Group Project 2

“Splash”

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Flow Visualization

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After the lecture given by Professor Sweetman on the birth of high-speed photography, I was captivated and enthralled by the idea of photographing splashes. I approached my group with the proposition of photographing splashes and we attempted to capture splashes and large scale hydrodynamics on Boulder Creek at Fine Park on the west end of Arapahoe Road. I found that the fluid phenomenon present in the creek was very turbulent and difficult to capture with my camera. Therefore, I started experimenting with splashes in kitchen bowls and Tupperware containers at my apartment. My first attempts included dropping numerous objects such as M&M's, hazelnuts, large bouncy balls, and somewhat spherical rocks into water dyed with food coloring, milk, and even mixtures of milk and dish soap. Finally, after much experimenting I purchased a bottle of All Brilliant laundry detergent, a bag of marbles, a smaller rubber ball, and a black light. The intent of my image was to capture the crown of splashes of a fluorescent material lit by a black light. Through trial and error I quickly learned that the black light I had purchased was not strong enough to adequately light the phenomenon, so a camera flash and several 60 W incandescent household lamps were also used. The following images are three of the 256 images captured. Please note that the term "crown" generally applies to formations similar to these but created by impinging a liquid droplet on another liquid surface. The two liquids may be homogeneous or different.

Figure 1: Distinct crown forms on splash

Figure 2: Crown extended (different splash)

Figure 3: Another example of extended crown (again a different splash)

Although, the experimental setup used to create these images is very simple, the capture of an image that fulfills the project intent required both time and patience. The flow apparatus is shown below,

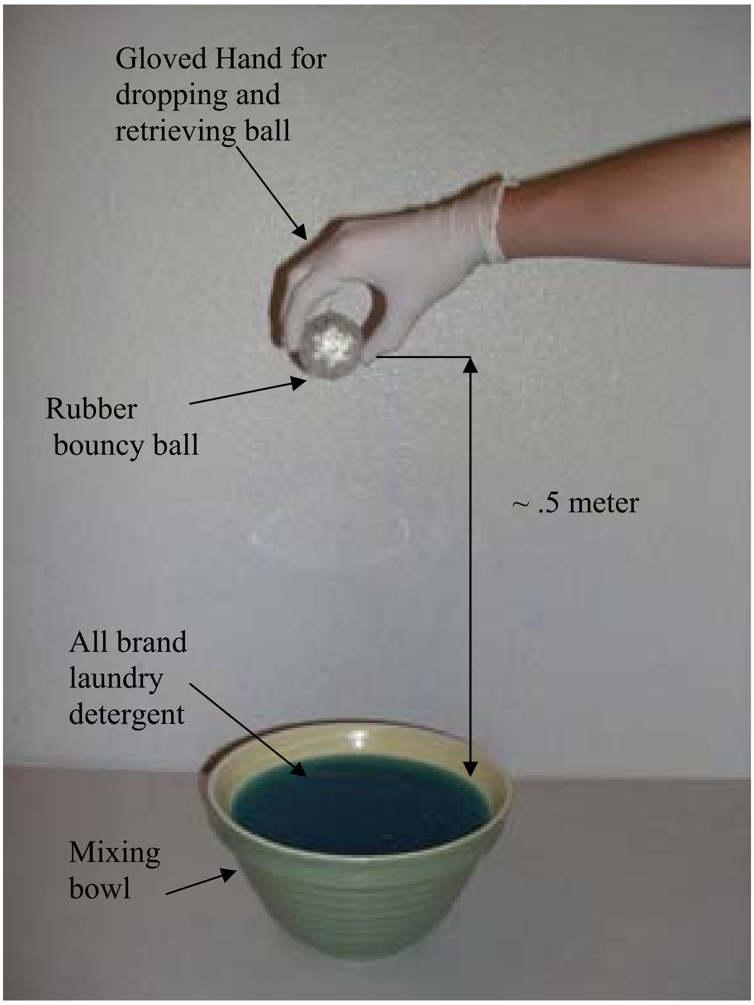

Figure 4: Experimental setup

The rubber ball weighed approximately 1 kg and was dropped into a bowl with a diameter of .23 meters (9 inches). The diameter of the ball was 5.1 cm and before dropped it was initially at rest. Rubber gloves were used for retrieving and releasing the ball because after the initial photo shoot, I notice that my hands were reacting badly to the concentrated detergent. The flow is created when the ball was dropped from .5 meters and impacted the settled surface of the All brand laundry detergent. This phenomenon can simply be termed as a fluid reaction to an impact by a solid. The base of the resulting splash was approximately 7.5 cm to 10.1 cm in diameter. The speed of the ball when it impacted the fluid can be determined according to constant acceleration formulas if all losses such as air resistance are neglected. According to Engineering Mechanics –Dynamics by R. C. Hibbeler the equation for the velocity of the ball assuming constant acceleration is,

