Numerical studies of a highly elastic fibre settling under gravity in a very viscous fluid

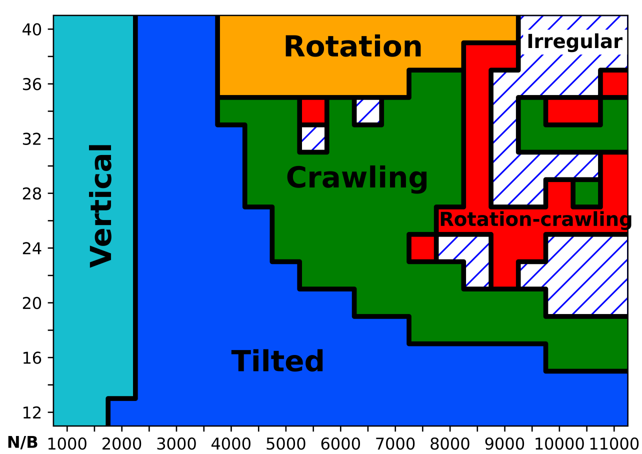
Yevgen Melikhov* and Maria L. Ekiel-Jeżewska†

Sedimentation of elastic objects of different shapes in viscous fluids remains an active research topic because of the importance of such phenomena in numerous biological systems and technological processes. Even the sedimentation of basic objects, such as fibres or loops, can display rich dynamics if structural flexibility is allowed. For instance, the sedimentation mode changes from a stationary, planar, U-shaped configuration oriented vertically for moderately flexible fibres to a mode in which the U-shaped configuration is no longer stationary for highly flexible fibres[1,2,3].

This study presents a numerical investigation of the sedimentation of a highly elastic fibre under gravity in a viscous fluid. The fibre is modelled as a chain of N identical spherical beads of the same diameter. There are stretching and bending forces within pairs and triplets of consecutive beads. A dimensionless elasto-gravitation number B, which relates the gravitation and bending forces acting on the fibre, and the fibre aspect ratio N are used to describe the fibre's flexibility. The mobility matrix, which accounts for hydrodynamic interactions between all beads, is calculated from the multipole expansion of the Stokes equations by the precise numerical codes HYDROMULTIPOLE, for all the time-dependent fibre configurations. The fibre evolution is monitored over an extended period to identify the attracting modes by systematically varying B and N in a wide range.

The phase diagram of different attracting modes, and the top view (i.e., the projection perpendicular to gravity) of their centre-of-mass trajectories, are shown in Figure 1. In addition to one planar (vertical) and two non-planar (tilted and rotation) stationary configurations, we discovered two new families of the dynamical modes with periodic deformations of the fibre's shape: one translating (crawling) and one rotating (rotation-crawling)[4]. A brief analysis of the characteristic features, such as characteristic time scales and fibre deformation patterns, of all these sedimentation modes is presented. Our results demonstrate that the dynamics of highly elastic fibres are sensitive not only to the elasto-gravitation number B but also to the fibre's aspect ratio N.

We acknowledge the support from the National Science Centre under grant UMO-2021/41/B/ST8/04474.



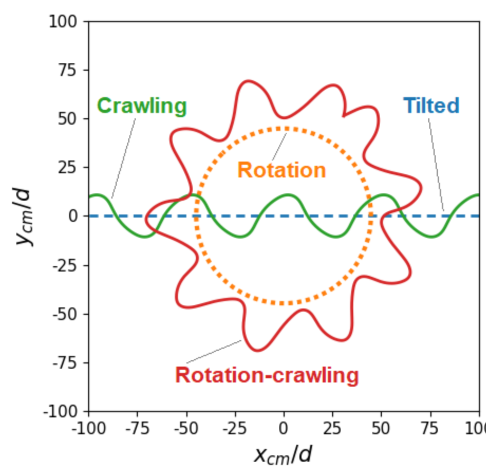


Figure 1: (*left*) Attracting dynamical modes achieved by an elastic fibre with aspect ratio N and elasto-gravitation number B, and (*right*) top view of their centre-of-mass trajectories.

* *Yevgen.Melikhov@ippt.pan.pl*, Institute of Fundamental Technological Research PAS, ul. Pawińskiego 5B, 02-106 Warsaw, Poland
† Institute of Fundamental Technological Research PAS, ul. Pawińskiego 5B, 02-106 Warsaw, Poland

[1] Cosentino Lagomarsino, Pagonabarraga et al., *Physical Review Letters* **94** (2005)
[2] Saggiorato, Elgeti et al., *Soft Matter* **11** (2015)
[3] Shashank, Melikhov et al., *Soft Matter* **19** (2023)
[4] Melikhov and Ekiel-Jeżewska, *Journal of Fluid Mechanics*, submitted for publication (2024)