On the polymer coil-stretch mechanism in turbulent viscoelastic channel flows: statistical and tensor investigation

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1. Introduction

The polymer coil-stretch mechanism in turbulent drag reducing flows is analyzed using direct numerical simulations of viscoelastic FENE-P fluids. The study is carried out taking into account low and high drag reduction regimes. The polymer stretching and the alignment between the conformation tensor and other relevant entities are investigated using statistical and tensor analysis. The significant alignment between the former and the velocity fluctuations product tensor indicates that the initial polymer pre-stretching due to the mean shear is increased by the flow stress fluctuations, providing a supplementary polymer extension. In addition, interactions between the turbulence and the polymer are evaluated from an instantaneous turbulent energy exchange perspective by considering the Reynolds stress equation in elliptical and hyperbolic flow regions, separately.

2. Results

In order to better understand the polymer coil-stretch process from the energy perspective, we divide the flow into two different regions by using the *Q-criterion* (Hunt et al.[1]): the elliptical (or vortical) regions ($Q > 0$); the hyperbolic (or extensional) regions ($Q < 0$).

The energy exchanges between the polymers and turbulent structures are highlighted by the open symbols in Fig.1, where the *x-y* plane average of the instantaneous streamwise polymer work fluctuations, E'_x, is plotted against the normalized wall distance, z^+, for both the elliptical (*a*) and the hyperbolic (*b*) regions. The instantaneous polymer work term, E'_α, indicates the amount of energy stored ($E'_\alpha < 0$) or released ($E'_\alpha > 0$) by polymers from the fluctuations of the velocity field in the α direction (see Dubief et al.[2]). In addition, the solid symbols in Fig.1 indicate the cosines of the angles between the first principal directions of the conformation tensor, $\boldsymbol{C}$, and the instantaneous Reynolds stress, $\boldsymbol{\tau}'$, whose components are given by $u'_i\,u'_j$.

Polymers release energy to elliptical and hyperbolic parts located in the near-wall region (region I in Fig.1). In contrast, molecules extract energy from such structures in the buffer and log-law region (regions II and III, respectively). On the other hand, in the wall-normal direction as well as in the spanwise direction (not shown here), the polymer molecules predominantly store turbulent energy from the elliptical and hyperbolic structures by stretching in the log-law. It is important to emphasize that the polymer-turbulence exchanges of energy are more pronounced in hyperbolic regions, especially in the streamwise direction.

Lastly, regarding $\langle \cos\Psi(e_1^{\mathcal{C}}, e_1^{\tau'}) \rangle$ (solid symbols), the more significant alignments between $\boldsymbol{C}$ and $\boldsymbol{\tau}'$ are situated in the hyperbolic regions (*b*). These alignments decrease monotonically from the viscous sublayer to the centre of the channel.

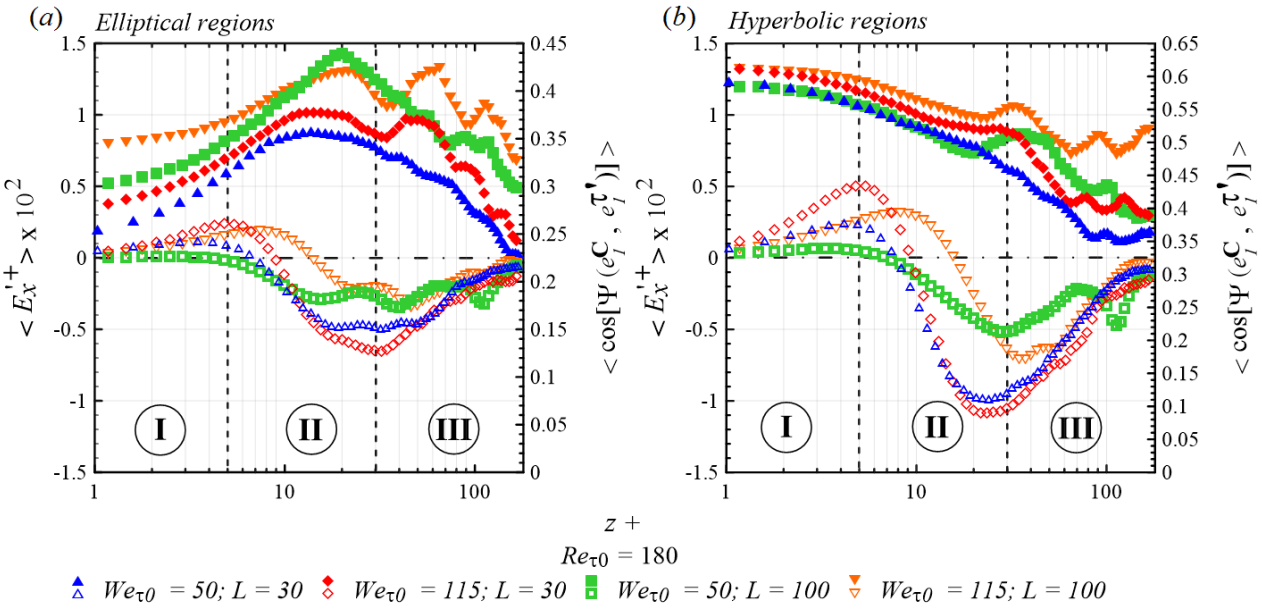

Fig.1 The open symbols show the normalized streamwise polymer work fluctuations against the wall distance (z^+) considering the elliptical (*a*) and hyperbolic (*b*) regions, separately. The solid symbols show the profile of $\langle \cos\Psi(e_1^{\mathcal{C}}, e_1^{\tau'}) \rangle$ against the wall distance, in the same two domains.

3. Concluding Remarks

Near the wall, polymers not only release energy to the streaks, but also to the elliptical (vortices) and hyperbolic (extensional) structures. At this location, molecules tend to abandon their extensional stretch history by rotating in the spanwise direction. Polymers can be also dragged around near wall vortices, passing through hyperbolic regions and experiencing a significant straining within both these turbulent structures and storing their energy. Hence, polymers weaken elliptical and hyperbolic structures leading to a tendency of a dominant parabolic character in the flow domain (Q tends to zero). Polymer release of energy occurs primarily in the streamwise direction, which is in agreement with the enhanced streamwise velocity fluctuation observed in drag reducing flows (Thais et al.[3]).

References:

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