von Kármán Vortex Street

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10-8-24

MCEN 5151: Flow Visualization – Team First

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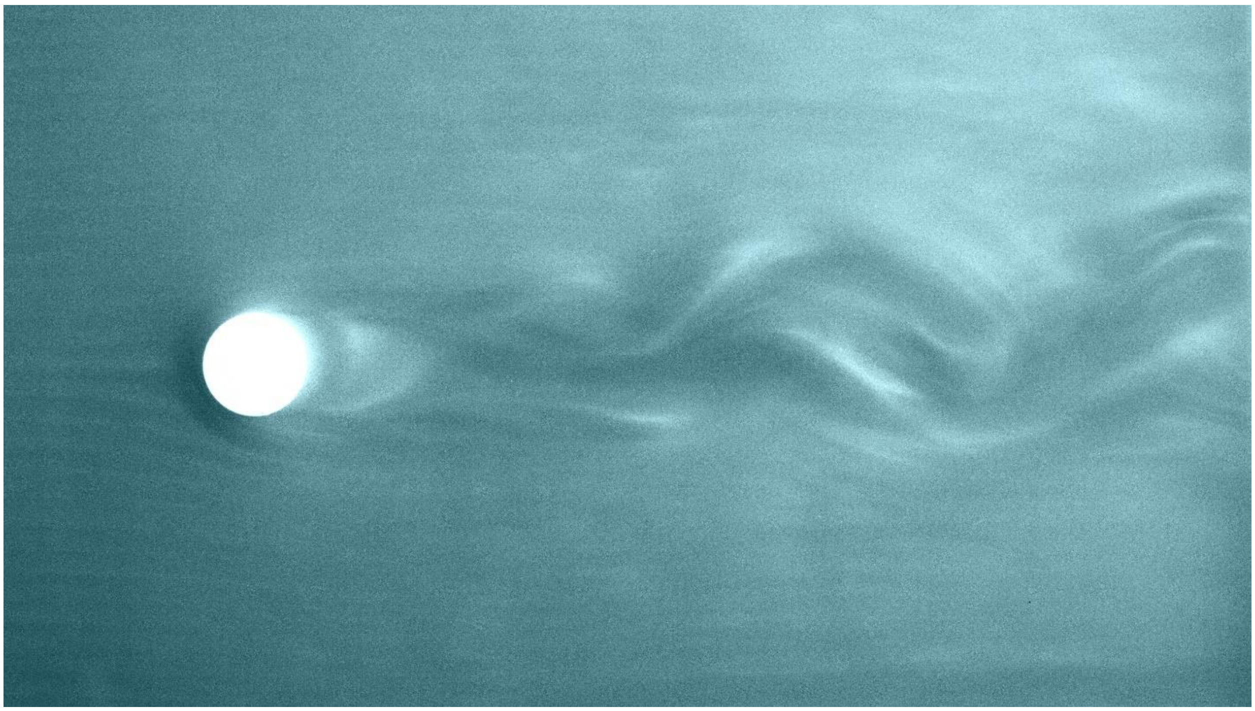

Figure 1: von Kármán vortex street behind cylinder

Introduction

Figure 1 shows a von Kármán vortex street behind a cylinder. Vortex shedding is an extremely common fluid phenomenon, occurring frequently in wakes, especially behind cylinders. It is an important phenomenon to study because it causes vibrations and fluctuating loads on objects placed in a crossflow. This visualization was created by placing a cylinder in a water tank and adding a rheoscopic fluid to the tank to make the flow visible. The goal was to clearly visualize wakes behind objects. The tank was put together with assistance from Lia and Kate, and Lia provided photography advice.

When a cylinder is placed in a crossflow at a very low velocity, a stable wake will form behind it. As the velocity increases, the wake becomes more sensitive to perturbations until it reaches the point where a perturbation in either direction will cause a vortex to be shed. This induces an opposite vortex behind it, which also sheds, and the cycle continues indefinitely. As the vortices shed, they drift downstream, and a "street" of vortices is visible.

