EXPERIMENTAL MEASUREMENTS OF DILUTE POLYMER SOLUTIONS IN A VON KÁRMÁN SWIRLING FLOW

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Abstract Understanding the ways in which non-Newtonian fluids modify turbulent flows is relevant to many natural and industrial processes. Although skin-friction drag reduction in turbulent wall-bounded flows has been studied for over fifty years, there is comparatively little data on the effect of complex fluids on bulk turbulence far from the wall. To begin to fill this gap, we present measurements of the modification of bulk turbulence by small amounts of long-chain polymers in a von Kármán swirling flow. To complement existing work, we focus on Lagrangian measurements in order to characterize in detail the changes to the flow statistics.

OVERVIEW

When small amounts of additives, including long-chain polymers, surfactants, or microbubbles, are added to a turbulent flow, the structure and dynamics of the flow can change dramatically. The most celebrated effect of additives is skin-friction drag reduction [7, 8]: tiny amounts of polymers or surfactants can reduce the drag in a turbulent wall-bounded flow by up to 80%. After many decades of research, the community is beginning to reach consensus on the fundamental physics of this drag reduction.

But additives may also modify the structure of the turbulence far from any walls [4, 3, 2, 5], where the Newtonian is reasonably well approximated as homogeneous and isotropic. Much less, however, is known about the details of how the flow is modified by the additives in this case, and current models do not accurately explain the observations.

EXPERIMENT

Our experimental apparatus, pictured in Fig. 1, consists of a cylindrical container with a diameter of 0.6 m, in which counter-rotating baffled impellers stir the fluid inertially [1]. The turbulence has an integral length scale of approximately 10 cm that is roughly independent of Reynolds number. We work with dilute solutions of polyacrylamide in water, and study both the effects of the polymer concentration (ranging from 1 to 15 parts per million (ppm) by weight) and the molecular weight (up to 18×10^6 a.m.u.). Although the apparatus can reach Taylor-microscale Reynolds numbers of up to $R\lambda \approx 1200$, we work at lower Reynolds numbers in order to avoid scission of the polymer chains by the flow gradients.

To measure the turbulence, we use stereoscopic Lagrangian particle tracking. We image the motion of fluorescent tracer particles with three high-speed Photron SA5 cameras, and extract the particle trajectories using a predictive tracking algorithm [6].

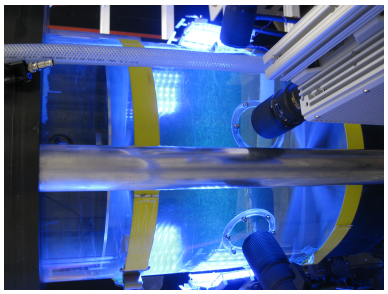

Figure 1. Picture of the experimental setup.

ANALYSIS

In order to complement existing measurements of Eulerian structure functions [5], we consider Lagrangian statistics to quantify the differences between the polymer solution and the pure solvent. In Fig. 2, we show the second-order Lagrangian structure function for a range of polymer concentrations. Even a small amount of polymer changes the magnitude of the structure functions by nearly an order of magnitude, but the overall shape of the curves is not significantly changed. We will additionally report measurements of the dependence of this effect on polymer chain length, which has proved to be crucial for understanding drag reduction [8].

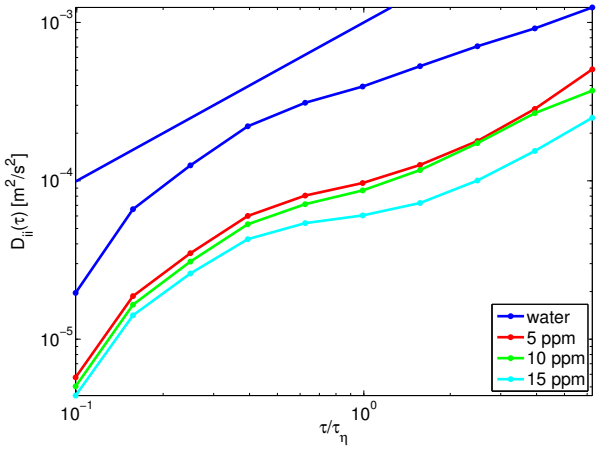

Figure 2. Second-order Lagrangian structure functions for different polymer concentrations for a molecular weight of 18×10^6 a.m.u. The straight line is linear in τ (the expected Kolmogorov scaling).

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