Fluctuating Flow Acceleration in a Heated Supersonic Jet

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Understanding the noise produced by jet engines has always presented a challenge to aero-acousticians, and continues to do so as the interest in reducing this noise grows. In the present work, as aspect of the behavior of equivalent noise source quantities are examined by leveraging the information contained within Lagrangian accelerations. Specifically, the contribution from pressure and viscous stresses to Lighthill’s stress tensor is directly related to flow accelerations, where \( p_{ij} \) is the pressure/viscous tensor defined by Lighthill. As such, one may write the gradient of Lighthill’s stress tensor as

\[
\frac{\partial \sigma_{ij}}{\partial \xi_j} = \rho \frac{\partial u_i}{\partial \xi_j} + \mu \frac{\partial^2 u_i}{\partial \xi_j^2}
\]

(2)

where \( p_j \) is the pressure/viscous stress defined by Lighthill.

Turbulence measurements are presented in figure 1 for Reynolds stresses and fluctuating acceleration. The same shear layer similarity used by Lau et al. (1979) faithfully scales the Reynolds stresses; and in this new result, the fluctuating accelerations, as well. To note that the radial and axial acceleration fluctuations appear isotropic, a result that does not hold for the Reynolds stress due to anisotropic production and compressibility-reduced velocity/pressure gradient correlations that drive re-distribution from the axial to radial stress. In the full manuscript, measurements are compared with incompressible results from Lehmann et al. The differences in acceleration fluctuation magnitude—scaled results are larger in the incompressible flow—with varying convective Mach number exhibit consistency with the trends for pressure fluctuation suppression obtained via direct numerical simulation by Freund et al. (2000), an analogy made via equation (1).

\[ \frac{\partial u_i}{\partial t} = \frac{d \nu_{ii}}{dx} + U_j f \frac{d}{dx} \frac{d}{dx} \]

(3)

where \( U_j \) is the velocity component sensed, \( f \) the Doppler frequency, \( d \) the fringe spacing and \( x_i \) the coordinate measured perpendicular to the fringes. The seminal work on this technique was reported by Lehmann et al. (2002). In this study, the discrete chirp Fourier transform is used to find the change in Doppler frequency.

Key Results

The Virginia Tech Hot Jet Facility was used for the experiments reported. For the current study, measurements are made with a design Mach number 1.65 bi-conic nozzle with an exit diameter of 38.1 mm (1.5”), an exit-to-throat area ratio of 1.295, and a design nozzle pressure ratio (NPR, total pressure to ambient pressure ratio) of 4.58. The jet was run at a total temperature ratio (TTR) of 2. Measurements were acquired along the lip-line out to 8 diameters and radially at stream-wise station of 4 and 8 diameters.

For this investigation, an advanced two-velocity-component, single transceiving lens, laser Doppler velocimeter (LDV) was used to acquire measurements within the heated supersonic jet. The new LDV has a measurement volume diameter of 60 µm and a fringe spacing of approximately 1.7 µm. This probe has a random single-sample uncertainty of \( \Delta u_i / U_i = 0.03\% \) for both velocity components. In order to find the acceleration of a particle as it passes through the measurement volume, the raw burst must be post-processed to find the rate of change in Doppler frequency with respect to time, as is evident in the dual beam LDV equation relating the acceleration to the instrument signal.

Approach