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Hydrodynamic Instabilities and Turbulent Mixing: what is it, what is known, what is new, and what remains to be done?[1]

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Hydrodynamic instabilities are of crucial importance in describing many phenomena, from very large scales such as stellar explosions (supernovae) to very small scales, such as inertial confinement fusion (ICF) implosions. Such mixing causes overturn of massive stellar cores in supernovae, and has affected attempts at ICF ignition. The Rayleigh-Taylor (RT) instability occurs at an accelerated interface between two fluids with the lower density accelerating the higher density fluid, and the Richtmyer-Meshkov (RM) instability occurs when a shock wave passes an interface between the two fluids. Buoyancy causes "bubbles" of the light fluid to penetrate the denser fluid, while "spikes" of the heavy fluid penetrate the lighter fluid. In the deep nonlinear regime, this interpenetration evolves into turbulent mixing which has been notoriously difficult to predict quantitatively. With realistic multi-mode initial conditions, in the deep nonlinear regime, the mixing zone width, h, and its internal structure, progress through an inverse cascade of spatial scales, reaching an asymptotic self-similar evolution: h= $\alpha_{\mathrm{RT}}\mathrm{Agt}^2$ for RT and h= $\alpha_{\mathrm{RM}}\mathrm{t}^{\theta}$ for RM. While this characteristic behavior has been known for about 30 years, the self-similar parameters α_{RT} and θ_{RM} and their dependence on dimensionality and density ratio have continued to be intensively studied and a relatively wide distribution of those values have emerged. A new, physically intuitive formulation of mode-coupling and bubble-competition models can yield a unified and compact description of this turbulent mixing evolution, greatly reducing the spread in α_{RT} and θ_{RM}. This allows building more effective engineering models for the extent of the turbulent mixing in such diverse settings as ICF capsule implosions and stellar explosions. The implications for ignition and the potential to use NIF for quantitative testing of this theoretical advance will also be discussed.

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