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MCEN 4151

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MCEN 4151 Flow Visualization

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Background

The purpose of this first team assignment was to photograph flow phenomena in teams. Having a team of 3-4 individuals usually allows for the team to pursue complex experimental and practical demonstrations more easily. Our team, Kohlrabi, decided to photograph a seeded medium (fog in air) illuminated with a laser sheet. The expectation was to be able to capture stagnant airflows in still air and be able to calculate certain physical parameters (Reynold's number) from the photographs produced.

Experimental Setup

The experimental setup involved the following 3 instruments.: 1) A fog machine. 2) A rotating laser pointer and 3) a black velvet blanket. The equipment was set up in an empty room in the engineering center which we deemed dark enough to produce the effect we needed. The fog machine was placed perpendicular to the laser pointer. The laser pointer projected onto the black velvet blanket a few feet away. The purpose of the black velvet blanket was to reduce any reflections from the laser pointer, and served as a dark background in which the flow could be seen more clearly. The fog machine was no more than 2 feet away from the centerline of the laser. This laser has a rotating mirror at its base, which, at a high enough rotational rate, creates an elliptical projection. We used the laser in this mode as it allowed us to capture more of the flow in our photographs. The figure below shows the setup.

Physics behind the flow

The main physical parameter that team Kohlrabi aimed to measure through this experiment was the Reynolds number. The Reynolds number is a dimensionless quantity that relates the mechanical forces of a fluid to the intermolecular forces of a fluid. This number is useful to know in many situations, since it can predict the behavior of the flow. High Reynolds numbers usually demonstrate turbulent flows (chaotic, irregular), while smaller numbers demonstrate laminar flows (coherent, predictable). The equation for the Reynolds number for *external flow* is shown below[2]:

$$Re = \frac{\rho V L}{\mu} = \frac{1.05\frac{kg}{m^3} * 0.5\frac{m}{s} * 0.66\, m}{1.802 * 10^{-5}\frac{kg}{ms}} = 19{,}229$$

Where ρ is the density of the fluid. In this case, it was air at ~5000 ft ASL so roughly 1.05 kg/m^3. V is the velocity of the fluid, which was estimated to be roughly 0.5 m/s. L is the characteristic length, and in this case, it was ~2ft of 0.66 m. Finally, μ is the viscosity of air, in this case it was 1.802x10^-5 kg/m-s.

It is essentially the ratio between the mechanical forces of a fluid to the viscous forces of the fluid[1]. I calculated the Reynolds number to be ~19,000. For external flows, turbulence usually occurs above a Reynolds number of 3600. So, in this case, the flow was highly turbulent.

Why was it turbulent? I hear you ask.

Well, the longer a fluid travels, the more likely it is to transition from laminar flow to turbulent flow. Air lacks viscosity when compared to other fluids, so even slow-moving air in a room can trip to turbulent if it travels some distance. It does not take a lot of energy to make something as light as air lose all order and turn chaotic!

Vortices of a variety of sizes can be seen in the photographs taken – particularly in the left, right, and bottom of the of the elliptical cone generated by the laser sheet. This is characteristic of fully developed turbulent flow – turbulence occurs at all scales, large and small alike.

Visualization Techniques

The main visualization technique used for this photography session involved air seeded by fog illuminated by a 532nm green laser. The laser was placed perpendicular to the fog machine and beamed onto the black velvet. The laser illuminated the fog particles and revealed flow phenomena while at the same time scattering the green laser light. As such, this flow proved quite luminous in the right conditions. As such, no additional sources of lighting were needed.

Photographic Techniques

There were several cameras in this setup. I will go over the techniques and camera values for the camera used to take the image featured in this document. This camera was placed at roughly 45 degrees from the laser.

