Team Third Report

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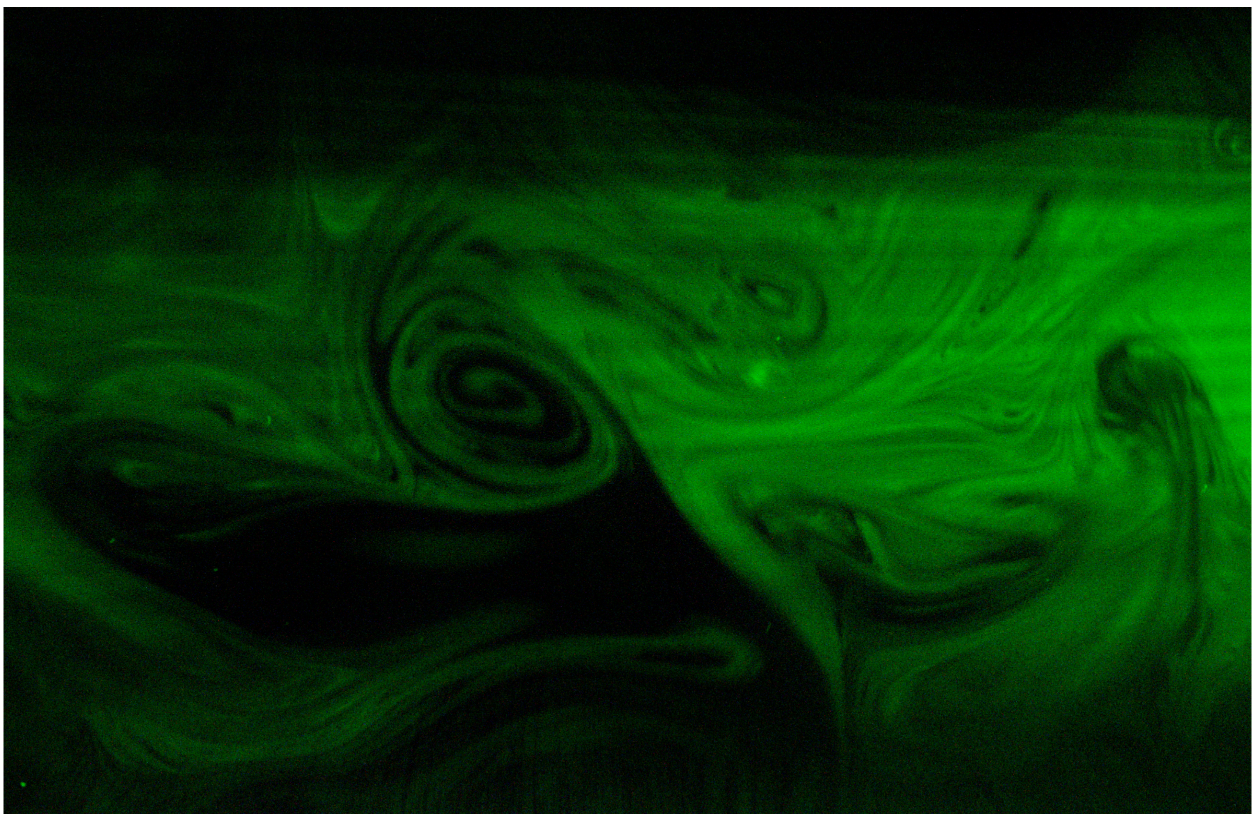

Figure 1. Final Image of Fog Swirling Through a Laser Sheet

Background

This image was created for the fifth assignment of the Flow Visualization course, Team Third, with the assistance of Jessica Vo and Adiba Ashrafee. This image captures swirling fluid flow patterns in the fog illuminated by a green laser sheet. The goal of this experiment was to visualize the dynamic interaction of light and fluid motion, emphasizing the swirling vortices, turbulence, and laminar-turbulent transitions present in the illuminated plane. For the experiment, fog was introduced into the flow field using a fog machine and illuminated using a green laser to highlight the motion of particles suspended in the medium. This setup allowed for a two-dimensional slice of the flow to be visualized, revealing details such as vortex formation and flow instabilities. I had issues with getting a clear image in the dark, so the final image is a little grainy but it still shows the flow quite well. I cut down an optical glass rod to create the laser sheet and Adiba, Jessica, and I collaboratively set up the experiment and took turns shining the laser and turning on the fog. All of the materials used were borrowed from Professor Hertzberg. The photography phase involved careful positioning of the laser and camera to capture the intricate details of the illuminated flow.

Fluid Physics

The fluid dynamics observed in this image illustrate key flow phenomena, such as swirling vortices, turbulence, and the transition between laminar and turbulent flow. These patterns are created by the motion of fog particles within the flow field and shown using a green laser sheet. The behavior of the fluid can be explained by the interplay of inertial forces, viscous forces, and instabilities within the system.

