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Application of a Lattice Boltzmann-Immersed Boundary Method for Fluid-Filament Dynamics and Flow Sensing

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Abstract

Complex fluid-structure interactions between elastic filaments, or cilia, immersed in viscous flows are commonplace in nature and bear important roles. Some biological systems have evolved to interpret flow-induced motion into signals for the purpose of feedback response. Given the challenges associated with extracting meaningful experimental data at this scale, there has been particular focus on the numerical study of these effects. Porous models have proven useful where cilia arrangements are relatively dense, but for more sparse configurations the dynamic interactions of individual structures play a greater role and direct modelling becomes increasingly necessary. The present study reports efforts towards explicit modelling of regularly spaced wall-mounted cilia using a lattice Boltzmann-immersed boundary method. Both steady and forced unsteady 2D channel flows at different Reynolds numbers are investigated, with and without the presence of a periodic array of elastic inextensible filaments. It is demonstrated that structure response depends significantly on Reynolds number. For low Reynolds flow, the recirculation vortex aft of successive filaments is small relative to the cilia spacing and does not fully bridge the gap; in which case the structure lags the flow. At higher Reynolds number when this gap is fully bridged the structure and flow move in phase. The trapping of vortices between cilia is associated with relatively lower wall shear stress. At low to intermediate Reynolds, vortex bridging is incomplete and large deflection is still possible, which is reflected in the tip dynamics and wall shear stress profiles.

Keywords: Lattice Boltzmann, Immersed boundary, Cilia, Fluid-structure interaction, Flow sensing

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