

Laser Sliced Fog Vortices

Sam Lippincott, Kenny Olavarria, Peter Jakubczak, Hannah DelGuercio

October 6, 2023

Flow Visualization: The Physics and Art of Fluid Flow

Project 2: Team First

Introduction

The intent of the photo captured was to image slices of turbulent flow made visible by a green laser illuminating fog generated by a small fog machine. We hoped to be able to capture vortices in order to demonstrate turbulent flow denoted by a high Reynolds number.

Our team was made up of Hannah DelGuercio, Peter Jakubczak, Kenny Olavarria, and myself. We were all involved in setting up the shots and all took photos on our individual cameras and decided to share the raw files amongst ourselves so that we could individually select our favorite and edit independently. The photo I chose to use was shot by Kenny Olavarria. All post-processing and reporting is my own.

Physics Discussion

The flow on display in the image is turbulent flow. Flow can either be laminar or turbulent flow. The type of flow is determined by the Reynold's Number Re , which is defined by u velocity of the flow, ρ the density of the fluid, L the characteristic length the flow is occurring from the source, and μ the dynamic viscosity of the fluid, all in standard units.

$$Re = \frac{\rho u L}{\mu} = \frac{(2.761 \frac{kg}{m^3})(\sim 0.01 \frac{m}{s})(0.5 m)}{(1.825 \times 10^{-5} \frac{kg}{m \cdot s})} \approx 760$$

In the above equation I'm using the density of ethylene-glycol gas $(2.761 \text{ kgm}^{-3})^1$, and the dynamic viscosity of air $(1.825 \times 10^{-5} \text{ kgm}^{-1} \text{ s}^{-1})^3$. The speed and the characteristic distance are estimates.

Turbulent flow occurs when the Reynold's number is low, laminar flow occurs when the Reynold's number is high. As we can see from the above equation, for a medium as ubiquitous as air, when the velocity is particularly low, the Reynold's number will be one denoting turbulent flow. In our scenario the velocity of the flow was reasonably low, indicating the flow was turbulent. Any Reynold's number under ~ 2000 is considered a value characteristic of turbulent flow².

This hypothesis is further confirmed through the image where we can see vortices. Vortices only occur in turbulent flow.

Experimental Setup

The experimental setup was fairly simple. We hung a piece of black velvet, about a meter by two meters, from the wall so that it hung freely. Approximately half meter from the velvet, we set up the rotating laser facing the velvet so that the cone it spins out is shone onto the cloth. About half a meter from the path of the lasers and a few centimeters from the velvet backdrop, we set up the fog generator perpendicularly so that it would pump fog into the laser's path.

We rented three items from Professor Hertzberg's Flow Vis lab. They are as follows:

Equipment	Notes*
Stage Fog Generator (cooled)	Fog is a nontoxic water-based glycol solution. Can leave residue, and may trigger smoke alarms in high concentrations.
Green Laser with Rotating Mirror	
Black Velvet	

*From Flow Visualization Equipment and Facilities page on FlowVis.org

No flash or lighting sources were used other than the light directly from the laser scattering off fog particles. We thought any additional light would scatter off the fog particles as well, decreasing the effect of the intended visualization technique.

