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Subgrid Scale Dynamics of Rayleigh-Taylor Turbulence and Mixing

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The energy transfer process and the interaction of different scales in a flow induced by the variable-density Rayleigh-Taylor instability in miscible fluids is investigated using a three-dimensional DNS dataset with a resolution of $512^2 \times 2040$. The method used to quantify the energy transfer between the supergrid and subgrid scales in the homogeneous planes, determined by partitioning the modes into resolved and unresolved scales defined by a two-dimensional, artificial cutoff wave number k_c in Fourier space, is applied to the kinetic energy evolution equation. Using a sharp Fourier cutoff filter, the kinetic energy transfer is decomposed into the resolved part, a part corresponding to the interaction between resolved and unresolved scales, and a part corresponding to the interaction between unresolved scales. These z-dependent spectra are computed for k_c = 8, 16, and 32 to investigate the dependence of the transfer process on the range of scales contributing to the subgrid interactions. The kinetic energy transfer is further decomposed into its positive and negative components corresponding to the forward and backward cascades of energy, respectively. The decomposition into resolved and unresolved scales is used to define an effective eddy and backscatter viscosity. The principal conclusions are: (1) the transfer spectra and eddy viscosities exhibit a strong dependence on k_c; (2) the contributions from the interaction between resolved and unresolved scales dominate the contribution to the total subgrid eddy viscosities and are responsible for the cusp at large k/k_c; (3) the contributions from the interaction between unresolved scales dominates the contribution to the total subgrid eddy viscosities at small k/k_c and are responsible for the small, negative contribution, and; (4) backscatter is strongest in the regions near the boundaries of the mixing layer. The implications of these results for subgrid-scale modeling in large-eddy simulation (LES) of Rayleigh-Taylor instability-induced turbulence are discussed.

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