Group Project Three

Bolt to the Future

MCEN 5151: Flow Visualization

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Introduction

This project, the last of the semester, was a chance for the groups to produce one final set of images/videos for the semester. The idea was to use all of the acquired knowledge and experience working with the teams to create a great final product. For this set of captures, my team chose to use a high-speed camera capable of shooting high resolution at over 3000 frames per second (fps). With this awesome piece of technology the team was able to capture many interesting physics phenomena including my capture of a bolt impacting a pool of water.

The Physics behind the Video

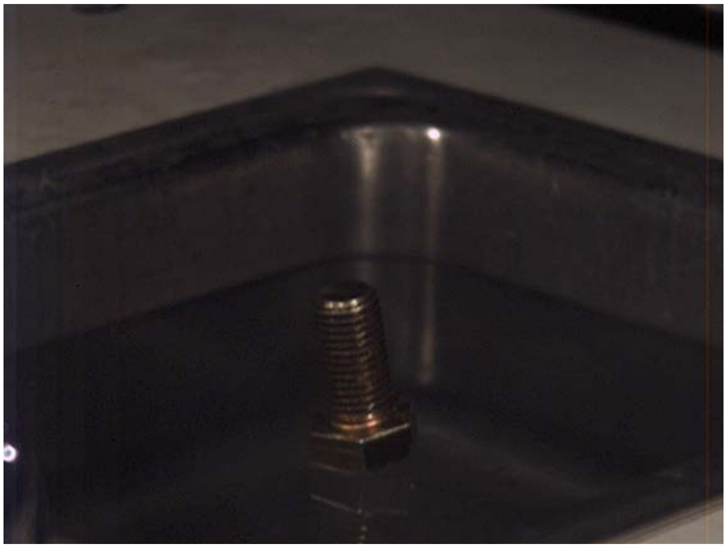

Figure 1 - Bolt just at the point of impact

In order to correctly analyze the impact of the bolt, the first thing that is required is to determine the impact velocity. This can be done by determining the approximate distance the bolt covers over the course of the frames in the video. After reviewing the video, I determined that the bolt fell approximately 39/64" (the height of the bolt head (McMaster Carr, 2014)) in 0.6 seconds in the original video. The video was played back at 30 fps from the original. With all of this data, it can be determined that the bolt was falling at approximately 2.5 m/s. With the velocity determined, I used Solidworks, as well as CAD from McMaster Carr, to determine that the bolt had a weight of 0.709 pounds or 0.322 kilograms. With these two data points, one can determine the kinetic energy of the bolt at the point where it impacts the water using the equation below:

$$KE = \frac{1}{2}mv^2$$

The kinetic energy was found to be 1.006 Joules. Another important number for properly analyzing the impact is the Weber number. The Weber number is a dimensionless number that is defined by the ratio between the fluid's inertia and the surface tension (Heister, 1996). It is defined by the following equation (Heister, 1996):

$$We = \frac{\rho v^2 D_o}{\gamma}, \text{ Where}$$

ρ = Density
v = Velocity
D_o = Hydraulic Diameter
γ = Surface Tension

The properties of water were assumed to be a 20 degrees Celsius and are as follows: ρ = 998.2 kg/m^3 (Nave, 2014), γ=0.728 N/m (Nave, 2014). The Hydraulic Diameter was taken to be the bolt head diameter that is 1.5" or 0.0381 m (McMaster Carr, 2014). With these numbers, the Weber number was calculated to be 326.5. What can be concluded from this is that the inertia forces for the bolt's impact are significantly higher than the water's surface tension. This is what is expected since the bolt crashes through the water with the majority of its velocity remaining. With high velocity impacts a hemispherical dome is formed over the cavity left from the impact (Shin & McMahon, 1990). The phenomenon of this dome are best explained by the following quote: "*If the wall is thinner above than below, then the upper part will contract faster than the lower, through there being less liquid to accelerate. Now the supply of liquid is from below, and will thicken the lower part of the walls first, and thus account for the faster closing of the mouth. On the other hand, the uppermost edge of the crater is the place where the checking influence of the surface-tension on the upward flow is first felt, with the result that the edge of the rim is thickened by the influx from below, so that a more or less regular rope-like annulus is formed round the edge. Now calculation shows that such an annulus, so long as its thickness is not more than 1·61 times the thickness of the wall below, will contract quicker than the wall, and this will tend to close the crater, somewhat as a bag would be closed by the contraction of an elastic cord round the mouth.*" (Worthington, 1908). The radius of this dome can be estimated using an equation that is dependent upon the Weber, the Froude, and the Reynolds numbers. Using Figure 2 to correlated between the weber number and the estimate that the Froude number is approximately 200 for this impact. The Froude number is another dimensionless number that describes the ratio of inertial and gravitational forces (Furniss, et al., 2006). The Reynolds number is also a dimensionless number that describes the ratio of the inertial forces to the viscous forces of the fluid (Benson, 2009). Using the water properties above, the Reynolds number at the point of impact was estimated to be 94.7 meaning the fluid was within the turbulent regime. With these values one can write a energy balance and solve for the diameter of the cavity. Unfortunately, due to various unaccounted for losses, the force balance must be multiplied by a scaling constant to match experimental results (Ogawa, Utsuno, Mutou, Kouzen, Shimotake, & Satou, 2007). As a result of the complexity required to determine an accurate scaling factor, this analysis has not been performed in this paper.

