

Abstract

Flapping wings have significant importance in the field of micro aerial vehicles (MAVs). MAVs are capable of performing operations such as environmental monitoring, surveillance, and assessment in highly defended areas. Flapping Wing Micro Aerial Vehicles (FWMAVs) with particularly hovering capability are especially significant in military applications because flapping-wing flight offers a power-efficient and highly maneuverable basis for MAV design especially under low Reynolds number operating conditions, when compared to rotary-wing and fixed-wing UAVs. Further, fixed-wing UAVs are not capable of hovering, while rotary-type UAVs, although capable of hovering, are less efficient because of their small rotor size. While compared to military and transport aircraft, these micro aerial vehicles operate in the low Reynolds number regime of 10^5 or lower. It is evident that the main aerodynamic parameters, like a lift-to-drag ratio, considerably vary between the low and high Reynolds numbers and the aerodynamics associated with flapping wings are unsteady. The interplay between flapping wing kinematics and dimensionless parameters such as Reynolds numbers and reduced frequency also plays an important role in the performances of the micro-aerial vehicle.

Motivated by the hummingbird figure-of-eight pattern wing kinematics during hovering conditions, we studied the influence of kinematics parameters such as frequency, stroke amplitude, pitch amplitude, and plunge amplitude by using force measurement and smoke flow visualization. The optimum wing kinematic conditions are identified by using surrogate modelling techniques. We designed and built an adjustable flapping wing mechanism with brushless DC servo motors with active and passive pitch types. This flapping wing mechanism can produce a figure-of-eight pattern. The experiment results show that a higher frequency of flapping leads to a higher value of force production, but it also results in a greater magnitude of negative force. The production of force positively correlates with the stroke amplitude, and larger amplitudes improve aerodynamic performance.

The plunge amplitude varies non-linearly with the output force, peaking at intermediate plunge amplitudes around 18° in the active pitch mechanism. Similarly, the higher pitch amplitudes enhance force production at higher frequencies. The optimal combination of higher frequency with increased pitch and stroke amplitudes with moderate plunge amplitude

gives optimum force output. An important observation is that frequency and plunge amplitude are more significant than stroke and pitch amplitude in lift generation. Additionally, the active pitch flapping mechanism produced higher forces compared to the passive pitch mechanism. Flow visualization showed a formation of vortices. Vortices, especially leading-edge vortices significantly enhance lift by generating low-pressure regions above the wing. This phenomenon is critical in unsteady flows, which enables high angles of attack without stall. Moreover the trailing edge vortices interact with LEVs to maintain circulation and stabilize the vortex system that contribute to the sustained lift. Additionally, wake capture mechanisms, where wings interact with the previously shed vortices, further enhance the lift.

Overall, we optimized the kinematic wing parameters for maximum lift force production. This hummingbird-inspired study to understand the influence of wing frequency, stroke amplitude, pitch amplitude, and plunge amplitude can lead to the development of next-generation flapping wing unmanned aerial vehicles with higher aerodynamic efficiency.