Team 1 Image Report

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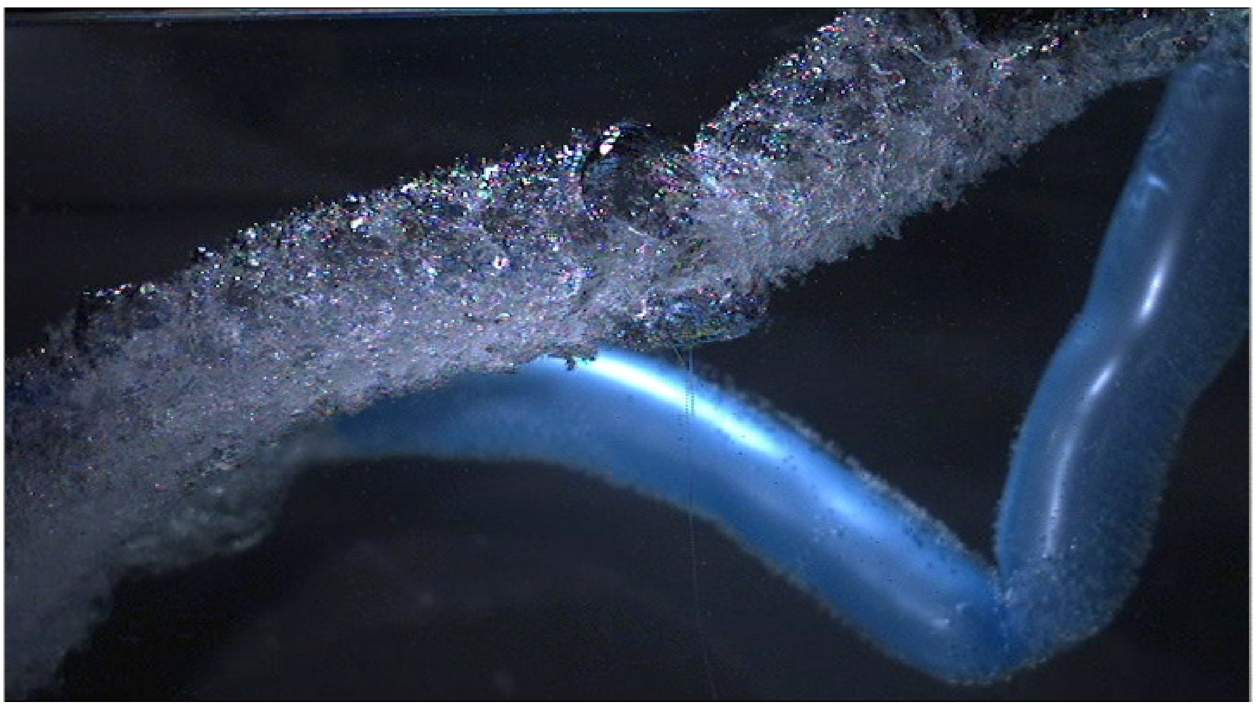

The purpose of this image was to test the limits of high speed flow visualization and discover how time resolved a momentary event could become. Various events that happen within less than a tenth of a second were brainstormed such as instantaneous chemical reactions, spraying flammable materials, or smashing paintballs. Finally, underwater balloon popping was chosen since it is a unique phenomenon without much documentation. The first attempt involved popping a small air filled water balloon underwater, but the video was out of focus and the popping uninteresting. This attempt was done more as test trial to ensure all equipment and test specimens were working as expected. The second balloon pop was done by a long balloon animal balloon where the pop was expected to start on one end and propagate underwater to the opposing end. The final video was perfectly captured and modified to take its final form.

The setup of this flow visualization experiment involved a ten gallon glass fish tank filled with water to the rim, a sharp needle, fishing line, weights, and several types of long balloon animal balloons (referred to as balloons from here forward). The balloon was filled to its full length and placed in the tank filled with water. The balloon was tethered down below the surface at several lengths to bottom of the tank by fishing lines connect to weights. A diagram of the setup is shown in figure 1. The balloon was popped on the foreground end above water and the resulting pressure explosion was filmed.

