Laminar Stream Break Up

Image-Video 3
MCEN 5151-001: Flow Visualization
University of Colorado Boulder
25 November 2020

Author: Matthew McCallum

Instructor: Jean Hertzberg

Contributors: Gavin Zimmerman

1. Introduction

This report will outline the setup that enabled this image, discuss the fluid dynamics involved in this image, and describe the visualization and photographic techniques used to take this image. This image was taken for the Image-Video 3 assignment for the "Flow Visualization" course (MCEN 5151) at CU Boulder. The image shows the result of poking a hole in a balloon full of water. A piece of tape was placed over the area that the hole was to be put to prevent the balloon from bursting. Once the hole was created, a steady stream of water began to flow out of the hole. The flow did vary over time, but this was very slow due to low flow rate relative to the volume of water in the balloon. I originally wanted the flow to come out in a consistent laminar flow, but the hole in the balloon had irregularities in it. This resulted in the flow exiting in an elliptical shape that switched axes until the flow broke up into droplets.

2. Experimental Setup and Procedure

A diagram of the experimental setup can be seen in **Figure 1**. The experiment was performed by filling a regular rubber party balloon with tap water to about 6 inches in diameter. The outside of the balloon was then dried off and a piece of clear tape was placed where the hole was to be put. The balloon was then put in a sink and a hole was put in the balloon using a thumb tack. A flashlight was held several inches above the cup to light up the water stream. The camera was held above and to the side of the water stream and pointed down at about a 45-degree angle. This is when the image was taken. After a few minutes, either the balloon had shrunk enough for the tape to lose its grip on the rubber and the balloon burst or the balloon was manually popped by making another hole where there was no tape. The experiment could then be repeated from the beginning.

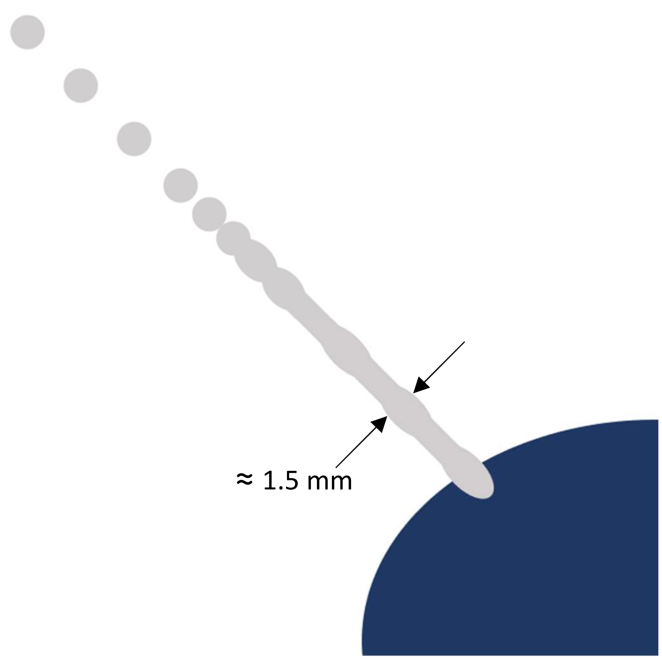

Figure 1 Diagram of the experimental setup.

Gavin Zimmerman (someone who lives with me and is not in the course) assisted me in performing the experiment. He aided in filling the balloon and held the flashlight above the flow to illuminate it.

3. Flow Discussion

The balloon is at the bottom right of the image. Looking at the bottom right of the image, the flow initially forms an elliptical shape that switches axes as it travels away from the balloon. The ellipse switches from being aligned with the camera to being perpendicular to the camera. The flow performs this axis switching 4-5 times as it flows away from the balloon. After these oscillations the flow becomes fairly cylindrical before it breaks up into the droplets. The flow begins in the shape of the opening in the balloon, then as the axis switching happens the viscous effects cause the axis switching to decay and the flow slowly transitions to a cylindrical shape.[2] Knowing that the flow starts in roughly the shape of the opening, it can be determined that the hole that was put in the balloon was an oblong shape. This is likely due to the wiggling of the thumb tack that was done to try to make the hole bigger. The balloon and tape seemed to have a direction that they preferred to break in, so the wiggling would have made the hole oblong in that direction.

