CONDITIONAL VELOCITY AND SCALAR STATISTICS FOR PASSIVE-SCALAR MIXING IN CONFINED TURBULENT SHEAR FLOWS

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A detailed understanding of turbulent shear flows is crucial for the development of environmentally benign, commercially efficient chemical processing technologies. In the present work, a combined particle image velocimetry (PIV) and planar laser-induced fluorescence (PLIF) system was employed to investigate turbulent mixing in a confined liquid-phase plane-wake flow and in a confined liquid-phase planar-jet flow. The Reynolds number based on bulk velocity and hydraulic diameter of the wake flow was 37,500, whereas that of the jet flow was 50,000. The Schmidt number for the passive scalar was approximately 1,250. In each case, 3,250 sets of simultaneous velocity and scalar fields were collected at each of the observed six downstream locations.

The measurement data were analyzed for flow statistics such as mean velocity, Reynolds stresses, scalar mean and variance, turbulent fluxes, turbulent viscosity and diffusivity, and turbulent Schimdt number. In the wake flow, the streamwise and transverse turbulent fluxes were found to be of the same magnitude, although the former was symmetric about the centerline of the test section, whereas the latter was antisymmetric about the centerline. The dimensionless turbulent viscosity was initially around 0.002 and increased in the streamwise direction. Two components of the turbulent diffusivity tensor were evaluated, showing that the mean scalar gradient was not aligned with the turbulent flux. The turbulent Schmidt number was found to be around 0.8 in the confined plane wake.

The spatial correlations of turbulent fluxes and concentration fluctuations were evaluated to identify the characteristics of large-scale turbulent structures in the wake. In the $R_{u'\phi'}$ correlation field, there were a positive and a negative vertically-oriented-elliptical correlation region, which were symmetric around the basis point. The $R_{v'\phi'}$ correlation region was a horizontally oriented ellipse with negative values of the correlation coefficient. The correlation field of $R_{\phi'\phi'}$ was also an ellipse with a horizontal major axis. The behavior of large-scale structures in both the velocity and scalar field was then studied using linear stochastic estimation with a defined event of scalar fluctuation. The streamwise growth of the structure size increased linearly initially but then grew more slowly. The stochastic estimates of the velocity field indicate the presence of a well-defined vortex street. The flow statistics and spatial correlations for the jet flow have been reported in [1].

Velocity components conditioned on the scalar for both the wake and jet flows were also evaluated. It was found that the conditional velocity was consistent with a linear model, suggesting that the joint velocity-scalar PDF was nearly Gaussian in these flows. Another model for the conditional velocity proposed in [2] was also tested against the experimental data. The model predicted the cross-stream conditional velocity very well, but gave poor predictions for the streamwise conditional velocity. Finally, the scalar fluctuations conditioned on velocity (an important quantity in molecular-mixing models) will also presented and analyzed against existing models.

References

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