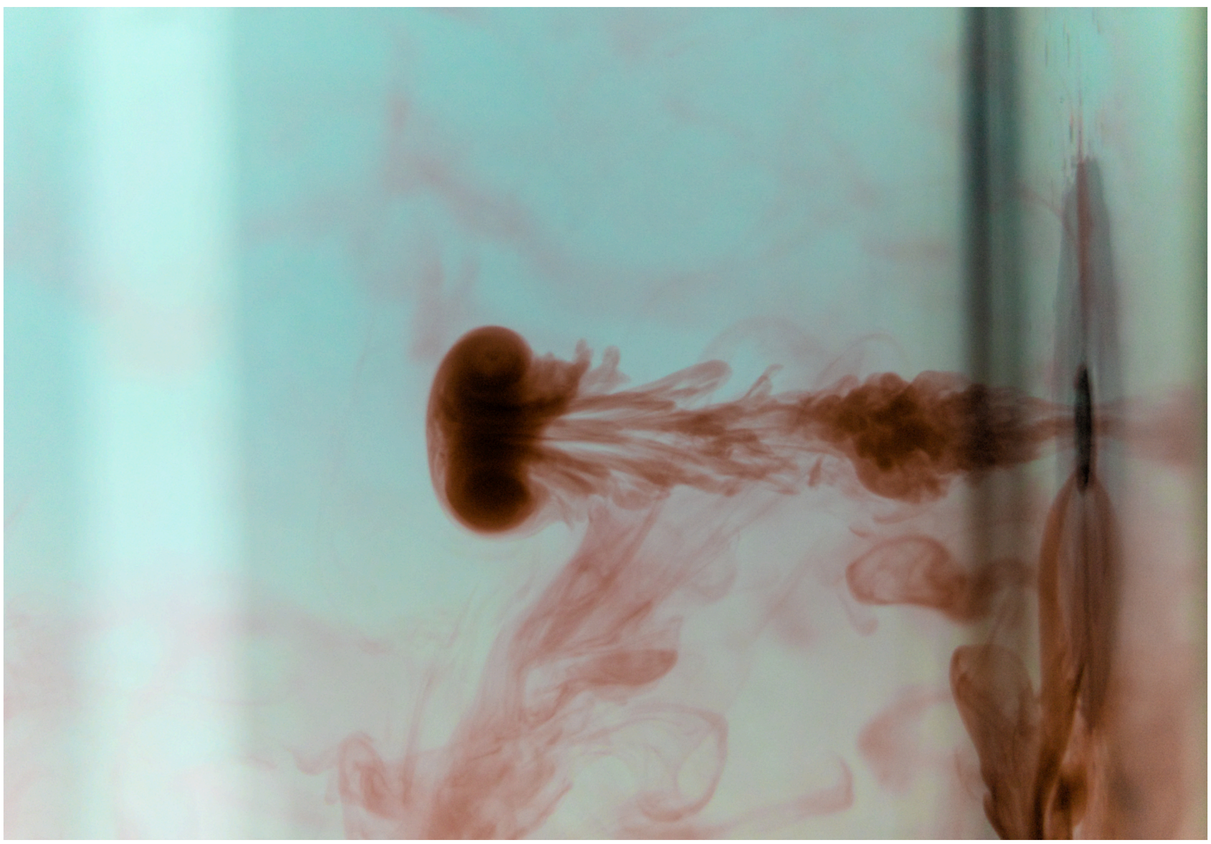
Toroidal Vortex Ring in Water

Isaac Lammers
MCEN5151: Flow Visualization
Aerospace Engineering
University of Colorado, Boulder
11/23/2021



Introduction

The objective of the Image 3 project was to capture a vortex ring in water. Many people have done this with smoke and air, but I wanted to create a set up that utilized water as the medium in which the vortex ring traveled. There were many challenges that came with this set up and it was a tricky shot to accomplish but I think the resulting image turned out wonderfully.

