Estimation of particle sample bias in shear layers using velocity-data rate correlation coefficient

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Particle sampling bias in laser velocimetry measurements occurs in shear and mixing layers where the spread of the particle-laden flow is not only dependent on the mixing of the flows, but also on the spatial distribution of particles within the original flow. This study presented in this paper discusses the application of a velocity-data rate correlation coefficient as a measure of statistical dependence and thus the degree of velocity bias.

The motivation to investigate potential velocity bias effects arose when conventional flow statistics did not provide sufficient insight into the behavior of high-speed, jet-related shear layers. Since little or no research exists regarding bias effects in high-speed flows, guidance must be obtained from research in low-speed shear layers such as conducted by Meyers et al. (1990). Their work clearly showed using the velocity-data rate correlation that bias was present only in shear regions where particle number densities between the two flows cannot be balanced.

The correlation between velocity and data rate was verified by calculating the standard correlation coefficient between any two processes as shown in equation 1, under a hypothesis that high velocity increases the data rate while lower velocities decrease the data rate.

\[ C = \frac{\langle U - u_i \rangle \langle R - r_i \rangle}{\sigma_u \sigma_r} \] (1)

Equation (1) was recommended by a panel of nine recognized experts in laser velocimetry in determining whether or not sampling bias was present in a given data ensemble (Edwards (1987)) wherein \( U \) (mean velocity) and \( R \) (mean data rate) are standard calculations. Expanding on the original work by Edwards and Jensen (1983), Edwards and Meyers (1984) developed an approach of calculating the instantaneous velocity \( \langle u_i \rangle \) and instantaneous data rate \( \langle r_i \rangle \) by estimating the Taylor temporal microscale (Edward-Meyers approach). In equation (1), \( \sigma_u \) is the standard deviation of instantaneous velocities or the first measurement in each Taylor microscale and, \( \sigma_r \) is standard deviation of instantaneous data rates or the number of measurements in each Taylor microscale.

The study presented in this paper reports on the location-specific changes in velocity bias in a free shear layer of a round supersonic jet using the velocity-data rate correlation coefficient as a post-facto measure, building on earlier work by Meyers et al. (1990). Velocity-data rate correlation coefficients were calculated for laser velocimetry data by alternately seeding primary (core) flow and secondary (entrained) flow at every measurement location. Subsonic (Mach 0.25), supersonic (Mach 1.4) and partially confined supersonic jets were accordingly investigated, using a single component, forward-scatter LDV system.

Subsonic jet (Mach 0.25) data, considered as a baseline measurement, demonstrated mixing activity emanating at 6 diameters downstream of the jet source with high correlation values \( (C \approx 0.1) \). Within the extent of axial measurement locations, supersonic jet (Mach 1.4) data was void of mixing activity as demonstrated by a low range of correlation values \( (-0.05 \leq C \leq 0.03) \). This suggested that the axial length scale of mixing between primary and secondary flow streams occurred several diameters downstream of the circular supersonic jet source. Partially confining the supersonic jet enhanced mixing activity as evidenced by the increase in correlation coefficient \( (-0.08 \leq C \leq 0.08) \), skewness towards the baseline measure \( (C \approx 0.1) \) and alternating trends between primary and secondary flow measurements.

The results reported in this study suggest that velocity-data rate correlation provides a means to enhance our understanding of spreading and mixing in particle-laden shear layers and necessitates further application-specific examination. With several potential applications ranging from shear layer detection to vortical size estimation, where conventional flow statistics may not yield insights, the velocity-data rate correlation coefficient will clarify and elucidate flow behavior provided the measurements are statistically stationary and involve high data rates.

References


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