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Energy Harvesting in Micro Aerial Vehicles with Hybrid Stall Control

AEROSPACE ENGINEERING

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Abstract

In the present work, a finite wing with leading-edge tubercles is introduced for use in micro aerial vehicles (MAVs). Experimental and numerical investigations provided clear evidence of the advantages of this biomimetic-inspired strategy for passive stall control. Whereas major improvements are obtained at the post-stall regime, some deterioration occurs at pre-stall as well. This drawback is circumvented by the use of active flow control at the latter regime. For this purpose, piezoelectric energy is harvested, thus converting mechanical vibrations into useful electrical power for use in hybrid stall control.

Motivation and Main Results

In the past decade, the interest in MAVs has increased immensely and these have been widely used due to many important practical applications, both by the military and civilians. However, the combination of small size and low flight velocities in such vehicles makes them to operate in the low Reynolds number regime, i.e., *Re* < 200,000. Laminar separation and early stall occurring in this regime of operation thus present enormous challenges to aerodynamicists. As a consequence, the need for passive or active flow control is highly desirable. Aiming to achieve this goal, it is perhaps not surprising that researchers have sought inspiration in Nature using Biomimetics. For instance, the agility and maneuverability of a humpback whale (figure 1), resulting from the distinctive design of its pectoral flipper, has inspired engineers to modify the leading edge of lifting surfaces (such as wings and hydrofoils) to the shape of turbercles.

Figure 1: Humpback whale and detail of tubercles along the flipper

Hence, a prototype with a sinusoidal leading-edge has been numerically and experimentally investigated for passive control in MAVs. The wing was based on a NASA LS(1)-0417 section, designed via CAD software and subsequently built using additive manufacturing. Numerical studies on aerodynamics (figure 2a) were performed employing Detached Eddy Simulations and experiments were carried out at a low-speed, open-circuit wind tunnel (figure 2b).

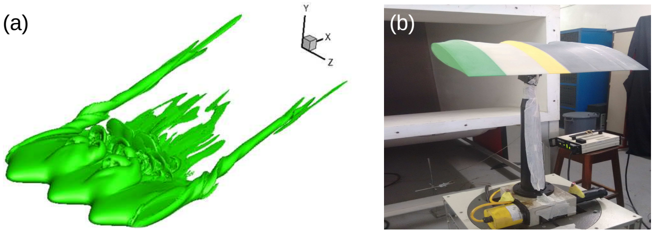

Figure 2: Wing prototype with leading-edge tubercles for (a) numerical simulations and (b) wind tunnel testing

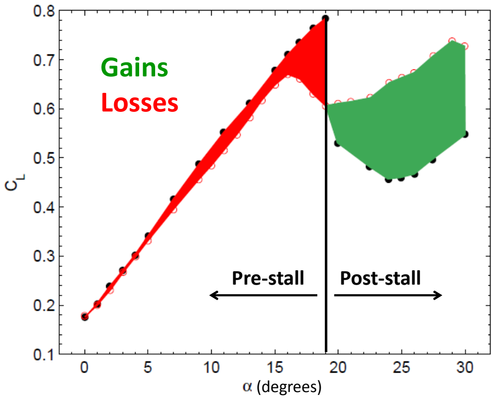

Figure 3: Gains and losses in lift coefficient for the wing with passive stall control with respect to the baseline geometry, at *Re* = 140,000

Only mild active flow control is expected to be required in order to offset the losses at the pre-stall regime (figure 3) resulting from the use of passive stall control. Small amounts of structural vibration energy may be scavenged to feed active flow control electronics, using piezoelectric harvesters. An experimental device was designed and optimized with wind tunnel testing (figure 4). Voltage and power measurements have been successfully predicted via adequate computational modelling of the electromechanical harvester (figure 5) .

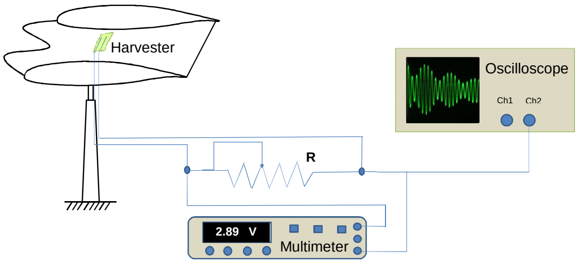

Figure 4: Experimental setup for optimization and testing of the piezoelectric energy harvester mounted inside the prototype wing

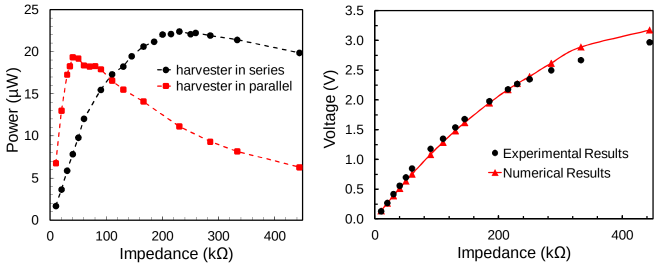

Figure 5: Experimental results and numerical predictions of the piezoelectric energy harvester response after optimization

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