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On the evaluation of a root$^{\mathrm{k}}$-type transformation for the conformation tensor applied to turbulent channel flows of FENE-P fluids

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1 Introduction

Over the last 20 years, the direct numerical simulation (DNS) of viscoelastic fluids has been providing relevant information on the polymer-induced drag reduction phenomenon. The polymer contribution to the Newtonian solvent is usually taken into account by means of a dumbbell model. Most of such models make use of a conformation tensor to describe polymer orientation. This tensor is formed by the instantaneous orientation of polymer dumbbells, q_i, and has entries $c_{ij} = \langle q_i q_j \rangle$ (the angle brackets stand for an ensemble average). By definition, the conformation tensor is symmetric positive definite (SPD). Nevertheless, simulations of turbulent flows of viscoelastic fluids may breakdown by reason of the loss of the SPD property.

In this context, Sureshkumar and Beris [1] firstly overcame this issue by adding an artificial diffusion term into the evolution equation of the conformation tensor. However, even if this solution is largely used, it brings a non-physical term into the equation, which must be adjusted to be as small as possible. More recently, Dallas *et al.* [2] presented results for drag-reducing flows without any artificial assumption by adapting an eigendecomposition method [3] that preserves the finite extensibility of the polymer chain (if the model predicts so) and the SPD property of the conformation tensor.

Other remarkable methodologies are available in the literature, as, for instance, the log-conformation [4], the square-root [5] and the kernel [6] transformations. However, far as we know, except for an adaptation of the log-conformation applied to turbulent drag-reducing channel flow [8], these promising methods have only been applied to (very) low Reynolds number cases and high Weissenberg numbers in 2D or three-periodic cases, and, therefore, without drag reduction.

In the present work, we apply the square-root [5] and the root^k kernel [6] transformation to turbulent drag-reducing channel flows. Such results are compared with those obtained with the standard formulation by Thais *et al.* [7]. The need of maintaining (or not) an artificial stress diffusivity in order to preserve numerical stability is also assessed.

2 Methodology

The flow of a FENE-P fluid is solved by DNS for a channel of dimensions $L_x \times L_y \times L_z = 8\pi \times 2 \times 1.5\pi$ with a mesh $N_x \times N_y \times N_z = 512 \times 129 \times 128$. The friction Reynolds number, Re_τ, is equal to 180 and the friction Weissenberg number, Wi_τ, and the maximum extensibility of the polymer chain, L, were varied to give four different levels of elasticity.

The numerical method is the same of that presented by Thais *et al.* [7], but instead of using the standard evolution equation for the conformation tensor, we consider either the square-root [5] or the root^k kernel [6] transformation.

3 Results

Early attempts to simulate turbulent channel flows using the square-root and the root^k kernel (with $k = 2$) transformations resulted in unbounded values for the conformation tensor which led to numerical divergence. Thus, analogously to [1], we introduced an artificial stress diffusion into the evolution equation of the transformed conformation tensor.

Regarding computation time, when compared to the standard formulation, the square-root transformation showed to be just a bit slower ($\approx 12\%$), while the root^k kernel transformation can be more than 500% slower.

As shown in Fig. 1, the square-root transformation provides results which are underestimated with respect to the standard formulation (at $Re_\tau = 180$, $We_\tau = 50$, $L = 100$), even for higher Schmidt numbers ($Sc = \nu_0/\kappa$, where ν_0 is the solution kinematic viscosity at zero shear and κ is the stress diffusivity). It is worth noting that underestimations are also observed for other quantities (*e.g.* velocity profile, Reynolds stresses and drag reduction percentage).

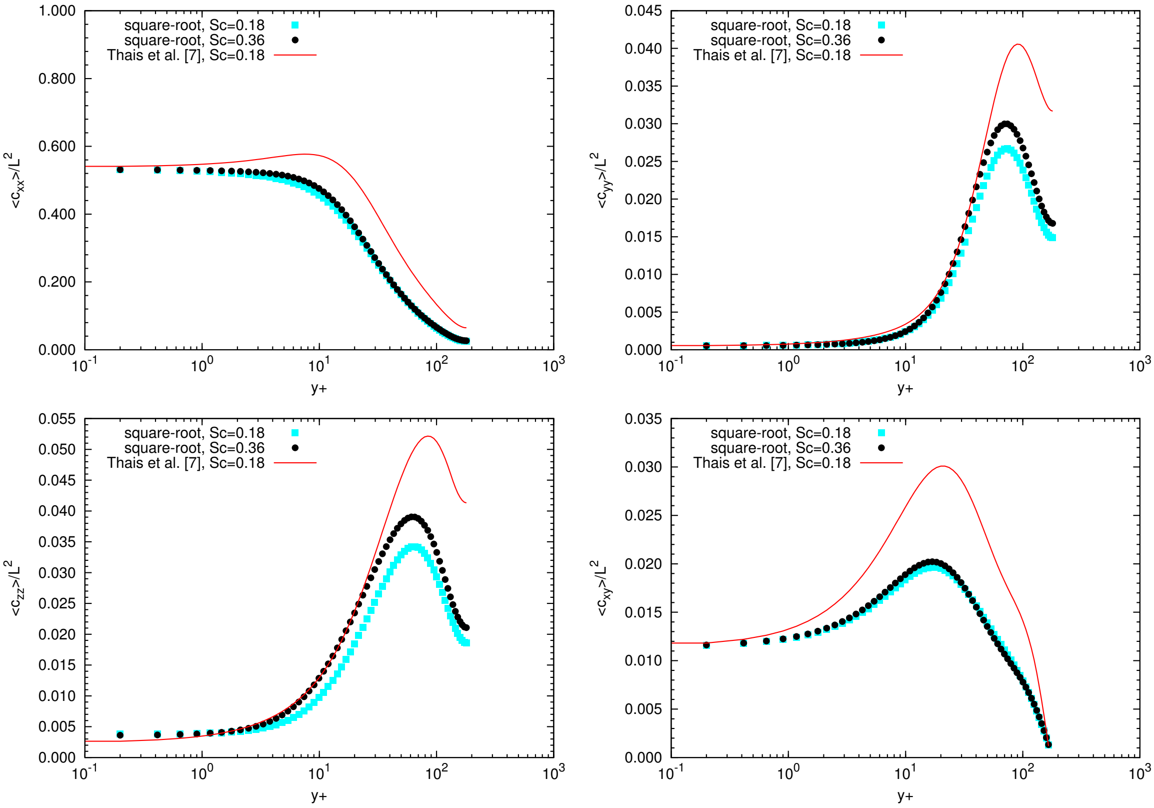

Figure 1: Normalized time-averaged non-null components of the conformation tensor.

We currently explore higher Schmidt numbers as well as other values of k $(= 2, 4, 8, 16)$ for the root^k kernel transformation in order to evaluate if these transformations can provide quantities that are closer to benchmark results.

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