Team Image #2:
The Karman Vortex Street

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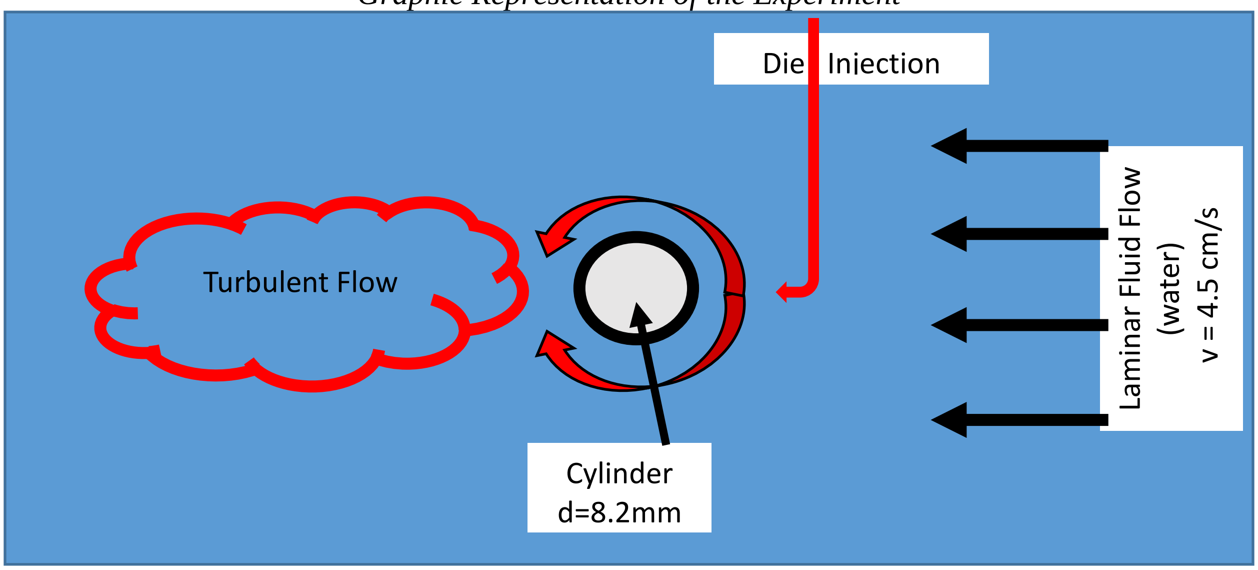
For our second project working as a group, my team chose to photograph laminar fluid flow over a cylinder. Specifically, the goal was to achieve the correct conditions to induce a Karman Vortex Street; a phenomenon where turbulent eddies that are created from the cylinder oscillate between the top of the flow and the bottom. To achieve the laminar fluid flow we used a flume filled with water. We initially found that we could not lower the fluid flow velocity low enough to achieve the conditions for the Karman Vortex Street using the cylinders that were provided for us, so we cut a Bic pen in half and used it as our cylinder because it was smaller than the provided ones. We introduced streams of different color inks just upstream of the cylinder in order to visualize the turbulent flow after the obstacle in the flow.

The device that we used to achieve laminar and evenly distributed fluid flow for this experiment is called a flume. The purpose of the flume is essentially to allow water to flow across a large, clear tank with constant velocity across the entire tank. The apparatus is designed in such a way that as long as the flow is not disturbed during its travel it will maintain laminar fluid flow. The goal of our experiment was to create a very specific type of turbulent flow in the flume tank by introducing a cylindrical obstacle into the flow. Laminar fluid flow that is interrupted by a cylindrical obstacle is a very well-studied and understood area of fluid dynamics, and the behavior of the fluid as it passes over the cylinder is defined by a non-dimensional number called the Reynold's number. The Reynold's number is calculated using the equation $R = \frac{\mu * D}{\nu}$, where μ is the velocity of the fluid flow, D is the diameter of the cylinder, and ν is the kinematic viscosity of the fluid [1].

