Routes to turbulence for complex fluid flows in pipe

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Résumé

The transition to turbulence in cylindrical pipes remains incompletely understood, despite significant advances [1 2 3]. Controlling flow regime transitions is of industrial importance, such as in sludge transport within wastewater treatment plants. In the first place, our study focuses on the transition to turbulence for complex fluids with purely shear-dependent viscosity and no elastic effects. Using an dedicated experimental setup, we identified flow regimes in a cylindrical pipe through flow visualization and pressure drop measurements. We obtained novel results of the **rheo-inertial transition to turbulence** [4], including the new regime occurring at a critical Reynolds number below the onset of turbulent puffs during the laminar-turbulent transition and specific to viscosity stratification. This pre-transition regime features evolving flow asymmetry as the Reynolds number increases. Its stability likely arises from a balance between the nonlinear contributions of rheological behavior and flow inertia. Additionally, we quantified puff intermittence, see Figure 1, revealing that shear-dependent viscosity characteristics delay turbulence onset. For the first time, we observed distinct rheo-inertial behavior in intermittency evolution versus Reynolds, showing a smoother and broader transition range.

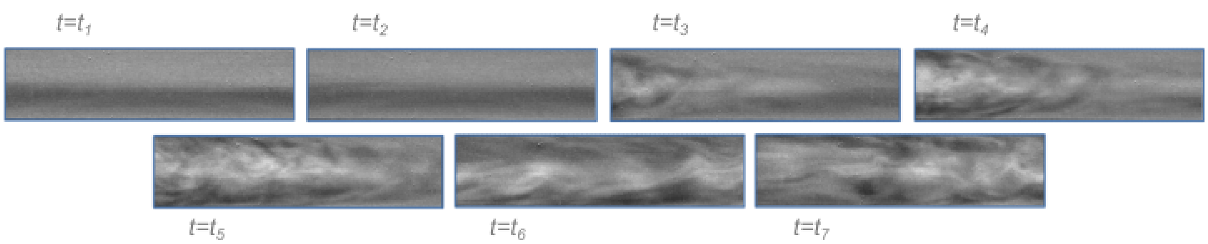

Figure 1. Flow visualisations of a turbulent puff transit on a shear-thinning yield-stress fluid (Carbopol 0.08 %) at parietal Reynolds number 3875 for successive times (from top to bottom, and left to right).

The second axis of this work aims to investigate how polymer additives, commonly used in industrial processes like sludge thickening in wastewater treatment, significantly alter complex fluid flows in cylindrical pipes and influence the transition to turbulence. Their addition creates fundamental differences from Newtonian turbulence, leading to elasto-inertial turbulence—a chaotic state driven by the interplay of inertia and viscoelasticity [5], characterized by energy transfer from small elastic to large flow scales [6]. Using advanced metrology, we are exploring how elastic properties in aqueous solutions affect the competition between rheo-inertial and elasto-inertial transitions, capturing and quantifying velocity field patterns across the pipe longitudinal and cross sections.

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