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Dynamics of flexible fibers in shear flows

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Dynamics of a flexible non-Brownian fiber in a simple shear flow at the low-Reynolds-number is analyzed numerically for a wide range of the ratios A of the fiber bending force to the hydrodynamic force. (Definition of the parameter A can be found in Slowicka,Wajnryb & Ekiel-Jezewska (2013).)

A fiber is modeled as a chain of solid beads as in Gauger & Stark (2006). The centers of the consecutive beads are linked by springs with the equilibrium length so small that the consecutive beads almost touch each other. The spring constant is so large that the fiber's length practically does not change. At the equilibrium, the fiber is straight. At a deformed configuration, there appear a bending force exerted on each bead, proportional to the bending parameter A.

Time-dependent velocities of the beads are evaluated with the use of the Hydromultipole numerical code, based on solving the Stokes equations by the multipole expansion, see Cichocki, Ekiel-Jezewska & Wajnryb (1999). The time-dependent positions of the beads are determined by the adaptive fourth order Runge-Kutta method.

Initially, the fiber is aligned with the flow, and the springs are at the equilibrium. Owing to symmetry, the centers of all the beads move in the plane perpendicular to the vorticity direction. The fiber end-to-end vector tumbles, in a similar way as a rigid elongated body, see Jeffery (1922). While the fiber turns, its shape evolves accordingly, and the center-of-mass oscillates across the flow.

A surprisingly rich spectrum of different modes is observed when the value of A is systematically changed, with bifurcations, period doubling and transition to chaos (For the details, see Slowicka,Wajnryb & Ekiel-Jezewska (2015).)

For a range of very small and a range of large values of A, the center-of-mass trajectories are periodic with a single tumbling time τ, and there is no migration across the flow. For small values of A, the center-of-mass trajectories are regular, but consecutive tumbling times differ from each other, what leads to migration. For moderate values of A, a chaotic behavior is observed - a large sensitivity to a small change of A with (typically) many irregular values of τ or (exceptionally) a regular migration.

At a moderate value of A, a transition is observed between the straightening out mode of more stiff fibers to the coiled mode of more flexible fibers. In the straightening out mode, the fiber significantly changes its shape while tumbling - from almost straight and aligned with the flow to S-shaped. In the coiled mode, the fiber is always compact, it never straightens out.

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