Flow Visualization: Team Second Report

MCEN 5151: Flow Visualization

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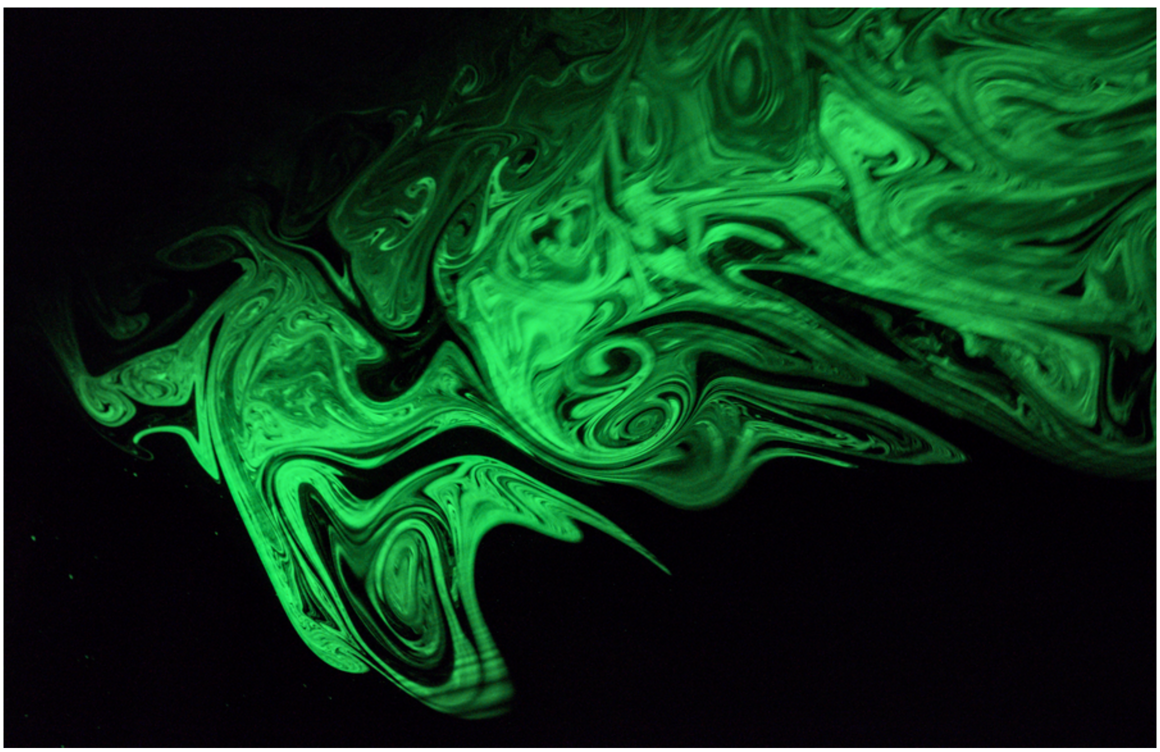

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I Introduction and Background

Visualization of fluid flow plays a pivotal role in the fields of fluid dynamics and engineering, offering invaluable insights into the characteristics and dynamics of fluid motion. Furthermore, a considerable portion of these experiments can be carried out using easily accessible and cost-friendly materials, producing captivating visual representations that illustrate the underlying physics. With this in mind, the overall purpose of this experiment was to collaborate with a team in order to capture the fluid phenomenon of our choice. As Team Purslane, we decided to photograph fog being sprayed into a green 2-D planar laser in order to capture the turbulence generated by the expanding fog. This would then allow us to calculate certain parameters such as the Reynolds number.

II Experimental Set-up

For the experimental setup, I used a green laser pointer from Amazon, a fog machine, a glass cylinder, and a black backdrop in order to force more of the fog into the laser plane.