Graphic Representation of the Experiment



The Karman Vortex Street is a phenomenon that occurs when this non-dimensional number is between 40 and 400. When the Reynold's number is less than 40, the fluid flow rejoins on the other side of the object and remains mostly laminar. When the number is greater than 400, the flow becomes too turbulent for the Karman Vortex to occur [2]. This phenomenon is caused when the small vortexes that form on the edges of the cylinder begin to shed off of the cylinder oscillating between the top and bottom [2]. When an ink is introduced to the system, these vortexes are visible as swirls that shed off the obstacle in a very cool way.

In order to achieve the correct conditions for the Karman Vortex Street, we slowed the fluid velocity in the flume down to the lowest level that the pump could safely handle. We measured this velocity by placing a small floating bead in the water and measuring how far it moved over 10 seconds. We measured the fluid velocity to be approximately 4.5 cm per second. The cylinder was made out of the body of a round BIC pen. The outer diameter of the pen body was measured with a caliper and found to be 8.2 mm. The kinematic viscosity of water is 1.004 m^2 per second at 20^0C [3], which is a standard assumption for room temperature in the winter. The Reynold's number for these conditions was calculated to be 320, and indeed a Karman Vortex street did form.

In order to visualize the physics of the vortexes, we injected India Ink into the flow just slightly upstream of the cylinder. We used a syringe to inject the ink, and did our best not to disturb the laminar fluid flow by not injecting with high velocity. India Ink is a very dark, black ink that can be purchased from any art supply store. We placed a large whiteboard directly behind the tank in order to achieve a high contrast with the black ink. No flash was used: light for the experiment was supplied by a large floodlight that was placed directly over the tank and shined straight down onto the experiment. Nearby fluorescent lights were turned off, but there was still a large amount of ambient light from the fluorescent bulbs in the rest of the building.

The image was captured using a Canon EOS REBEL SL1 digital DSLR. The camera was facing directly at the tank, at the height of the cylinder, approximately 12 inches from the tank. The field of view of the original, unedited image was approximately 8 inches wide and 6 inches tall. The sensor was exposed for 1/250 of a second, with the aperture set to f/5. The sensitivity was at ISO-800 and the focal length 42 mm. The dimensions of the unedited image were 5184 pixels by 3186 pixels. The final image was cropped slightly, and the final dimensions were 3981 pixels by 2260 pixels.

Original, Unedited Image

All post-processing was done using the photo editing software GIMP. Post processing of the image started by cropping out some of the less interesting turbulent flow on the left side of the image in order to zoom in on the vortexes. Next some changes were made to brightness and minor work was done to the contrast using the curves tool. I decided that the metal wire that was supporting the cylinder was distracting to the image and irrelevant to the physics, so I used the clone stamp and smudge tools to remove it.

I believe that this image does an excellent job of capturing the physics of a Karman Vortex Street. I especially like the vortex that is closest to the cylinder because it so clearly shows the swirling vortex. The oscillating pattern is also captured well, even if the vortexes aren't quite as clean due to the turbulent mixing. The glass wall of the tank did subtract from the quality of the image, but the only thing that I think could be improved there is doing a very thorough cleaning of the glass before the tank is filled with water. I attempted to remove some of the color spots in the image but I was unable to do so in a clean fashion that did not take away from the integrity of the flowing fluid. Overall I am very satisfied with the image and I think that the initial intent of the experiment was achieved and the Karman Vortex Street was captured in high detail.

References

[1] “Reynolds Number.” Accessed November 29, 2015. http://www.engineeringtoolbox.com/reynolds-number-d_237.html.

[2] “Strouhal Instability - Von Karman Vortex Street.” Accessed November 29, 2015. http://hmf.enseeiht.fr/travaux/CD0102/travaux/optmfn/gpfmho/01-02/grp1/phy_know.htm.

[3] “Water - Dynamic and Kinematic Viscosity.” Accessed November 29, 2015. http://www.engineeringtoolbox.com/water-dynamic-kinematic-viscosity-d_596.html.