UNIVERSITY OF COLORADO, BOULDER

Visualization of the Rayleigh-Plateau Instability

"Get Wet" Assignment

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MCEN 4151
Flow Visualization

Introduction

The image pictured on the front page was created for the CU Boulder course Flow Visualization as part of the first "Get Wet" assignment. The image captures the result of a stream of water falling into water. The interaction results in an aesthetically pleasing phenomenon, a Worthington Jet, that can be captured on camera using a fast shutter speed. By carefully selecting light options, camera settings, and post-processing effects, the physics of the jet come to life in a beautifully artistic way.

Apparatus & Flow

The setup used to capture this image was created using common household items, including:

- 9" x 5" Baking pan
- Purple folder
- iPhone light
- Styrofoam cup
- Spoon
- Small bowl
- Water

Figure 1: Diagram of setup

The baking pan was filled with water and placed in front of the purple folder. An external light (an iPhone flashlight) was aimed to shine onto the folder so the purple color of the folder was reflected in the water. The Styrofoam cup was used in place of a tripod to make sure the camera remained steady during the shot. To set the focus, a spoon was placed in the baking pan with water at the same range that the water interaction would occur. Once set, the focus was locked and the spoon was removed and used to drop the stream of water into the baking pan of water. As the water fell, the camera was used to capture the flow.

The phenomenon captured in the image is called a Worthington Jet. When an object (or in this case, water) impacts a body of water, a cavity is formed below the surface. Once the cavity closes, a quick, slender jet of water is propelled upward; this is what we call the Worthington Jet. The height of the jet produced is dependent on the impact velocity of the water drops making contact with the larger body of water.

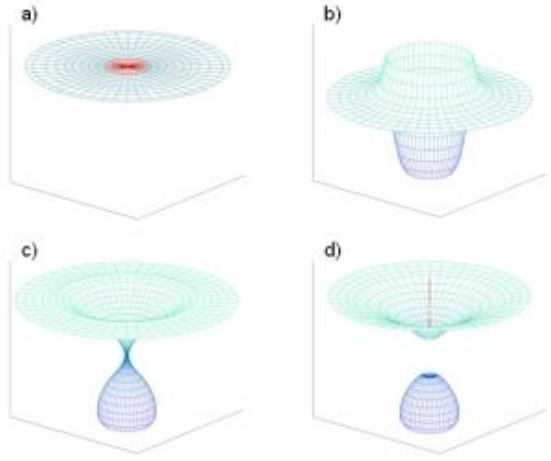

Figure 2: Formation of a Worthington Jet (Gekle)

Because the impact was caused by a series of water droplets, close to a constant stream at the time the image was taken, image captured from this interaction also demonstrates quite clearly the Rayleigh-Plateau Instability. The Rayleigh-Plateau instability describes the behavior of a jet that falls vertically with gravity. In

this scenario, the jet is working against gravity, however, the instability still holds true and can be seen in the image. Below is a comparison of the image captured in this experiment, and one from a jet falling vertically with gravity.

Figure 3: Comparison of images displaying Rayleigh-Plateau instability. Image from Breslouer, 2010 on left. Image from Kennedy, 2014 on right.

In the images above, you can see that gravity works on a jet the same way whether the jet is falling, or shooting upward (forming). The perturbation growth (as pictured above) and the length over which the instability grows are the two defining factors for the Raleigh-Plateau instability (Breslouer).

The Reynolds number of the jet can be calculated using the following equation and assumptions:

$$Re = \frac{VL}{\nu} = 6.4E4$$

Where:

V = 3.08 m/s
L = 0.127 m
v = 1.004 $m^2/s * 10^{-6}$

Since Re < 5E5, the flow cannot be categorized as turbulent. Because the water acting on the surface is a quick combination of continuous drops of water, rather than a full stream, the resulting jet is caught in the transitional phase, rather than full turbulence. If the water acting on the surface were in the form of a single drop, we could expect a Re closer to the laminar regime.

Technique

The Worthington Jet is a quickly occurring phenomenon that usually occurs in less than one second. Because of this, I chose the shutter priority option on my digital Nikon DX40, and opted for a fast shutter speed (1/200 s). The ISO was set to 400, and the resulting aperture was f/4.8. The flash was used, in addition to the iPhone light, to assist in capturing the image. The original image can be seen on the following page.

Figure 4: Original Image. (3900 x 2613 pixels)

In the image above, you can see the effect of the iPhone light shining on the purple folder, and the result of the seemingly purple water in the pan. A black pan was used to minimize the reflection and details in the bottom of the pan. In post-processing, using Photoshop, I manipulated the color transfer functions to enhance the contrast, as well as change the tones to rich blues. The purple was aesthetically pleasing, but some areas were too dark and did not go well with the desired contrast.

Conclusion

The original intent was to capture the effect of a single water droplet, rather than a continuous stream of droplets, and though I got good results from that setup, I found the physics of the Rayleigh-Plateau instability to be much more interesting. This image was the result of testing the stream (hence the larger than necessary field of view), but it ended up producing the best representation of the phenomenon. The most difficult part was getting the lighting to work. My limited background in photography casued me to spend a great deal of time learning how to adjust lighting as well as camera specifications such as aperture and ISO. To develop this idea further, I can create a better controlled setup improve the functionality of the setup (mainly lighting!) to allow myself to capture a better image with less distractions.

References

Breslouer, Oren. *Rayleigh-Plateau Instability: Falling Jet*. 8 January 2010. Document.

Gekle, Stephen. *Impact on Liquids. Impact on Liquids: Void Collapse and Jet Formation*. N.p., n.d. Web. 23 Feb. 2014.

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