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Image: Group Project #1

INTRODUCTION

The purpose of this image is to fulfill the first group assignment of the Spring 2011 semester of the Flow Visualization course at CU-Boulder. My team and I set out to catch balloons popping underwater with a high-speed camera. In more scientific terms, we hoped to catch the physics apparent when you rapidly remove a boundary between air and water or water and water. The image I have displayed shows the water-to-water interaction scenario. It is a still taken from high-speed footage and it captures a moment immediately after the boundary (latex balloon) has been removed. It highlights an interesting moment as the two bodies of water begin to interact.

SETUP

The setup for this experiment was quite simple. We used a clear, 20-gallon glass fish tank. It required some light cleaning beforehand to ensure that the shot would not be obstructed by smudges. We filled the tank to about two inches below the rim. We then anchored the balloons so that they would not move. We used 200-gram weights with hooks to do this. The diagram to the right shows the setup.

Figure 1: Setup

In order to differentiate the water inside the balloon from the tank water, we utilized food coloring. In each balloon there are around ten drops of coloring (red and blue respectively). Once the balloons were anchored and the water stopped moving, a teammate of mine carefully positioned a needle above each balloon and simultaneously popped each. The high-speed video* very clearly showed the balloon peel away and the colored water begin to dissipate.

FLOW DISCUSSION

When examining the fluid dynamics at work here, there are two important aspects to highlight. First, we are very quickly removing the latex balloon from around the dyed water inside it. This brings to the table discussions of shear and frictional forces as we essentially have a fluid flow over a solid object (retracting balloon). The second fluid interaction is the dispersal of the dyed water into the clear water of the tank.

Viscous Drag

As the latex balloon quickly retracts away, its surface drags against both the dyed water on its inside and the clear water on its outside. We will observe different behaviors of the fluid after retraction based on the viscous nature of the fluid and the friction exhibited between the solid and the liquid (in this case latex and water). In this circumstance, the water was around room temperature (65 degrees Fahrenheit), which gives it a viscosity of around 1.10 ft^2/sec x 10^{-5}.[1] This relatively low value equates to a liquid that flows easily. The low viscosity of the fluid will prove to have effect on the behavior shown in the picture.

In the case of moving solid over resting fluid (or vice versa), it is known that the fluid closest to the solid object will remain in contact with the solid's surface (at least at low velocities). Then as you move farther away, the velocity field will exhibit the movement of the fluid as a whole (in this case, stationary).[2]

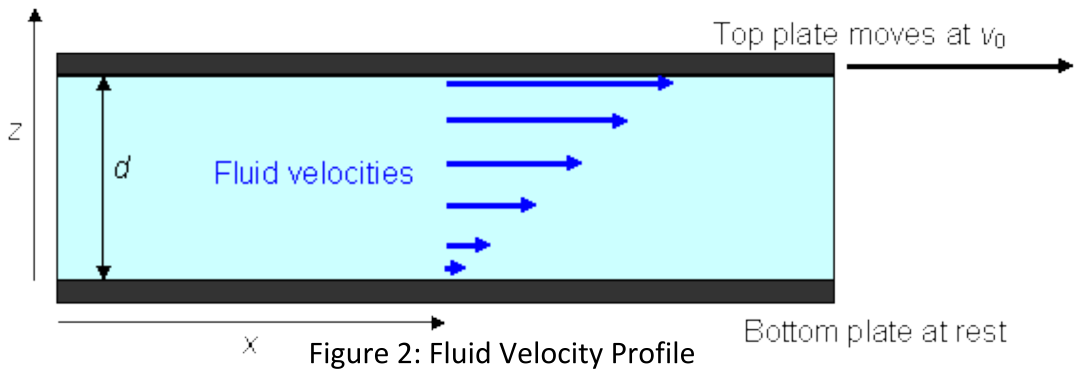

Figure 2: Fluid Velocity Profile

However, in the case of a water balloon popping, the latex is moving too quickly for this typical behavior to occur. The frictional forces due to low viscosity and the coefficient of friction between latex and water are too low to "grab" the liquid. You can see in the picture that there is no real movement of the water in the direction of the retracting balloon. If it were a different fluid in the balloon (perhaps something more viscous) and if the balloon retracted at a slower rate, we would most likely see the fluid being pulled by the balloon's skin.

There are many interesting studies examining shear stresses and frictional fluid effects on different fluids. For example, we can examine the shear effects of plates moving over a fluid with liquid crystals. By manipulating the orientation of the crystals, and in turn the viscosity of the fluid, we observe varying results in terms of shear on the fluid.[3] An interesting experiment to do with respect to this image would be to try different fluids in the balloons and observe the fluid movement in high-speed as the balloon retracts. We could then compare on an empirical level, the changes in observable fluid flow due to the retracting latex.

