ICLASS 2012, 12th Triennial International Conference on Liquid Atomization and Spray Systems, Heidelberg, Germany, September 2-6, 2012

Explicitly Filtered Large Eddy Simulation of Two-Phase Flows with Evaporating Drops for Separating Numerical and Modelling Aspects

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Abstract

Numerical computations of sprays in turbulent flows provide a cheaper alternative to performing experiments in order to determine an optimal design envelope. The most accurate method for numerically simulating the flow is based on Direct Numerical Simulation (DNS) of the governing equations in which all scales of the flow relevant to dissipation are resolved. DNS, however, requires high computational cost and cannot be used in engineering design applications where iterations among several design conditions are necessary. Large Eddy Simulation (LES) provides a cheaper alternative to numerically simulate multiphase turbulent flows, although it has modeling requirements which do not exist in DNS. In LES only the energy-containing large scales, which are of engineering interest, are resolved and the more universal small scales are modeled thereby minimizing computational costs. The LES equations are obtained by filtering the Navier-Stokes equations. Thus, in the LES equations, the effect of the filtered small-scale motion on resolved large scale motion appears as Subgrid-Scale (SGS) terms and it represents the effect of the unresolved or "sub-grid" flow field which is unavailable; thus, these terms must be modeled. This modeling is typically done through representing the subgrid scale terms as functions of the large scale, i.e. LES, flow field. Despite great strides in LES, several unresolved problems remain. One of these problems plaguing model validation when comparing with a trusted template is the lack of grid independence of LES results. It is often assumed that the filter width is the same as the local grid spacing, an assumption which introduces considerable error in the smallest resolved scales that are most affected by numerical errors and considerable error in regions where the grid spacing varies drastically, as for instance in simulations where adaptive grid refinement is used in some regions to better capture the physics. To investigate whether predictions from conventional Large Eddy Simulation (LES), which are known to be grid-spacing and spatial discretization-order dependent, can be rendered grid-spacing and discretization-order independent, LES has been reformulated by explicitly filtering the non-linear terms in the governing equations. This reformulation leads to different gas phase equations, different gas-phase SGS terms and correspondingly, different gas-phase SGS models. Because in two-phase flow LES the effect of the drops on the gas mathematically manifests as source terms in the gas-phase equations, upon filtering the governing equations, the resulting filtered source terms can no longer be computed from the flow field solution, and instead must be modeled. Thus, SGS models must be developed for the drop field to compute these filtered source terms. The template for comparison with either LES or explicitly-filtered LES (EFLES) was obtained by creating a DNS database which is then filtered (FDNS). Conventional LES is conducted with the Smagorinsky model for the gas phase, and EFLES is also performed with Smagorinsky model; the drop-field SGS model is the same in all these simulations. The conventional LES method yields solutions which are both grid-spacing and spatial discretization-order dependent. The EFLES solutions are found to be grid-spacing independent for sufficiently large filter-width to grid-spacing ratio, although for the highest discretization order this ratio is larger in the two-phase flow compared to the findings in a similar study conducted for single-phase flows. For a sufficiently fine grid, the results are also discretization-order independent.

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