DNS STUDY OF THE ELASTIC TURBULENCE IN A 3D PARALLEL PLATE CHANNEL

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Abstract In the present paper, the purely elastic turbulence was firstly generated in a 3D parallel plate channel by direct numerical simulations (DNSs). Then, the spectrums of both kinetic energy and elastic extension were investigated to show the effect of velocity gradient and wall on the characteristics of elastic turbulence. It is observed that the wall damps the decay of the spectrum of the fluctuating motions. Moreover, away from the wall the velocity gradient modifies the strength of spectrums at the largest scale for kinetic energy and all the scales for the elastic extension but has little effect on the decaying exponents of the spectrums.

INTRODUCTION

In viscoelastic fluid flows, there are two nonlinear effects, i.e., the nonlinear inertial and nonlinear elastic effects, which may or may not coexist. The additional elastic effect could make the flow exhibit a variety of different regimes depending on the Weissenberg number (Wi), as compared with Newtonian fluid flow. It has been verified that even at extremely low Reynolds number (Re), the flow could exhibit some turbulent features (the so-called 'elastic turbulence'), e.g. random fluid motions with a broad range of spatial and temporal scales, significant increase in the rates of momentum and mass transports solely due to the nonlinear elastic effect [1]. The excitation of this phenomenon could be used as an effective way for enhancing the fluids mixing or improving the efficiency of heat transfer in a low-Re flow systems, such as in microfluidic channels.

Despite its great fascination to the researchers, the elastic turbulence was still partially understood because the experimental techniques and measurements are limited nowadays. So far the comprehensive researches on elastic turbulence have been carried out mainly by experiments in flow systems with curvilinear passage geometry. However, in the rectilinear shear flow, there were no experimental observations due to the degradation of the elastic microstructures such as polymers except for several reports on transitional shear-banding flows of viscoelastic fluid in a micro-scaled rectilinear channel [2]. Similar to the nonlinear inertial effect, it is theoretically reasonable to generate elastic turbulence at sufficient Wi in the rectilinear shear flow, which has been verified numerically [3-5].

In this paper, following the previous study [5], we further conduct DNS study of elastic turbulence in a 3D parallel plate channel to enrich our understanding of elastic turbulence without curved passage geometry. During the simulations, Giesekus model was used to describe the viscoelastic fluids and a sinusoidal force was added to the momentum transport equations to generate and maintain the turbulent motion. Fig. 1 shows the schematic of the flow geometry and the function of the additional force. The detailed numerical procedures have been described in [5]. The effects of the wall and velocity gradient on the characteristics of spectrums of both kinetic energy and elastic extension are discussed to understand the energy cascade process in elastic turbulence.

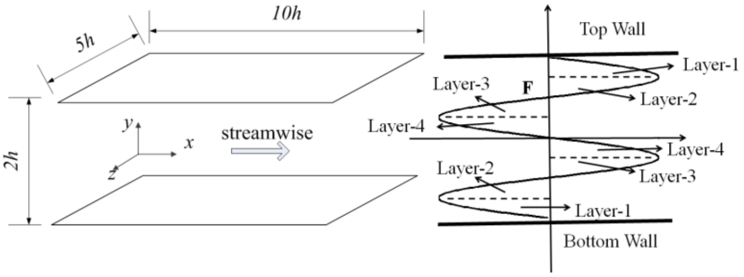

Figure 1. Schematic of the simulated flow geometry and form of the additional force F. To show the wall effect the flow was divided into 4 layers according to the form of the additional force.

RESULTS & DISCUSSIONS

Firstly, the temporal evolutions of the global instantaneous and turbulent kinetic energies were shown in Fig. 2. The fully-developed flow with the relative turbulent intensity increasing with Wi to 5.2% at Wi =30 was achieved. Besides, the fluctuations become stronger and the flow intermittency with larger-time-scale appears with the increase of Wi. This is attributed to the slow elastic-dissipation when the relaxation time of polymers increases.

