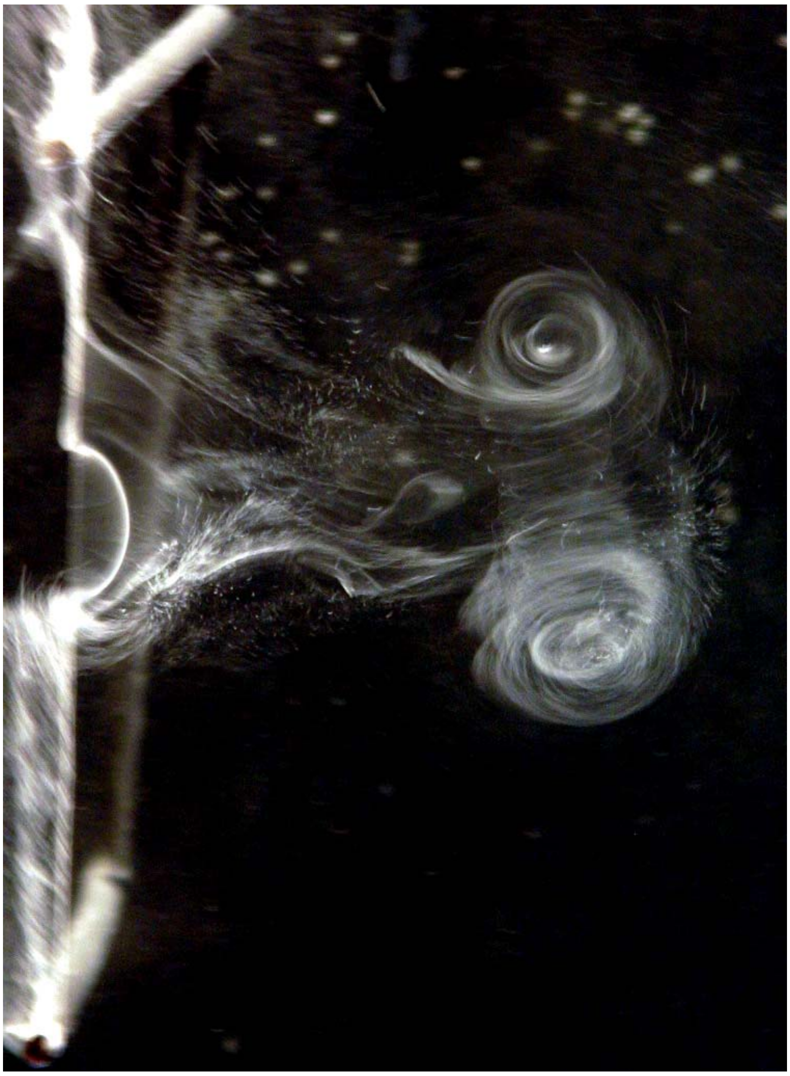
Vortex Ring Using Hydrogen Bubble Visualization Technique



