INFLUENCE OF LIQUID-GAS INTERFACE DYNAMICS IN SUPERHYDROPHOBIC SURFACES FOR DRAG REDUCTION

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Abstract Direct numerical simulation (DNS) is used to investigate liquid flow in turbulent channels with superhydrophobic surfaces. The effect of the gas bubbles trapped between surface protrusions is modeled as both a slip effect and, for the first time in literature, a deforming interface. The dynamics of the interface are modeled with a linearized boundary condition, derived from the equilibrium between the surface tension and the pressure jump across the interface. We study two- and three-dimensional patterned surfaces, analyzing the effect of the surface tension and the pattern geometry and alignment.

MOTIVATION

Superhydrophobicity enables textured surfaces to entrap pockets of air within its grooves, for small enough groove sizes, in the so called Cassie-Baxter state. Under those conditions, an overlying water flow can effectively slip over the surface, experiencing reduced friction compared to a conventional smooth wall [1]. The drag-reducing properties of superhydrophobic surfaces on turbulent flows have received increasing attention recently, both in experimental [2, 3, 4] and numerical [5, 6, 7] studies. However, the interaction of superhydrophobic surfaces with turbulent flows is not yet fully understood. For instance, if only the slip effect is considered [6, 7], the predicted reduction in friction scales linearly with the groove dimension in wall units, λ^+, for each given surface geometry. In real flows, however, the superhydrophobic effect is completely lost for a sufficiently large λ^+, when the Cassie-Baxter state transitions to the Wenzel state, and the surface is fully wetted. To analyze possible degrading effects on the predicted linear performance for smaller λ^+, we study the dynamics of the gas-liquid interface. In previous studies [6, 7], this interface was assumed to produce perfect slip while mantaining a rigid, wall-parallel shape. We suppose that, under pressure fluctuations, the interface is able to deform following the Young-Laplace equation, $\nabla^2 y_i \approx \frac{1}{\sigma}\delta p$, where y_i is the interface wall-normal coordinate, σ is the surface tension, and δp is the pressure jump across the interface. We introduce the effect of the deformation on the overlying turbulent flow as a linearized boundary condition for the wall-normal velocity. Some recent studies have considered the effect of stationary interface curvature [8, 9], but this is the first study considering interface dynamics in turbulent flow.

RESULTS

We perform DNSs in turbulent channels at $\mathrm{Re}_\tau = 395$, with superhydrophobic surfaces in both walls. We study patterned configurations consisting of posts and streamwise- and spanwise-aligned ridges, studying the influence of the dimensionless geometric parameters and surface tension. We will present turbulent statistics in the full conference paper. One interesting result is illustrated in Figure 1, which compares instantaneous pressure fluctuations at the wall for a conventional smooth wall, a superhydrophobic slip/no-slip pattern of posts with rigid gas-liquid interface, and one with deformable interface. The turbulent fluctuations typical of smooth-wall channels, of order $p'^+ \approx 3$, are also present in the second case, although a larger term ≈ 10 dominates, which is due to the time-averaged deformation of the surface. However, once the interface dynamics are considered, the time-varying fluctuations essentially dissapear, and only the stationary term persists. Furthermore, this term is associated to the geometry of the pattern, and is negligible in the case of streamwise-aligned ridges. The vanishing of the time-varying fluctuations is observable even for very small dynamic interface deformations, typically smaller than 1 wall unit.

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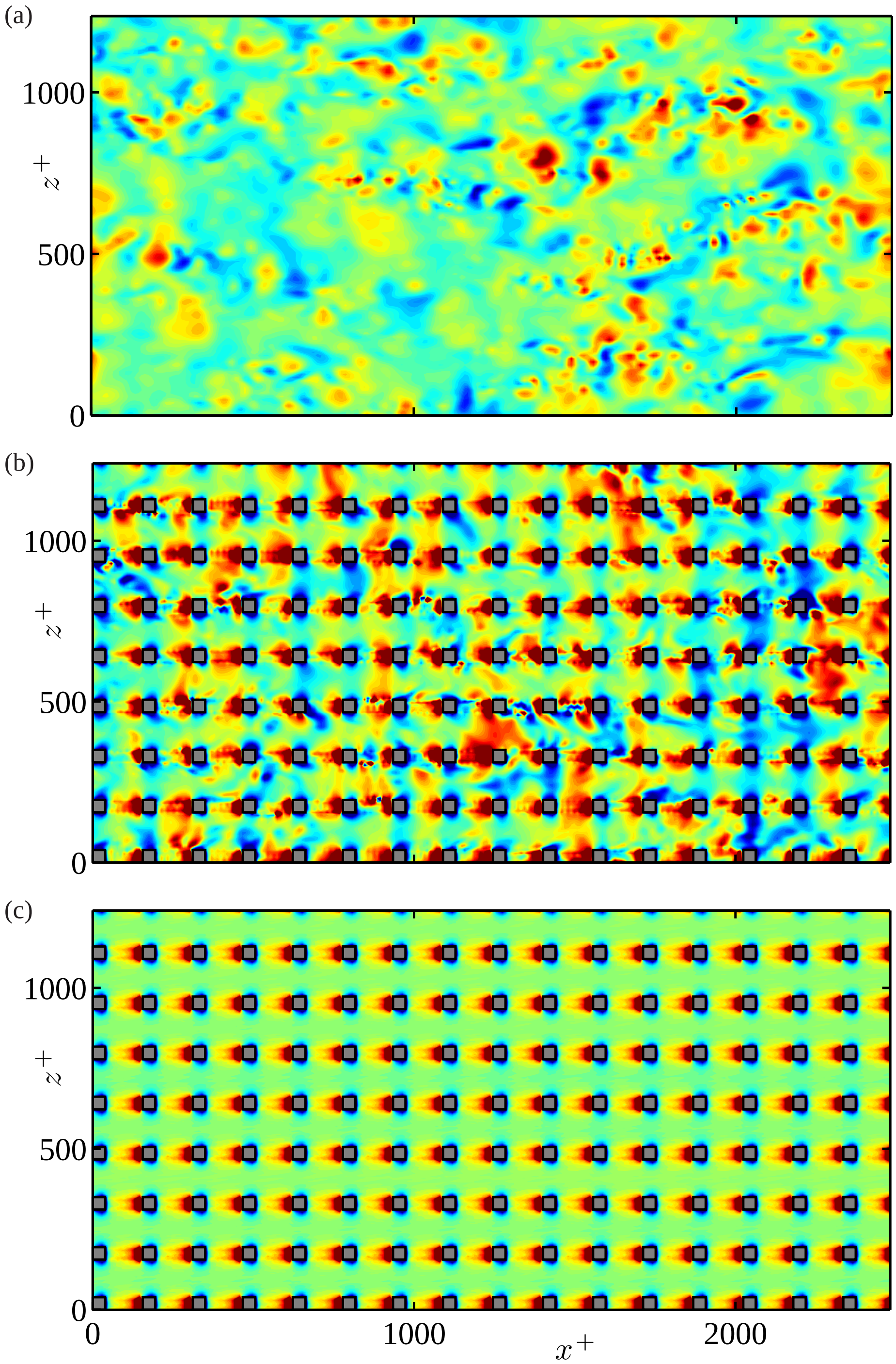

Figure 1. Instantaneous realization of the pressure fluctuations at the wall for channels at $\mathrm{Re}_\tau \approx 395$ with (a) smooth walls, (b) no-slip solid posts and rigid, perfect-slip gas-liquid interface, and (c) no-slip solid posts and deformable, perfect-slip interface. From blue to red, fluctuations between -10 and $+10$ wall units.