Visualization of Turbulent Flow of Air using Machine Generated Fog and a Laser

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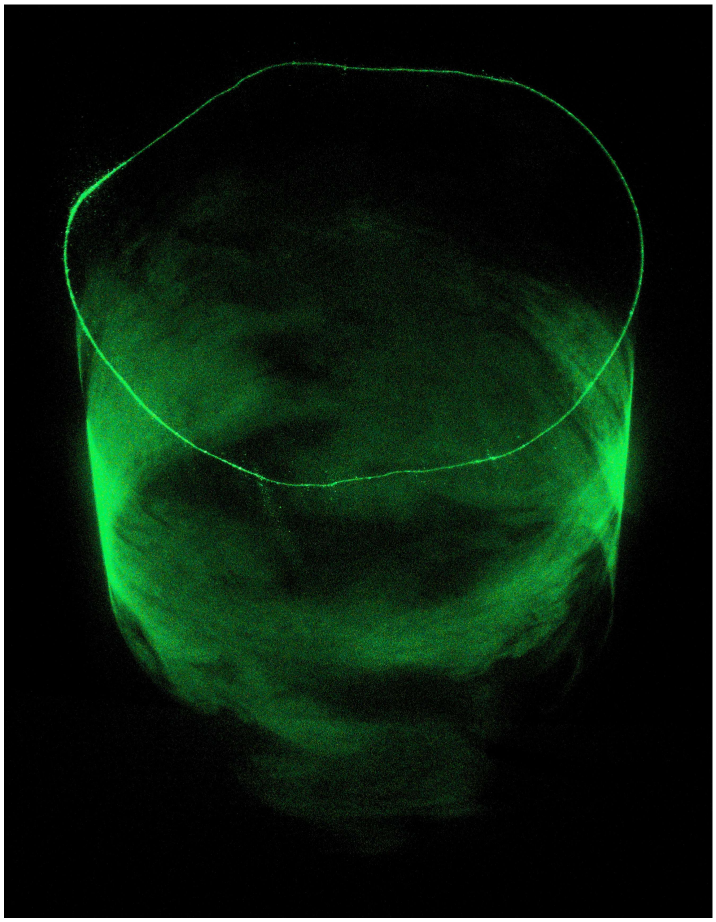

Figure 1. Fog Illuminated by a Laser Demonstrating Turbulent Flow of Air

Background

The image in Figure 1 is of machine generated fog illuminated by a laser in a dark room. The intent of the image is to depict the turbulent flow of air caused by the installed ventilation, demonstrating key physics principles such as Reynolds Numbers, Rayleigh-Taylor Instability, and Karman Vortex Street. Further analysis of these principles helps explain why certain characteristics are in the image.

Set Up

The equipment for this experiment included a laser sheet desk toy, stage fog generator, and a black velvet sheet. The fog generator and the laser were set up perpendicular to each other, with the output of the fog machine approximately one foot away from the center of the laser. The laser was pointed at the black velvet sheet to reduce reflection from any light in the room as well as prevent bounceback from the laser. To capture the photograph, all the lights in the room were turned off, excess light was reduced, and the laser was set to spin in a circle at the highest rate allowed by the laser toy. The spinning laser created a cone in the fog, illuminating the fog particles which allowed it to be captured by camera.

