Theory of Drag Reduction by Polymers in Turbulent Systems: Universal and Non-universal Aspects

Itamar Procaccia
Department of Chemical Physics, The Weizmann Institute of Science, Rehovot 76100, Israel

Drag reduction by polymers in wall turbulence is known since the 1940's but a theory of the phenomenon remained elusive. I will present such a theory, explaining both the universal and the non-universal aspects of the phenomenon. The universal aspect is that the amount of drag reduction is bounded from above by the so-called maximal drag reduction (MDR) velocity profile that is a log-law, estimated experimentally by Virk as $V^+(y^+) \approx 11.7 \log y^+ - 17$. Here $V^+(y)$ and y^+ are the mean streamwise velocity and the distance from the wall in "wall" units. I will show how to derive this law from first principles, using the fact that this MDR profile is an edge solution of the Navier-Stokes equations (with an effective viscosity profile) beyond which no turbulent solutions exist. This insight rationalizes the universality of the MDR and provides a maximum principle which allows an ab-initio calculation of the parameters in this law without any viscoelastic experimental input. The non-universal aspects have to do with the crossovers from the MDR to the Newtonian plug. These crossovers depend on many parameters: the Reynolds number, the concentration of the polymers, the number of monomers in a polymer and what not. I will show that the theory predicts correctly these crossovers as a function of the parameters.