Characteristics of the flow around a superhydrophobic obstacle

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Extended abstract

The flow around a partially buried circular cylinder on a smooth plane boundary is studied using Particle Image Velocimetry. The cylinder axis is perpendicular to the incoming flow. The burial ratio B/D is equal to 0.5, where B is the burial depth and D is the diameter of the cylinder. The ratio between the span of the obstacle and its diameter is equal to 11.7. The flow is considered nominally two-dimensional. The case in which the obstacle is coated with a random-textured superhydrophobic surface is compared with the case of a smooth surface. In the superhydrophobic case the surface was prepared by using a double layer spray coating method (NeverWet solution). An extreme contact angle of about 165° was evaluated. Measurements were carried out in a closed-loop water tunnel for a Reynolds number, based on the cylinder diameter and on the incoming flow velocity $U_e$, of about 360. The incoming boundary layer is laminar and the boundary layer thickness, in absence of the obstacle, is of the same order of the obstacle height. The present research is related to the understanding of the role of slip conditions in presence of pressure gradients (see e.g. [1], [2]) in order to provide useful information for flow control strategy.

Few results are shown in the following figures. The maps of the longitudinal (U) and vertical (V) component of the mean velocity are shown in figure 1 and figure 2 respectively. On both figures the time-averaged streamlines are also represented. Although the separation point does not appear greatly influenced by the different slip conditions, appreciable differences between the smooth case and the superhydrophobic case can be seen in the wake of the buried cylinder. The superhydrophobic obstacle shows a wider (and presumably longer) wake. In figure 3 the maps of the probability for the flow to have positive longitudinal instantaneous velocity (forward flow probability, FFP) are reported. From this representation of the flow it is clearly evident that the superhydrophobic obstacle possesses a much less unsteady wake. In the superhydrophobic case an extended region of the separated flow is characterized by FFP values almost close to zero while values close to 0.5 are observable in a large part of the wake of the canonical case. The much less unsteady flow configuration in the wake of the obstacle for the superhydrophobic case is also evidenced by the spectra shown in figure 4, where the amplitude is normalized with respect to the peak amplitude corresponding to the canonical case. The Strouhal number (St) is based on the cylinder diameter and on the flow velocity $U_e$. The spectra refer to the vertical component of the velocity and were computed in the wake shear layer at $x/D \approx 0.52$ and $y/D \approx 0.45$. While the canonical case shows a strong peak at St equal to about 0.27, indicating a von Karman type vortex shedding from the obstacle surface, this shedding appears to be almost suppressed as a consequence of the slip conditions present in the superhydrophobic case. In order to capture the essential flow dynamics in the two cases a proper orthogonal decomposition (POD) analysis was performed. In figure 5 an example of the reconstructed snapshots using the first three POD modes are shown. The instantaneous velocity field is superimposed to the colour map representing the spanwise vorticity. High values of positive and negative vorticity are visualised with red and blue colors respectively. In both cases over the upper surface of the obstacle high positive values of the vorticity are observable. High negative values of the vorticity are observed over the rear surface of the buried cylinder when a vortical structure is shed (figure 5a). Analysing the time series of the reconstructed signal for the superhydrophobic case (see for instance figure 5b), the almost complete absence of vortical structures shed from the obstacle is observable.
Fig. 1 Longitudinal component of the mean velocity and time-averaged streamlines. a) Smooth surface; b) Superhydrophobic surface.

Fig. 2 Vertical component of the mean velocity and time-averaged streamlines. a) Smooth surface; b) Superhydrophobic surface.

Fig. 3 Forward flow probability (FFP) and time-averaged streamlines. a) Smooth surface; b) Superhydrophobic surface.
Fig. 4 Relative amplitude spectrum in function of the Strouhal number. Black line: canonical case. Red line: superhydrophobic case.

Fig. 5 POD reconstructed snapshots. The instantaneous velocity field is superimposed to the colour map representing the spanwise vorticity. a) Smooth surface; b) Superhydrophobic surface.

References
