

Team 3: Vortex Rings

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Introduction:

The purpose of this assignments photos and videos were to capture the characteristics of vortex rings that are formed in water. The interest was not only based in how they are formed and travel in a fluid but also how they behave when they collide with one another.

Image Background and set up:

In order to produce these vortex rings in water an apparatus was made that could generate a consistent vortex ring. A modified acrylic box would produce these rings with a circular cut out on one of its faces. The general set up of this box is shown in diagram 1. From this image we can see that on the end opposite of the circular cut out there is a balloon that used to cover the other end, this would allow for the die inside of the box to be ejected out and form the vortex rings. [The formation of the rings will be discussed later] Applying a force on the balloon side of the box generated the rings. Varying the rate and amount of pressure added could control the size and speed of the rings.

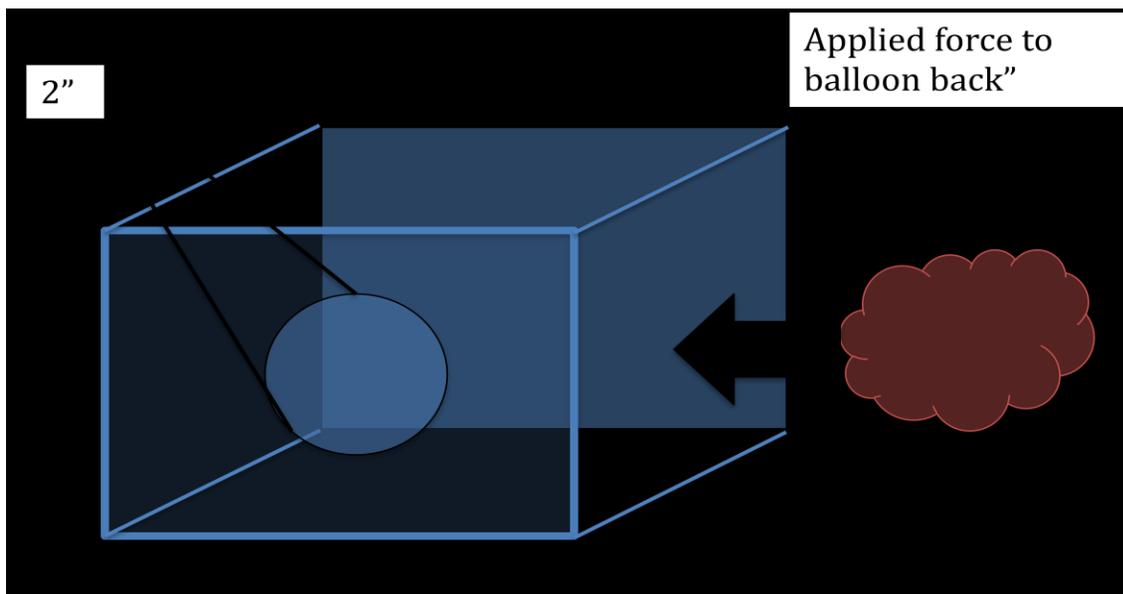


Diagram: 1

The 'Vortex' generators where the first step in the set up for this experiment, the next step was to submerge the generators and fill them with die. In order to produce these rings a 50-gallon glass fish tank and filled half way with water. [The water was approximately 20C] The vortex generators were then partially filled with water and then submerged in the water, this process is very delicate as any spilling of the die would contaminate the rest of the water and make it difficult to see the rings. In diagram 2 there is a picture that shows the general set up of the apparatus that was used to generate the vortex rings and collisions. The collisions were produced by having two people on either side of the tank activating the generators with their hands at the same time. This would produce the collisions, however it was very difficult to get to rings that were identical, thus the colliding rings often formed oblique collisions.

