Dynamics of Flexible Wings in and out of Ground Effect

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HIGHLIGHTS

- Time-synchronized load-cell, DIC and PIV measurements are conducted on membrane wings for MAVs
- POD is applied on flow oscillations to determine their spatiotemporal evolution
- Loads, membrane motions and flow dynamics are correlated to reveal underlying coupling physics
- Chordwise location of peak membrane dynamics found crucial for strong flow-membrane coupling
- Membrane flexibility found beneficial in ground-effect, suppressing premature shedding and drag increase

ABSTRACT

Bio-inspired flexible membrane wings of bats offer performance benefits for Micro-Air-Vehicles (MAVs) at low to moderate Reynolds numbers. Their key relies on energy entrainment into the weak boundary layer by offering dynamic fluid-structure interaction. The usage of MAVs with flexible wings in ground-effect could be one further operational option to combine benefits of flexible wings with efficiency enhancement in close proximity to the ground. Wind tunnel measurements are conducted at Re = 56,000 measuring rigid flat-plates and perimeter reinforced flexible membrane wings from free-flight into ground-effect conditions. Load cell measurements, digital image correlation (DIC) and particle image velocimetry (PIV) are applied in high-speed (800 Hz) to resolve time-synchronised lift, drag and pitch oscillations simultaneously to membrane and flow dynamics (Fig. 1). Proper orthogonal decomposition (POD) is applied on flow oscillations to determine their spatiotemporal evolution. Loads, membrane motions and flow dynamics are correlated to each other to investigate their underlying coupling physics. Ultimately, we are exploiting the flow modifying nature of ground-effect to understand the ways in which flexible wings benefit from separated flow conditions.

Membrane wings ability of static cambering and dynamic membrane oscillations are found to be beneficial in ground-effect, where the descent in height forces premature leading-edge vortex-shedding and drag increase. The dynamic motions of membrane wings (Fig. 2) help to promote (low height/high angle induced) vortex-shedding from the leading edge that ensures attached flow to the wing upper surface, resulting in even further lift enhancement. The membrane of a perimeter wing frame is found to benefit specifically from its leading and trailing-edge constraints as the boundary conditions enable motions along the entire chord that enhance flow-membrane interaction. Membrane mode shapes with two chordwise peaks involve large membrane motions close to the leading-edge, promoting the formation and growth of leading-edge vortices and their impact to the wing dynamics. Ultimately, membrane wings can specifically exploit dynamic flow structures to their benefit, resulting in enlarged performance windows compared to rigid wings.