Jacob Christiansen
Assistance from Mark Chernyshov
University of Colorado Boulder
College of Arts & Sciences Undergraduate
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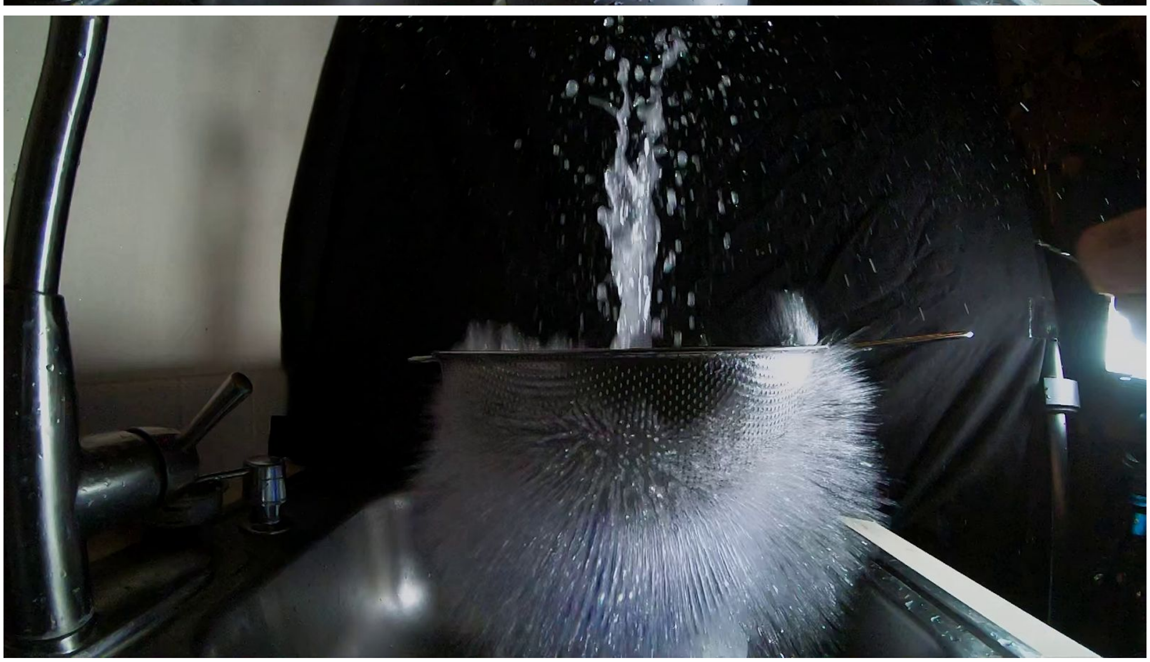
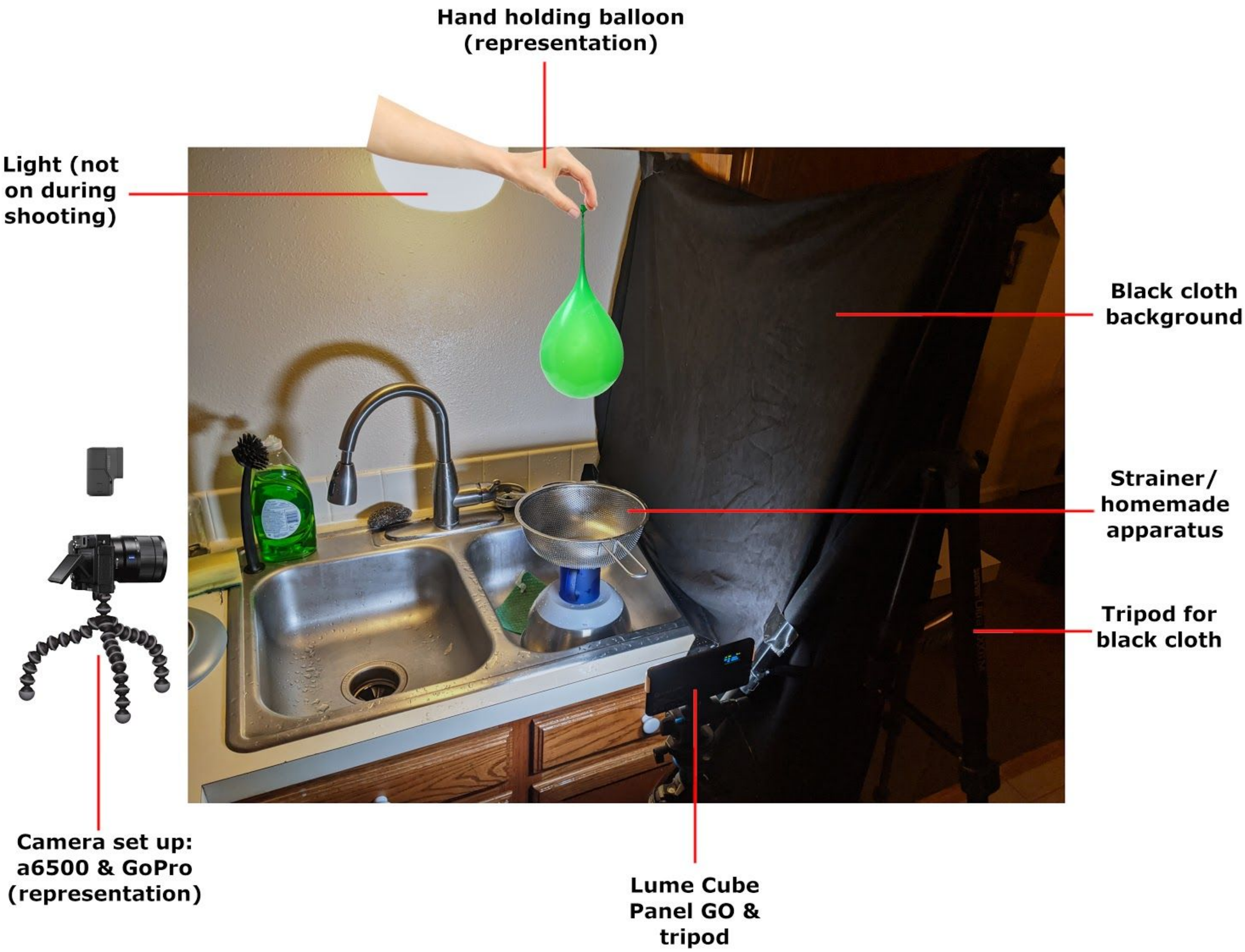
Flow Visualization: Water Balloons and Jets

