Visualization of Rayleigh-Taylor instability

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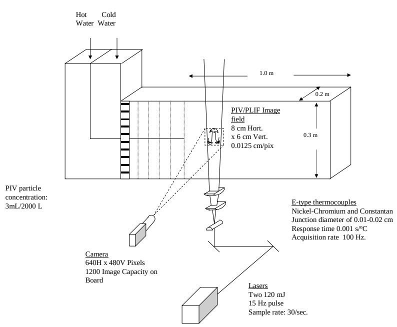
1. Rayleigh-Taylor Instability: Background

- Rayleigh-Taylor instability (R-T) occurs when a density gradient is accelerated by a pressure gradient such that $\nabla p \bullet \nabla \rho < 0$
- When a heavy fluid rests above a light fluid under the influence of gravity, the density interface is unstable to infinitesimal perturbations.
- The resulting flow evolves in three stages:
  - Exponential growth of infinitesimal perturbations
  - Nonlinear saturation of perturbations
  - Transition to turbulence and self-similar growth
- RT flows occur in the ejecta of supernovae, in atmospheric flows, and in the ablation interface of Inertial Confinement Fusion capsules.

2. Schematic of the Texas A&M Water R-T experiment

Cold and warm water enter through separate inlet plenums. As they pass through flow straighteners and wire meshes, they are kept separated by a splitter plate. As the different-density streams leave the edge of the splitter plate, they form an unstable interface resulting in a statistically-steady R-T mix.



3. Photograph from experiment: Visualization using dye

Flow direction

$$A_t = \frac{\rho_{cold} - \rho_{warm}}{\rho_{cold} + \rho_{warm}}$$

$A_t = 10^{-3}$

$\Delta T = 5°C$

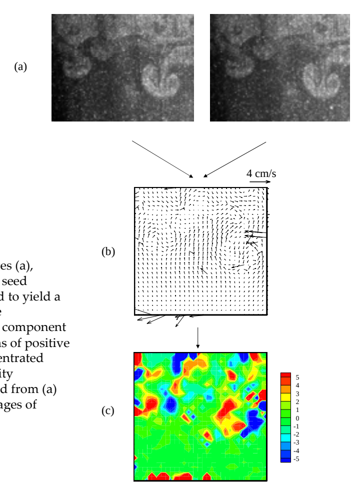
$U_0 = 4.4$ cm/s

Figure shows a snapshot of the experiment, with nigrosine dye added to the cold water stream. The evolution of the mix is quadratic in x (downstream coordinate), with the mix width depending on the Atwood number (A_t), and the acceleration due to gravity. In this experiment,the distance downstream can be related to time through the Taylor hypothesis.

4. PIV-S

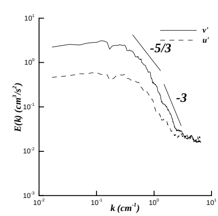
- PIV-Scalar (PIV-S), a variant of conventional PIV, was developed to simultaneously measure density and velocity fields in an R-T mix.
- Different concentrations of seed particles used in light and heavy fluid streams to mark density differences.
- Density measurements show good agreement in the mean and rms with thermocouple data.

5. PIV-S : Visualization using seed particles (x = 35 cm)



Consecutive grayscale images (a), separated by $\Delta t = 0.033$ s, of seed particles are cross-correlated to yield a velocity vector field (b). The corresponding out-of-plane component of vorticity (c) shows regions of positive and negative vorticity concentrated within the R-T rollup. Density information may be obtained from (a) through local window averages of particle concentration.

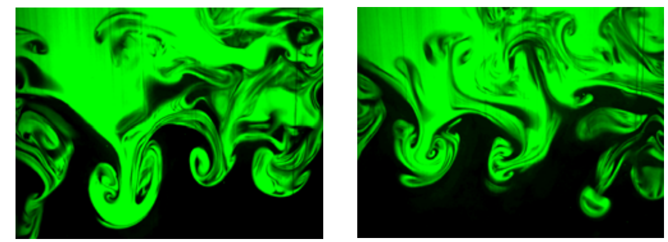
6. Velocity Spectra from PIV



Velocity power spectra at x = 35 cm (obtained from PIV) show the vertical velocity component dominating over horizontal velocity fluctuations. A developing inertial range ($k^{-5/3}$) and a dissipative range (k^{-3}) at the high-wavenumber end is visible.

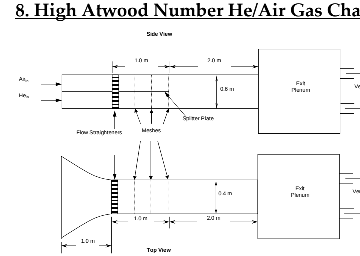
7. Planar Laser Induced Fluorescence (PLIF)

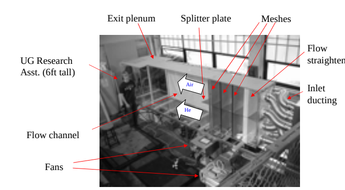
- PLIF relies on the fluorescence properties of dye markers for visualization.
- High-speed, high-resolution, non-intrusive, visualization technique.
- Rhodamine 6G used as dye marker.
- 2-D measurements of scalar quantities.



At late time, complex vortical structures show streaks of heavier fluid trapped fully inside the light fluid. This can only occur if there is significant three-dimensionality that results in out-of plane fluid being entrained in to the plane of visualization. Single-wavelength perturbations have interacted and paired into larger scales. The nonlinearity is evident here from the presence of a wide range of scales not seen close to the splitter plate. The bubbles (light fluid penetrating in to heavy) are traveling upward with a terminal velocity. These mushroom-shaped structures are typical of R-T mixing layers. These figures also show many secondary roll-up processes, especially on the large inverted mushroom, slightly left of the vertical centerline. Often these secondary roll-ups are driven by shear resulting in a localized Kelvin-Helmholtz instability.

8. High Atwood Number He/Air Gas Channel





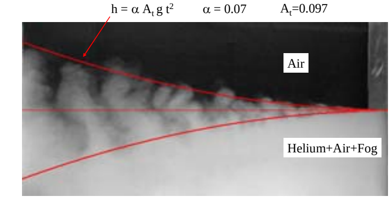
Air/Helium Facility as of December 8, 2003.

9. Design Parameters

- $0 \le At \le 0.75$
- Air/Helium (gases at room temperature).
- Statistically steady.
- Lewis # ~ 1 (ratio of thermal & mass diffusion).
- Heat air & use temperature as fluid marker.

10. Early Results

$h = \alpha A_t g t^2$ $\alpha = 0.07$ $A_t = 0.097$



11. Acknowledgements

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