Flow Visualization

Assignment 1: Get Wet

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MCEN 4151
Get Wet Report

The first assignment in my flow visualization class at the University of Colorado Boulder was to get our feet wet with taking photos of fluids and fluid flow. After watching some videos of interesting fluid flows, I came across a video of some guys filming water as they injected colored dye with syringes. I thought the images they captured were very pretty and represented some cool phenomena. Inspired by this, I set out to capture my own picture of the same phenomena, hopefully learning and visualizing the fluid flow inherent to the conditions. I thought I'd also add another aspect to my image by getting another person to drop colored dye into the water while I injected colored dye with a syringe. For this job I thank Nicole Barney, a fellow mechanical engineering student. Lastly, as one might notice, my photo is flipped upside down. This is purely an aesthetic choice; the descriptions of flow will be referenced as if the photo were right side up.

My set up was considerably smaller and less professional than the one I was inspired by, but I still got good results. I used a square storage container made up clear plastic with very smooth sides so that the image wouldn't be distorted at all. I used two syringes, both approximately one inch in diameter with a 5mm opening. One syringe (the one with green dye) was flicked so that a single drop would come out while the other one was emptied with as much force as my fingers could provide.

Both of the dye flows can be described by plumes. Plumes are formed when one fluid moves through another. Density and momentum are the two main factors that drive plume shape and formation. With this said, the drop is fairly easy to describe. Gravity was the only force acting on a single drop of green food dye until it entered the water. Water and food dye have the same density, however when the dye hit the water a plume began to form. The momentum from the gravitational force on the drop was conserved in the form of body movement when the drop hit the water. This body motion is what we see when we see vortex rings and the dissipation of dye into the water. The dye is doing work (although a very small amount) on the water to conserve its momentum, thus spreading out. Visually, this looks like an upward force from the water causes a pillow of dye to form. The upward force from the water on the dye then keeps the dye from continuing downward, thus making the sides of the dye pillow plume outwards in all directions. These smaller plumes have a normal force acting on them from the surrounding water, thus making them swirl into smaller pillows before the process continues. One can see the small pillows as vortex looking structures that resulted from the conservation of momentum. Once these structures have developed, gravity and the buoyant forces are the only ones acting on the dye, causing the dye to sink slowly while dissipating into the water. This creates a very different visual when compared to the injected dye.

The injected dye looks quite different from the drop. This visual change begins with the much higher forces acting on the dye when it enters the water. The high velocity causes a very turbulent dye stream when it enters the water. This turbulence causes really efficient mixing, but also means that the dye has more momentum to conserve. Because there is is more momentum to conserve, more vortex rings are generated. Remember, these vortex rings are the dye doing work on the surrounding fluid. Visually, we see this momentum conservation as the surface of the dye stream tearing off dye in small portions. At this point, the pillowing we saw before happens again to the small portions of dye that are sheared from the stream. The normal forces from the water create small vortices. This process repeats itself until the potential energy has been fully converted into kinetic energy and then converted again into body movement, or work. Once the work has been done on the water, the plume has fully developed and continues to dissipate into the water. One can also see air bubbles in the picture; this is a possible human error when filling the syringes and results in some dye being lifted out of the stream towards the surface of the water.

