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Team Third

MCEN 5151

November 21, 2025

Figure 1: Final image showing a water stream that followed a rapidly surfacing object

Context and Purpose

This image was created for the Team Third assignment. The artistic intent was to experiment with high-speed photography to capture a very specific moment in time. The original scientific intent was to capture an image of an object quickly surfacing right before the surface tension broke around the object. I was able to capture the following two images; the first in figure 2 shows my original intent, and the second in figure 3 shows the moment right as surface tension breaks. The images are also included, as they give good context into how the experiment was performed.

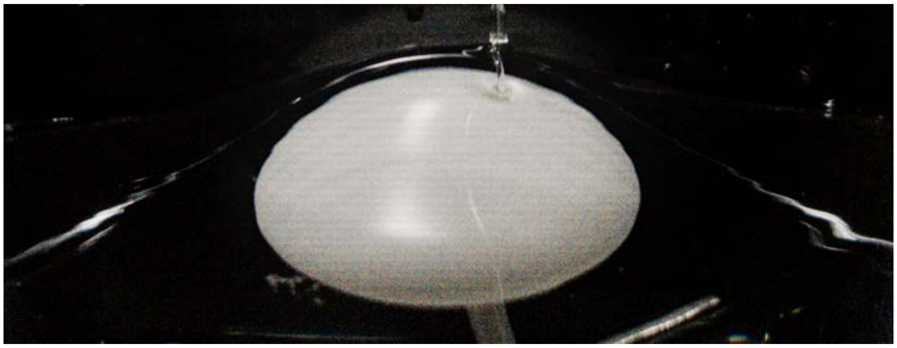

Figure 2: Moment before surface tension breaks around a rapidly surfacing object

Figure 3: Moment just as surface tension breaks around a rapidly surfacing object

Though these images were interesting in their own right, I ultimately chose the final image because of how visually striking it was. The chosen photo captures a stream of water as it follows a rapidly surfacing object out of the water.

Flow Apparatus and Physics

The experiment was performed in a clear, rectangular container made of plastic. The container was 9 inches deep and had a square cross section that was 6.5 inches long and wide. The water level was placed at around 2 inches from the top. To create an object that can be quickly pulled out of the water, two holes were poked into a ping pong ball. A knot that was larger than the hole was tied on one end of some stretch cord. This knot was squeezed through one of the holes in the ping pong ball. The second hole in the ping pong ball was widened so that it could fit an Allen wrench in it for extra weight. To set up the experiment, the ping pong ball was submerged in the water until it completely filled up. Then, the alan wrench was inserted to help it sink to the bottom of the container. The other end of the stretch cord was held in my hand above the container. The cord was pulled quickly upwards to forcefully eject the ping pong ball out of the surface of the water.

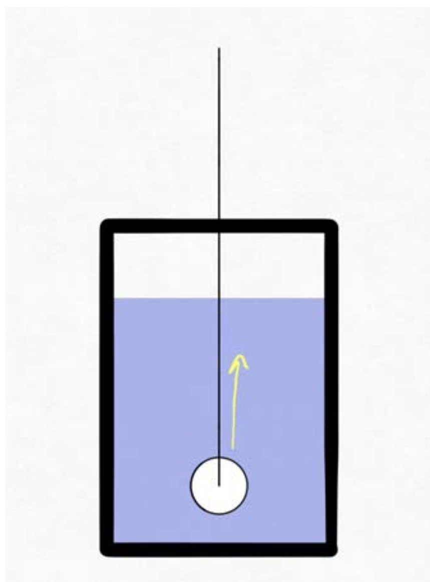

Figure 4: Sketch of experiment setup

The behavior of the water stream can be described by the concepts of inertia, adhesion, cohesion, and surface tension.

When the ping pong ball is accelerated upward, the water that is in direct contact with or near it is also accelerated. Because of inertia, the water has the energy to “follow” the ping pong ball out of the water.

The combination of adhesion and cohesion is what keeps the water in a single unbroken column. Adhesion, which is the attraction between different substances, causes the water molecules to stick to the surface of the ping pong ball. Cohesion, which is the attraction between like molecules, causes the water molecules to stick to one another. This interplay forms an unbroken column of water that connects to the object and extends into the main body of water until the force of gravity overcomes the forces at play and “breaks” the chain of water.

Surface tension, which is a direct result of cohesion, creates a “skin” at the surface of the water column, which helps maintain the column’s integrity and resist breaking apart.

As the water column travels through the air, it is subject to something called Plateau-Rayleigh instability. This concept is usually used to describe how a falling stream of liquid eventually breaks up into smaller droplets, but this can also be applied to a column of water rising upwards. A simplified explanation of this is that surface tension dictates that liquids will naturally pull themselves into the smallest possible surface area in order to minimize energy. In the case of my final image, it is clear that the water column is not perfectly smooth, but even in a situation where a jet of liquid looks perfect, there will be tiny variations. Surface tension is stronger where the liquid bulges, which grows the perturbations until a droplet separates. These variations and droplet separation can be seen within my final image.

The math behind the Plateau-Rayleigh instability is quite complex and involves combinations of Navier-Stokes equations and Bessel functions among other things [1], but one mathematical concept within the Plateau-Rayleigh instability that can be used to analyze my final image that is plain to see is the Weber number. This non-dimensional number compares inertial forces to surface tension forces in a fluid [2]. The formula to calculate the Weber number is as follows:

$$W_e = \frac{\rho * v^2 * L}{\sigma}$$

In this formula, ρ is the density of the fluid, v is the velocity of the fluid, L is the characteristic length (i.e. droplet diameter, column diameter, etc.), and σ is the surface tension.

