144a Turbulent Poiseuille-Couette Flow

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Direct numerical simulations (DNS) of turbulent flow were used to investigate the structure of the velocity field in a Poiseuille-Couette flow channel. The goal is to identify the changes that occur in the fluctuating velocity field close to a channel wall when the boundary conditions at that wall do not force the fluid velocity to be zero.

During the past two decades numerous investigators have studied turbulent flow in an infinite channel using DNS, starting with the famous Kim, Moin and Moser paper (J. Fluid Mech., 177, 133-166, 1987). Recently, Reynolds numbers that are about an order of magnitude higher than the original DNS of Kim et al. have been achieved. However, plane Couette flow has not received that much attention, and the combination of Poiseuille-Couette flow has been investigated scarcely with either experimental (Thurlow E.M., and J.C. Klewicki, Phys. Fluids, 12(4), 865-875, 2000; Nankabayashi, K., et al., J. Fluid Mech., 507, 43-69, 2004) or numerical methods.

There is a strong motivation to study this type of flows, which emerged from recent findings about drag reduction in laminar flows over ultra-hydrophobic surfaces. The obvious question that arises is whether turbulence drag reduction can also be achieved over ultra-hydrophobic surfaces, and, if so, how does the surface affect the structure of the turbulence close to the wall. A Poiseuille-Couette flow imposes a boundary condition to the moving wall of the channel that forces the streamwise velocity to have a specific value. This is equivalent to forcing a specific slip at the wall of the channel, and such behavior can be viewed as the effect that an ultra-hydrophobic surface can have. (In laminar flows, it has been found that ultra-hydrophobic surfaces generate velocity slip at the wall). Our investigation focuses on the effects that a specified wall velocity (or specified wall slip) can have on the turbulence structure.

Computations have been completed for plane Poiseuille channel flow at a Reynolds number equal to 2600 (based on centerline mean velocity and half channel height). The Poiseuille-Couette flow runs included the cases where one wall moved with 1, 2 and 4 viscous wall velocity units in the positive streamwise direction relative to the opposite wall of the channel. It was found that the mean velocity maximum shifted towards the moving wall as the wall velocity increased, as well as the point at which the Reynolds stress crossed zero. The turbulence intensity was lower close to the moving wall side. However, the correlation coefficients for the velocity fluctuations did not appear much different than for the plane Poiseuille channel. The differences between the flows appeared in the third and higher order statistics and in the probability density function for the spanwise and vertical velocity fluctuations. The paper will discuss these findings and the implications on slip-induced drag reduction for turbulent flows.