Karman Vortex Street

Team Project I

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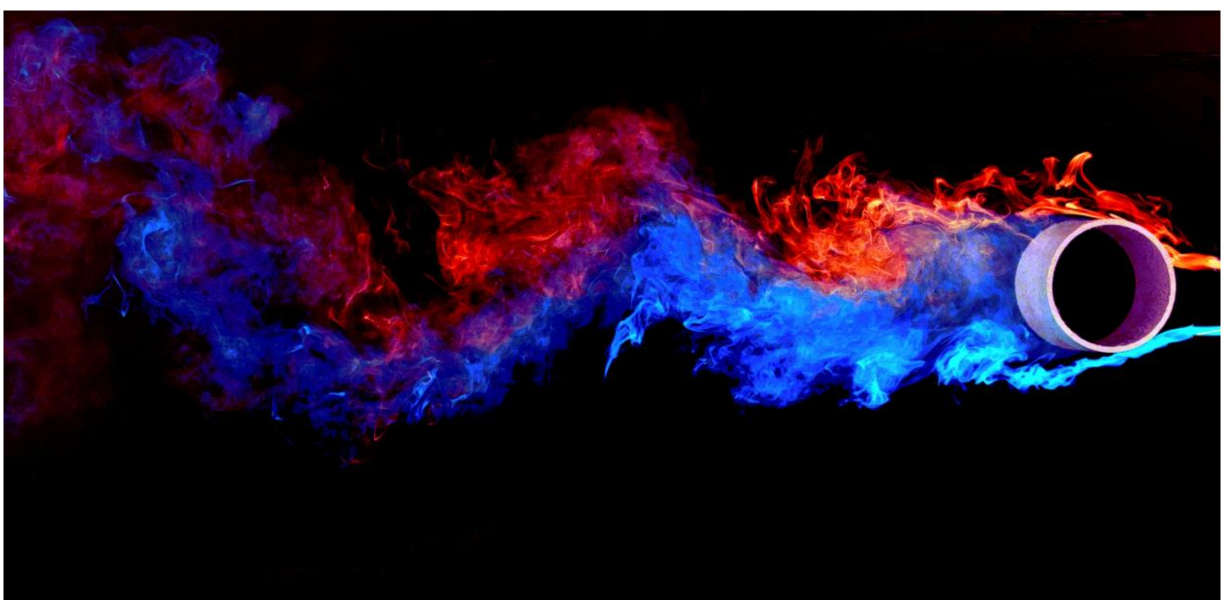
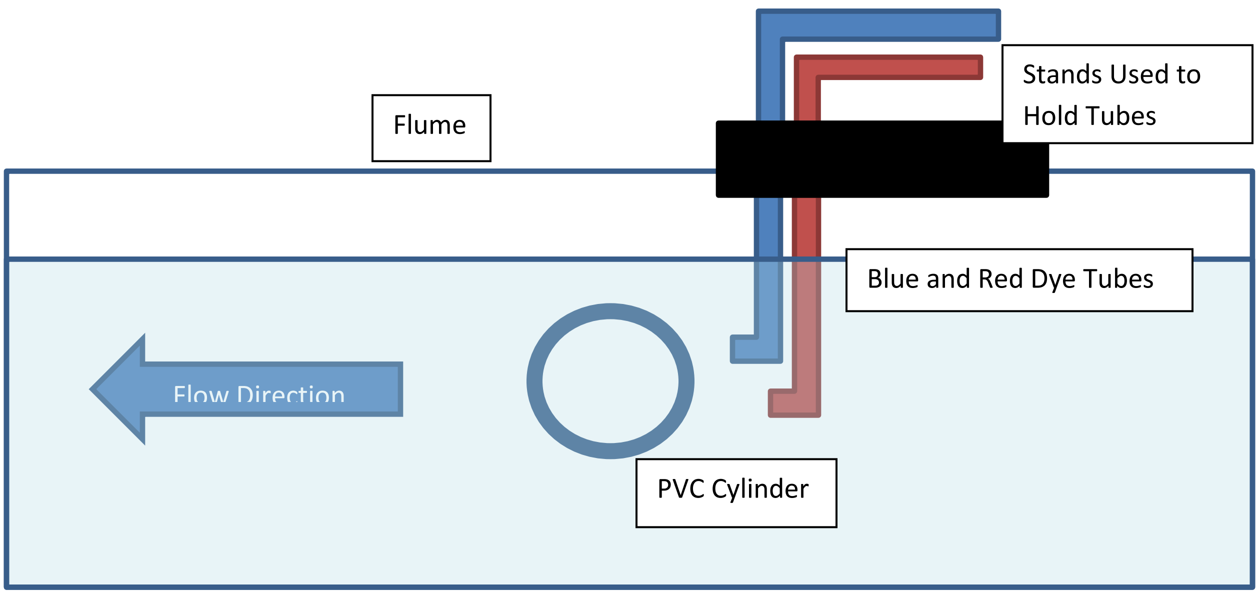
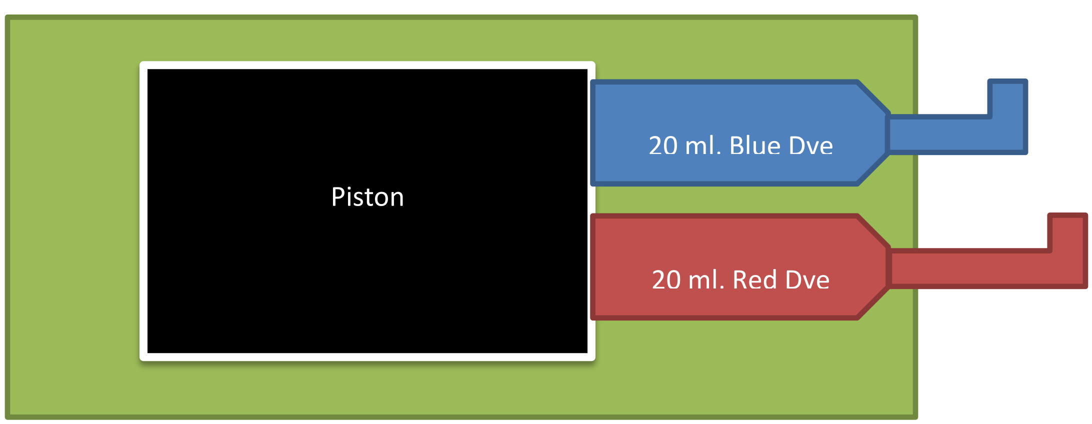


