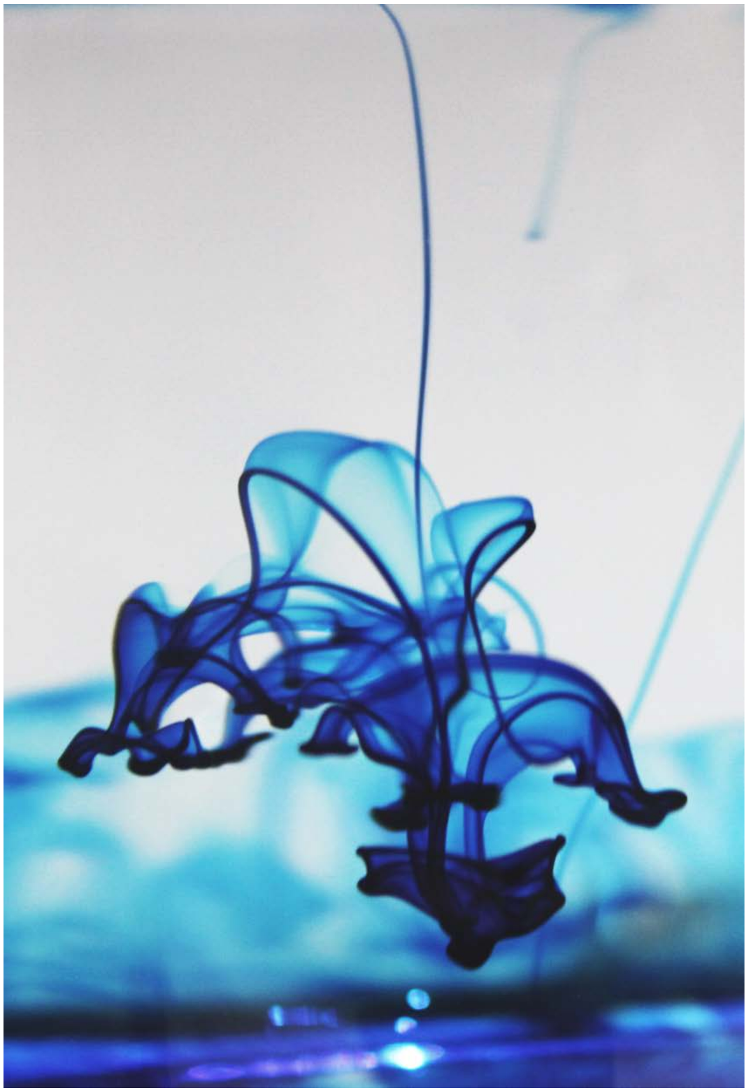
Project 1 – Get Wet



MCEN 5151 – Flow Visualization

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Introduction:

The purpose of this "Get Wet" assignment was to simply get a feel for what this Flow Visualization class will be like in the future. We were told to take a picture that demonstrates the phenomenon being observed while still being a pleasant picture[1]. I tried to achieve several more complicated phenomenon in my kitchen without much success. After several failures, I turned to previous classes so I could focus more on getting a good image than just producing the phenomenon. When I browsed through previous submissions, I kept finding one simple, yet beautiful image. I decided to replicate that image and ended up going the route of food coloring in water producing the Rayleigh-Taylor, or "umbrella" instability.

Physics:

A simple schematic showing the flow set up is shown below in figure 1. The food coloring was dropped from a height of about two inches above the water surface. The glass containing the water had a diameter of about three inches, and the water was filled to a depth of about two and a half inches. I tried to get the dye droplet to land in the exact middle of the glass.

