Arbitrarily shaped particles in shear flow

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Abstract: Particle motion in shear flow plays an important role in many industrial as well as biomedical applications. In order to study the motion of differently shaped particles within a shear flow, the incompressible Navier–Stokes and the rigid-body-dynamics equations are solved coupled together by means of an implicit iterative approach. An immersed boundary method is used to take into account the presence of moving particles within the fluid domain, without having to regenerate or deform the computational grid. The method has been validated at first by computing flows past a fixed and an oscillating circular cylinder at various values of the Reynolds number (Re). Then, the motion of three differently shaped particles immersed within a low-Re Couette and planar Poiseuille flow has been studied to ascertain their lateral migration and orientation behavior. Finally, numerical solutions are presented to understand the influence of increasing Re upon the lateral migration and orientation behavior of the elliptic particle immersed in a Couette flow.

Keywords: Immersed Boundary Method, Fluid-Structure Interaction, Sedimentation, Margination.

The transport of arbitrarily shaped particles is of great importance in several biomedical applications: particles of various shapes, e. g., spheres, disks and rods [1] have been developed for controlling and improving the systemic administration of therapeutic and contrast agents. Once administered, the particles are transported by the blood along the circulatory system until they reach their targets, their shape playing a crucial role in the phenomenon. Understanding how the shape of the particles influences their lateral migration and orientation within pressure driven flows could help enhancing the design of more effective drugs.

The aim of this work is to develop a numerical tool able to resolve the flow field around arbitrarily shaped particles and to predict their motion when transported by a shear flow, with particular emphasis on the near wall dynamics. In order to achieve such a goal, the immersed boundary (IB) method of [2] is employed, more suitable than unstructured body fitted methods, since the governing equations are solved on a fixed structured grid, insofar as it avoids the time-consuming regeneration or deformation of the grid and the successive interpolation of the flow field. Here, such an approach is used combined with a second-order-accurate finite-difference fluid solver [3] and a fully coupled fluid-structure-interaction (FSI) algorithm to deal with the particle dynamics. The solver adopts Cartesian non uniform grids, while the immersed boundaries are described by a triangulation of their surface, independently of the underlying fluid mesh.

Firstly, the method has been validated by means of several test cases of increasing complexity: steady and unsteady flows past a fixed circular cylinder at various values of the Reynolds

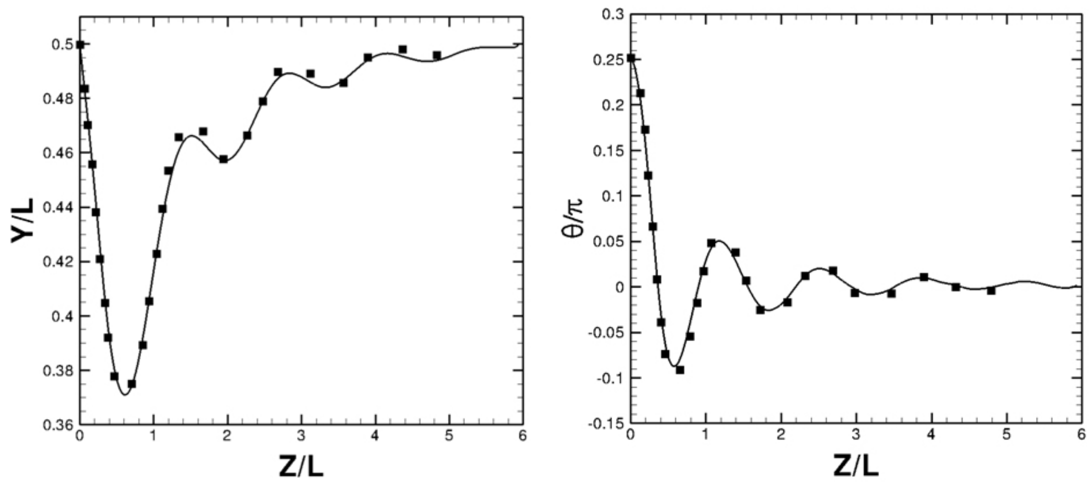

Figure 1: Crosswise (left) and angular (right) position of an elliptic particle falling into a fluid. The lines and squares indicate the present results, and the numerical results of [4], respectively.

number (Re); flow past a transversely oscillating circular cylinder; flow past an elliptic particle sedimenting in a channel; flow past a a sphere falling under gravity in a fluid-filled box. A good agreement has been obtained in all cases with both experimental and numerical results available in the literature, also when bodies move and the FSI model is involved. Figure 1 shows the present results for an elliptic particle falling into an incompressible fluid, compared with numerical results of [4].

Then, the method is used to simulate the transport of single differently shaped particles within unidirectional (in the absence of particles) flows, namely, Couette and plane Poiseuille flows. Only single and two-dimensional particles are considered, for the time being, in order to evaluate the influence of their shape on their lateral migration, and for simplicity.

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