MATHEMATICAL, PHYSICAL AND NUMERICAL PRINCIPLES ESSENTIAL FOR MODELS OF TURBULENT MIXING

HYUNKYUNG LIM*, YAN YU†, JAMES GLIMM‡, AND DAVID H. SHARP§

Abstract.

We propose mathematical, physical and numerical principles which are important for the modeling of turbulent mixing, especially the classical and well studied Rayleigh-Taylor and Richtmyer-Meshkov instabilities which involve acceleration driven mixing of a fluid discontinuity layer, by (respectively) a continuous acceleration or an impulsive delta function force.

The fundamental mathematical issue is the nonuniqueness and thus indeterminacy of solutions of the 3D compressible Euler equation. Verification (demonstration that the numerical solution of the equations is mathematically correct) is meaningless for such a model of turbulent mixing. Uniqueness requires physical fluid transport, i.e. the compressible (multifluid) Navier-Stokes equation.

The same fundamental issue, formulated in terms of physics, is that the properties of the mixing depend on dimensionless ratios of the transport coefficients, namely the Schmidt number (viscosity/mass diffusion) and Prandtl number (viscosity/thermal conductivity). Validation (meaning that the simulation equations correctly model the problem to be solved) is impossible without specification of fluid transport. It is in effect an effort to validate an answer for 0/0.

The fundamental issue, formulated in numerical terms is that the physical transport terms are so small that they cannot be resolved at feasible grid levels. Large eddy simulations (LES) are needed. For these, subgrid scale (SGS) terms must be added to the equations, to correctly reflect the influence of the unresolved transport on the grid scales that are resolved. In the absence of such an approach, numerical artifacts intrude, leading to apparently converged solutions, with answers that depend on the computer code.

Plainly, this issue, in its three guises, poses a challenge for verification and validation (V&V), and since V&V is a major scientific enterprise, it is of great importance.

Keywords: Schmidt number, Prandtl number, Mass Diffusion, Turbulence, Multiphase Flow

Turbulent mixing is central to a number of problems, including turbulent combustion and inertial confinement fusion. Classic acceleration driven instabilities (Rayleigh-Taylor for continuous acceleration and Richtmyer-Meshkov for impulsive acceleration) have been a numerical challenge for 50 years. A satisfactory solution should

1. use a compressible code,
2. satisfy V&V standards,
3. achieve mesh converged joint probability distributions for temperature and mixture concentrations as is required for turbulent combustion,
4. not require full resolution (DNS) of all turbulent length scales,
5. apply over a range of physical parameters, including high Schmidt numbers,
6. provide sufficient intellectual understanding that others can follow and improve.

The progress summarized here is based on recent series of articles that achieve these six goals.

The compressible code is the LANL-Stony Brook code FronTier, whose main two innovative features are

- Front tracking to eliminate numerical mass diffusion across fluid interfaces and
- Dynamic subgrid scale (SGS) models to represent turbulent fluctuations at levels below the grid resolution.

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