Modeling and numerical simulations of elastic turbulence in polymer solutions

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Elastic turbulence is a phenomenon characterized by the emergence of a chaotic flow in viscoelastic fluids such as solutions of long-chain polymer molecules. In contrast to Newtonian turbulence, which requires large Reynolds number (Re) to drive the fluid motion into a chaotic regime, the Re number in elastic turbulence is arbitrarily low, i.e., the flow is purely driven by the amplification of elastic instabilities. As a consequence, elastic turbulence is a useful tool for enhancing mixing in microfluidics [Steinberg, Annu. Rev. Fluid Mech. 53 :27–58, 2021].

Simulating elastic turbulence by using the continuum-level differential constitutive equations coupled with the Navier-Stokes equation has been a great challenge in terms of properly resolving the steep gradients that emerge in the polymer stress field [M.A. Alves et al, Annu. Rev. Fluid Mech. 53 :509 –541, 2021]. The lack of accuracy in calculating the numerical solution generates large-scale errors in the flow fields, thereby modifying the spatial flow structures. In the literature, to overcome the numerical instabilities, various reformulations of the conformation tensor field, which describes the average extension and orientation of the polymer chains at each point in the fluid, have been proposed, such as the symmetric square root and the Cholesky decompositions. We introduce a necessary criterion that must be satisfied for a numerical simulation of elastic turbulence to be accurate. This consists of a lower bound on the trace of the conformation tensor. We show that the violation of this bound is associated with a misrepresentation of the large-scale flow structures as shown in Fig. . We also show that numerical methods that involve a logarithmic transformation of the conformation tensor resolve its steep gradients more accurately, and therefore are more effective in preserving the lower bound on its trace.