Visualization of a von Kármán Vortex Street in Water

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Figure 1: Final image submitted for the first team project

The goal of the first team project was to visualize the vortex shedding that occured behind a cylinder from a fairly uniform flow upstream. This was done by immersing a PVC pipe into a flume and using blue and red dyes to trace the fluid moving past the cylinder. The group set out from the beginning of this project to do this after looking though Van Dyke's *An Album of Fluid Motion* [1]. The group liked the images on pp. 56 and 57 showing the vortex shedding behind a circular cylinder. Our hope was to create a more laminar image; however the dye would diffuse into the surrounding fluid before a vortex street would exist. Hence the final image is more turbulent and shows several different vortices behind the cylinder.

The setup that the group used for this project in order to visualize the von Kármán vortex street was done by injecting a food coloring dye and water mixture controlled through a syringe pump into a flume of moving water. Figure 2 on the following page shows a picture of the setup. A 38 mm diameter PVC pipe was used as a cylinder in order to create the disturbance necessary to initiate the vortices. The cylinder was cut to length such that it could be lightly wedged between the walls of the flume. Tubing was attached to the syringes in order to have the dye injected at a location of about 1 cm before the cylinder. Paper clips were then attached to the tubing to hold the tubes together and get them to inject the dye in the same direction of the flow. Two separate syringes were used for the blue and red dyes. Red and blue colors were chosen so that the image would contain a good amount of contrast. A white plastic screen was used in combination with two halogen lamps in order to illuminate the flow from behind. A glass cleaner was also used to remove any smudges from the flume walls before it was filled. The syringe pump speed was adjusted so that it would match the speed of the surrounding flow in the flume. The flume speed was varied between different runs in order to see different vortices form at different Reynolds numbers.

In this setup the flow is moving through the flume from the right to left in figure 2. As the fluid moves through the flume it passes two tubes where some diluted red and blue dye is added to the flow in order to track the flow further downstream. With the dye added the flow then proceeded to move past a 38 mm cylinder. The channel width was 78 mm wide by 230 mm high. The point of interest lied beyond the cylinder where the flow created oscillating vortices. In estimating the dimensionless numbers relevant to this flow there are two Reynolds numbers of interest. There is a Reynolds number of the channel flow without the cylinder (using the channel width as a length scale) and a Reynolds number of the flow with the cylinder (using the cylinder diameter as the length scale). The Reynolds number is defined as:

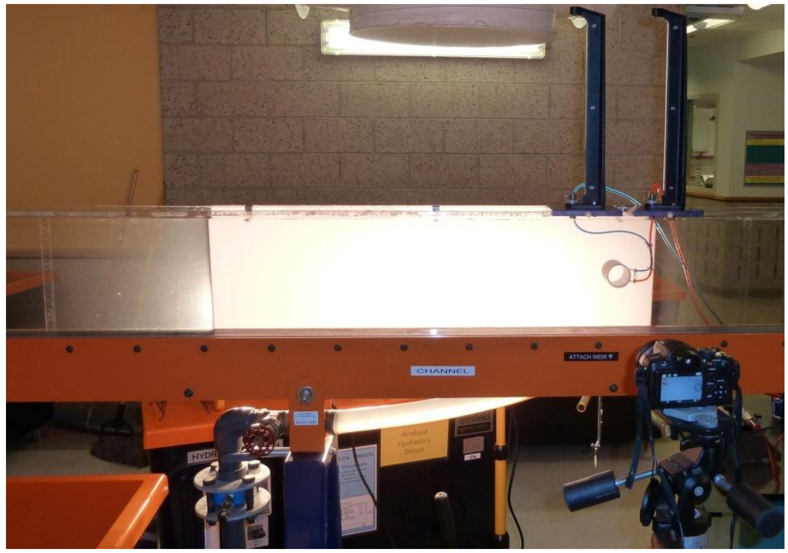

Figure 2: Photo showing the setup for the project. The syringe pump is located in the lower right corner of the image

