Team Project 1[1]

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A high speed camera was used to examine the behavior of various fluids upon their release from the confines of a balloon. The fluid discussed in this paper is simply water that has been dyed with blue food coloring; the fluid was released from the balloon with the use of a pin which popped the balloon from the bottom, out of the camera frame of view. Upon the application of the pin, the balloon quickly recedes from the surface of the water and the water momentarily remains in the balloon shape before gravity takes over and the water "splashes" to the floor.

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Images were created in order to observe the behavior of fluids released from a balloon when that balloon is popped. A high speed camera was used in order to allow a more in-depth of the observation of the extremely fast process. The videos generated with the high speed camera enables us to observe how the fluid flows downward under the force of gravity after the tension of the balloon, which originally held it in place, is released. The use of different liquids, such as honey and ketchup, also helps demonstrate how the differing properties of various fluids, namely viscosity, can affect how the fluid behaves under the influence of an applied body force.

The setup of the actual fluid "flow" process is quite simple. For the balloon in question, a small water balloon was filled with water and then a few drops of food coloring were added. As much air as possible was released from the balloon but the process of tying the balloon always resulted in a small bubble of air trapped inside. The prepared balloons were placed on a small roll of electrical tape, the empty circular center of the roll acting surprisingly well as a way to keep the balloon steady. The balloon and tape setup was placed on a cooling rack above a large Rubbermade container. The screen of the cooling rack allowed the released fluids to flow down and out of the field of view; the Rubbermade below the cooling rake captured the released fluids to prevent any mess and make cleanup exceedingly easy. This balloon setup was illuminated with two 500W halogen work lamps on one side and four 500W halogen work lamps on the other and photographed from the front as seen in the schematic in figure 1.

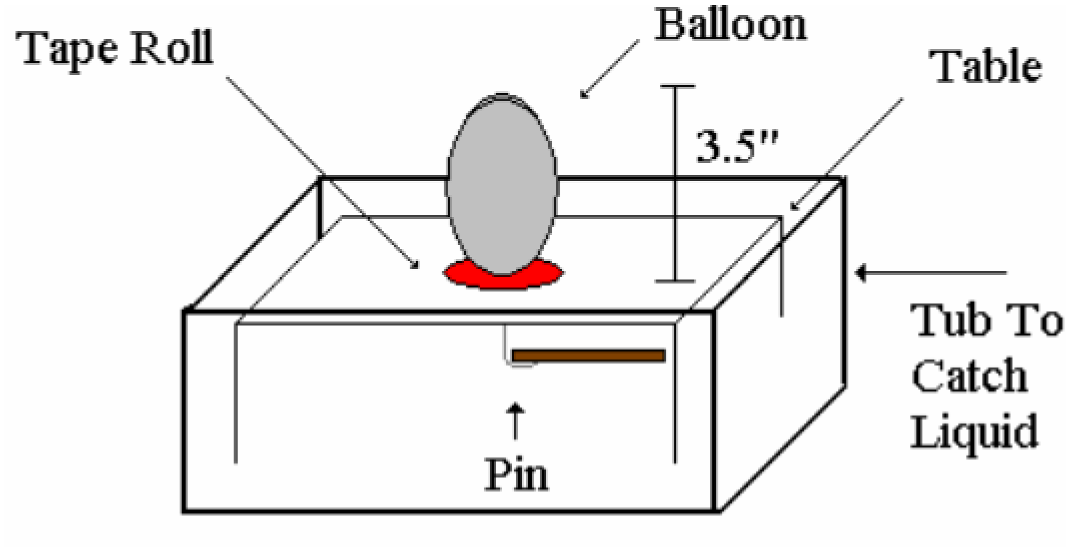

Figure 1: Schematic of balloon setup

There are two main physics issues that can be observed in the slow motion video. The first, more simple, physics interaction is the quasi-equilibrium of the balloon before it is popped. The tensile forces generated in the balloon as it is stretched are equal and opposite to the sum of the water reaction forces and the gravitational body forces exerted on the water in the balloon.

