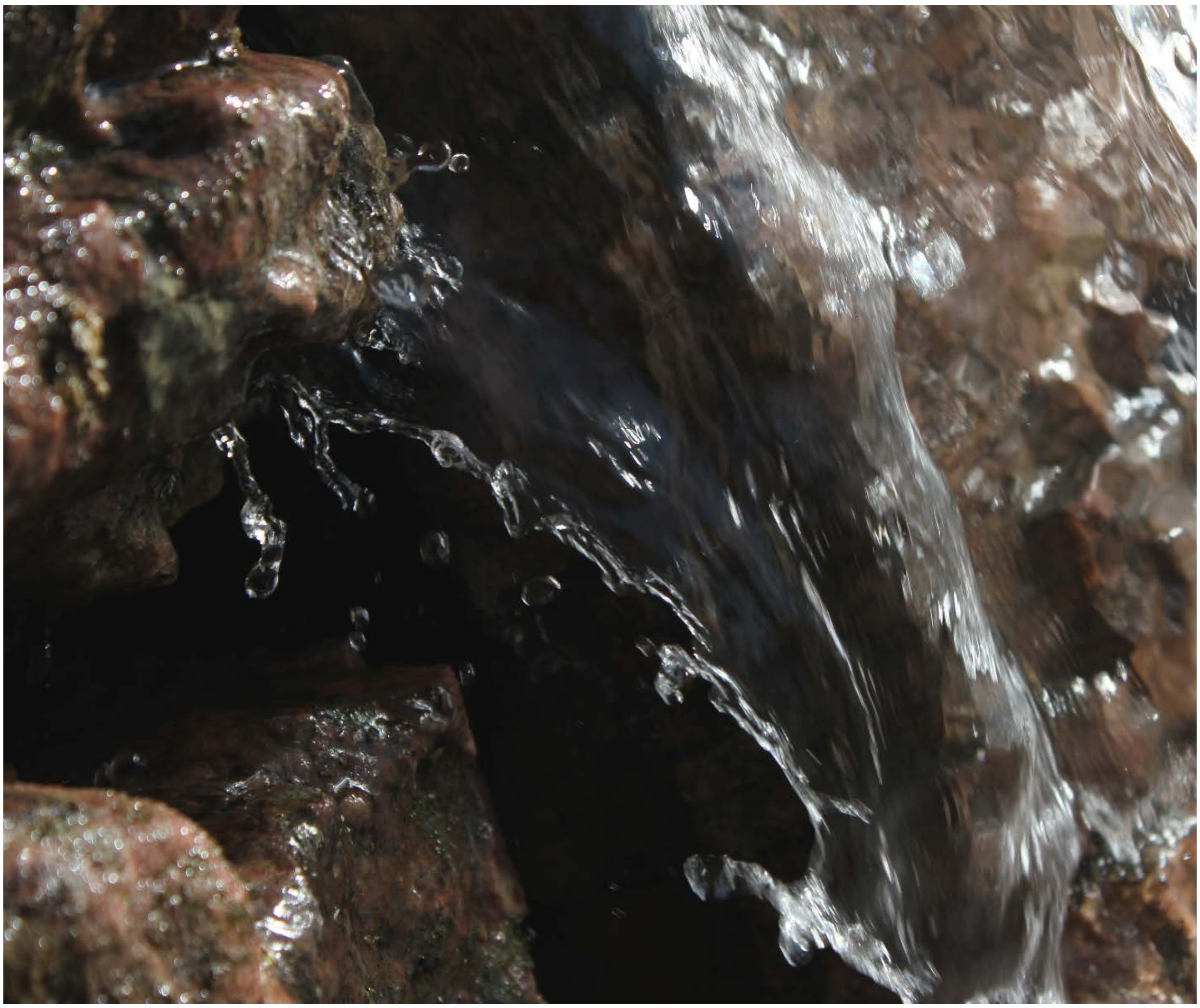
Team Project 3



MCEN 5151 – Flow Visualization
David Zilis
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Introduction:

The purpose of the team image is to capture a beautiful flow image that is a good example of flow physics. My parents recently installed a small pond with a small waterfall at their house. Since then, I've been enthralled by the thin sheets of water that waterfall forms and how these sheets break apart into fingers and droplets. Unfortunately, as cool as this flow is, I couldn't get a really exciting picture or video out of it. This picture is a little boring, but I think it's quite beautiful as well.

Physics:

A simple schematic showing the flow set up is shown below in figure 1. The water fall just continuously runs forming sheets that break. I set the camera up about six inches away and took many pictures hoping to get lucky and get a good one. The sun was the only source of light for these photos. The final field of view after post processing is about an 8 inch square.

