UNIVERSITY OF COLORADO - BOULDER

Flow Visualization

Team Project #3

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MCEN 4151 – Professor Jean Hertzberg

The purpose of the “Team Project #3” assignment was to work with our team members and capture an image that clearly exhibits the fluid dynamic phenomenon being observed. The group aspect of the project encourages communication and allows students to attempt to image more complex fluid phenomena’s. This image was created for Professor Jean Hertzberg’s flow visualization course at the University of Colorado in the spring of 2012. The original intent of the image was to capture the popping of a soap bubble. By doing so, we hoped to capture an interesting image where the bubble was half popped and half intact. However, after producing unimpressive results, it was decided to try a different approach. The chosen image captures a combination of two images, before and after the bubble was popped. Specifically, the image displays the surface tension of a soap bubble and the behavior of it as it explodes.

In order to produce the image, a bright ambiance was created in the family room of my apartment by opening up all of the blinds as well as the window so as to allow as much natural sunlight into the room as possible. The equipment used to create the fluid phenomenon was a bubble wand (length = 7 inch, diameter = 0.5 inch.) and Bubble Fun bubble wand soap. To create the first image, bubbles were made using the bubble wand and the biggest one was caught on the edge of the wand. Then to create the second image an assistant’s finger was used to pop the bubble. The camera was held straight in front of the bubble at a distance of about 6 inches from object to lens. Figure 1 below shows the set up that created the final image.

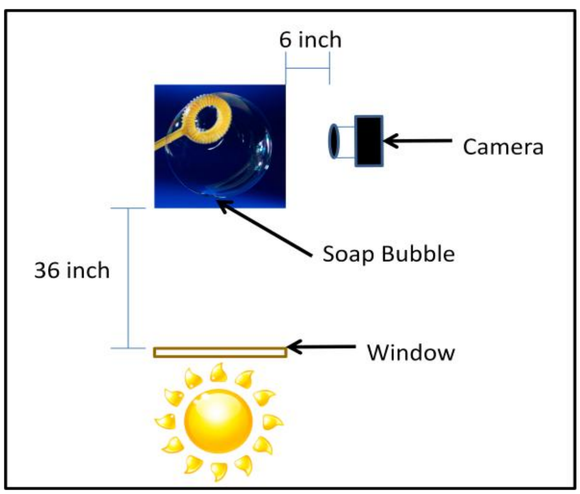

Figure 1: Top view of the final image setup

Bubble Fun bubble wand soap is made from a combination of soap and water. This combination is ideal for the creation of bubbles because it creates a three layered film as seen in figure 2 below. In this soap film, a thin layer of water is located between two layers of soap molecules. The chemistry behind this orientation comes from each soap molecules polar (hydrophilic) head facing towards the water molecule and its hydrocarbon tail (hydrophobic) extending away from the water molecule [1]. A common misconception is that a bubble forms because soap increases the surface tension of water. However, surface tension forces decrease as the distance between the water molecules increase. As a result, the soap molecules actually decrease the surface tension, compared to the surface tension of pure water [2]. In reality, soap stabilizes the water molecules. This is because when air crosses a soap film, the solution will stretch away from the stream of air. Then as the soap film begins to form a bubble, the soap molecules attract towards the weak points in the bubble, thus stabilizing those areas by decreasing the surface tension and preventing them from stretching further [3].

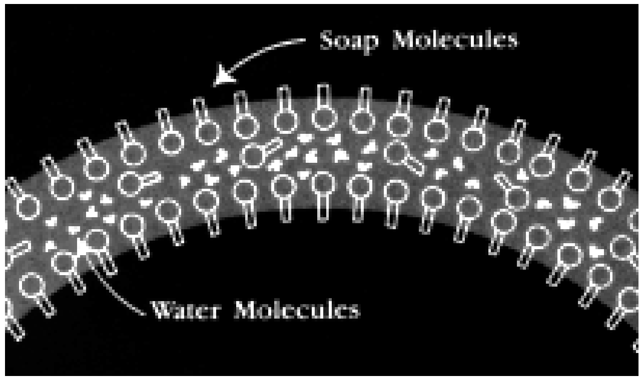

Figure 2: Three layered film of soap and water molecules [2]

Additionally, surface tension causes bubbles to always form into spherical shapes. This is because as the bubble forms the soap molecules are dispersed more widely across the bubbles surface, as a result increasing the surface tension. Since, surface tension needs to stay low; the bubble will form into a sphere because it utilizes the lowest possible surface area to enclose a given volume, thus creating the least amount of strain on the soap film [3].

