Role of Enhanced Mixing on the Far-Field Noise of Supersonic Jets

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Abstract

The paper examines the question: Does a mixing enhancement necessarily result in far-field noise reduction in supersonic jets? Several experiments were conducted to come up with an answer to the above question, The first experiment deals with examination of noise generated by a Mach 2 ideally expanded supersonic with counterflow. The counterflow technique depends on the creation of a counterflowing stream of air around the periphery of the primary jet column in the neighborhood of the nozzle exit. The creation of the secondary flow gives rise to a reduction in the jet exit plane pressure, which requires that the total pressure supplied to the jet be correspondingly reduced to maintain a nominally ideally expanded jet flow field. Experiments were conducted at a primary stream Mach number of 2 for jet stagnation temperatures between 286 K (cold jet) and 715 K (hot jet). The mixing characteristics of the jet were examined by conducting mean and fluctuating total pressure measurements in the axial and radial planes of the jet downstream of the nozzle-collar assembly. Fluctuating pressures measured along the geometrical axis of the jet indicate that the peak turbulence level lies closer to the jet exit when counterflow is applied. Complementary measurements made in the shear layer under similar flow conditions, indicate a significant increase in the overall turbulence level in the jet shear layers due to counterflow. These observations were essentially independent of the jet stagnation temperature. The corresponding mean total pressure measurements indicate that annular counterflow reduces the potential core length of the supersonic jets by a factor of two. Exhaustive studies conducted in our laboratory and summarized in Strykowski, Krothapalli & Jendoubi [1] attribute this mixing enhancement to increased shear layer growth rates by more than 60% compared to incompressible shear layers at similar velocity and density ratios. These aerodynamic measurements indicate that the counterflow significantly reduces the potential core, and therefore the supersonic region of the jet, and hence would appear to be an attractive control scheme for supersonic noise reduction. The most surprising result of the study was that the angle between the jet axis and the peak in the Overall Sound Pressure Level (OASPL) remained fixed when counterflow was supplied, despite the rather dramatic upstream shift in the peak turbulence level in the jet. This cast doubt on the notion that the primary source of the low frequency Mach wave radiation lies near the location of the peak rms pitot pressure. However, a closer examination of the measurements as outlined in King, Krothapalli & Strykowski [2] revealed that the reduction in the convection velocity of disturbances in the jet shear layer with counterflow essentially balanced the upstream shift in source location. Noise spectra obtained as a function of circular arc angle were used to explain why the OASPL of the counterflowing jet was higher at some angles relative to the free jet, but lower at others. In general, counterflow increases the noise levels at higher frequencies, suggesting that counterflow excites the smaller scale turbulence, a notion that is consistent with earlier findings that the rms pressure level in the jet shear layer was increased due to counterflow. At larger angles, the counterflow caused a reduction in the sound pressure level at all frequencies. Thus, the counterflow seems to interfere with the Mach wave radiation mechanism. In summary, these measurements suggest that enhanced mixing in the region close to the nozzle exit may not necessarily result in far-field noise reduction of a supersonic jet. This is primarily due to increased turbulence production that is closely associated with the enhanced mixing processes. The potential for using devices such as tabs and modifications to the nozzle exit geometry which may allow superior mixing through the introduction of streamwise vorticity without . significant thrust loss is explored. Although the mean and turbulent flow field of a jet at the nozzle exit with significant streamwise vorticity is very different than a corresponding axisymmetric jet, it does not appear to have a significant effect on the far field mixing noise of a supersonic jet. The flow and noise fields of a diamond-shaped jet are used to substantiate the above observation.