$$v^2 = v_o^2 + 2a_c (s - s_o)$$

Thus, this calculation yields the downward velocity of the ball as it hits the surface to be 3.1 m/s. The Reynolds number for this flow is very difficult to approximate, as the material properties of the laundry detergent were not available. However, from the approximation of the speed of the ball, the Reynolds number of the fluid can be assumed to be of a low to medium value because the viscosity of the fluid as well as the free-stream velocity are relatively low.

Most resources on splashing and the crown phenomenon examine the creation of crowns by dropping a droplet of various liquids into a pool of another liquid. While the physics guiding this fluid-to-fluid interaction are different, they are similar enough to provide valuable insight on how to learn more about the flow. According to "An experimental study of a water droplet impinging on a liquid surface", an article written by Manzello and Yang in Experiments in Fluids in 2002, the type of splash created depends on the Reynolds number, Froude number, and the Weber number as well as the geometry of the system and the material properties of the liquids. (http://fire.nist.gov/bfrlpubs/fire02/PDF/f02065.pdf). The Reynold's number relates the inertial force to the viscous force, which could aid in determining the geometry of the crown and the splash. The Froude number relates inertial force to gravitational force and is obviously important in a problem of this natural where gravitational force provides the impact force and finally, the Weber number relates the inertial force to the surface tension force. Thus, the values of all three of these dimensionless groups are integral to learning more about this phenomenon. By defining these values, predictions and models of the flow behavior could be further developed. Another interesting article that observed splash and crown effects was entitled "Impact" by Lohse et al. This study featured dropping a ball onto a surface of fine sand and examining the effects on the resulting crown and jet. (http://arxiv.org/PS_cache/cond-mat/pdf/0406/0406368.pdf). Amazingly, the photographs of the flows of the solid ball impacting the sand, solid ball impacting the liquid, and the liquid droplet impinging on the surface on pool of liquid are all remarkably similar. In general, the impacting particle collides with the stationary surface and displaces whatever fluid was there prior to the impact. Usually, the majority of the fluid displaced moves vertically across the interface with the free surface in part because there is less resistance to movement here.

The spatial resolution of the images can be determined by comparing the size of the pixel to the size of the smallest feature in the image. Because all of the images were created in the same way and display similar properties, only the spatial and temporal resolution of Figure 1 will be determined. In Figure 1, the size of the pixel was 28.346 pixels per centimeter or 0.0003527 meters per pixel. Next, the temporal resolution can be approximated by assuming that the fluid jet is traveling no faster than the ball that impacted its surface. Therefore, the fluid in the image is assumed to not travel faster than 3.1 m/s. Thus, by multiplying the velocity of the flow by the shutter speed, the distance traveled by any given feature traveling at this speed can be determined. The value of the temporal resolution is .051 m. For this image, the value of the temporal resolution is much greater than the spatial resolution and hence a shorter exposure time should be used to achieve better resolution. This measurement concurs with the articles reviewed in that a much smaller shutter speed is more appropriate.

Several different techniques were combined to give the optimal flow visualization with the given resources. The first technique used to help visualize the flow was the black background. This background effectively contrasted the flow and allowed many of the delicate features to be evident through boundary effects. Secondly, the fluid used for the final set of images was one hundred percent All brand laundry detergent. In normal everyday applications, All is light blue colored liquid. Yet, this detergent is also known for exhibiting fluorescence when exposed to a black light. For this reason, a black light was part of the overall lighting scheme. However, as mentioned previously, the black light purchase was not strong enough to light the entire frame. Thus, the flash on the camera and the two ambient household lights were also used. The lighting configuration follows.

