Recent Progress on Coarse Grained Simulations of Turbulent Mixing (+)

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We are interested in detailed understanding of the late-time consequences of mixing driven by hydrodynamical instabilities promoted by initial conditions at accelerated material interfaces, as in Inertial Confinement Fusion (ICF) capsule implosions. The flow physics is driven by flow instabilities such as Richtmyer-Meshkov, Kelvin-Helmholtz, Rayleigh-Taylor (RT), and vortex stretching. The initial conditions dependent flow involves transition to turbulence, turbulence decay, and non-equilibrium turbulence. Such flow physics can be captured with coarse-grained simulation (CGS) paradigms such as LES/ILES, [1] where small-scale flow dynamics is presumed enslaved to that of largest scales, and mix transition criteria and effective turbulence Reynolds numbers are used for macroscopic convergence metrics. [2]

We revisit CGS strategies for turbulent material mixing applications, based on LANL's *Radiation Adaptive Grid Eulerian* (xRAGE) – LES/ILES, and Besnard-Harlow-Rauenzahn (BHR) – Reynolds-Averaged Navier-Stokes (RANS), using newly-available xRAGE HLLC numerical hydrodynamics options, [3] including a Low-Mach Correction (explicit subgrid scale model) [4] to address the well-known issue of excessive numerical diffusion of upwinding schemes for low Mach numbers. [5] The latter is a serious concern given that mixing of interest involves weakly compressible flow between shock events. [6]

RANS typically presumes equilibrium turbulence and enstrophy production slaved to kinetic energy production, and 1D/2D computations are often involved. [7] There are outstanding problems using such standalone RANS for shock-driven turbulence, specifically: 1) transitional initial-conditions-dependent flow physics is 3D and non-equilibrium; 2) enstrophy generation is inherently very different from energy production; 3) transition to turbulence is driven by large-scale vortex dynamics, capturable with CGS, but not by single-point-closure RANS. [8]

Dynamic BHR [9,10] bridging BHR and xRAGE for applications involving variable-density turbulent mixing applications was recently proposed. The bridging approach exploits the structure similarity of the RANS & LES/ILES equations. It is based on the Flow Simulation Methodology,[11] locally blending a high-resolution computational strategy with RANS modeling in terms of a contribution function

$$f = f\,(\Delta/L),$$

ranging between $0 < f < 1$ – with $f \rightarrow 0$ denoting the high-resolution limit, and $f \rightarrow 1$ the pure RANS, at the low-resolution limit, and where Δ is the smallest grid size and L is a resolution reference length scale.

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Dynamically solving for f decomposing the full stress into modeled and resolved components – using a differential filter as secondary filtering operation [12] to define the resolved part, was first proposed [13] and recently extended [9,10] by additionally requiring the resolved stress to approach the full stress with grid refinement to ensure realizability of the generated bridging-based LES. In contrast, classical FSM [11] defines $f(\Delta/L)$ explicitly in empirical ad hoc fashion.

We report progress with xRAGE LES and Dynamic BHR simulations for relevant test cases including, shock tube experiments [3,10,14,15] and RT driven flow and mixing. [16,17] We note the significant impact of the new HLLC numerical hydrodynamics in xRAGE with Low-Mach Correction [3,10,14,16,17] – e.g., Fig.1, enabling higher-fidelity scale-resolving simulations on coarser grids.

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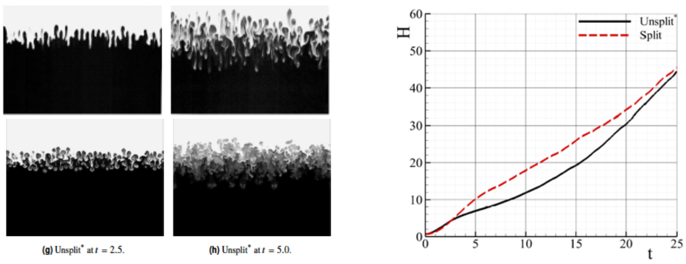

Figure 1. Mass density distributions and mix-width from *At-0.5 RT* xRAGE simulations (split on the top, unsplit* with Low-Mach Correction, below). Unsplit* capably captures: 1) early-time mix-width quadratic growth, 2) late-time RT small-scale mixing; 512^2 x 1536 simulations [16,17].

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