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

Experimental investigations on the effect of corner roundness and angle of attack on the BARC configuration

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SUMMARY:
We experimentally investigate how the high-Reynolds-number flow around a 5:1 rectangular cylinder vary by modifying the sharpness of the upstream corners and the angle of attack. For perfectly sharp corners and zero angle of attack this configuration is the focus of the international benchmark BARC. Experiments have been carried out at Reynolds number $Re = Du_\infty/\nu = 40000$, being D the crossflow dimension of the cylinder, u_∞ the freestream velocity, and ν the kinematic viscosity of air. We consider different values of the upstream-corner rounding ranging from almost sharp corners ($r/D = 0.0005$) up to $r/D = 0.1104$, together with different small angles of attack in the range $|\alpha| \leq 2\,\text{deg}$. Differently from numerical predictions, for a fixed α a low sensitivity to the upstream-corner rounding is found up to $r/D = 0.0360$, whereas starting from $r/D = 0.0781$ the size of the mean recirculation region on the cylinder side decreases noticeably by increasing r/D. On the other hand, even small angles of attack have a significant impact on the length of the mean recirculation region. As in simulations, the growth of the velocity fluctuations along the shear layers detaching from the upstream corners is highly correlated with the location of the onset of Kelvin-Helmholtz instability and, in turn, with the length of the mean recirculation on the cylinder side. This, in turn, influences pressure distributions and the near-wake flow features.

Keywords: Rectangular 5:1 cylinder (BARC), wind-tunnel tests, upstream-edge rounding and angle of attack

1. INTRODUCTION

The flow around the 5:1 rectangular cylinder is the object of the international benchmark BARC (http://www.aniv-iawe.org/barc). The flow is characterized by shear layer separation from the upstream edges. Vortical structures of different sizes form from the roll-up of these shear layers, move downstream and interact with the classical vortex shedding in the wake. The corresponding mean flow is characterized by a recirculation region along the lateral surface of the cylinder. The mean flow features on the cylinder side have been shown to be highly sensitive to the shear-layer dynamics, which is influenced by set-up parameters in both experiments and in simulations (Bruno, Salvetti, et al., 2014). In experiments, the mean recirculation shortens by increasing the turbulence level of the incoming flow (Mannini et al., 2017). In numerical simulations, the increase of grid resolution (Bruno, Coste, et al., 2012; Mariotti et al., 2017) and the decrease of the SGS dissipation (Mariotti et al., 2017) provide a shortening of the mean recirculation region on the cylinder side. Moreover, in simulations a significant difference is present between sharp edges and rounded edges, the former causing a premature onset of Kelvin-Helmholtz instability in the separated shear layer. Even a small curvature radius significantly changes the flow features by moving downstream the mean flow reattachment point (Rocchio et al., 2020). That is because sharp edges introduce significant velocity fluctuations in the shear layer at separation that, when not artificially damped by numerical or SGS dissipation, cause an upstream roll-up of the shear layers and, hence, a short mean recirculation region. This effect is probably related to the resolution typical of LES simulations (e.g., Lunghi et al., 2022) since the impact of upstream-edge rounding was found to be much smaller in DNS simulations in Chiarini and Quadrio (2022) at a lower Reynolds number. On the other hand, the effect of pitch misalignment has been investigated by, e.g., Cardenas-Rondon et al. (2022), Guissart et al. (2022), Schewe (2013), and Wu et al. (2020), because it may provide a high variation in flow topology, up to preventing the mean flow reattachment on one of the cylinder sides. Now we investigate experimentally the importance of upstream-corner sharpness and of the angle of attack on the BARC flow. We consider a variation of the upstream-corner rounding in a range such that they might be relevant for practical applications and of the angle of attack which takes into account the effect of a possible small misalignment with respect to the flow direction.

