Rayleigh-Taylor Instability of Alcohol Paint in Water

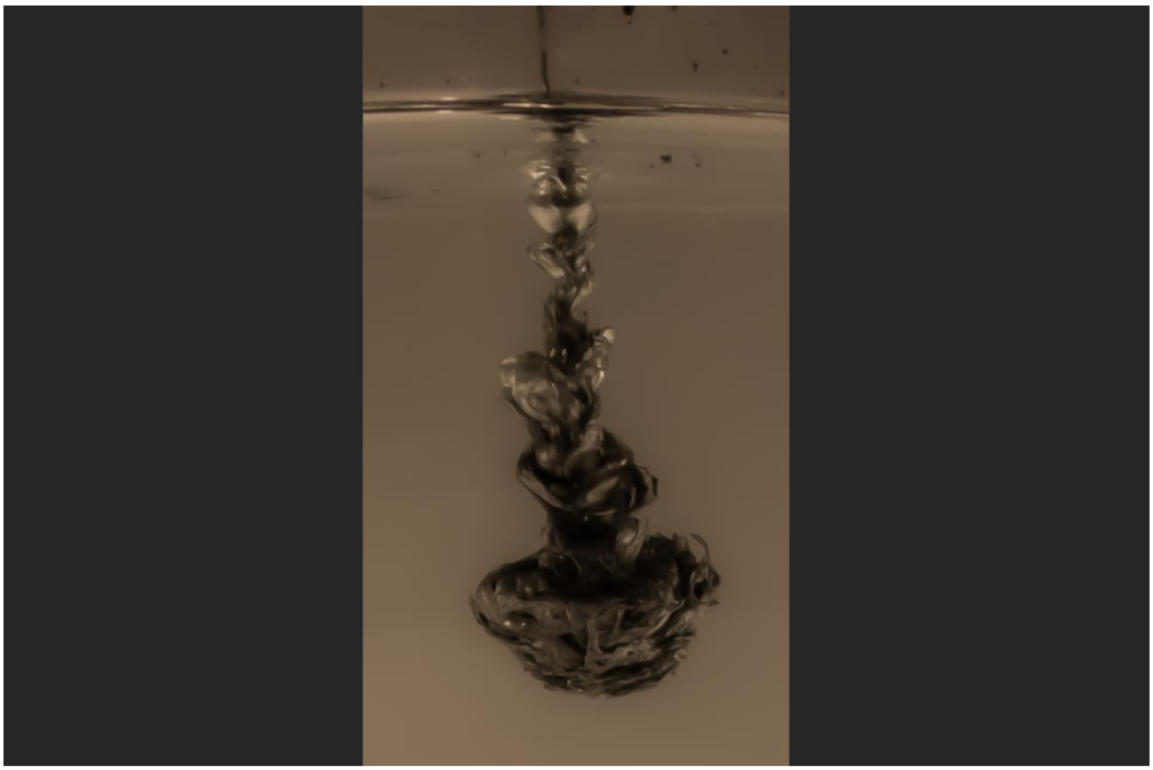

Photo Assignment #1

MCEN 5151

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Introduction:

This photo, taken for the get wet assignment of the flow visualization course, is an attempt to depict the Rayleigh-Taylor instability, a phenomenon caused by the interpenetration of fluids of different densities. Traditionally, this experiment is carried out with a higher density fluid placed above a lower density fluid, allowing the two to mix due to the force of gravity. For my experiment, I added a level of dynamics to the setup by injecting the low-density fluid into the high-density fluid from above, creating a larger and, in my opinion, clearer Rayleigh-Taylor shape. The setup for the photo included artificial lighting as well as a poster paper backdrop to ensure the fluids were the focus. I postprocessed this image with Adobe Lightroom to better highlight the shape of the instability. Overall, this photo successfully illustrates the classic geometry of a Rayleigh-Taylor instability by mixing an alcohol-based paint with water.

