EXPERIMENTAL AND NUMERICAL STUDY OF THE TURBULENT/NON-TURBULENT INTERFACE IN A TURBULENT ROUND JET FLOW

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Abstract Based on two large-eddy simulations (LES) of a non-reacting turbulent round jet with a nozzle based Reynolds number of 8,610 with the same configuration as the one that has recently been investigated experimentally [4, 5, 6], we examine the scalar turbulent/non-turbulent (T/NT) interface layer in the mixture fraction field of the jet flow between ten and thirty nozzle diameters downstream. Based on the simulations, we investigate probability density functions (pdfs) of the mixture fraction and compare the results to the experimental ones. Furthermore, statistics of the T/NT interface are studied from simulation and experiment with a focus on the pdf of the location of the interface and the mixture fraction profile across it.

LARGE-EDDY SIMULATIONS

The LES of the non-reacting turbulent round jet are conducted using a parallel finite difference code [1], which solves the filtered Navier-Stokes equations in the low Mach limit. Additionally, a transport equation is solved for the filtered mixture fraction. A dynamic Smagorinsky-type model with Lagrangian filtering [8, 9] is employed to achieve modeling of the unclosed subfilter stress and subfilter scalar flux terms. A multi-grid HYPRE solver is used for the Poisson equation of the pressure [3]. The code uses a Crank-Nicholson type time advancement, and an iterative predictor-corrector updating scheme. Velocity gradients are determined using second order schemes, while scalar gradients are calculated based on a third order WENO [7] finite difference scheme. To increase the accuracy of spatial and temporal discretization a staggered-variable formulation is employed in the code [1].

The LES are carried out on two different meshes to assess the influence of the grid resolution on the T/NT interface layer. The numerical domain is discretized by a structured mesh with cylindrical coordinates. The coarse mesh consists of 1.5 million grid cells, which are distributed with $256 \times 96 \times 64$ grid cells in axial, radial and circumferential direction, respectively. The fine mesh consists of 3.1 million grid cells, with the count of grid cells equal to the coarse mesh in axial and circumferential direction. In radial direction the number of grid points is doubled to increase the resolution of the T/NT interface layer so that the grid consists of $256 \times 192 \times 64$ grid cells. The numerical domain extends from x/d=-1 upstream of the jet (a small portion of the inlet nozzle geometry is included) to x/d=50 downstream of the nozzle exit in axial direction and extends to a radius of r/d=33 in radial direction. For a first validation, we have compared the simulation results against the experimental data using the axial decay of the mean velocity and the mean mixture fraction as well as based on radial self-similar profiles of mean and root mean square values of these two quantities. The results of this validation suggest, that the proposed method is adequate.

RESULTS

Probability density functions of the mixture fraction at various axial and radial positions are compared and the quality of the LES is discussed. In general, the LES results are consistent with the experimental data. However, in the flow region where the imprint of the T/NT interface layer is dominant in the mixture fraction pdf, see Fig. 1(a) for an exemplary result, discrepancies are observed. In addition, we have included the pdfs one obtains by modelling the experimental pdf using a