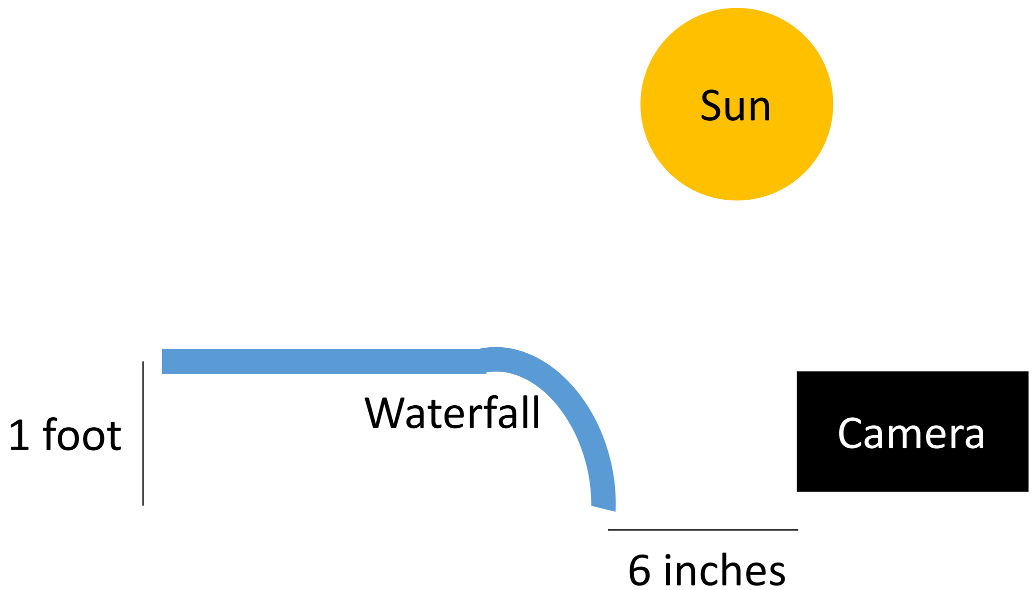

Figure 1 - Schematic of the Experiment

Looking at this image, I thought the rock in the upper left hand corner would be the main contributor to the break-up of the fluid sheet. Surprisingly, that is not correct. Instead, fluid sheets usually break up due to shear forces caused by flowing through another medium (in this case air).[1] The distortion and breaking of the sheet are an example of the Kelvin-Helmholtz instability. Prior to breaking apart, the fluid sheet first forms a sinusoidal wave with its own wave number. This wave number can be calculated using fluid properties and the speed of the fluid. In order to estimate fluid speed, we can look at the motion blur in the picture. The droplets at the bottom of the picture moved about 0.25 inches in a shutter speed of 1/640 s.

$$v = \frac{distance}{time} = \frac{0.25}{1/640} = 160\ inches/\sec = 13.3\frac{ft}{s} = 4.05\frac{m}{s}$$

With this velocity in hand, we can now calculate the wave number using the equation below:[1]

$$W = \frac{2\pi\sigma}{\lambda v^2}\left(\frac{1}{\rho_1} + \frac{1}{\rho_2}\right) = \frac{2\pi(0.0728)}{(0.0127)(4.05)^2}\left(\frac{1}{1000} + \frac{1}{1.225}\right) = 1.795$$

Where σ is the surface tension of the water, λ is the disturbance wave length (estimated as 0.5 inches), and ρ is the density of both fluids (water and air).

That analysis looked at the body of the sheet. The edges of the sheet, however, are determined by very different physics. The edges of the sheet are typically described by the Rayleigh-Taylor and the Rayleigh-Plateau instabilities.[2] Unfortunately, most analysis of these instabilities require information and resources I don't have. All calculations contain the normal vector at the point at which they are calculated. Not only do I not know that, but I don't have the ability to analyze every point in this image. However, most of this analysis is powered by the Bond number[2] which I can determine. The bond number measures the ratio of inertial force to surface tension forces and is given by the following equation:[2]

$$Bo = \frac{\rho L^2 a}{\sigma} = \frac{(1000)(0.00254)^2(9.81)}{0.0728} = 0.869$$

Where L is the sheet thickness which I estimated to be 1/10th of an inch. Because we found a Bond number less than one, we can say that surface tension dominates over body forces, which makes sense since we now know that shear forces are what dictate the shape of the sheet. The surface tension forces are directly counteracting the shear forces from the air.

Photo Setup:

The setup for this photo was very simple. The waterfall is constantly running, so I just set up my camera at a good spot to get a picture. The sun provided plenty of light to be able to use a quick shutter speed and capture the fluid well. A schematic of the set up was shown in figure 1.

As for the specifics, the camera was held about six inches away from the waterfall. The waterfall is about a foot and a half tall, but after cropping, the image only captures around 8 inches. The flow was quite difficult to capture though. I really wanted to capture a sheet breaking, but it happens so fast that I was almost always a second too fast or a second too slow.

Photo Technique:

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

Figure 2 - Unedited photos

The field of view in this image is still about 8 inches vertically, but closer to 10 inches horizontally. The picture has pixel dimensions of 5184x3456. The photo was taken with the camera about 6 inches away. 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 these images, a shutter speed of 1/640 s, an aperture f-stop of f/7.1, and an ISO setting of 100 were used. I chose the values because I really wanted to get a fast shutter speed. There was plenty of light, so exposure wasn’t really an issue. A relatively low ISO was used to avoid any grains that come with higher ISO values.

After the image was taken, there was some minor post processing done in Gimp. The image was cropped to eliminate the extra stuff to the right and really focus on the water sheet. After cropping, the field of view was an 8 inch square with pixel dimension 4114x3445. After cropping, I upped the contrast a little bit and upped the red in the rock very slightly to make it look a little earthier. Very slight post processing, but I feel it improved the image.

<u>Conclusion:</u>

I ended up not being super pleased with this image. It’s sort of boring to look at because try as I might, I just couldn’t get one of the sheets mid-break. This image is close, but slightly after the sheet had fully broken. Also, the photo seems to be more in focus of the rock just behind the fluid sheet than on the sheet itself. If I were to do this again, I might try a more controlled environment to see if I could really get an image of the sheet breaking. I would also definitely make sure the focus was in the correct spot. In all, not a terrible photo, but it could have been better.

References

1. Rangel, R. H., and W. A. Sirignano. "The Linear and Nonlinear Shear Instability of a Fluid Sheet." *Physics of Fluids A: Fluid Dynamics* 3.10 (1991): 2392-400. *AIP Physics of Fluids*. Web. 28 Apr. 2014.
2. Krechetnikov, R. "Stability of Liquid Sheet Edges." *Physics of Fluids* 22.9 (2010): n. pag. *AIP Physics of Fluids*. Web. 28 Apr. 2014.