Vortex shedding has been studied for decades. Theodore von Kármán, in 1912, is credited with the earliest major publishing on the subject. He observed that the pattern of alternating vortices appeared consistently and had certain constant traits, such as the ratio between the vortex transverse separation and longitudinal separation (von Kármán, 1912). Von Kármán also visualized the vortex street by taking long-exposure photographs of a vertically oriented cylinder in a water tank with Lycopodium seeds sprinkled on the water surface.

Experiment Overview

This experiment uses a cylinder oriented horizontally in a water tank. The channel width of the tank is approximately 3 cm to approximate a two-dimensional flow, and the cylinder spans the entire channel. The test section in the water tank is approximately 40 cm tall and 122 cm long. The fluid in the tank is water with a rheoscopic fluid added to it. The velocity in the tank was $3.5\ \frac{\mathrm{cm}}{\mathrm{s}}$. The exact parameters of the experiment are listed in Table 1.

Table 1: Experiment setup parameters

Parameter	**Value**
Tank height	$0.4064\ \mathrm{m}$
Tank depth	$0.03175\ \mathrm{m}$
Tank width	$1.2192\ \mathrm{m}$
Cylinder diameter	$0.0254\ \mathrm{m}$
Fluid velocity	$0.035\ \frac{\mathrm{m}}{\mathrm{s}}$
Fluid viscosity	$1.00 \times 10^{-6}\ \frac{\mathrm{m}^2}{\mathrm{s}}$

Borrero-Echeverry et. Al suggests a procedure for creating a low-cost rheoscopic fluid for flow visualization (Borrero-Echeverry, Crowley, & Riddick, 2018), and their procedure was used here, which is as follows:

1. Mix shaving cream with water using a shaving cream to water mass fraction of 1:20. Mix until a homogeneous mixture is formed.
2. Allow mixture to rest undisturbed for a few hours until fluid separates into a liquid and a foam.
3. Separate and discard the foam. The remaining liquid is a rheoscopic fluid which can be further diluted with water as needed.

There are 34 L of rheoscopic fluid in the tank, and the remainder of the fluid is water. The total interior dimensions of the tank are $12" \times 18" \times 48"$.

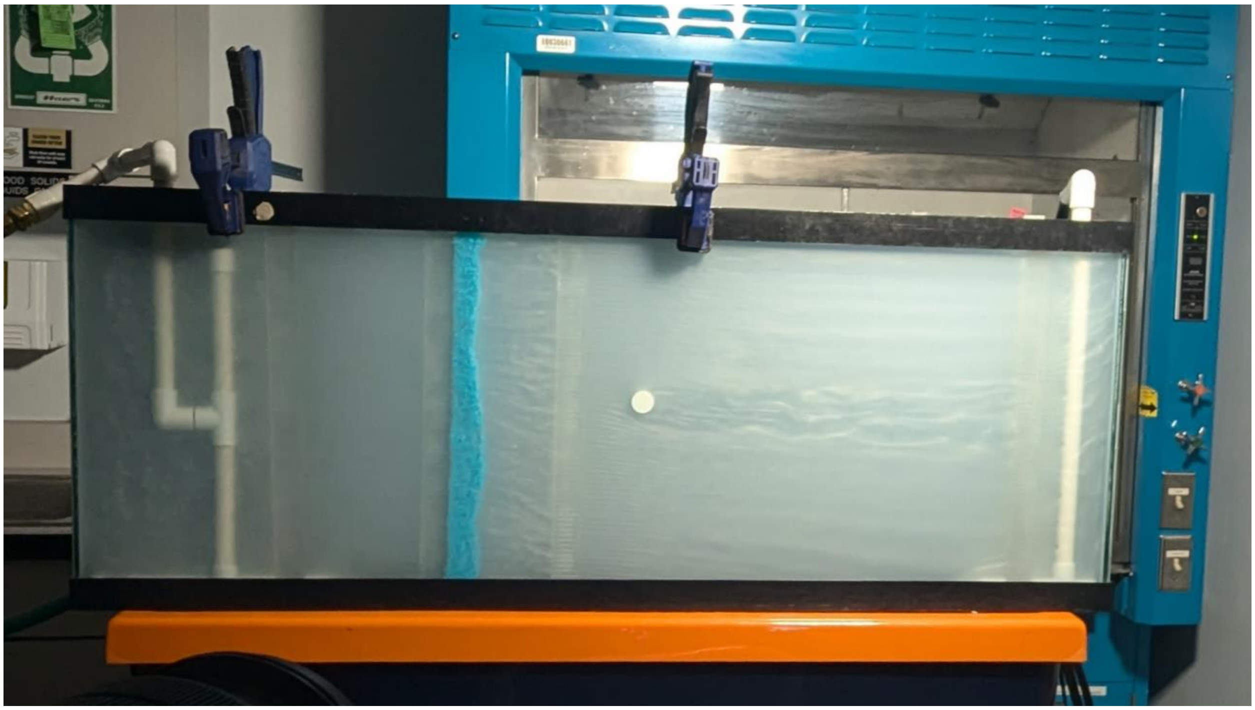

Figure 2: Experimental setup

The experimental setup is shown in Figure 2. A March Pump AC-2CP-MD centrifugal pump is used to draw water from the right side of the test section and pump it into the left section, creating a left-to-right flow. The fluid leaves and enters the test section via 9/16” ID PVC pipes with four 3/16” holes evenly spaced along their length. The flow that comes out is initially quite turbulent, and is straightened via a series of flow straighteners, pictured in Figure 2. The first type is a 1.25” deep, 1/4" acrylic grid. There is one of these immediately after the fluid inlet, and approximately 6” after that. The next flow straightener is a 1” thick piece of an open-cell foam (Dial Duracool #3073). Approximately 4” after that, there is another grid-type flow straightener, which is the final one before the test section. After the test section, there is a final grid-type flow straightener which helps eliminate the flow drifting toward the outlet suction holes in the test section. The cylinder is 3D-printed PLA, and is held in place with a small amount of plumber’s putty and by friction between the tank wall and the back of the test section. The back wall of the test section is a matte black acrylic sheet which is held in place with two quick-release clamps during testing.

The Reynolds number is:

$$\mathrm{Re_D} = \frac{VD}{\nu}$$

$$\mathrm{Re_D} = \frac{\left(0.035\,\frac{\mathrm{m}}{\mathrm{s}}\right)(0.0254\ \mathrm{m})}{1.00 \times 10^{-6}\,\frac{\mathrm{m}^2}{\mathrm{s}}}$$

$$\mathrm{Re_D} \approx 889$$

This indicates that the flow is laminar, and high enough for vortex shedding, which typically happens above Reynolds numbers of 90 or 100. Figure 1 shows flow which appears laminar apart from the wake, supporting this conclusion.

Visualization Technique

The rheoscopic fluid described was created using six cans of 10oz Smartly shaving cream (UPC: 371661828549). The contents of each can were mixed with 1.5 gallons of water and mixed thoroughly by hand in a five-gallon bucket. The mixture was then allowed to settle for at least two hours until it was thoroughly separated, then the underlying liquid was gently poured out from underneath. The tank was placed in a dark room an illuminated with a single Dimmable Bi-color 660 LED Video Light. This light was turned to the maximum brightness and all the way to the “blue” color. The light was approximately 3’ above the tank and 3’ horizontally away from the test cylinder, placed at about a 10° angle with the tank face, pointing to the left of the cylinder. The camera was placed directly in front of the cylinder, about 40” from the tank face.

Photographic Technique

Table 2 lists the camera information and the size of the original image.

Table 2: Camera information/settings

Camera model	Canon EOS REBEL T3i
Lens	EF-S18-135mm f/3.5-5.6 IS USM
Focal length	50.0mm
Aperture	5.0
Exposure	1/250
ISO	400
Image size	5184 x 3456
Field of view	45.31cm x 30.274 cm

The original image is shown in Figure 3. The image was cropped to 2818 x 1585 to cut out the flow straighteners. The contrast was increased, and the image was recolored and denoised.

