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Validation and uncertainty framework for variable-density mixing experiments

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ABSTRACT

Variable-density mixing (e.g., mixing due to the Rayleigh–Taylor (RT) and Richtmyer–Meshkov (RM) instabilities) is observed in many engineering applications. For example, RT mixing is observed in geophysical flows, stratified oceanic or atmospheric layers, and contaminant mixing, such as oil spills or pollution. Although less common, RM mixing is present in hypersonic combustion, supernova, and inertial confinement fusion. Current computational fluid dynamics models inadequately predict variable-density mixing physics and developments need to be validated with experimental data. However, variable-density experiments are complicated due to the range of spatial mixing scales and inherent coupling of density and velocity. This requires simultaneous measurement of the density and velocity fields and is typically accomplished via simultaneous particle image velocimetry (PIV) and planar laser-induced fluorescence (PLIF) with two distinct measurement systems. This introduces additional error sources to traditional PIV. Correlated density-velocity quantities (e.g., Favre-averaged Reynolds stresses and mass fluxes) are contaminated by both PIV and PLIF uncertainties. Moreover, spatial registration and sheet alignment errors between PIV and PLIF measurements are introduced for all flow quantities and magnified for correlated quantities. The Extreme Fluids Team at Los Alamos National Laboratory (LANL) is conducting multiple variable density validation experiments. The vertical shock tube (VST) is designed to statistically characterize RM mixing, whereas the turbulent mixing tunnel (TMT) investigates RT and Kelvin–Helmholtz mixing. Simultaneous two-component PIV and PLIF diagnostics are used in both facilities. Although the TMT can acquire large ensemble averaged datasets, the ability of acquiring large numbers of dataset realizations from the VST is severely limited. A framework for variable-density uncertainty quantification and validation is presented for both experiments. This framework follows the validation experiment assessment criteria presented by Oberkampf and Smith [1] with a goal of achieving at least a Level 2 completeness level. Both facilities have been designed to accurately describe the experimental conditions. The most difficult issue is quantifying the measurement uncertainties. Instantaneous PIV uncertainties are estimated using the uncertainty surface method [2] the peak ratio method [3], then propagated into the velocity statistics [4]. The effects of spatial registration sheet alignment errors are also assessed and initial uncertainty estimates due to these quantities are presented. Using the same methods as [4], PIV, PLIF, registration and alignment uncertainties are propagated into the Favre-averaged stresses and mass fluxes.