

RELEVANT TERMS FOR LARGE-EDDY SIMULATIONS OF VISCOELASTIC ISOTROPIC TURBULENCE

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Abstract Direct numerical simulations of isotropic turbulence with polymer additives are used to analyse the relevant terms for large-eddy simulations (LES) of turbulent flows with polymer solutions, the rheology of which is described by the finitely extensible nonlinear elastic-Peterlin (FENE-P) model for polymers. Equations for the evolution of the kinetic energy and subgrid-scale kinetic energy are derived including the effects of polymer additives, where the grid and subgrid-scales of motion are defined through the application of a box filter. With this decomposition it is possible to isolate the effects of the (i) 'classical' energy cascade, (ii) grid/subgrid-scale interactions induced by the polymer, and (iii) the subgrid-scale/polymer interactions. The energy transfer between GS and SGS induced by the polymer is predominantly to the SGS, even if there are important contributions from inverse cascade, as in the classical (Newtonian) GS/SGS energy transfer. The results show that the energy transfer between GS/SGS and the energy transfer between the SGS/polymer are strongly correlated with the (Newtonian) viscous dissipation. The results suggest that SGS closures could be developed for viscoelastic turbulence based on a transport equation for the SGS kinetic energy.

INTRODUCTION

Turbulent flows with polymer additives present a number of interesting features which make them very attractive for industrial applications, *e.g.* dramatic drag reduction [1] but, presently the simulation of these flows is not an easy task. Given that the use of direct numerical simulations (DNS) remains unfeasible for industrial applications, the natural alternative would be to resort to large-eddy simulations (LES). However, LES of inertial turbulence with viscoelastic fluids raises formidable challenges: whereas classical subgrid-scale closures can make use of the concept of scale separation *i.e.* the grid-scale (GS) and subgrid-scales (SGS) are statistically independent, in turbulence with viscoelastic fluids the interplay between all the existing scales of motion is known to be much more involved [1], hampering the development of adequate subgrid-scale closures for LES of turbulence with viscoelastic fluids flows with polymer additives. In order to develop future subgrid-scale strategies for LES of viscoelastic turbulence, more insight is needed into the relationships between all the existing scales of motion and the complex fluid model and the polymer in these flows.

RESULTS

Here DNS of decaying isotropic turbulence with polymer solutions are used to analyse the interplay between the GS, SGS and polymer turbulence. The rheology of the polymer solutions is described by the finitely extensible nonlinear elastic-Peterlin (FENE-P) model. The simulations and their physical and computational parameters are similar to those in [2] involving four DNS, one for Newtonian fluid and three for viscoelastic solutions. In these viscoelastic simulations we used $\beta = 0.6, 0.7,$ and 0.8 , where β is the ratio between the zero shear rate viscosities of the solvent and of the solution. Equations for the evolution of the GS kinetic energy and subgrid-scale kinetic energy are derived by the application of a spatial filtering operation which separates the GS and SGS as used by [4]. We focus on three particular terms/effects: (i) classical kinetic energy transfer between GS and SGS, $Q = -2\tau_{ij}\overline{S_{ij}}$, (ii) GS/SGS interactions induced by the polymer stresses $U = \frac{2}{\rho}\overline{T_{ij}^{[P]}}\overline{S_{ij}}$ and, (iii) SGS/polymer interactions $T = -\frac{2}{\rho}\overline{T_{ij}^{[P]}}\overline{S_{ij}}$, where the overbar represents a filtering operation and τ_{ij} and $T_{ij}^{[P]}$ are the subgrid-scale stress tensor and the polymer stress tensor, respectively (see Fig. 1 a). In the GS and SGS kinetic energy transport equations there are four new terms, responsible for the interactions between GS and SGS induced by the polymer and between SGS and polymer. The two new terms, that do not exist in the classical (Newtonian) case in the GS kinetic energy transport equation, represent the diffusion and the transfer of energy between the GS and the SGS, caused by the polymer. Thus, in turbulence with viscoelastic solutions there are two different types of energy transfer associated with the energy cascade: the classical inviscid energy transfer Q (also found with Newtonian fluids) and the energy transfer induced by the presence of polymer additives U . Both are dominated by forward scatter (transfer down to small scales), but backward scatter is also present in both but more evidently in the classical energy transfer (see Fig. 1 b). Naturally, as the polymer solution case approaches the Newtonian fluid case, the importance of the induced viscoelastic energy transfer vanishes.

In the SGS dynamics, there are four new terms. Two of them are the symmetric of the terms present in the GS kinetic energy equation, because they represent the interactions between GS and SGS, and thus they have to appear in both

equations. The other two terms describe the interactions between the SGS and the polymer (diffusion and transfer - T). These terms were found to have the same relevance as the terms responsible for the energy transfer induced by the polymer, in the dynamics of the GS kinetic energy. The GS/SGS transfer induced by the polymer and the SGS/Polymer transfer have similar behaviours, and similarly the SG/SGS diffusion terms. Moreover, the term that quantifies the energy transfer between the SGS and the polymer is predominantly negative, i.e. the kinetic energy goes mainly from the SGS to the polymer and not in the opposite way. However, for small filter sizes and for higher values of β reverse energy transfer *i.e.* energy transfer from the polymer to the SGS becomes more important. It is interesting to observe that in contrast with the 'classical' energy transfer (newtonian turbulence) the correlation between the energy transfer between the GS and the SGS induced by the polymer and the viscous dissipation is quite high (see Fig. 1 c). The same occurs with the energy transfer between the SGS and the polymer suggesting that a large fraction of the energy transferred from the polymer to the SGS is locally dissipated by the (newtonian) viscous dissipation.

