DIRECT NUMERICAL ORIENTATION OF FIBER IN SHEAR FLOW FOR COMPLEX FLUIDS

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Introduction
The first works devoted to the evolution of elongated particles date from 1922. They are mainly due to Jeffery [5], which exhibits the evolution equation describing the orientation of ellipsoidal particle in a viscous fluid. The description an ellipsoid of revolution requires the knowledge of two parameters: a length L and an orientation vector, $\mathbf{p} = (\sin\theta\cos\phi, \sin\theta\sin\phi, \cos\theta)$. Jeffery has showed that the evolution of the orientation $\mathbf{p}$ depends on the flow and a geometric parameter describing the ellipsoid of revolution: the aspect ratio $\beta = L/D$, where D is the diameter of the larger section (perpendicular to $\mathbf{p}$) of the ellipsoid. For an aspect ratio β and a shear flow, $\mathbf{u} = (\dot{\gamma}y, 0, 0)$, an analytical solution is obtained for both angles. Moreover, the applied macroscopic shear rate $\dot{\gamma}$ can be directly related to the rotation period $T = 2\,\pi(\beta^2 + 1)/\beta\dot{\gamma}$. Then, the fibre follows an orbit around the $0z$ axis. The amplitude of this orbit depends on the initial position and the fibre has a "kayaking" like motion.
For viscoelastic fluids, there are many studies that show that this equation is no longer valid. Early works [6] have studied the effects of non-Newtonian ('second-order fluid') first contributions: the authors show that the fibre tends to align along the axis of vorticity. With this model, this effect is connected to the second normal stress difference. However another theoretical study on Oldroyd-B fluid [2] exhibits the same behaviour but related in to the first normal stress difference. This behavior is observed experimentally for low elasticity and low fiber concentration [4]. Moreover for larger elasticity or shear rate, the observed behaviour can be more complex [1,3,7]. More recently, the reference [8] shows that for spherical particle ($\beta = 1$) the period of rotation T increases as the elasticity increases (the elasticity can be connected to a Weissenberg number defined as the ratio between the first difference of normal stress and shear stress).

Numerical results
In this work, direct numerical simulations [9–11] are used to study the motion of an ellipsoidal particle in a shear flow. In this study, the constitutive law of Oldroyd-B is used to describe the behaviour of viscoelastic fluid. This model can be written such as the stress tensor has this form:

$$\sigma = -p\mathbf{I} + 2\eta_s\dot{\epsilon} + \frac{\eta_p}{\lambda}(3\mathbf{s} - \mathbf{I}) \tag{1}$$

where η_p and λ are respectively the viscosity and relaxation time of the polymeric part. The conformation tensor $\mathbf{s}$ satisfies the relation

$$\frac{\partial\mathbf{s}}{\partial t} + \mathbf{u}\cdot\nabla\mathbf{s} - \left[\nabla\mathbf{u}\cdot\mathbf{s} + \mathbf{s}\cdot\nabla\mathbf{u}^T\right] + \frac{1}{\lambda}(3\mathbf{s} - \mathbf{I}) = 0 \tag{2}$$

A cubic domain is chosen with an ellipsoidal particle in its center. As there is only one particle, the center of mass of the particle is fixed and its orientation is changed due to the flow motion

and extra-stress. A shear flow is imposed fixing the rate on the upper and lower walls the cube and Couette is imposed on the vertical walls. The calculations are made for $\dot{\gamma} = 1$ and the particle size is $L = 0.3$, $R = 0.05$ ($\beta = 3$). The initial position is $\theta_0 = 30^o$ and $\phi_0 = 45^o$. The Olroydd-B fluid has the following characteristics: $\eta_s = 0.1$; $\eta_s = 0.9$; $\lambda = 0.1, 0.5$ and 1.
Numerical computations show that for small and moderate values of relaxation time, the particle moves towards the axis of vorticity. Same kind of results are found for shear thinning fluids. That confirm some experimental and theoretical results. The duration of this transition depends on the relaxation time as shown in figure 1. At the end of this transitory particle mainly rotates about its axis of revolution.

Figure 1: *Orbits of extremity of orientation vector* **p** *for* $\lambda = .1$ *and 1. The black orbit corresponds to the Newtonian case.*

References

[1] D.Z. Gunes, R. Scirocco, J. Mewis, J. Vermant,Flow–induced orientation of non–spherical particles: Effect of aspect ratio and medium rheology, *J.Non-Newtonian Fluid Mechanics*, 155(1–2): 39–50, 2008

[2] O.G. Harlen, D.L. Koch,Simple shear flow of a suspension of fibres in a dilute polymer solution at high Deborah number, *J. Fluid Mechanics*, 252:187–207: 1993,

[3] Y. Iso, C. Cohen, D.L. Koch,Orientation in simple shear flow of semi-dilute fiber suspensions 2. highly elastic fluids, *J. Non-Newtonian Fluid Mechanics*, 62(2–3): 135–153, 1996

[4] Y. Iso, D.L. Koch, C. Cohen,Orientation in simple shear flow of semi-dilute fiber suspensions 1. weakly elastic fluids, *J. Non-Newtonian Fluid Mechanics*, 62(2–3): 115–134, 1996

[5] G.B. Jeffery,The motion of ellipsoidal particles immersed in viscous fluid, *Proc. R. Soc. London*, A 102: 161–179, 1922

[6] L.G. Leal,The slow motion of slender rod-like particles in a second-order fluid, *J. Fluid Mechanics*, 69: 305–337, 1975

[7] M.P. Petrich, M. Chaouche, D.L. Koch, C. Cohen,Oscillatory shear alignment of a non-brownian fiber in a weakly elastic fluid, *J. Non-Newtonian Fluid Mechanics*, ,: 9, 1 (1):1 – 14, 2000.

[8] F. Snijkers, G. D'Avino, P.L. Maffettone, F. Greco, M.A. Hulsen, J. Vermant,Effect of viscoelasticity on the rotation of a sphere in shear flow, *J. Non-Newtonian Fluid Mechanics*, 166(7–8): 363–372, 2011

[9] R. Glowinski, T.W. Pan, J. Periaux,A fictitious domain method for Dirichlet problem and applications, *Comp. Meth. Appl. Mech. Eng.*, 111: 283–303, 1994

[10] P. Laure, G. Beaume, O. Basset, L. Silva, T. Coupez,Numerical methods for solid particles in particulate flow simulations, *Eur. J. Computational Mechanics*, 16: 365–383, 2007

[11] L. Silva, R. Valette, P. Laure, T. Coupez,A New Three-Dimensional Mixed Finite Element for Direct Numerical Simulation of Compressible Viscoelastic Flows with Moving Free Surfaces, *Int. J. Material Forming*, 5(1): 55–72, 2012