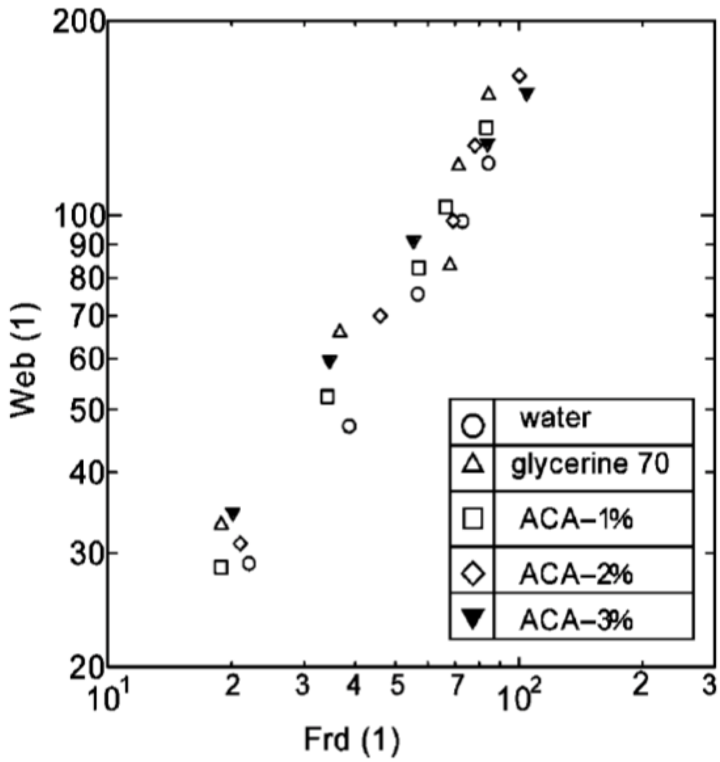

Figure 2-Correlation between Froude and Weber Numbers for an impact (Ogawa, Utsuno, Mutou, Kouzen, Shimotake, & Satou, 2007)

Creating the Setup

In order to capture the video, we used an Olympus i-Speed high-speed camera. One of the biggest challenges when capturing the video was providing enough light to capture adequate video. This is a result of the extremely high frame rates only allowing a limited amount of light in per frame. Since each frame has such a small exposure time, the light required is immense. The team used four halogen floodlights all within 12 inches of the bolt impact point in order to provide the necessary light. These floodlights were in combination with the florescent lights already fully illuminating the room. With enough lighting for the video taken care of, the group found it necessary to protect the camera from any splashes due to its extremely high cost. The team used a plastic bag to surround the camera in case of any splashes. In parallel with the camera cover, the team also used a clear plexiglass sheet to provide a barrier between the camera and the pool of water. These two pieces ensured that the camera would remain safe even with the large splashes of water observed with the one-inch bolt. The bolt was dropped from approximately 12 inches above the pool of water. The head was held downward in order to ensure the impact was with the head of the bolt as seen in the video.

Figure 3 - Video Capture setup before moving lights closer

Capturing the Video

Once the lighting for the shooting high-speed video had been figured out, the team began shooting many different impacts with various different objects. The team realized that the bolt provided a very intense splash and subsequent Worthington jet and decided to save this capture. The camera used as mention above is an Olympus i-Speed LV camera. The camera provide video capture at anywhere from 60 fps to 33000 fps with degrading capture as the frame rate is increased. For this reason, the team felt that we had found a fine balance between decent video capture and high frame rate. The raw video was captured at 3000 fps for this very reason. The camera's capture settings were all set to automatic with the lens being focused manually with an f-stop of 1.4.

Post Processing

In order to get the most out of the captured image, I edited the video to make it more viewer friendly. The stock video was almost 2 minutes long and seemed to drag on before the impact and in the transition between the cavity and the Worthington jet. As a result of this conclusion, I chose to begin the video with the Worthington Jet, the part that I felt was most interesting, and work my way backwards exposing how this jet had been created. I sped up and slowed down different areas of the video in order to add some focus on specific moments within the splash. Since I was playing with the speed and direction of time in the video, I felt that the title “Bolt to the Future” was a good play on words for the video. The music was chosen for the same reason as it is very reminiscent of a 70s detective show theme. The music is a default clip within Final Cut. The final component that was added to the video was a small title bar near the beginning of the clip and a short credit near the end. Other than editing the videos playback speed, direction, and adding music and text; the video is completely unedited, as I do not have enough background in video editing to enhance the video further.

The Video

I love the final product for this project. I took it upon myself to put in a little bit extra work and capture a video for the final project. This was much more of a challenge than I had originally thought it would be. Since I have an extremely limited background in photography and film, I hit the ground running with this project. Luckily, I had Andrei Molchanov, a film major, to help guide me through the difficult process. With his help and artistic direction, we were able to set up a great video. He helped guide me through the capturing and editing for my video. With his help, I was able to create something that has a unique feel with its music and advanced video cutting. I really like how I began the video with the Worthington jet and worked back to the original beginning, the foreshadowing here helps to establish a bit of mystery to the final video. Overall, I am tremendously satisfied with the outcome of my final group project.

Works Cited

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