Once a bubble is penetrated a liquid jet will form at the bubbles edges, spraying fluid outwards. This fluid phenomenon occurs when a hole forms in the thin soap film, retracting the edges of the bubble. When retraction of the soap film commences, the compressed gas located within the bubble will then equilibrate with the outside atmospheric pressure, resulting in a net inward force along the edges of the soap film due to capillary effects. This along with surface tension causes the bubble to collapse. Finally, as the bubble collapses, the inertia of the soap film will create an outward trajectory of soap film droplets [4]. By analyzing the original images, the radius of the bubble was estimated to be approximately 0.0508m (2 in). The bond number, which is a dimensionless number that expresses the ratio of gravitational forces to surface tension forces can be calculated using equation 1 below. Where τ = the skin thickness of a nominal bubble (estimated to be 1μm for a nominal bubble) and L_C = the capillary length of soapy water (≈ 1.6 mm for soapy water) [5].

$$B_O = \frac{\tau R}{L_C^2} \tag{1}$$

From equation 1, the bond number for the bubble can be estimated to be 0.02. This indicates that the relative variation in surface tension over the bubble is approximately 2%. This indicates that the bubble soap film must be stretched by a similar amount to produce the required elastic Marangoni forces [5].

The visualization technique used to capture the final image was the popping of a bubble and its resulting spray of soap film droplets. The fluid used in creating this effect was bubble wand soap, which is made from a combination of soap and water. In order to make the spraying of the popped bubble visible, the image was taken in front of a white wall. In order to get the iridescent colors present in the image, the correct lighting was critical in capturing this fluid phenomenon. The lighting was produced by opening up all of the blinds and windows in the room. This allowed as much natural sunlight as possible to penetrate the room. Additionally, the flash on the camera was not used in order to prevent saturating the iridescent colors present in the bubble. The air temperature of the room was approximately 73°F.

The field of view of the original images was approximately 6 inch (wide) by 6 inch (height). A Canon PowerShot SX230 HS digital camera was held on a tripod straight on with the bubble at a distance of about 6 inches from object to lens. This provided an ideal viewing angle of the bubble because it allowed the photographer to see all of the surface tension effects that occurred as well as the exploding soap as the bubble was popped. In order to prevent motion blur, the camera was held stationary on a tripod. This orientation created an original image with pixel dimensions of 1984 x 1488. The final pixel dimensions were 950 x 681 after being cropped in Gimp. In order to attain a clear image the aperture was set to f/3.1 and a corresponding shutter speed of 1/2000 sec was chosen by the camera to allow for sufficient light to enter the lens. The timing of the image was obtained through having the camera in high speed burst mode. This allowed multiple images to be continuously taken, while the bubble was being popped. Additionally, the image was taken with an ISO setting of 500, ensuring a clear capture of the exploding bubble. Furthermore, the image was taken in macro mode, with the focal length of the lens being 5mm (35mm equivalent focal length = 28.5mm). The original images before being edited in Gimp can be seen in figures 3 and 4 below.

Figure 3: The first original image of the bubble before popping

Figure 4: The second original image of the bubble after popping

After the original image was captured it was imported to Gimp and converted from JPG to a TIF file so that the image would maintain its format. The original image was then significantly cropped in Gimp to focus on the bottom left corner of both images. Next, the two images were mirrored on top of each other so that a full sphere could be visualized. After this, the two halves were combined to form a single image of a bubble exploding in one half and an intact bubble in the other half. Additionally, the curves tool was extensively used to darken the background and create more contrast with the bubble. The image was then improved by using the clone stamp tool to blend any blemishes created by the background. Finally, the image was enhanced with the unsharp mask tool, so as to create a sharper overall image. The final edited image can be seen in figure 5 below.

