec Dynamics company.

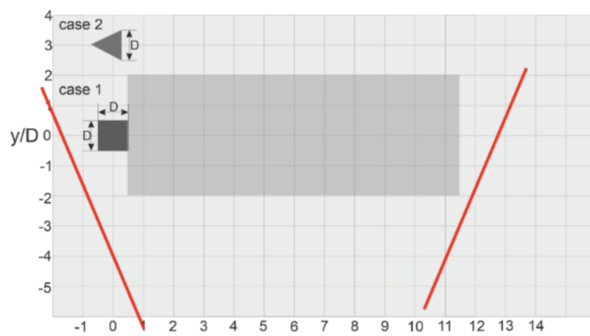

Figure 1. An overview of the measuring section.

3. RESULTS

The airflow around cylinders is creating a number of characteristic zones in the surrounding region which is manifested by vortices formation and local acceleration. Presentation of the results begins with a qualitative assessment of the streamwise (U_x) velocity fields for cases S-Re1 and T-Re1, which are presented in Figure 2.

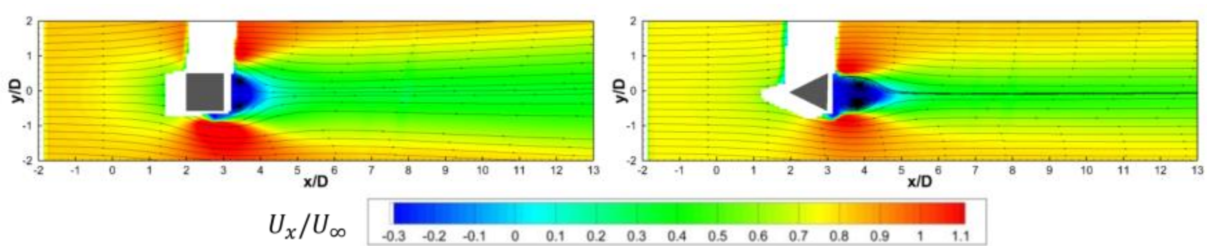

Figure 2. Mean streamwise velocity fields with superimposed streamlines pattern for cases S-Re1 and T-Re1.

Streamlines are superimposed to highlight the flow structures especially in the near wake. At a first glance, the case S-Re1 exhibits much wider wake which should be attributed to the flat front of the square cylinder. The other observation that can be made is that the vortex shedding is different for each configuration. In both cases, S-Re1 and T-Re1 the vortex path behind objects cause an alternate vortex shedding. There is a much stronger recirculation area for T-Re1 which is manifested by the presence of regions with negative values of U_x/U_∞ (Figure 2) which should considerably contribute to the drag force. In addition, the stronger variation of the transverse component behind the square cylinder is noted, which directly accounts for the wider wake.

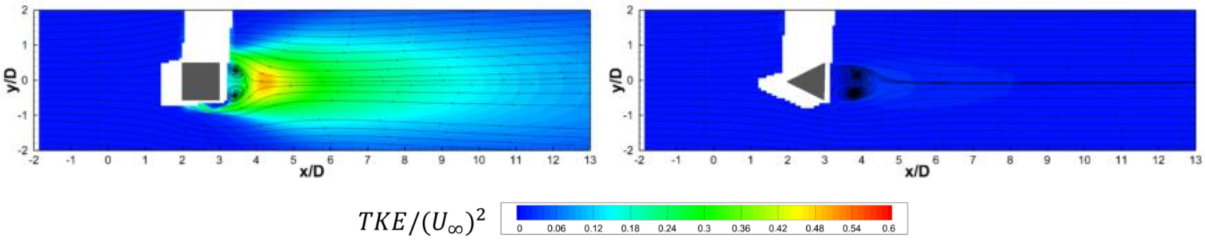

Figure 3. Mean TKE contours with superimposed streamlines pattern for cases S-Re1 and T-Re1.

Figure 3 shows the contour maps of TKE for cases S-Re1 and T-Re1. When both geometries were compared, for the case S-Re1 the local maximum in TKE is much higher compared to the case T-Re1. The accumulation of TKE is associated with the separation observed for the square objects.

4. CONCLUSIONS

The paper examines the effect of cylinder shape on the air flow around the object. Two different cylinder shapes were investigated, namely square and triangular cylinder for three different Reynolds numbers.

The results shown that the cylinder square shape exhibits a much wider wake downstream object compared to the triangle cylinder. For T-Re1 case, there is a much stronger recirculation area which should considerably contribute to the drag force. The maximum streamwise averaged velocity deficit behind the object is a notably smaller minimum in U_x/U_∞ [-] for the case with triangle compared to square. The effect of Re (for the considered range of change in Re in this study) on velocity field was found to be marginal for each configuration, which confirm the finding of Derakhshandeh and Alam, 2019 for the subcritical regime.

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