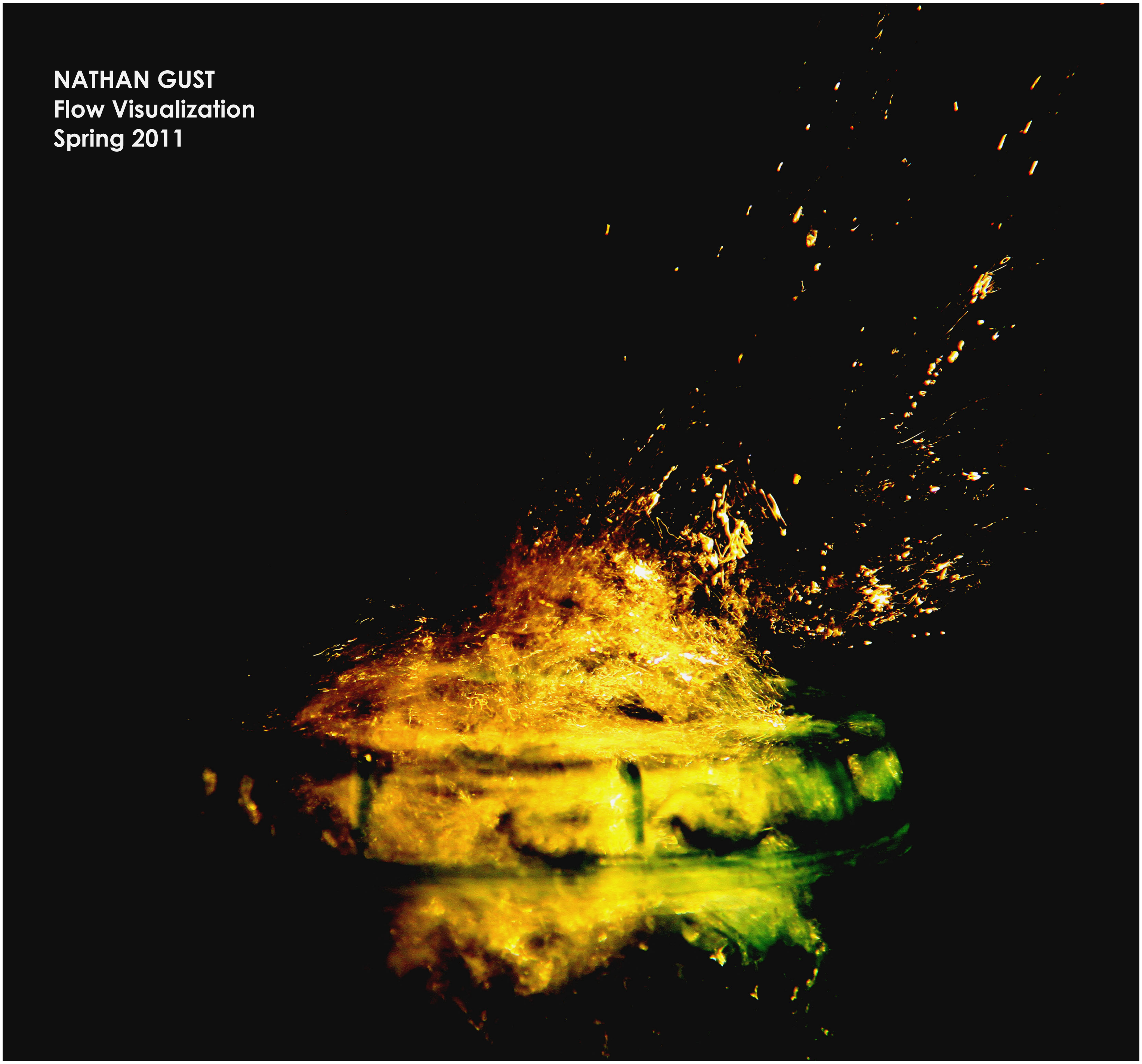

Get Wet Report
Turbulent Water Ejection
February 14, 2011
Hertzberg

INTRODUCTION

The purpose of creating this image was to capture the fluid dynamics associated with a relatively large-scale splash – specifically a shot glass being dropped into a larger cup of liquid. I must admit that the idea for this image came to me when I was enjoying what many call an "Irish Car Bomb" which is a rather aggressive mixture of several Irish alcoholic beverages. However the dialogue on that evening shall end here while the remainder of this report will focus on the fluid dynamics of said experiment. Specifically, I wanted to capture the apparent chaos of a turbulent splash in a scientifically descriptive but aesthetically pleasing way.

