Team Image Report 1

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Submitted 3/22/12

MCEN 5151

Flow Visualization

The Flow Visualization class at the University of Colorado is a course where students learn about flow dynamics and photography techniques by capturing photos of fluid phenomenon. The third assignment in the class involved a group of four to five students working in a team to capture a complex dynamic flow by working together. For this assignment, I -- Joshua Hecht-- was placed on a team with Mitch Stubbs, Hamed Yazdi, Ernesto Grossman, and Sam Sommers. As a team, we determined that we would like to utilize the Mechanical Engineering high speed camera for the assignment. For my shot, I personally had wanted to capture a shock wave coming off a whip as it "cracks" through the air. I had planned on lighting up a room full of fog, and videotaping the shockwave moving through the cloudy air. Unfortunately, the whip I purchased for this assignment broke irreparably before a good shot could be captured. I had to rethink my shot, since my original idea was not going to work. I decided to utilize the camera for a water based shot instead, since I had helped Hamed Yazdi with his water droplet photograph and was impressed by the results. The next morning, I went out with a baseball and dropped it in a dish full of water, hoping to see interesting dynamics as the baseball hit the bottom of the dish. Upon viewing the final video, I was quite pleased to realize I had captured quite a few fluid dynamics in one shot, for the water wave caused by the baseball propagated outwards in a very unique manner.

The high speed shot was captured in the following fashion. A clear dish was filled two thirds with water and was placed upon the ground. The high speed camera was set up about two feet away, level with the top of the waterline in the dish. Once the video started recording, the baseball was dropped into the dish from approximately six inches above the waterline. A visual representation of the overall setup is shown in Figure 1.

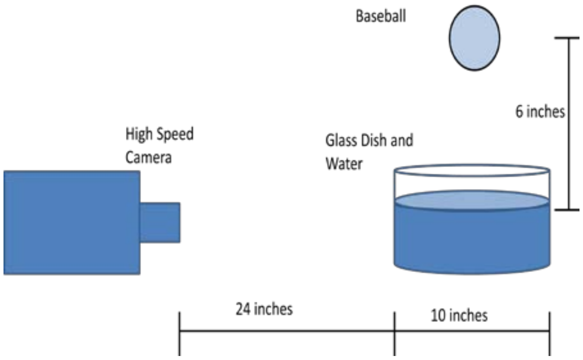

Figure 1: Experimental Test Set Up

When the baseball fell into the water, the solid baseball's momentum carried it through the water's surface. This action displaced the water, causing the water level to rise close to the ball, and traveled outwards until it traveled up the edge of the glass dish. The ball was dropped fairly close to the center of the dish, so it was suspected that the waves coming off the baseball would reach the edge of the dish at the same time. However, upon viewing the video, it can be seen that this is not what happens.

As the ball falls through the water, the waves that reach the edge of the dish first are the ones in line with the laces as the ball is in the water. As the initial waves fall from the sides of the wall, the wave lined up with the smooth portion of the wall climbs up the sides of the dish, reaching an even higher height than the two waves beforehand reached. This phenomenon is demonstrated in figure 2 below:

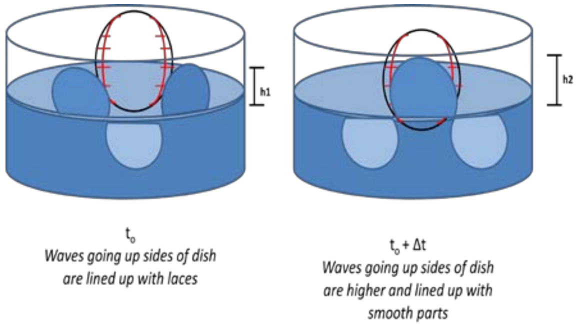

Figure 2: Wave position on side of glass

In the above figure, the amplitudes of the waves are approximated by comparing the heights of the wave to the size of the ball: 7.5 cm. (Yates, 2007). The initial waves are approximately 2 cm. high, and the second wave is approximately 3 cm. high. The time between the waves appearing is about one second in the video. Since the video is played back at 1/8 speed, this means the waves were separated by about 1/8 of a second.

There are two distinct phenomenon observed in the video: the wave timing, and the varying wave height up the sides of the dish. The wave timing phenomenon is due to different flows occurring at the surface of the ball as it falls through the water. Laminar and turbulent flows are commonly associated with an object traveling through a fluid. Laminar flows are relatively stable streamlines of fluid sticking securely to and traveling around the object, whereas turbulent flow is described as unstable flow that travels away (perpendicular) to the surface of the object faster than laminar flow (Anderson, 2005). Therefore, the hypothesis is that the waves coming off of the laces are turbulent flows, and the waves coming off the smooth portion of the ball are from laminar flow.

The two types of flow can be estimated with a unitless measurement called the Reynolds number:

$$Re = \frac{UD}{v} \qquad (1)$$

Where U is the velocity of the object (m/s), D is the diameter of the object (m), and v is the kinematic viscosity. The velocity of the object can be calculated by assuming earth normal gravity and the six inch height above the surface of the water.

$$Vball = \sqrt{2 * g * ht} \qquad (2)$$

$$Vball = \sqrt{2 * 9.81 * (6in * (}0.0254\frac{m}{in}))$$

$$Vball = 1.729\, m/s$$

The standard diameter of a baseball is 0.075 meters, and the typical viscosity of water is $1.004 * 10^{-6}$ m^2/s (Hertzberg, 2011). Therefore, the Reynolds number can be calculated as:

$$Re = \frac{0.075m * 1.729\frac{m}{s}}{1.004 * \frac{10^{-6}m^2}{s}}$$

$$Re = 130000$$

Since a laminar flow of water around a cylinder generally only occurs if the Reynolds number lower than 1000, (Anderson, 2005) the hypothesis that different flows were the timing reason was incorrect, since the flow was clearly turbulent at all points during the flow phenomenon.

