Dynamics of highly elastic fibers in a shear flow

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Elongated, elastic micro-objects moving in fluids can be found in many fluid environments: cilia or flagella of micro-organisms such as bacteria or algae, microtubules or actin in cells of living organisms, flexible fibers produced by modern technologies for various applications, e.g., waste-water treatment, drug delivery, wound healing or tissue engineering. Usually, the fluid velocity is non-uniform, which causes shape deformation and rotation of such filaments. Therefore, an important problem in fluid dynamics is to predict and control the shapes and orientations of elastic fibers in a fluid shear flow.

It is known that moderately elastic fibers in shear flow periodically bend and then straighten along the flow[1]. Our work demonstrates experimentally and numerically that the dynamics of highly flexible filaments are entirely different: they escape the shear stresses and, after a relatively long time, often form more or less regular, elongated double helices, oriented almost perpendicular to the flow, and almost parallel to the vorticity direction (see figure 1). Previously, in shear flows very compact, often tangled clumps of highly elastic fibers were reported at short times[2]. In contrast, we found in the experiments and simulations that a double helix is formed by a highly flexible fiber after a very long time, much longer than the timescales typical for the buckling instability[3]. The double helices preserve their shape for extended periods, with only very small deformations, spinning and performing effective Jeffery's orbits. Such a bending pattern has not been reported so far.

In experiments, we use the fiber fabrication method described in Ref.[4] In the simulations, we apply the bead model with the harmonic stretching and bending forces, and the multipole expansion of the Stokes equations, corrected for lubrication, to account for the hydrodynamic interactions within the HYDROMULTIPOLE programs of a controlled accuracy[5].

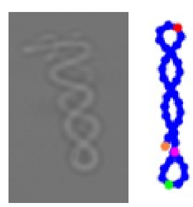

Figure 1: In our experiments and simulations, highly elastic micro-filaments in a shear flow after a relatively long time often form spinning elongated double helices, gyrating around, and close to, the vorticity direction.

Our findings are essential from the fundamental point of view, and also for designing new applications because elastic micro-fibers in a shear flow are common in nature and technology. Recognition of these oriented shapes, and how they form in time, may prove useful in the future for understanding the time history of complex microstructures in fluid flows and considering processing steps for their synthesis.

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[4]Nunes et al., *Lab Chip* **12** (2012).
[5]Cichocki et al., *J. Chem. Phys.* **111** (1999).