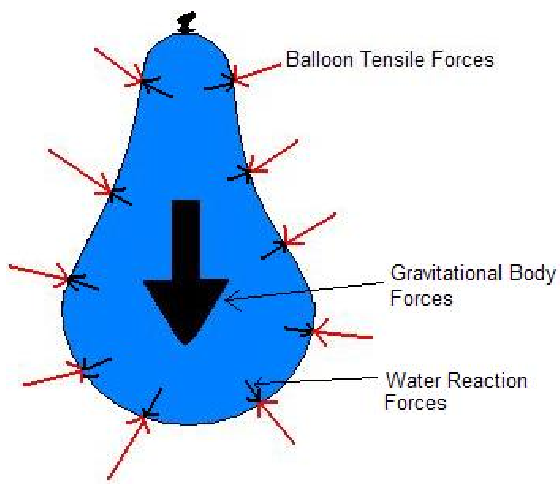

Figure 2: Force balance diagram for un-popped balloon.

This balanced state is referred to as quasi-equilibrium, rather than full equilibrium, because only a small change in state causes equilibrium to be lost and dynamic behavior to occur. In this case, the small state change is a reduction in balloon tensile forces due to a tear generated in the balloon by the application of a pin.

The second portion of physics that needs to be explained is the behavior of the water once it is released from the balloon. For the most part, the motion of the fluid is governed by the effects of gravity; upon the popping of the balloon, the water no longer has the balloon to hold it above the ground. Therefore, the water begins to accelerate under the force of gravity. This seems quite simple but there is, however, another phenomenon occurring as the fluid falls. If one watches the video of the collapsing fluid, it appears that the upper portion of the falling fluid has a shape that looks like the crater of a volcano.

This central crater exists due to the small amount of air still trapped in the balloon when it is tied. The tensile forces exerted by the balloon means that this air is pressurized higher than the air outside of the balloon. Therefore, when the balloon is popped, this small piece of pressurized air exerts an impulse force upon the top portion of the water in the balloon. The force is referred to as an impulse force because it is only exerted for an instant (Engineering Mechanics Dynamics by Meriam and Kraige). The pressurized air very quickly returns to the normal atmospheric pressure and therefore exerts no more pressure on the top portion of the fluid than is exerted anywhere else on the fluid. We still observe the crater shape, however, because during the tiny instant that the pressurized air exerts force on the upper portion of fluid, that fluid accelerates just a little bit faster than the fluid below which only feels a gravitational force. Thus, this top portion of fluid falls faster and burrows the deep center of the crater, forcing the slower fluid outward and as it is falling slower, it is soon above the fast fluid and we see our lovely crater shape. Interestingly, this crater formation is not observed when there is no air present in the balloon. This is most easily seen with fluids such as honey and ketchup which are more viscous and therefore do not try to spray out of the balloon as one attempts to release the last bit of air prior to tying.

Although it may not be readily apparent, the visualization technique utilized is boundary marking. The boundary that exists between the two fluids present, air and water, is quite readily observed (especially upon the addition of the blue dye) but the behavior on either side of the boundary is either obscured, as is the case for water, or simply cannot be seen without the addition of particles, as is the case for air. The lighting used was three sets of halogen work lights. Each set consists of two 500W bulbs spaced six inches apart. One set of lights was placed on the left side of the field of view, approximately three feet from the balloon; the other two sets were placed next to each other on the right side field of view, again three feet from the balloon.

The camera was placed on a tripod approximately four feet from the front of the balloon. The camera was an I-speed high video system with a Nikon 28-35mm lens attached. The lens was set at an aperture of f/3.8 and zoomed to the 35mm setting, resulting in a field of view approximately one foot square. The camera was set at 500fps and the video playback speed is 10fps. The video was processed using Windows Movie Maker with the intent brightening the image. For that reason, the video was brightened slightly; also, the length of the video was reduced.

The final videos generated for this project are quite exciting; when going into this project, our team was not entirely confident that we could generate sufficiently detailed images of the popping balloons because of the high speed nature of the process. The final videos provide direct evidence of the effectiveness of the high speed camera, the popping of the balloon is so clearly visualized that in certain videos it is possible to observe the torn balloon flying through the field of view. The only major drawback of the videos is the low light; when shooting at 500fps it is necessary to have an enormous amount of light in order to have a bright video. Despite the use of 3000W of light our video is still quite dark; perhaps in the future the high speed camera must be used out in the sunlight because it does not seem to be possible to efficiently generate enough artificial light to create good videos.