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DNS OF TURBULENT CHANNEL FLOW PAST ULTRAHYDROPHOBIC SURFACES WITH PERIODIC MICROFEATURES

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ABSTRACT

The interaction between solid surfaces and liquids is of fundamental importance in engineering flows where solid surfaces are the primary means for controlling or manipulating fluids. We will show that by treating a solid surface to make it ultrahydrophobic it is possible to significantly enhance how the surface interacts with a flowing liquid. In particular, in our recent work, we have shown that ultrahydrophobic surfaces can be utilized to reduce drag [1, 2] and enhance mixing [3] in low to moderate Reynolds number internal flows. In this presentation we will demonstrate through a series of numerical simulations that ultrahydrophobic surfaces can also be used to delay the transition to turbulence and dramatically reduce drag in both external and internal turbulent flows.

Ultrahydrophobic surfaces are engineered by taking materials with micron or nanoscale surfaces roughness and chemically treating them to make them hydrophobic. Because of the hydrophobicity of these microscale and nanoscale protrusions, the water does not move into the pores on the surface, rather it remains in contact with only the peaks of the surface topology resulting in a shear-free air-water interface. The underlying physical mechanism for drag reduction is a slip along the shear-free air-water interface supported between the peaks of micro or nanoscale protrusions present on the ultrahydrophobic surface.

We will present the results from direct numerical simulations of the flow over a series of model ultrahydrophobic surfaces chosen to directly match the surfaces used in our concurrent experiments. In the simulations, the top of the microposts or microridges are assumed to be no-slip and the air-water interface between them is assumed to be shear-free and flat. Both of these assumptions are reasonable, however, under certain conditions, the air-water interface can deflect and the recirculation of air within the gaps between the microposts or microridges can produce some drag along the air-water interface. The numerical algorithm used to simulate the has been under development for almost a decade [4, 5] and over the last year it has been modified to apply directly to turbulent flows past ultrahydrophobic surfaces. The code uses non-uniform grid spacing

to place more resolution near the channel walls and a Cartesian staggered mesh method with exact projection for the pressure solution. The Navier-Stokes equations are solved using a conjugate gradient solver and a modified Runge-Kutta time marching method. The code is fully parallelized with MPI. The code was validated by comparison of the velocity and Reynolds stress profiles to the direct numerical simulations of Moser et al. [6] which is considered to be a benchmark for DNS simulations of channel flow in the literature. Additionally, we will show that these results match nearly exactly with the experimental measurements at roughly the same Reynolds number.

DNS of flow through a rectangular channel where one wall is smooth and the other wall is ultrahydrophobic are performed for a number of different ridge sizes and spacings over a modest range of Reynolds numbers. The presence of the ultrahydophobic wall can be obseved both in the instantaneous and time-averaged velocity profiles. Both the average velocity profile and the relavent Reynolds stresses are found to be antisymmetric in the ultrahydrohobic case. The velocity profile is observed to shift towards the ultrahydrophobic wall, while the Reynolds stresses near the ultrahydrophobic wall are significantly reduced. Additionally, slip velocity is observed at the ultrahydrophobic wall that can reach values of more than 50% the average flow velocity. The slip at the ultrahydrophobic wall results in a shear stress reduction of more than 20% in some cases. The drag reduction is observed to increase with increasing ridge spacing and decreasing ridge width, however, the the drag reduction appears to be much more sensitive to the spacing rather than the width of the ridges. These results are all in good agreement with experimental observations of turbulent flow over ultrahydrophobic surfaces.

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