The goal of this project was to capture the effects of balloons popping in slow-motion, as well as the jet properties of free falling liquid. The medium chosen for this project was tap water. The intended execution for this experiment was to record slow-motion video on one camera, but I instead opted to capture varying speeds at different resolutions, and using multiple cameras. The results of this experiment was this video: https://youtu.be/ZP2L1AZSVqw. Here are some stills for reference.





The set up for this experiment was relatively simple. Please refer to the diagram above. I used a metal strainer (approx. 6in tall, 12in diameter) sitting atop a mug & bowl, a one-directional lighting set up, coming from the right of frame (for highest contrast/detail), and black backdrop. The cameras were positioned ~36in from the edge of the strainer, attached to a small tripod. I held a balloon filled with tap water ~6in from the top of the strainer. My roommate **Mark Cherynshov** (markchernyshov.com) assisted me by penetrating the balloon with a needle.

As for the flow specifically, there's a couple things going on. The moment the balloon pops is when the flow begins. It's important to note that a balloon can pop in two different ways, opening regime (single break line) and fragmentation regime (multiple brake lines) (Ball, 2015). Our needle caused the balloon to have an opening regime, so our flow of water is relatively intact immediately after the pop. This is easy to see in the slow-motion footage, as the water still maintains the balloon's shape even after the pop. Then gravity comes into play, and the water falls relatively uniform until it hits the bottom of the strainer. What's so interesting about this experiment is the apparatus I used, specifically in how the stainer is set up. Normally, the water would fall through the strainer, with little splash-back or spread. But in the video, you can see the water "flowers" out in all directions, and even splashes back out of the strainer. This is because the bottom of the strainer, directly where the water lands, is blocked by the upside-down mug. When the water lands there, it instantly spreads out to the sides of the strainer, and then continues falling on top of itself. Combined with the tiny holes, and the gravitational forces acting upon the water, hundreds of small jets are created. The water coming out of the sides of the strainer are high-velocity jets, whereas the water coming out the top of the strainer are Worthington/Rayleigh jets (from the fluid colliding with itself). It is important to note that the water was cold, as temperature changes jet physics (Planinšič, 2011).