The spectrums of turbulent kinetic energy E(k) and the polymer extension $E_p(k)$ at different locations were shown in Fig. 3. Away from the wall (starts from layer-2), E(k) exhibits a power law decay with the exponent of -3.8, and it is inconsistent with the exponents observed in the experiments with curvilinear geometry [1]. However, in the layer next to the wall, even with the stronger velocity gradient than that in the center layer E(k) shows a much faster decay. It indicated the elastic turbulence was locally suppressed by the wall. This is different from the role of the curvilinear wall in the experiments, which is regarded as the source of the generation of elastic turbulence and near the curvilinear wall the stronger turbulent intensity is generated. Therefore, it implies an effective way to induce the elastic turbulence in the real rectilinear shear flow by generating the strong shear in the center away from the wall. Besides, the local mean velocity gradient has little effect on E(k) in the layers away from the wall, except for the modification of the amplitude in the largest scale related with the local turbulent intensities. Moreover, $E_p(k)$ shows a power law distribution with the exponent of -2.8 in the regions where the flows behave turbulent state (in layer 2 to layer 4). The decaying exponent (-2.8) is equal to that of E(k) in the range where E(k) shows a power law decay. As compared with E(k), the local mean velocity gradient modifies $E_p(k)$ at all scales. In addition, it is also observed that the decaying range of $E_p(k)$ is much narrower than that of E(k), which may be related to the energy cascade process in the elastic turbulence. But it still needs further investigation.

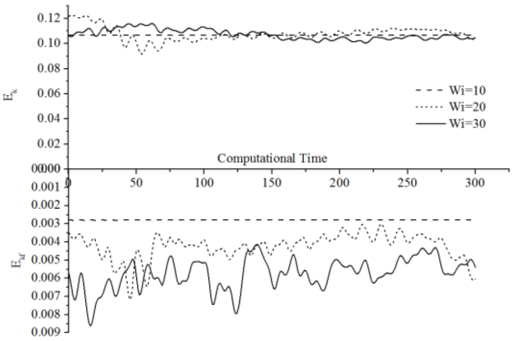

Figure 2. Temporal evolution of the global kinetic energy E_k, and turbulent kinetic energy E_{kf} at different Wi.

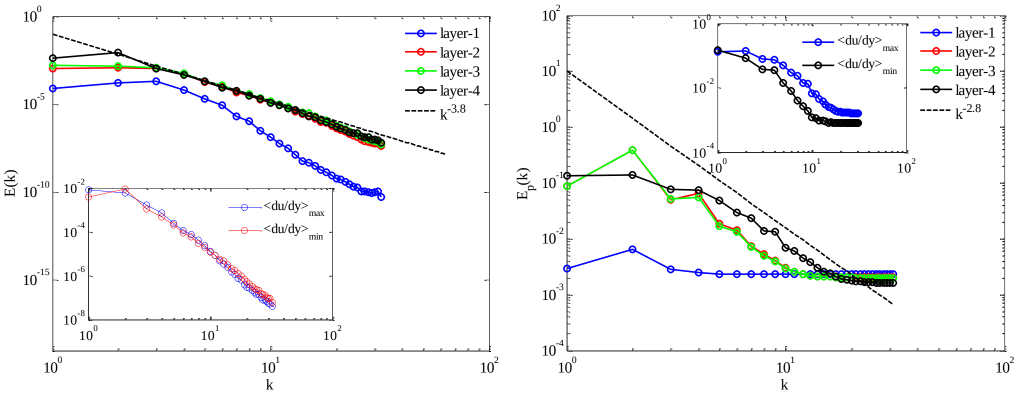

Figure 3 Spectrums of (a) velocity fluctuations and (b) polymers extension in four layers (as shown in figure. 1) with maximum local velocity gradient at Wi=30. The velocity gradient effects on the spectrum are shown inside the figures.

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