17th U.S. National Congress on Theoretical and Applied Mechanics
Michigan State University, June 15-20, 2014

Abstract: F-10-427

Direct numerical simulation of the Rayleigh-Taylor instability in a pre-existing turbulent field

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The Rayleigh-Taylor (RT) instability occurs in a variety of applications at different scales, ranging from inertial confinement fusion to supernova explosion. In RT-unstable configurations, initial perturbations at a heavy-light interface may evolve to a turbulent mixing region, in a process in which the initial potential energy feeds the instability growth. In this process, baroclinic vorticity is generated due to the misalignment of the density and the pressure gradients. The local density gradient depends on how the two different fluids get mixed with each other due to large-scale entrainment and dispersion by turbulent eddies. In addition, mass diffusion in miscible fluids acting at small scales tends to destroy the sharp interfaces between the heavy and light fluids resulting in molecularly mixed regions. Thus, turbulent mixing affects the local density gradient and consequently the local rate of baroclinic vorticity generation. A better understanding of turbulent mixing, which plays an important role on flow dynamics inside the mixing region in RT flows, is desired. Particularly, measures of flow isotropy at different scales in different directions are of great interest. Due to the presence of the gravitational field and the large-scale density gradient across the mixing region, the resulting turbulence is anisotropic at the Taylor microscale while flow remains isotropic at the Kolmogorov microscale [1]. However, these two effects (density gradient and gravity) are generally coupled, such that it is difficult to assess each one individually.

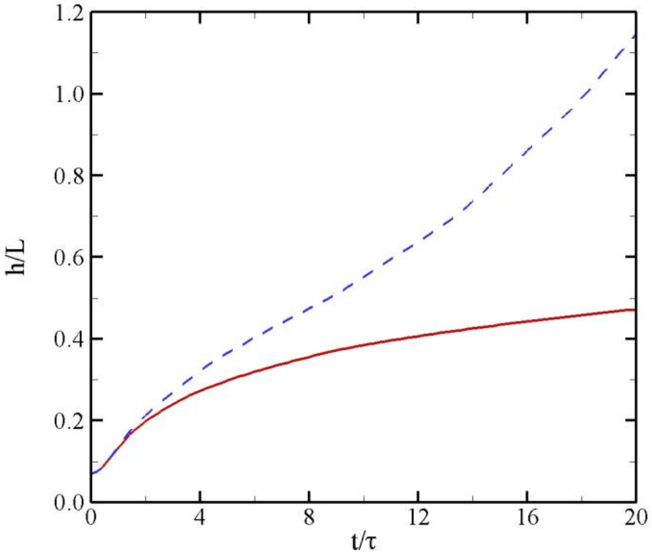

Figure 1. Temporal evolution of the mixing region width. Red: without gravity; blue: with gravity.

The goal of this study is to better understand anisotropy in turbulence through the Rayleigh-Taylor instability using direct numerical simulation (DNS). We use a novel set-up to study the temporal evolution of the mixing region starting from an unperturbed material interface in an existing isotropic field in the presence and absence of gravity [2]. First, we ignore gravity and focus on the temporal evolution of the mixing region due to turbulence diffusion. This set-up allows us to study the role of density gradient across the mixing region individually. The initial mid-plane moves toward the lighter fluid in agreement with momentum considerations. Different quantities regarding flow isotropy and intermittency inside the mixing region are investigated. Second, we assess the role of gravity in a RT unstable configuration, in comparison to our first set of runs. Now, the baroclinic vorticity due to the gravitational field provides energy driving the initially decaying turbulent field. A comparison of relevant physical quantities regarding isotropy and mixing is made between both cases. The role of different initial most energetic wave numbers of the initial decaying field and Reynolds number are investigated. The DNS are performed using a high-order accurate minimally dissipative kinetic-energy preserving and interface capturing scheme [2,3].

Figure 1 shows the temporal evolution of the mixing region width. The mixing region grows initially due to turbulence diffusion. In the absence of gravity, the growth rate decreases with time as the initial turbulent field freely decays due to physical diffusion. Several arguments are proposed to describe the observed growth based on eddy diffusivity concepts and energy budget arguments. The current results suggest that the mixing region grows self-similarly after an initial transient period and in particular, the mixing region grows as t^{θ}, where θ is found to be between 2/7 and 0.5 based on the initial Taylor-scale Reynolds number and the density ratio between the two fluids. In the presence of gravity, the mixing grows initially due to turbulence diffusion. The density field also gets perturbed due to the initial turbulent velocity field. Consequently, these perturbations lead to the RT instability inside the mixing region. Baroclinic vorticity generated due to the instability provides turbulent kinetic energy for the initial decaying field. This results in a larger mixing region width compared to the simulations without gravity as shown in figure 1.

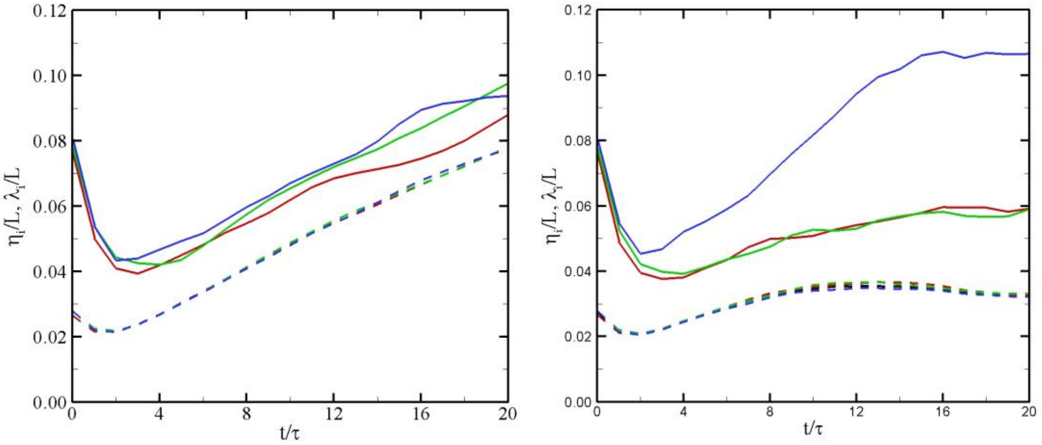

Figure 2. Time evolution of the directional Taylor (solid) and Kolmogorov microscales (dashed). Blue corresponds to the direction of large-scale anisotropy.

Figure 2 depicts the temporal evolution of the directional Taylor and Kolmogorov microscales. The flow becomes anisotropic at the Taylor microscale in the direction of large-scale anisotropy in the RT unstable set-up [5] while still remains nearly isotropic in the absence of gravity. This suggests that at a modest density ratio of 3, the large-scale anisotropy in the density gradient is not sufficient to force the turbulence to become anisotropic at the Taylor microscale. At the Kolmogorov scale, the flow is found to remain isotropic for both set-ups. We will report the energy spectra, the large-scale anisotropy tensor, the measurement of mixedness, the Corrsin microscale, and the flow intermittency for different Reynolds numbers and density ratios at the conference [4,5].

Acknowledgments

This work used the Extreme Science and Engineering Discovery environment (XSEDE), which is supported by National Science Foundation grant number OCI-1053575.

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