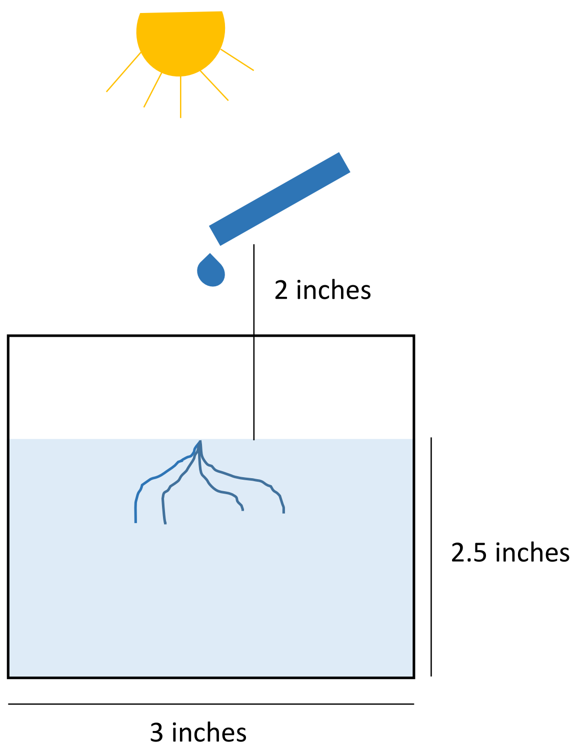

Figure 1 - Schematic of the Experiment

The flow of the dye is actually fairly simple to understand. The dye is slightly denser than the water, so it wants to sink. This sinking happens in two different ways. The water rises through the dye at some points, pushing the dye aside. At other points the dye falls through the water, pushing the water aside (which we can't see)[2]. The mixture of these two actions creates the phenomenon captured.

The science of it gets a little more complicated when you go in depth. A Rayleigh-Taylor instability occurs at an interface of two fluids when a light fluid is trying to support a heavy one[3]. There are two types of the Rayleigh-Taylor instability, vortex-ring instability and bag or umbrella instability[4]. Which of these instabilities will occur is determined by the Atwood number, given below[2].

$$A = \frac{\rho_H - \rho_L}{\rho_H + \rho_L}$$

Where ρ_H is the density of the higher density fluid (the dye), and ρ_L is the density of the lower density fluid (the water). In this case, the density of the dye[5] is 1026 kg/m^3 and the density of water is known to be 1000 kg/m^3. Using these numbers, we find an Atwood number of 0.01. Because this number is closer to zero than one, we get the umbrella instability seen in the image[2].

An important thing to consider when analyzing any flow is the Reynolds number of the system. The Reynolds number is a dimensionless number that is the ratio of inertial force to viscous force on a fluid element[6]. It is most commonly used to determine whether a flow is laminar or turbulent. In this case, we are expecting a turbulent flow just by looking at the image, but it is good practice to calculate the Reynolds number anyway. The equation to find the Reynolds number is given below[6].

$$Re = \frac{\rho v R}{\mu}$$

Where ρ is the density of the dye, v is the velocity of the dye, R is the radius of the dye droplet, and μ is dynamic viscosity of the dye. All these values can easily be looked up except for the velocity of the dye. To find this, we assume that it is moving at its terminal velocity in water. The equation to find this terminal velocity is given below[7].

$$v = \frac{(\rho_{Dye} - \rho_{Water})R^2 g}{\mu_{Water}}$$

The radius of the drop was about 2mm = 0.002m, gravitational acceleration, g, is given as 9.81 m^2/s, and μ_{Water} is given to be[6] $1.002*10^{-3}$ N*s/m^2 at room temperature and atmospheric pressure. Using these numbers, we find a velocity of 1.018 m/s. Using this velocity and $1.002*10^{-3}$ N*s/m^2 as the dynamic viscosity of food coloring (since it is made mostly of water), we find a Reynolds number of 2085.1. Turbulent flows occur at Re>1000, so it is safe to say that we are in turbulent flow. This was expected because the flow in the picture looks very turbulent.

<u>Photo Setup:</u>

As shown on the front cover, the image submitted is a drop of food coloring falling through water. The water is in the widest glass I could find. I chose this to try to avoid any distortion due to the curvature of the glass and to be able to crop out the glass without leaving an awkwardly skinning photo. Blue food coloring was chosen to give the best contrast against the white background. The background is just a laminated piece of printer paper. The lighting is the LED on a cell phone shined from above the glass. I chose this lighting because it is a very nice, clean white light to go with the white background.

As for the actual experiment, the camera was set up on a tripod about a foot away from the glass. The food coloring was dropped in the middle of the glass from about 3 inches above. Once the drop hit the water, I took as many pictures as possible until it hit the bottom. After a few tries, I decided that I liked the way the food coloring didn't totally settle in the bottom of the glass. For several attempts after, including the final photo, I put a few drops in before taking pictures to get this effect.

Photo Technique:

The photos were taken with a Canon EOS Rebel T2i D-SLR camera. The original photo can be seen below in figure 2.