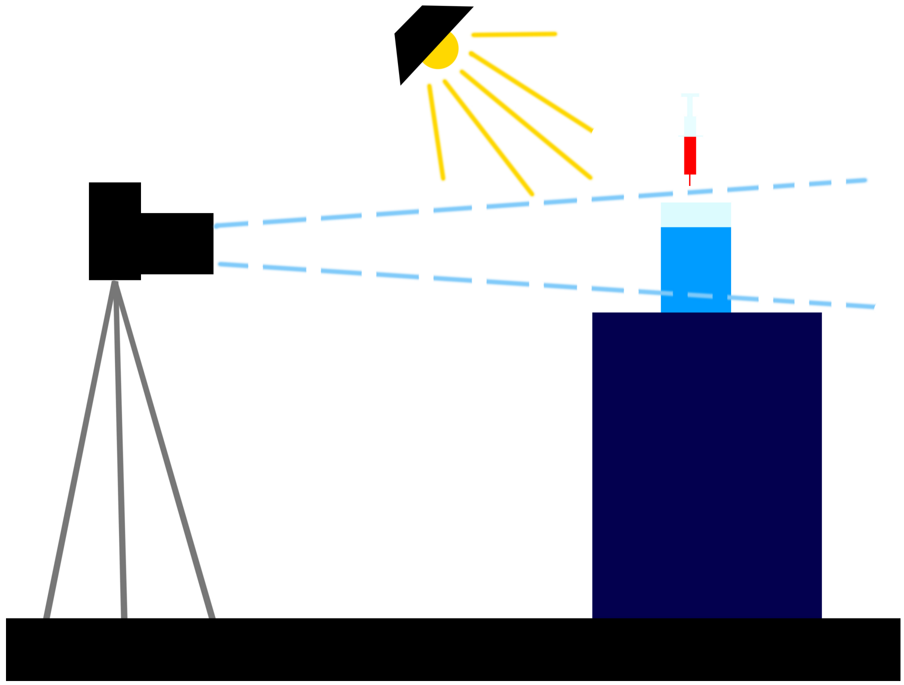
I only calculated the Reynolds number for the injected dye because the drop of dye doesn't really apply to the same principles. I estimated that I pushed the syringe plunger at about 0.1 m/s. Because the syringe tip was much smaller than the rest of the syringe by a factor of 0.22, the dye exiting the tip was traveling about 0.484 m/s. I found that the Reynolds number to be roughly 2410, which makes sense. As soon as the fluid exits the syringe, turbulent flows began mixing water and dye in the most efficient way possible. The mixing we see is essentially the kinetic energy converting to body movement. The equation below shows my Reynolds number calculations.

$$\frac{(0.484\frac{m}{s})(0.005\;m)}{(1.004E-6\frac{m^2}{s})} = 2410.36$$

2410 > 2100, which means turbulent flow inside a pipe

To obtain my image, I used a basic food dye that can be bought at any grocery store. The environment was well controlled because it was inside my garage, at normal room temperature. The water I used was normal tap water and no other mixtures were used. The lighting I used was a single florescent lamp aimed directly at the container but was mounted off to the side to minimize glare. The positioning of the lighting isn't important as long as the container is getting good exposure to the light while minimizing glare in the frame. One can see a depiction of this setup in figure 1.

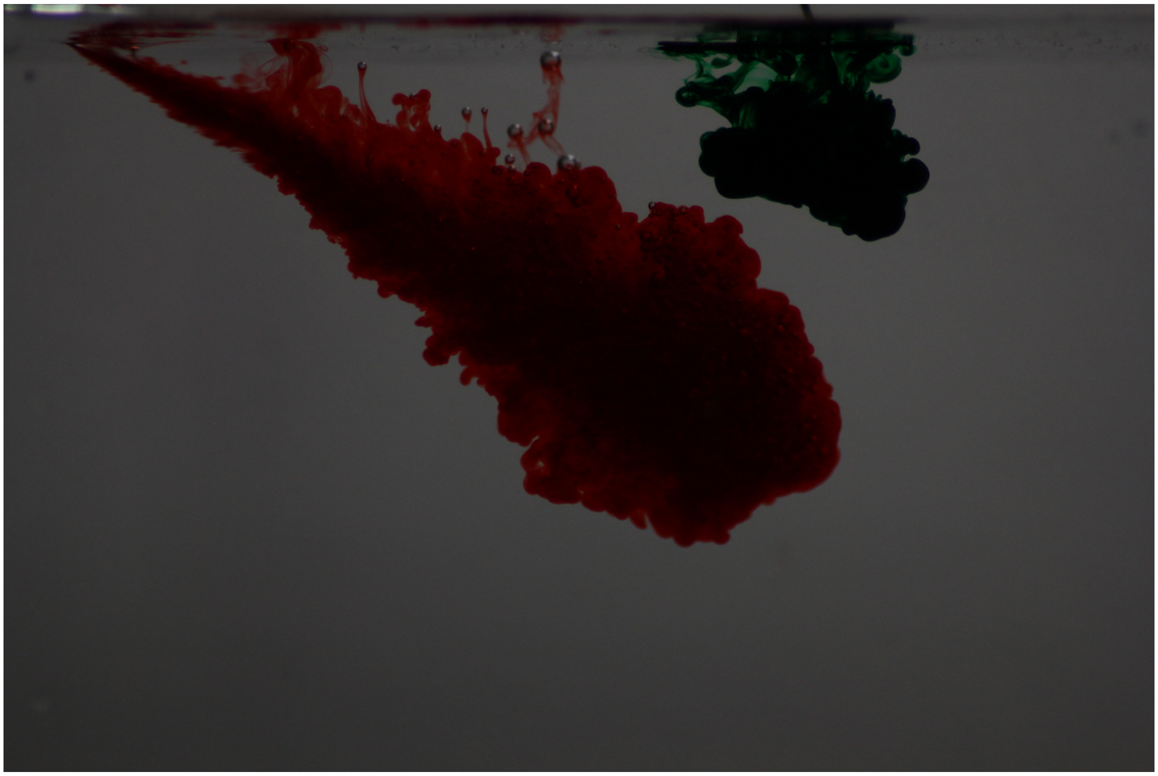
Figure (1.)