Experiment Setup

For this setup a fish tank was used and configured to make a vortex ring generator. At its simplest description you need a hole and a way to push a fluid through the hole evenly. To accomplish this, I cut a hole in the fish tank side that was 5/16 of an inch in diameter. I then placed a 2-inch section of 2-inch diameter PVC pipe on the outside of the fish tank concentric with the drilled hole and glued it to the fish tank. The outside hole of the PVC tube was then covered with a balloon to create a thin flexible membrane that could easily be depressed. The balloon was secured with a rubber band. I then drilled a hole in the top of the PVC tube and fitted a straw into it so the reservoir could be filled with dye (food colored water). A diagram of the set up can be seen in Figure 1.

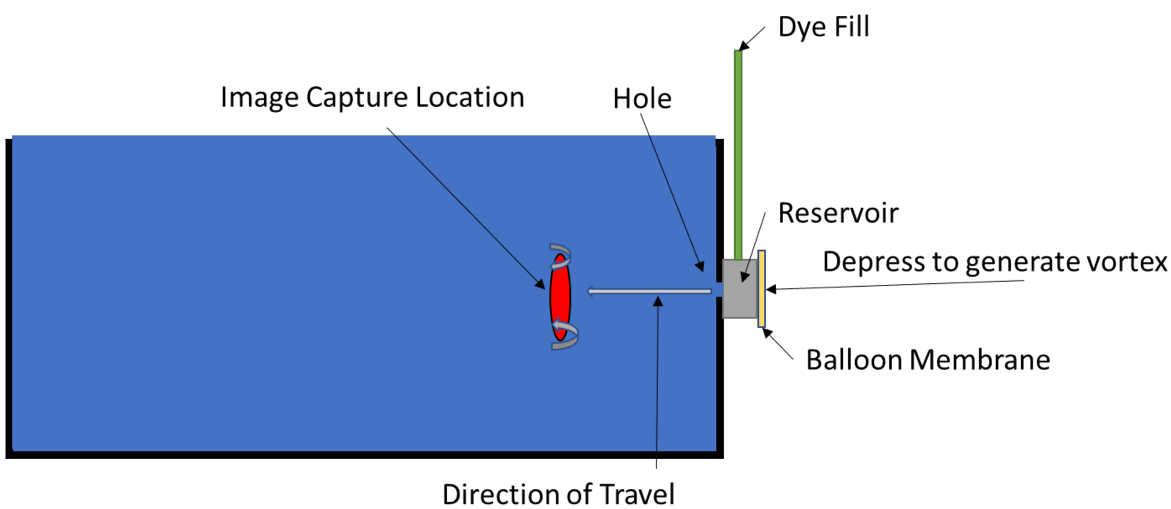


Figure 1: Vortex Ring Generator Tank

With this set up I could then fill the fish tank with clean, clear, water, add dye to the reservoir, and then begin generating vortex rings to capture on the camera simply by tapping the balloon membrane with my hand. It was a challenge to capture the image correctly the first time and several iterations took place. Blue dye did not contrast enough with the water and the images came out poorly. Red dye was then used but it quickly made the water red so if you did not capture the image on the first few attempts the water quickly became dark and a reset of the set up was needed. All the water would be dumped out, the tank filled again, and the reservoir filled with dye again. I performed this process five times. This design was influenced by the work of Morales and Zenit, who were creating a set up to capture vortex rings at low Reynolds numbers. I did not use a piston or laser sheet but used the idea of having a hole in a tank and an external reservoir (R. Zenit, 2012).

Explanation of Forces

The following theorems govern the formation of vortex rings.

1. Vortex lines move with the fluid.
2. Strength of a vortex tube, that is the circulation is constant along its length.
3. A vortex tube cannot end within the fluid. It must either end at a solid boundary or form a closed loop (a “vortex ring”).
4. Strength of a vortex tube remains a constant in time.

