Image/Video 3 Report

MCEN 5151

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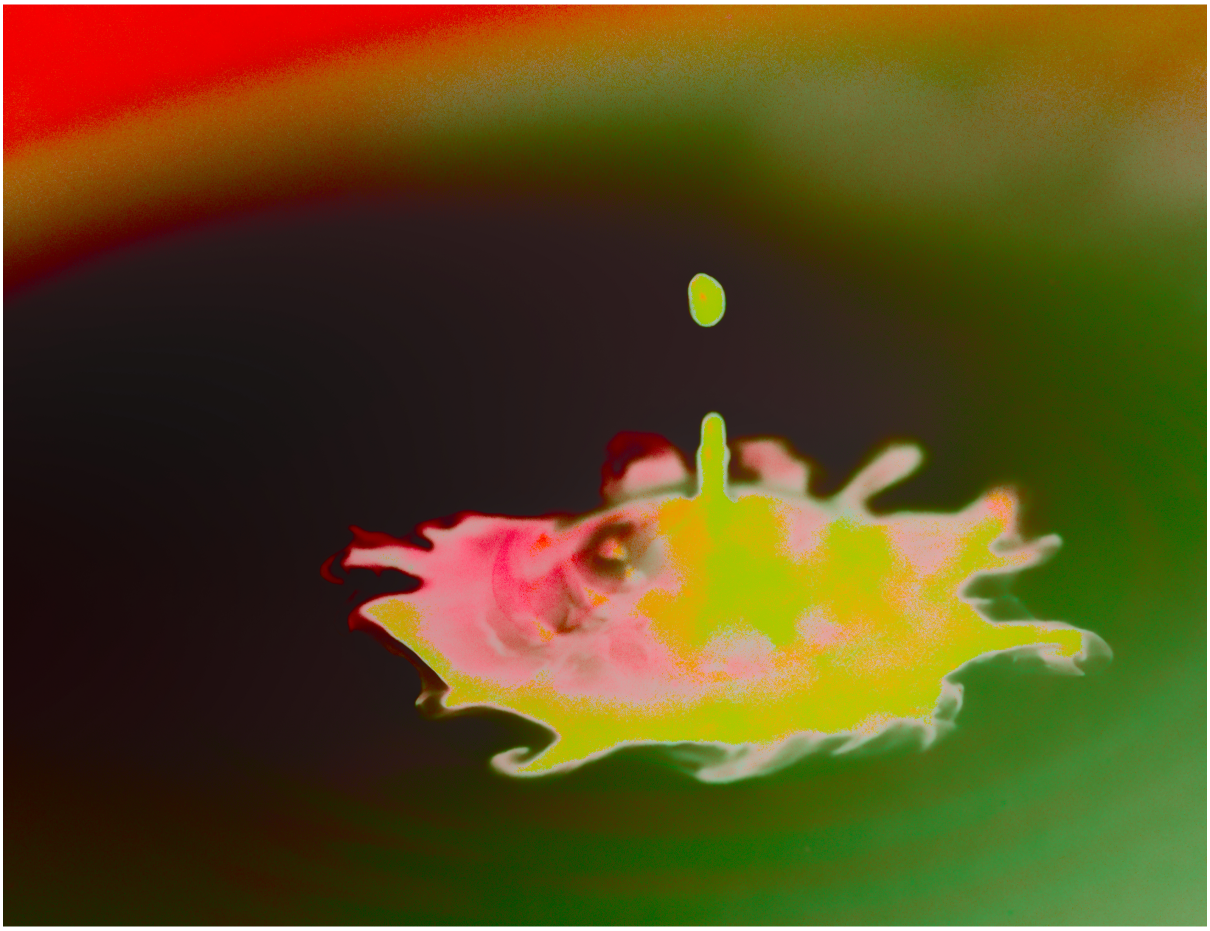
11/15/2021



1 Introduction

For this assignment I wanted to capture an image of a vortex phenomenon. Vortices create interesting visuals and can also lead to interesting physics. Often times flows become turbulent due to the entanglement of vortices. Vortices are also applicable in many different realms of science including meteorology and aeronautics. With a wide application and the ability to create interesting and unpredictable shapes, it seemed worthwhile to attempt to capture a rotational phenomenon.