2. EXPERIMENTAL SET-UP

Experiments are carried out in the subsonic closed-return wind tunnel of the University of Pisa, having an open test section of 1.42 m long, a cross-section of 1.1 m diameter, and a turbulence level of 0.9%. The aluminum-alloy model is the one described in Pasqualetto et al. (2022). The crossflow dimension of the cylinder is $D = 40$ mm, its streamwise length is $L = 200$ mm, and the model is extruded in the spanwise direction for $S = 800$ mm. The Reynolds number is $Re = Du_\infty/\nu = 40000$. Two end plates are placed at the spanwise ends to prevent three-dimensional effects. Two Pressure Systems EPS-16HD miniature electronic pressure scanners for differential pressure measurements are placed inside the model, which is equipped with 495 pressure taps on its surfaces. Velocity measurements are obtained through X-wire hot-wire probes, which can be moved by a three-axis computer-controlled traversing system (see Pasqualetto et al., 2022 for further details on experiments). Referring to Fig. 1, four different roundings of the upstream corners are investigated, viz. $r/D = 0.0037$, $r/D = 0.0360$, $r/D = 0.0781$ and $r/D = 0.1104$, and we compare their results to the ones for the sharp-edge case ($r/D = 0.0005$) from Pasqualetto et al. (2022). The different experimental models are obtained by using C-profiles with rounded edges, whose rounding values are measured through a digital microscope RS PRO. In addition to the case $\alpha = 0\,$deg, four different angles of attack are considered, viz. $\alpha = \pm 2\,$deg and $\alpha = \pm 1.18\,$deg. The support strut allows to set the angle of attack α with an accuracy of ± 0.02 deg.

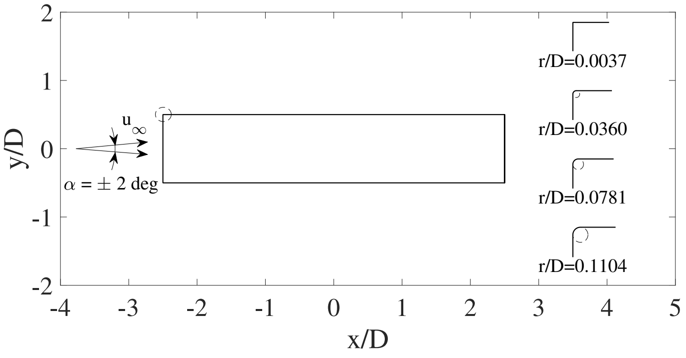

Figure 1. Sketch of the experimental model and of the roundings of the upstream edges.

3. RESULTS AND DISCUSSION

The effect of the upstream-corner sharpness on the distributions along the rectangular cylinder of the pressure coefficient averaged in time and in the spanwise direction, is shown in Fig. 2a,b for the case at $\alpha = 0$ and $r/D = 0.0037$, respectively. The pressure coefficient is defined as $C_p = \frac{p-p_\infty}{1/2\rho u_\infty}$, where p_∞ and u_∞ are the freestream pressure and velocity, respectively, and ρ the density of air. For a fixed α negligible differences are found between the cases $r/D = 0.0005$ (Pasqualetto et al., 2022), $r/D = 0.0037$ and $r/D = 0.0360$, whereas starting from $r/D = 0.0781$ the size of the mean recirculation region on the cylinder side decreases by increasing r/D, as confirmed also by the more upstream pressure recovery. This effect is due to the different behavior of the mean separated shear layer detaching from the upstream corners, which is reported in Fig. 3a. For large values of the roundings, the shear layers are closer to the cylinder wall, whereas no significant effects are found for $r/D \leq 0.0360$. On the other hand, the angle of attack has a significant impact on the mean recirculation length and, thus, on the pressure distribution, producing an upstream movement of the pressure recovery on the windward side and an analogous downstream movement on the leeward side (see Fig. 3b).

Physical discussion on these effects, in terms of the growth of the TKE along the shear layers borders and the location of the Kelvin Helmholtz instability, will be given in the final presentation. Stochastic sensitivity techniques (generalized polynomial chaos) will be used to obtain continuous response surfaces of the quantities of interest in the parameter space and to quantify the impact of each parameter and of their coupling.

