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Transition to turbulence in pipe flow for complex fluids

Antoine Charles^{*}, Jorge Peixinho[†], Marcos Oliveira[‡], Sabrina Guérin[‡], S. Amir Bahrani^{*}

The transition to turbulence in cylindrical pipes is not fully understood although several new insights have emerged^{1,2} since Reynolds experiment in 1883. It is of great industrial interest to control the flow regimes transition, for example when transporting sludge in wastewater treatment plant. We focused here on the mechanism leading to the transition to turbulence in pipe according to a non-Newtonian-like road to turbulence for complex fluids. Our recent experimental work³ regarding the purely shear-dependant viscosity fluids without elastic effects and so called here *rheo-inertial transition to turbulence*. An experimental setup has enabled us to identify flow regimes in a cylindrical pipe, using both flow structures visualisations and pressure drops measurements. We observed a new regime in the laminar-turbulent transition which is specific to viscosity stratification of fluids, triggered at a critical Reynolds number below the turbulent puffs onset. This pre-transition regime is associated with a flow asymmetry in which its position and degree evolve as the Reynolds number increase. The origin for the stability of this rheo-inertial regime is discussed, as it could be due to a favourable competition between the non-linear contributions of rheological behavior and flow inertia. Beyond this regime, we quantified the intermittence of puff transit (see Figure 1), revealing the delay to turbulence caused by the shear-dependant characteristics. We spotted for the first time a different rheo-inertial transitional behavior in the intermittency evolution versus Reynolds, displaying a smoother transition on a broader range.

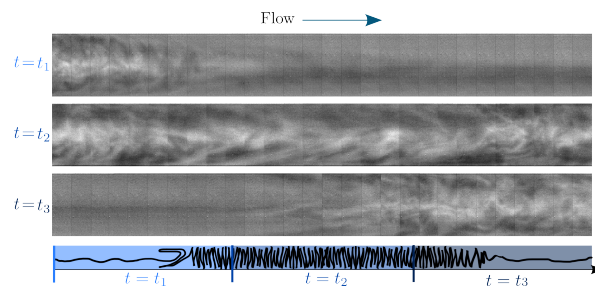


Figure 1: Flow visualisations of a turbulent puff transit on a shear-thinning yield-stress fluid (Carbopol 0.08 %) at parietal Reynolds number 3875 for 3 successive times from top to bottom. Schematic view shown below.

The objective of the current work is to study the influence of polymer additives on the route of the transition to turbulence. Polymer additions are widely used in industrial processes, such as in the sludge thickening in wastewater treatment plant, changing these complex fluid flows over long distances of cylindrical pipe. The addition of polymers is known to provoke fundamental differences in the transition to turbulence from the Newtonian inertial turbulence, resulting in an elasto-inertial turbulence. Elasto-inertial turbulence is a chaotic flow state that develops upon both non-negligible inertia and viscoelasticity⁴ driven by polymer dynamics. It is observed across many orders of magnitude in Reynolds number and involves energy transfer from small elastic scales to large flow scales⁵. We are investigating, using coupled PIV and PLIF advanced metrology techniques, how the addition of elastic characteristics to the aqueous solution modifies the competition between the rheo-inertial and the elasto-inertial transition routes. In this context we quantified the different flow patterns captured by the velocity field across the entire pipe cross section.

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