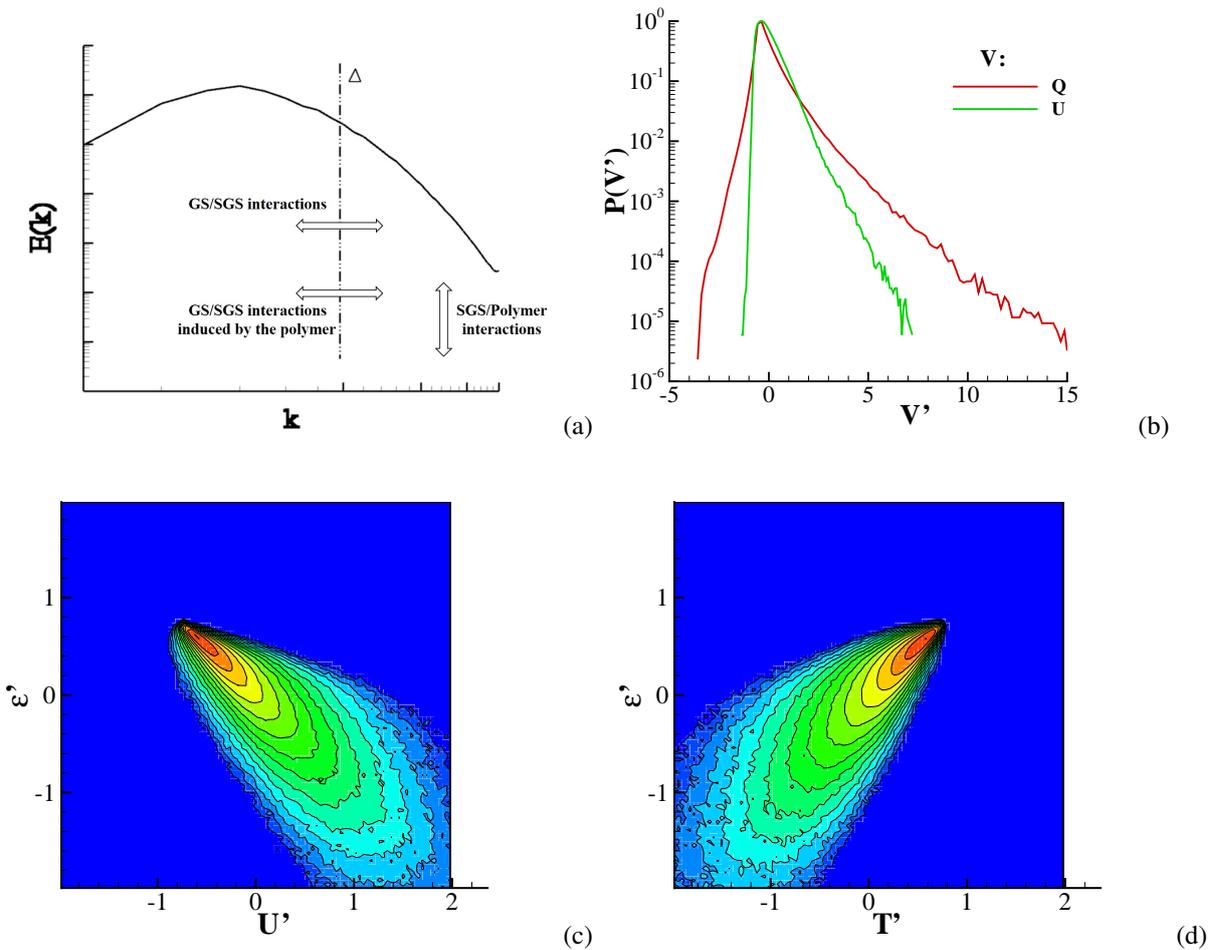


Figure 1. (a) Energy exchanges studied in the present work (i) GS/SGS interactions (ii) GS/SGS interactions induced by the polymer stresses and, (iii) SGS/polymer interactions; (b) Probability density function (PDF) for the GS/SGS energy transfer (Q) and GS/SGS energy transfer induced by the polymer (U); (c) Joint Probability density function (JPDF) between the GS/SGS energy transfer induced by the polymer (U and the viscous dissipation ε); (d) Joint Probability density function (JPDF) between the energy transfer between SGS and the polymer (T) and the viscous dissipation ε .

References

- [1] Thais, L., Tejada-Martínez, A. E., Gatski, T. B. and Mompean, G. Temporal large eddy simulations of turbulent viscoelastic drag reduction flows *Phys. Fluids.*, 22:013103, 2010.
- [2] W.-H. Cai, F.C. Li and H.-N. Zhang. DNS study of decaying homogeneous isotropic turbulence with polymer additives. *J. Fluid Mech.*, 665:334-356, 2010.
- [3] C. M. Casciola and E. De Angelis. Energy transfer in turbulent polymer solutions. *J. Fluid Mech.*, 581:419-436, 2007.
- [4] C. B. da Silva and O. Métais. On the influence of coherent structures upon interscale interactions in turbulent plane jets. *J. Fluid Mechanics*, 473:103-145, 2002.