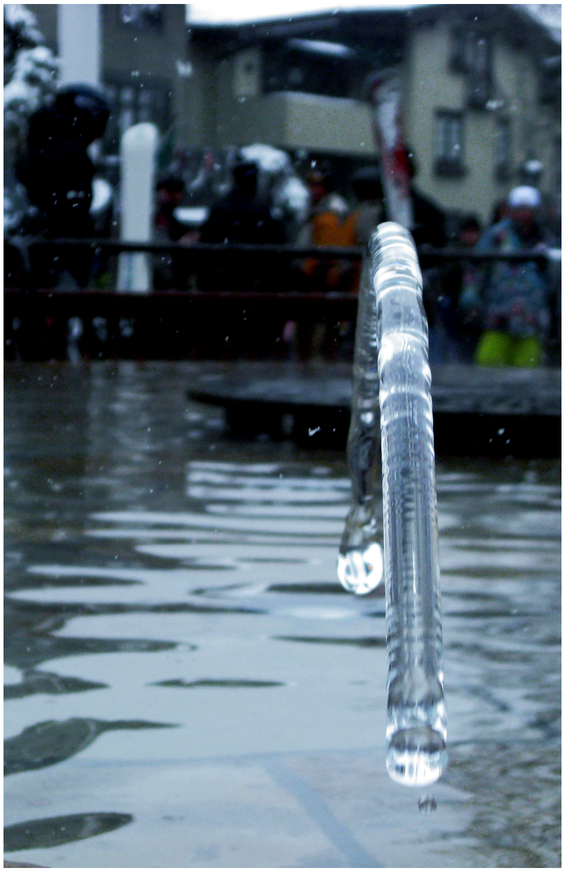
MCEN 5228- Flow Visualization



"Water Slinky"

Assignment: Team Project 2
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Water is an amazing fluid that not only sustains life on this planet, but also captures our imaginations. Water in an integral part of our world, and we can we recognize its presence in many ways such as it seeing it in a lake or in our bodies. This picture was taken for the second team project for Professor Hertzberg's Flow Visualization class for the University of Colorado at Boulder. The team members worked independently from each other on this project since they were unavailable to work with each other due to tests the first week of the project, and people being out of town for the second week of the project. The intent of this picture was to capture the beauty and simplicity of water in a normal world circumstance. So far in this class, students have manipulated fluids to make wonderful and beautiful designs in a lab setting, yet few have really captured the pure essence and nature of fluids as we may encounter it in our every day lives. Therefore, while I performed some minor image processing, the picture's originality and simplistic nature transcends all aspects of production from setup, to image acquisition, and to final processing. The picture shows a water jet in a water fountain in Vail, CO. The picture is especially picturesque because it captures the full stream of water fully suspended in the air without being attached to either the fountain jet or pool.

The simplicity of this picture permeates throughout all aspects of the picture making process including the creation and setup of the effect. The fountain sits in Vail, CO in their main village near the Vista Bahn lift. The fountain has six jets, each with a one-inch exit diameter. These jets are on a timer and release different amounts of water at different times to create a pleasing aesthetic show for guests. In order to capture the image, I stood directly behind the jet and gained interesting perspective of the water coming out of the jet. I ended up taking the picture at eye-level with the lowest jet flow. Since the show cycled ever 12 minutes, it took an hour of waiting for specific instances where this jet only shot out the desired amount of water. Figure 1 shows the basic experimental setup. The flow is certainly repeatable, but takes patience to capture the exact flow due to the variability of the fountain's show.

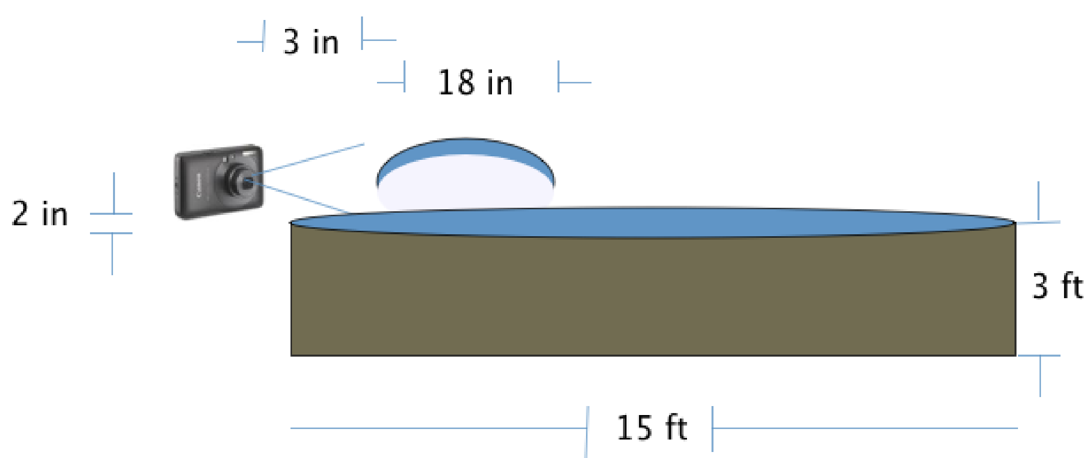

Figure 1: Experimental Setup

The physics of the fluid flow air fairly simple and straightforward at first, but even this simple phenomenon has a tremendous amount of physics to describe it. The first place to start is to discuss the propulsion of the water through the air. The jet has a valve that is turned off while a pump increases the water pressure. An actuator then opens the valve according to the programming of the fountain show. This release of pressure causes the fluid to "escape" once the valve is released and the water is propelled forward. The arc of the flow is determined upon two things, namely the angle of the jet and the pressure: the smaller the angle, the lower the arc while at higher angles the arc becomes taller. The optimal range for the jet occurs when the angle above the horizontal is at 45 degrees (Meriam et al, 2006).