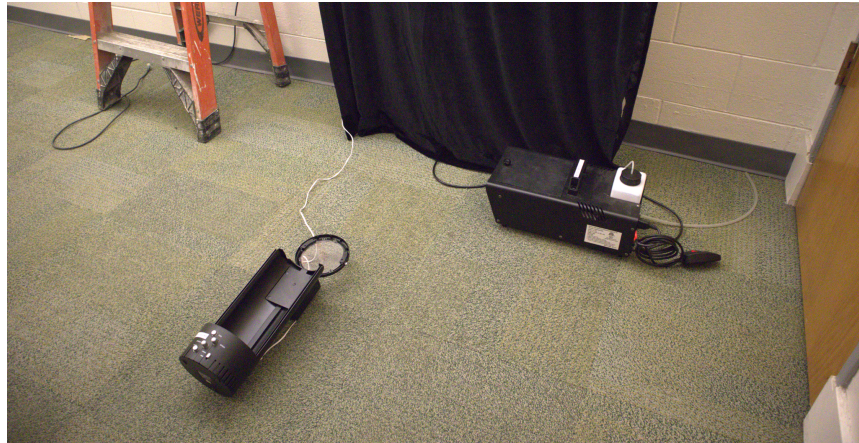


Fig. 1: Photographed Setup

Photography

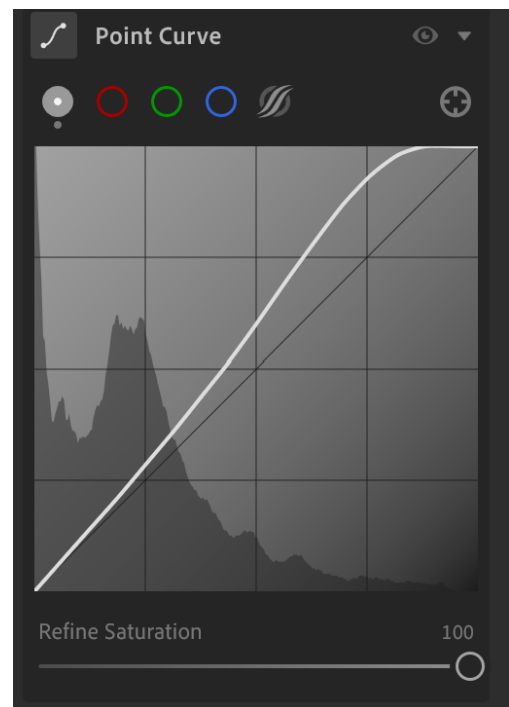
The photo itself was taken by Kenny Olavarria. The setting was a room with no windows, with the lights turned on, and ventilation on. The photo was taken from about a quarter of a meter from the fog.

The camera specifications and settings Kenny used are as so:

Camera Make and Model	Canon EOS Rebel T7
F-Stop	F/3.5
Exposure Time	1/13s
ISO	6400
Focal Length	20mm
Maximum Aperture	3.625

When it came to image post-processing, all was done in Adobe Lightroom. I removed all saturation to make the image black and white. Then, in order to bring out the vortex patterns in the imaged fog, I specifically aimed to increase the contrast, increasing the intensity of blacks and whites. The black and white lightcurve can be seen to the left. In addition to the lightcurve, I adjusted the 'Blacks' slider to -16%. A slight vignette was also added to draw focus to the notable features of the image. To do this, the 'Vignette' slider was set to -27%.

There is what appears to be image grain in the final edited image. I don't believe this is actually grain. I believe what is seen is light refracted by individual fog particles.



An interesting feature of the image can be seen in the seeming tiled replication of some fog vortices. This is due to the shutter speed the image was captured with. As the laser is tracing circles along the velvet, it cuts two slices in the fog's path at two locations each laser rotation cycle. The exposure time appears to have been long enough such that we were able to capture at least three of these cycles, creating the tiled features. Not every feature appears tiled however, which indicates that the features that were tiled are faster moving than those that don't appear tiled.

