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Stereoscopic PIV Measurements of a Screeching Supersonic Jet

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Abstract: The effect of acoustic feed back on global flow response is illustrated through an example of a rectangular screeching jet operating at a nominal Mach number of 1.69. Using a stereoscopic Particle Image Velocimetry, the detailed flow characteristics within a screeching cycle are obtained with fidelity. To resolve the "bias" errors inherent with standard PIV image processing technique, a novel mesh-free and high spatial resolution scheme is implemented to yield accurate velocity measurements in a complex three-dimensional supersonic flow. The axis-switching phenomenon that arises due to unusual mixing enhancement in the minor axis plane of a rectangular jet is vividly displayed. Strong streamwise vortex structure in the jet shear layers, enhanced by the inherent instability of the shear layer, is reported.

Keywords: supersonic jets, aeroacoustics, screech, 3D PIV, stereoscopic PIV, flow-acoustic interaction.

1. Introduction

A promising approach for the diffusion of high convective Mach number free shear flows utilizes the efficient energy transfer between mean and turbulent velocity fields caused by global flow instabilities. One such phenomenon, known as screech (Powell, 1953), exemplifies the dramatic effect of a self-sustained feedback loop in the global flow response (Krothapalli et al., 1986).

Unlike isolated shear layers, we find that compressible jets are unstable over a wide range of disturbances for all Mach numbers (Bearman and Ffowcs Williams, 1970). Consequently, the jet can be regarded as a high gain broadband amplifier. Any feedback loop on such an amplifier is liable to transform the system into a narrow band oscillator. A typical example exhibiting such a behavior is the screeching jet; a self-sustained oscillatory condition common to non-ideally expanded supersonic jet flows. The feedback loop as described by Powell (1953) consists of a disturbance traveling downstream that strikes a region at the end of a shock cell to scatter intense sound. This sound propagates through the subsonic ambient medium, and upon reaching the nozzle lip, excites the shear layer leading to the generation of new traveling disturbances thus closing the feedback loop. The frequency of operation is determined by the feedback loop. The instability waves that are part of this process are of convective type having negligible upstream influence. As a result, the jet could be excited at non-screech frequencies if driven by an upstream disturbance of sufficient strength. If an efficient energy transfer mechanism between the undisturbed shear layer and the oscillatory disturbance (in the region covering the first few instability wave lengths) is devised, the resulting motion of the jet could be as violent as that experienced by a screeching jet. Indeed, using the flow induced cavity resonance at the nozzle exit, Yu and Shadow (1995) have increased the initial shear layer growth rate by nearly a factor of three at high convective Mach numbers ($M_c = 1.4$).