Aeroacoustic Properties of Supersonic Cavity Flows and Their Control

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ABSTACT

A detailed experimental study of supersonic, Mach 2, flow over a 3D cavity was conducted using shadowgraph, particle image velocimetry (PIV), and unsteady surface pressure measurements. Large-scale structures in the cavity shear layer and visible disturbances inside the cavity were observed. The PIV data reveals the highly unsteady nature of the entire flowfield and the presence of a large recirculation zone with reverse velocities as high as 40 % of the free-stream velocity. Supersonic microjets at the leading edge are used to control the cavity flow and suppress resonance in the cavity. Using minimal mass flux through the microjets, overall sound pressure level (OASPL) was reduced by greater than 9 dB with tonal reductions greater than 20 dB. The PIV data reveals that microjet injection modifies the cavity shear layer and results in a significant reduction in the unsteadiness of the cavity velocity-field.

INTRODUCTION

Cavity flows have been the subject of research since the 1950s. Although geometrically simple, the fluid dynamics in such flows are complicated, involving shear layer instability, flow-induced resonance and turbulence. Much of the flow physics governing cavity behavior remains unclear. Due to the additional complexity and measurement challenges inherent in supersonic cavity flows, to-date very limited data is available, especially in terms of detailed flowfield measurements.

Under certain conditions, flow induced resonance in cavity flows can be very intense such that it may produce significant unsteady hydrodynamic and acoustic loads on the nearby surfaces. In the context of cavity flows in open weapon bays and landing gears, among others, these loads can lead to significant structural fatigue. Many control devices have been tested in order to suppress this resonance. Among the many passive actuators explored, sawtooth spoilers (Shaw et al. 1988) and leading edge ramps (Zhang et al. 1999) have been shown to reduce the amplitudes of cavity tones. However, many of these devices are only effective within a limited range of flow conditions and usually have an associated penalty, such as increased drag. Hence, in more recent studies, active control devices have been explored for cavity flow control.

Cattafesta et al. (1999), developed a real-time adaptive piezoelectric flap actuator, which suppressed the amplitude of the first mode. However, the results were less encouraging when this actuator was tested at a different facility at a higher Mach number. Vakili et al. (1994) reported a significant reduction of the dominant tone by blowing a fairly large mass flux through a highly perforated plate, just upstream of the cavity. However, the effect on the overall sound pressure level (OASPL) was not reported in that paper. Stanek & Raman (2002) developed Power Resonant Tubes to suppress flow-induced resonance by forcing the shear layer at a single frequency. However, mass flow rates as large as 0.4 lbm/sec were required to achieve the desired suppression and the performance was not uniform over the entire range of test conditions. Furthermore, it is still unclear whether the frequency of forcing, which was unrelated to resonance frequencies, plays a role in the control efficacy.

Supersonic microjets have a strong potential to effectively disrupt the self-sustained feedback loop. They are small, robust and capable of producing high momentum flux with very small mass flux. They have been successfully used in controlling the feedback loop which occurs in high-speed impinging jets (Alvi et al.,

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