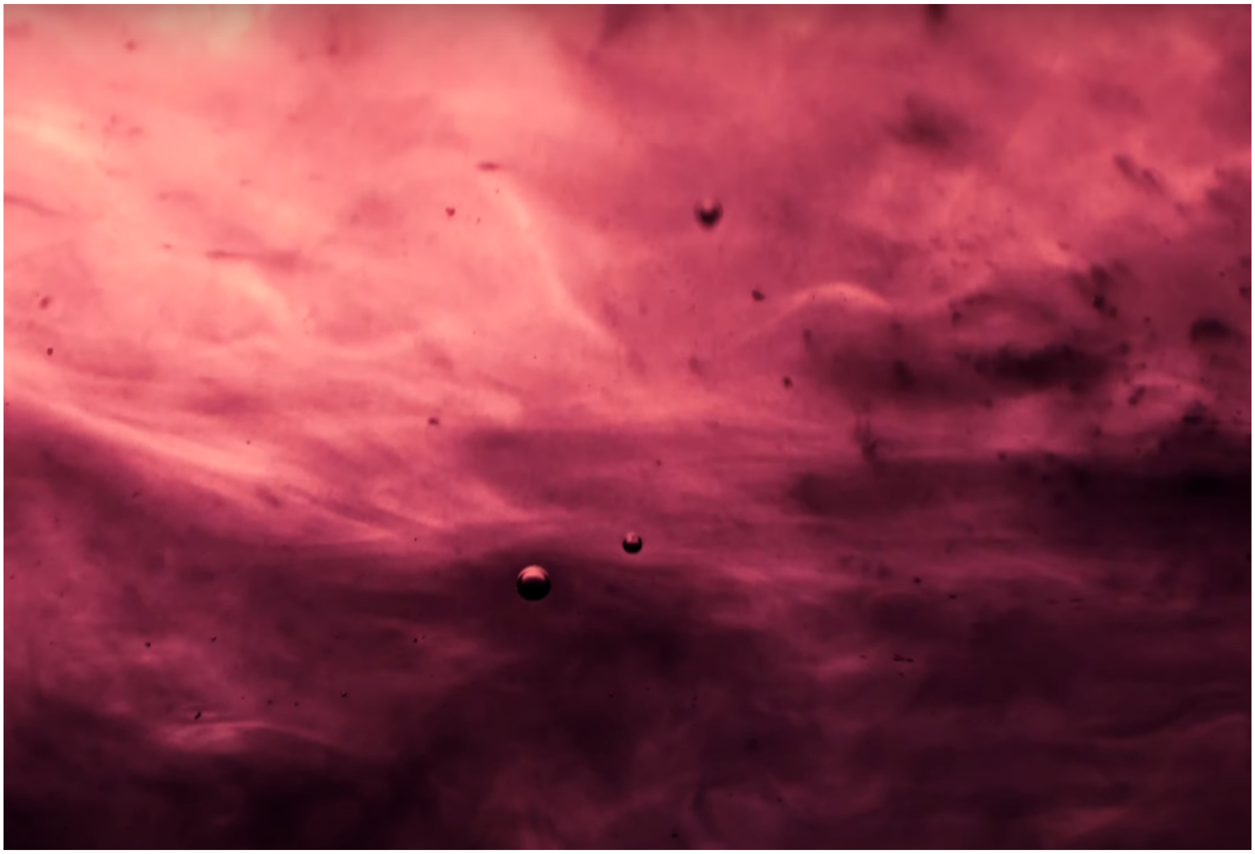

Recreation of Oppenheimer Practical Effects

MCEN 4151-001 Flow Visualization

Teams First Report

Oct 6 September 2023

Ciaran Rochling

Background & Introduction

My video, "Oppenheimer Practical Effects Recreated," is my attempt to delve into the world of flow visualization, a medium that bridges the realms of art and physics. For this assignment, I embarked on a weekend trip into the mind of Cristopher Nolan's Robert J Oppenhimer.