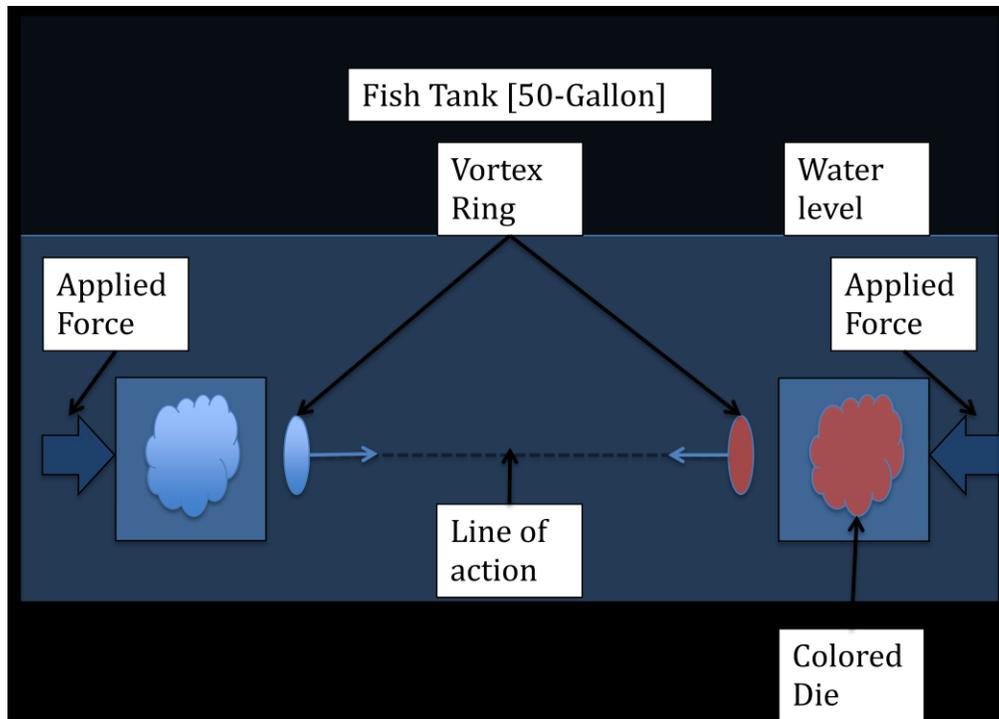


Diagram: 2

In diagram 3 we can see a top view of our set up, this displays how we had the lighting setup as well as the field of view for most of the picture and videos shown.

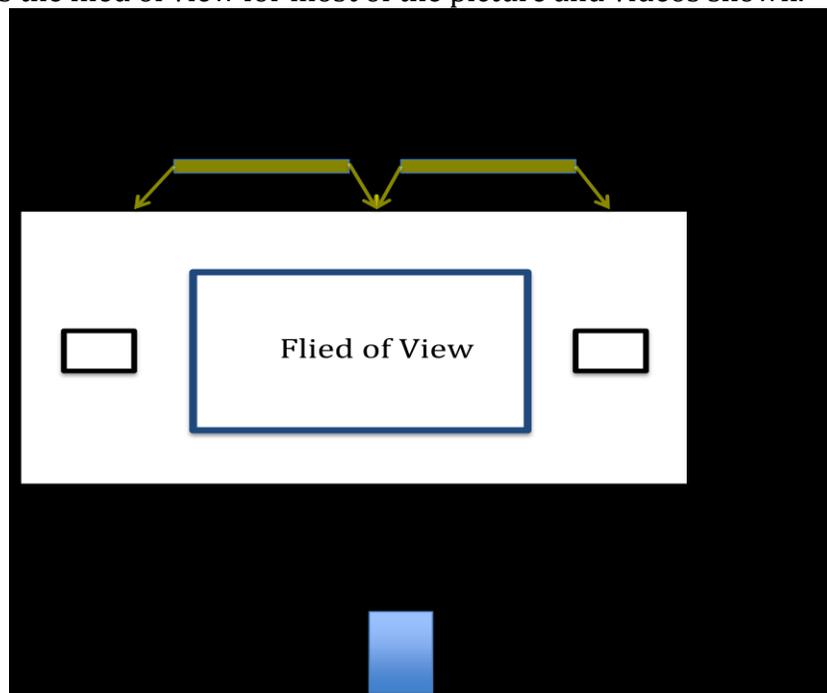


Diagram: 3

Physical Information

Vortex rings have long been an object of fascination for physicists and common people alike. A vortex ring is, as it may seem, a ring of vortices. A cross sectional view of a vortex ring would look like this:

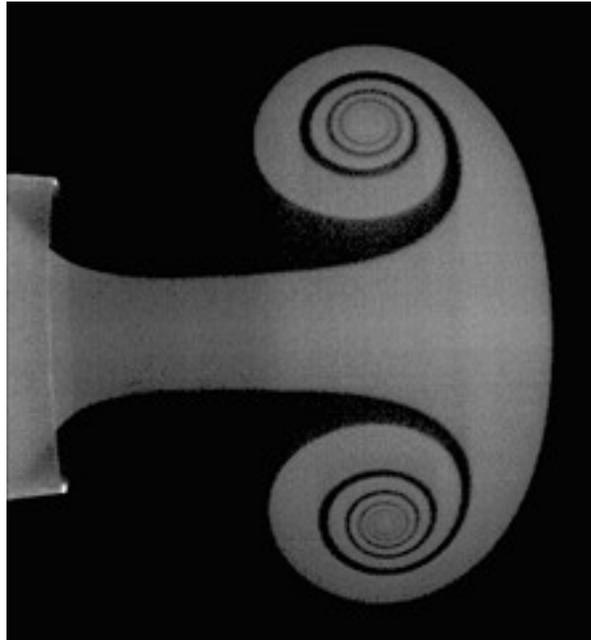


Figure 1: Cross-section of vortex ring formation^[1]

The rings created in this experiment were created using small “bursts” as described in the **Image Background and Setup**. The vortex rings in these images and videos were created due to the frictional force between the edges of the box opening and the dyed fluid. As the dyed fluid leaves the box, the fluid near the edges of the box is slowed due to an effect known as the boundary layer. As the fluid at the outside moves slower than the fluid at the inside, the fluid begins to recirculate^[2]. This recirculation occurs around a region of the ring called the vortex core.

