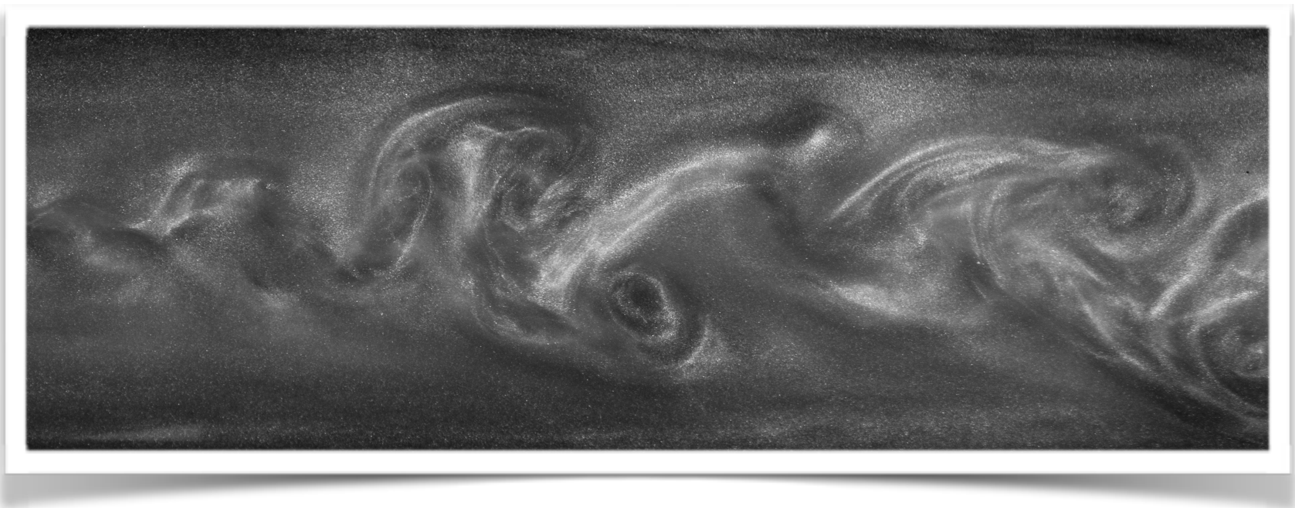

Team Image 3

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Flow Visualization 2014

With Help From:

Millie Blackstun

Purpose:

In the final project of the year a basic set up was contracted to visualize a complex fluid phenomena. A Von Karman vortex street occurs in a variety of situations in nature and is quite difficult to capture in the lab. It was chosen to undertake this experiment to finish the semester off strong with an image that can properly illustrate the fluid phenomena at hand in a simple elegant way. Having a rudimentary set up proved to hinder the success of the experiment but as parameters were changed in the hopes of increasing the success of the experiment, the success of producing a vortex street became even more difficult. Turns out simpler is better in some cases.

Flow Set-Up:

To achieve a Von Karman vortex street a single PVC tube capped on both ends was used to house the working fluid. This PVC tube is approximately 3 feet long and is cut in half length wise. This tube is shown in Figure 1 of the experimental set up. Cutting the PVC in half allows the user to be able to draw a shape (cylinder in this case) through the fluid and produce the Von Karman vortex street. The half tube is then filled half way with water, which becomes the fluid of study in this experiment. Two stands were made to hold the PVC tube stable since it would be hard to keep the tube from rocking when moving the fluid around in the tube if the tube was sitting on the table. Pearl Swirl is used in the fluid to act as the agent to visualize the phenomena taking place. This shiny fluid has a closely guarded formula so it is hard to describe what the agent actually is besides saying that it looks like sparkly or shiny shampoo. The agent is bottled in a high concentration so only a couple drops are needed to achieve good dilution in the water. In this experiment 10 or so drops were used and spread out along the length of the PVC tube. Once the fluid was set in the PVC tube lighting was achieved by two work lamps that shown light along the length of the tube to reduce shadows when taking photos. The camera was roughly a foot from the tube and almost directly overhead the tube.