MCEN 5228: Flow Visualization
Group Project 3
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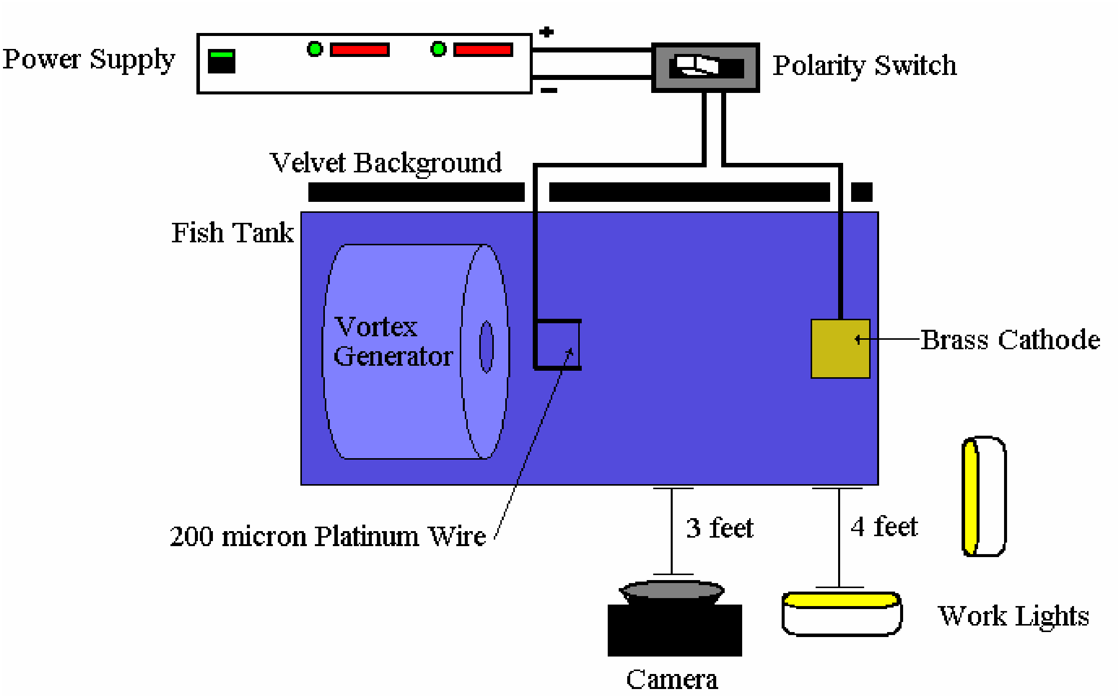
Chris Kuhn
Tyler Harrison
Ryan Mansfield
Jake Lilevjen
Chris Ostoich

The purpose of this image was to capture a vortex ring by use of entrained hydrogen bubbles. The phenomenon used to produce the hydrogen bubbles is called electrolysis. A power supply that could produce high current and voltage was needed to create this phenomenon. Because large amounts of current can be life threatening, safety was a major concern throughout the course of the experiment. Proper emergency procedure was reviewed and extra caution was taken when power supply was on. The experiment was conducted in Professor's Hertzberg's lab which allowed for a safe uninterrupted environment. The electrolysis device was found to be very sensitive as a result of 200 micron diameter platinum wire required to produce the phenomenon. Keeping this extremely thin wire intact was the most difficult part of fabricating the electrolysis device.

Sketch of flow apparatus:



The flow represented in the photograph is a vortex ring. This is created by forcing a column of fluid through a smaller aperture into a field of hydrogen bubbles. In this case, the aperture was a circular hole drilled in the face of a submerged vertical plate. The fluid flow through the hole begins to separate once it has passed into the open flow. This separated flow begins to reverse in direction, folding back over the fluid column. This motion causes circulation in the flow, and begins to form a vortex. Properties of fluid mechanics state that the vorticity of any system is conserved. Simply put, this is a statement of conservation of angular momentum. Before the column passes out from the aperture, the total vorticity of the system can be assumed to be zero. Therefore, due to conservation of angular momentum, the total vorticity must remain zero. The vortex ring is able to maintain a net vorticity of zero because the symmetry of its rotation. For each element of the ring that has vorticity in one direction there is a corresponding element with exactly the opposite vorticity on the opposite side of the ring. When summing the angular momentum vectors, the total vorticity is found to be zero. Since the vorticity of the vortex ring is zero, the flow is said to be *irrotational.* The Reynolds number for this flow can be estimated using the equation $Re = UD/\nu$, where U is the velocity of the vortex, D is the hydraulic diameter, and ν is the kinematic viscosity. Since this flow is in water, the kinematic viscosity of water at room temperature will be used. This value is 1×10^{-6} m^2/s. The hydraulic diameter is 0.025 m, and the velocity of the vortex ring is estimated to be 0.2 m/s. The Reynolds number is therefore approximately 5000. The low Reynolds number leads to the conclusion that the flow is laminar. Laminar flow contributes to the smooth, well defined streamlines displayed in the image.

