ABSTRACT

Emerging aviation trends have extensive applications for remotely or autonomously piloted MAVs, which can perform crucial roles even in day-to-day civilian activities. A TPDS (Targeted Payload Delivery System) vehicle can transition a payload from the base to the objective and then execute a delivery phase, which may include indoor loitering, close-quarter surveillance, and precisely placing a payload near the objective. The vehicle must fly efficiently at a low speed, navigate in tight spaces, and effectively control the impact. We propose a conceptual Flapping Wing MAV(FWMAV) design "*Dartfly*", created by fusing the flapping flight inspired by Dragonfly and the passive stabilization adapted from the Dart. Dragonfly also inspires the *flap-glide gait*, which is intermittent bursts of Escape flight mode (EFM) or Normal flight mode (NFM) with frequent gliding, very crucial for longer endurance in *transition*. Whereas the *Dart* exhibits in-flight 'self-correcting' behavior, providing positive longitudinal stability, crucial for the success of the *flap-glide gait* and the successful penetration near the objective.

From an aerodynamics perspective, the preliminary design challenges are the lack of knowledge of wing kinematics for executing EFM and NFM, the aerodynamics of the dart in low Reynolds number, the aerodynamic performance of *Dartfly* in gliding, and its ballistic trajectory. A comprehensive study combining experiments, numerical simulations, and mathematical modeling was therefore conducted to address these challenges.

Our high-speed Schlieren imaging shows that *Pantala flavescens* regulates the inclination of momentum jet, flow-induced structures, and their interactions by carefully choreographing wing kinematic parameters such as the stroke-plane inclination, wing phasing, and the flapping frequency to carefully select EFM or NFM. Direct measurement of forces produced in the flap cycle substantiates this finding and further elucidates a frequency transfer ratio to identify a flap cycle as EFM or NFM. The statistically significant demarcation of the wing kinematic parameters using this ratio yields a combination of low wing phasing ($< 90°$) and stroke plane inclination ($< 50°$) along with high flapping frequency ($> 30Hz$) for EFM and vice versa for NFM.

The estimates from the numerical simulations and wind tunnel force measurement yield a robust pitching moment for small to moderately high angles of attack, which are responsible for the 'self-correcting' behavior. It degrades at high angles of attack due to different vortex-vortex and vortex-wall interactions in the wake of the dart. Using the stability derivatives obtained, we developed a scalable validated mathematical model for predicting *Dartfly* trajectories and gauge launch conditions with zero influence of the high angle of attack and body angle favorable for successful penetration. Lastly, we numerically estimated the aerodynamic characteristics of the *Dartfly* for gliding flight at an operational speed. It illustrated the advantage of the *Dartfly* over a tailless configuration to facilitate superior pitch stabilizing moment with no loss to aerodynamic performance.

Overall, the proposed conceptual FWMAV design *Dartfly* shows great prospects for fulfilling the need for a highly maneuverable, energy-efficient, low-speed flying, agile FWMAV, which can facilitate positive longitudinal stability and effective control of the impact.

Keywords: bio-inspired aerodynamics; sports aerodynamics; insect flight; MAV