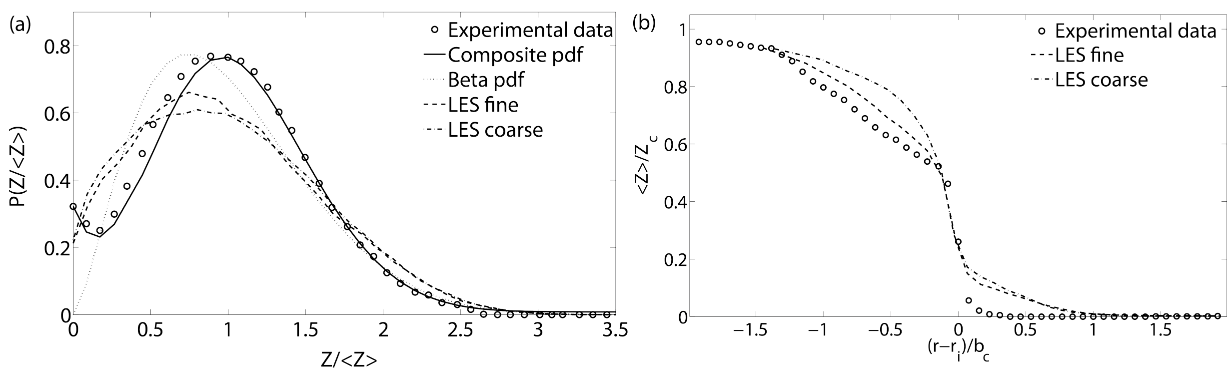

Figure 1. (a) Comparison of mixture fraction pdfs from LES, experiment and composite model at x/d=15 and $\tilde{r}$=0.135 and (b) Comparison of the profiles of the conditional mean mixture fraction across the T/NT interface layer for x/d=30 from LES and experiment.

beta pdf and the composite pdf, cf. [2], for comparison.
Furthermore, statistics of the T/NT interface layer are studied. To this end, it first has to be detected in the scalar field. We follow a threshold procedure described by Prasad and Sreenivasan [10]. The threshold value at which the so called envelope, cf. [11], is located is determined as the local minimum value if the histogram of the mixture fraction within one planar image in the experiment or within the whole domain for the LES data is bimodal. In those cases, however, where the histogram is not bimodal, the average mixture fraction over the entire image is calculated as a function of the threshold using only those values that exceed this threshold. Then, the latter is simply calculated numerically by finding the inflection point of the threshold average mixture fraction curve. For the two LES this procedure yields a value of Z=0.05 which is in good agreement with the experimental one (Z=0.045), see fig. 2 for an instantaneous mixture fraction field with a three-dimensional visualization of the envelope for the mixture fraction field.

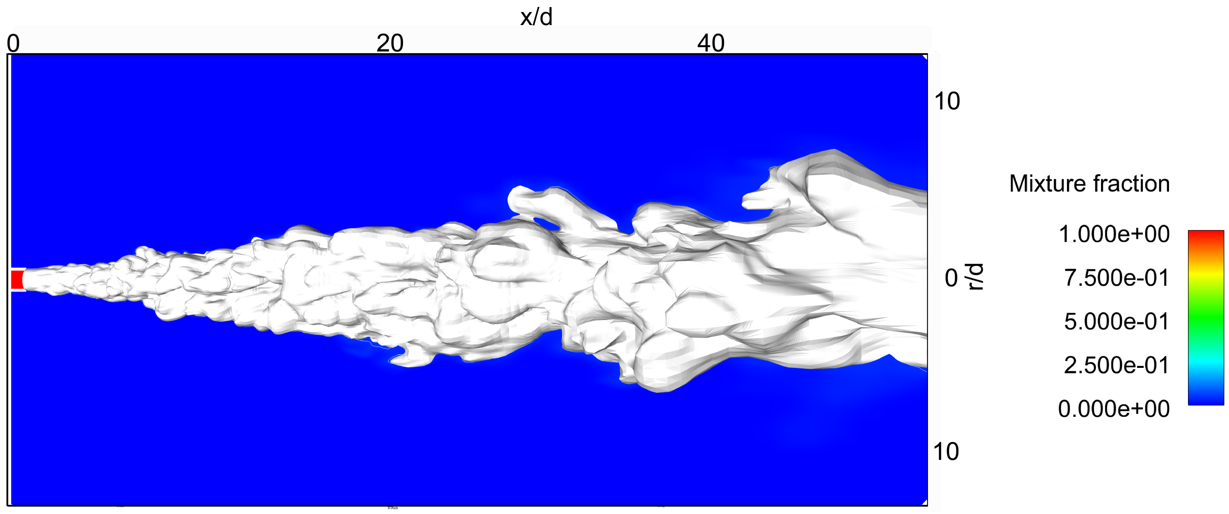

Figure 2. Three-dimensional illustration of the instantaneous envelope iso-surface from the fine LES. For clarity only a small part of the domain is shown.

We observe a satisfactory agreement for the pdf of the location of the interface layer from the higher resolved LES with the experimental data, while the one with the coarse grid exhibits considerable deviations. Finally, the mixture fraction profile across the interface is investigated where the same trend as for the pdf of the location is present. In particular, it is found that the sharp interface that is present in experimental studies [5, 11] is less distinct in the LES results and rather diffused in radial direction outside of the T/NT interface layer, see Fig. 1(b).

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