As was stated earlier, the setup used hydrogen bubbles to visualize the flow in a glass fish tank. The hydrogen bubbles were produced by adding a large electrical current into the water, using a platinum wire cathode, and a copper plate anode. In order to facilitate the flow of current through the water, 10mL of table salt was added 30L of water to create an ionized solution. We used power settings of 30V, and 0.2 amps. This electrical current caused a dissociation of the water into hydrogen and oxygen. The chemical formula can be seen below.

$$2H_2O \rightarrow 2H_2 + O_2$$

Originally, the flow was produced by using a non conductive plastic stick to stir and agitate the water. However, better results occurred when a vortex generator was added into the tank. Water in the vortex generator was forced out of a small hole in the front, due to the compression of a syringe connected to the back of the vortex generator. The advantage of this technique was a thin line of hydrogen bubbles streaming in front of the vortex hole. This essentially caused for the vortex to be visualized only in a thin sheet, allowing for the center line of the vortex to be clearly seen. It was found that quickly moving vortex rings provided better visualization conditions. This is due to the fact that the buoyancy of the bubbles is better ovecome by straonger flows, as is described in *Translational velocity oscillations of piston generated vortex rings*. (Kumar, [1]) The lighting used for the setup was a pair of 500W shop lights. It was recommended that the lights be oriented at 115° to the camera (Smith, [2]), however, we achieved better results by pointing the lights directly down from the top of the fish tank. Flashes were not used.

In terms of imaging we tried a lot different angles and distances away from the apparatus to see what worked best. The photograph that we decided to use was taken eye level to the side of the setup 1.2 m. away from it. The field of view before cropping was the exact height of the tank 0.29m and about 0.43m wide. This corresponded to an image that was 3456 pixels wide by 2304 pixels high. This image was taken with a Cannon 28-135mm f/3.5-5.6 IS USM lens on a Canon EOS Digital Rebel camera. The focal length was all the way out at 135mm and the flash wasn't necessary due to the 1000 watts of lighting. The exposure was hard to judge because it was nearly impossible to focus on the hydrogen bubbles and get a sharp picture. An aperture stopped at f/5.6 and a shutter speed of 1/60 sec allowed for some of the individual bubbles in the vortex ring to be visible without distorting the apparatus (which we left in the image to better show the phenomenon). The bubbles in the image moved across 11 pixels during the exposure. However, the vortex ring itself seemed to be time resolved. This indicated that vortex rings as a whole move slower than the fluid particles that make it up. The only use of Photoshop in the final image was for cropping and changing the brightness/contrast.

The small hydrogen bubbles had a diameter of approximately 200 microns which decreased their buoyancy and enabled them to flow along with fluid and create a clear representation of the flow field inside a vortex ring. The slow shutter speed allowed the bubbles to map out the path that each fluid particle took during that time which allowed for a better understanding of the flow. The image shows that the vortex ring concentrated entrained hydrogen bubbles to the average circumference of the annulus. Although not shown in the image, it was noted that further down stream a ring of large hydrogen bubbles formed due to the convergence of the small bubbles. The probe and platinum wire can be seen in the image and may be considered distracting. However, the presence of these elements adds to the understanding of the image and also reveals the development of another vortex ring. Although the brilliant form of the vortex ring phenomena is very common in nature, people are not aware of it. It takes a visualization technique to see the beauty and physics involved in a vortex ring.

Sources

[1] Kumar, Manoj, Arakeri, J.H. and Shankar, P.N.. Translational velocity oscillations of piston generated vortex rings.Bangalore, India: Indian Institute of Science & National Aerospace Laboratories, 1995.

[2] Smith, C.R., Seal, C.V., Praisner, T.J., and Sabatino, D.R.. Hydrogen Bubble Visualization.