The Collision of a Worthington Jet

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Final Team Assignment: Flow Visualization MCEN 5151

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Introduction

The intent of this photograph was to capture the separation of a droplet from a Worthington Jet and then the collision between it and a second droplet. As the semester was coming to a close I looked back over my images and was excited about my progress as a photographer, but not as much with the phenomena captured. So many of the images seemed simple or common, and so for the last image Wayne Russell and I began talking about the feasibility of one much more complicated project and asked our respective teams and our mutual co-worker Gabe Bershenyi if they would be interested in this phenomena. The final team was comprised of Wayne, Gabe, Kelsey Spur, Blake Buchannan, and myself. For this project a timing and control circuit was created, actuated by an AVR Atmega8 micro-controller, which would time and actuate the valves, control the camera shutter, and control the 3 flashes integrated into the system. The end result was 5 incredible images of a collision frozen in time. This paper goes into the actual physics, in detail set-up, and final product of this project.

Flow Apparatus

When Wayne and I first began talking about this project we knew we were going to need a solenoid valve, and a micro-controller to time the drops and the camera. Wayne had a development board already built which could be reprogrammed to time transistor switches and control the actuation of a solenoid, and camera. Meanwhile I had machined parts from senior design to test the loss coefficients of valves with make shift nozzles. We met up again with the valves and circuit to debug the system code and actuation of the valve. With the code mostly debugged Wayne went off to finalize the circuit and both of us expressed that we each had some friends who were interested in joining the project. From this talk Gabe and Kelsey joined the project and we made a time to meet and actually test the circuit.

The four of us met in the Eco-Car room of the Durning lab set up the system as pictured below in figure 1.

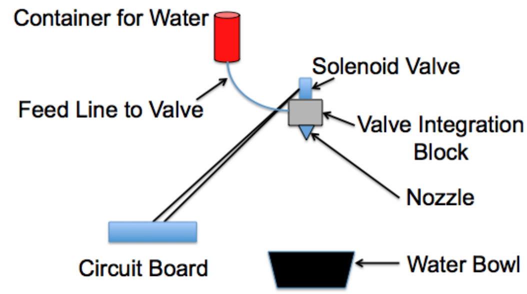

Figure 1: Initial Setup

Using a small hand held high speed camera provided by Kelsey, the team began timing out the system by actuating two drops from the valve and visualizing the effect frame by frame. The timing was then adjusted using calculations from the high speed video until the system was creating the desired effect repeatedly.

The system functionality was only half of the project though, the visualization needed to be spot on as well. After further research it was determined that a shutter (at least those on our cameras) could not move fast enough to capture the phenomena, and that the typical method is to use a long exposure in a dark room with a timed flash [1]. Noting this Blake Buchannan was introduced to the team. Blake had access to high quality flash systems which could be actuated using the same circuit as the camera. This flash was then timed using feedback from the high speed camera and the system was finalized. The final outline for the code was as follows, and the actual physical set up can be seen below in figure 2.

1. Open shutter for a 1.5s exposure
2. Open valve releasing 1 droplet then wait
3. Open valve again releasing second droplet
4. Actuate flash at moment of impact producing clean photo

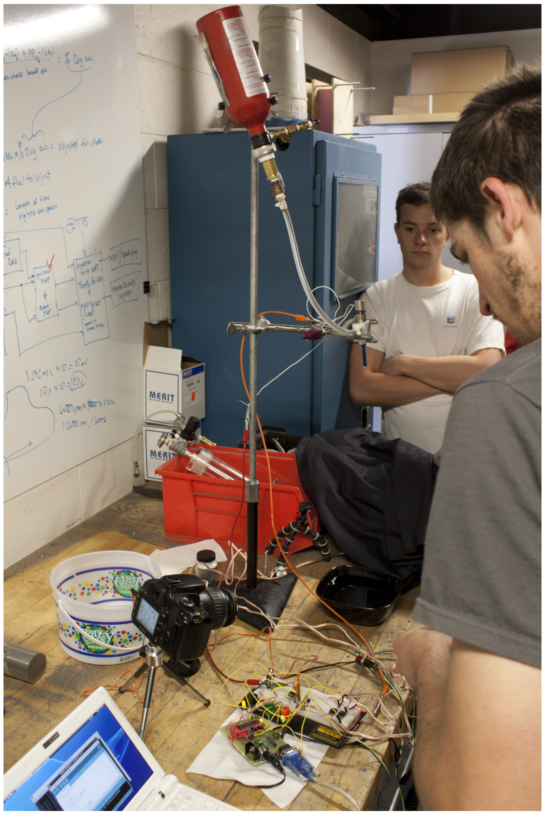

Figure 2: Actual Set Up

Flow Analysis

The phenomena imaged is roughly a two stage process, and thus two different types of flow. The first is the creating of the pillar or "jet" known as a Worthington Jet. The next is the impact dynamics at play when a second droplet is released onto the jet moments later.

