Air Tight: Team First Fall 2018

MCEN 4151

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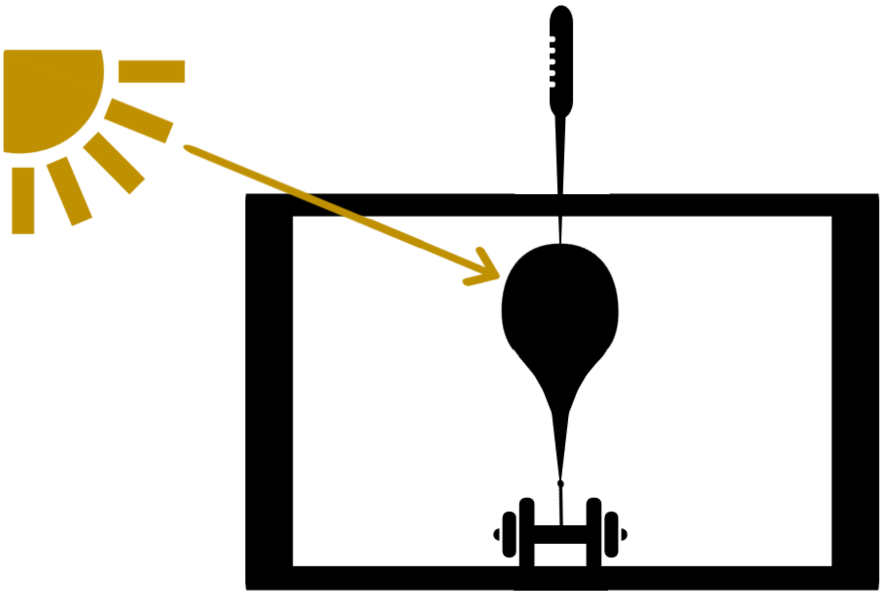
10/08/2018

For our first team shoot, we set out to capture an air balloon popping underwater in slow motion video using an iPhone 7. We brainstormed about visual effects of air and water and realized that air being released underwater is a unique phenomenon that would most likely reveal some fascinating physics. Joe Ryan provided us his house as a location for filming and transported the tank in which the experiment was done. Morgan and Ziwei aided in setting up the balloons and weights for the experiment as well as planning the lighting in the shot.



A 24” x 12” x 14” water tank was used to contain the experiment and a weight with a string attached was tied to the balloon to keep it submerged and resist its buoyancy force. An area of about 16” x 9” was kept in-frame to encompass the balloon and area above it in the shot while excluding the weight. As seen in the visual diagram above, a knife was held from above to puncture the submerged air balloon while sunlight came in from an angle (about 30 degrees from the vector orthogonal to the back of the tank). The balloon was about 8” tall and 5” wide, yielding an approximate volume of $V = \frac{4}{3}\pi r^3 = \frac{4}{3}\pi(0.0762m)^3 = 1.85 * 10^{-3}\ m^3$, where $r = 76.2mm = 0.0762m$. The buoyancy force is given by $B = \rho_f V g$ where ρ_f is the density of the fluid in which the object (air-filled balloon) is submerged $\rho_f = \rho_{H_20} = 997(\frac{kg}{m^3})$ [2]. Therefore, summing the forces in the y-direction (vertical), yields the tension force in the string [2]:

$$T = \rho_f Vg - \rho_{air} Vg = 9.81\left(\frac{m}{s^2}\right)(1.85 * 10^{-3}\ m^3) * \left(\left(997\frac{kg}{m^3}\right) - \left(1.225\frac{kg}{m^3}\right)\right) = 18.072\ N$$

Given that the balloon is resisting this force equally in the upward direction, the force on the air once released from the rubber shell is $F_a = T = m_{air} * a$. Thus, $a = T/m_{air} = \frac{18.072\ N}{\frac{1.225\ kg}{m^3} * 1.85 * 10^{-3} m^3} = 7.974 * 10^3 \frac{m}{s^2} = \frac{dv}{dt} = \frac{u}{1sec * \frac{30fps}{240fps}}$. Given this equation, we know that $u = 7.974 * 10^3 \frac{m}{s^2} * 1sec * \frac{30fps}{240fps} = 9.968 * 10^2 \frac{m}{s}$ which is the maximum velocity of the air in the water as the bubbles traveled upward for 1 second when the 240 fps footage was played back at 30 fps. From this value of u, we can calculate the Reynold's number given the characteristic diameter of about 6 inches = 0.152 m and the kinematic viscosity of air: $1.48 * 10^{-5} \frac{m^2}{s}$ [4].

$$Re = \frac{uD}{v} = \frac{\left(9.968 * 10^2 \frac{m}{s}\right)(0.152\ m)}{1.48 * 10^{-5} \frac{m^2}{s}} = 1.024 * 10\text{^}7$$

Since turbulent flow occurs for $Re > 3{,}000$, This aspect of the flow is turbulent and unstable [4]. This discovery makes sense as the fluid particles appear to be in a chaotic state in the video [1]. The wavy shapes on the boundary of air and water once the balloon is popped are formed from capillary waves reacting to the sudden relative movement of water falling in empty air due to the density differential between the two fluids [3]. The motion of these capillary waves in slow motion are fascinating and have a beautiful dynamic.

We used two drops of red food die in our final shot to enhance the motion of the water with respect to the air. Also, in shots not including the die, we utilized a white background (paper taped to the back of the tank) to show the contrast of the shadow in the fluid. The bright sunshine provided our lighting and came in at an angle about 30 degrees from the orthogonal vector to the surface of the back wall of the tank.

The field of view was narrow because we used the iPhone 7's wide aperture of f/1.8 which worked well since the autofocus of the camera locked onto the balloon. The camera was only about one foot from the subject. The lens has a focal length of 28mm allowing for close-up shots, and the automatic ISO adjusts well for bright shots and is optimized by tapping on the subject in the viewfinder. We shot in the slow-motion setting which provided a frame rate of 240 fps at resolution of 1280 x 720 pixels. The shutter speed was 1/480th to eliminate motion blur at 240 fps. Corel Video Studio was used to edit the clips spatially in time, however no color adjustments were made. The sequence of clips in the video was designed to represent symmetry and violence in natural forces. The mirroring effect was used as well as temporal effects, slowing and speeding up footage to reveal the sudden explosion of fluid motion.

I like how this video reveals the power of fluid potentials due to differences in density between air and water. The submerged balloon at first appears peaceful until violently punctured, giving way to an underwater explosion, inverting the relatable water balloon explosion. The effect of the film is disorienting and mysterious, adding to the mystery behind the natural forces contained in air and water and the buoyant force of air contained in a membrane. I wonder what the effect would be if we used a higher-speed camera and better caught the appearance of capillary waves on the balloons' vanishing surface. We fulfilled our intent of capturing an inverted water balloon explosion scenario but would like to further develop this project by using higher frame rates and better capturing the capillary physics at the air-water interface.

References

[1] Abramson, H.N. "The Dynamic Behavior of Liquids in Moving Containers." NASA SP-106, 1966.

[2] Acott, Chris (1999). "The diving "Law-ers": A brief resume of their lives". South Pacific Underwater Medicine Society journal. 29 (1). ISSN 0813-1988. OCLC 16986801. Archived from the original on 2 April 2011. Retrieved 13 June 2009.

[3] "Floater clustering in a standing wave: Capillarity effects drive hydrophilic or hydrophobic particles to congregate at specific points on a wave" (PDF). 23 June 2005. Archived (PDF) from the original on 21 July 2011.

[4] "Reynolds Number". www.grc.nasa.gov.