Get Wet Assignment Write-Up

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Flow Visualization – MCEN 5151

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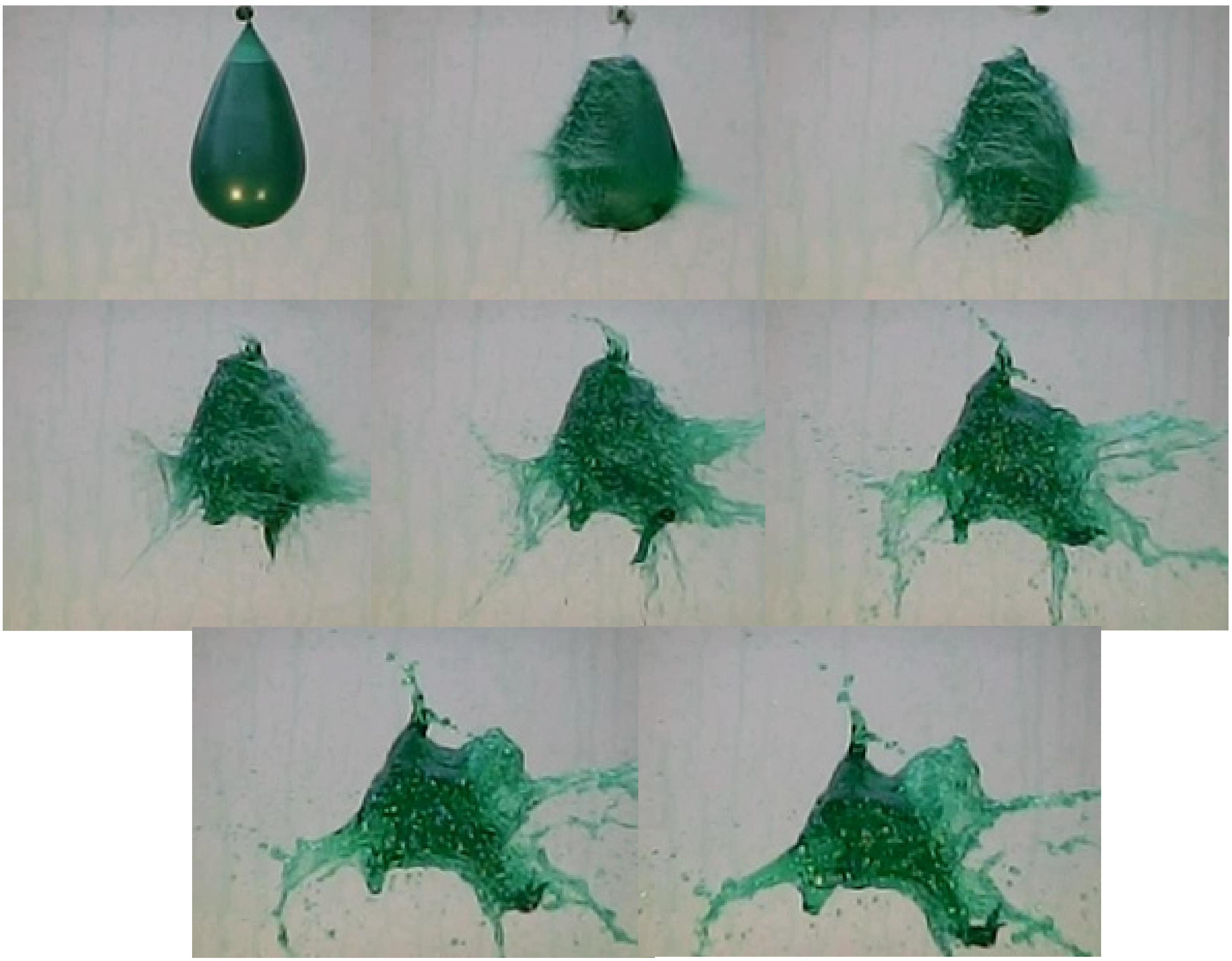

I. Introduction

One of my personal favorite demonstrations of flow visualization is the puncturing of a water balloon. The speed at which the latex balloon pops leaves the water inside it floating for a mere second before it plummets to ground. In order to best show this phenomena, I decided to use a high-speed camera and a high frame rate. I decided that the best way to demonstrate this would be to string up several water balloons, and puncture them almost simultaneously using a pellet gun. Three major setups would be used, one setup would utilize only one balloon, one would use three balloons, and one would use five balloons. In order to increase the visibility of the water, food dye was put into each balloon, and a white background was placed behind the balloons. Thanks must be given to fellow Flow Vis student Kelsey Spurr and Austin Nossokoff for their help in filming and set-up.

