Effects of Dropping a Playing Die into Water

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Get Wet Assignment
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Introduction

The initial photography assignment, "Get Wet," for Flow Visualization is to capture flow phenomena that might be taken for granted in everyday life. From time to time, my friends and I will play a game where the objective is to sink a playing die in the opposing team's glass. To have a legal throw, one must throw the die approximately 10 feet above and onto the opposing team's side of the table. Obviously, this is not an easy task to accomplish and whenever a die is sunk into the glass, it often results in a fair amount of up-roar. Because of this, I was inspired to see exactly what happens when a die contacts the surface of the water. Unfortunately, attempting to set up an experiment that mimics the exact outcome of the game is nearly impossible; to make my life easier, I decided to control my environment to allow for the best odds of capturing this unique shot.

Experimental Setup

The experimental setup can be seen in Figure 1. The bowl used in the image is a white, standard sized, cereal bowl that holds roughly 16oz of liquid. For this experiment 1 cup of water was placed into the bowl, 3 drops of cyan gel food coloring were dropped into the water and agitated with a metal fork to mix with the water. I specifically used a light color dye because I

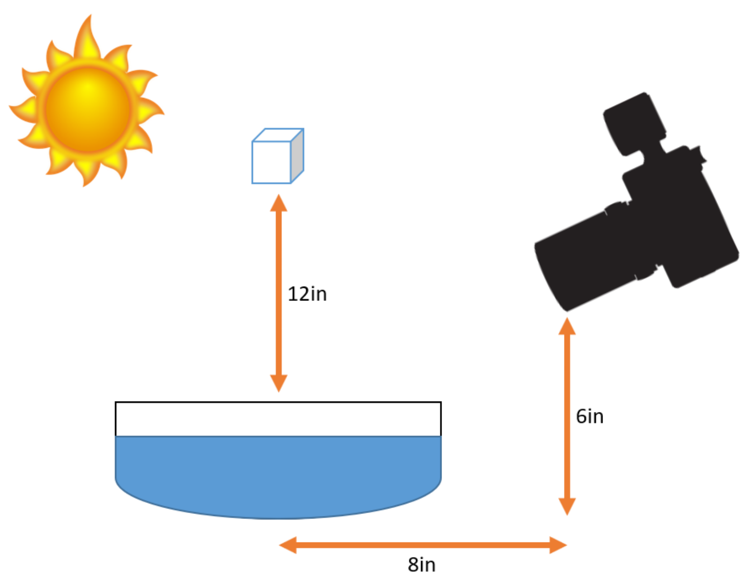

Figure 1: *Experimental Setup*

wanted to keep a light feel to the main subject of the image while allowing the background to be darker. The color choice was primarily based on aesthetics, the other colors that I had available did not seem as though they would be as pleasing to the eye (note that color is not vital to the experiment). The background of this experiment was not ideal. Unfortunately, I did not have any solid black backgrounds, using the limited resources available I used the backside of a doorway mat to provide a background that would contrast the subject of the image.

Flow Physics

The image captured depicts a very interesting phenomena related to water that many people simply ignore and move on. This phenomenon is called water caustics. Water caustics are caused by light being refracted by the waters surface. Because the water's surface is no longer completely flat when the die strikes the surface, some spots are more illuminated than others due to the refraction.

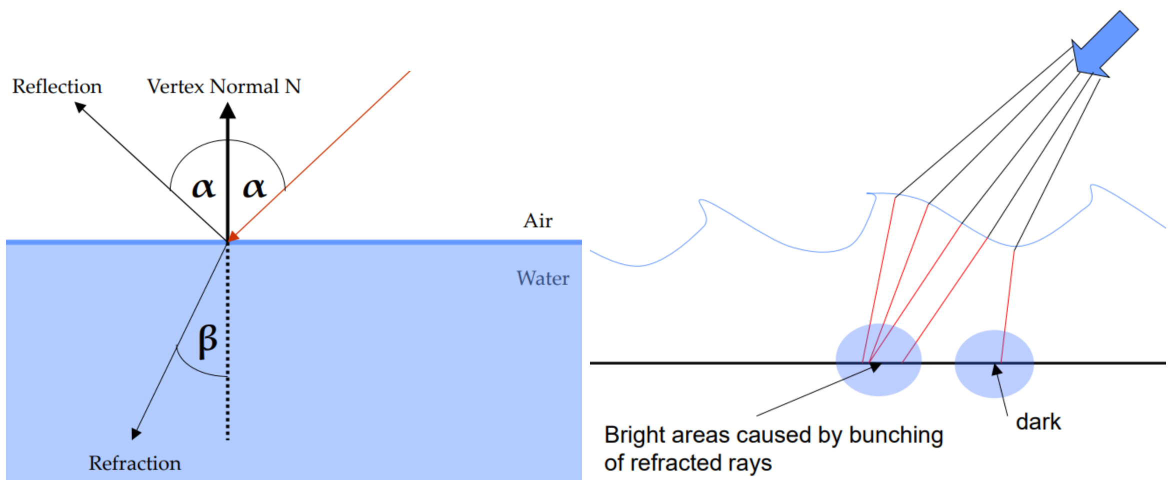

***Figure 2[1]:** Visualization of refraction per Snell's Law (left) and light rays through a rough water surface, creating caustics on the surface below (right).*

As shown in Figure 2, as the light approaches the waters surface, the light rays can be approximated as parallel lines (for the case of direct sunlight). When the light hits a change in material, in this case air-water, the light is refracted following the rules of Snell's Law[2]. Snell's

