# Direct Numerical Simulations of Rayleigh-Taylor instability with gravity reversal

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**Abstract:** The development of the Rayleigh-Taylor mixing layer is studied using data from an extensive new set of Direct Numerical Simulations (DNS), performed on the 0.5 Petaflops, 150,000 compute cores BG/L Dawn supercomputer at LLNL. This includes a suite of simulations with grid size of $1024^2 \times 4608$ and Atwood number ranging from 0.04 to 0.9, in order to examine small departures from the Boussinesq approximation as well as large density ratio effects, and a high resolution simulation of grid size $4096^2 \times 4032$ and Atwood number of 0.75. After the layer width had developed substantially, additional branched simulations have been run under reversed and zero gravity conditions. While the bulk of the results will be published elsewhere, here we focus on the modifications in the mixing layer structure in response to acceleration change.

*Keywords:* Direct Numerical Simulations, Turbulent mixing

Rayleigh-Taylor instability (RTI), which is generated at the interface between a heavy and light fluid, in the presence of a constant gravitational field (or, more generally, acceleration) in an unstable configuration, is of fundamental importance in a multitude of applications ranging from fluidized beds, oceans and atmosphere, to ICF and supernovae [1, 2]. Although this instability has been subjected to intense research over the last 50 years, until recently, numerical studies have been restricted to coarse mesh calculations. On the other hand, it is notoriously difficult, in laboratory experiments, to accurately characterize the initial conditions and provide the detailed measurements needed for turbulence model development and validation. Thus, a large number of open questions remain unanswered about this instability and even first order global quantities, such as the layer growth, are not completely understood and still give rise to intense debate [3]. Nevertheless, today's petascale computers allow fully resolved simulations of RTI at parameter ranges comparable to those attained in laboratory experiments, but providing, in carefully controlled initial and boundary conditions studies, much more information than the actual experiments. These extremely high resolution simulations are enabling a look at the physics of turbulence and turbulent mixing in unprecedented detail, hopefully contributing to a significant advance in our understanding of these phenomena.

The primary nondimensional parameter characterizing differential acceleration effects is the Atwood number, $A = \frac{\rho_2 - \rho_1}{\rho_2 + \rho_1}$, where $\rho_1$, $\rho_2$ are the densities of the light and heavy fluids. $A$ ranges from 0 to 1. For air inter-penetrating helium, for which the density ratio is $\frac{\rho_2}{\rho_1} \approx 7$, $A \approx 0.75$. For air and hydrogen, $A \approx 0.85$. In contrast, the Boussinesq approximation corresponds to $A \to 0$.

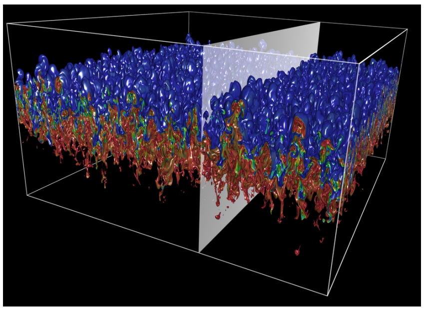

Figure 1: Three-dimensional visualization of the density field showing the asymmetry of the Rayleigh-Taylor mixing layer at $A = 0.75$, with the development of bubbles on the heavy fluid side and spikes on the light fluid side, from the $4096^2 \times 4032$ simulation.

Most previous studies address the low to moderate $A$ and no DNS have been reported, prior to the present set, for $A > 0.5$. At high $A$, the velocity field is no longer solenoidal even when the two fluids are incompressible. The development of the instability and the mixing itself are fundamentally different at high and low $A$ (figure 1) [4, 5]. The numerical methodology we have used for this problem is based on a hybrid Fourier-high order compact finite differences method, coupled with a novel, high accuracy variable coefficient Poisson equation solver [3]. In addition, we have performed extensive resolution studies to ensure that the solutions are converged and the relevant scales of motion are fully resolved. The current set of RTI simulations, on meshes up to $4096^2 \times 4032$, represents the largest, fully resolved instability simulations to date.

Our preliminary analysis of the data has shed new light on the long standing open question regarding the discrepancy between the numerically and experimentally computed mixing layer growth rates [5] and has shown, for the first time, that the mixing layer consists in a fully turbulent inner region and a turbulent/non-turbulent interface near the edges. The former is similar for all cases considered, while the latter retains the memory of the initial conditions and can grow at different rates for various classes of initial conditions. In many practical problems, the driving acceleration is not constant and may even reverse its direction. None of the existent RTI models can explain the change in the mixing layer behavior following gravity reversal. Here, we use our new dataset to address, for the first time, the flow physics resulting from the acceleration change, including the modifications in the layer structure as the turbulent/non-turbulent interface is violently stirred and mixed with the inner turbulent region.

## References

[1] W.H. Cabot and A.W. Cook. Reynolds number effects on Rayleigh-Taylor instability with possible implications for type-ia supernovae. *Nature Phys.*, **2**:562–568, 2006.

[2] D. Livescu D, J.R. Ristorcelli, R.A. Gore R A, S.H. Dean, W.H. Cabot and A.W. Cook. High-Reynolds number Rayleigh-Taylor turbulence. *J. Turbul.*, **10**:1–32, 2009.

[3] D. Livescu, J.R. Ristorcelli, M.R. Petersen and R.A. Gore. New phenomena in variable-density Rayleigh-Taylor turbulence. *Phys. Scr. T*, **142**:014015–1–12, 2010.

[4] D. Livescu and J.R. Ristorcelli. Variable-density mixing in buoyancy-driven turbulence. *J. Fluid Mech.*, **605**:145–180, 2008.

[5] D. Livescu, T. Wei and M.R. Petersen. Direct Numerical Simulations of Rayleigh-Taylor instability. *To appear J. Phys.*, 2011.