This experiment was aided visually by the use of a black backdrop, and one directional lighting. While the backdrop doesn't cover the entire frame, the goal was to showcase the detail in the falling water, which it does. Furthermore, the water coming out of the strainer is visually aided by the single light source. In terms of materials, the strainer was IKEA branded, and the balloons were actually generic brand condoms. This experiment can be reproduced with any type of balloon and strainer with similar results.

The lighting in this experiment was output from a Lume Cube Panel GO set to 100% power at 3500K. It was put on a tripod to the right of the frame, ~16in from the strainer. There was negligible practical/natural lighting from the surrounding environment.

Shooting this was a trial-and-error experience. With higher framerate comes lower quality and vice versa. I started by shooting on my mirrorless Sony a6500 at 120 FPS*, 1920x1080p. This is the first video shown, played back at 100% speed. Note that the framerate of the final video edit is 24FPS*, so frames are lost. However, the second video shown is the same shot slowed down to 20% speed, or 1/5th of real-time. Since 120 divided by 5 is 24 (the edit framerate), we see every frame the camera captured. Playing the shot at different framerates, back-to-back, is important. It allows the viewer to get a reference of how fast the flow was moving in real time, and see the detail of the flow in slow-motion.

The same principles apply to the third and forth videos shown. After capturing the flow on the a6500, I decided that the 1/5th of real-time wasn't slow enough, so I took out my GoPro Hero 6 Black. The Hero 6 has the capability of recording 240FPS*, double the a6500. However, the quality takes a hit since the sensor on the Hero 6 is much smaller, thus requiring more light and introducing more grain. Even though the resolution is the same, 1920x1080p, you can tell the difference between the two cameras. But I thought it was important to include an even slower video that showcases the movement of the flow more precisely. Again, I chose to show the videos back-to-back, in real-time, then at 1/10th of real-time (10% speed).

Additional Specs:

Sony a6500	GoPro Hero 6 Black
Narrow-Medium FoV (varied)	Wide FoV
~30in from nearest edge of strainer	~30in from nearest edge of strainer
Manual Focus	Infinity Focus
1/125 Shutter Speed	Auto Shutter Speed, avg. ~1/250.
1250 ISO (varied)	Auto ISO, avg. ~2400
f/3.5 Aperture (varied)	f/2.8 Aperture
24-50mm Zoom (varied)	N/A
Color grade: contrast boost, color temp shift (towards blue), and sharpness filter. Done to increase clarity and realistic depiction. Edited in Adobe Premiere Pro 2020.	Color grade: contrast boost, color temp shift (towards blue), and highlights decrease. Done to increase clarity and realistic depiction. Edited in Adobe Premiere Pro 2020.
Digital	Digital

**Note: All framerates follow NTSC standards. For example, when referring to 24FPS, I specifically mean 23.976FPS (aka, 24 - (24 * 1/1000)).*

Sony a6500 before/after:

GoPro Hero 6 Black before/after:

These videos revealed to me a lot of the physics behind this flow that I was unaware of, since I experience it in real-time. When slowing time down, you really can see how the liquid interacts with the strainer and itself in ways I didn't realize before. The biggest question that came up for me in this process is "How can I make this process better?", in terms of image quality. Specifically, I want to play around with different cameras and in future projects maybe capture video at higher framerates.

Works Cited

Ball, P. (2015). Two Modes of Balloon Bursting Revealed. Retrieved from https://physics.aps.org/articles/v8/105

Planinšič, G. (2011). Holes in a bottle filled with water: Which water-jet has the largest range? *European Physical Society*. Retrieved from https://cdn.ymaws.com/www.eps.org/resource/collection/016775D4-8888-474D-887F-3E33AEA5E6D0/EPSPED_MUSE_bot_holes.pdf