Science of the Rayleigh-Taylor Instability:

Rayleigh-Taylor instabilities occur when fluids of differing densities are mixed, with the lighter fluid pushing on the heavier fluid [1]. The classic example of this effect is the placement of water on top of oil, letting gravity mix the fluids. In addition, the Rayleigh-Taylor instability describes the mushroom cloud that forms after an atomic bomb detonation [2]. In an ideal simulated situation, the Rayleigh-Taylor instability should look like this [3]:

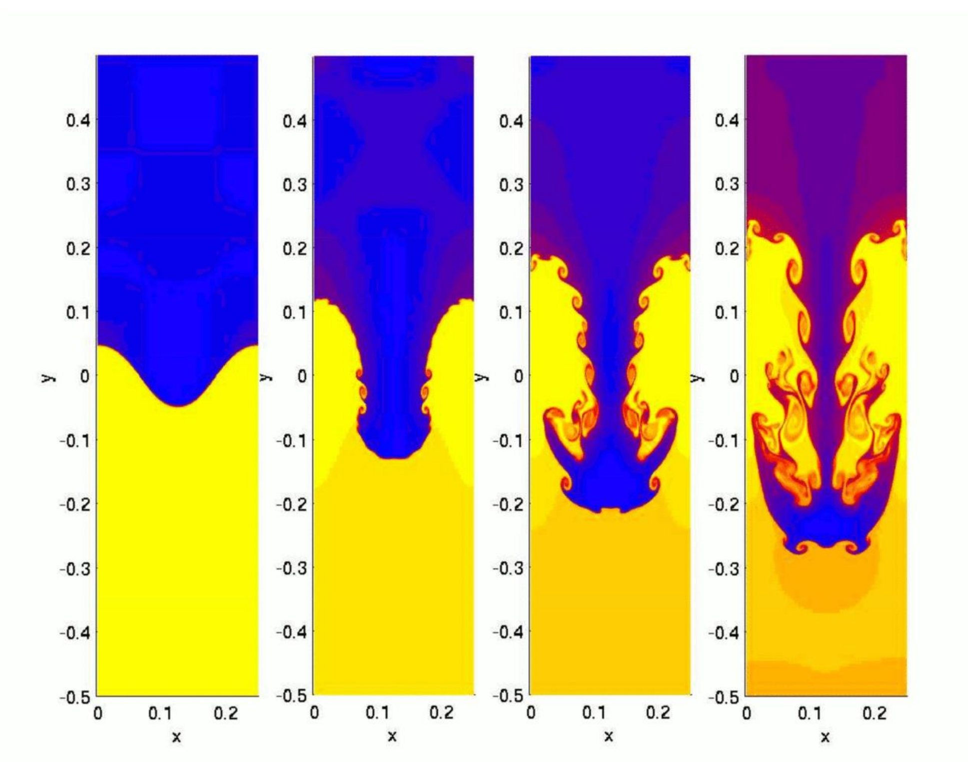

Figure 1 - Simulated Rayleigh Taylor Instability

In my experiment, I was able to generate very similar geometry to the theoretical solution shown above. In figure 2, the simulated model of the instability is compared to my experimental result:

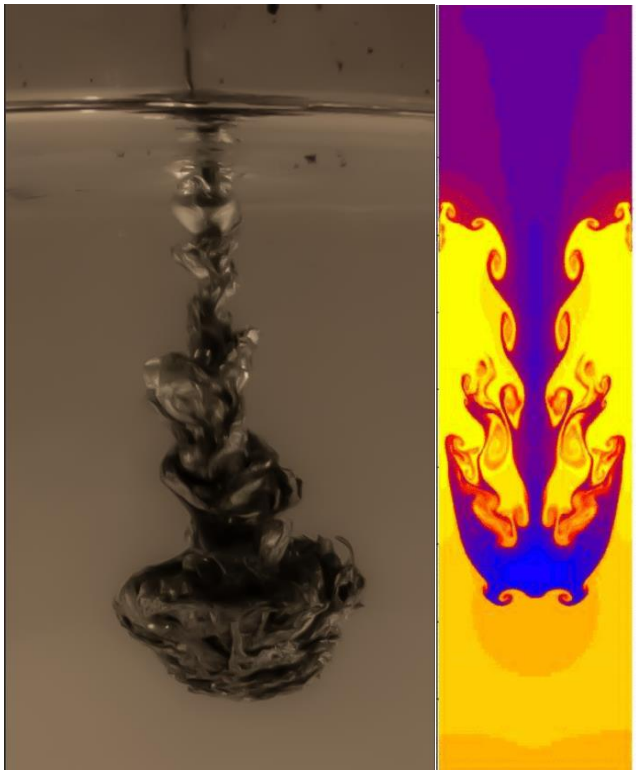

Figure 2 - Comparison of experimental and theoretical results

The Rayleigh-Taylor instability can be described by three conservation laws:

$$\frac{\partial \rho Y_i}{\partial t} + \nabla \cdot (\rho Y_i \vec{u} + \vec{J}_i) = 0\ ;\ (i = 1,2)(1)$$

$$\frac{\partial \rho \vec{u}}{\partial t} + \nabla \cdot [\rho \vec{u}\,\vec{u} + p\vec{\delta} \rightarrow - \vec{\tau} \rightarrow] = \rho g$$

$$\frac{\partial E}{\partial t} + \nabla \cdot [(E + p)\vec{u} - \vec{\tau} \rightarrow \cdot \vec{u} + \vec{q}_c + \vec{q}_d] = \rho \vec{g} \cdot u$$

The main variables that contribute to these equations are the densities (ρ), the velocities ($\vec{u}$), and the pressures (p) of the involved fluids [1]. In my experiment, I used a relatively high velocity to accelerate the expansion of the low-density fluid, resulting in a larger mushroom cloud shape than what would develop under initially at rest fluids.

Experimental Setup:

This photo was taken using artificial lighting in an organized setup. The water was held in a two-liter plastic bottle, where it was allowed to rest for the duration of the experiment. The alcohol-based paint was then injected into the bottle from the opening at the top, creating the high velocity mixing that is critical to the success of the experiment. The camera, a Canon Rebel T2i, was placed on a tripod and leveled to match the plane of the water. Two light bulbs were used to generate the lighting for this image, placed on either side of the two-liter bottle. The overall experimental setup is shown here in figure 3:

Figure 3 - Experimental Setup

The camera was set up to rapidly take images to ensure the flow could be captured at numerous points throughout the process. The camera settings are compiled in the following table:

Camera model	Canon Rebel T2i
ISO speed	ISO-800
F-stop	f/4.5
Exposure time	1/640 sec
Flash mode	No flash
Focal length	28 mm

Table 1 - Camera settings

Conclusion:

In this experiment, I was able to successfully capture the iconic geometry of a high velocity Rayleigh-Taylor instability. The fluids in this photo were a gray alcohol-based paint and water, mixed by the injection of the paint into the water. Overall, I was happy with how the image turned out. I think it clearly depicts the Rayleigh-Taylor instability geometry, which was the goal of this experiment. In future attempts, I would be interested in having a range of varying density fluids to fully explore the Rayleigh-Taylor instability.

Bibliography

[1] D. Youngs, "Rayleigh-Taylor instability and mixing," 18 02 2009. [Online]. Available: http://www.scholarpedia.org/article/Rayleigh-Taylor_instability_and_mixing.

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[3] L. S. &. H. Li, "Parallel AMR Code for Compressible MHD or HD equations," *Los Alamos National Laboratory,* 2006.

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[5] J. Matsumoto, "Linear theory of the Rayleigh-Taylor instability at a discontinuous surface of a relevativistic flow," *Monthy Notices of the Royal Astronomical Society,* vol. 472, no. 2, 2017.