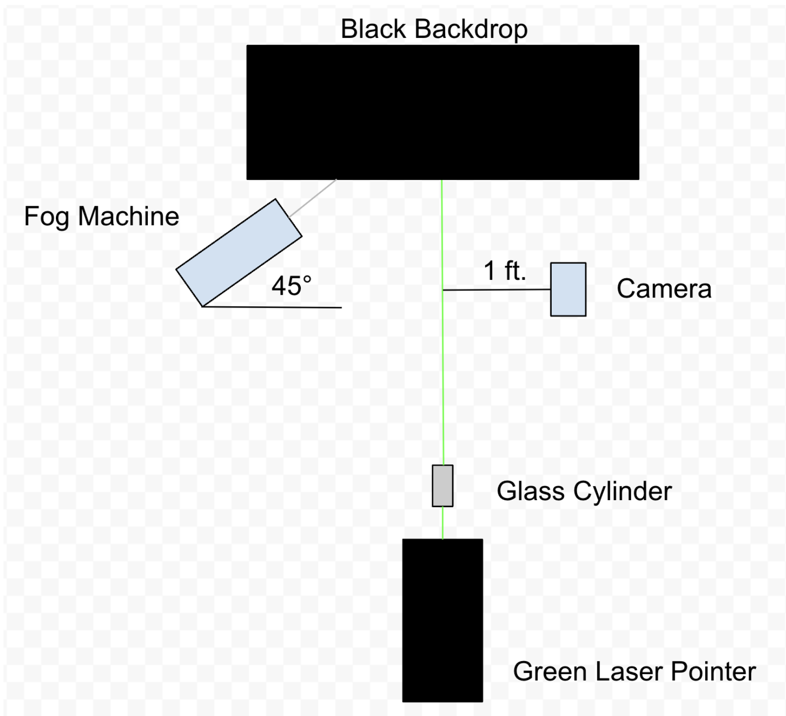


Figure 1: Diagram of the Experimental Setup

Figure (1) showcases a diagram of the experimental setup in order to get a better idea of where everything was placed. Additionally, Table (1) below showcases a summarized list of all the equipment used in the experiment

#	Equipment
1	High Power Green Laser Pointer (2000 Meter Range)
2	6 in. tall glass rod and 1/2 in. thick
3	Small Fog Machine from Amazon
4	Cannon EOS Rebel T7
5	Black Backdrop Sheet

Table 1: Elements of the Experimental Setup

To begin, the laser was set up on top of an existing box to give it some distance from the ground (About 2 ft.). This would allow for a more effective 2D plane to be created as having it too close to the ground could cause interference. Next, the black backdrop was pinned in front of an existing wall along with the fog machine placed at about a 45-degree angle relative to the backdrop. The reasoning behind this is to force more of the fog coming out into the planar laser and have it develop in a particular way that we found to be quite effective for turbulence. The final piece to this is creating the vertical 2D laser plane by placing the glass rod in front of the opening of the laser, this causes total internal reflection which results in the 2D plane that allows the fog to be visible. Once this was done, the lights in the room were turned off to prevent any interference with the laser plane. The fog machine would then be remotely controlled to release fog for about 3 -5 seconds. However, a photo was not taken immediately as the fog had to continue developing into turbulence for about another 5 seconds. A recommendation here is to have someone at the side of the 2D laser plane looking into their camera throughout the entire process. This is because there are several interesting forms the fog can take and they are equally interesting to what I captured. This was repeated several times to get a different pattern each time but was relatively quick once all the equipment was set up.

III Fluid Mechanics

The main parameter that Team Purslane was trying to capture in this experiment is the Reynolds Number. This is a dimensionless quantity that serves to categorize a fluid's motion in terms of laminar or turbulent flow, each having very different properties. It essentially relates the inertial forces to viscous forces within a fluid mechanical system [2]. A high Reynolds number, usually beyond 2100 classifies it as turbulent whereas numbers equal to or less than 2100 would be classified as laminar flow [3]. The equation to find this value is as follows in Equation (1).
Where:

$$Re = \frac{\rho u d}{\mu} \tag{1}$$

Such that:

ρ = Density of the Fluid
u = Velocity of the Fluid
d = Diameter of the Passage
μ = Dynamic Viscosity of the Fluid

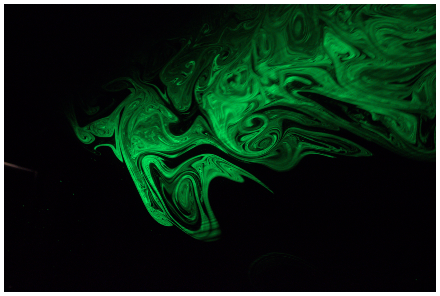
In this case, the diameter of the passage is the exit from the fog machine and is estimated to be 0.0508 m (2 in.). The velocity of the fog exiting is estimated to be 1 $\frac{m}{s}$. Although different, for ease of calculation, we can assume the fluid to be air rather than fog. The density of air can be estimated to be 1.292 $\frac{kg}{m^3}$. Finally, the viscosity of air can be estimated as $1.802E-5\frac{kg}{m-s}$.
Putting all these values into Equation (1):

$$Re = \frac{1.292 * 1 * 0.0508}{1.802^{-5}} = \boxed{3642 > 2100} \text{ and hence is a turbulent flow.}$$

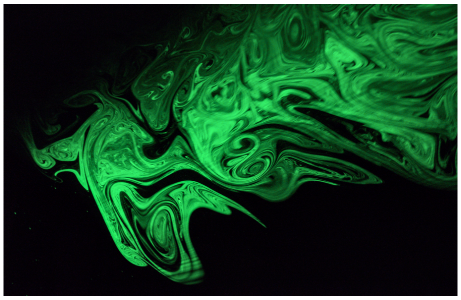
Aside from the Reynolds number, a unique feature of this experiment is how the fluid coming out of the fog machine also coalesces into one fluid. From the video I took which is visible on flowvis.org, the fluid initially leaves as as two different fluids seen from the two different textures but eventually develops into a single form. Although there are visible eddies in the final image this could signify how this is caused by the two different fluids trying to unify rather than the flow actually developing to be turbulent. Although this is a possibility, there isn't necessarily a proper way to prove this at the moment, and the Reynolds number further supports its turbulent flow.