2 Apparatus

To produce this image, tap water, red food dye, and corn starch were mixed together in a large glass bowl. This red mixture acted as the background for the image. The bowl was placed on a white bed sheet to help lighten the image. The bowl was illuminated using an LED flashlight and an iPhone XR light. The flashlight was placed against the left side of the bowl and the iPhone light was placed at the back of the bowl. The camera was mounted on a tripod on the floor in front of the table about 6 inches away. To create the focal point of the image, green food dye was dropped into the red mixture while the red mixture was stirred to initiate a counter clockwise rotation. Below are schematic diagrams of the setup.

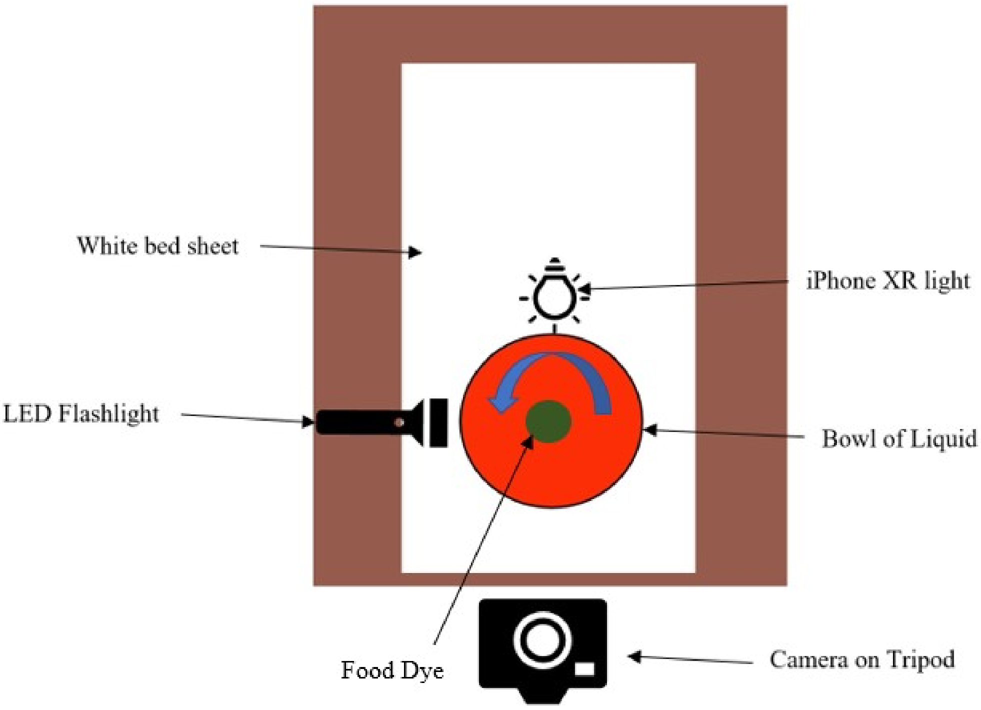


Figure 1: Diagram of experimental setup from above.

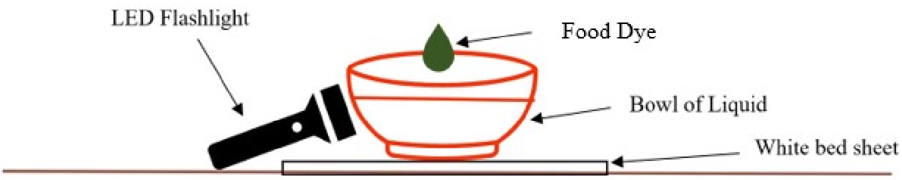


Figure 2: Diagram of experimental setup from plane view.

3 Physics Explanation

The main spectacle captured in this image is a result of rotational interactions. The two main values used to quantify rotation in a fluid are circulation and vorticity [3]. Circulation is a scalar quantity and is a macroscopic measurement of the rotation for a finite area of the liquid [3]. Vorticity is a vector field quantity, which gives a microscopic measure of the rotation at any point in the fluid [3].

