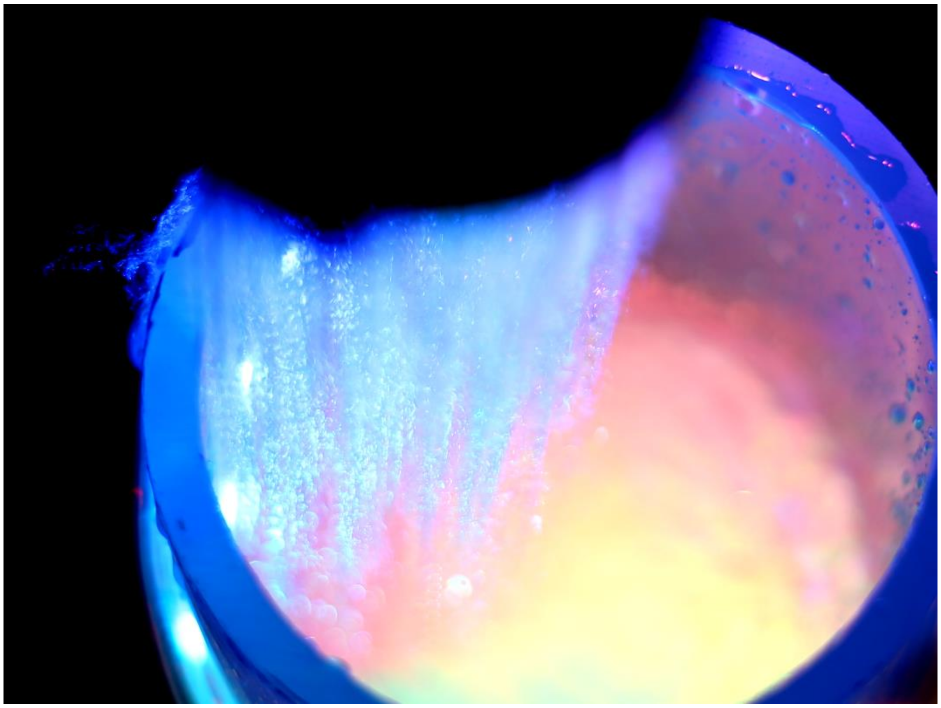
Luke Collier
Flow Visualization
Spring 2018



Sunrise Shower

Figure 1. The final image from the Team Second

Team Second Report
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The avenues a single project can take are quite surprising. My original purpose for this project when I pitched the idea to my teammates was to make a system where water or colored paint appeared to be flowing from a stoplight. The water is the actual mechanism for moving the cars. It was going to be a statement on how there are forces hidden in our day-to-day communication that compel us to do the things we do, like respond almost automatically to stoplights. This idea was explored via taking pictures of a tube with 3 laminar flows of water pouring from a large container. It was adapted by my teammate Eric Robinson. With editing, he was able to convey part of what I had envisioned. I had taken shots of Hot Wheels cars being pushed by water glowing green, but they hadn't turned out as well as I had hoped. After studying laminar flow jets, I had become more interested in how the velocity of water across an area can become turbulent or laminar. Even though I was optimizing for a laminar jet in the project, I chose an image featuring a very turbulent flow; that of a standard eye wash station. This image still focuses on the velocity profile of a fluid along a given path, thus building on the research I had done on laminar jets. I want to thank my father who provided the 3.5-inch tube and the LED lights. Zach helped with both triggering the water flow and drilling the three drain holes. Phil provided the camera most able to capture the shot and headed scheduling of our group. Yousef manned the lab's lights and material retrieval. Without the dedication each teammate had *poured* into this project, this image would not have existed.

The flow apparatus was basically continuous turbulent water flow through a transparent reservoir. The turbulent flow was provided by a 1.5-inch diameter washing station nozzle in the chemical lab at the bottom floor of the ITLL in CU-Boulder. The reservoir was a 3-inch clear PVC pipe. The nozzle's shape allows for water to flow evenly out at a low pressure, yet once released from the nozzle, becomes highly turbulent. The water was estimated to be exiting the nozzle at a flow speed (U) of ten centimeters per second, while the diameter (D) of each of the many holes in the shower nozzle was estimated to be 1/8 inch or 3mm. With the kinematic viscosity (ν) of water being 1.004E-6 m^2/s, this makes for a Reynolds number of $Re = \frac{UD}{\nu} = 299$. Given this number, the flow is laminar just before water exits the nozzle. Once it exits, a great amount of surface tension between the water and air is introduced; thus, the water's viscous forces become trivial compared to