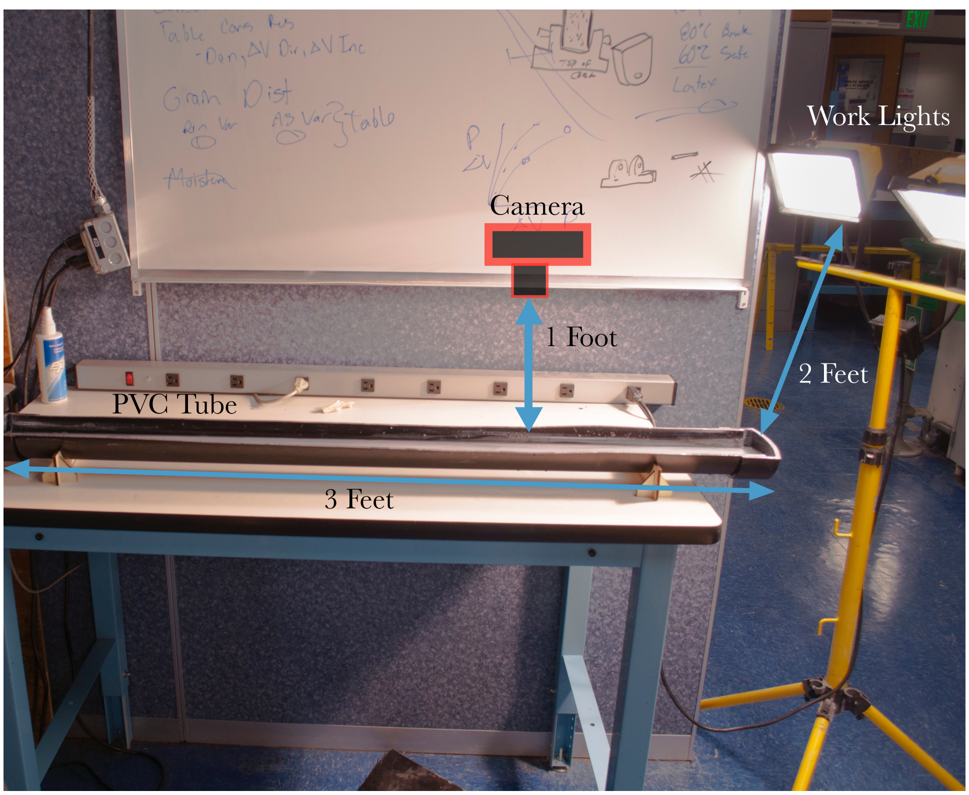

Figure 1: Experimental Set-Up

To generate the Von Karman vortex street a bubble wand was used that has a shaft diameter of roughly a quarter of an inch. This size proved to be the best at generating the fluid phenomena. As the diameter got larger the flow began to interfere with the walls of the PVC tube and the phenomena would be lost to large scale turbulence in the tube. If the shape of a cylinder/ shaft was not used the effect would not take place at all. The shape of the instigating device is crucial to the success of the experiment.

The procedure for executing the experiment went as follows, first the pearl swirl was dropped into the water in the tube and this was then mixed around using a stir stick. once the fluid settled down and the pearl swirl became uniform across the surface the bubble wand was placed into the fluid and dragged length wise through the center of the tube. The vortex street then forms behind the shaft of the wand as it is moving through the fluid.

Flow Physics:

A Von Karman vortex street is quite unique to the shape that is hindering the flow. In this case it is a cylinder and the flow is passing around the cylinder which in turn results in the Von Karman vortex street. In addition to being geometry dependent the phenomena is also dependent on the Reynolds number of the fluid, Equation 1. If the Reynolds number is roughly 55 or more broadly 80 - 200 than these oscillating vortices appear. The Reynolds number is defined as the ration between the inertial forces in the fluid and the viscous forces.

$$Re = U_\infty d/\nu$$

The reason for this oscillation is due to the circulation of the fluid around the cylinder as the fluid flows past it. Due to the boundary layer and separation of the flow off the cylinder the sign of the circulation begins to change from negative to positive and back again which results in the two vortices that oscillate behind the cylinder itself.[1] This circulation then describes the way in which the vortex moves, there is a two-dimensional flow with the axes of the vortex parallel with the cylinder axis.[3] This oscillation can be of great importance in various applications of engineering and fluid dynamics. For instance in a heat exchanger in an HVAC system there are a series of tubes that carry the working fluid around to then cool the air that is passing over and through the heat exchanger. These tubes are circular and can have the same Von Karman vortex street shedding as depicted in this experiment. Figure 2 illustrates this. The result of this effect in the heat exchanger can lead to an over all oscillation of the bulk fluid that is moving through the HVAC system. Given that the Von Karman vortex sheets have a specified frequency the bulk fluid will now take on that frequency of the shedding vortices. When this happens and it reaches the natural frequency of the HVAC system at hand noise from a vibrating system will result. This is the reason that baffles are used in HVAC systems in an effort to "detune" the bulk fluid in an effort to keep the system quiet and reduce vibrations.[2] The very same thing can occur in structural buildings in which there are large cylindrical exposed columns. The vortex shedding off of these columns can result in a structural vibration and surrounding supports. Such a phenomena could prove detrimental to structures like suspension bridges, oil drilling platforms, and various car components.[1]

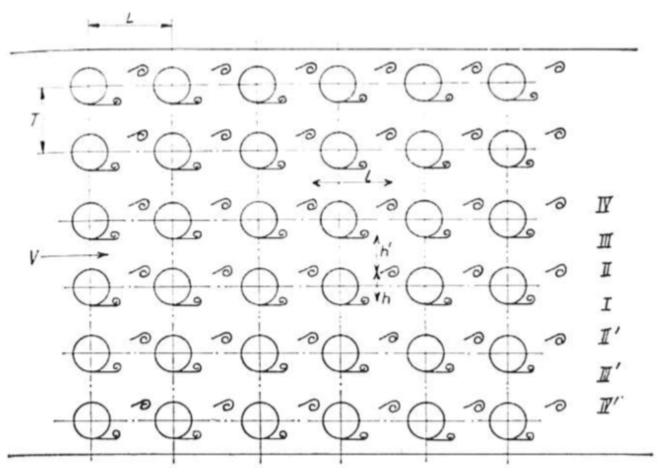

Fig. 2(a) Von Karman vortex streets in an in-line tube bank arranged in a rectangular duct (heat exchanger)