Circulation is mathematically defined in equation 1. $\mathbf{U}$ is the velocity and $d\mathbf{l}$ is the vector tangent to the chosen line integral path (see figure 3). Circulation is useful to determine which direction a fluid is rotating. If the circulation is positive, the liquid is rotating counter-clockwise. Similarly, if the circulation is negative the rotation is clockwise.

$$\Gamma = \oint \mathbf{U} \cdot d\mathbf{l} \tag{1}$$

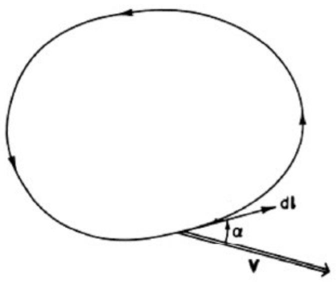


Figure 3: Diagram of circulation line integral from reference [3]. Here, $\mathbf{V}$ is equivalent to $\mathbf{U}$ in equation 1.

Vorticity is defined as the curl of the velocity vector (equation 2). A non-zero vorticity indicates a swirling motion in the liquid.

$$\boldsymbol{\omega} = \nabla \times \mathbf{U} \tag{2}$$

In this photo there happens to be multiple vortices. There is one large vortex (in the red liquid) and multiple smaller vortices near the edges of the green food coloring. Below is a diagram denoting their rotational directions (see figure 4).

We can make some conclusions given the direction of rotation for each vortex. We know that there is a swirling motion in the liquid, so $\boldsymbol{\omega}$ from equation 2 is non-zero. From the directions of the vortices we know that the large vortex present in the red liquid has a positive circulation, while the smaller vortices in the green food dye have a negative vorticity since they are rotating clockwise.

When the green food dye was dropped into the mixture, it began to expand outwards and later contract. This was due to the rotation of the background fluid. If the background fluid was not rotating, the liquid would have solely expanded as expected, however the introduction of the rotation caused the green structure to contract. At the instance this photo was taken, the food dye was expanding (denoted by the outward arrows in figure 4).

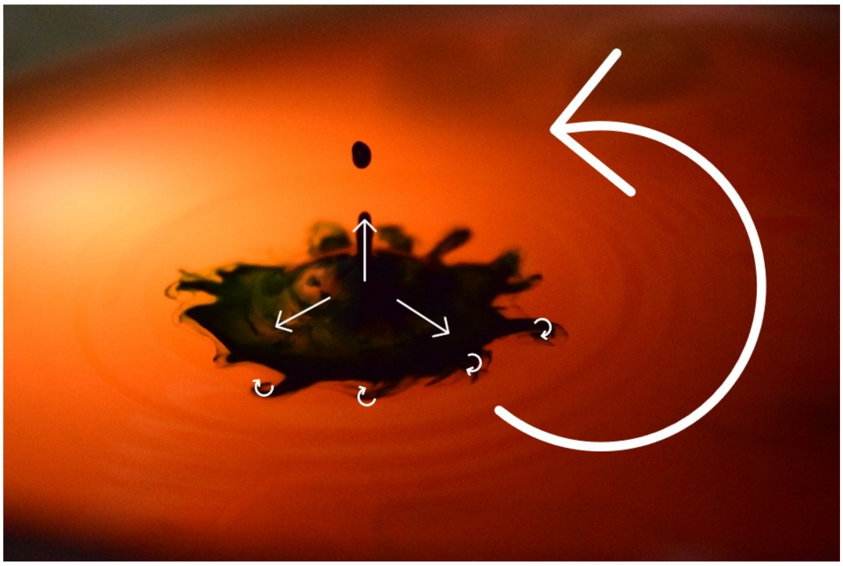


Figure 4: Diagram denoting the direction of fluid movements. The straight arrow pointing up denotes the worthington jet and the arrows pointing outward denote the expansion of the green food dye. The red background liquid is rotating counterclockwise while the smaller vortices are rotating clockwise.

Another interesting structure in the green food dye is the presence of a worthington jet. A worthington jet is typically one of the final steps in drop-splash phenomena and forms after a droplet hits a free surface. The droplet causes ejecta when it hits the free surface while simultaneously creating a crater. The free surface reacts and creates a spike formation and often forms a free droplet as well [2]. This process is illustrated in figure 5. Although this worthington jet was not the focus of this image, it added complexity to the physics and the composition of the photo.

