A fluid-structure solver for confined microcapsule flows

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ABSTRACT

We present a fluid-structure solver designed for microcapsules flowing in confined geometries. The aim of our work is to understand the motion of deformable microvectors in microfluidic chips for drug delivery applications. In the present study, we simulate a capsule of radius a flowing under an average inlet velocity U in a square cross-section channel of half-width l. Its motion and deformation are governed by the following dimensionless numbers: the aspect ratio $\frac{a}{l}$, the Reynolds number $\mathrm{Re} = \frac{\rho U l}{\mu}$ and the viscoelastic capillary number $\mathrm{Ca} = \frac{\mu U}{G_s}$, where ρ and μ are the density and viscosity of the suspending fluid, and G_s is the surface shear modulus of the capsule membrane.

The fluid-structure solver is based on two independent existing fluid and solid solvers. The solid solver is a part of Caps3D [1]. It solves for the capsule membrane equilibrium using a membrane Finite Element solver over a Lagrangian grid. The fluid solver is Basilisk [2], a Finite Volume open source solver that solves the Navier-Stokes equations over an Eulerian grid. The two solvers are connected using an Immersed Boundary Method [3]. At each time step: 1) Caps3D uses the position of the Lagrangian capsule nodes to compute the membrane surface elastic forces, which are then converted to volume forces by the Immersed Boundary Method; 2) Basilisk uses the volume forces as the source term for the fluid resolution. A new fluid velocity field is obtained and used to update the position of the capsule nodes.

The fluid-structure solver has been validated by verifying its convergence to the Stokes flow solution for low Re, which is an interesting non-trivial validation test. The steady-state capsule shape and velocity have been determined for aspect ratios a/l between 0.8 and 1.2 and compared to existing numerical results. A good consistency has been found. For long time simulations, we find that the volume variation of the capsule is less than 0.1%, which is much lower than values found by recent studies (e.g. [4]). The novelty is that the fluid-structure code can resolve the flow of capsules of aspect ratios greater than 1 and non-zero Reynolds numbers, which are required to study capsules in microsystems.

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