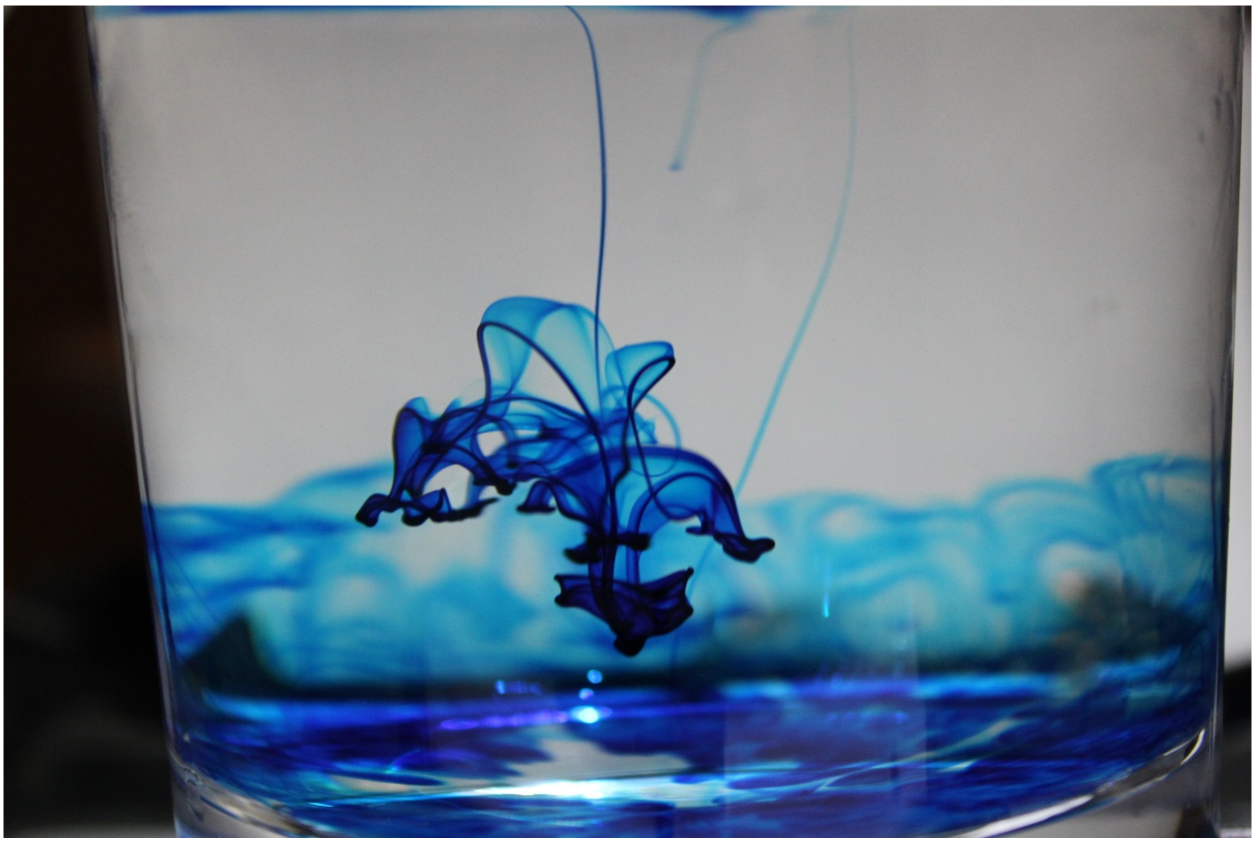

Figure 2 - Unedited Get Wet image

The field of view in this image is about 3.5 inches by 2.5 inches with pixel dimensions of 5184x3456. The photo was taken with the camera about 1 foot away and zoomed in slightly (I wish I could recall exactly how much). The lens used was just the stock lens that came with the camera. It has a focal length of 18-55 mm and a focus distance of 0.8 ft to infinity. For this image, a shutter speed of 1/50 s, an aperture of 4.5, and an ISO setting of 1250 were used.

After the image was taken, there was some minor post processing done in Gimp. The image was obviously cropped to take out the glass and focus on the flow phenomenon. The cropped image had pixel dimensions of 2800x4096. After that the sliders discussed in class were used to increase contrast and brightness and decrease saturation until the final image, shown on the cover, was obtained.

Conclusion:

I feel this image does a great job of capturing the Rayleigh-Taylor instability in its “umbrella” form. To begin this project, I was really trying to just produce a good looking photo. Before this, most photos I took felt like they were missing something or were focusing on the wrong thing. I think this image turned out really well and didn’t have that same issue. I fulfilled my intent in that respect. There are only a few things that I don’t like about the image. It’s slightly out of focus which I think I’ll get better at with practice. Also, there are a few unwanted glare spots near the bottom due to the overhead lighting. When I attempted to crop those out, it threw the whole image off balance, but things like that should be actively avoided in the future. To develop this idea further, I might get a denser fluid to drop, or a less dense fluid to drop into. That way I may be able to observe vortex-ring instability instead of the umbrella instability.

References

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