At the height of the Second World War, the superpowers of the world were in a military arms race to harness the power of the atom. During the 1930's and 1940's, the study of nuclear physics had exploded in popularity and volume. It was not until the Trinity Test in the early morning of July 16, 1945 where the world would truly understand the power behind the atom.

Fast forward to July 21, 2023 where Cristopher Nolan, famed movie maker and director of the 21st century, released his newest cinegraphic masterpiece title, "Oppenheimer." This film dives into the chaotic and turmoiled life of the one Mr. Robert J Oppenheimer, the appointed head of the Los Alamos Nuclear Test Program, as he struggles with his political and nationalistic beliefs with regards to the Second World War and nuclear physics. During this film, Christopher Nolan takes hold of the reins and dives the captivated audience into the mind of Oppenheimer. We see the quantum entangled particles swirling about, popping into and out of existence. We see the bitter strife of love that plagues Oppenheimer. We see the pain and suffering caused by nuclear destruction. And we see the fluid nature of chaos needed to conquer the world. All of these effects were designed and produced using practical methods. In essence, little to no computer generated images or effects were used in the production of the film.

I was captivated by this. I couldn't believe that Christopher Nolan's team of filmmakers could wrangle chaos and violence so beautifully. I knew I had to try my hand at recreating some effects. I knew it could be done. I just had to figure out how. For these reasons, I challenged myself to complete this project on my own, without the aid of my teammates.

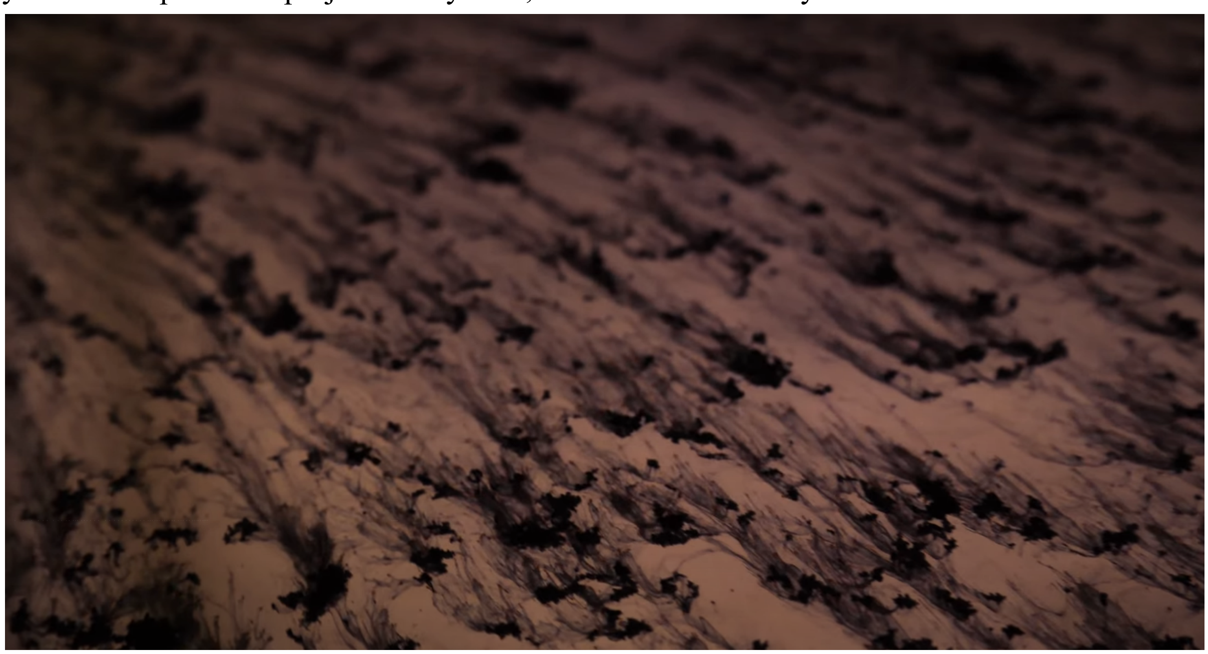

Figure 1: Screen shot from 0:30 of my short film, "Oppenheimer Practical Effects Recreated"

