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CONTROL OF COMPRESSIBLE DYNAMIC STALL USING MICROJETS

C. Shih, J. Beahn, and A. Krothapalli
Department of Mechanical Engineering
FAMU-FSU College of Engineering
Tallahassee, FL 32310

M.S. Chandrasekhara
Department of Aeronautics and Astronautics
Naval Postgraduate School
Monterey, CA 93043

ABSTRACT

Control of the dynamic stall process of an NACA 0015 airfoil undergoing periodic pitching motion is investigated experimentally in a high-speed wind tunnel facility. Multiple microjet nozzles distributed uniformly in the first 15% chord from the airfoil's leading edge are used for the control. Point Diffraction Interferometry (PDI) technique is used to characterize the control effectiveness, both qualitatively and quantitatively. The microjet control has been found to be very effective in suppressing both the emergence of the dynamic stall vortex and the associated massive flow separation at the entire operating range of angles of attack. At the high Mach number case (M=0.4), the use of microjets appears to eliminate the shock structures that are responsible for triggering the shock-induced separation, establishing the fact that the use of microjets is effective even in controlling dynamic stall with a strong compressibility effect. In general, microjet jet control has an overall positive effect in terms of maintaining leading edge suction pressure and preventing flow separation.

Keywords: dynamic stall, microjet control, compressible flow, unsteady aerodynamics, separated flow

INTRODUCTION

The dynamic stall process on a helicopter rotor blade is initiated by the unsteady boundary-layer separation near the airfoil's leading edge. During a rapid pitch-up motion, vorticity production is greatly enhanced by the presence of a favorable pressure gradient at the leading edge. At the same time, vorticity accumulates locally due to the slowdown of downstream convection process caused by an adverse pressure gradient and a local boundary-layer flow reversal further downstream. The accumulation process is eventually interrupted by a sudden emergence of unsteady flow separation and the subsequent eruption of the accumulated vorticity into the outer flow. Consequently, it initiates a sequence of spontaneous events such as local viscous/inviscid boundary-layer interaction, formation and convection of large energetic and, finally the "stall" and all associated adverse effects. Thus, in order to control the dynamic stall process, a better physical understanding of the unsteady boundary-layer separation is necessary.

A detailed theoretical description of the unsteady separation process was first made by van Dommelen and Shen (VDS)[1] using an innovative Lagrangian approach. In short, the process is initiated by a local flow reversal as the result of the adverse pressure gradient. The fastest reversing particles quickly collide with the slower moving particles ahead of them. This results in a local eruption of the particles away from the wall and initiates the separation process. Unlike the traditional shear layer instability mechanism, which selectively amplifies random perturbations in the initial region to develop into organized vortical structures, the deformation triggered by the VDS interaction provides a deterministic perturbation to the local vorticity distribution. After this sudden distortion, the local vorticity arrangement is highly unstable and quickly rolls up into a large dynamic stall vortex (see figure 1)[2]. Once generated, the energetic vortical structure is extremely robust and is difficult, if not impossible, to control. Therefore, any effective control of the dynamic stall process has to be carried out before the formation of the vortex. That is, one has to control the unsteady separation process as described by the VDS model in order to prevent or alleviate the sudden eruption of vorticity from the wall.

There are many ways to implement control on the dynamic stall process to produce the desirable effect. Only active control strategies will be considered here since, unlike passive control elements, they can be switched on and off instantly, therefore, they will not degrade the operational performance when they are not needed. For example, Wang[3] used uniform suction near the separation region and his computational results show that the formation of the dynamic stall vortex can be significantly delayed or even eliminated. However, the power required to achieve effective suction makes this proposal

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