I used a Canon EOS 60D, which is a digital SLR camera along with a telephoto lens. Both the original photo and final image were 5184x3456 pixels. I chose to not maximize the focal length on my lens because I wanted to have some flexibility with focus so although my lens has a maximum focal length of 300mm I used 248mm. During the photography session I maintained roughly five feet between the camera and the water container. I also chose a low aperture because I had difficulty underexposing my photo, so I chose an F-number of 6.3. I was also having difficulties with noise in my photos so I found a decent balance of 800 for ISO to still maintain good exposure. Lastly, I experimented with different shutter speeds and quickly found that I was getting a lot of time shifts in the flow. To avoid this, the smallest shutter speed I could get away with while still minimizing blurriness was 1/1250th of a second.

I did all post processing in Adobe Photoshop CS6. I changed the exposure using "curves" by increasing the slope of the line using the input sliders. This operation was also used to enhance the contrast. I also ended up using the normal "exposure" adjustment built into Photoshop to increase my exposure. Unfortunately, light was at an absolute premium during my shoot and my original photo was very under exposed. If I were to replicate this photo, I would want to shoot it outside on a sunny day. I've included the original photo below, followed by my edited one. Again, for aesthetic purposes, I thought it would be fun to flip the photo vertically.

Original Picture



Edited Picture

Physically, this an incredibly difficult phenomenon to describe. One could spend an entire semester studying plumes and hydrodynamics, but I do not have that luxury. Hopefully I've done a complete job of describing plume phenomena technically and visually. As far as my actual photo, I think I fulfilled my intent to capture dye being injected into water. However, I'm not sure I was completely happy with my photo. The aspects of my photo were decent, I think it shows the fluid physics pretty well. My image reveals energy conservation in the form of vortices. These aspects are well presented, but I think I could've been more creative. It would've been fun to push the bounds of my creativity for this first assignment. Once I was inspired by that video, I went for a relatively conservative route. Overall, I am happy with my photo and the fluid physics it reveals, but I don't think I'm happy with my choice for a subject.

References:

I used this document as a reference for some water physics that I hopefully explained well enough in my description of the fluid flow.

Bernard Cabane, Rodolphe Vuilleumier. The physics of liquid water. Comptes Rendus G´eoscience, Elsevier, 2005, 337, pp.159.

The Slow Mo Guys injecting ink into a tank of water, which was my original inspiration for my photograph.

"Hypnotic Ink Physics in 4K Slow Motion – The Slow Mo Guys." You Tube. You Tube, 28 Feb. 2015. Web. 24 Aug. 2015. https://www.youtube.com/watch?v=gzkB574jivA.

This was a very helpful reference when I was researching hydrodynamics and plumes. This subject is still very complex to me.

Weber-Shirk, Monroe. "Turbulent Jets and Plumes." Cornell University, Ithaca, NY. 30 Sept. 2015. Lecture.