So, how does the vortex move so easily through the fluid? Again the motion is a result of friction. One can imagine the recirculating fluid in the ring to be similar to a common wheel. This concept is described visually in Figure 2. As the dyed fluid recirculates, there is a frictional force between the dyed fluid and the stationary fluid. This force “pulls” the ring through the stationary fluid^[2]. This form of motion leads to the often surreal imaging of vortex rings.



Figure 2: Vortex ring motion explained

Calculation of Reynold's Number

Based on the time it took for the vortex ring to travel across the tank we can estimate the speed of the ring to be 0.25m/s, and the fluid properties of water to be taken at standard conditions. The diameter of the ring is used in this relationship as well to define the characteristic length. This will then yield a Reynolds number of approximately 12,300 suggesting that we have turbulent flow. This make sense that we would have turbulent flow as we can see in the selected image there is a lot of disturbances in the die inside of the ring.

$$Re = \frac{\rho V L_c}{\mu}$$

$$Re = \frac{988 \left(\frac{kg}{m^3} \right) 0.25 \left(\frac{m}{s} \right) 0.05m}{1.002 \times 10^{-3} \left(\frac{Ns}{m^2} \right)}$$

$$Re = 12325.349$$

Calculation of Motion Blur

The shutter speed of the still image was 1/200s. The rings were estimated to move across the tank at .25 m/s. This speed was based on observations that the rings would travel across the entire fish tank in 4-5 seconds. The tank was approximately 1 m long. Thus, in 1/200s the ring moved:

$$\left(\frac{1}{200} s\right) \left(.25 \frac{m}{s}\right) = (.00125m) = .125cm$$

The camera field of view was approximately 1/3 the fish tank, or 34cm. This means that the image blur was:

$$(.125cm) \left(\frac{4272px}{34cm}\right) \approx 16px$$

Photographic Information

Stills:

Camera: Canon EOS Digital Rebel XSi
Shutter Speed: 1/200s
Aperture: f/9
ISO: 1600
Focal Length: 40mm
Original Dimensions [X,Y] px: [4272, 2848]
Final Dimensions [X,Y] px: [5814, 1904]

Video:

Camera: JVC Everio GZ-MS130
Image Dimensions [X,Y] px: [720,480]

Post-Processing

The still image was processed using Adobe Photoshop CS4. The image layer was first duplicated. The duplicated layer was set to blending mode overlay and opacity 40%. This had the effect of increasing the contrast and “pop” of the image. The levels were then adjusted slightly to whiten the background. The canvas width was then doubled. The image was duplicated and mirrored. The original and final submitted images can be seen below.

The videos were edited using Adobe Premiere Pro CS4. This program allowed the team to slow down and reverse the video as desired. The first video showed a single collision at

50% speed. The same collision was then played at -50% (backwards, half speed). The sound of a passing motorcycle was placed with the moving vortex rings. An explosion was used for the collision. Then a cymbal strike in reverse was used when the video began playing back in reverse.

The second video utilized the same backwards cymbal but different “zooming” sounds. In addition the second video showed three collisions. Two collisions were nearly concentric while one was ~1” off-center. The clips in the second video were slowed to 50% speed.

Recommendations for Duplicating the Experiment

The team set-up this experiment 4 times before acquiring high quality photographs. The use of a fish tank and dyed water created great contrast. Unfortunately, this set up also led to murky water. After only 5-6 rings had traveled across the tank the images were no longer coherent. Running the experiment in a tank where a cross-flow is possible to clean the water would be ideal. Also, larger rings would be easier to photograph.

References

1. “Fluid Entrainment by Vortex Rings”. Mech. Engineering SMU. 4/29/2010. <<http://lyle.smu.edu/~pkrueger/vrentrainment.htm>>
2. "Science." ZeroToys.com. 4/22/2010 <<http://www.zerotoys.com/shtml/science.shtml>>.
3. “Vortex Ring”. En.Wikipedia.org/wiki/Vortex_ring. 4.29.2010.
4. *Chapter 4: Vortex Ring Formation. Vortex Rings. Akhmetov. pp. 89-103.*

Images Not Submitted

There were several visually interesting images that were not submitted. Those images are included here:

