Team First Project: Toroidal Bubble
MCEN4151: Flow Visualization
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This video is a submission for the first team assignment in MCEN4151 Flow Visualization at the University of Colorado, Boulder. The intent of this attempt was to capture a toroidal bubble leapfrog effect. After many attempts, it was realized that the leapfrog effect was very difficult to create. This video captured a single toroidal bubble rising from 14' below the surface of a pool. The bubble was produced by a swimmer's mouth and the video was recorded with a camera in the swimmer's hand. William Vennard and Ian Durkin were taking pictures with other camcorders, though those pictures will not be analyzed in this report. The set up as well as the camcorder settings will be spoken of later in this report.

The apparatus used to create this bubble ring was a swimmer's mouth. To create the bubble, his tongue was held between his lips with air held in his cheeks. Then, quickly, his tongue was pulled into his mouth. This started the poloidal spin of the bubble exiting his mouth.

The bubble travels upward as it left his mouth. This motion is driven by buoyancy and self-induction. The air occupied a volume submerged under water. This caused an upward force exerted on the bubble that is equal to the weight of the volume of air plus the mass of air multiplied by acceleration.[1] The buoyant force is depicted and derived in Figure 1 and Derivation 1, respectively.

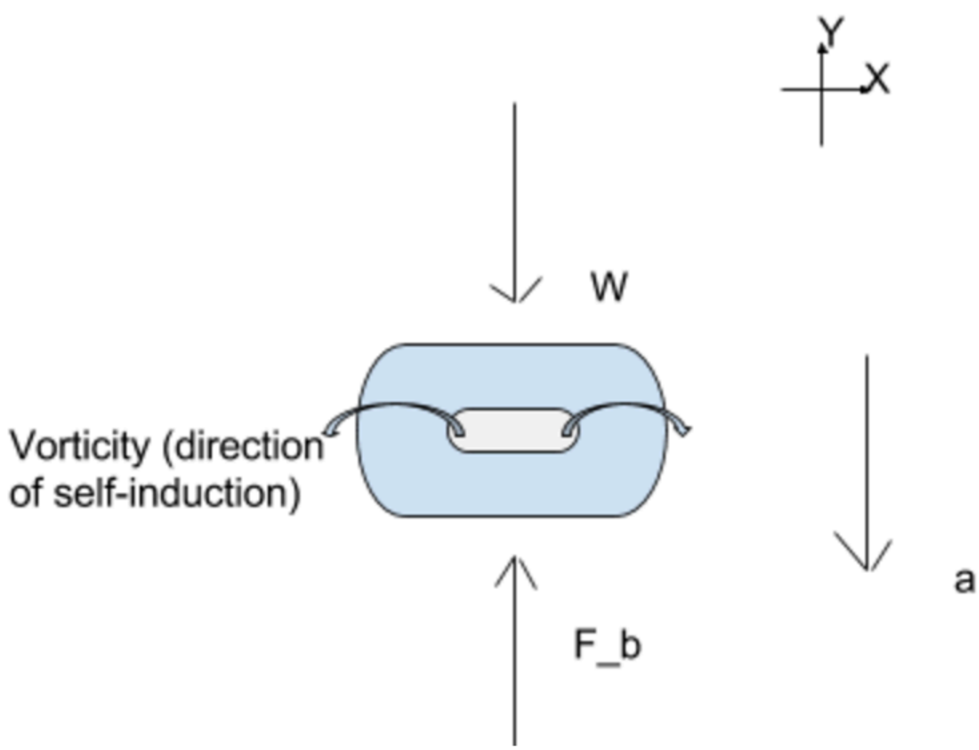

Figure 1: Diagram of forces and vorticity of toroidal bubble

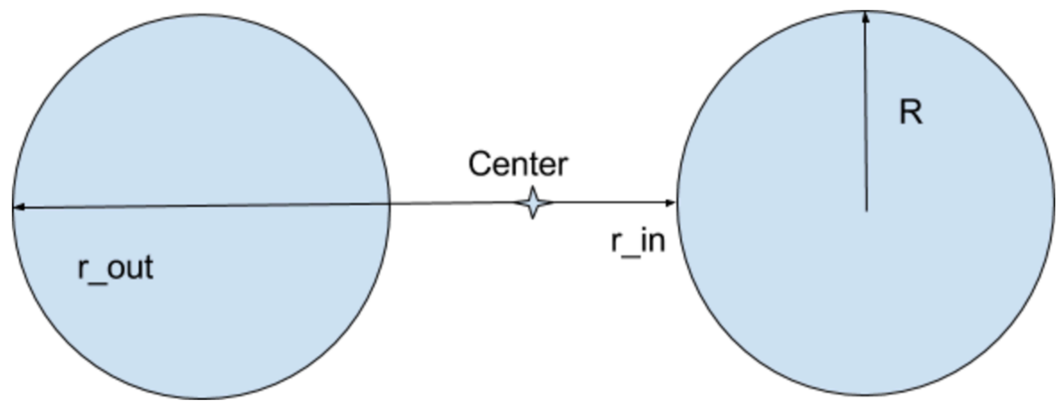

Figure 2: Cross section view of toroidal bubble

Derivation 1: The derivation of the buoyant force on the toroidal bubble

Sum of forces on ring in Y: $\Sigma F = F_b - W = m_{air}a$

Weight of air in bubble: $W = m_{air}g$

Buoyant force: $F_b = m_{air}(a + g)$

Diameter of cross section: $2R = r_{out} - r_{in}$

Circumference of top view: $C = 2\pi(r_{in} + R)$

Volume of air in bubble: $V = \pi R^2 C$

Now solving for F_b: $W = V\delta$

$$m_{air} = \frac{V\delta}{g}$$

$$F_b = \frac{V\delta}{g}(a + g)$$

Where r_{in} ~= 0.33m (distance from center to inner surface), r_{out} ~= 0.38 (distance from center to outside surface), R is the radius of the cross section of the bubble, V = 0.004 m^3 (volume of air), delta = 1.165 kg/m^3 (density of air), g = 9.8 m/s^2 (acceleration due to gravity), and a = -2 m/s^2 (approximation of acceleration of the bubble). The acceleration was negative because the bubble slowed as the radii increased. Plugging these values in yields