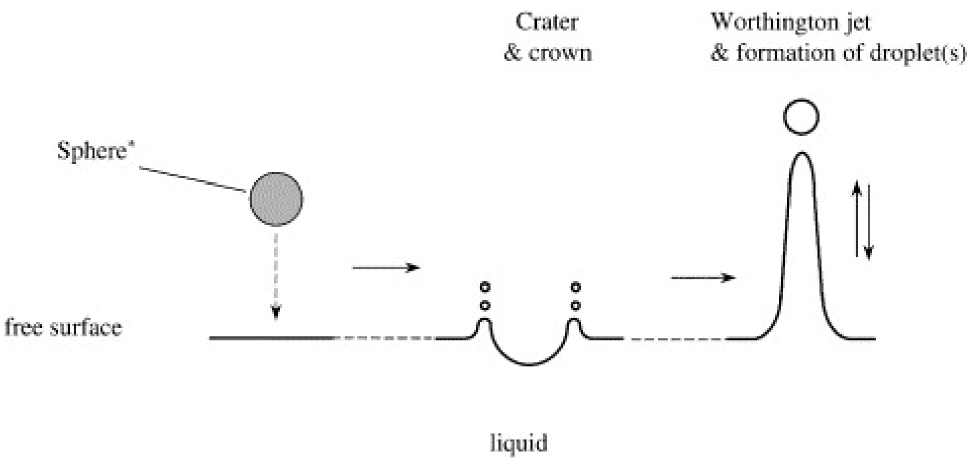


Figure 5: Diagram of worthington jet development from reference [1].

4 Visualization Technique

To help capture this image, cornstarch was added to the water to reduce the glare and transparency of the red mixture. I added 2 teaspoons of cornstarch to 2 L of tap water, which made the liquid much more opaque. To color the liquid, I used 6 drops of Kroger's red food dye. The coloring of the base liquid was meant to create a stark contrast with the green food dye (also Kroger's brand). The green food dye allowed us to easily visualize the vortex motion. Without the addition of the green food dye it would be impossible to visualize the resulting motions from the largest vortex.

5 Photographic Technique

Below is a table summarizing the camera settings used for this image. A Nikon D330 DSLR camera was used with a 18-55mm lens. The photos from this experiment were also shot in continuous mode in order to capture the different formations over time (a .gif was also created and posted to the flowvis website with these images). The flash on the camera was not utilized as this created a large glare in the image.

Property	Value
Shutter Speed	1/4000 sec
Focal Length	55 mm
ISO	9000
Aperture	f/5.6
Pixels	6000 x 4000

5.1 Post Processing

Since one of the goals of this course was to become familiar with how to process flow images, I wanted to see how different I could make my final image from my original, while preserving the integrity of the physical phenomenon. Below are the original image and the final edited image.

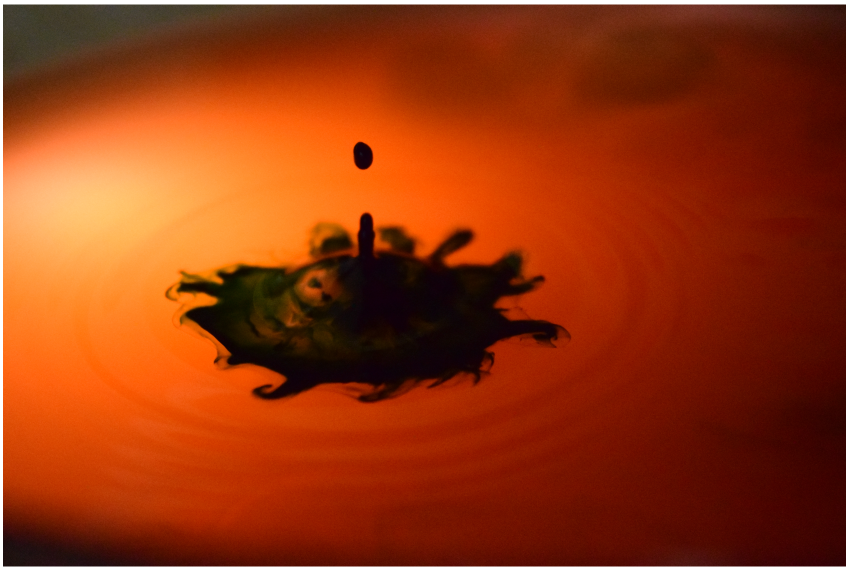


Figure 6: Original image without edits.