Figure 1 – Experimental set-up

II. Flow Apparatus

Part of what is so intriguing about watching a water balloon pop is the inherent simplicity. There are only three major components to the physics of a water balloon popping: parasitic drag, surface tension, and gravity. The flow apparatus can best be seen in Figure 2. It shows the balloon, suspended by a string from above, being impacted by a BB traveling at roughly 1000 feet per second. After impact, the balloon skin seems to vanish immediately, leaving the water suspended for a mere millisecond, kept in its shape by surface tension. As the downward pull of gravity combined with the initial impact of the BB overcomes the surface tension, the water breaks its shape and spreads on its downward fall.

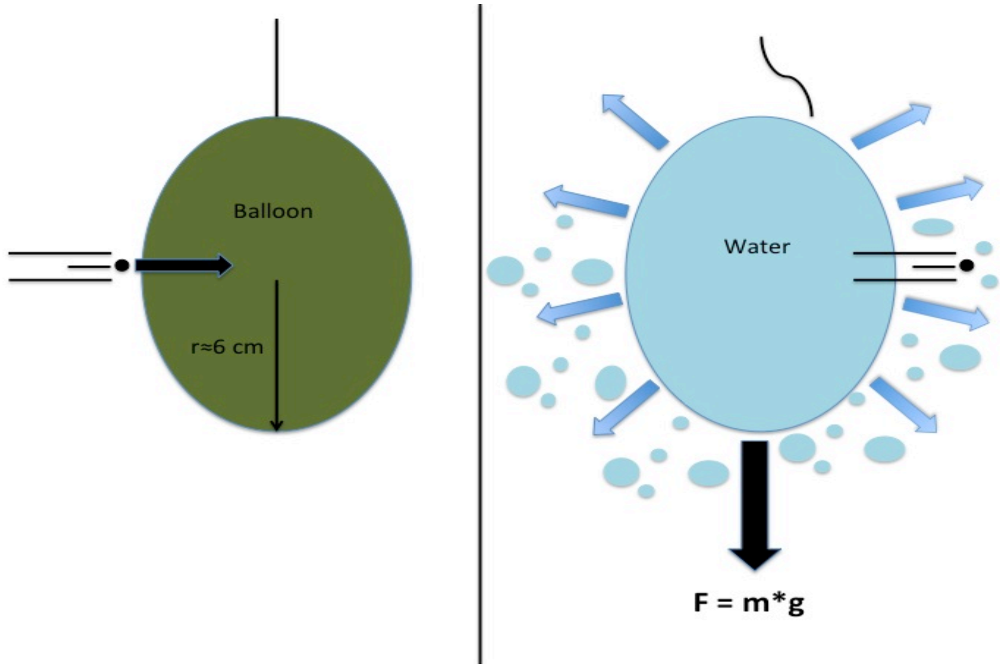

Figure 2 – The flow apparatus

One of the major forces acting during this process, parasitic drag, is the interaction of the quickly moving latex balloon against the water once it's popped. Skin friction is the type of parasitic drag that occurs in this case and it can be described as the friction acting on a solid body when it is moving through a fluid. Skin friction is directly affected by surface area of the solid, in this case, the balloon skin, and it also follows the drag equation, having its own coefficient of drag [1]. The coefficient of skin friction can be calculated by[2]:

$$C_f = \frac{\tau_\omega}{\frac{1}{2}\rho U_\infty^2} \qquad (1)$$

Where τ_ω is the local wall shear stress, ρ is the fluid density and U_∞^2 is the free-stream velocity. Since it follows the drag equation, the force of drag can be found by [3]:

$$F_D = \frac{1}{2}\rho v^2 C_d A \qquad (2)$$

Using estimated values of 0.04 for the drag coefficient of a lubricated rubber, 3 m/s for the speed of the balloon surface over the water, and assuming a radius of roughly 6 cm yields a surface area of .045 m^2, and a density of water of 1,000 kg/m^3, we obtain a drag force of approximately F_D = 8.1 N.

