INERTIAL FLOW OF IMMERSED ELASTIC CAPSULES THROUGH A CORNER

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ABSTRACT

The study of immersed elastic membranes enclosing an inner fluid, or capsules, has seen tremendous interest in the past two decades owing to the fact that capsules are a good model to describe a wide range of flowing biological cells, including red blood cells (RBCs), leukocytes and circulating tumor cells (CTCs). The ability to accurately model and numerically simulate flowing capsules can help develop microfluidic “lab-on-chip” devices, used to perform a variety of tasks such as cell segregation and cell characterization based on size, membrane deformability and inner fluid properties[1]. In particular, the inertial-based migration technique has been recently developed and offers the potential to achieve non-destructive blood plasma extraction and enhanced size-based cell segregation[2]. Such microfluidic devices usually include long spiral channels of micrometric widths, as well as several other layers of channels connected together by sharp turns.

Motivated by such devices, we propose to study the deformation of capsules in a model square channel presenting a 90 degrees angle. To this end, we use our open-source adaptive front tracking solver based on the Basilisk software[3]. In this solver, the solid boundaries are represented using the conservative, sharp embedded boundaries method, and the capsule stresses are resolved using a linear finite element method and a paraboloid fitting technique. The flow is controlled by the channel Reynolds number Re and the Capillary number Ca:

$$Re = \frac{\rho U W}{\mu}, \qquad Ca = \frac{\mu U}{E_s},$$

where ρ is the fluid density, U is the average fluid velocity, W is the channel width, μ is the fluid viscosity and E_s is the elastic modulus of the capsule. We show validation results in the non-inertial regime and compare them to those obtained by Zhu & Brandt[4]. As the Reynolds and Capillary numbers vary, we measure the capsule velocity, its area dilatation (a proxy for the capsule potential elastic energy), as well as the general structure of the surrounding flow field. A collection of snapshots is shown in figure 1 for two Capillary and Reynolds numbers. In addition to studying the inertial flow of a solitary capsule, we also introduce a secondary capsule and study its effect on the flow field and the capsule properties as a function of its initial distance from the leading capsule.

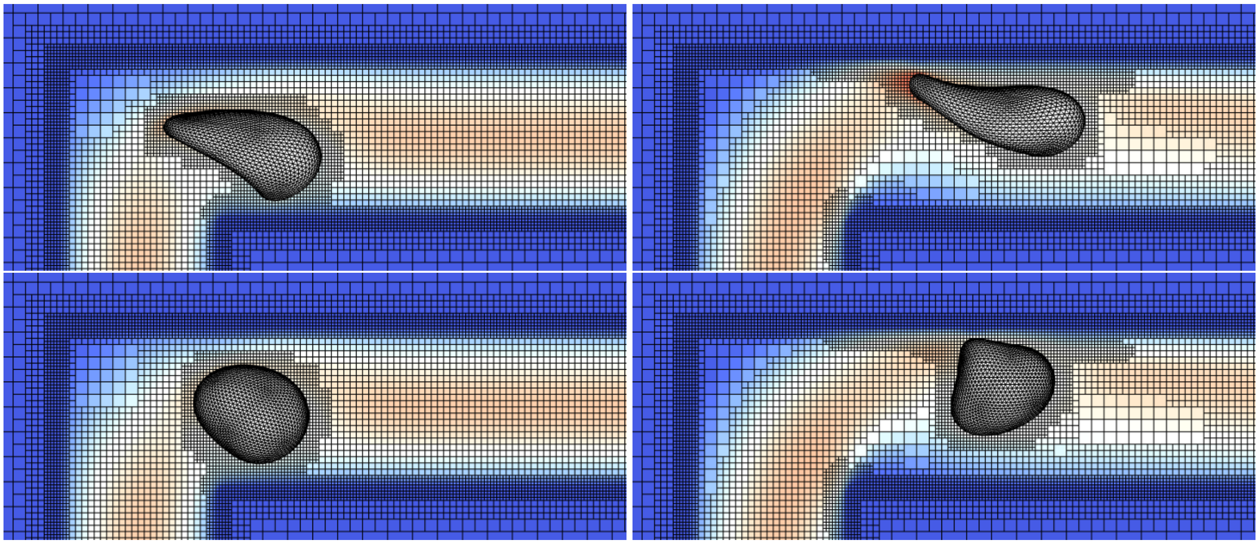

Figure 1: Visualization of the capsule and its surrounding flow field at $Ca = 0.12$ (top) and $Ca = 0.025$ (bottom); as well as $Re = 0.01$ (left) and $Re = 50$ (right). The capsule inlet is located 10 capsule diameters below the corner, and the outlet is located 10 capsule diameters to the right of the corner. The color field represents the norm of the velocity (dark blue is zero and red is max).

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