After the axis switching decays, the flow begins to break up into droplets. This effect is known as the Plateau-Rayleigh instability. This instability occurs when oscillations in the flow are grown by surface tension effects that cause the areas with a smaller diameter to shrink and areas with a larger diameter to grow. This eventually leads to the diameter reaching zero and a droplet forming. The oscillations that grow are the ones where the ratio of the wavelength of the oscillation to the diameter of the opening is near π.[1] The hole was put in the balloon shortly after it was filled with water. This means that there were likely oscillations in the flow within the balloon over an extremely wide range of frequencies. Oscillations whose wavelength does not make the ratio of wavelength to diameter close to π will decay, so those oscillations will not affect the flow.[1] Since oscillations of other frequencies will not effect the other oscillations, then the wide range of oscillation frequencies means that there will likely be some with the correct wavelength to cause the droplets to form and this is what happened during the test that resulted in the image.

Both the axis switching and Plateau-Rayleigh instability do not require specific fluid properties to occur, so properties like viscosity and Reynolds number are not important to having these effects occur. The fluid properties do affect these flow phenomena, but they only change the shape of the flow. More viscous fluids like honey will take much longer for Plateau-Rayleigh instabilities to occur and will cause the axis switching to decay faster and vise versa for less viscous fluids.

4. Visualization Technique

The fluid flow was visualized using the refraction of light through the water stream. The fast shutter speed meant that anything not illuminated by the flashlight appeared black. This meant that the shape of the flow could be seen by the gradient of black to white in the background being refracted through the water stream. The balloons were purchased at Michael's, but I forget to document the brand of the balloons (they are standard party balloons, not water balloons). The water used was tap water from Boulder, Colorado. The sink was the one installed in the house I was living at.

The experiment was lit up by a white LED flashlight held several inches above the balloon. I do not know what the wattage of the flashlight is, but it is significantly brighter than a standard room light. The flashlight was used to provide enough light to see the water stream, since the image was very dark due to the low exposure time needed. An interesting effect with the flashlight was that at certain exposure times, a black bar would appear on the image as can be seen in Figure 2. This appears to be a result of the duty cycle that the flashlight uses to control the brightness. A duty cycle is the percentage of the time that power is flowing through the

Figure 2 Image showing the black bar that results from the duty cycle of the flashlight.

circuit. To control the brightness of a flashlight, the power can be turned on and off at a very high frequency and the ratio between how long the light is on and off can be varied. If the frequency is high enough, then a human would not be able to tell when it is on and off and would just see the light as a dimmer. However, when the camera is at a low enough exposure time, these gaps in the light being on can occur during the exposure time of the image. This results in a portion of the pixels being measured while the scene in front of the camera is dark and therefore a black bar shows up in the middle of the image.

5. Photographic Technique

The main issue that arose in taking the image was that the variations in the water stream occurred at a high frequency. This forced the exposure time to be dropped significantly to be able to see the individual droplets, however this caused a significant darkening of the image. This darkening was countered by pointing a bright flashlight at the flow. This was chosen to counter the darkness because the aperture of the camera being used could not be changed and I wanted to keep the ISO as low as possible to minimize the amount of noise in the image. The camera was held a few inches from the hole in the balloon, and the camera setting that the image was taken with were:

Camera:	Samsung SM-G960U (Galaxy S9)
Aperture:	f/1.5
Exposure:	1/12000 s
Focal Length:	4 mm
ISO:	800
Width:	2217 pixels
Height:	2419 pixels

The image was edited using Darktable and the built-in photo adjustments from the phone’s camera app. I originally tried to edit the image only using Darktable, but there was still a significant amount of noise in the image after the denoise filter was used. Therefore, I used the image that the phone modified instead of the raw image. I then used Darktable to crop the image to the final shape. The unedited image can be seen in Figure 3 in the appendix.

6. Image Commentary

This image allows for a common everyday flow phenomenon to be seen and investigated. Plateau-Rayleigh instabilities commonly occur in the fluid flow out of a faucet, hose, syrup container, etc. This is an effect that a lot of people have seen many times throughout their lives and this image allows for this effect to be frozen in time and investigated. In the investigation for this paper, I learned that the flow breaking up into droplets is a result of oscillations in the flow occurring around a very specific wavelength. It is very interesting that such a common effect requires such a specific initial condition. The Plateau-Rayleigh instabilities requiring such a specific condition shows how random everyday fluids are.

This image turned out quite well. The flashlight causing a gradient on the surface in the background that allowed the refraction in the water to be seen was quite a lucky effect that I did not initially plan on. If I were to perform this experiment again, I would do something to better show the fluid flow. One way would be to put an object in the background with a nice gradient in it (maybe a rainbow) to better show the refraction from the water stream. Another way would be to get a dye stream to flow in the water stream to show a streakline in the flow.