SETUP

In understanding what is physically happening here, it is important to first discuss the set up of the experiment. The figure to the right depicts the layout used to create the image. The object being dropped is a standard 1.5 fluid ounce shot glass, 1.75" in diameter, filled with water. The other object is a 32-ounce clear-green plastic cup that bows out at the top. The height of the cup is 7.5" and the opening at the top is approximately 3.5". Seated on top of the cup is a ribbed plastic cap. The cup is filled with approximately 30 fluid ounces of water, leaving a gap from the top of the water to the cap of approximately ¾". I cut a hole 2.5" in diameter in the center of the ribbed cap for the shot glass to fall through. The reason for the inclusion of this top was to induce more fluid churning and turbulence and will be discussed further in the following section. Finally, the shot glass is dropped from a height of 18" above the top of the cup, directly through the cutout in the cap.

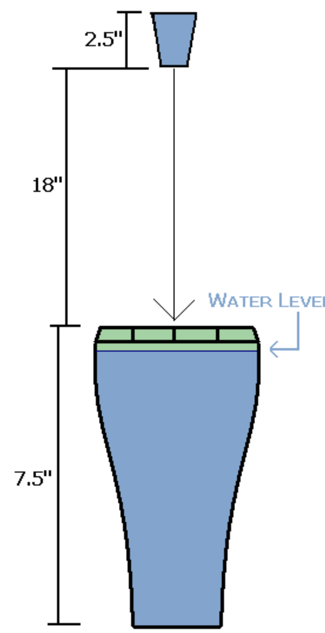

Figure 1: Setup

FLOW DISCUSSION

Essentially what is happening in the image is we have a solid object impacting water, which forces flow through the cutout in the cap. The speed of the glass at impact coupled with the orientation of the fluid exit hole causes the water to exhibit a turbulent flow. In turn, there are two main discussions surrounding the flow physics depicted in this image: the physics of a solid object impacting a liquid and the properties of turbulent flow. First, we'll look at the physics of a solid object impacting a liquid. The specifics can obviously differ based on numerous factors, i.e. the shape of the object being dropped, its speed at impact, the properties of the liquid, etc. For this discussion, we will focus on the basic flow features of such an impact.

IMPACT OF SOLID OBJECT WITH WATER SURFACE

Everybody is familiar with what happens when a solid object impacts the surface of water – it makes a splash. As the object breaks through the surface tension of the water it displaces the liquid and causes upward jetting around the edge of the object. As the object descends into the water, cavitation occurs behind it. It essentially creates an air pocket in its wake that will be filled in by the surrounding water[1]. The image below shows what happens as a circular disk breaks the water's surface – which is of similar axial profile to a shot glass.

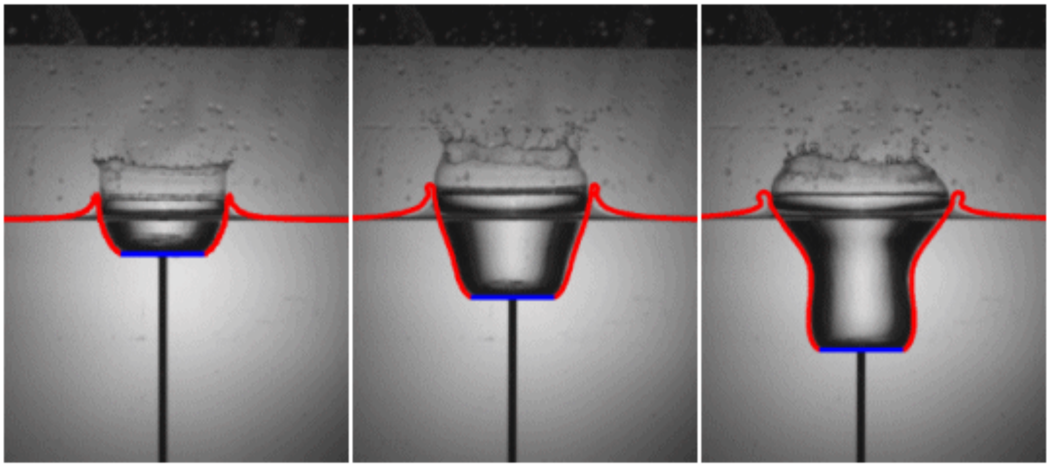

Figure 2: Images of splash caused by circular disk[1]

Now, in order for the splash to exhibit the properties shown in the image above, it must have little to no buoyancy. This is why I filled the dropped shot glass with water. First, to give the object more weight, ensuring the cleaner penetration of the water's surface tension. The second reason was to ensure there was no lag in the shot glass sinking due to the buoyancy of an empty glass. An object's buoyancy is a function of its mass and the volume of water it displaces. By filling it with water, I was ensuring its timely trip to the bottom of the cup. The upward ejection of water from the impact is what is important to focus on in the discussion of this specific image. In the next section, we'll discuss how the orientation of the setup induced a turbulent flow.

TURBULENT FLOW

The difference between the splash exhibited above and the splash in the image I created is that the upward flow of the ejected water is limited to the shot-glass sized cutout in the cap. In this case, when the shot glass displaced the water, it caused the flowing water to impact with the walls of the cup, the inside of the cap, and the other fluid trying to escape through the top. The epicenter of this picture (where the water is ejected from the cup) highlights the chaos and turbulence of this flow. The fluid is moving in all directions as it exits. The water at the base of the picture is churned up as the air cavity caused by the descending shot glass has just snapped shut. And the ejected droplets seem to have an oblong profile instead of the nice spherical drop shape that water wants to take due to its surface tension. These are all properties of a turbulent flow. Two important values to look at when discussing turbulence are the Reynolds number and the Weber number.