Research & Methods

During my research I ran across a video titled "We RECREATED the Nuclear Explosion from Oppenheimer with ZERO CGI," uploaded to YouTube by William H Baker [1]. This video dives into some of the effects used in Oppenheimer's multiple movie trailers. Of which, the third effect caught my eye. Through multiple failures and perceived victories, William H Baker and his team of videographers stumbled upon the solution. To recreate the desired effect, all they would need to mix together was pigment powder and water. Boom, problem solved. I had my effect. I had my solution, all I had to do was recreate it myself.

Rewatching Baker's video, I noticed the solution for the desired effect required the use of a backlit/lightbox lightsource positioned behind and below the fluid containment vessel. For this reason I decided to use a fish tank light placed behind an elevated diffusion tarp to operate as the primary system light source. I had checked out the fish tank light from Professor Hertzberg.

During my material procurement phase, I struggled obtaining any pigment powder. Rather than pigment powder, I decided to use charcoal powder instead. Thankfully, charcoal powder and pigment powder occupy roughly the same size scale of around **10-20 microns per grain.** Using a different powder medium to recreate the practical effect from the film would end up having its own advantageous side effects in that I could add my own artistic flavor to my effects, rather than sticking directly to what Christopher Nolan's film team had put together.

To capture the water and charcoal powder mixing together, I set my camera to video and filmed myself dropping the charcoal powder into water then mixing them together. See Fig. 2 for a sketch depiction of my setup and Fig. 3 for my actual setup.

