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Opinion

The Influence of Flexibility on Turbulent Aerodynamic Forces

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OPINION

The flapping Micro Air Vehicle (MAV) has been a hot research area in the last two decades, inspired by the agile flight of natural flying creatures, and many protocols have been developed, such as the Nano Hummingbird invented by AeroVironment Inc., Delfly by Delft University of Technology, and Robobee by Harvard University. Initially, designers focused on emulating the wing motions of natural flyers, but recently, much more attention has been placed on the optimum design for lift augmentation, drag reduction, and power efficiency enhancement. Passive wing deformation caused by structural flexibility has been demonstrated to improve aerodynamic performance of both insects and MAVs. Insect wing deformation is often classified as spanwise bending, spanwise twisting, and chordwise camber. Wing deformation in spanwise bending and chordwise camber is advantageous for increasing aerodynamic force, whereas spanwise twist increases power efficiency. MAV wings, which are made up of veins and membrane, resemble insect wings. The aerodynamics of MAV wings differ significantly from those of their natural counterparts due to changes in wing architecture and material properties. As a result, flapping MAV designers explored the relationship between aerodynamic performance and wing structures in order to discover the best structural design. All of these research and discoveries provide us with a useful reference for optimising wing aerodynamics by leveraging wing flexibility. The spanwise stiffness of the wing was discovered to be three times more than the chordwise stiffness, implying that chordwise deformation is substantially more severe than spanwise deformation.

As a result, increased attention has been drawn to the influence of chordwise flexibility of the wing on its aerodynamic forces, as calculated using 2D airfoil models that combine plunging and pitching motions. Non-dimensional structural characteristics that affect aerodynamic performance in such a system include density ratio and stiffness. Until now, most research on the aerodynamics of a vertically plunging flexible airfoil has concentrated on the influence of flexibility on propulsive performance at zero angle of attack, with little emphasis on the airfoil's capacity to generate lift. Despite its role in propulsion, a vertically flapping can also be employed for lift creation. In cruising flight, natural insects such as dragon flies, butterflies, and drone-flies flap their wings vertically. A vertical plunging model like this is also used in MAV designs, such as the micro flapping rotary wing. The pitching motion is one of the fundamental kinematics influencing the lift produced by a diving airfoil. However, while building MAVs, the precise implementation of this optimum pitching motion necessitates complicated mechanics that significantly increase aircraft weight. One technique is to fix the wing's initial angle of attack and produce pitching by passive deformation.

A vertically plunging flexible airfoil is often a self-propelled system with thrust generated mostly by the unstable motion of the Trailing Edge (TE). Lift is produced as an airfoil cruises and plunges, with the majority of the lift coming from the Leading Edge (LE) area, which is caused by the Leading Edge Vortex (LEV). Flexibility might always reduce airfoil drag, whereas lift and lift efficiency both peak at moderate flexibility with stiffness at 1. The maximum lift of a flexible airfoil is nearly 2.8 times greater than that of a rigid airfoil because trailing edge deformation increases the resultant force and causes aerodynamic forces to tilt towards the lift direction. When the freestream velocity is constant, the initial angle of attack corresponding to the lift peak is around 40° and decreases to 15° for an airfoil in drag-balanced mode. Other than camber deformation, the passive pitching motion is primarily responsible for airfoil drag reduction, lift enhancement, and efficiency increase. In the initial design stage of an MAV wing, a stiff plunging and pitching airfoil provides an alternative model for estimating the aerodynamic performance of a simply plunging flexible airfoil. A fully flexible airfoil with moderate flexibility produces less drag and more lift than a partially flexible airfoil, but a fully flexible airfoil with very high flexibility is only advantageous for drag reduction. To improve aerodynamic performance, an MAV wing should be moderately flexible and totally malleable.

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