Turbulent Wake Behind an Object

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4/28/18
MCEN 4151-001

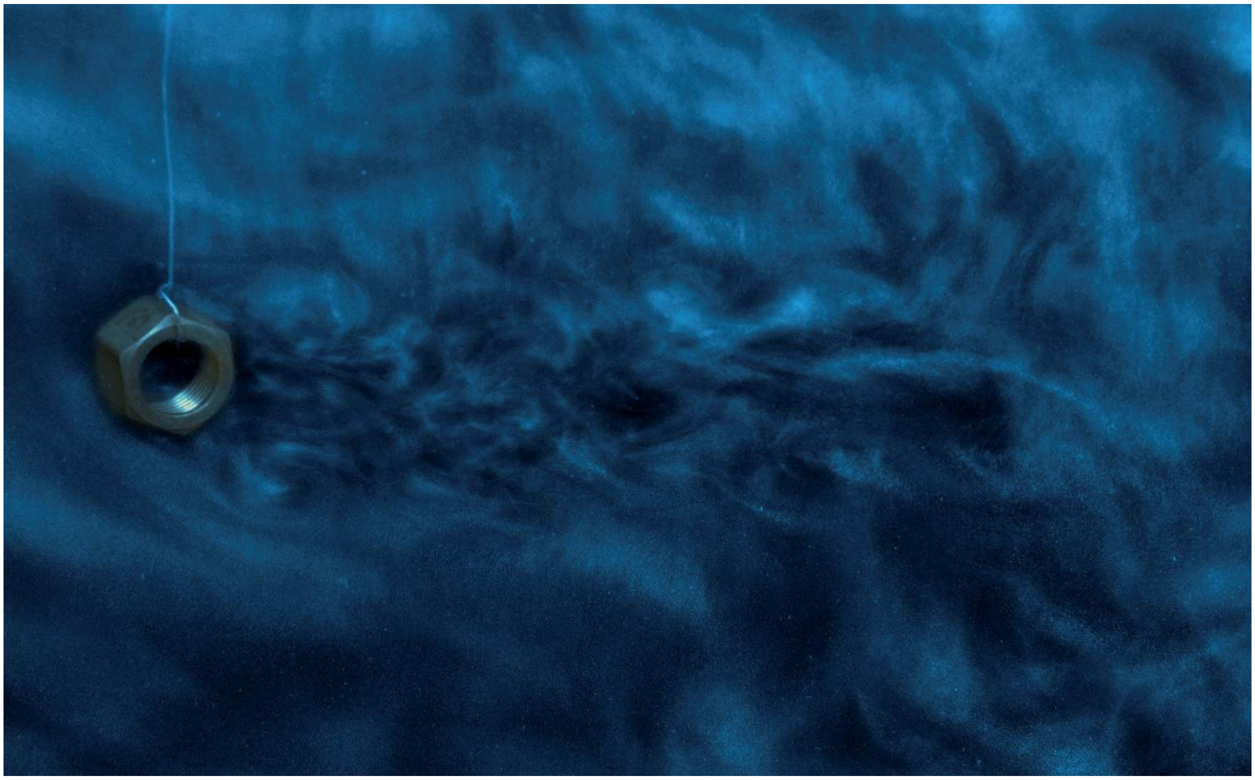

Figure 1: Final Image

INTRODUCTION

This image was created for the Team Third Project in the Flow Visualization class. The purpose of this image is to show the laminar and turbulent flow in front of and behind an object. This image was very difficult to make. The set-up was sophisticated, and there was a lot of trouble with glare due to the glass tank containing the water, so only a few good photos were produced from the experiment. The image shown in Figure 1 was one of a few images that had a clear depiction of the transition from laminar to turbulent flow. This image was taken in collaboration with Michael Guenther, Cara Medd, and Madison Emmett. Each team member had a hand in the setup of the experiment as well as image capture.

