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Drag reduction by polymer additives: the Maximum Drag Reduction asymptote

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In turbulent wall-bounded flows, the addition of a tiny amount of long-chain polymers can drastically reduce friction[1]. A peculiar feature of drag-reducing polymer flows is the existence of a Maximum Drag Reduction (MDR) state, at which the velocity profile assumes a universal state, independent of both solvent and polymer parameters. Reviewing many experimental data, Virk proposed a log law for the mean velocity scaled with wall-units, $U^+ = 11.7 \ln y^+ - 17$. Despite appropriate in the limit of large Reynolds and polymer concentrations[2], the validity of this law has been questioned in the last years[3] as both experimental[4,5] and numerical data [6] seems to deviate from the logarithmic shape.
We used Direct numerical simulations, coupling the Navier Stokes equations to the Lagrangian evolution of the polymers (modelled as dumbbells), to investigate the dynamics at MDR at constant friction Reynolds number $Re_\tau = 310$ and large Weissenberg number $Wi = 10^4$. The mean velocity, shown in fig. 1 (left), approaches an ultimate profile if the number of polymer chains is large enough and the Reynolds stress, reported in the inset, becomes negligible for the largest value of concentration considered in the simulations. The mean velocity profile does not exactly fall on the Virk's log law, but its shape is similar to experimental profiles at a comparable Reynolds number[7,8].
Analysis of the turbulent kinetic energy budget shows that the path of turbulent kinetic energy that characterises wall-bounded turbulent flows is completely eradicated; see fig. 1 (right). Turbulent kinetic energy is not transferred across the wall-normal direction, and the production of turbulence, mainly associated with the polymers (solid black line), is in balance with viscous dissipation (solid red line) at any distance from the wall.
During the oral presentation, a physical interpretation of the results will be given, and the deviation of numerical and experimental data from Virk's law will be discussed.

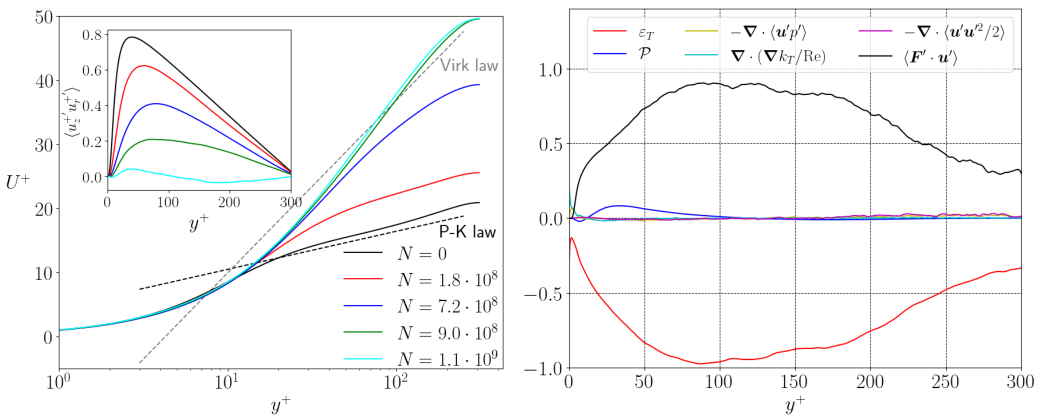

Figure 1: Left panel: mean velocity profiles and Reynolds stress profiles (inset) with increasing number of polymers at $Re_\tau = 310$ and $Wi = 10^4$. Right panel: budget of turbulent kinetic energy at MDR).

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[4] Ptasinki et al, *Flow, Turbulence and Combustion* **66**, 159 (2001)
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