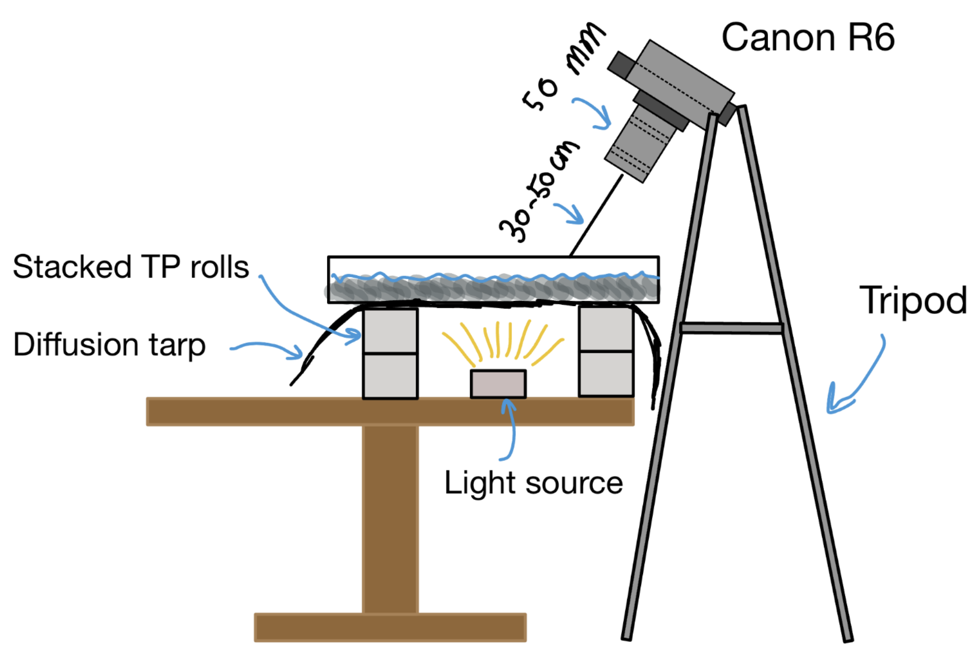

Figure 2: Sketch depiction of my setup

Figure 3: Image depiction of my setup

Physics

The main fluid phenomenon on display in "Oppenheimer Practical Effects Recreated" is that of Ficking mixing. In fluid mechanics, the defining characteristic of mixing mediums is that of Fickian Mixing. When molecules or small particles are suspended in a liquid, two opposing forces, gravitational force and buoyant force, can dictate the overall composition of the mixture. If one force dominates the other, then particles in the suspension will either *cream* or *sediment*. If the density of the particles, $\rho_{particle}$, is less than the density of liquid, ρ_{liquid}, they are suspended in, the particles rise, or *cream*. If the density of the particles, $\rho_{particle}$, is greater than the density of liquid, ρ_{liquid}, they are suspended in, the particles sink, or *sediment*. If the density of the two mediums are almost equal, or if the net force is too small to influence the general motion of the particles, the behavior of the suspension is then primarily influenced by random Brownian motion.

In my experiment, I mixed charcoal powder and water. Charcoal powder has a density $\rho_{particle}$ = 2100 kg/m^3; whereas water has a density of around ρ_{liquid} = 997 kg/m^3. Given the large difference in mixed material density, one would expect the charcoal powder to immediately sink and mix into the water solution, given the understanding of *cream* and *sediment* above. While performing the experiment, I realized that this was not the case. In fact, when I first dropped the charcoal powder into the water and began to mix, it would stay clumped together and float on top of the water. It was not until the clumps of charcoal powder had entirely separated that it would begin to thoroughly mix with the water, only to inevitably sink to the bottom of the containment vessel.

Provided this, I determined that the surface tension of water played a crucial role in suspending the charcoal powder on top of the fluid before it eventually separated and sank. Surface tension is a property of liquids that arises due to the cohesive forces between their molecules. In the case of water, these forces cause water molecules at the surface to bond together tightly, creating an invisible "skin" or surface layer. This cohesive force was strong enough to support the weight of the charcoal powder particles, preventing them from immediately sinking upon contact with the water. Instead, the surface tension held the charcoal particles aloft, allowing them to float temporarily. However, as the charcoal particles became saturated with water, their density increased, eventually overcoming the surface tension's ability to support them, causing them to sink into the fluid. This dynamic interplay between surface tension and gravity explains how the charcoal powder was initially suspended and later separated and sank in the fluid.

As per Biolin Scientific, the surface tension of water measures at approximately 72 mN/m at room temperature [2]. Using the following calculations, we can see that until the charcoal powder was sufficiently saturated with water during mixing, it was unable to break the surface tension of water.

Mass calculation for a single grain of charcoal.

$$Density = \frac{mass}{volume} \rightarrow \rho = \frac{m}{V} \quad (1)$$

$$\rightarrow m_{charcoal} = \rho_{particle} V \quad (1.1)$$

$$\rightarrow m_{charcoal} = 2100[\frac{kg}{m^3}](2\cdot 10^{-5})^3[m^3] \quad (1.2)$$

$$\rightarrow m_{charcoal} = 1.68 \cdot 10^{-11}[kg] \quad (1.3)$$

Using Newton's second law , $F = ma$ where a is the acceleration due to gravity, we can calculate the weight in Newtons for one grain of charcoal as follows

$$F = ma, \ a = 9.81 \ [\frac{m}{s^2}] \quad (2)$$

$$F = 1.68 \cdot 10^{-11}[kg] \cdot 9.81 \ [\frac{m}{s^2}] \quad (2.1)$$

$$F = 1.64 \cdot 10^{-10}[N] \quad (2.2)$$

Dividing the weight of one charcoal grain by its critical length of 20 microns we can see that the surface tension of water is strong enough to support unsaturated charcoal powder.

$$T_{surface,water} = 72 \ [\frac{mN}{m}] > \frac{1.64\cdot 10^{-7}[mN]}{2\cdot 10^{-5})^3[m]} \quad (3)$$

$$T_{surface,water} = 72 \ [\frac{mN}{m}] > .0082 \ [\frac{mN}{m}] \quad (3.1)$$

The interaction between the charcoal powder and water remains in effect until the charcoal powder is sufficiently mixed into the water and thoroughly saturated. Once the charcoal powder is thoroughly saturated with water, it becomes too dense for the surface tension of water to properly support the powder. Once this happens the charcoal powder begins to disperse within the water until it sinks to the bottom of the containment vessel.