$$F_b \sim= 0.004 \text{ N } **$$

**Though the buoyant force changes as the bubble accelerates. This is a good approximation of the magnitude of buoyant force at the time the parameters were as defined above.

Self-induction is defined in the 2015 Vortex Dynamics lecture notes for this course. It is said, “Self-induction: each part of the ring tries to get the rest of the ring to rotate around it. Net result: every part of the ring moves forward the same.”[2] Forward is defined as the direction in which the vortex ring was projected. In this case, the toroidal bubble was projected upward in the same direction as the buoyant force.

As the bubble ring travelled to the surface, it began to break into a ring of spherical bubbles, shown in Figure 3. Though many sources suggested this is due to the Rayleigh-Plateau instability, no source was found that explains this phenomenon explicitly. The Rayleigh-Plateau instability describes why a falling stream of fluid perturbs and breaks into smaller globules.[3] This is a decent approximation of the phenomena because many infinitely small linear sections of the air make up the toroid shape. The toroid physics can then be approximated by the physics that governs streams of fluids, as discussed in Rayleigh-Plateau instability. Toroidal bubble physics calculations are beyond the scope of this class. The forces considered on the object though are a good calculation topic, as shown above.

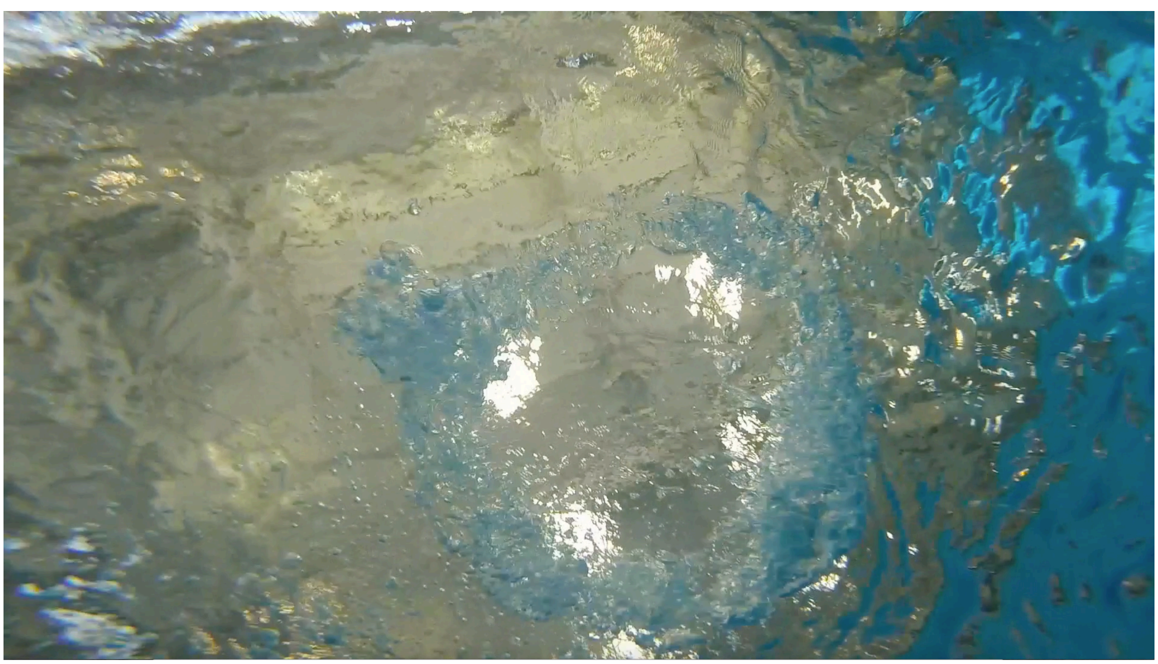

Figure 3: Laminar toroidal bubble perturbs and breaks into spherical bubbles following the same toroidal vortex

The pool the video was taken in is a dive well. That said, the temperature of the water was slightly higher than a typical swimming pool—around 85°-88°F. The ceiling of the indoor pool deck was white with large fluorescent bulbs, which provided a fairly bright background. The bubble was blown at approximately 14' deep. The camera was never farther than 15" from the bubble as it rose to the surface. This was done to obtain the optimal image while shooting with a wide-angle camera. All lighting came from above the object though the white bottom of the dive well provided reflected light from behind the point of view of the camera.

