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The Aerodynamics of Hummingbird Flight

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[Abstract] Hummingbirds fly with their wings almost fully extended during their entire wingbeat. This pattern, associated with having proportionally short humeral bones, long distal wing elements, and assumed to be an adaptation for extended hovering flight, has lead to predictions that the aerodynamic mechanisms exploited by hummingbirds during hovering should be similar to those observed in insects. To test these predictions, we flew rufous hummingbirds (*Selasphorus rufus*, 3.3 g, n = 6) in a variable–speed wind tunnel (0-12 ms^{-1}) and measured wake structure and dynamics using digital particle image velocimetry (DPIV). Unlike hovering insects, hummingbirds produced 75% of their weight support during downstroke and only 25% during upstroke, an asymmetry due to the inversion of their cambered wings during upstroke. Further, we have found no evidence of sustained, attached leading edge vorticity (LEV) during up or downstroke, as has been seen in similarly-sized insects - although a transient LEV is produced during the rapid change in angle of attack at the end of the downstroke. Finally, although an extended-wing upstroke during forward flight has long been thought to produce lift and negative thrust, we found circulation during downstroke alone to be sufficient to support body weight, and that some positive thrust was produced during upstroke, as evidenced by a vortex pair shed into the wake of all upstrokes at speeds of 4 – 12 m s^{-1}.

I. Introduction

WITH a few exceptional intersections, the evolution of human-engineered flight and the study of the evolution of animal flight have been essentially parallel. Given the results of the earliest such meetings (e.g., DaVinci's ornithopter), this has probably been for the best; the disparity in scale between these lineages and its effects on structural and fluid mechanics has necessarily cloistered these two fields and prevented further fruitless and dangerous intercourse. However, interest in the development of micro-air-vehicles (MAVs) has thrown a debutante ball, and it would seem that the convergence, the meeting and mixing of these lines – now working at similar scales and Reynolds numbers (Re) – could produce useful offspring. The key to the viability of such products will be determining which of those characteristics described for biological fliers are results of natural selection, rather than results of ancestry. That is, the utility of our understanding of biological flight to the engineering community rests upon our ability to determine adaptation – a question fundamental to biologists.

Certainly, some of the loveliest of biological models to walk onto the dance floor are the hummingbirds. Possessing the right range of sizes (from 2-20 grams), unmatched aerial performance for animals of those sizes, along with important research intangibles (i.e., tractability and warmth), hummingbirds seem likely sources of useful design

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