Through looking at the pictures taken directly before and after my final image, I found that the water column in said image was captured around the moment where there was no vertical movement. In other words, the velocity was near 0 m/s. Because the velocity is in the numerator of the Weber number formula, it can be reasoned that the Weber number was also near zero. At the very least, the Weber number during this moment of time was closer to zero than when the water column first started rising out of the water. At higher Weber numbers, inertial forces dominate over surface tension, and liquids tend to break up into smaller droplets. At lower Weber numbers, a fluid tends to break into larger, more stable droplets. This was captured in my final image as shown in Figure 5 below. The droplet circled in red is one that formed earlier when the velocity of the fluid was higher, and the parts of the image circled in blue show larger droplets that are about to form now that the liquid is closer to stationary.

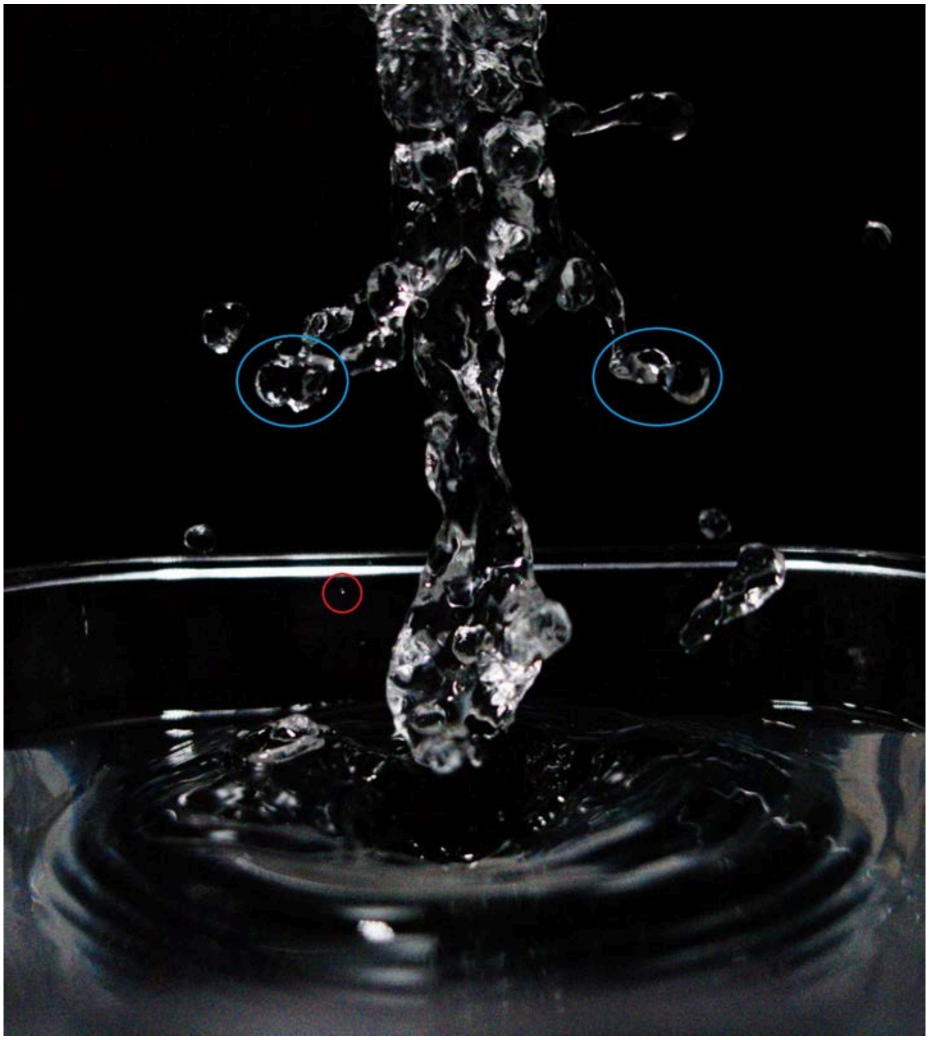

Figure 5: Droplets formed/forming with different Weber numbers

Visualization Technique

This visualization was achieved by using water, a studio light and a black background. The intent was to capture the refraction of the light in the outline of the water to see what was going on. The studio light was held directly above the container and shined directly downwards. During post processing, the contrast was increased in order to make the black background darker and increase the contrast of the bright white outlines of the water.

Photographic Technique

The flow phenomenon was captured using a Sony ZV-1 camera. The capture settings were as follows: ISO of 2500, shutter speed of 1/1250, focal length of 9.4 mm, and an aperture of f/2. The camera was positioned about 9 inches from the center of the container. The lens was slightly above the top of the container and angled slightly downward.

Not too much was done in regard to post processing. The image was cropped from 5496 x 3672 pixels to 3211 x 3587 pixels to draw more focus to the water stream. In addition to this, the contrast was increased, the lower light level values were decreased, and saturation was lowered slightly to take out some of the color shown in the pool of water. All of this was done using Darktable. The original image is shown below.

Figure 6: Original image of the water stream

Reflection

This image depicts the stream of water that follows a rapidly surfacing object as it is ejected from the surface of a body of water. I really like how the contrast between the black background and the reflections of light in the water came out. I would've preferred if the photo were a little sharper, but it is sharp enough to fulfill my intent. The fluid physics are shown quite well, especially when taking into account the context photos in Figures 2 & 3. One thing that I would like to do in the future is record a slow motion video rather than taking still images; I believe a video may have more to offer in regard to analyzing the physics.

References

[1] Milind Hegde. "Fluid Dynamics and The Plateau-Rayleigh Instability". *Columbia Math Department*, 1 September 2013.
[2] How Engineering Works. "What is the Weber number, and what does it represent?". *How Engineering Works*, 10 May 2025.