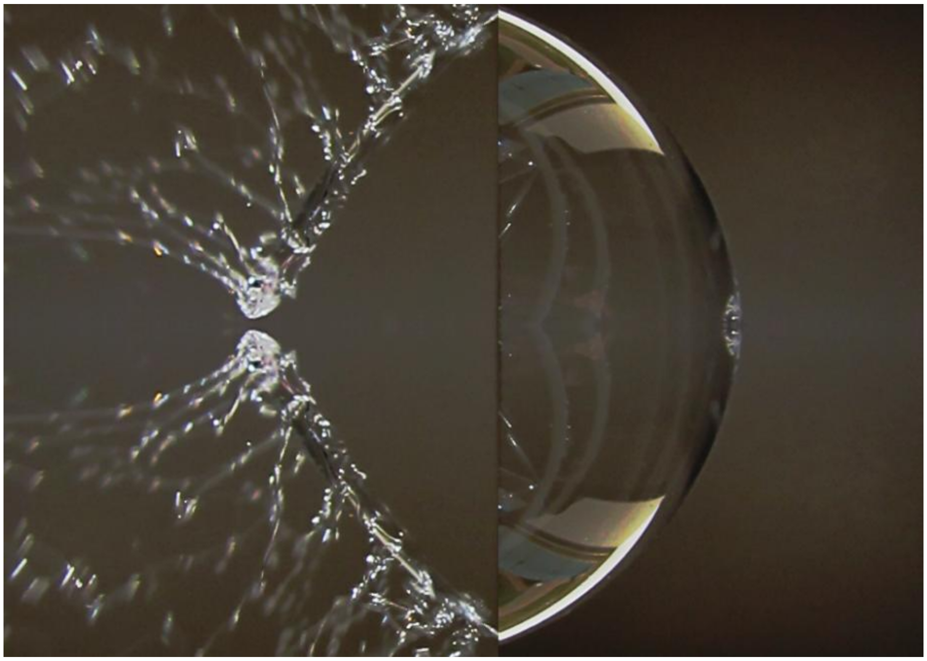

Figure 5: Final edited image

Ultimately, the image reveals the before and after effects of a bubble as it is popped. Specifically, it displays the surface tension of a soap bubble (on the right) and the behavior of it as it explodes (on the left). By cropping the original two images, mirroring their effects, and combining the two instances I was able to create an image that is especially beautiful and intriguing to look at because it makes you wonder how this phenomenon was captured. I really like the clarity of the fluid as well as the great contrast between the brown background and the white jetting fluid. I also like the combination of the two images. It gives an appearance of the bubble half exploding. However, because this is a combination of two images and the two images had to be cropped so much, due to the poster in the original background, the image does not illustrate a single instance in time. This ends up diminishing the dynamic effects of the image, as it reveals two separate phenomenons. If the group were to do this again, we would experiment with the high speed camera so that the original intent of capturing an interesting image where the bubble was half popped and half intact could be achieved. Additionally, if the high speed camera were unavailable we would chose to shoot in front of a different background so that more of the original image could be used and thus no mirroring would be needed. This would ultimately allow for an even clearer illustration of the dynamics of a popping bubble.

Works Cited:

[1] "Bubble Science." *About.com Chemistry*. Web. 30 Apr. 2012. <http://chemistry.about.com/od/bubbles/a/bubblescience.htm>.

[2] "Soap." *Exploratorium: The Museum of Science, Art and Human Perception*. Web. 30 Apr. 2012. <http://www.exploratorium.edu/ronh/bubbles/soap.html>.

[3] Isenberg, Cyril. *The Science of Soap Films and Soap Bubbles*. Clevedon: Tieto, 1978. Print.

[4] *Nature.com*. Nature Publishing Group. Web. 30 Apr. 2012. <http://www.nature.com/nature/journal/v465/n7299/abs/nature09069.html>.

[5] Lautrup, Benny. "Surface Tension." Web. 3 May 2012. <http://www.cns.gatech.edu/~predrag/courses/PHYS-4421-10/Lautrup/surface.pdf>.