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Nonlinear dynamics of turbulent drag reduction by polymers

MICHAEL GRAHAM, SUNG-NING WANG, University of Wisconsin-Madison, FRIEDEMANN HAHN, Univ. Stuttgart — Minimal channel flow of Newtonian and drag-reducing polymer solutions is studied computationally. Even in the Newtonian limit, intervals of "active" and "hibernating" turbulence exist, the latter displaying many features of the maximum drag reduction (MDR) asymptote observed in polymer solutions: weak streamwise vortices, nearly nonexistent streamwise variations and a mean velocity gradient that quantitatively matches experiments (i.e. the Virk log-law). Polymer stretching is very weak during hibernation. As viscoelasticity increases, the frequency of the hibernation intervals increases, leading to flows that increasingly resemble MDR. This observation can be explained with a simple mathematical model that posits that the lifetime of an active turbulence interval is the time that it takes for the turbulence to stretch polymer molecules to a certain threshold value beyond which the active turbulence is suppressed. An extended Karhunen-Loeve analysis is introduced and used to illustrate how the velocity and stress fields change as MDR is approached. These results and others indicate that the MDR dynamics are governed by an underlying Newtonian state – a saddle point in phase space – that is unmasked as viscoelasticity suppresses normal turbulent fluctuations.

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