References

[1] Andreeva, O., Bulavin, L., & Tkachenko, V. (2020). Rayleigh-Plateau Dissipative Instability. East European Journal of Physics, (2), 38-47. https://doi.org/10.26565/2312-4334-2020-2-02

[2] Nan Chen, Huidan Yu, Mechanism of axis switching in low aspect-ratio rectangular jets, Computers & Mathematics with Applications, Volume 67, Issue 2, 2014, Pages 437-444, ISSN 0898-1221, https://doi.org/10.1016/j.camwa.2013.03.018

[3] Plateau-Rayleigh Instability, Wikipedia, viewed on 25 November 2020, https://en.wikipedia.org/wiki/Plateau%E2%80%93Rayleigh_instability

Appendix

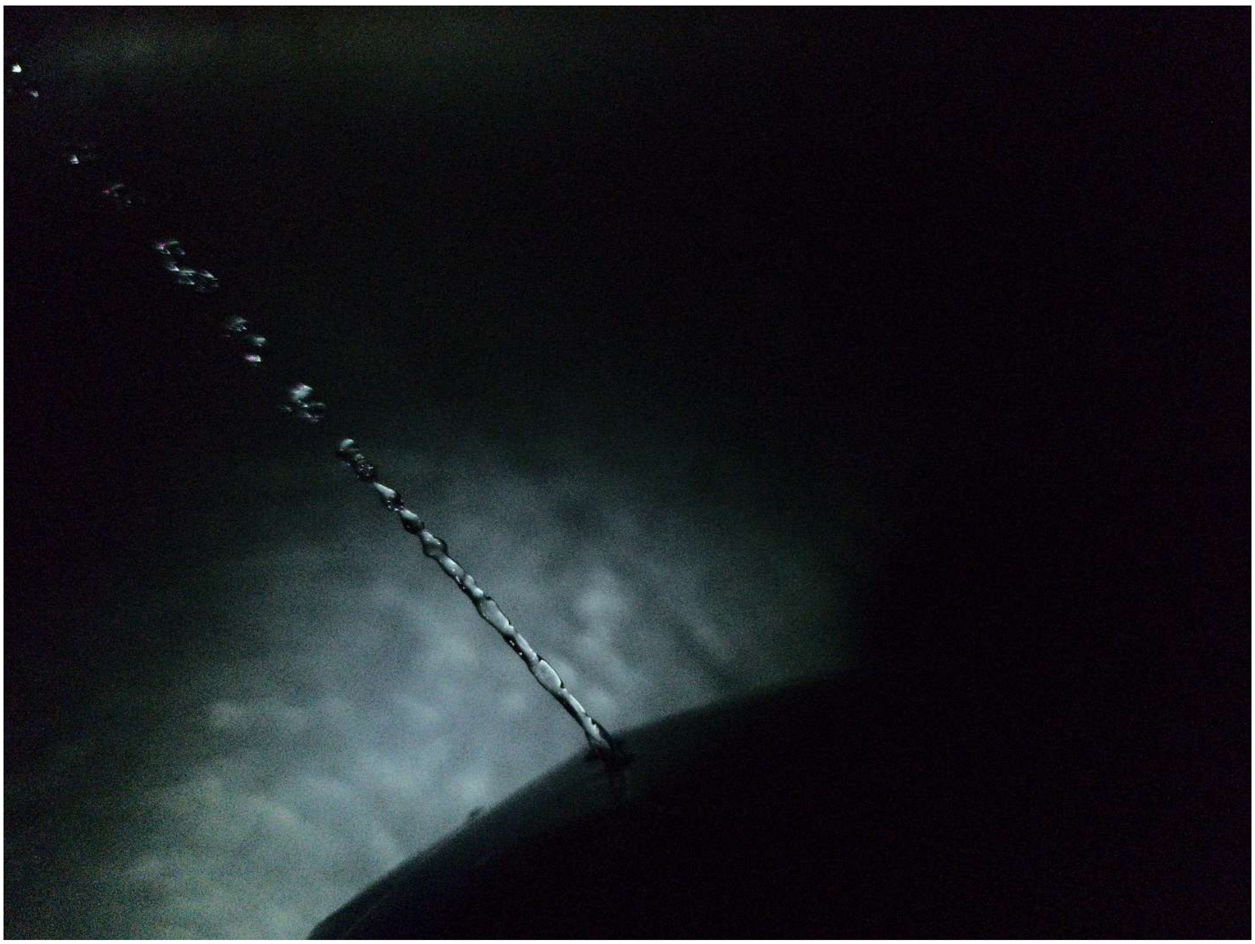

Figure 3 Unedited image of the flow