On the evolution of flow, pressure, lift, and moment during dynamic stall of an oscillating airfoil

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Time-resolved stereo PIV measurements have been performed in a refractive index matched facility to study the flow and pressure fields around a harmonically oscillating NACA 0015 airfoil undergoing dynamic stall. The experiments have been performed for varying reduced frequencies (k=0.047-1.571) and Reynolds numbers (Re=13500-135000), while the airfoil oscillated with a mean angle of 15° and amplitude of 10°. Refractive index matching facilitates simultaneous measurements on both sides of the transparent airfoil. Assuming a 2D flow, the instantaneous pressure fields are estimated by spatial integration of the material acceleration[1], and the lift and moment are calculated by integration of the surface pressure. As the incidence angle exceeds the static stall angle, the flow separation on the suction side of the airfoil near the leading edge causes roll-up of a large dynamic stall vortex (DSV) and an associated pressure minimum which then detaches and migrates downstream creating a large moving pressure minimum that propagates along the suction side at about 30% of the free stream velocity. For the current range of oscillation angles, the DSV detachment time is a constant fraction (∼0.3) of the oscillation period for all k and Re. Maps of pressure difference across the airfoil demonstrate that the broad low pressure induced by the DSV delays the stall onset, and increases the maximum lift well beyond the static level. As the DSV moves aft of midchord, it becomes fragmented, broadening the pressure minima and causes an abrupt drop in lift. As the DSV fragments reach the vicinity of the trailing edge, they entrain opposite sign vorticity originating from the pressure side into the suction side. The entrained positive vorticity rolls up to create a pressure minimum near the trailing edge which causes a sharp increase in the leading-edge moment. When the time scales shifted based on the detachment time of the DSV, the all the lift curves nearly collapse. Proper Orthogonal Decomposition of the pressure shows that the evolution of mode coefficients also collapses in the shifted time scale, and the peaks of the coefficients of third mode correspond to the times of DSV detachment, maximum lift, and maximum moment.

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[1] Liu and Katz, *Exp. in Fluids* **41(2)** (2006).