Realistically these values are only approximations. In reality not every charcoal grain is 20 microns in length. Some may be larger and others may be adhesively bound together from their own inherent water content, making them larger. In general these calculations are satisfactory for my system and the scope of my experiment.

Photographic & Visualization Technique

This short film was shot on a Canon EOS R6 Mark II mirrorless camera with a kit 24-105mm zoom lens. This system uses charcoal powder as a discrete visualization technique to aid in visualizing the flow of water in a containment vessel. Since this project required my camera to be in video mode, I made no outright changes to the camera's native ISO, shutter speed, and aperture size. I decided to shoot my film in 4k 60fps. This is the highest resolution video and the highest framerate my camera can capture at.

To capture the highest quality flow dynamics, I decided to film my experiment at night where the only source of light was the fish tank light located underneath the containment vessel, separated by a diffusion tarp. I used an old clear tupperware plastic bin as my containment vessel and a white party table throw cover as a light diffusion tarp. To offset the fish tank light from the tarp and containment vessel, I used stacked toilet paper rolls to act as uniform stilts. In total, I used eight toilet paper rolls with two at each corner.

To perform the experiment I filled the containment vessel to a water level of about 1-1.5 inches. From here I could begin recording and slowly add charcoal powder from above the field of view of the camera at a height of about 30 cm from the water level. Once the charcoal powder was added to the containment vessel, I began stirring the water & charcoal fluid with a butter knife. After about 10 minutes of adding charcoal powder, stirring, and filming, I changed the water in the containment vessel as it had become too saturated with charcoal powder to achieve the desired effect I was aiming for. This process was repeated 3 times. In total I captured about 30 minutes of raw footage of varying fields of view. Some shots were taken directly overhead about half a meter from the water's surface. Other shots were taken at about 15-30 cm distance from the water's surface, offset to either side for a different perspective. On average the total field of view of each clip in my final video is about 1 foot, or 30 cm across.

Once I had completed recording my experiment, I cleaned up and transferred the video files into IMovie for editing. During the editing phase, I selected the clips that I wished to use and cut out parts where my hand was in frame, stirring the system. I also decided to color correct/color grade the images to various degrees. This was done to engage the audience more with a wider range of the color in the system. While some unedited video clips were used in the final video, most clips seen were color corrected/color graded to a level that I felt would be intriguing to the audience. There was no rhyme or reason for how I decided to color grade the video clips. I just chose whatever felt best for each clip. See Fig. 4 and Fig. 5 below for an unedited still compared to a color corrected still from the final video. Notice the difference in color vibrancy from Fig. 4 to Fig. 5. As well, some shots in the final video were sped up or reversed. While doing this impacts the visual appeal of the video, it does not impact the intended fluid mechanics I was attempting to capture.

