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Active Control of Supersonic Impinging Jets: Flowfield Properties and Closed-loop Strategies

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Supersonic impinging jets produce a highly unsteady flowfield leading to a very noisy environment with very high dynamic pressure loads on nearby surfaces. In prior work, we demonstrated that supersonic microjets can be used to disrupt the feedback loop inherent in high-speed impinging jet flows, thereby significantly reducing the adverse effects produced by this flow. In this paper, we explore two aspects of the microjet control scheme. First, detailed PIV measurements are used to examine the role of streamwise vorticity in the feedback interruption using microjets. Second, a novel closed-loop control strategy which uses on-line pressure measurements near the nozzle exit to achieve optimal flow control irrespective of flow conditions, is explored. The PIV measurements revealed that the activation of microjets produces substantial streamwise vorticity in the form of well organized, counter-rotating pairs of streamwise vortices. The production of significantly higher streamwise vorticity due to microjets comes at the expense of the azimuthal vorticity in the shear layer. This weakens the large-scale axisymmetric structures in the jet shear layer while also introducing more three-dimensionality into the flow. Both these factors, lead to a weakening of the feedback loop, which may account for the success of this control scheme. The closed-loop control strategy consisted of determining the dominant POD mode using pressure measurements at the nozzle exit and using a 'mode matched strategy' to determine the microjet pressure distribution along the nozzle. The results demonstrated a significant reduction in the unsteady pressure loads along with a consistent improvement compared to an open-loop control strategy where the microjet pressures were kept constant. It is proposed that this improved reduction may be due to the fact that the mode-matched strategy results in the intensity of the microjets to be proportional to the corresponding acoustic wave intensity near the nozzle. The stronger microjets then provide a stronger local disruption and perhaps generate more streamwise vorticity, both of which lead to more efficient local disruption of the feedback loop resulting in larger reductions in the flow unsteadiness.

1. Introduction

The impingement of high-speed jets, on a surface, generally results in an extremely unsteady flowfield accompanied by a host of undesirable aeroacoustic properties. These include, but are not limited to, very high ambient noise levels dominated by discrete frequency tones – referred to as impingement tones – and highly unsteady pressure loads on the ground plane and on nearby surfaces.

Unfortunately, high-speed impinging jets are ubiquitously present in Short Take-Off and Vertical Landing (STOVL) aircraft during hover. In this context, the flow induced effects such as the high noise levels and impingement tones can lead to structural fatigue of the aircraft surfaces in the vicinity of the nozzles, while the high dynamic loads on the impingement surface results in increased erosion of the landing surface. For STOVL aircraft these problems are collectively referred to as ground effect.

A host of studies on the aeroacoustics of impinging jets by Neuwarth (1974), Powell (1988), Tam and Ahuja (1990), and more

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