An overview of Rayleigh-Taylor experiments at Texas A&M University

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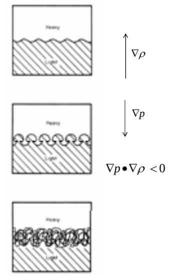
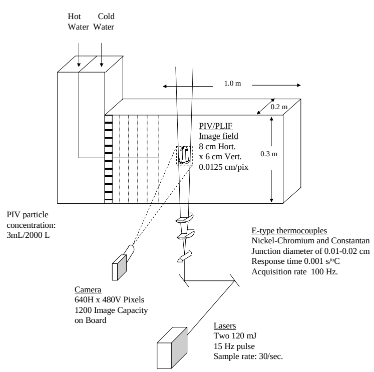
1. Rayleigh-Taylor Instability: Background

- Rayleigh-Taylor instability (R-T) occurs when a density gradient is accelerated by a pressure gradient such that $\nabla p \bullet \nabla \rho < 0$.
- Rayleigh-Taylor *mix* experiments are difficult!
- Modern turbulent mix models involve statistical quantities and demand extensive experimental data sets for validation.
- Transient Rayleigh-Taylor experiments do not lend themselves to statistical data collection.
- Over the past 8 years we have developed a statistically steady R-T experiment that facilitates statistical data collection.
- Our Rayleigh-Taylor mix data is used to validate models for the description and understanding of hydrodynamic instabilities that develop during the implosion phase of ICF capsules.

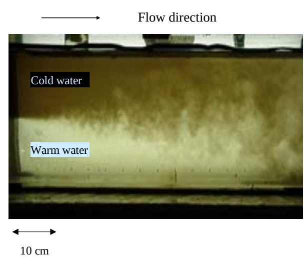


2. Schematic of the Texas A&M R-T experiment

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



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

$A_t = 10^{-3}$

$\Delta T = 5^{o}C$

$U_0 = 4.4$ cm/s

The figure shows a snapshot of the experiment, with Nigrosine dye added to the cold water stream. The flow is from left to right. 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. Measurement of α

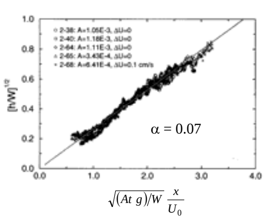
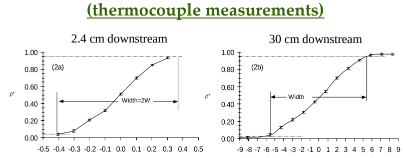


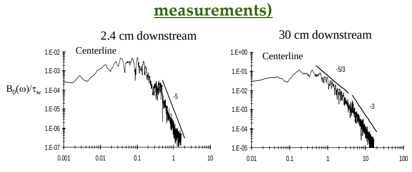
Figure on the left shows the time evolution of the mix-width h. The mix-width was deduced from the 5% and 95% contours of the volume fraction obtained from the above dye images. When normalized by self-similar coordinates, a value of 0.07 for the growth constant α may be inferred.

5. Mean Density Profiles (thermocouple measurements)



Mean density profiles across the mix, measured using thermocouples.

6. Density Fluctuation Power Spectra (thermocouple measurements)



7. Parameter Definitions

$$B_0 = \lim_{T\to\infty}\frac{1}{T}\int_0^T \left(\rho - \overline{\rho}\right)^2 dt / \Delta\rho^2 = \lim_{T\to\infty}\frac{1}{T}\int_0^T (\rho')^2 dt / \Delta\rho^2$$

$$B_2 = \overline{\rho^*}\left(1 - \overline{\rho^*}\right) = f_1(1 - f_1) \qquad \theta \equiv 1 - B_0 / B_2$$

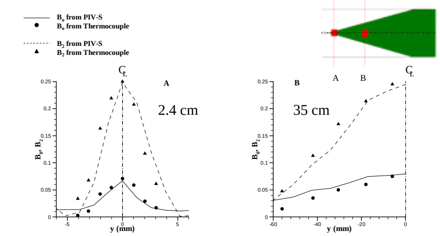
$$\rho^* = \frac{(\rho - \rho_{\min})}{(\rho_{\max} - \rho_{\min})} \qquad \overline{\rho^*} = \frac{\sum_1^n \rho_i^*}{n} \qquad B_0 = \frac{n\sum_1^n \rho_i^{*2} - \left(\sum_1^n \rho_i^*\right)^2}{n(n-1)}$$

$$B_0(\omega_n) = \frac{2\delta t}{N}\left|\sum_{i=0}^{N-1} (\rho_i^*)' e^{2\pi j \omega_n t_i}\right|$$

8. PIV-S

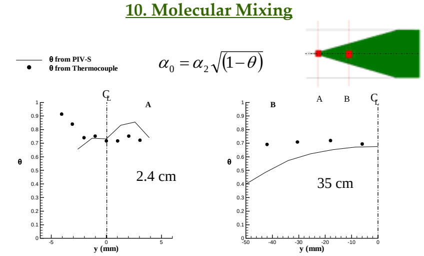
- PIV-Scalar (PIV-S), a variant of conventional PIV, was developed to simultaneously measure density and velocity fields in an R-T mix.
- Different concentrations of seed particles used in light and heavy fluid streams to mark density differences.
- Density measurements show good agreement in the mean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

9. Density Fluctuations

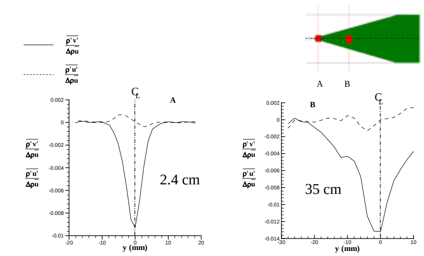


10. Molecular Mixing

$$\alpha_0 = \alpha_2\sqrt{(1-\theta)}$$

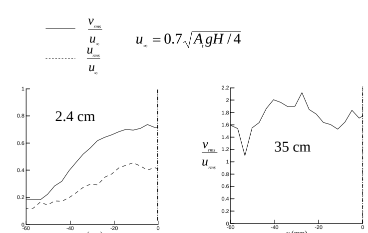


11. Density/Velocity Correlations



12. Velocity Fluctuations (x = 35 cm)

$$u_\infty = 0.7\sqrt{AgH/4}$$



13. Energy Dissipation

$$PE_i = \int_0^w \rho_{step}\, z\, dz \quad \Rightarrow \quad \int_0^{\frac{w}{2}} \rho_1 g z\, dz + \int_{\frac{w}{2}}^w \rho_2 g z\, dz$$

$$PE_f = \int_0^w \rho_{measured}\, z\, dz \quad \Rightarrow \quad \sum_{i=0}^n \rho_i g\, z_i\, \Delta z$$

$$PE_{released} = PE_i - PE_f$$

where, $\rho_{measured}$ is the measured density, and ρ_{step} is the step-profile of density at the interface corresponding to the initial condition

$$KE_i = 0 \qquad KE_{generated} = \tfrac{1}{2}\int_0^w \rho\, v'^2 dz$$

where, W = mix width, v' = rms velocity

Dissipation, $D = PE_{released} - KE_{generated}$

$$\left|\frac{D}{PE_{released}}\right| = 0.49$$

14. Acknowledgements

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