Get Wet Report

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Context

The goal of this assignment was to “Get your feet wet”. Generally, this meant that we used this assignment to familiarize ourselves with our cameras, as well as the different methods of capturing flow we can use. For my image, I decided that I wanted to capture the vortex created after a 2-liter bottle is turned upside-down and spun in a circle as it empties. Most of the images that I captured were of the vortex that formed inside the bottle as it emptied. However, during the editing of the photographs I discovered that I preferred the water vortices that were produced after the water had left the bottle, and before the centripetal forces dispersed the water. I had a partner hold the draining bottle while I took the pictures and held the lighting.

Flow Analysis

This flow was generated through the rotation and dumping of water out of a clear 2-liter bottle. This action crates a vortex in the draining water which is then photographed with front lighting. Due to the relatively high speed of the flow, and the bright illumination, a high shutter speed is used, allowing for the pictures to be captured by hand without a tripod needing to be used. The setup for this experiment is outlined in Figure 1.

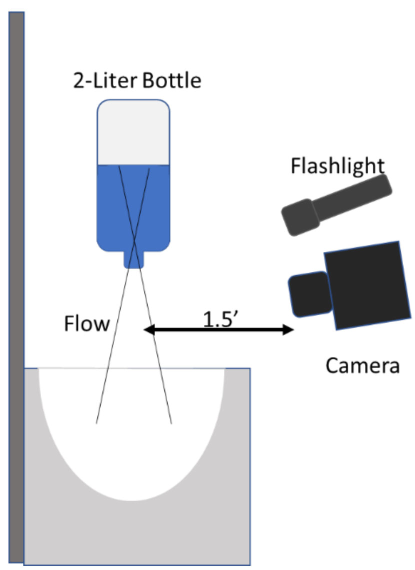

Figure 1: Experimental Setup

This flow is based on the well-known ‘vortex in a bottle[1]’, wherein a bottle filled with water is swirled and turned upside-down. This motion allows the water to drain around the lip of the opening and, as gravity pulls the water to the opening and the centripetal forces pull the water to the walls, an air channel is formed in the middle of the flow that allows air to enter the bottle at the same time as the water is draining from the bottle. This flow allows for the air pressure inside the bottle to be constantly equalized with the outside air pressure. Because of this balance, the water inside a vortex bottle drains

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[1] “Tornado in a Bottle | Science Experiments For Class 5.” CBSE Class 6-10, byjus.com/cbse/tornado-bottle/.

faster than if you were to simply dump out the water[2][3]. What my image depicts is the flow of water once it has left this vortex pattern generated by the bottle. It is observed that, though there are no longer any walls to induce a force to form a vortex, the water stream appears to maintain some form of periodicity and vorticity as it falls. The water channel has a diameter of roughly 30cm, and appears to begin to taper off as it falls. Furthermore, the water falls roughly 1.5m in the picture.

Upon analysis of the image, I believe that this flow is an example of a water jet. More technically, I believe that the terms to describe this flow are that the flow is a 'Rotational Plateau-Rayleigh Instability with Stable Asymmetric Detached Throat Flow'. A Plateau-Rayleigh flow is defined by the instability created in a jet of heavy liquid, such as water into air, through the "operation of the capillary force, whose effect is to render the infinite cylinder an unstable form of equilibrium…"[4]. In layman's terms, this instability explains how a jet of water breaks into droplets as it falls. An example of this is how a faucet's water will fall in droplets, even with a continuous stream of water. An example of this flow without rotation or a water sheet due to a vortex can be seen in Figure 2.

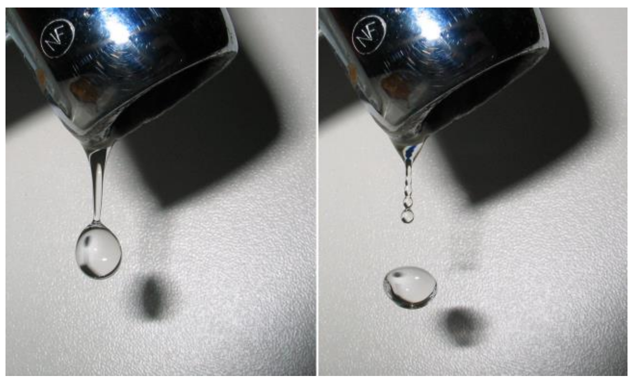

Figure 2: Plateau-Rayleigh Instability demonstrated by dripping faucet[5]

For rotational detached throat flow, the vortex detaches from the bottle lip as the rotation of the water lessens enough to prevent a constant stream of air to enter through the center of the throat. This detachment forms a rotating sheet of water that creates the swirls seen in my image.