IV Visualization and Photographic Techniques

The photograph was captured by using marked boundary techniques [1]. This is done by introducing a green 2D laser plane into a system that initially contained only fog. This allowed for the more detailed patterns within the fog to be captured after a few seconds of development. This also assisted in providing lighting to the fog as the image needed to be captured in a dark room to provide the black and green contrast. Figure (2a) showcases the final photo captured using this technique, however, the green felt lackluster which is where editing helped enhance this.



(a) Original Photo



(b) Edited Photo

Figure 2: Original vs. Edited Photo

The final photo was captured on a Cannon EOS T7 Rebel which is a DSLR camera. The camera settings were set to ISO-3200, with an aperture of f/4.5, a focal length of 23 mm, and a shutter speed of $\frac{1}{13}$. The pixels of the final image were captured at 6000x4000 but sized down to 900x1300 in the cropped version. As for the video I recorded, it was originally captured at 4K with 60 fps, however, due to converting to YouTube, the quality was reduced to 1080p with the same frame rate. The final image was then edited in Darktable where the contrast was adjusted to increase the brightness of the green hue. Additionally, the RGB curve was also adjusted to darken the background while also further enhancing the green color as I wanted as much contrast between the fog and background. Figure (2b) showcases all of these implemented changes.

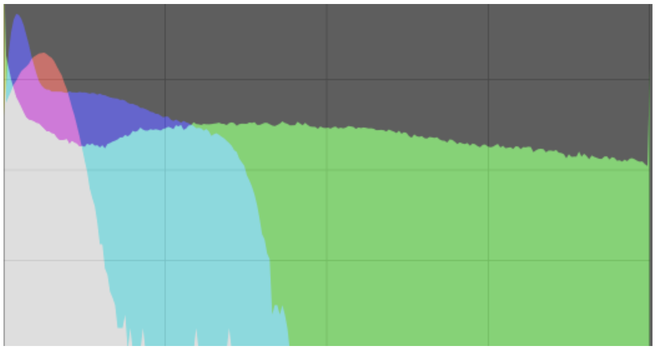


Figure 3: Final Color Histogram

Figure (3) above showcases the final color histogram of the final image after applying all of the edits within Darktable. The green is emphasized much more compared to every other color leading to a vibrant final piece.

V Conclusion

I believe this image reveals some interesting insights into how turbulence behaves as a flow expands. The fog is initially dense, and lacks many of the details seen in the final image taken. However, over time it develops distinct features, such as vortices, eddies, and showcases the common characteristics of turbulent flow. The final image I took contained some great color which was only further enhanced by using Darktable to brighten the green and darken the background. One thing I disliked was the slight motion blur on the right side of the image. I think this would've been even better if I somehow captured it completely still as seen in the left side of the photo. This would allow for more observable details to be seen rather than a blur. However, this is quite challenging to do given that the flow keeps moving and the image has to be taken in a dark room. If I were to perform this experiment again, I would have a way of holding the glass rod in front of the laser without having to have a person do it. This would allow for more stability in the plane as one of our issues was holding the rod for long periods would lead to the person's arm being fatigued and the laser plane being unstable. I would also consider experimenting with different colored lasers. We previously tried a red laser which led to very subpar results, however, we do wonder if a color other than green is capable of providing even finer details within the developing fog. Nonetheless, I consider this experiment a success, the flow pattern of the fog is astounding to me and there were several more iterations of this pattern captured during this experiment that are as note-worthy as the one I took.

VI References

[1] Hertzberg, J. (2023, July 13). Overview 2: Visualization techniques. Flow Visualization. https://www.flowvis.org/Flow

[2] Rapp, B. E. (2016, December 6). Fluids. Microfluidics: Modelling, Mechanics and Mathematics. https://www.sciencedirect.com/science/article/pii/B9781455731411500095

[3] Rehm, B., Haghshenas, A., Paknejad, A., & Schubert, J. (2013, October 30). Situational Problems in MPD. Managed Pressure Drilling. https://www.sciencedirect.com/science/article/pii/B9781933762241500085