ABSTRACT

Recently, researchers and scholars have been engaged in a more profound examination of insect flight as it represents one of nature's best cases of species presented with amazing mobility and direction-finding abilities and that has motivated designers to plan micro air vehicles (MAVs) on a comparable idea. In any case, the aerial fluttering flight includes complex fluid-dynamical phenomena that do not follow the traditional quasi-steady hypotheses pervasive in fixed-wing optimal design. Moreover, the scientific understanding of how the instability of periodic flow associated with plunging wing effects the onset of propulsion is far from complete, especially with regard to the plunging frequency and amplitude of insect wings. Thus, in this study, a real plunging insect wing is mimicked by utilizing a fluid-structure interaction system. The aerodynamic forces on the plate are determined by an in-house fluid solver that utilizes a novel translating continuous-grid-block model using a multiple-relaxation time variant of the lattice Boltzmann method.

The key parameters expected to play a significant role in self-propulsion are the plunging Reynolds number (Re_f), plate thickness to chord ratio (δ), non-dimensional amplitude or Keulegan-Carpenter number (KC) and non-dimensional frequency or Stokes number (β). Numerical simulations are performed on a self-propelled plunging rectangular plate to understand the impact of these parameters on the breaking of symmetry that leads to the onset of propulsion. The non-dimensional trajectory of the centre of mass of the plate and flow structures associated with the plate on the asymmetry side in the proximity of the transition boundary in KC-β space are also examined.

The onset of asymmetry that leads to the propulsion of a self-propelled plunging plate in a quiescent fluid is predicted using Floquet analysis. This analysis utilizes a periodic base flow of initial plunging cycles obtained through the fluid solver. The governing equations for Floquet

analysis, discretized using the finite-difference method in two-dimensions, are subsequently written in the form of perturbed equations with two-dimensional disturbances. These equations are linearized around the base flow, which results in a set of partial differential equations that govern the evolution of the perturbations. The eigenvalues, stability of the periodic base flow and the points of bifurcations are resolved through the normal mode analysis.

Simulations show that the transition boundary in KC- β space shifts to smaller KC for given β as δ is reduced, suggesting that breaking of symmetry is motivated for a plate with lower δ. Furthermore, four distinct movement of non-dimensional coordinate of the center of mass of plate with respect to plunging cycles are identified. These movements are further differentiated with flow patterns associated with the plunging plate during propulsion and the frequency of coefficient of horizontal thrust. Finally, the effect of ground clearance (ς) on the propulsion of the plate is investigated.