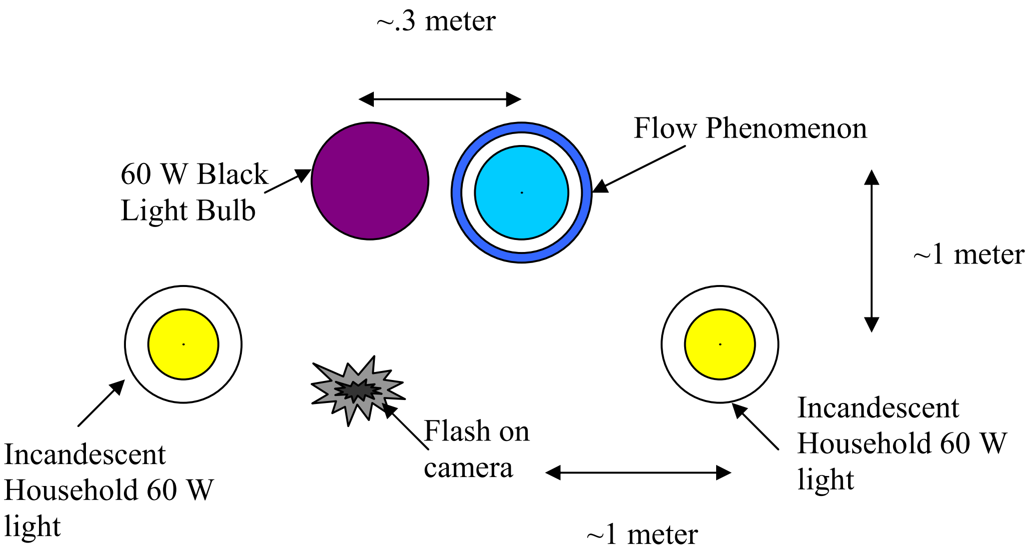

Figure 5: Lighting Configuration (not to scale)

The flow phenomenon was centered between the two 60 W incandescent bulbs which were suspended approximately 2 meters about the table the bowl was set on. The black light was approximately .5 meters above the plane of the table. The camera with the flash was about 1-1.5 meters away from the center of the bowl. This lighting configuration provided the proper amount of light and minimal amount of reflection off of the fluid.

A 4.0 effective megapixel Nikon Coolpix 4300 digital camera was used to capture these images. For all of the images captured, the camera was in AutoFocus mode. This mode was used so that, with experience, I could appropriately time the splash and thus the crown created by the ball to the exact instant when the image was taken. This timing was relatively simple to achieve over a large number of image captures, but in many cases the timing was slightly off. This accounts for the large number of images captured over the length of this project. As the camera came to a final focus, the mechanical elements created a distinct sound, which triggered me to release the ball. The following settings and information relate to the capture of the images.

Table 1: Properties of Images

Settings	Figure 1	Figure 2	Figure 3
Original File Size	.98 MB	.98 MB	.99MB
Digital Zoom	1.0x	1.0x	1.0x
Focal Length (mm)	f24.00	f24.00	f24.00
Aperture Setting	F4.9	F4.9	F4.9
Shutter Speed (sec)	1/60	1/60	1/60
ISO Equivalency Number	100(Auto)	100(Auto)	100(Auto)
Final Dimensions (pixels)	1569 x 1917	1485 x 1832	1467 x 1821
Final Image Field of View	8 in x 9.75 in	8.0 in x 9.85	8.0 in x 9.95 in

Adobe Photoshop was used to crop the images to a smaller size in order to eliminate distracting elements from the frames. An Auto Levels filter was also applied in order to balance the colors more appropriately and provide an enhanced aesthetic experience. Images prior to Photoshop processing are included on same disk as this article.

This image shows the development of the crown phenomenon as a function of time from impact of the object with the surface of the fluid. As time progresses, the crown goes from being very developed with vertical walls to more spread out, less distinct to, and the points of the crown progress away from the central axis of the splash. Thus, the fluid physics observed are a fluid's reaction to a sudden impact of a spherical object. I feel that these images have very nice composure and are also very striking. However, I wish I could have removed the bowl in the images or at least covered the back lip of it with some type of material to match the background. I completed my aesthetic intent with my images, but I am very interested in learning more about the fluid physics behind the flow. I would like to further explore this image and imaging technique in several different ways. First, I would like to accumulate more black lights and create images lit entirely with black lights. Secondly, I would like to use the high-speed video camera to capture a complete splash from impact to the point when the splash falls back into the pool. I believe that this would be not only very interesting to observe, but it would also reveal what is happening to the flow at multiple points in time during the same splash. Finally, I would like to invest more resources into the project and devise a method to trigger the drop of the ball based on when the camera was shot to obtain more consistent images. Additionally, the effects of dropping objects that are not spheres or dropping liquid droplets could be investigated.