This set of theorems were presented in (Kundu & Cohen, 2008) and are called the Helmholtz Vortex Theorems. When talking about vortex rings it is important to focus on the third theorem. For this experiment I created a vortex ring that forms a closed loop and behaves according to this theorem. The vortex ring travels along a path about the axis of the vortex line and the center of the ring is this axis. The vortex is formed because of viscous forces in the fluid. When the membrane is depressed the fluid in the center of the hole is accelerated while the fluid at the edge of the hole is slowed due to viscosity “dragging” on the edge of the hole. This creates the vorticity necessary to cause the fluid to generate stable ring circulation that can translate through the fluid medium, in this case water. The vortex rings translation in water occurs due to this circulation imparting a force on the surrounding fluid medium. I like to think of it like it is a toroidal tire and the surrounding medium is pavement, by which it is rolling and carries momentum through the fluid allowing it to move from one end of the tank to the other, until it impacts the wall on the other side and dissipates.

Just like other areas of fluid flows vortex rings can be in laminar, transitional, and turbulent states. In the image I captured, I think the vortex ring is in a transitional state of flow. There are clear circulation lines that you can see in the upper part of the vortex ring and the trail left by the vortex ring is like images in (Glezer, 1988), where the transition to turbulent flow is reference. I did not capture any velocity data but based on the image captured this seems to match what was found by Glezer. The vortex ring that I generated likely fell somewhere between a Reynolds number of Re = 7500 and Re = 27000. Its not quite fully laminar but it is also not broken up to the point that it is unrecognizable as a vortex ring.

Visualization Method

To capture the image, I put the camera very close to the fish tank and had to add as much light as possible to create an environment that allowed for high contrast of the dyed fluid from the clear water. I place two LED light bars on the top and side of the fish tank directed at the image capture location. Then I put white paper on the back of the fish tank to create a nice background that would allow for the fluid to have a high contrast against it.

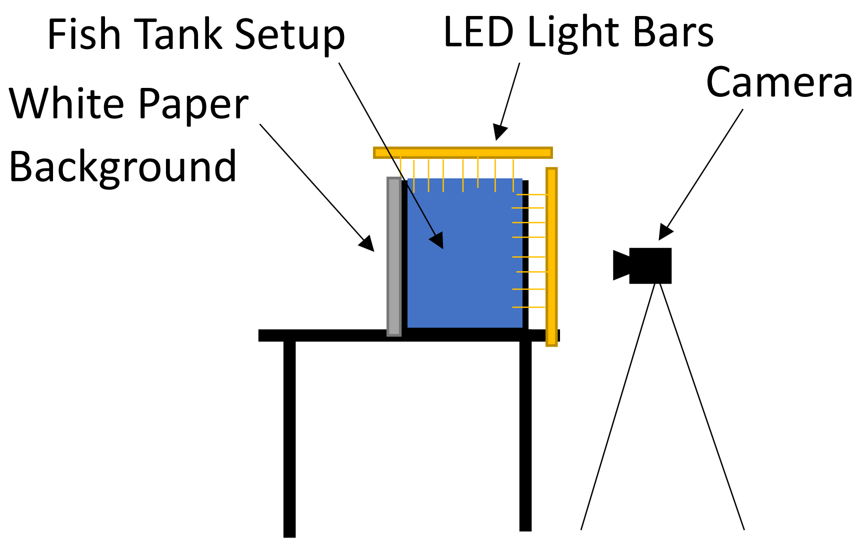


Figure 2: Lighting and Camera Setup Diagram

To focus the image, I used the straw technique that was brought up in class. I put a drinking straw into the fish tank where I expected the vortex ring to be when I wanted to capture the image. Then I focused manually on the straw, removed the straw, locked the focus, and began shooting the vortex rings. This worked well and was necessary for getting the final image in focus. I used a dye seeding method where I made a mixture of food coloring and water that I would then pour into the reservoir for use in generating the vortex ring. To capture the image, I used my Sony A6000. The following settings were used.