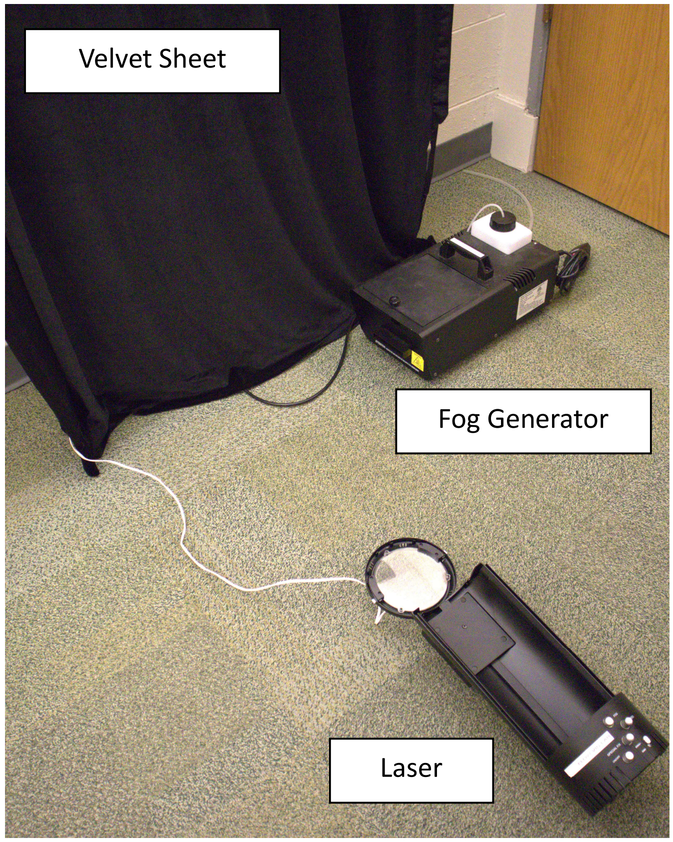

Figure 1. The Fog Machine and Laser Setup

Physics of the Fluid

Figure 1 captures three different types of fluids phenomena: 1) Reynolds Numbers, 2) Rayleigh-Taylor Instability, and 3) Karman Vortex Street. Each directly influences the photograph and helps explain why and how the fog is shaped.

Reynolds Number

Reynolds Number is a mathematical approach to describe whether the flow is turbulent or laminar. Laminar flow is smooth flow where the layers of the fluid move undisturbed and is described by a Reynolds Number of less than 2000. Turbulent flow has a Reynolds Number higher than 4000 and the layers of the fluid regularly mix. The Reynolds Number for the experiment was estimated to be 3.94x10^6 using equation 1 [1]. The mean velocity was estimated using average ventilation data for a main supply duct [2].

$$Reynolds\ Number\ (Re) = \frac{\rho DV}{\mu} = \frac{1.23\frac{kg}{m^3}*8\ m*6\frac{m}{s}}{0.15*10^{-4}\frac{m^2}{s}} \quad \text{Eq.1}$$

$$\rho = density\ of\ air;\ D = length\ of\ the\ room; V = mean\ velocity;\ \mu = viscosity\ of\ a\ fluid$$

A high Reynolds Number is regularly characterized by vortices, which can be seen on both the right and left sides of the photograph towards the edge of the cone. Another important characteristic to note is that the vortices are different sizes. The different sizes are indicative of fully developed turbulence. Another key component affecting the flow captured, is the wall near the photograph location. Walls create predictable vortex structures, down sweeping motion, and bursting [3]. This phenomenon helped create the vortices captured in the image.

Visualization Techniques

To capture this image, there were several different approaches used before the final image was captured. While the fog machine was running, we had three different people capturing photographs from different angles with different aspects. We also rotated our positions throughout, so each photographer took pictures from each angle. The three angles we took pictures from were from behind the fog machine, behind the laser, and across from the fog machine. Each camera also had varying settings, listed in Table 1.

Table 1. Camera Specifications for each Camera

Specification	Camera #1	Camera #2	Camera #3
Aperture	f/5.6	f/3.5	f/5.6
Exposure	1/5 seconds	1/2 seconds	1.3 seconds
ISO	12800	6400	6400
Focal Length	30 mm	21 mm	18 mm

Photographic Techniques

Several different photographic techniques were used throughout the experiment, including various settings, distances, and angles. However, for my final image, I selected an image from directly behind the laser. It best demonstrates the flow of the fluid while providing the most artistic image. The camera used to photograph this experiment was the Canon EOS M50 Mark II with a 15 to 45 mm lens. The photograph selected had the camera characteristics listed in Table 2 at the time of the photograph.

Table 2. Camera Specifications for the Photograph

Specification	Description
Aperture	f/5.6
Exposure	1/5
ISO	12800
Focal Length	30 mm
Focal Distance	1.43 m

Once the photograph was selected, it was edited to better demonstrate the desired flow visualization techniques. The original photograph, seen in Figure 3, dimensions were 6024 pixels wide and 4020 pixels tall. The image final image was cropped to 2670 pixels wide and 3442 pixels tall to emphasize the smoke particles. Next, an s-curve was added to the RGB curve. The intent of this adjustment was to accentuate the turbulent flow of the fog illuminated by the laser and mitigate fog particles illuminated by reflecting light. It also enhanced the contrast between colors [4].