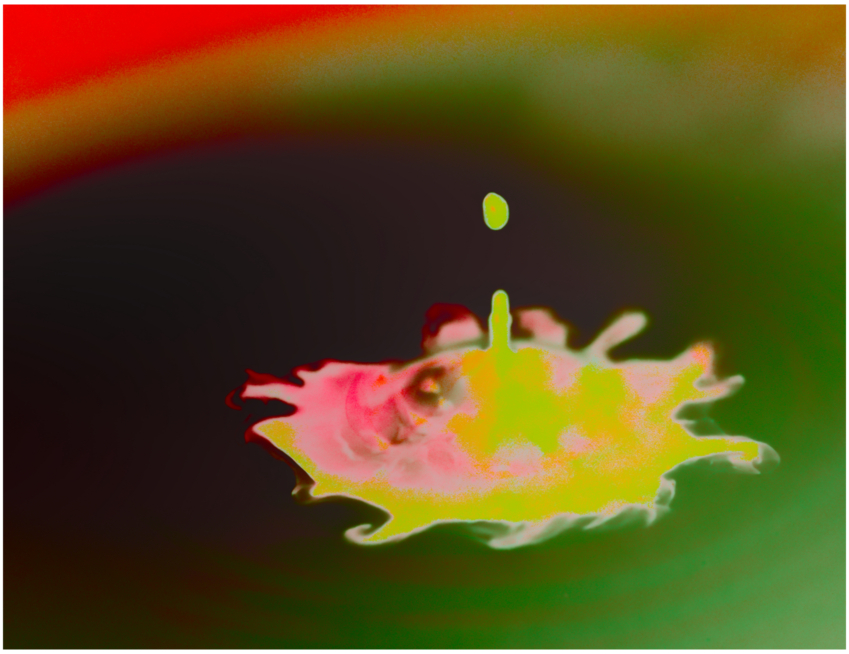


Figure 7: Final image including edits.

To create the final image, I used darktable. The first edit was to crop the image closer to the green food coloring. The second adjustment was to invert the colors of the image using negadoctor. This effect allows you to pick a color for the film base. For this I chose a red/orange. This meant that the red in the original image would become black and the balck in the original film would become red. The next adjustment I used was split toning. This allows you to change the colors of the highlights and shadows and which of the two will be dominant. For this, I chose contrasting colors, green and pink. This is highlighted in the coloring of the green food dye.

6 Final Thoughts

The most interesting part of this photo is the small vortices on the edges of the food coloring. The shapes created by the different forces are non-uniform and create visual interest. The worthington jet also adds to the composition of the image as the stand-alone droplet creates a vibrant focus on the black background. I am happy with the in-depth post-processing on the image since it made it more vibrant. The green food coloring structure has a smoke-like effect to it and I also like that it is not easy to know exactly what you're looking at upon first glance. I like that you need to read a caption to understand the image. I'm very happy with the variety of swirling shapes in the image and believe I effectively captured some vortex dynamics.

7 References

[1] Cheny, J.-M, and K Walters. "Rheological Influences on the Splashing Experiment." Journal of Non-Newtonian Fluid Mechanics, Elsevier, 25 Aug. 1999, https://www.sciencedirect.com/science/article/pii/S0377025798002080.

[2] Krechetnikov, Rouslan, and George M Homsy. "Crown-Forming Instability Phenomena in the Drop Splash Problem." Journal of Colloid and Interface Science, http://www.math.ualberta.ca/ rkrechet/files/publications/jcis2009.pdf.

[3] Yu, Jin-Yi. "Lecture 4: Circulation and Vorticity." UCI, Department of Earth System Science, https://www.ess.uci.edu/ yu/class/ess228/lecture.4.vorticity.all.pdf.