Recent progress on the LS-STAG Immersed Boundary Method for the computation of viscoelastic and non-Newtonian flows

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Abstract: This communication presents a progress report on viscoelastic and non-Newtonian flow computations performed with a well established Immersed Boundary method, the LS-STAG method (Cheny & Botella, Journal of Computational Physics 2010). One of the distinguished features of our method is to use level-set (LS) techniques in the cut-cells near the IB boundary, where accurate discretization is of paramount importance for stability and accuracy of the computations. For this purpose, we have achieved an unified framework for the computation of the Navier-Stokes equations, viscoelastic constitutive law and non-Newtonian viscosity on the LS-STAG mesh. Several benchmark computations will show the efficiency of the method.

Keywords: Immersed boundary method, Incompressible flows, non-Newtonian and Viscoelastic fluids.

Problem Statement

This communication presents a progress report on an ongoing project aiming at the computation of complex fluid flows with a realistic constitutive law, which would take into account the pseudoplastic, viscoelastic and thixotropic behavior of the materials. The flow solver is based on the LS-STAG method, which is an immersed boundary (IB) method that allows the computation of flows in complex geometries on simple Cartesian meshes, reducing thus the bookkeeping of body-fitted methods. One of the distinguished features of our method is to use level-set (LS) techniques for computing efficiently the governing equations in the cut-cells near the IB boundary. The LS-STAG method has been validated in [2] for canonical Newtonian flows in both fixed and moving geometries.

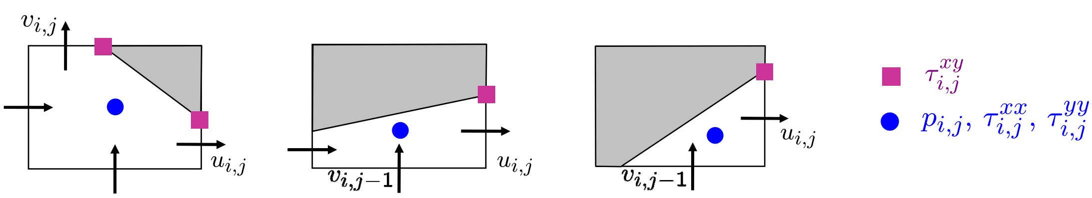

Figure 1: Location of the normal and shear stresses in the 3 generic cut-cells.

In a recent work [1] we have applied the LS-STAG method to viscoelastic flows, for which accurate discretization of the viscous stresses up to the cut-cells is of paramount importance for stability and accuracy. For this purpose, the LS-STAG discretization of the Newtonian stresses has been extended to the transport equation of the elastic stresses (Oldroyd-B constitutive equation), such that the node-to-node oscillations of the stress variables are prevented by using a velocity-pressure-stress staggered arrangement (see Fig. 1).

The next step is to incorporate the pseudoplastic behavior in the numerical model. The crucial part for taking into account shear-thinning effects is the computation of the shear rate in the vicinity of the immersed boundary. We have been able to achieved an accurate discretization that fits elegantly with the staggered arrangement of Fig. 1 and the special quadratures developed previously for the viscoelastic constitutive law. The method will be validated on the flow of power-law fluids past a rotating cylinder (see Fig. 2), for which benchmark results obtained with a commercial CFD code are available [3]. Finally, we will compare the results of the LS-STAG code against the recent PIV measurements of the wide-gap non-coaxial Couette flow of xanthan solutions at various concentrations performed at LEMTA.

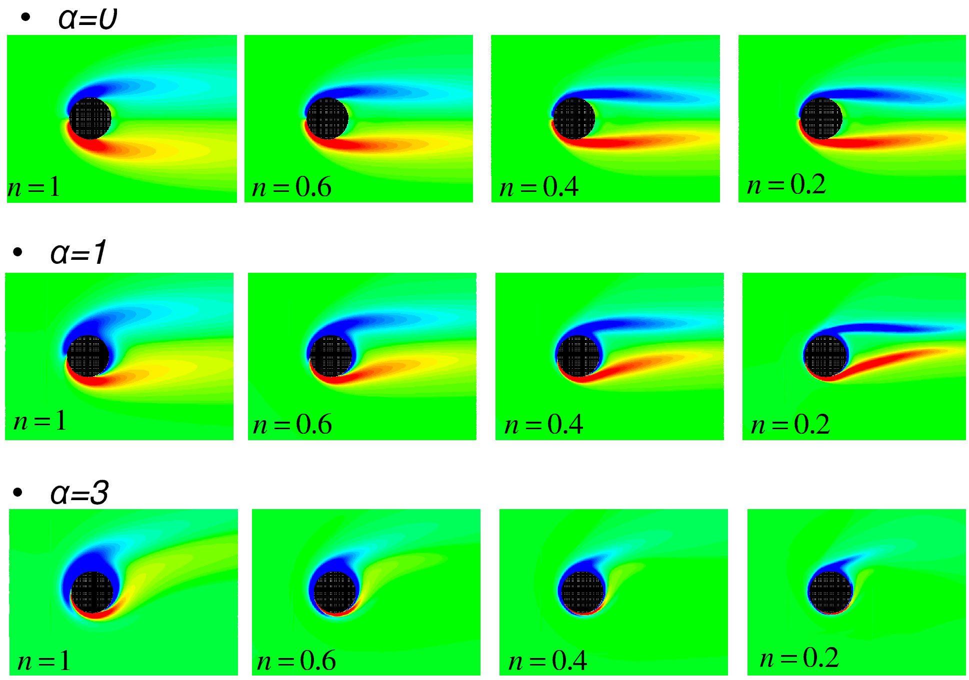

Figure 2: Vorticity at Re = 40 for various values of α (rotational velocity of the cylinder) and n (power-law index for shear-thinning fluid with viscosity $\eta(\dot\gamma) = k\dot\gamma^{n-1}$) .

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