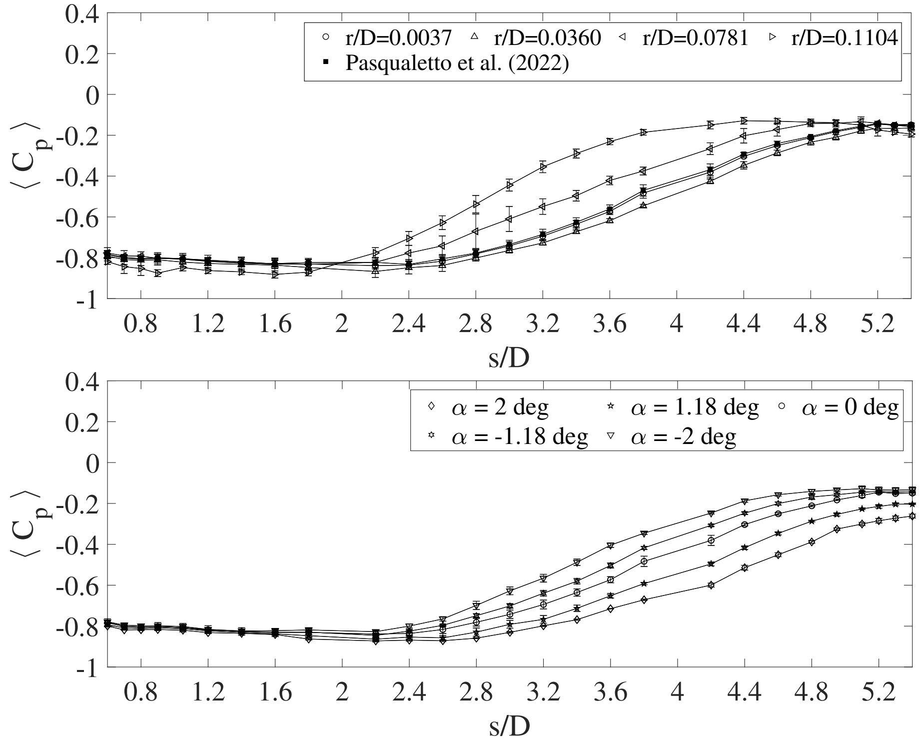

Figure 2. Time- and spanwise-averaged distributions of the pressure coefficient for the lateral surfaces at $y \geq 0$ for the cases with $\alpha = 0$ (top) and for the ones with $r/D = 0.0037$ (bottom).

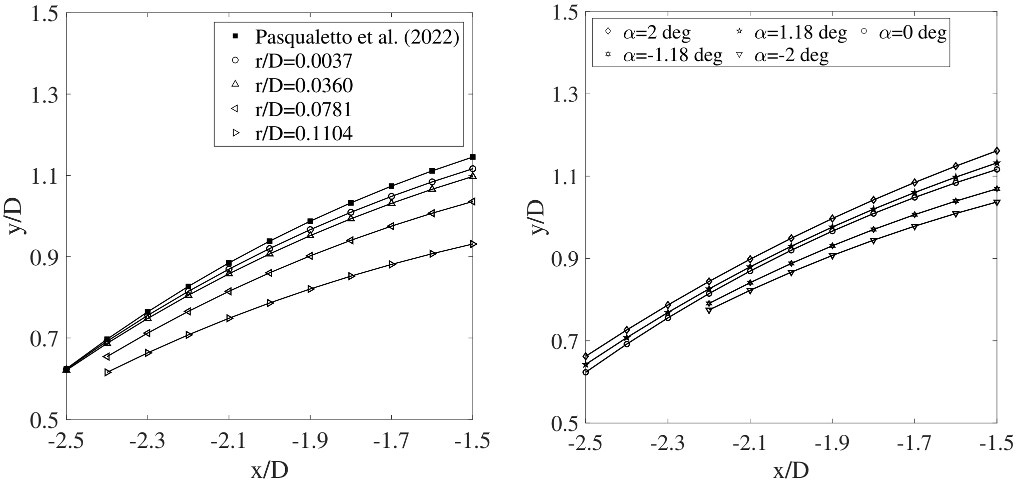

Figure 3. External borders of the mean separated shear layers for the cases with $\alpha = 0$ (left) and for the ones with $r/D = 0.0037$ (right).

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