Direct Numerical Simulations of turbulent planar jets of viscoelastic FENE-P fluids

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1 Introduction

Spatial direct numerical simulations (DNS) of turbulent planar jets of dilute polymer solutions, described by the finitely extensible non-linear elastic constitutive equation closed with the Peterlin approximation (FENE-P), were carried out in order to understand this canonical flow and formulate a theory for the far-field. The Reynolds number based on the inlet flow was fixed at $Re = 3500$ with $L^2 = 10^4$, $\beta = 0.8$ and the Weissenberg number (Wi) was varied between 0 (Newtonian) and 2.2. These are the first massive DNS of viscoelastic jet flows, which relied on the algorithm proposed by [1] to tackle the complex numerical challenges posed by these heavy computations.

2 Results

The data cover the entire transitional region as well as the fully turbulent far-field up to 18 slot widths. The influence of Wi on the turbulent statistics is discussed, revealing considerable changes in comparison to the Newtonian flow. In particular, the maximum value of the mean rate of dissipation of turbulent kinetic energy by the solvent is reduced by more than 80% for the maximum Wi flow, clearly showing the influence of the polymers on the flow development. The jet spreading and decay rates, as well as the Reynolds stress and mean velocity profiles were also significantly affected.

An order of magnitude analysis and the assumption of self-similar behavior of the mean flow successfully lead to a theoretical description of mean flow characteristics, validated by the DNS data. This far-field theory showed the laws of variation of the jet width (δ) and centreline velocity (U_c) to be $\delta \sim x$ and $U_c \sim x^{-1/2}$, with the maximum shear polymer stress varying as $\sigma_c^{[p]} \sim x^{-3}$.

References:
[1] T. Vaithianathan, A. Robert, J. G. Brasseur, L. R. Collins; An improved algorithm for simulating three-dimensional, viscoelastic turbulence. *J. Non-Newtonian Fluid Mech.*, **140**, 3–22 (2006).