Water Dispersion

The other interesting phenomenon we can exhibit in such an experiment is the dispersion of a small portion of water into a larger body of water. In this case, because the balloon slipped out with relatively no interaction with either body of water, we specifically see laminar dispersion. It is not shown in this image, but it took several seconds for the blue and red clouds of water to grow in size just a few inches, and several minutes for them to fill the tank. It does, however, only take a few hundredths of a second (which is the instance caught here) for the cloud to develop that fuzzy, peach resemblance as the water immediately begins to disperse. This is most likely due to small disturbances in the water caused by the latex balloon whipping through.

VISUALIZATION TECHNIQUE

As I briefly discussed earlier, the visualization technique used here was color differential. We dyed the water in the two balloons red and blue with food coloring so that it would greatly stand out against the clear water and white background. To do so, we put about ten drops of typical food coloring and a small balloon and filled it with water (about eight to ten fluid ounces of water). This gave the water in the balloons a sufficient darkness and color saturation.

Since we captured the original footage with a high-speed camera, we had to ensure that the setup included a sufficient amount of light. To do this, we used two relatively high-powered lights, with one shining directly down on the balloons from above (about 12" away) and one aimed directly at the front of the setup (about 8" away). Specifically these lights were 250 Watt 25" Northstar lights with a clamp base. They provided sufficient power for the camera to capture this phenomenon with well-lit clarity.

PHOTOGRAPHIC TECHNIQUE

In order to highlight the physics of this very moment, it was important to use a high-speed camera that had capacity to utilize a very high frame rate. Luckily, the guys at Vision Research were generous enough to demo one of their excellent cameras for us. We were able to capture some amazing video that we would not otherwise have been able to obtain. The video from which this image was taken was recorded at over 20,000 frames per second. This way we could ensure that the balloon recession (taking only a few thousandths of a second) could be captured. Below, is a list of some of the important photographic data associated with this image.

Field of view: ~7 inches
Distance from lens to object: ~16 inches
Type of camera: Vision Research – Phantom Flex digital high-speed camera
Image size: Original – 512 x 600 pixels, Final – 512 x 490 pixels

PHOTOSHOP PROCESSING

In order to really bring out the part of the image I wanted to highlight, I needed to do a relatively high amount of Photoshop processing. The steps involved cropping the height from 600 pixels to 490 pixels. I then edited out my teammates fingers, the needles, and the weights used to anchor the balloons. This helped to single out the phenomenon occurring in the center of the picture. The last step I took to improve the image was increasing the contrast. This brought out the bright white background and gave each bulb of colored water a more significant effect. Below, you can see the changes that were made in Photoshop and the resultant effect that the changes had on the overall feel of the image. The original is shown on the left.

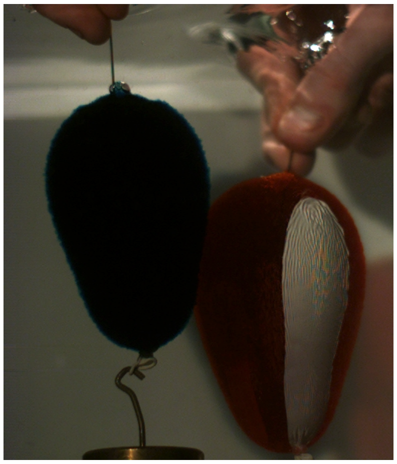

Figure 4: Final Image

Figure 3: Original Image

CONCLUSION

Overall, the intent of this image was realized. It highlights a not-oft-seen moment in the life of a popping balloon and brings about good discussions of water-to-water boundary layers. The fluid physics of the dissipating balloon water as it joins with its surroundings are highlighted by the fuzzy, peach-like nature of the image. I, personally, was surprised by how non-violently the two bodies of water reunited. I had anticipated some sort of churning and mixing caused by the boundary whipping through the two liquids with intense speed, but in fact, it had almost no effect. If I were to re-make such an image, I may try to obtain a higher pixelated image (i.e. 2000 x 3000 pixels) as it may have allowed for zooming in on the edges of the boundary layer. This, however, would be difficult as the timing necessary to capture this with a still camera would be near impossible. And again, we were very lucky to have the ability to use such a high-powered high-speed camera, but it limited the amount of control we had on certain photographic techniques.

References

[1]Engineering Toolbox. "Water – Dynamic and Kinematic Viscosity." http://www.engineeringtoolbox.com/water-dynamic-kinematic-viscosity-d_596.html

[2]Fowler, Michael. University of Virginia. "Viscosity: Intro to Friction at the Molecular Level." June 2007. Accessed at http://galileo.phys.virginia.edu/classes/152.mf1i.spring02/Viscosity.pdf

[3]Janik, Joanna. Tadmor, Rafael. Klein, Jacob. "Shear of Molecularly Confined Liquid Crystals." Department of Materials and Interfaces, Weizmann Institute of Science. April, 2001. Accessed at - http://dept.lamar.edu/chemicalengineering/WWW/Tadmor/papers/confinedliquidcrystals/shearforcesinLC.pdf