The angular velocity of the water as it leaves the bottle can be calculated through the equation

$$\omega^2 * D = G * g,$$

Where ω denotes angular velocity, D is the diameter of the vortex, G is the vortex tube gradient, and g is the gravitational acceleration. Through analyzing the flow and bottle dimensions, D is found to be roughly 30cm, and G is roughly 9. Therefore, using the above equation,

[2] "The Quick-Pour Soda Bottle Race | Science Experiments | Steve Spangler Science." The Lab, www.stevespanglerscience.com/lab/experiments/tornado-in-a-bottle1/.
[3] "Vortex." Exploratorium, 16 Mar. 2016, www.exploratorium.edu/snacks/vortex.
[4] Rayleigh. "On The Instability Of Jets." Proceedings of the London Mathematical Society, vol. s1-10, no. 1, 1 Nov. 1878, pp. 4–13., academic.oup.com/plms/article-abstract/s1-10/1/4/1503187?redirectedFrom=fulltext.
[5] McLassus, Roger. "Detaching Drop." Wikipedia, 21 Jan. 2006, commons.wikimedia.org/wiki/File:2006-01-21_Detaching_drop.jpg.

$$\omega^2 * 0.3m = 9 * 9.81\, {}^{m}/_{sec}\text{, and } \omega = \sqrt{\frac{9*9.81}{0.3}\frac{rad}{sec}} = 54\frac{rad}{sec}.$$

This is a relatively fast flow, and using this calculated velocity we can also calculate the Reynolds number. Using previously known numbers and water constants, Re is calculated as:

$$Re = \frac{v*L}{\upsilon} = \frac{54\frac{rad}{sec}*0.3m}{1.6438*10^{-6}\frac{m^2}{sec}} = 9.8 * 10^6.$$

This calculation shows that the flow generated in the vortex is highly turbulent. This calculation is backed up by observation of the flow that I filmed in slow motion on my phone.

Setup

To create this image the only materials used were clear water, and a clear 2-liter plastic bottle. A high-powered light is shined on the stream of water to highlight the reflection and refraction, and a camera is used to capture the image. The image was taken in a standard room temperature room, at a standard Colorado level of humidity. The water was also roughly room temperature. The 2-liter bottle was only open on one end. Finally, the lighting was achieved through a handheld flashlight outputting roughly 600 lumens in a darkened room. This flashlight illuminates the front of the phenomenon, and allows for the camera to also capture the shadow of the flow.

Photographic Technique

To take this image, considering the limitations in my lens, I determined that, due to the fast flow and low light level, a high shutter speed and ISO would be needed to capture a clear picture. To start with, I used a fixed FOV lens of 40 mm. This lens can focus as close as 0.163 meters from the target, has a aperture range from f/2.8 to f/22, and a maximum AOV of 38°50'. To get the image I wanted I took the picture with an aperture f f/5.6, a shutter speed of 1/1000 sec, and an ISO of 1600. I used a Nikon D7000 at around 1.5 feet away from the flow to take my pictures. The initial image's pixel size was 4928x3264, and the final image was 2662x2849.

For post-processing, I exported the image to Adobe Lightroom 6. To better highlight the flow, I cropped the image and changed it to black and white. Furthermore, I adjusted the exposure, highlights, whites, and blacks. The final image settings can be seen in Figure 3.

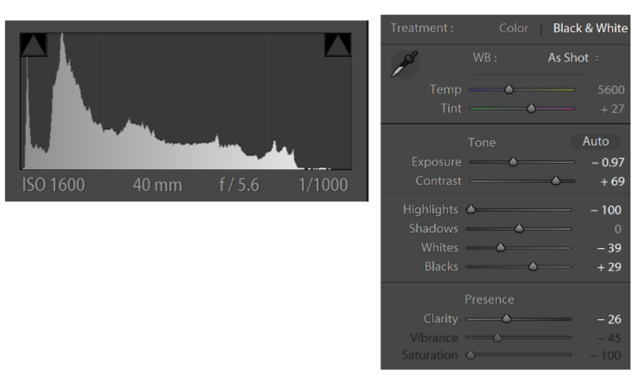

Figure 3: Image Histogram and Color Scales

A comparison between the initial and final images can be seen in Figures 4 and 5.

Figure 4: Original raw image

Figure 5: Final edited image

Conclusion

This image demonstrates the turbulent flow that occurs in a draining water vortex. The flow begins uniform, but as it falls it twists, and after it has fallen a certain distance individual beads begin to form at each flow wrinkle, closely correlating to a Plateau-Rayleigh Instability. I like how the image is well focused, and how you can see the shadow in the flow in addition to the actual flow. I also like how sharp the image is, but I think I could have cropped it more or taken the picture at a faster shutter speed to reduce the motion blur towards the bottom of the image. I think this image shows the fluid physics very well, and the black and white helps draw attention towards this flow. If I was to develop this further I would record a video of this flow with a high definition slow motion camera to better grasp the transitions experienced by this flow, and to more accurately trace the path that the flow takes as it falls.