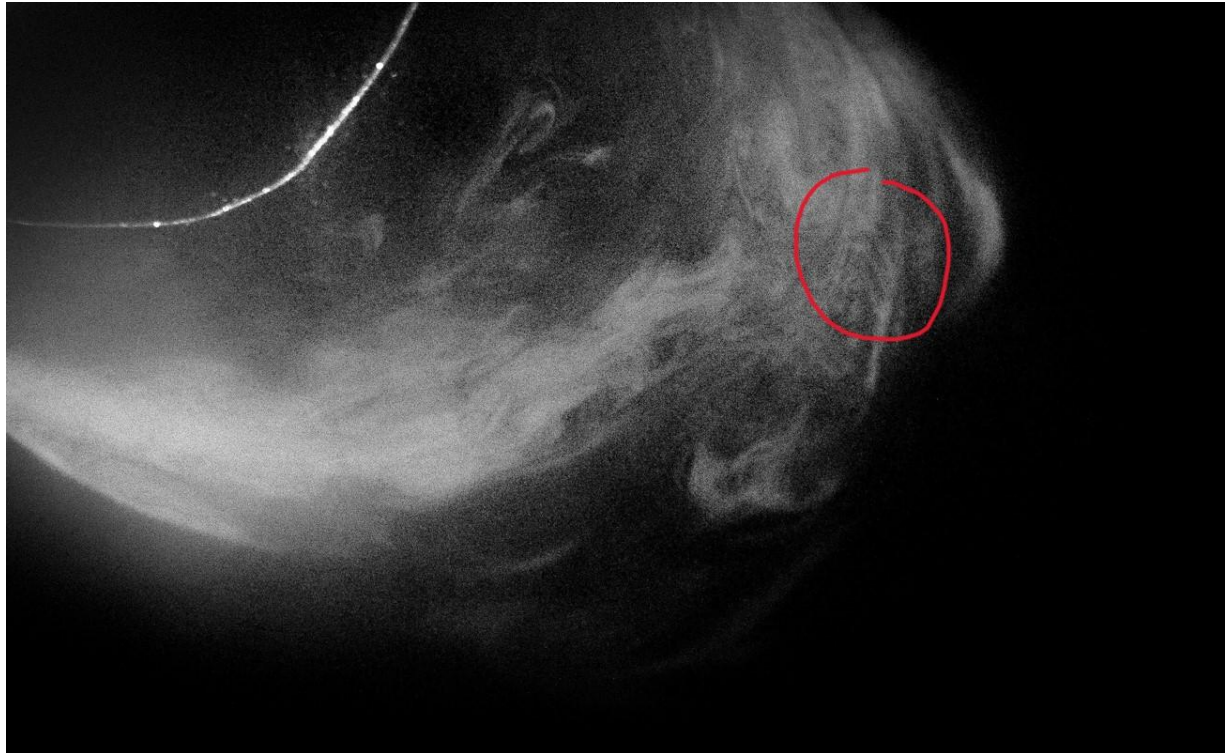
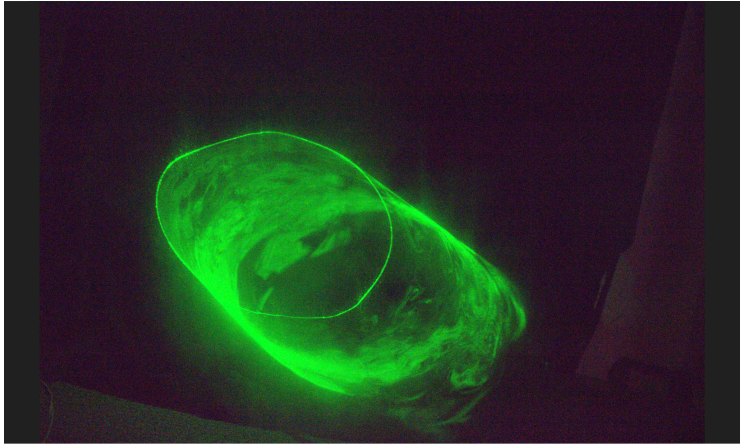
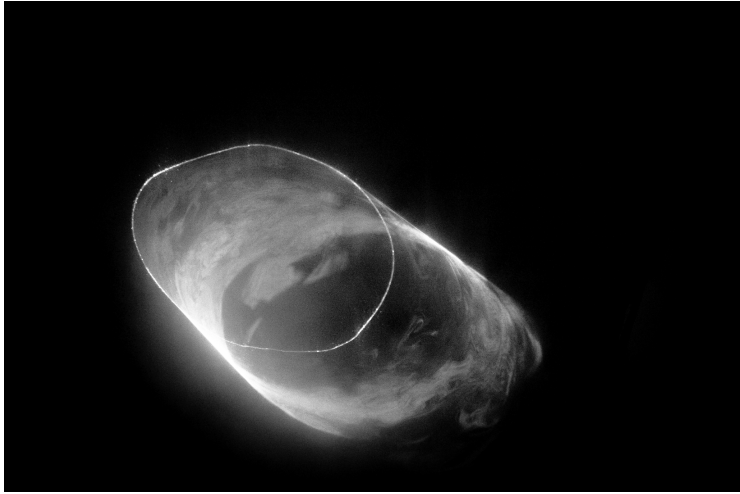
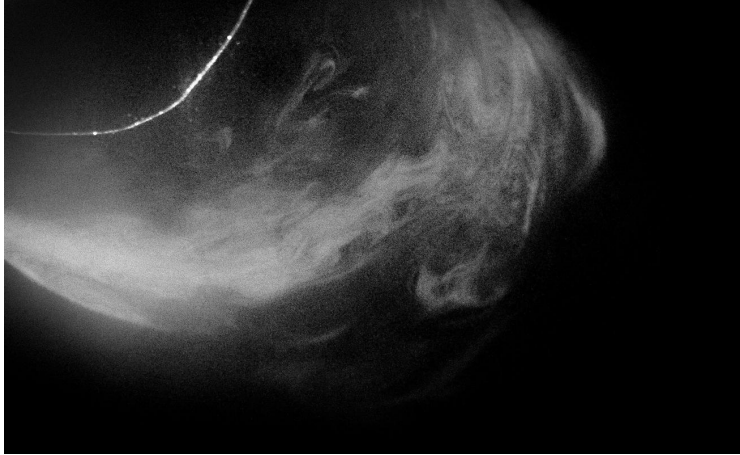