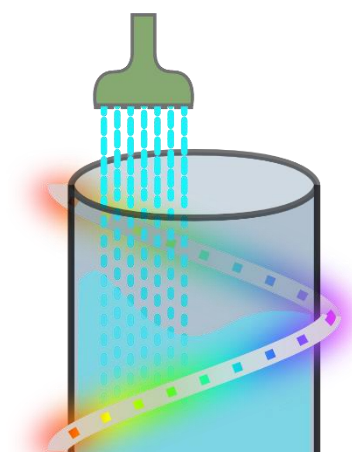

Figure 2. Diagram of the fluid demo setup.

the pressure forces from the surface tension.[1] As the diameter a free liquid jet is reduced due to gravity, the surface tension of the stream constricts the fluid inside and causes it to bunch up, like honey through a honey stick, then form droplets. Any perturbance, whether it be wind or turbulence from the tube it came from, will cause droplet formation and is known as the Plateau-Rayleigh instability.[2] Spherical droplets conserve energy more than thin cylinders when surface tension forces overcome viscous or inertial forces.

The technique we leveraged involved mostly water, as well as a clear 3-inch PVC pipe gathered from my father's resources. A 3-inch test cap was purchased to turn the pipe into a vessel, then three holes were drilled with a #10 drill bit and spaced 1 inch apart starting 0.5 inches from the bottom of the pipe. The apparatus was mounted above a sink and a side sprayer provided water flow. It was held face down and the flow rate was precisely controlled via the trigger to keep the water level constant. Too much, and it would overflow. Dawn dish soap was occasionally added to provide bubbles for other teammates' shots. At the time this image was shot, very little soap was present. The LED strip acquired from my home's electronics supply was controlled by an Arduino running the FastLED DemoReel100.[3] It was on the traveling rainbow setting at the time the image was taken. The was a 1-meter enclosed, flexible, 60-unit WS2182 RGB-LED strip. The enclosed feature was valuable for our project; because it was waterproof, we got to visualize how light interacts closely with liquid.

I was captivated by the wake caused by the flow pouring into the tube. Phil let me take control of the camera and I positioned the camera behind the tube pointing down and facing the opposite wall. I focused the camera about 20 cm away between where the flow exited the nozzle to where it landed in the pool below, also about near the rim of the pipe. The camera, with its 50mm lens, was set to Aperture Priority. At f/1.8, the depth of field was very

Figure 3. Original Image

[1] Vladimir Grubelnik and Marko Marhl. *"Drop formation in a falling stream of liquid,"* University of Maribor, Slovenia. (2004)
[2] "Wikipedia. *Plateau-Rayleigh Instability*" https://en.wikipedia.org/wiki/Plateau%E2%80%93Rayleigh_instability
[3] FastLED Overview. *fastled.io*

short, causing the majority of the photo to be obscured. At ISO 100 and exposure 1/20 sec, the flow was well-resolved in time. One can clearly see the sharp patterns of water droplets as well as a small yet sharp splash on the left side. At an original image size of 5472x3648, I had some room to play with when it came to cropping in GIMP. While cropping the image, I found that slight differences in composition made a huge difference, including use of the Rule of Thirds, the Golden Ratio, or landscape/portrait sizes. I tested several different croppings before I found the most powerful one. In this image, there were some hues of orange and blue that I wanted to highlight – but Hue/Saturation balance wasn't going to cut it: given the contrasting hues, there were actually quite a few grayscale tones. When I raised the saturation, edges formed where the gray separated from the color. What did a better job was a simple brightness/contrast adjustment (see Fig. 4). Overall, my photographic technique has seen significant improvements from this project.

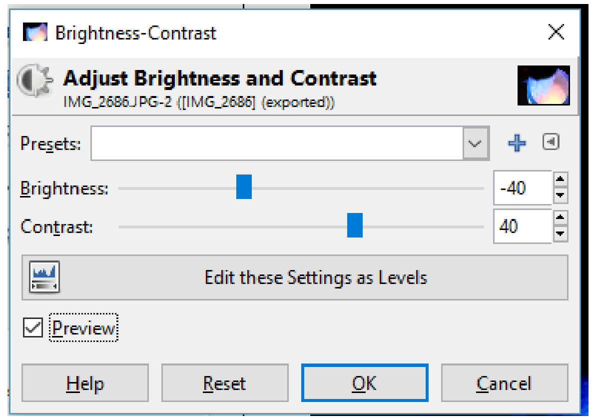

Figure 4. Brightness/Contrast adjustment in GIMP

This image has a strong relation to the Clouds images produced in this class. It looks like a sunset sets the background for a cloud with sharp eddies, but it is all contained in a scientific-looking tube. The splash on the left is the one bold character stepping outside the boundaries of the cylindrical sunset testing chamber. My jaw dropped at the vibrancy when I stumbled across this photo while reviewing that session's pictures. I was driven to choose this one over a photo or video that stayed true to my plan. Moving forward, I would like to explore laminar jet fountains that serve as the mechanisms for my original stoplight idea.