REYNOLDS NUMBER

This number essentially compares the inertial forces of a flow to its viscous forces. Therefore a flow with a high Reynolds number has a relatively high inertial force compared to its viscous force – which typically corresponds with a higher flow velocity. Based on the basic velocity equations, ($x = ½ g t^2$ – where x is distance, g is acceleration due to gravity, and t is time), the approximate velocity of the shot glass at impact was 3 meters/sec. This means we can approximate this flow as water flowing over a 1.75" diameter, 2.5" long shot glass at 3 m/s. It is essentially a cylinder axially aligned with a fluid flow. Then using the Reynolds number equation (Re = Velocity * Diameter / Dynamic Viscosity) we achieve a surprisingly high value of 120,000+. Now, clearly the velocity of the shot glass will decrease very rapidly as it descends into the water and an object moving though a fluid is different than a fluid moving passed an object, but this still gives us a clear indicator that a turbulent flow is present, especially at impact. In general, flows around an axially aligned cylinder (or circular flat plate) will have relatively high Reynolds numbers due to orientation[3].

WEBER NUMBER

This number is another dimensionless value, this time comparing inertia and surface tension. The data necessary to investigate the Weber number associated with this flow is not really reasonable to estimate based on the image. Values for droplet diameter, velocity, and surface tension are all needed and these values cannot really be obtained from the image or the setup. But what we can tell is that a high relatively high Weber number is being exhibited here. Some of the higher velocity drops have taken a more oblong shape, indicating that the inertia of the water is fighting against the surface tension. This phenomenon would be better shown by high-speed video perhaps, or an image with a much faster shutter speed. For example, experiments have been done where the limits of water droplet surface tension are tested and the size-to-speed ratio is closely examined. Specifically, when a droplet impacts a surface with a lower velocity, it will maintain its sphere shape until impact, "pancake" into a near flat pool, and then rebound as a Worthington jet. At higher velocities, the surface tension is overcome at impact and essentially explodes into oblong "fingers" forming more, smaller drops[2].

VISUALIZATION TECHNIQUE

In order to create an image that captured this chaotic flow, I had to be sure that the water itself was highlighted – that is, that it stood out intensely against the background. The most important aspect of the setup to do this was the lighting. The room was completely dark except for a high-powered flashlight positioned above the setup. The flashlight was held in place two feet above the impact point aimed directly down at the center. This way every droplet was illuminated. The refractive properties of the water came in handy here as the churned up ejected water caught the light so well and became so intensely bright compared to the relatively still water in the cup. It really helped to highlight the flowing portion of the fluid specifically.

PHOTOGRAPHIC TECHNIQUE

Figure 3: Original Image

In deciding the best way to capture this image, I kept in mind several important factors. First that I wanted the image to be relatively sharp even though light conditions were low and the subject of the picture would be moving rather quickly. I held the camera in my hand rather than using a tripod and timed the picture such that I was snapping immediately after impact. Below is a list of the settings used to capture the image.

Field of View Dimensions: Original – 8.25” x 6.0”, Final – 6.0” x 5.5”

Distance from Object to Lens: 12”

I wanted to be close enough so that the image was sharp and took up the majority of the frame but I wanted to be far enough way that I could see the drops of water that were ejected farthest.

Lens Specs: Lens - EF-S18-135mm f/3.5-5.6 IS, Focal Length – 135.0mm

Type of Camera: Canon EOS 7D – Still

Image Dimensions: Original – 5184 x 3456, Final – 3318 x 3090

Exposure Specs: Aperture – f/5.6, Shutter Speed – 1/32 sec, ISO 800

With relatively low light, I could not use a shutter speed faster than 1/32 second, but it worked out because I wanted to be able to see some streaking in the ejected water. I believe it really helped to highlight the chaotic motion.

Photoshop Processing: First I cut a couple inches off the height of the image and half inch off the width. This was just to accentuate the boldness of the image by making it fill the frame. Second, I adjusted the curves layer to give it that red, yellow, and green coloring and make the black background even darker.

CONCLUSSION

In the end, I am very happy with how this image came out. I would not say that it is exactly what I had in mind when I first started this experiment, but this image does an excellent job showing the chaos of a turbulent water ejection. The churning impact area along with the higher speed ejected drops make an image that resembles a crackling campfire. I really like how the colors came out and the contrast of the bright flow against the black background. If I were to develop this idea further, I might change the shape of the cutout in the top of the cup, or add more holes. This may result in some interesting water ejections and in turn, a very neat picture. Also, I might focus more specifically on either the turbulent flow around the shot glass or the oblong “finger” droplets associated with a high Weber number.

REFERENCES

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