The formation of vortices is driven by differences in velocity and pressure within the flow, a phenomenon governed by the Navier-Stokes equations. Vortex structures represent regions where rotational motion dominates, and their size and intensity depend on the Reynolds number (Re):

$$Re = \frac{\rho U L}{\mu}$$

Here, ρ is the fluid density, U is the characteristic velocity, L is the characteristic length scale, and μ is the fluid's dynamic viscosity. A high Reynolds number, as seen in this image, indicates that inertial forces dominate over viscous forces, leading to turbulent flow and the development of chaotic, multi-scale vortices.

The transition from laminar to turbulent flow is marked by the appearance of instabilities, such as Kelvin-Helmholtz instabilities, which arise from velocity gradients between fluid layers. These instabilities can be observed in the wavy structures and swirling motion in the illuminated fog.

Light scattering by the fog particles reveals the fluid motion and highlights regions of higher velocity gradients and mixing. This interaction is described by Mie scattering, where the intensity of scattered light depends on the particle size relative to the laser wavelength.

Visualization Technique

The visualization techniques used to capture the final image (Figure 1) are straightforward and somewhat easy to replicate with the right materials and safety measures. To achieve this effect, we used a fog machine, a high power green laser pointer, a small piece of optical rod, a 3 prong lab clamp & stand, black velvet fabric, a black metal back plate, laser safety goggles, black foam core, a tripod, and a way of holding up the fabric. The fabric was draped over two chairs, and secured using hair ties, to create a backdrop as the velvet helps absorb light better and create a dark background for the image. I cut down an optical rod into a shorter piece that would fit into the laser pointer cap to create a flat laser sheet that sliced the fog. We then tuned on the fog machine for short bursts, and captured the flow being sliced by the laser sheet. We also occasionally flapped a piece of foamcore to introduce air into the fog and create more turbulence. We had one person turning on the laser and one person turning on the fog machine because the laser pointer button had to be held down constantly to be on. We also made sure we were being safe the entire process, we only had one pair of goggles so the person turning on the laser wore those, and then we used the foam core boards to check if there was any laser scatter where the rest of us were standing. I had my camera set up on a tripod to make sure my camera was steady while the image was being taken, which is important when using slower shutter speed. Some of the striations in the laser might be due to surface imperfections on the optical rod the laser was passing through.

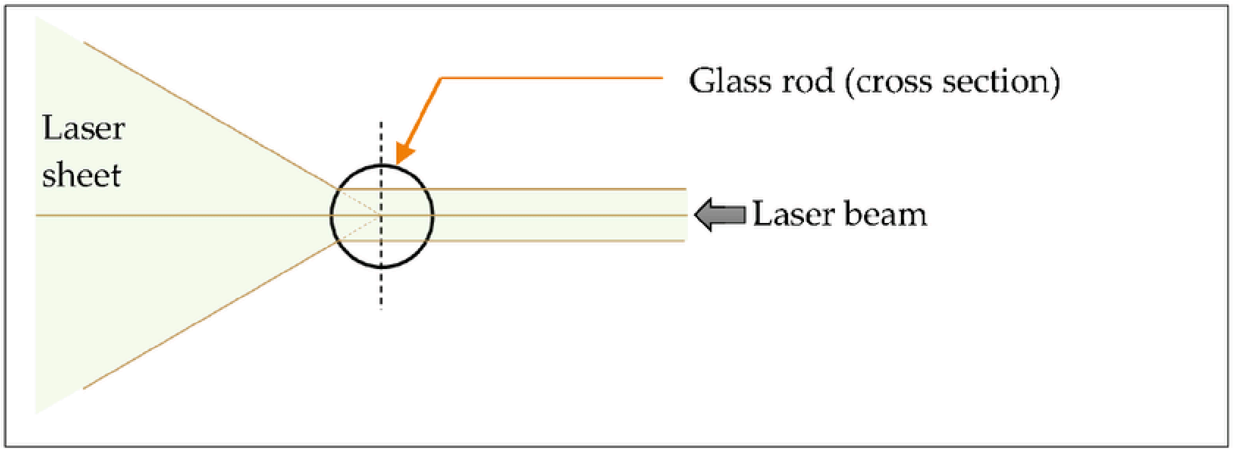

Figure 2. Cross-section of the optical arrangement to create a flat laser sheet. The laser beam is perpendicular to the glass rod.

Photographic Technique

The image was taken on a Canon EOS 2000D (also known as the Canon EOS Rebel T7) from about 1-2 ft away from the laser sheet. The lens used was a Canon zoom lens with an 18-55mm focal length, 1:3.5-5.6 aperture, and a thread diameter of 58mm. The original picture (*Figure 3*) was 6000 x 4000 pixels and was cropped to 6013×3195 pixels (*Figure 1*) which removed some of the background area and non visually stimulating areas.