Eqn. 1: $$\mathrm{Re} = \frac{V \bullet D}{\nu}$$

where Re is the Reynolds number, *V* is the velocity, *D* is the characteristic length scale, and υ is the kinematic viscosity. For both of the Reynolds numbers discussed above a velocity of 0.129 m/s, and a kinematic viscosity of 1.005 x 10^{-6} m^2/s were used. The Reynolds number for the channel was then calculated to be about 10,000 and the Reynolds number for the flow behind the cylinder was calculated to be about 4,900. For this range of Reynolds numbers the flow is said to be in a transition between laminar flow and fully turbulent [2-4]. The flow exhibited in the final image is very similar to that of the flow seen for a Reynolds number of 4,000 as seen in figure 1 from [3]. Below a Reynolds number of 80 the flow does not oscillate but either remains attached or has a small recirculation zone behind the cylinder [2]. Above a Reynolds number of 80 the recirculating eddy behind the cylinder breaks off in an alternating pattern [2]. The vortices then expand as they move further downstream with the surrounding flow.

Since the flow would be in a transition between a laminar and fully turbulent flow good resolution needed to be accounted for. In order to see some of the smaller vortices created in the flow it was estimated that a spatial resolution of about 10 pixels per mm would be sufficient. To freeze the flow with this spatial resolution a fast exposure would need to be used. It was calculated that a 1/1000 second exposure time would be necessary to do this.

To visualize the flow for this project standard food coloring dye was mixed with water. 25 drops of blue dye were mixed with 60 mL of water. 23 drops of red dye were mixed with 60 mL of water. The amount of dye used was determined by a trial and error process to get enough contrast in the fluid for the image. The water temperatures used were room temperature. The flow speed was varied in the image to try to get different vortex shapes. Initially it was done much slower, but the dye was diffusing into the fluid too much to visualize a very laminar flow.

The speed was then ramped up to a final speed of 0.129 m/s. The lighting used for the image was two backlit halogen lamps behind a white plastic screen.

The image was created by setting up the camera on a tripod on one side of the flume. The other side was covered with a plastic screen and illuminated with two halogen lamps. The field of view in the image is about 0.4m wide by 0.25 m high. The distance from the flume to the lens was about 1.5 m. The focal length of the lens was 70mm and an image stabilizer was used. A digital Canon EOS 10D camera was used. The original pixel dimensions of the image were 3072 wide by 2048 high. The final image was cropped down to 3021 wide by 1328 high. The exposure of the image was 1/1000 seconds with a f/4.51 aperture at a 400 ISO. Once transferred to a computer some post processing was then done using GIMP version 2.6. The first thing that was done was to convert the file from *.crw to a *.tif file format. The image was then cropped to remove the unwanted portions of the image. Then using GIMP's airbrush and smudge tool the tube in the upper right corner was removed. Specks were then removed using the smudge tool. The thing that was done was to use the levels tool to add contrast, and correct the white balance to make the image cooler. With these changes the smudge tool was then used again to further blend in where the tube was. The image was then cropped again to make the flow more symmetric. Finally a little more saturation and contrast was added to the image.

This image reveals that after a relatively uniform flow passes a cylinder it becomes very disturbed creating an oscillation pattern of vortices. What is really interesting in the image is that there are several scales in the image. First off there are the large vortices that are visualized by the blue and red sections of the flow. Then in each of these vortices there are additional smaller vortices. With the two different colors the physics of the vortex shedding is visualized well, hence fulfilling the groups' intent. To improve the image it would be neat if the flow could be made more laminar to see crisper lines of the vortices. This would require using a different dye that wouldn't diffuse into the surrounding water so quickly. Additionally it would also be interesting if the timing of the frequencies of the vortex oscillations were recorded so that a Strouhal number could be computed. This is an important phenomenon to study as the frequency created by the vortex shedding could resonate with the natural frequency of the object in the flow [2]. Another interesting idea would be to try to rotate the cylinder in the flow to see what kind of antisymmetric vortex patterns could be created. This would be done to try to repeat the experiments from [5]. The patterns seen in the images of [5] are very intriguing and would be fun to try to reproduce. Another experiment that could be done to extend this work would be to explore the eddy patterns created by a staggered mesh of cylinders and compare that to the work of [6].

References:

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