WIND TUNNEL EXPERIMENTS ON THE EFFECT OF COMPRESSIBILITY ON THE ATTRIBUTES OF DYNAMIC STALL

Abstract

by

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Experimental results and analysis of an airfoil oscillated in pitch are presented at Mach numbers from 0.2 to 0.6 and Reynolds numbers up to $3.5 \times 10^6$. The design of a novel pitch-mechanism and dynamic stall rig is discussed. High-speed surface pressures and the airfoil’s instantaneous incidence angle are simultaneously sampled and used to characterize the temporal pressure field, static and dynamic loading, and cycle and transient aerodynamic stability under harmonic prescribed incidences.

This work focuses on three distinct problems in regard to dynamic stall and the influence of Mach number, as follows:

1. **The stall vortex convection properties:** The low pressure signature of the stall vortex’s travel aft over the chord is tracked through deep dynamic stall conditions and moderate to high reduced frequencies. The gestation or growth period of the dynamic stall vortex and its ultimate convection rate are quantified. Increased Mach number decreased the gestation period of the stall vortex and the duration the stall vortex resides over the airfoil chord. The surface pressures and surface pressure gradients found at low-speed as the stall vortex migrates over the chord are shown to be substantially altered following shock-induced dynamic stall.
2. **Shock induced dynamic stall and surface flow features:** A focused schlieren system is designed and constructed to glean information regarding the temporal evolution of shock structures on the airfoil’s upper surface. The flow visualization is used to interpret the corresponding surface pressures measured through the on-board pressure instrumentation. A $\lambda$-shock is shown to develop near the leading-edge. The foot of the developing shock remains near the leading-edge whereas the shock front travels aft over the chord. At a critical incidence, the flow separates, and an off-surface shock structure propagates upstream toward the leading-edge. The effect of two-dimensional trips on the shock’s formation is examined.

3. **Compressibility effects on aerodynamic damping:** The ensemble averaged pitch-moment is used to determine the net cycle damping. The transient damping, discussed here for the first time, is shown to be calculable through a Hilbert transform of the pitch-moment. This time-based damping analysis offers new incite into the mechanism of stall flutter in helicopter rotor operations. The test includes a comprehensive investigation of forcing parameters (mean angle of attack, amplitude, and reduced frequency), including the effect of free (un-tripped) and forced (tripped) laminar to turbulent transition. It is shown that the cycle damping factor masks the local behavior of the damping, and, in many cases, may be positive despite large, negative (unstable) transients.