Predicting Aerodynamic Loads on Highly Flexible Membrane Wings

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Abstract
Through passive adaptation to incidental flow, flexible aerodynamic surfaces exploit effects of increased lift, delayed stall and disturbance rejection. Wings of birds, bats, and insects exhibit these passive effects, and at the same time through the use of structural state feedback sensed from the loads on the wing, active control is applied to achieve stable and highly dynamic maneuvers. The goal of this research is to predict flexible wings’ aerodynamic loads by sensing their structural responses to static and dynamic airflow conditions. Three approaches are presented to estimate aerodynamic loads on highly flexible membrane wings, under static and dynamic conditions, at low Reynolds number. The first applies a linear membrane formulation to correlate the wing’s structural strain to lift, through wing-tip vorticity. In the second, the Poisson equation for a 2D linear-elastic membrane with out-of-plane deformation was used to calculate normal pressure distribution from virtual strain sensors using proper orthogonal decomposition basis functions and a recursive least squares minimization. Finally, potential flow theory and a first order state space representation is applied to the transient flow effects around a pitching membrane airfoil to model the time varying loads due to dynamic pitching.

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