CONFINED SUSPENSIONS OF RIGID FIBRES: COMPLEX FLOW KINEMATICS AND RHEOLOGY

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Introduction

The motion of a rigid fibre immersed in a flow of a Newtonian fluid was obtained in the pioneering work of Jeffery in 1922 [1]. Most descriptions of fibre suspensions are based on this model and some phenomenological adaptations of it. We refer to the review by Petrie [2] and the reference therein for an overview of the rheology of fibre suspensions.

All these studies concerned unconfined flows, despite the fact that processes of industrial interest often involve narrow gaps where wall effects play an important role. In our work [3,4], we extend Jeffery's model to confined flows occurring when the thickness of the flow domain is narrower than the rod length.

Modelling confined suspensions of rods

The model is built upon the classical dumbbell model to represent the rod [5], enriched with an extra bead located at its centre of gravity (Fig. 1). By considering the forces (hydrodynamic and contact) that act on the beads, we obtain the rod kinematics. We only present here the final expression obtained using our modelling framework. The derivation of the rod kinematics is detailed in [3] and is generalized in [4].

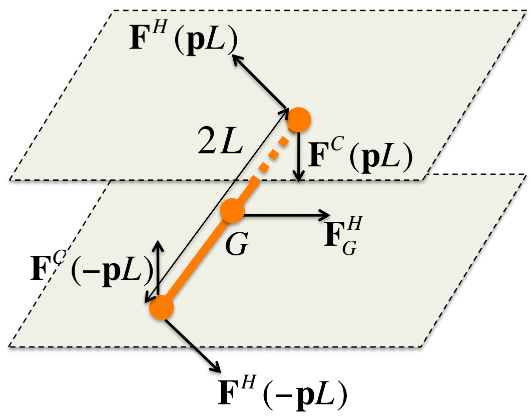

Figure 1: *A suspended confined fibre is modelled as a rigid dumbbell on which act hydrodynamic ($\boldsymbol{F}^H$) and contact ($\boldsymbol{F}^C$) forces.*

The main modelling ingredients required to address scenarios encountered in composite forming processes concern: (i) consideration of the rod interactions with one or both gap walls and their effects on the rod orientation kinematics; (ii) consideration of non-uniform strain rates at the scale of the rod, requiring higher-order descriptions.

When the rod is not interacting with the surrounding walls, the kinematics given by the classical Jeffery model [1] (for ellipsoids with infinite aspect ratio) is recovered:

$$\dot{\boldsymbol{p}} = \dot{\boldsymbol{p}}^J = \boldsymbol{\nabla v} \cdot \boldsymbol{p} - \left(\boldsymbol{\nabla v} : (\boldsymbol{p} \otimes \boldsymbol{p})\right) \boldsymbol{p}. \tag{1}$$

In this expression, the rod orientation is specified by the unit vector $\boldsymbol{p}$ located at the rod centre of gravity and aligned with its axis and $\boldsymbol{\nabla v}$ is the gradient of the unperturbed velocity field.

When the rod is interacting with one or both gap walls, the confined kinematics then read

$$\dot{\boldsymbol{p}} = \dot{\boldsymbol{p}}^J + \dot{\boldsymbol{p}}^C, \tag{2}$$

and simply consists in Jeffery kinematics plus a correction term that prevents the rod from leaving the flow domain.

Simulation in squeeze flow

Figure 2 depicts the evolution of the position and orientation of a short fibre immersed in a squeeze flow (constant squeezing velocity) and interacting with the upper gap wall. The fibre is represented by the blue line, and the red curve shows the trajectory of its centre of gravity.

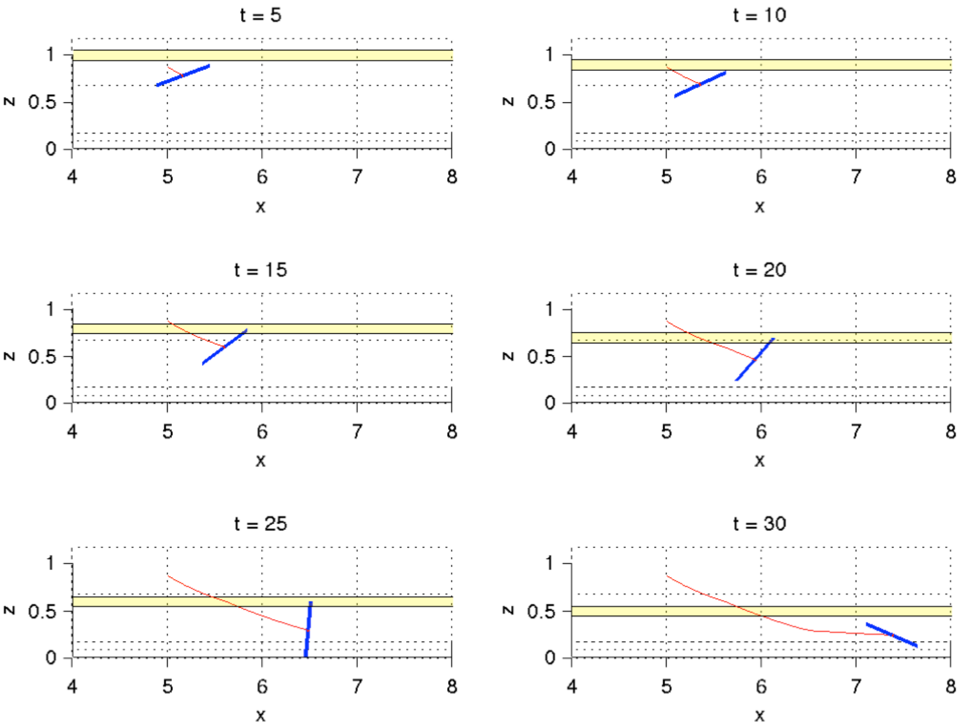

Figure 2: *Evolution of the position and orientation of a short fibre immersed in a squeeze flow and interacting with the upper gap wall.*

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