Based on the velocity of the fluid, the flow is estimated to have moved about 0.14 mm during the exposure period, which is negligible.

$$\text{Exposure time} = V \times \Delta t = 0.035\,\frac{\mathrm{m}}{\mathrm{s}} \times \frac{1}{250}\ \mathrm{s} = 0.14\ \mathrm{mm}$$

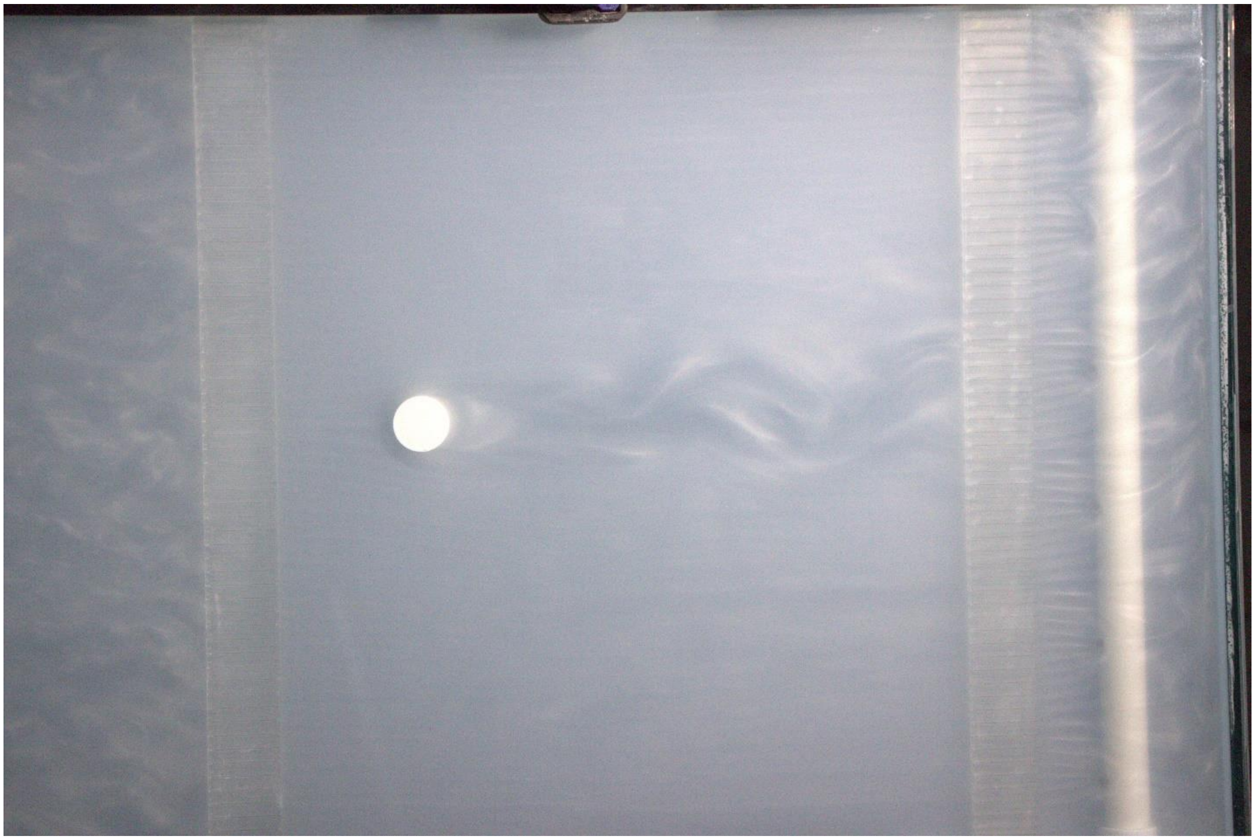

Figure 3: Original unedited image

Conclusion/Recommendations

The final image shown in Figure 1 clearly shows the wake behind a cylinder. The first two alternating vortices are captured well. However, there are things that could be clearer. Most importantly, if this experiment were repeated, more care would be taken to straighten the flow in as short of a distance as possible to maximize the length of the test section. The current test section is not long enough to clearly show the vortex street, although it does show the first few vortices. Additionally, a camera with better low light resolution might capture a less noisy image.

References

Borrero-Echeverry, D., Crowley, C. J., & Riddick, T. P. (2018, 8 1). Rheoscopic fluids in a post-Kalliroscope world. *Physics of Fluids*, 30. doi:10.1063/1.5045053

von Kármán, T. (1912). On the mechanics of resistance experienced by a body moving through a fluid. *Gottinger Nach, 13*, 547-562.