Another solution lies within the laces themselves, and how they are oriented relative to the surface of the ball. The laces interacting with the water make the flow even more turbulent where the two are in contact. The approximation shown in Equation 1 is for a smooth ball. Where the laces are, the Reynolds number is increased, since the friction from the laces causes the flow to become less stable than the smooth portion. (Pallis, 2002) With an increased Reynolds number, the boundary layer on the surface of the object increases. (Anderson, 2005) The waves propagating out faster from the laces is actually this same increase in boundary layer from the lace orientation of the ball. This is why a baseball curves when thrown with a particular spin, because the air is able to act in a unique way around the turbulent flow caused by the laces on the baseball. (Pallis, 2002)

The second phenomenon that was seen during the course of the video was in the secondary wave that showed up between the two “lace-based” waves. The two collapsing waves acted to increase the size of the wave that came up between them, by an act called wave superposition. When two waves come together in such a superposition, the event is called “constructive interference.” (Feynman, 1969)

Constructive interference is essentially where waves meet one another and they add onto one another. In this case, the two waves that hit the top of the dish first were forced to transfer their energy parallel to the sides, rather than outwards from the ball. The two waves moved towards where the slower wave was coming towards the side of the dish. The slower wave likely had the same energy as the first two waves, but due to the breakdown of the waves on the surface of the dish, the slower wave came up higher on the side than the first two. This type of effect is seen in a much larger scale with tsunamis, most notably in the Hyogo-ken Nambu earthquake of January 17, 1995. With this earthquake came tsunamis that crashed into the city of Kobe. The geometry of Kobe caused waves to superimpose upon each other in certain points. These superimposed waved achieved constructive interference over the “damage belt” of the city, which is where the most damage to the city occurred. (Kawase, 1996)

In terms of visualization scale, the smallest viewable flow phenomenon was approximately a half centimeter across. The entire field of view for the flow phenomenon in the video is approximately two feet across. Therefore, with the following equation, the scale of the resolution can be determined:

$$Resolution = \frac{Entire\ field\ of\ view}{Smallest\ viable\ flow}$$

$$Resolution = \frac{60.96\ cm}{0.5\ cm} = 121.92$$

$$Resolution = 1.21e2$$

Therefore, since the resolution is in the hundreds, the scale of resolution is two decades, which is well resolved for the flow shown in the video.

When it came to capturing the flow itself, the visualization technique was fairly simple. A four inch circular dish was filled up two thirds with water, and was laid upon the ground. No dyes were added to the water. The camera was placed at a slight angle up, about 10 degrees, in order to give a bit more frame space above the dish so the ball could be seen falling down. The lighting source was from the sun outside. The shot was captured at 9:30 in the morning, Mountain Standard Time. The day was rather cloudy, which is why the video appears a bit darker than it might have otherwise.

The photographic technique involved starting the high speed recording, dropping the ball, and stopping the recording. The depth of field was limited to the dish and the ball itself by adjusting the focus on the camera to capture images about 6-12 inches away from the camera, which is where the dish and the ball were located. This depth of field choice blurred out a good portion of the background, which helps in getting the viewer to focus on the dish and flow dynamics, rather than the background.

The camera used for the shot is an Olympus i-SPEED LT high speed video camera. The Olympus camera has a sensor resolution of 800 x 600 and a pixel size of 14 microns. (Olympus, 2012) The lens used was a standard Olympus lens that allowed for closer shots, having a focal length of 10.2 mm. The video was recorded digitally, saved onto a disk, and transferred over to a laptop using a USB device.

The camera was set to capture the ball falling at 400 frames per second. The aperture was open all the way (f-stop=1), to let the most light in. The ISO was set fairly high, at 600, since the lighting was not ideal for the shot. The playback speed was at 50 frames per second, which showed the ball falling at 1/8 regular speed.

No video editing was done when the video was complete. Initially, when the video was saved, there was a recorded portion that extended beyond the front and back part of the video. This portion did not show any fluid dynamics, and was cut off to show the flow around the baseball more vividly. No lighting, sounds, title, or any other addition was put into the video besides editing the video length itself.

Overall, the image reveals interesting dynamics of fluid traveling away from an object dropped in water. The interaction between the baseball and the water is interesting in that the fluid propagated away from the baseball at different rates, depending on the surface of the ball. I like that the shot shows the clear dynamics of the fluid moving around the ball, and learning about the frictional forces upon a baseball was interesting. I still would like to know exactly how the boundary layer broke down as the baseball hit the bottom of the dish, since the layer crashed down in an unfamiliar fashion around the baseball as the motion was rapidly stopped. In the future, I would like for there to be more lighting in the image to allow for additional detail on the finer aspects of the flow. Also, when editing the video, I wish I would have added a title, or some kind of music to the overall presentation. In the end, I feel that I learned quite a bit from this project, and that I fulfilled my intent of capturing a unique flow using a high speed camera.

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