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Structure of a screeching rectangular jet: a stereoscopic particle image velocimetry study

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The unsteady velocity field generated by an underexpanded jet has been investigated using stereoscopic particle image velocimetry (PIV). A 4:1 aspect ratio converging–diverging rectangular nozzle designed to operate at a fully expanded condition of $M = 1.44$ was used. The nozzle was operated at off-design conditions to generate imperfectly expanded jets with intense screech tones. Phase-locked PIV measurements show the spatial and temporal evolution of the three-dimensional jet with high fidelity. In addition to the globally averaged mean and turbulence velocity field data, the phase-averaged data for the velocity and vorticity fields were also obtained. The turbulence quantities were resolved into contributions from the periodic and random motions. The deformation of the periodic spanwise structures results in the formation of strong streamwise vortices that appear to govern the mixing of the jet. It is shown that the presence of coherent vorticity of significant strength, in addition to the shock cell strength, is largely responsible for determining the screech intensity.

1. Introduction

The primary motivation for the examination of the flow field of a screeching rectangular jet is to provide some guidance towards developing control methods for high-speed jet noise suppression and enhanced mixing for combustion applications. A promising approach for the diffusion of high convective Mach number free shear flows uses the efficient energy transfer between the mean and the turbulent velocity fields caused by global instabilities (Strykowski, Krothapalli & Jendoubi 1996). One such phenomenon, known as ‘screech’ (Powell 1953) exemplifies the dramatic effect of a self-sustained feedback loop in the global flow response, as shown in figure 1. Unlike isolated shear layers, compressible jets are unstable over a wide range of disturbances for all Mach numbers (Berman & Ffowcs Williams 1970). Consequently, any feedback loop is liable to set up a resonance phenomenon that leads to a self-sustained oscillatory condition common to non-ideally expanded supersonic jets. Powell described the screech phenomenon as being generated by disturbances in the shear layer, which convect downstream and come into contact with a shock cell boundary. This interaction, particularly at the end of a shock cell, results in the generation of intense sound. The sound propagates upstream in the ambient medium, interacts with the incipient shear layer at the nozzle exit and produces a new downstream travelling disturbance that continues the feedback cycle. It is assumed that the sound waves moving in the upstream direction adjacent to the jet are of