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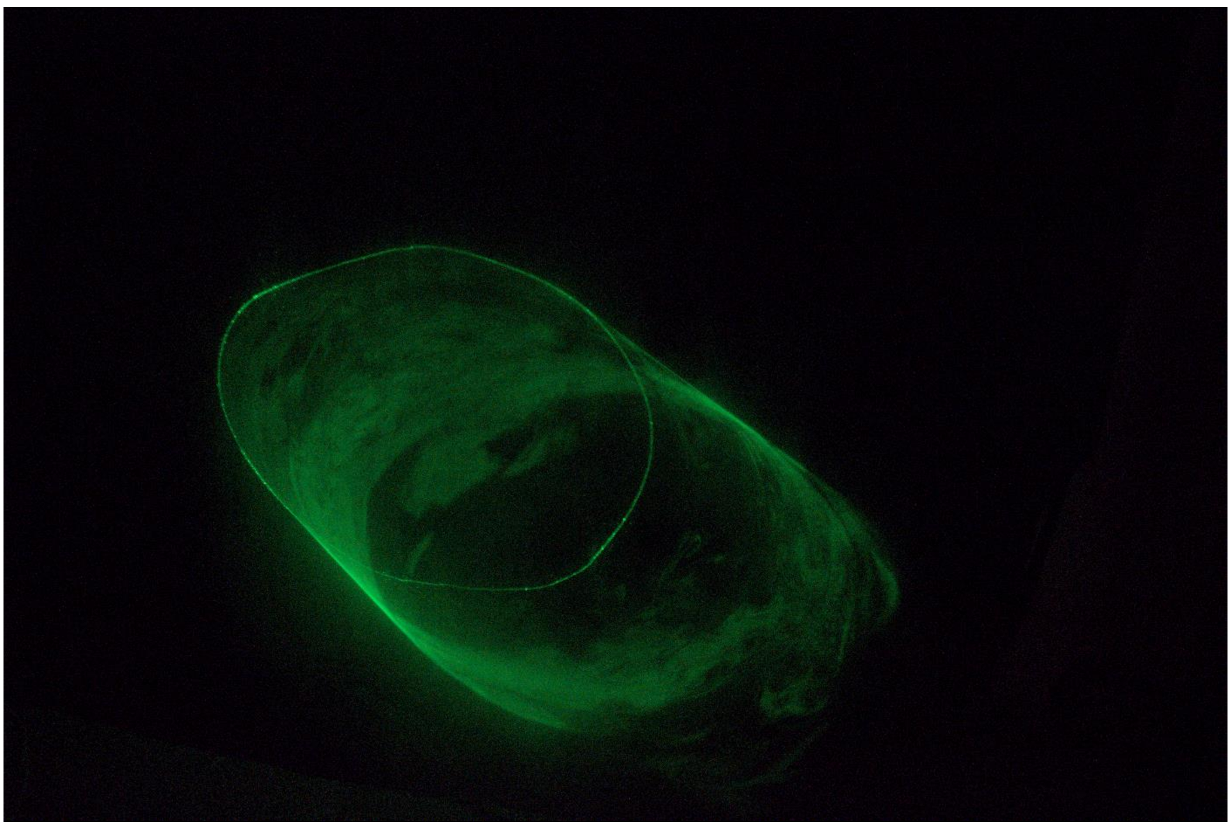
Specification	Description
Aperture	f/3.5
ISO	6400
Exposure	1/13
Focal Length	20 mm
Focus Distance	0.67 m

I decided to conduct some image processing on the selected photograph. I found that the green laser light was rather too intense and bright to properly highlight any interesting flow phenomena. As such, I processed the image using Darktable. Here, I converted the image to black and white, and used the RGB curve to reduce the intensity of the prominent green light. I also used a rather high ISO of 6400, so the image was somewhat noisy, especially in the background. As such, I also reduced the background noise on Darktable. The image was also cropped to make sure that the flow phenomenon were highlighted as much as possible.

The original, raw, unedited photograph is displayed below.