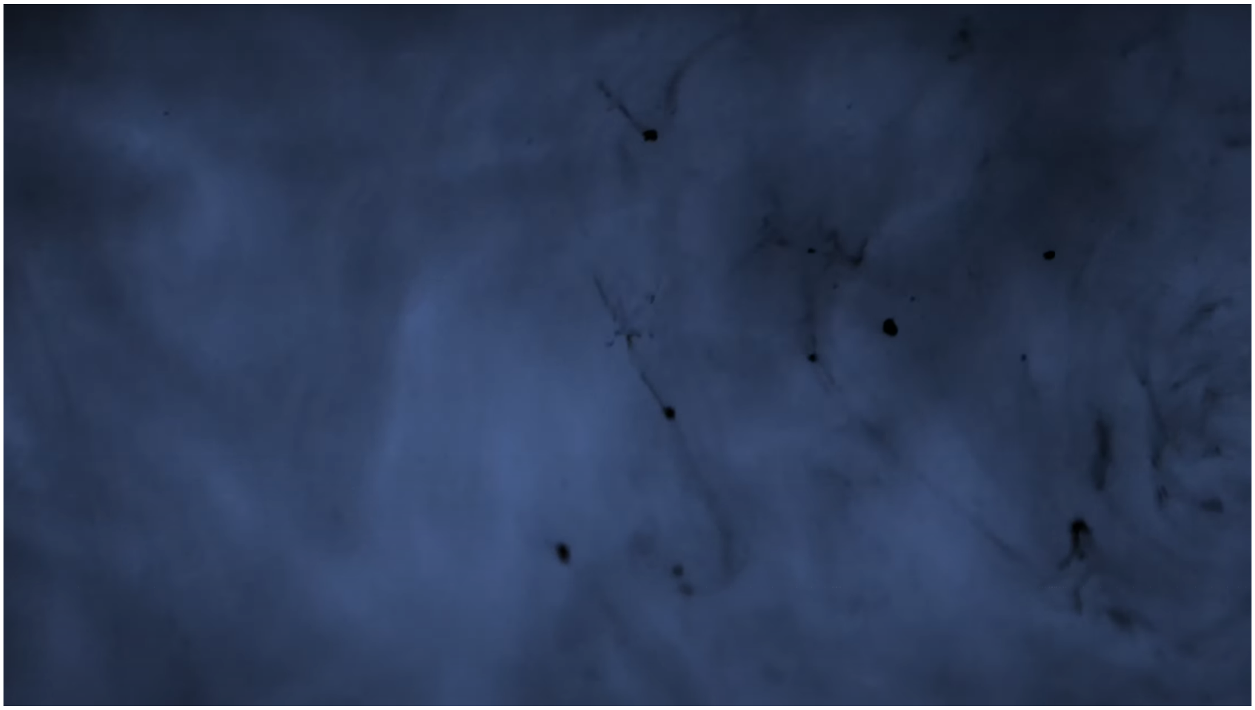

Figure 4: Unedited still from a clip used in final video

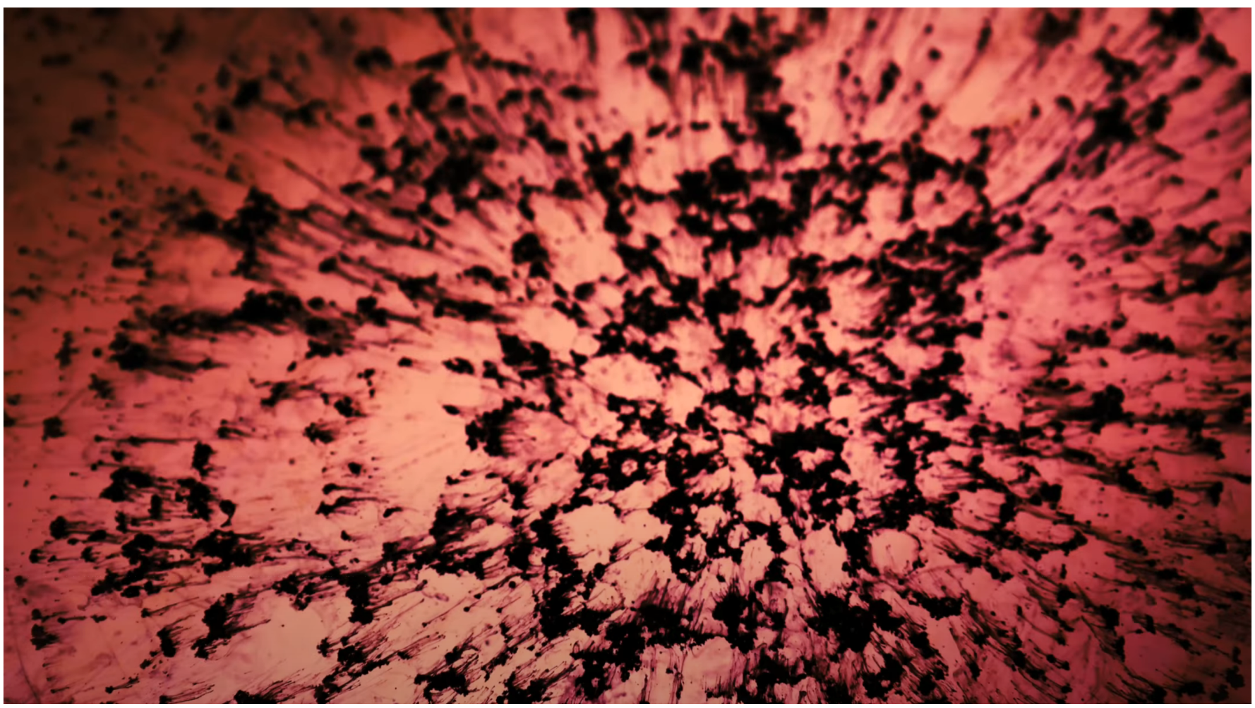

Figure 5: Edited still from a clip used in final video

I also decided to add Ludwig Göransson's " " as a backing track [3]. This instrumental piece is taken from the original score of Christopher Nolan's Oppenheimer.

Once I had completed editing the video, I downloaded the completed product in 4k, 60fps, and uploaded it to YouTube for unlisted viewing.

Artistic Revelation

In this captivating video, my interpretation of the combating forces inside the mind of Robert J Oppenheimer are vividly depicted. The rising action of the video and chosen score impassionately dance until an emotion-filled black screen crashes at the end, releasing the built up tension. This striking juxtaposition engages the audience at every turn, grossly and thoroughly bringing them into the chaotic mind of Robert J Oppenheimer. This captivating composition not only captures the beauty of Oppenheimer's cursed duality, but also evokes a sense of balance and harmony amidst the dynamic forces at play in his mind.

Conclusion & Future Notes

I believe the video I created is of appropriate class quality and accurately represents the principles of fluid physics I aimed to capture. The balanced portrayal of suspended and chaotic flow, combined with the inclusion of relevant background music, makes it a compelling and informative