Modifications of the friction drag and coherent structures in turbulent boundary layers via local polymer solution ejection

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In wall-bounded turbulence, it is known that a small amount of polymer additives significantly reduce the skin friction and modify the coherent structures. In this presentation the effects of polymer additives on skin friction decomposition and large-scale structures are experimentally studied in a flat plate turbulent boundary layer. Particle-tracking-velocimetry (PTV) and Particle-image-velocimetry (PIV) are used to capture the flow field at friction Reynolds number ($\mathrm{Re}_\tau = 864$). High concentration polymer (300ppm PEO, molecular weight 8×10^6) solution are ejected to the boundary layer via a flash mounted slot at the wall.

Friction decomposition is analyzed through the FIK identity[1] to evaluate the contributions of various terms to the friction drag. Furthermore, the skin friction is determined by the sum of four terms, i.e., the viscous term, the Reynolds stress term, the total stress gradient term and the polymer stress term that is evaluated by $(1-y/\delta)$ fitting[2]. The contribution of the polymer stresses to the friction drag for up to 18.5%. The skin friction is obtained by a linear fitting of velocity in viscous-sublayer. It is shown that the polymer reduce the friction drag by 52.6%.

The effects of polymer on the large-scale tuebulent structures are analyzed via the uniform-momentum-zones (UMZs). The UMZs of large and irregularly shaped regions with uniform streamwise momentum are extracted from the instantaneous flow fields by a histogram method[3]. It is shown that the averaged number of UMZs increases with the polymer concentration, due to the enriched large-scale structures near the wall. Meanwhile, the averaged size of UMZs near the wall decreases with the increase of the polymer concentration. Our results indicate that polymer enhance the coherence of the flow structures in the streamwise direction and attenuate that in the wall-normal direction. In addition, a two-point-correlation method is used to calculate the inclination angle of the large-scale structures. The inclination angle is decreased from 48.01° for the pure water case to 29.05° for the case with polymer solution ejection.

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[1] Fukagata et al., *Phys. Fluids* **14**, 11 (2002).
[2] Y Hou et al., *Exp. Fluids* **40**, 589-600 (2006).
[3] de Silva et al., *J. Fluid Mech.* **786**, 309-331 (2016).