EXPERIMENT

Flow Apparatus

This experiment was done in the basement of the ITLL in the CU Engineering Center. A 55-gallon water tank was converted into a small water tunnel using a recirculating water pump, able to pump about 3 liters per minute, and simple PVC plumbing techniques. The tank was set up with a black plastic divider, which served as the background for the photos and let water flow through an inch-and-a-half-wide gap between the tank glass and the divider. On each side of the tank, between the divider and the glass, were laminar manifolds, which helped keep the flow through the tank section laminar. Also on each side of the tank were PVC pipes with holes in their sides to allow water to flow out and in during recirculation. A fluorescent light was set on top of the tank to help light the flow and the camera was placed about 6 inches away from the tank. Figures 1 and 2 show this setup in more detail.

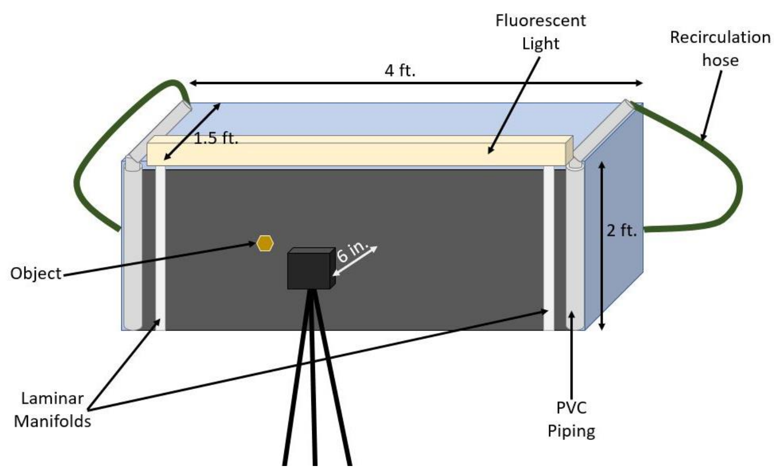

Figure 2: Experimental Setup

Figure 3: Experimental Setup

To highlight the water flow through the tank, rheoscopic fluid was poured into the tank and allowed to circulate through. A small object (the nut in Figure 1) was placed in the space between the tank and the divider to create a turbulent wake. The rheoscopic fluid used was called Pearl Swirl, a proprietary mix by Steve Spangler Science. The mix is non-toxic but the composition is not publicly known, the MSDS sheet for Pearl Swirl simply says it is a proprietary mixture, with no ingredients listed[4].

Flow Physics

To visualize the wake behind the object in the water, Pearl Swirl was poured into the circulating water to illuminate the flow. Though the actual composition is unknown, Pearl Swirl acts just like any other rheoscopic fluid. The fluid is made up of microscopic oblong particulates. In a shearing field the particles line up with the shear field. As the fluid moves, the orientation of particles change and the reflection changes. This changing reflection is what gives the pearlesque effect to the water.

The flow in Figure 1 can be described as three-dimensional turbulent flow over an object (in this case, a nut). To mathematically explain the flow, we can calculate the Reynold's Number using the following equation[3]:

$$Re = \frac{\rho V x}{\mu} = \frac{\rho Q x}{A\mu}$$

Where ρ is the density of water (it is assumed the density of water remains constant even after the addition of the Pearl Swirl.), Q is the volumetric flowrate, $3\ \frac{L}{min}$, A is the cross-sectional area of the tank, 2 ft. x 1.5 ft., x is the length of the tank, 4 ft., and μ is the dynamic viscosity of water[5], $9.737 \times 10^{-4}\,\frac{N*s}{m^2}$. The Reynold's Number of the flow turns out to be 211. This low Reynold's number indicates the flow of the water through the tank is laminar[1]. When the flow encounters the object, flow separation occurs in the wake, creating turbulence. This phenomenon can be seen in Figure 1 in the area behind the nut. The flow is three-dimensional because the nut does not span the entire area between the tank and the divider. Because of this, flow in the x, y, and z direction can be disturbed.

IMAGE CAPTURE

Image Properties

This image was taken with a Nikon D3300 DSLR camera with an 18-55mm 1:2.5-5.6 lens. The exposure time was 1/15 sec, the f-number was f/5.6, and the ISO was set at ISO-400. As shown in Figure 2, the camera was set about 6 inches from the glass tank and was angled down slightly in an attempt to reduce glare from the glass. The field of view of the image is about 7 inches from the nut to the end of the photo. The original image (shown in Figure 4) has dimensions 6000x4000 pixels while the final image has dimensions 4258x2634 pixels.