The frame size chosen for this image was GoPro's "normal view" setting (vertical field of view 72.2˚, horizontal field of view 94.4˚, diagonal field of view 115.7˚). This still provided a very wide angle. The only other option with this camera was the "SuperView" setting which would have created too large of a field of view and made the subject look too small (vertical field of view 94.4˚, horizontal field of view 122.6˚, diagonal field of view 149.2˚). As mentioned before, the camera was never more than 15" behind the bubble as it rose to the surface of the pool. This ensured the bubble stayed in the frame and ensured that the camcorder would capture as much close up detail of the fluid flow as possible. The GoPro is a handheld digital camcorder. The underwater casing was used and pushed past to its depth limit of 3 meters, though the case did not fail. The GoPro used for this video was a Hero3+. The video was captured in 960p at 100 frames per second. The ISO was set to 1600. These settings created the highest quality of a video that could be captured with this camera in this application. The video was slowed down to 15 frames per second. No other editing was done.

The video reveals the toroidal bubble phenomena. I like that both the laminar and turbulent flow of the bubble were captured in the video. The lighting was also fairly ideal in that the camera captured much of the information necessary to depict the phenomena appropriately for a scientific discussion, such as this, to be had. I do not like that the image is slightly blurry. With a better camera, such as some of the new GoPro models, a clearer image could have been captured. Though the intent was to capture a leapfrog effect with two toroidal bubbles, the fluid physics was still captured very well and made for a technical discussion. I am happy that I was able to capture the phenomena of a toroidal bubble at all. If I were to recreate the video I would do it in a shallower pool. The depth of the dive well made it fairly difficult to blow as clear of bubbles as done in say a 6' deep pool.

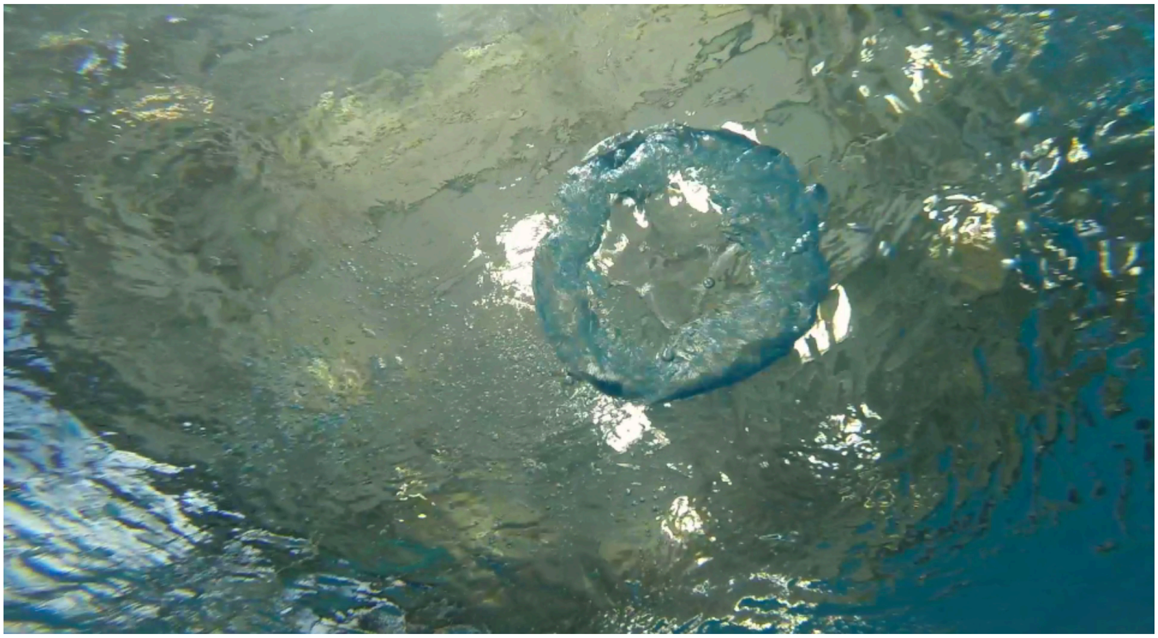

Figure 4: Screenshot of toroidal bubble in video just before it separates to spherical bubbles. Link to video: https://vimeo.com/144779236

Works Cited

1. *Bouyant Force - Archimede's Principle*. Western Washington University. Web. 3 Nov.

2. 2015. Hertzberg, Jean. "Vortex Dynamics." MCEN4151.

3. "Lecture 5: Fluid Jets." Massachussetts Institute of Technology.