video. Moving forward I would like to venture further into proper image framing and composition. While I believe the product I settled on is able to convey the intended fluid mechanics I attempted to achieve, I also believe that there is plenty of room to improve. For instance, while most of the short film is properly in focus, I struggled to capture all shots in the video with ideal focus. Some clips have an off center focus that requires the viewer to relocate their eye from the center frame. Other shots are properly in focus and appropriately capture the fluid motion. Moving forward I would like to scale up the concept of mixing different fluids in different mediums. I am excited to continue this new hobby of mine and I am eager to get out there and capture my next Video!

References

[1] Baker, William H, director. *We RECREATED the Nuclear Explosion from Oppenheimer with ZERO CGI*. *YouTube*, William H Baker, 12 Aug. 2023, https://youtu.be/o2FqU2f6DRc?si=ReuZgSxf3-hgs8lo. Accessed 20 Aug. 2023.

[2] Laurén, Susanna. "Surface Tension of Water – Why Is It so High?" *Biolin Scientific*, 13 June 23AD, www.biolinscientific.com/blog/surface-tension-of-water-why-is-it-so-high#:~:text=Water%20exhibits%20a%20remarkable%20surface,with%20the%20highest%20surface%20tension.

[3] Göransson, Ludwig. "Can You Hear The Music." *Spotify*, Back Lot Music, Universal Studios, 21 July 2023, https://open.spotify.com/artist/24eDfi2MSYo3A87hCcgpIL. Accessed 21 July 2023.