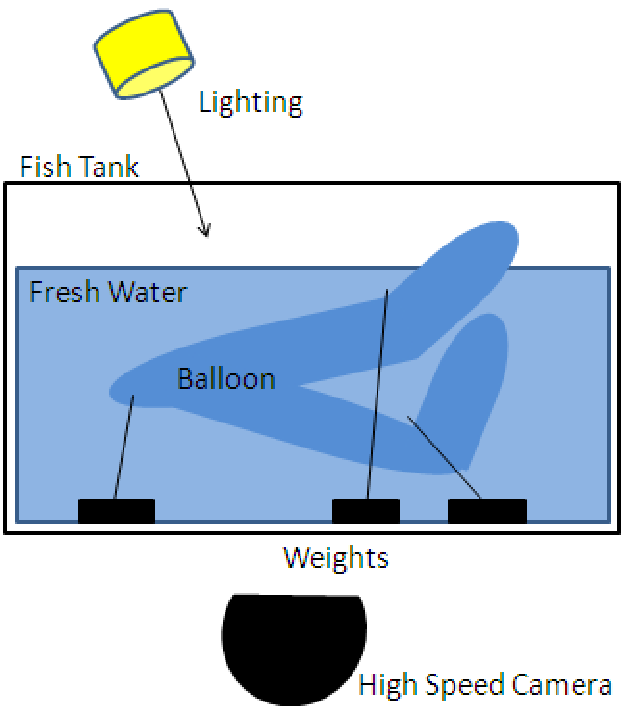

Figure 1: Setup diagram

There are two main types of physics at work in this problem. The rough surface of the revealed bubble is caused by turbulence induced by the high speed of the impulsively started rubber surface surrounding it. Additionally, later in the film a segmented part of the balloon in the background continues to release air in an unsteady jet until finally exhausting itself. Each of these flow phenomenons will be explained individually.

As the balloon retracts, the surface of the resulting bubble is looks very rough and textured. This is because the rapid retraction of the surface separating the air from the water has left a turbulent gas/liquid interface. Many studies have taken place examining the effect of an impulsively started plate since it is one of the few flows in which the Navier-Stokes equation can be solved analytically[1]. The effect from this action can be seen in figure 2 if the flow was laminar where the shear forces dominate the flow. However, in this case the rubber skin is moving too fast to leave the Reynolds number in the laminar realm. It is difficult to assign a hard Reynolds number to the flow seen here since it is hard to determine a characteristic length scale. The full length of the skin is constantly changing and has different values in each direction. The length scale was chosen to be the diameter of the balloon at 5.08 cm. This length value combined with the 50 m/s skin retraction velocity as taken from the high speed video gives a Reynolds number in the following form:

$$Re = \frac{UD}{\nu}$$

$$Re_{water} = \frac{\left(50\,\frac{m}{s}\right)(0.0508\,m)}{1.004 \times 10^{-6}\,\frac{m^2}{s}} = 2{,}529{,}880$$

$$Re_{air} = \frac{\left(50\,\frac{m}{s}\right)(0.0508\,m)}{15.68 \times 10^{-6}\,\frac{m^2}{s}} = 161{,}990$$

This puts the flow immediately next to the rubber skin above the critical Reynolds number and into the turbulent regime causing the flow at the surface interface to look more like the flow that is depicted in figure 3. A numerical simulation of this effect found, “the development of a number of centers of vorticity along the primary separating shear layer.”[2] These centers of vorticity are another key characteristic of turbulence. This turbulence is what causes the surface of the initial bubble to look rough. Once the flow slows down the bubble takes on a smooth surface as is normally expected.