Karmen Vortex Street

The objective of this photo was to, as working as a team, produce an image capturing important physics of flow. It was determined that the group wanted to produce an image demonstrating the turbulent wake downstream of a cylinder. The intent was to produce a visible von Karman vortex street utilizing the flume available in the Integrated Teaching and Learning Laboratory. The grouped iterated through several variations and setups over two-three hour sessions before reaching a setup that provided the wanted results. In doing so it was determined that utilizing two dyes injected over and under the cylinder produced the best results. To that extent multiple trials were spent determining the proper dye concentrations and injection rates for each color. Under non-optimal concentrations the red dye over powered the blue. Additionally, under the wrong injection and flow rates the color dispersed and mixed quickly, which, while still producing beautiful images, did not give us the detailed image of the von Karman vortex street desired.





The setup that the group used for this project in order to visualize the von Karman vortex street was done by injecting a food coloring dye and water mixture controlled through a syringe pump into a flume of moving water. 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 3 1/8", slightly larger than the flume width, 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 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 calculated at 0.05 m/s. The mixture final ratios of dye to volume water were 59 drops red dye to 180ml and 65 drops of blue dye to 180ml of water. The syringe sizes used were 20 ml.

Channel Rates & Calculations		
Measured Volumetric Flow Rat	0.8876	L/s
Flow Rate	0.0009	m^3/s
Channel Height	0.2300	m
Channel Width	0.0778	m
Channel Cross Sectional Area	0.0179	m^2
Flow Velocity	0.0496	m/s

Dye Concentrations	
Red	59 Drops Dye
	180 ml Water
Blue	65 Drops Dye
	180 ml Water

The Karman vortex street in fluid dynamics refers to swirling vortices caused by unsteady flow separation as fluid flows over a body and occurs within the Strouhal instability[2]. The Reynolds number is calculated for both flows within an open water channel utilizing the hydraulic radius as the characteristic length. This quantity is defined as the cross sectional area divided by the wetted perimeter. The calculation for the Reynolds number is as follows[1].

$$Re = \frac{RV}{\vartheta}$$

Where v is the kinematic viscosity [m^2/s], V is velocity [m/s], and R is the hydraulic radius [m] defined as

$$R = \frac{A_{Cross\ Sectional}}{Wetted\ Perimeter}$$

Then for flow through the flume, treated as an open water channel, the Reynolds number is calculated to be approximately 4430. For an open water channel a Reynolds number greater than 1000 tells that the flow is turbulent. Next the Reynolds number for a cylinder in flow can be calculated as follows

$$Re = \frac{D_{pipe}V}{\vartheta}$$

Where the hydraulic radius has been replaced with the pipe diameter and the flow is assumed to be fully developed. This produces a Reynolds number of approximately 1450. For a von Karman vortex street to occur the prime Reynolds number falls between 40 and 400. Past this point the vortices begin to shed inconsistently as turbulence begins to dominate the flow. From this information it can be seen that the water was turbulent beforehand and is most likely the cause for the true von Karman vortex street not forming. In order to produce a stable von Karman vortex street it would be best to implement a fluid with a higher kinematic viscosity and decrease the hydraulic radius[1].

In order to visualize the flow two colors of dye were implemented to flow above and below the cylinder. Different concentrations of dye were used to present a proper contrast. It was determined blue dye needed to have a higher drop per milliliter of water as the red dye dominated the flow. To better present these colors a white background was used for photography in addition to white PVC pipe. A piston was utilized to keep the injection rate of both dyes equal into the flow and bent paper clips were utilized to retain bends in the tubing so as to inject the dyes parallel to the water flow. Additionally narrow tubing was implemented to keep from affecting downstream flow. All supplies utilized were present and obtained from the Integrated Teaching and Learning Laboratory. The camera was place level on a tripod in line with the PVC pipe. Fluorescent lighting in the room was shut off and external flood lights were setup to shine on the back of the white background. Camera flash was disabled as enough lighting was provided.

The camera was adjusted so that the field of view included as much of the flume downstream of the cylinder in order to capture downstream results. This equates to a field of view of approximately 2.25 meters. The camera was set approximately 1.5 meters from the camera. The original image was 3072x2048 pixels. The photo was manipulated in Photoshop to remove the injection tubing along with the bottom edge of the flume. The colors were inverted to produce a black background and the curves were utilized to bring out the blues. Photoshop's sharpen filter and auto contrast features were utilized to sharpen and increase the contrast.

I really enjoy this photo and enjoy the vibrant colors. I believe these add great detail to the photo and bring out the contrast of the photo. This allows for better visualization of the vortices as the flow separates from the cylinder. While the flow was turbulent I believe the group was able to successfully produce the formation of the vortices and through video can see the frequency at which the vortices shed off. In future work I would work to decrease the Reynolds numbers and produce more laminar flows and work to match injection velocity with flow velocity to produce more stable vortices. I believe that for a first time experience the objective of this photo was well achieved with room for further improvement.

[1] Cengel, John, and John Cimbala. *Fluid Mechanics: Fundamentals and Applications*. International. New York: McGraw-Hill, 2006. 585-586,681-682. Print.

[2] Engels, Peter. "Observing the dance of a vortex–antivortex pair, step by step." *Physics* 3. (2010): 33. Web. 13 Mar 2011. <http://physics.aps.org/articles/v3/33>.

[3] Espeyrac, Lionel. "Strouhal Instability." *Physics Knowledge*. Physics Knowledge, 2009. Web. 13 Mar 2011. <http://hmf.enseeiht.fr/travaux/CD0102/travaux/optmfn/gpfmho/01-02/grp1/phy_know.htm>.