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Use of High-Speed Microjets for Active Separation Control in Diffusers

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Inlets to aircraft propulsion systems must supply flow to the compressor with minimal pressure loss, flow distortion, or unsteadiness. Flow separation in internal flows such as inlets and ducts in aircraft propulsion systems and external flows such as over aircraft wings is undesirable because it reduces the overall system performance. An experimental investigation is described that was carried out to study the feasibility of using high-speed microjets, supersonic for most cases, to control boundary-layer separation in an adverse pressure gradient. The geometry used is a simple diverging Stratford ramp equipped with arrays of 400-μm-diam microjets. Measurements include detailed surface flow visualizations, mean surface pressure distributions, and velocity field measurements using particle image velocimetry. The results clearly indicate that by activating these microjets the separated flow regions were eliminated. This led to a significant increase in the momentum of the flow near the surface where the gain in momentum was at least an order of magnitude higher than the momentum injected by the microjets. Given the simplicity of the system and its low mass flow requirements, combined with the benefits achieved by this approach, microjets appear to be promising actuators for efficient separation control for internal and external flow applications.

I. Introduction

BOUNDARY-LAYER separation entails significant energy loss, increases the flow unsteadiness, and limits the performance of many flow devices. The design of engine inlets is one area where the prevention of flow separation may be significant in improving the overall efficiency of the vehicle. Flow separation can be prevented in these engine inlets by increasing the inlet length, which generates a more gradual pressure gradient. However, the increase in the inlet length required to avoid separation and its associated losses may increase the size of the overall vehicle[1] (such as uninhabited air vehicles). In addition, for certain military applications, the inlet design is also constrained by low observability requirements. More commonly, a serpentine inlet is used to block the line of sight[2,3] to the compressor face, thereby reducing the radar signature from the compressor face. Similar "buried" propulsion systems have also been considered for the blended wing–body (BWB) design.[4]

In the case of a BWB, the engines are located at the aft end of the aircraft and, hence, require the ingestion of a thick boundary layer developed over the aircraft surface. The degraded condition of this boundary layer makes it much more susceptible to separation when it encounters the pressure gradients of a diffusing inlet duct. The pressure loss due to this separation reduces the overall system efficiency. Moreover, flow distortion and unsteadiness created due to this separation can also result in aerodynamic stall and a surge in the compressor and fan blades.[5,6] Consequently, it is highly desirable to avoid boundary-layer separation in inlets because it can significantly diminish the engine performance.

Not surprisingly, a substantial amount of research aimed at controlling boundary-layer separation[7,8] has been conducted. Conventionally, the following approaches have been applied for separation control: 1) tangential blowing to energize directly the low-momentum region near the wall,[9–11] 2) wall suction[12,13] to remove the low-momentum region, 3) vortex generators (VGs and micro VGs) in the form of vanes and bumps,[14,15] and 4) forced excitation devices, for example, acoustic excitation[16,17] and synthetic jets.[18,19] Tangential blowing and suction are very effective in controlling separation. However, they have the parasitic cost involving high-pressure (mass flux) sources and are infrequently used. VGs are among the most widely examined flow control methods, where VGs of various shapes and sizes have been used to control boundary-layer separation.[15] Although the mechanism is still not well understood, it has been suggested that the VGs produce strong vortices, which enhance the mixing between the high-momentum core flow and the low-momentum boundary-layer flow, thus energizing the boundary-layer fluid.[1] However, the performance of these VGs, which are passive in nature, has been somewhat limited; usually there is a need to optimize their location, size, and other parameters to achieve optimal performance for specific operating conditions. In addition, they have an associated parasitic drag when they are not in use.

An excellent review of active flow control techniques has been published by Greenblatt and Wygnanski.[20] As discussed in their review of the use of acoustic excitation methods for separation control (over airfoils) (Sec. 3.2 in Ref. 20), they note that certain methods, such as those used by Ahuja et al.[17] and Zaman et al.[16] have shown some benefits. However, these acoustic excitation studies were in most cases facility dependant and, therefore, perhaps of limited use from a practical perspective. To quote Greenblatt and Wygnanski "The drawbacks, however, outweigh these positive aspects." Other active flow control devices, such as synthetic jets,[18] have also been examined for separation control applications. Amitay et al.[18] demonstrate that their synthetic jet-based actuators provided some control of flow separation in a duct. The measurements by Amitay et al. consisted of pitot surveys that showed that flow attachment was generally obtained for a limited region of the flowfield and that complete reattachment was limited to a few cases. Similar flow control devices have been employed by Jenkins et al.,[19] who employed piezoelectric-synthetic jets to control flow separation over an adverse pressure gradient ramp essentially identical to the one used in the present study. Based on their results, Jenkins et al. concluded that their synthetic jets did not work, primarily due to the "insufficient velocity/momentum output" that is needed to achieve effective control.

A different approach, one that employs microjets to control flow separation, is presented in this paper. In this study, we plan to investigate the efficacy of using high-speed microjets (supersonic

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