Lens	50mm
Shutter Speed	1/2500 sec
F-Stop	f/1.8
ISO	1600

Table 1: Camera Settings

By increasing the amount of light in the image I was able to eliminate the need for a flash and could use a high shutter speed to capture the motion that was occurring rather rapidly. I used a large aperture to let in as much light as possible and I upped the ISO setting to aid in the amount of light captured.

Image Processing

I did some slight post processing to reduce the amount of red in the background of the image. I did this by adjusting the white balance and reducing the red tint. I didn’t want to over do it on the image processing so that is pretty much all I did. I think it turned out well and the image that was captured originally was even a great image without the post processing.

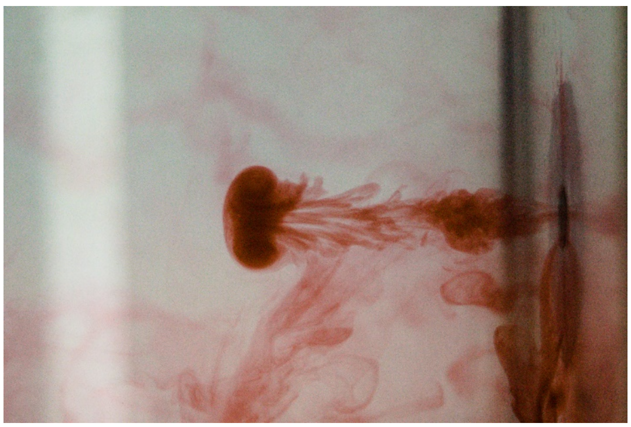


Figure 3:Original

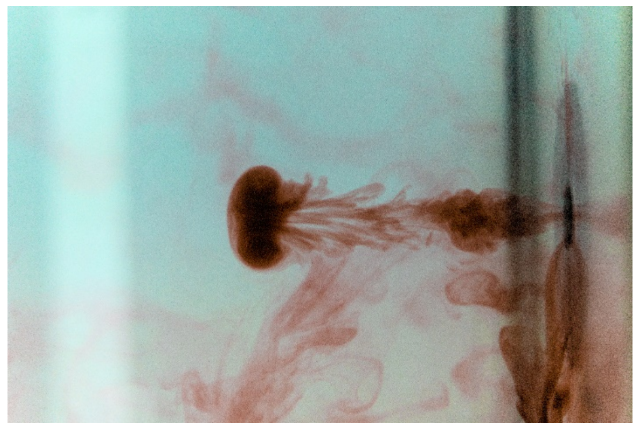


Figure 4:Edited

Final Thoughts

I think I did a great job of capturing a vortex ring. There are a few things I would do differently now that I have set up the experiment once. I think even with the amount of light I was able to add to the fish tank area, there could have been more light. The diffusion of light into the water was pretty extreme and I think more light in this set up would have allowed me to use a lower ISO and capture a crisper image. Unfortunately, I didn’t have any more light sources at my disposal. The vortex ring is traversing in the tank very rapidly and needs a lot of light to be able to capture the flow in a freeze frame manner. The second thing I would do differently is to drill a second hole in the bottom of the tank and the reservoir to facilitate draining the tank during the reset procedure. I did not think the dye would saturate the water so quickly. There were only 4 or 5 opportunities to capture a vortex ring clearly before the water became too murky. Overall, this was an incredibly fun set up to play with and there were some beautiful images captured from it. I look forward to trying to improve on this photo in the future.

References

Glezer, A. (1988). The Formation of Vortex Rings. *The Physics of Fluids*.

Kundu, P. K., & Cohen, I. M. (2008). *Fluid Mechanics* (4 ed.). Academic Press.

R. Zenit, C. P.-M. (2012). Vortex Ring Formation for Low Re Numbers. *Acta Mechanica*, 383-397.