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Control of Supersonic Impinging Jet Flows Using Supersonic Microjets

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Supersonic impinging jets, such as those occurring in the next generation of short takeoff and vertical landing aircraft, generate a highly oscillatory flow with very high unsteady loads on the nearby aircraft structures and the landing surfaces. These high-pressure and acoustic loads are also accompanied by a dramatic loss in lift during hover. Previous studies of supersonic impinging jets suggest that the highly unsteady behavior of the impinging jets is due to a feedback loop between the fluid and acoustic fields, which leads to these adverse effects. A unique active control technique was attempted with the aim of disrupting the feedback loop, diminishing the flow unsteadiness, and ultimately reducing the adverse effects of this flow. Flow control was implemented by placing a circular array of 400-μm-diam supersonic microjets around the periphery of the main jet. This control approach was very successful in disrupting the feedback loop in that the activation of the microjets led to dramatic reductions in the lift loss (40%), unsteady pressure loads (11 dB), and near-field noise (8 dB). This relatively simple and highly effective control technique makes it a suitable candidate for implementation in practical aircraft systems.

I. Introduction

AN UNDERSTANDING of the impinging jet flowfield is necessary for the design of efficient short takeoff and vertical landing (STOVL) aircraft. When such STOVL aircraft are operating in hover mode, that is, in close proximity to the ground, the downward-pointing lift jets produce high-speed, hot flow that impinges on the landing surface and generates the direct lift force. It is well known that in this configuration several flow-induced effects can emerge, which substantially diminish the performance of the aircraft. In particular, a significant lift loss can be induced due to flow entrainment by the lifting jets from the ambient environment in the vicinity of the airframe. Other adverse phenomena include severe ground erosion on the landing surface and hot gas ingestion into the engine inlets. In addition, the impinging flowfield usually generates significantly higher noise levels relative to that of a free jet operating under similar conditions. Increased overall sound pressure levels (OASPL) associated with the high-speed impinging jets can pose an environment pollution problem and adversely affect the integrity of structural elements in the vicinity of the nozzle exhaust due to acoustic loading. Moreover, the noise and the highly unsteady pressure field are frequently dominated by high-amplitude discrete tones, which may match the resonant frequencies of the aircraft panels, thus further exacerbating the sonic fatigue problem.

These problems become more pronounced when the impinging jets are supersonic, the operating regime of the STOVL version of the future joint strike fighter. In addition, the presence of multiple impinging jets can potentially further aggravate these effects due to the strong coupling between the jets and the emergence of an upward-moving fountain flow flowing opposite to the lift jets.[1] A schematic of a generic STOVL aircraft with multiple lift/impinging jets is shown in Fig. 1, where various regions where these problems might occur have been indicated.

A. Feedback Loop

To minimize their adverse influence on aircraft performance, it is evident that the undesirable effects of supersonic impinging jets need to be controlled. However, before one can devise an effective control scheme to eliminate these detrimental characteristics, one must have a fundamental understanding of the principal physical mechanisms governing these flows. The acoustic properties of single supersonic impinging jet flowfield have been investigated by a number of researchers, including Powell,[2] Neuwerth,[3] and Tam and Ahuja.[4] These studies conclusively demonstrated that the unsteady properties of impinging jet flows are dominated by the presence of discrete impingement tones. These high-amplitude tones are generated by highly coherent instability waves due to the emergence of a self-sustained feedback loop. For a detailed discussion of the feedback mechanism, see Refs. 2–4. Very briefly, large-scale vortical structures in the jet shear layer impinge on the wall and generate coherent pressure fluctuations, which result in acoustic waves of significant intensity. These acoustic waves travel through the ambient medium and, on reaching the nozzle (a region of high receptivity), excite the shear layer of the jet. This leads to the generation of a new set of enhanced instability waves, which rapidly evolve into large-scale vortical structures, thus closing the feedback loop. A similar feedback mechanism is also responsible for the production of discrete tones such as screech tones, which are conspicuously present in nonideally expanded, that is, over- or underexpanded, and edge tones generated due to the presence of an "edge" in the jet hydrodynamic field . In fact, the feedback mechanism responsible for discrete tones was first clearly articulated by Powell in classic papers on jet noise[5] and on the feedback loop responsible for edge tones.[6]

Flow properties of high-speed impinging jets have also been examined by a number of investigators, including Donaldson and Snedeker,[7] Carling and Hunt,[8] and Lamont and Hunt,[9] among others. These studies mainly emphasized the mean properties of this flow with most of the measurements limited to mean surface properties, such as the pressure distributions on the impingement surface. Recently, Krothapalli et al.[10] conducted an extensive investigation to obtain a better understanding of the physics governing some of the mean and unsteady properties of such flows, using the geometry shown in Fig. 2. One of the main findings of their work was the intimate connection between the discrete impinging tones and the

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