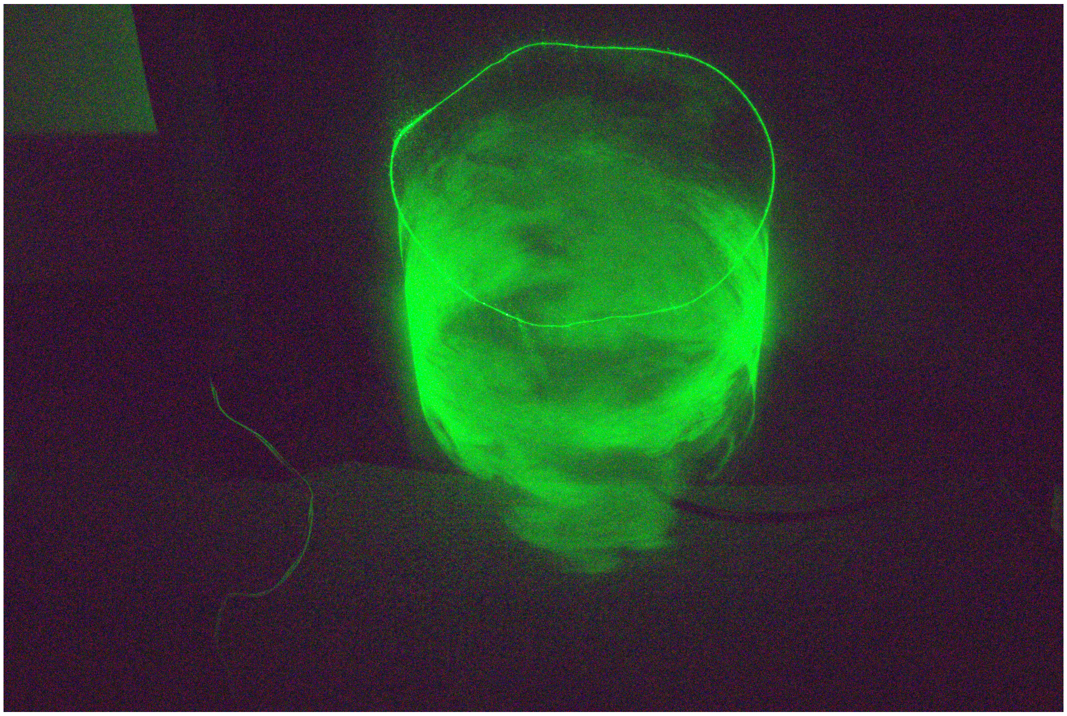

Figure 3. Original RAW Image

Conclusions

Taking photographs in low light settings is difficult. If I were to run this experiment again, I would use a tripod to stabilize my camera, slowed my shutter speed, and reduced ISO. This would have increased the quality of the initial photograph and reduced noise from the camera settings. However, this experiment enabled me to test the operational limits of my camera and explore new settings. Throughout this process I also learned about the exposure triangle which is the balance between aperture, ISO, and shutter speed. The triangle balances the camera settings to permit the appropriate amount of light into the camera for a photograph and will be useful when capturing future images [5].

References

[1] Kumar, Sudhir. Fluid Mechanics (Vol. 2). 2022. Springer EBooks, vol. 2, Springer Cham, 1 Jan. 2023, pp. 1–3, 95. Accessed 1 Oct. 2023.

[2] “Velocity Classification of Ventilation Ducts.” Www.engineeringtoolbox.com, 2003, www.engineeringtoolbox.com/velocities-ventilation-ducts-d_211.html.

[3] Sippola, Mark R, and Nazaroff, William W. Particle deposition from turbulent flow: Review of published research and its applicability to ventilation ducts in commercial buildings. United States: N. p., 2002. Web. doi:10.2172/815478.

[4] Boone, J. (2017, September 20). A Beginner's Guide to Color Curves for Powerful Correction. Frame.io Insider. https://blog.frame.io/2017/09/20/beginners-guide-to-color-curves/

[5] Deguzman, Kyle. "Exposure Triangle Explained — Download FREE Ebook." StudioBinder, 25 Dec. 2022, www.studiobinder.com/blog/what-is-the-exposure-triangle-explained/#:~:text=The%20exposure%20triangle%20consists%20of.