Abstract

Low Reynolds number (*Re*) aerodynamics is relevant in several biological and industrial applications, including insect flights, bio-inspired robots, micro-turbines, polymer mixing, etc. Flow over aerodynamic bodies in this *Re* regime (*Re* = 1000 - 10000) may be characterised by boundary layer separation, instabilities, and vortex departure phenomena. Transition to turbulence is observed in many of these cases, which may drastically change the force and power output. Furthermore, some of the applications involve complex fluids with non-Newtonian rheology. Computational modelling of flow in this *Re* regime is challenging and more involved due to instabilities and transition, owing to which turbulence models may fail. Therefore, a direct numerical simulation may be employed for such flows, but geometrical complexities and computational costs need further scrutiny. In this regard, a high-fidelity sharp interface immersed boundary (IB) method is developed in the present work to capture the flow dynamics in low *Re* flows efficiently. The geometrical complexities are resolved using a field extension-based IB method on a fixed Cartesian grid. The computational cost is reduced by designing algorithms that exploit the architectural nuances of a graphical processing unit (GPU), and the solver's acceleration on a GPU is achieved using OpenACC. A second-order single-point field reconstruction (interpolation/extrapolation) technique is devised to impose the boundary conditions in the near boundary points in both fluid and solid domains. The field extension method is further modified accordingly to tackle thin surfaces. Overall second-order accuracy is obtained for several problems pertaining to stationary and moving geometries. Reduction in spurious pressure oscillation for a moving boundary problem is also demonstrated. The developed methodology is then extended to predict lift characteristics of shear-thinning fluid motion over a stationary airfoil at different angles of attack. Different time-averaged vortex patterns are identified and associated with fluctuation's kinetic energy. Vortex departure mechanisms are explored with the help of instantaneous streamlines, Fast Fourier Transforms (FFTs), phase portrait diagrams, and time-averaged vortex transport rate analysis. Some of the Carreau fluids avoid stall altogether, even at high angles of attack. Afterwards, the effect of varying thickness in thrust generation of heaving airfoils at different frequencies and amplitudes is studied. Vortex shedding patterns are associated with thrust generation. Finally, the vortex structures over a robotic butterfly undergoing simplified oscillatory motion are identified, and a qualitative comparison is made with some of the previous work. These vortex structures are also correlated with mean thrust values.

Keywords: Immersed boundary method, GPU, Spurious force oscillation, Complex geometry, Rheology, Airfoils, Bio-inspired, Vortex dynamics, Low Reynolds number