A Worthington Jet forms when an object breaches the surface of a fluid which is bounded by air. In 1897 Worthington characterized this behaviour and documented its characteristics [2]. As an object breaches the surface of the fluid it drags the fluid surface down (an effect of the surface tension). Because of hydrostatic pressure, a cavity is formed and then collapsed around until there is only one singular point of closure (roughly halfway down the cavity). At this point fluid is pushed upward at much larger velocities than the impacting particle, producing a Worthington Jet. This phenomena has been simulated using computers and can be seen in figure 3

These types of flows generally will also expel a droplet from the tip which leads to the second part of this experiment; hitting the

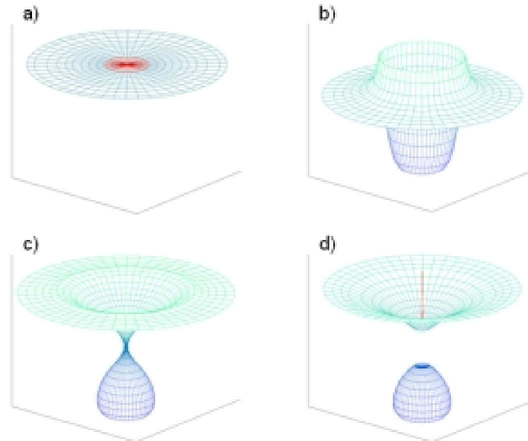

Figure 3: Computer Simulation of Worthington Jet [3]

expelled droplet with another droplet. The collision of two droplets induces an outward thinning flow which in turn creates a ring around the contact point (as visualized in the image). The flow induced on each droplet during collision can be visualized in the figure 4 below:

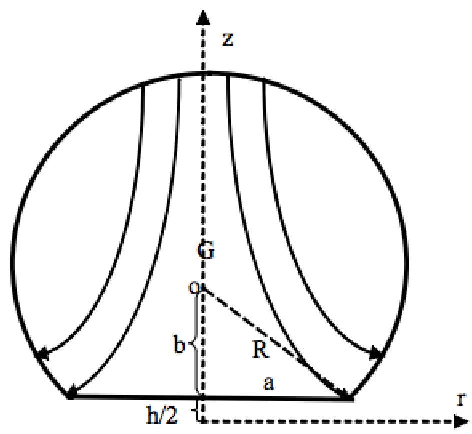

Figure 4: Flow induced on droplets during collision [4]

This ring as it thins begins to disperse into many smaller droplets as will be described here. As the water propagates outward the tendency should be for it to form a perfect disk around the collision point, however as can be seen in the image the disk slowly transforms into multiple fingers around areas where waves can be seen interacting.

The waves pictured are most likely capillary waves which behave differently than waves in deeper waters. Because of their small size the velocity decreases and the inertial forces are nearly negligible as the characteristic length is so small. As the waves propagate outward there are interactions causing positive interference which makes the waves bigger. At this point surface tension can take over and pull the water into droplets which are then expelled outward.

This is a beautiful phenomena and one which could not be captured with the naked eye.

Visualization Technique

In order to better visualize this phenomena the background had to be nearly non existent. Black non-glossy backdrops surrounded a black bowl in which stagnant water sat. This was then slightly back lit by a glow-stick for artistic effect. The overall goal was to remove all distractions from the image to get the most natural effect.

Photographic Technique

The speed at which this phenomena occurs greatly exceeds the abilities of my camera. In order to compensate for this the room was darkened (pitch black), the camera shutter was opened for 1.6 s, and the micro-controller was used to time the flash. This flash would freeze the image for the camera much faster than the shutter could move. Using this technique the final image was taken with a CANON Rebel EOS xsi with an f-stop of f/7, ISO of 400. In order to get the close up effect seen in the image, a number 1 extension tube was used with a EF-S18-55mm f/3.5-5.6 IS lens to create a makeshift macro lens. Using these settings resulted in a final cropped pixel resolution of 4044 X 2848. No alterations were made to this image other than the size.

Conclusion

The submitted image was meant to provide an artistic insight into an un-common phenomena, two water droplets colliding mid air. The use of an extended lens gave that insight on a close level, and produced an image worth looking at. I am incredibly happy with the result, and even more so with the cheapness of the set up. Most kits like this would cost upward of $450 where as ours was a mere $50. Overall I am very excited with this image and think it gives a good insight into the phenomena visualized.

This being the last project of the semester gives a chance to reflect on the progress and struggles with photography, especially that of fluids. This final image far exceeded the quality of any previous image and that was for multiple reasons. This was the first project where I had removed my self from my assigned group in pursuit on a phenomena I was genuinely excited about. This was also the first image where I felt I finally had a good grasp of how to use my camera effectively and artistically. Finally the resulting team from this project was phenomenal and proved that with 5 minds put together almost anything is possible. Looking at the progress throughout the semester was amazing, not only do the images get more complex, but also the phenomena visualized was imaged better in every one surmounting to one of the best images I will probably take in my lifetime.

I am excited to take my knowledge from this class and continue this hobby of photography. I hope to continue to produce photographs of this quality in the future and that the photography of fluids remains an active part of my work.

Bibliography

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2. "Gekle, Stephan, and J.M. Gordillo. "Generation and Breakup of Worthington Jets After Cavity Collapse." (2009): n. pag. Print.
3. Gekle, Stephan. "Stephan Gekle." Impact on Liquids: Void Collapse and Jet Formation. N.p., n.d. Web. 01 May 2013.
4. Zhang, P., and P.K. Law. Theory of Bouncing and Coalescence in Droplet Collision. Tech. N.p.: n.p., n.d. Print.