Figure 2: Von Karman Vortex Streets[2]

Photographic Technique:

This image was taken with a Nikon D5000 equipped with a 18-55mm focal length lens. The lens was adjusted to a focal length of 40mm in this image to result in an image size of roughly a six inches by eight inches. Positioning the camera directly overhead with the lights to the right of the tube lighting down the length of the tube reduced and eliminated all possible shadows on the phenomena at hand. A shutter speed of 1/200 of a second was used with a corresponding aperture of *f*/5.3. This combination allowed for the use of an ISO of 200. A tripod was used to ensure that there was no motion distortion while shooting the flow. The resolution of the image in camera RAW is 4288 x 2848 pixels, equivalent to 12 megapixels. The white balance on the camera was changed from auto to cool white fluorescent to get a more realistic coloring in the resulting image. This change was made to counted the lighting effects that can be caused by fluorescent working lamps.

After the image was taken it was moved into Photoshop Camera RAW to do post processing and editing. Figure 3 shows the before and after of the image. The first thing was done was to crop the image to focus on just the fluid inside the tube and eliminate all unnecessary background details.

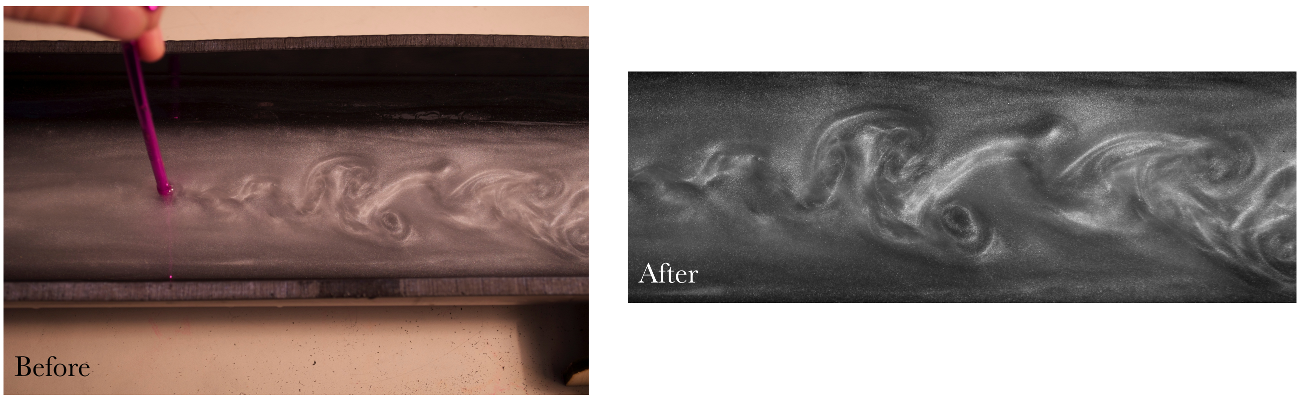

Figure 3: Before and after photo processing

The next step was to convert the image to gray scale to bring out the whites and blacks that really emphasize the fluid vortex street. To further enhance the image the contrast was adjusted by +28 and the whites slider was increased to +30 and the blacks slide was reduced to -37. These adjustments provided enhanced contrast while targeting specific aspects of the image to preserve quality. Last the clarity slider was increased slightly by +10.

Conclusion:

This experiment proved to be successful but the simplistic set up may have hindered the quality of the results. The Von Karman vortex street is visible but not as pronounced as anticipated or as much as what would have been liked. Reception to the image was positive and in the future a more complex set up may be required to properly capture this phenomena. A set up where the width of the tube is larger so the cylinder that is used can be increased and putting this on a slider would help to ensure perpendicularity to the fluid to increase the chances of capturing and producing a good vortex street. This was a good experiment to end the semester on because of its simplicity and its appearance, pearl swirl is highly recommended as a flow visualization technique when using a working fluid like water.

References:

1. Kundu, P. K., & Cohen, I. M. (2007). *Fluid Mechanics* (4th ed.). Burlington: Elsevier.
2. Chen, Y. N. "Flow-induced vibration and noise in tube-bank heat exchangers due to von Karman streets." *Journal of Engineering for Industry* 90.1 (1968): 134-146.
3. König, Michael, Bernd R. Noack, and Helmut Eckelmann. "Discrete shedding modes in the von Karman vortex street." *Physics of Fluids A: Fluid Dynamics (1989-1993)* 5.7 (1993): 1846-1848.