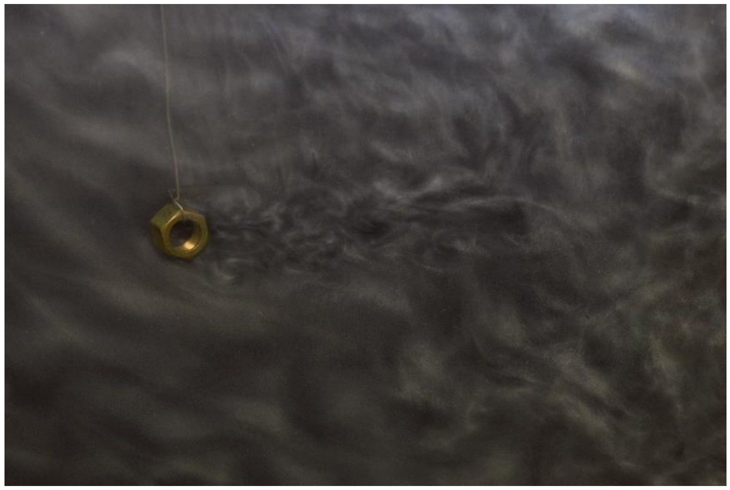

Figure 4: Original Image

Resolution

In order to determine the resolution of this photo, a pixel tolerance was calculated, allowing for a certain amount of "smear" due to motion blur. Using the final image dimensions and the field of view as a reference and assuming the water moved at a speed of 1 $\frac{ft}{min}$, (found by observation and estimation), it was determined that the shutter speed needed for a 1 pixel smear would be about 1/180 sec. This was determined by the following equation:

$$(pixels\ per\ meter) * (fluid\ speed) = \frac{pixels/_{s}}{tolerance} = \frac{1}{sec}$$

It was found that for a shutter speed of 1/15 sec, the pixel smear was about 12 pixels. This can be seen in the turbulent flow behind the nut, the details are just slightly blurred, showing some motion blur in that area.

Post-Processing

To obtain the image shown in Figure 1, the original image was cropped significantly to bring more focus to the flow. The image was made black and white and then a blue-colored photo filter was added in Photoshop. To bring some color back to the nut, the paint tool was used with a very transparent color yellow. The curves tool was used to brighten the image and then raise the contrast. This brought out the details in the rheoscopic fluid and helped further amplify the flow phenomenon.

CONCLUSION

As difficult as it was to capture this image, I do like how it came out in the end. I am glad I was able to use Photoshop to add color back into the photo. I think this photo does a good job of capturing the physics of turbulent flow while still being an aesthetically pleasing photo. If I were to repeat this experiment, I would spend more time figuring out how to reduce glare from the glass, as that caused a lot of problems in this experiment. I would also try to make a video of the fluid flow instead of just capturing one moment of the phenomenon.

REFERENCES

1) 14-2 Laminar and Turbulent Flows. (n.d.). In Y. A. Cengal, J. M. Cimbala, & R. H. Turner, *Fundamentals of Thermal-Fluid Sciences .*

2) *Pearl Swirl Rheoscopic Concentrate*. (n.d.). Retrieved from Steve Spangler Science: https://www.stevespanglerscience.com/store/pearl-swirl-rheoscopic-concentrate.html

3) *Reynolds Number & Pipe Flow.* (n.d.). Retrieved from https://ocw.mit.edu/courses/mechanical-engineering/2-000-how-and-why-machines-work-spring-2002/study-materials/TurbulentFlow.pdf

4) *Steve Spangler Science.* (n.d.). Retrieved from Material Safety Data Sheet (MSDS): http://sds.chemtel.net/webclients/texasaquarium/Rheoscopic%20Concentrate%20(Pearl%20Swirl%20Concentrate).pdf

5) *Water - Dynamic and Kinematic Viscosity*. (n.d.). Retrieved from The Engineering Toolbox: https://www.engineeringtoolbox.com/water-dynamic-kinematic-viscosity-d_596.html