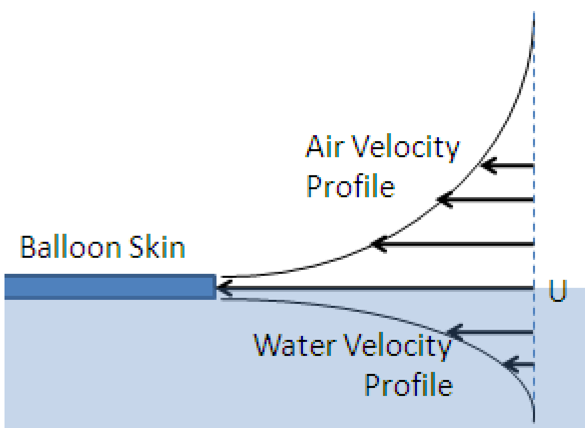

Figure 2: Laminar flow from impulsively started plate

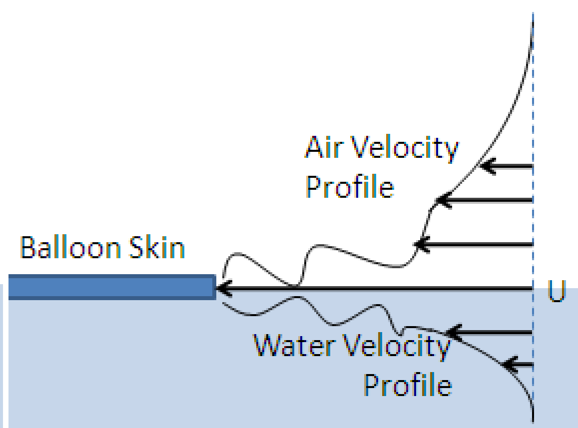

Figure 3: Turbulent flow

The final flow feature that is observed is the unsteady jet of air that is streaming out of an untorn region in the background balloon. Since much of the air is already turbulent, the jet from the balloon seems to pulse as it finally expends itself. This fluctuating jet flow was studied in depth in an experiment conducted by D. Olivari. The experiment found that though the nozzle of the jet was undergoing extensive perturbations, there was only a minimal increase in mixing with the surrounding fluid[3]. This explains why the bubble stays relatively whole exiting the jet and doesn’t break into a mass of tiny bubbles.

The visualization technique used in this experiment was basic boundary visualization. The interface between the air and the water was made clear against the black background when the balloon rubber was sheared back. The air then became bubbles that could clearly be seen rising towards the surface. Extensive lighting was required for this experiment since the shutter speed was so fast. Two bright lights were positioned directly above the tank to shine down on the submerged balloon below.

The camera used to capture this video was a Vision Research Phantom digital high speed video camera. The original video was shot at 20,000 frames per second (fps). This rate was chosen to fully time resolve the tearing back of the rubber and visualize the bubbles slowly rising. A lower resolution of 640x480 pixels was required since the shutter time was only 1/20,000th of a second. The balloon centered in the video is approximately 12 inches in length when bent in this orientation. The camera was set on a tripod approximately 1 foot away from the side of the tank. The editable version of the video was played back and saved at 20 frames a second. The video was edited using Adobe Premiere to speed up and slow down the original footage. The video was run forward at 25% of the recording speed, and then reversed at -50% recording speed. The full sequence was then set to run through at 500% speed to show the bubbles rising to the surface.

This video clearly reveals the mystery that is usually faster that human eye can see. Since a balloon pop is so momentary, the common observer would assume it was instantaneous. This video clearly shows otherwise demonstrating that the popping sequence in this case involved a tearing of the rubber down one side followed by a release of air through a jet created by an untorn region of the balloon. The sequence is very appealing to the eye and would be even more enhanced by accompanying music that is currently in production. It would be interesting to do a full series of these pops or to try a similar balloon with a set of twisted kinks in it. If the high speed camera used in the video becomes available again in the future there is a large variety of balloon popping phenomenon that could be tested.

REFERENCES:

[1]M. G. Hall, “The boundary layer over an impulsively started flat plate,” Proc. Roy. Soc. 310, pp401-414 (1969).

[2]P. Koumoutsakos and D. Shiels, “Simulations of the viscous flow normal to an impulsively started and uniformly accelerated flat plate,” Journal of Fluid Mechanics, vol 328, pp. 177-227 (1996).

[3]D. Olivari, “Analysis of an axisymmetrical turbulent pulsating Jet,” Von Karmen Institute for Fluid Mechanics, Technical Note 104, (1974).