Coherent Fine-Scale Eddy Cluster in a Turbulent Mixing Layer

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Clustering of coherent fine-scale structures in a turbulent mixing layer has been analyzed by a direct numerical simulation (DNS) database at Reλ ≃ 250. The coherent fine-scale structures are extracted based on the second invariant of the velocity gradient tensor and the vorticity vector. Their characteristics are consistent with the lower Reynolds number data (Tanahashi et al., 2001). The clustering is evaluated by the number density $N$ of coherent fine-scale eddies. The large-scale structures are extracted by low-pass filtering velocity data using a Gaussian kernel with a filter width of $\Delta = 160\eta$. The correlations between the number density and large-scale turbulence characteristics such as the enstrophy, the strain rate magnitude and the enstrophy amplification rate are investigated.

The enstrophy is more correlated with the number density compared to the strain rate and the enstrophy amplification rate. Figure 1 presents the filtered enstrophy $\langle \omega^2 \rangle_V$, strain rate magnitude $\langle S_{ij}S_{ij} \rangle_V$ and amplification rate of the enstrophy $\langle \omega_i S_{ij} \omega_j \rangle_V$ conditionally averaged on the number density of the coherent fine-scale eddies. The enstrophy constantly increases with $N$. On the other hand, the strain rate stays a value around average through from intermediate to high $N$ regions. The large-scale enstrophy amplification is active in the region where the coherent fine-scale eddies are moderately populated, whereas in the region where the coherent fine-scale eddies are highly populated, the enstrophy amplification at large-scale becomes weaker.

Figure 2 indicates the joint p.d.f.s of $\langle \omega_i S_{ij} \omega_j \rangle_V$ and $\langle S_{ij}S_{ij} \rangle_V$. For large-scale structures, the negative enstrophy amplification is not associated with the strong strain rate event. It is noted that the intense enstrophy event is significantly correlated with both negative and positive enstrophy amplification. This indicates that large-scale intense strain plays an important role in positive enstrophy amplification.

Furthermore, the alignments of the vorticity vector and the eigenvectors of the large-scale strain rate tensor are evaluated. These alignment are computed by imposing a condition on the number density or the strain rate magnitude. Under the intense strain rate, the vorticity vector and the eigenvectors indicate the strong preferential alignment. On the other hand, the alignment becomes weaker in the high number density region of the fine-scale eddies.

Finally, the inter-scale energy transfer is evaluated from the energy transfer between grid and subgrid scales. By definition, the significant positive correlation is observed in the magnitude of the strain rate and the inter-scale energy transfer while it is not much apparent with the number density.

REFERENCES