After the balloon is popped, the water seems to suspend itself almost perfectly in its spherical shape before spreading and falling to the ground. The water's surface tension is what allows this temporary holding of the spherical shape before is spreads apart, as can be seen below in Figure 3.

Figure 3 - Surface tension holding the spherical shape

Surface tension is defined as a cohesive force between molecules caused by residual electrostatic forces called Van der Waal forces [4]. Surface tension, γ, can be calculated by:

$$\gamma = \frac{F}{L} \quad (3)$$

where F is the force applied perpendicularly to the waters surface and L is the length over which the force is applied. In this case, the applied force would be gravity acting over the entire length of the balloon. From an engineering table, the surface tension of water is found to be roughly $\gamma = 0.0745$ N/m while interacting with air at 15°C [5].

The final force that is acting on the water is gravity. The downward force on the water is equivalent to $F = mg$, where m is the mass of the water, and g is the 9.8 m/s^2 pull of gravity. Using an estimated m of 0.9 kg calculated from the volume of water in the balloon and the density of water, the force from gravity is roughly 8.82 N, which explains why the gravitational pull overcame the water's surface tension.

III. Visualization Technique

Since the visualization of water falling from a popped water balloon against a distracting background, such as a sky, would be hard to see, an even white background was placed behind the balloons and food coloring was put in each balloon. Since it was quite overcast the day that filming was done, extra lighting was needed in order to allow the high-speed cameras to properly expose. The high-speed camera shutter operates so quickly, that they require even more light than normal cameras. In order to alleviate this, two large construction lights were used to illuminate the test set-up and can be seen in Figure 4.

Figure 4 - Experimental set-up and lighting

IV. Photographic Technique

In order to reduce the number of takes for the video, two high-speed cameras were utilized in order to record each shot at multiple frame rates and angles. The high-speed cameras used were Casio EX-ZR100s, which have the capability of up to a 1,000 frame per second capture rate. The quality of each video varies on the frame rate that it was taken at. During the video, three frame rates were used, 240, 480, and 1,000 fps. At 240 fps, the resolution is 432 × 320 pixels, 480 fps uses a resolution of 224 × 160 pixels, and 1,000 fps produces a quality of 224 × 64 pixels. Figure 5 shows a still frame taken at 1,000 fps; note the reduced quality since the quality decreases as frame rate increases.

Figure 5 - Experimental set-up and lighting

As can be seen from the tripod legs in Figure 4 one of the cameras was offset to the left of the setup, while the other camera was placed directly perpendicular to the set-up. Each camera was roughly five feet away from the setup, with the camera on the left using more of a wide angle, roughly 30mm zoom, and the centered camera used around a 100 mm zoom.

All of the video clips were assembled, trimmed, and published using iMovie 2011. Adjustments in brightness, contrast, and saturation were made to each clip in order to increase the visibility of the falling water against the background.

V. The High-Speed Video

Overall, the compilation of multiple high-speed video shots successfully demonstrated the intrinsic simplicity and beauty of the fluid after popping a water balloon. The use of high-speed video allowed the viewers to see much more than the human eye can see in real-time, such as the BB penetrating the balloon, the water hold its shape, and then finally disperse as it falls to the ground. This is something that one still picture can't quite capture.

My only regret is that during the shot with five balloons, the BB missed the fifth balloon, whereas it would have been perfect if all five were hit. Moving forward, I would love to repeat these experimental steps, except that I would like to use a .45 caliber pistol, due to its slow bullet velocity and large round, and I would like to do the filming with a Phantom high-speed camera for better quality. Since these cameras generally cost $3,000 per day to rent, it would be quite costly. However, with the materials and cameras available to me, I am very pleased with how the video demonstrated the fluid motion.

References

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