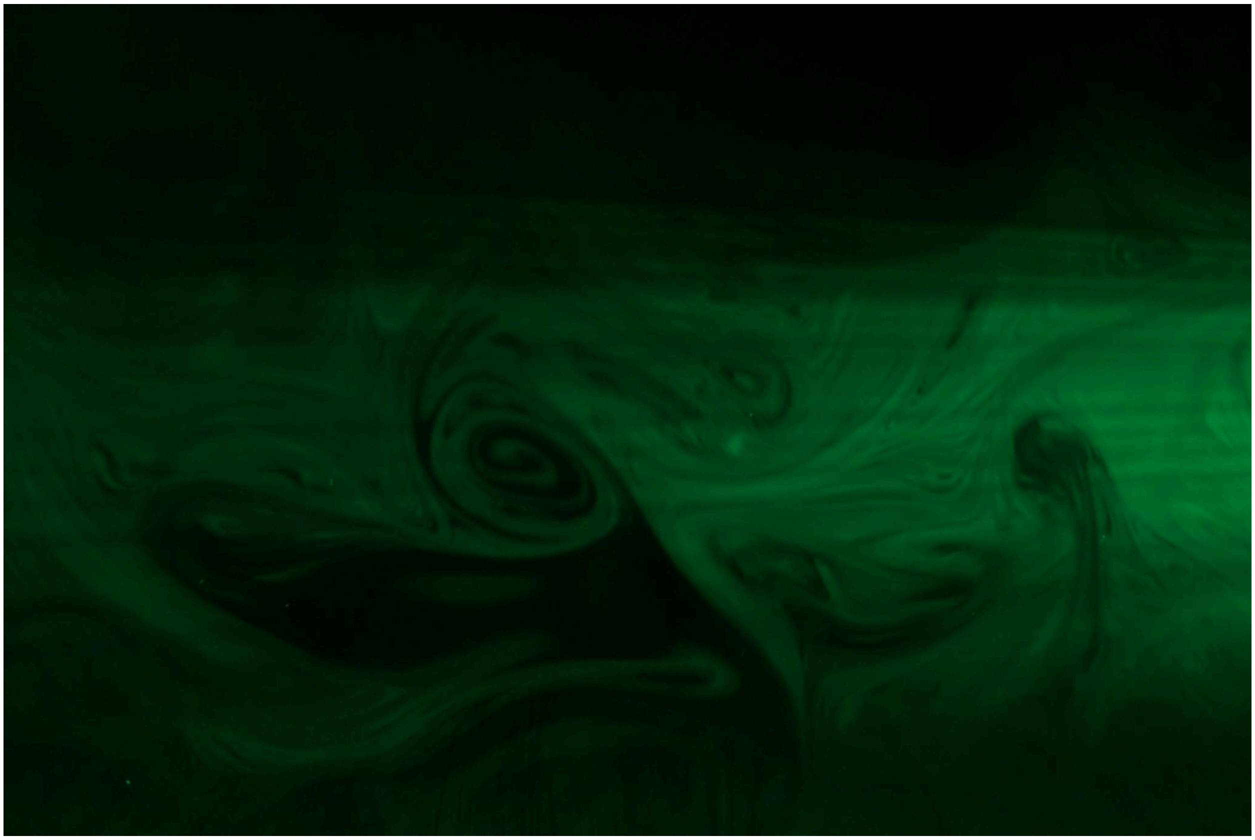

Figure 3. Original Image of Fog Swirling Through a Laser Sheet

The photo was taken with 3200 ISO, a focal length of 33mm, an aperture of *ƒ*9, and a 1/13s shutter speed. Using darktable the image was post-processed to increase the contrast and vibrance, highlighting the flow and creating more dimension within the image. The contrast was increased to emphasize the separation in the fog. I also messed with the saturation, hue, and color brightness to further enhance the colors.

Conclusion

The image highlights the intricate patterns of fluid motion, showcasing the beauty of swirling vortices and turbulence illuminated by the laser sheet. The interplay of fog and light creates a dynamic visualization of fluid dynamics, with the green laser effectively emphasizing the flow structures. I am quite pleased with how the laser sheet captured the details of the instabilities and the smooth yet chaotic transitions between flow sections. While I am satisfied with the final image, I wish it were less grainy, as achieving a sharper focus in the dark proved challenging. In the future, I would like to explore using a better camera for lowlight and experimenting with different lighting techniques to enhance clarity. Additionally, refining the setup to minimize light striations could further improve the image quality. Overall, I believe this image successfully captured the intended flow visualization and demonstrated the interaction between light and fluid motion.

References

A Modelling and Validation Approach for Predicting Particle Concentrations of Airborne Dust during the Filling Process of Cylindrical Silos - Scientific Figure on ResearchGate. Available from: https://www.researchgate.net/figure/Cross-section-of-the-optical-arrangement-to-create-a-flat-laser-sheet-The-laser-beam-is_fig3_349433468 [accessed 6 Dec 2024]

Mie, G. (1908). *Contributions to the optics of turbid media, particularly colloidal metal solutions* (translated by W. A. Gustafson). Retrieved from https://scattport.org/images/pdfs/SAND78-6018-Mie-1908-translation.pdf