[1] Jensen, Henrik. "Refractions, Reflections and Caustics: Basic Concepts." CMU Education. http://www.cs.cmu.edu/afs/cs/academic/class/16823-s16/www/pdfs/appearance-modeling-15.pdf.
[2] Gerhart, Philip M., et al. Munson, Young, and Okiishi's Fundamentals of Fluid Mechanics. 8th ed., John Wiley & Sons, Inc. 2016.

law relates the angle of light prior to reaching the material barrier to that of the light after it has been refracted through the following equation:

$$\frac{\sin \alpha}{\sin \beta} = Refractive\ Index$$

where α and β are the angle of light pre and post refraction, respectively, and the Refractive Index is a material dependent constant. The refractive index for each material is inversely proportional to the speed of light per Huygen's Principle. Based on research conducted by Alexey Bashkatov and Elina Genina[3], the refractive index for water at room temperature and exposed to a wavelength of light of 589 nm is 1.333. This can then be used to calculate the projected refraction angle of the light rays in the bowl. Unfortunately, this calculation can only be done for a discrete number of angles, in reality, the light is hitting the surface of the water infinite times generating the caustics that are seen in the bowl. Computer simulations can be conducted to estimate the locations of the caustics; however, in this case, one estimated angle will be used to demonstrate Snell's law. In this case, it is assumed that the light is hitting the surface of the water at a 30-degree angle (representing the sun being almost directly overhead).

$$\frac{\sin(30)}{\sin \beta} = 1.333$$

$$\sin^{-1}\left(\frac{\sin(30)}{1.33}\right) = \beta$$

$$\beta = 22.03\ deg$$

As shown here, the light refracts approximately 8 degrees as the light passes through the boundary of air to water.

The velocity of the fluid in this scenario was very quick, which required a fast shutter speed to prevent motion blur. In this image, a shutter speed of 1/2500 sec was used. When motion blur occurs in an image, the velocity of the object can be estimated using the following equation:

$$Blur = v * T$$

where blur is the length of the motion blur captured from the camera, v is the velocity of the object and T is the shutter speed. In this case, there is no motion blur, suggesting that the shutter

[3] Bashkatov, Alexey N., and Elina A. Genina. "Water Refractive Index in Dependence on Temperature and Wavelength: A Simple Approximation." 2003. doi:10.1117/12.518857.

speed could have been decreased. Unfortunately because there is no motion blur, the velocity of the fluid cannot be accurately estimated.

Photographic Technique & Post Processing

Conducting the experiment turned out to be much more of a challenge than I had originally anticipated. The camera that was used to take this photograph was a Canon EOS Rebel T6; this camera is capable of shooting in continuous mode. Unfortunately, even with the shutter speed cranked up, the continuous mode capture was not quick enough to capture the shot I was looking for. Because of this, I decided to set the camera up on a tripod facing the bowl roughly 45 degrees from horizontal, attach the camera's remote capture and manually try to capture the instant the die hit the water. To capture freeze the water, exposure time was increased. Direct sunlight was used to light this shoot. The camera settings used were as follows:

Photo Dimensions	5184 x 3456 Pixels
ISO Speed	ISO - 200
F-Stop	f / 4.5
Exposure Time	1 / 2500 sec
Flash Mode	No Flash
Focal Length	33 mm

Table 1: *Camera Settings*

After roughly 20 shots I was able to finally capture the image I was looking for. Because the image lighting and coloring wasn't quite what I was hoping for I decided to do some post-capture editing through Gimp. Figure 2 shows the progression through the editing process. The colors that were chosen for the bowl, water and background created a nice contrast, therefore there wasn't too much color correction to be done on this image. To generate the final image, a simple color correction curve was utilized to create a much more mellow image.

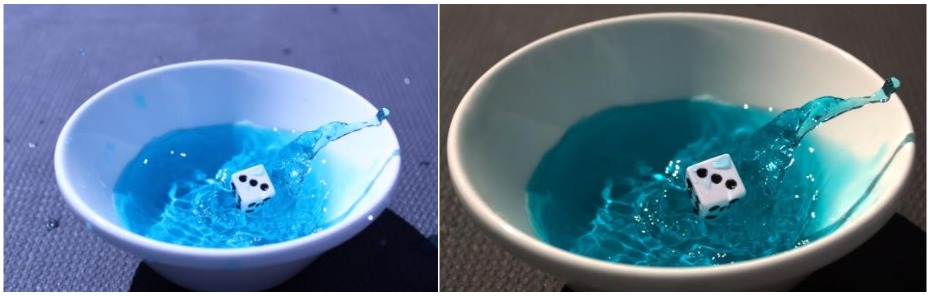

Figure 3: *Image progression after editing. Raw file is shown on the left, final edited photo on the right.*

Note that in Figure 2, the raw file contains many distracting elements such as the extremely bright color of the bowl and various water splashes on both the bowl and background. Using the clone and heal tool in Gimp I was able to remove many of these distracting elements and create an image that is much more aesthetically pleasing.

Visualization Technique

To better visualize the flow physics occurring in this image, I decided to dye the water a light blue color as described in the Experimental Setup. This allowed for a much more visually pleasing image while not interrupting the flow physics involved.

Results

Overall, the "Get Wet" image assignment not only allowed me to witness what actually happens when somebody sinks a die but also gave me valuable insight to my camera and photo environment. Setting up a controlled environment that would create the image that you have in your mind is no small task and was definitely something I had not anticipated prior to this assignment. I am excited to continue working with various fluids and attempted to capture more unique and impressive images over the course of the semester.