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Experimental Study and Analysis of a Free Pitching Flexible Cantilever NACA0012 Wing

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Abstract

An experimental investigation of a flexible cantilever NACA0012 wing in pitch-bending was conducted over a range of transitional Reynolds numbers. The aeroelastic apparatus consists of a 3D-printed airfoil mounted on a stainless steel plate that was allowed to rotate in pitch. The freely rotating base was attached to springs to provide rotational stiffness, and its angle was measured with a potentiometer. The steel plate was the primary structural component of the wing and experienced flexible body rotation, flap-wise bending and in-plane bending. Based on the wing's initial conditions, two forms of limited-cycle oscillations were expected: small and large amplitude. The small amplitude oscillations are believed to be caused by laminar separation flutter. This type of flutter occurs when a laminar separation bubble develops along the chord, and the flow reattaches before the trailing edge. It typically occurs in lower Reynolds number flows at small angles of attack. The large amplitude oscillations are thought to be caused by stall flutter or coupled flutter. Stall flutter occurs at high angles of attack when a separation bubble develops near the trailing edge. This bubble leads to a region of reversed flow, negative aerodynamic damping, and a transfer of energy from the flow to the system. Unlike laminar separation flutter and stall flutter, which are single degree-of-freedom (DOF) phenomena, coupled flutter requires two motions and thus 2-DOF. It occurs when two different motions have similar frequencies, causing them to resonate and increase the amplitude of the vibrations. The motions that are expected to participate in coupled flutter are pitching and flap-wise bending. Although flap-wise bending has been observed, it needs to be determined if it is part of driving coupled flutter, or a consequence of the pitching in stall flutter. Numerical, analytical and machine learning models are verified using the experimental pitch data. These models account for the structural and aerodynamic non-linearities in addition to the pitch-bending coupling. Future work will implement two cameras and object-tracking algorithms to measure the flap-wise bending deflection of the wing and compare it to the models. Further investigation of the work done on the system by the flow will include potential energy harvesting methods.