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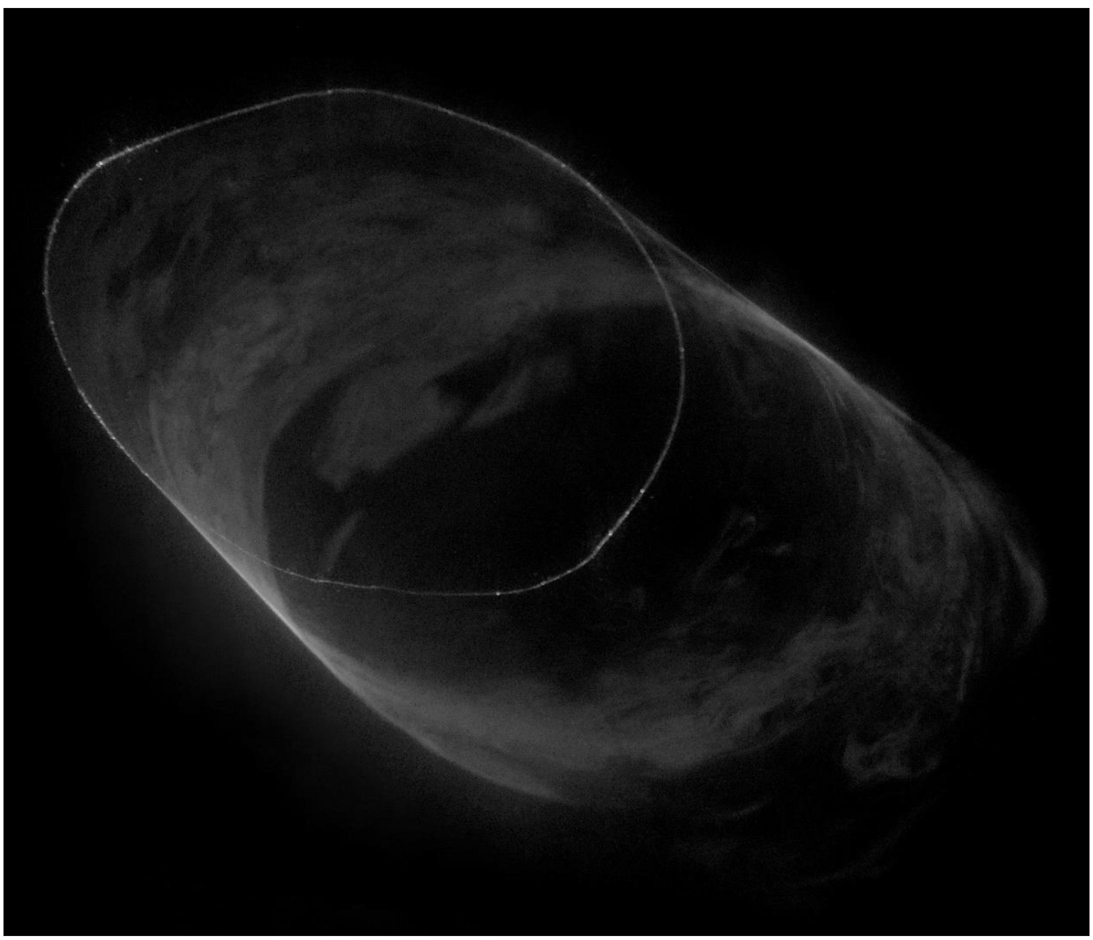
The Image Revealed

The final processed image is shown below. It reveals the turbulent flow generated by a fog machine in a room of stagnant air. One can see vortices/vortex streets forming on the left side of the ellipse. One can also see smaller vortices and turbulence on the bottom side of the ellipse as well. I do dislike the black and white colors of the image – it makes the flow appear more natural, and provides clear contrast between the flow and the surrounding environment. The fluid physics is shown quite well – turbulence is evident in this photograph. However, I do dislike that the image still appears rather blurry and noisy. Having a longer shutter speed really decreased the time resolution of the image, so the flow may appear more blurry than usual. The high ISO also reduced the overall sharpness of the image. I would say that the intent was fulfilled rather successfully. As for improvements, I could improve this experiment by using a tripod to stabilize the camera, and perhaps use a more luminous laser to increase the total light output of the system. I could then reduce my shutter speed, ISO, and aperture further to decrease any blur and get the “snapshot in time” that we were all looking for in this experiment.



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References

1. *What Is Reynolds Number? - ANSYS*, www.ansys.com/blog/what-is-reynolds-number. Accessed 6 Oct. 2023.
2. *Reynolds Number*. *Engineering ToolBox*, www.engineeringtoolbox.com/reynolds-number-d_237.html. Accessed 6 Oct. 2023.