The water flows out of the jet and travels as a cohesive unit until it reaches the fountain pool below. The cohesiveness of water is due to surface tension and also to laminar flow. There is a plethora of papers written about surface tension, so here is a brief explanation of how surface tension works. Net intermolecular inward attractive forces of the adjacent molecules cause surface tension, which create cohesion amongst the fluid of similar molecules (De Gennes et al, 2002). Since each water molecule is attracted to all other molecules, all of the attracted forces of water adjacent to other water molecules cancel, having a net attractive force of zero (wikipedia). However, the water molecules on the edge are not being pulled equally since the surface molecules are surround by half water molecules and half air molecules (wikipedia). Because air is less dense than water, there aren't as many molecules to pull the surface water molecules away from the jet; therefore the extra water molecules create a net inward pull. This phenomenon also causes water (or any liquid) to have the lowest surface area possible. Since there is a net inward pressure, the water molecules will have a tendency to arrange themselves so there is as little of a gradient as possible (De Gennes et al, 2002). This corresponds and is consistent with the second law of thermodynamics which states that molecules arrange themselves the lowest energy state possible (Cengel et al, 2006). An additional factor to water's cohesive nature includes hydrogen bonds and Vander Waal interactions. These bonds hold the water molecules together, increasing water's cohesive nature. An additional factor that allows an environment to have water be cohesive is a low Reynolds number and that the viscosity of the water allows the water molecules to move together. For this experiment, the kinematic viscosity of water at 2*C is equal to 1.6798×10^{-6} m^2/s, moving at .5 m/s at a diameter of .0254 m (engineering toolbox). The Reynolds number is calculated by the following equation below, and is equal to ~7,500. This Reynolds number indicates that the flow was transitioning from laminar to turbulent. The image shows this transitional nature since the edges of the stream are starting to ripple on the sides, however it is not enough to cause the stream to dissociate as can be seen by the generally smooth flow in the image.

$$RE = VxD/\upsilon$$

The visualization technique used to capture this image was less than ideal, but still worked to capture the image. The picture was taken in normal daylight in the late afternoon but it was an overcast day. Therefore, the light was rather flat and there was not enough of it to show the color contrast or brightness in the picture. Even though there was not enough quality light, I decided not to use the flash since it disproportionately illuminated the closer up objects with the background, making the picture look dreary and not capturing my intent. I also took the picture directly behind the jet level to the flow so as to gain an “eye level” perspective of the flow.

The photographic technique of the image includes many of the technical aspects already mentioned. The size of the jet stream is around 18 inches long and has a 1-inch radius. The size of the view of view about 3 feet at the jet stream. The distance of the object to the lens is 3 inches. The camera used was an 8 megapixel, point and shoot Canon Digital Elf. There is negligible motion blur since the exposure time is 1/1,250 sec., which corresponds to less than 1% error to motion blur. The rest of the photographic specifications are listed in Table 1 below.

Table 1: Image Specifications

Camera Data 1			
Make:	Canon		
Model:	Canon PowerShot SD850 IS		
Date Time:	3/26/2010 – 3:21:30 PM		
Shutter Speed:	1/1250 sec		
Exposure Program:			
F-Stop:	f/4		
Aperture Value:	f/4.0		
Max Aperture Value:	f/4.0		
ISO Speed Ratings:	400		
Focal Length:	14.333 mm		
Lens:			
Flash:	Did not fire		
	No strobe return detection (0)		
	Auto mode (3)		
	Flash function present		
	No red-eye reduction		
Metering Mode:	Pattern		
Camera Data 2			
Pixel Dimension X:	3264	Y:	2448
Orientation:	Normal		
Resolution X:	180	Y:	180
Resolution Unit:	Inch		
Compressed Bits per Pixel:	1		
Color Space:	sRGB		
Light Source:			
File Source:	DSC		

The intent of the image was to capture a simplistic yet powerful image of fluid flow and how we can harness its power to inspire beauty in many places. The image reveals how water moves as a unit together due to many of the previously explained physics properties. Additionally, the image appears to show a surreal nature of water and how it reflects and scatters the light as it travels. Its suspension in air also gives a unique perspective on the physics of the water flying through the air, giving it an almost life like quality. This life like quality and light reflection is my favorite part of the image. I would like to improve the image's framing/cropping and the lighting to get more reflection coming from the water jet. Overall, I am very pleased and satisfied with the image.

References:

Cengel, Yunus; Boles, Michael. Thermodynamics, An Engineering Approach, 7th ed. McGraw Hill Publishing, New York: New York. 2006.

De Gennes, Pierre-Gilles; Brochard-Wyart , Francoise. Capillary and Weeting Phenomena- Drop, Bubbles, Pearls, Waves. Springer Publications. 2002

Engineering Toolbox: http://www.engineeringtoolbox.com/ (3/30/2010)

Hyperphysics: http://hyperphysics.phy-astr.gsu.edu/Hbase/traj.html (3/30/2010)

Meriam, J.L. ; Kraige, L.G. Engineering Mechanics: Dynamics, 5th ed. John Wiley & Sons Inc. New York: New York, 2006.

Surface Tensions: http://en.wikipedia.org/wiki/Surface_tension (3/30/2010)

Original image: