Red Evolution

Get Wet Report

MCEN 4151 – Flow Visualization

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Introduction

Many people find the shapes created by Rayleigh-Taylor instabilities to be beautiful as is apparent by the abundance of images of such portrayal. Through my own experimentation with food dye and water involved in other ideas for this assignment, I too became fascinated by the physical process as well as the beauty created by the process. Originally, I had intended to show Rayleigh-Taylor instability in two forms I call the “bulb” and the “ring” in a single image as seen in Appendix A. However, I later decided to show the progression of the fluid flow through a series of pictures combined into a collage to give a new perspective on the process. In this way, the physical process is clearer. I wanted to show the fluid flow before apparent Rayleigh-Taylor instability became visible, as well as a beautiful image of that instability, followed by an interesting “ring” effect caused by the same physics. The resultant image is seen below in Figure 1.

Figure 1: Final image portraying progression of Rayleigh-Taylor instability

Rayleigh-Taylor Instability

In 1880, Lord Rayleigh considered the fluid movement involving two incompressible fluids at a constant gravitational field, where a heavy fluid is supported by a lighter one (Cook & Youngs). He wanted to understand the formation of cirrus clouds and found that the fluids exert surface forces on each other in an attempt to reduce their combined potential energy (Schmeling, 2003). The heavier fluid is accelerated through the lighter fluid by gravitational forces and any agitations between the interfaces of the two fluids by that acceleration will result in greater perturbation (Rayleigh-Taylor Instability). This growth in instability is dependent on the viscosity of the two fluids (Rayleigh-Taylor Instability). As this instability continues to grow and develop, “downward-moving irregularities (‘dimples’) are quickly magnified into sets of inter-penetrating Rayleigh-Taylor fingers” (Rayleigh-Taylor Instability).

In the image it is easy to see that food coloring is the fluid with the greater density. As the lighter water pushes the heavier food coloring, instabilities are amplified and the Rayleigh-Taylor fingers become predominant in the image, which can be seen in the transition from the first image to the second image. The instability is a fundamental fluid-mixing mechanism (Cook & Youngs), and eventually disperses the fluid at the bottom of the jar as seen in the third image. The ring is formed as soon as the food coloring coalesces at the surface and breaks from the surface tension created between that fluid and the oil. At which time the fluid forms more fingers.

The Reynolds number can be calculated in order to determine the flow regime. Based on the calculations below, because the Reynolds number is not above 5x10^5, the flow is in the laminar regime. This is indicative in the image by noticing the layering of the fluid flow as the die falls through the water.

$$Re = \frac{\rho V L}{\mu} = 15{,}988$$

- $\rho = density\ of\ water\ (@55°F) = 999.7\ kg/m^3$
- $V = average\ fluid\ velocity = 0.01524\ m/s$
- $L = characteristic\ length = 1.3716\ m$
- $\mu = viscosity\ of\ water\ \ @55°F\ \ = 1.307 \times 10^{-3} Ns/m^2$

The fluid flow took place in a glass jar large enough to minimize the impact of the fluid boundary on the visualized flow. As such, each image is approximately 3X5 inches. As you can see in Figure 1, the image presents three images to represent the progression of the same process. It's interesting to see that three very different shapes take place in the same process, involving the same physical laws.

Visualization Technique

The photographic setup can be seen in the diagram in Figure 2. The fluid flow took place inside of a large jar filled almost to the top with tap water. Because a glass jar was used, unwanted reflection was a major concern. Therefore, a white box frame was used to reduce reflection and create a seamless background. Two lights were used for lighting directly on the side of the white box. They were pointed toward the back corner of the box about 6 inches from the outer surface. The box allowed for that light to be diffused giving less of a halo effect on the side of the jar and more uniform lighting.

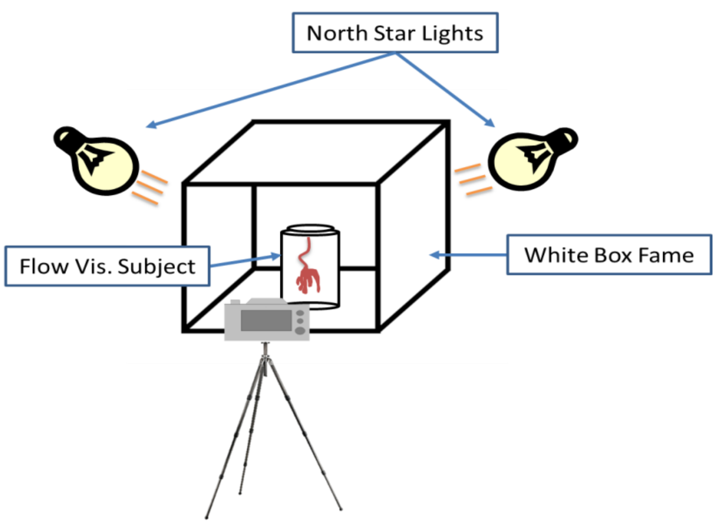

Figure 2: Image capture set-up

The visualization technique used to show the Rayleigh-Taylor instability in this project is of the seeded boundary technique. Tap water was used at a temperature of 55°F, and was seeded with two drops of red food coloring. The two drops were placed together on top of a thin layer of canola oil in the middle of the surface. The amount of oil used is unimportant and didn't affect the actual fluid flow seen in the image. Instead the thin film of oil allowed for the dye to move very slowly through the oil, (approximately 3 minutes) and start the flow through the water with, essentially, no velocity. This allowed for the "bulb-like" shape to form before being broken into obvious Rayleigh-Taylor fingers. The dye absorbs some of the incoming light creating a contrasting boundary between the two different fluids.

After the drops of food coloring had traveled through the thin film of oil, the flow through water took place in about 10 seconds. I took photographs in rapid succession in order to capture the progression of the fluid flow so that the best images could be presented. Approximately 5 minutes after the start of the flow through water, the "ring-like" formation would appear and more photographs were taken. In all, each experiment would take about 7-10 minutes to complete. By the end of the day I had taken close to 750 pictures!

The jar was placed approximately 1 foot away from the camera which was mounted on a tripod (see Figure 4, Appendix B). It was placed at the edge of a stand within the box frame so that the edges of the stand would not be visible by the lensing of the jar. Manual focusing was used and performed by holding a jumper wire in the middle of the jar for a focal point (see Figure 5, Appendix B). A fast shutter speed was selected to capture the fast-moving fluid motion in a crisp image. Other specifications are as follows:

- Field of view: 3X5 inch
- Distance from object to lens: 1 foot
- Camera: Panasonic DMC-FZ35
- Lens focal length: 12.4mm
- Image dimensions:each original – 3000x4000 pixels, final – 6611x2630 pixels
- Exposure specifications: 1/250 sec shutter speed, f/5.6, 125 ISO
- Post-processing: image cropping, color contrast – curves, cloaning image irregularities
    - one original image shown in Appendix C

Conclusion

The collage of images effectively shows the three stages of Rayleigh-Taylor instability of food coloring dropped in water. The flow starts in a "bulb-like" shape before the instability is visually evident in the first image, then transitions to the classic Rayleigh-Taylor fingers shown in the second image. The final image shows Rayleigh-Taylor fingers in a different form than normally seen along with the diffusion of the initial flow at the bottom of the jar.

I am very satisfied with the image and feel that I captured all of the shapes involved in the flow. I struggled in deciding whether or not I should keep the jar in the image but decided that its inclusion added to the image without distracting from the fluid flow. I like to see the brightness on the side of the glass and the dark contrast of the bottom of the jar. If I could change anything about the image, it would be the slight wrinkle in the background seen through the lensing of the jar. I'm very new to imaging techniques, and if I had any questions it would be how to get rid of background texture without post-processing.

The Rayleigh-Taylor instability has been well represented in this course by using food coloring in water. I had decided on showing the same fluid flow while attempting at originality. I believe the collage along with the change in effect caused by using a thin film of oil fulfilled that intent. However, in the future I hope to show fluid flows that have not been so well represented in the past. Rayleigh-Taylor instability can be seen in many different types of fluid flows as well, and it would be interesting to see how the shapes change with different conditions.

References

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Appendix A: Image of original intention

Figure 3: Rayleigh-Taylor instability taking two forms in a single image

Appendix B: Jar setup and focus method

Figure 4: Jar setup inside white photography box with lighting on both sides

Figure 5: Straight jumper wire used for manual focusing. Taken at long exposure.

Appendix C: Original, un-edited image

Figure 6: Unedited image of middle image in collage