Fig. 2: Tiled Features due to shutter speed capturing multiple

The original uncropped image was interesting but I felt details could be brought into focus if I cropped the image. The raw image is 6020 x 4015 px. The cropped image was reduced to approximately 2400 x 1500 px. I regretfully forgot to record the exact dimensions when cropping it initially so this is an estimation based on an attempt to re-crop the image to find the dimensions. The JPEG file exported for distribution was resized to 1300 x 802 px.

Below are the different image iterations between editing and cropping. The raw file is a screenshot of the actual file due to the raw file type not being supported for insertion.

Fig.	Notes	Image Iteration
3	The raw image. CR2 File	 A raw image showing a bright green, glowing, irregularly shaped object against a dark background. The object has a textured, almost crystalline appearance with some internal structure visible. The background is mostly black with some faint purple and blue hues.
4	Edited. Uncropped. PNG File exported through Adobe Photoshop	 An edited image showing the same object as in Fig. 3, but with a white outline and a black background. The object is now a bright white, glowing shape with a clear white border. The background is solid black.
5	Final cropped image. JPEG File	 A final cropped image showing the same object as in Fig. 3, but with a white outline and a black background, similar to Fig. 4. The object is a bright white, glowing shape with a clear white border. The background is solid black.

Conclusion

I'm fairly happy with my final image. I think it demonstrates the flow fairly well, though I think that because it captured multiple consecutive snapshots of the flow, that it could have demonstrated the flow more effectively if it only captured a single snapshot. To do this we would have needed to set the shutter speed to less than one cycle of the laser mirror's rotation rate. If pursued further, this is something that could be done to try to improve the physics portrayal.

However, artistically I enjoy that the photo shows multiple laser cycles were captured. I think it's an interesting element on display. The light scattering off individual fog particles may reduce the perceived detail of the image, but, as a fan of film grain, I enjoy that artistic element. I also feel that the cropping I chose transformed a fairly standard photo into one that appears interstellar or even ethereal in nature.

Works Cited

- ¹“ETHYLENE GLYCOL — Maritime Integrated Decision Support Information System on Transport of Chemical Substances.” *MIDSIS-TROCS*, 11 December 2020, <https://midsis.rempec.org/en/find-chemical/ethylene-glycol>. Accessed 4 October 2023.
- ²“Laminar and Turbulent Flow.” *Engineering Library*, <https://engineeringlibrary.org/reference/laminar-and-turbulent-fluid-flow-doe-handbook>. Accessed 4 October 2023.
- ³“Viscosity of Air, Dynamic and Kinematic.” *Engineers Edge*, Engineer's Edge, LLC, https://www.engineersedge.com/physics/viscosity_of_air_dynamic_and_kinematic_14483.htm. Accessed 4 October 2023.