Flow Visualization of Turbulent Airflow Through a Laser Beam

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Assignment: Team First

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Course: MCEN 5151-001, Flow Visualization

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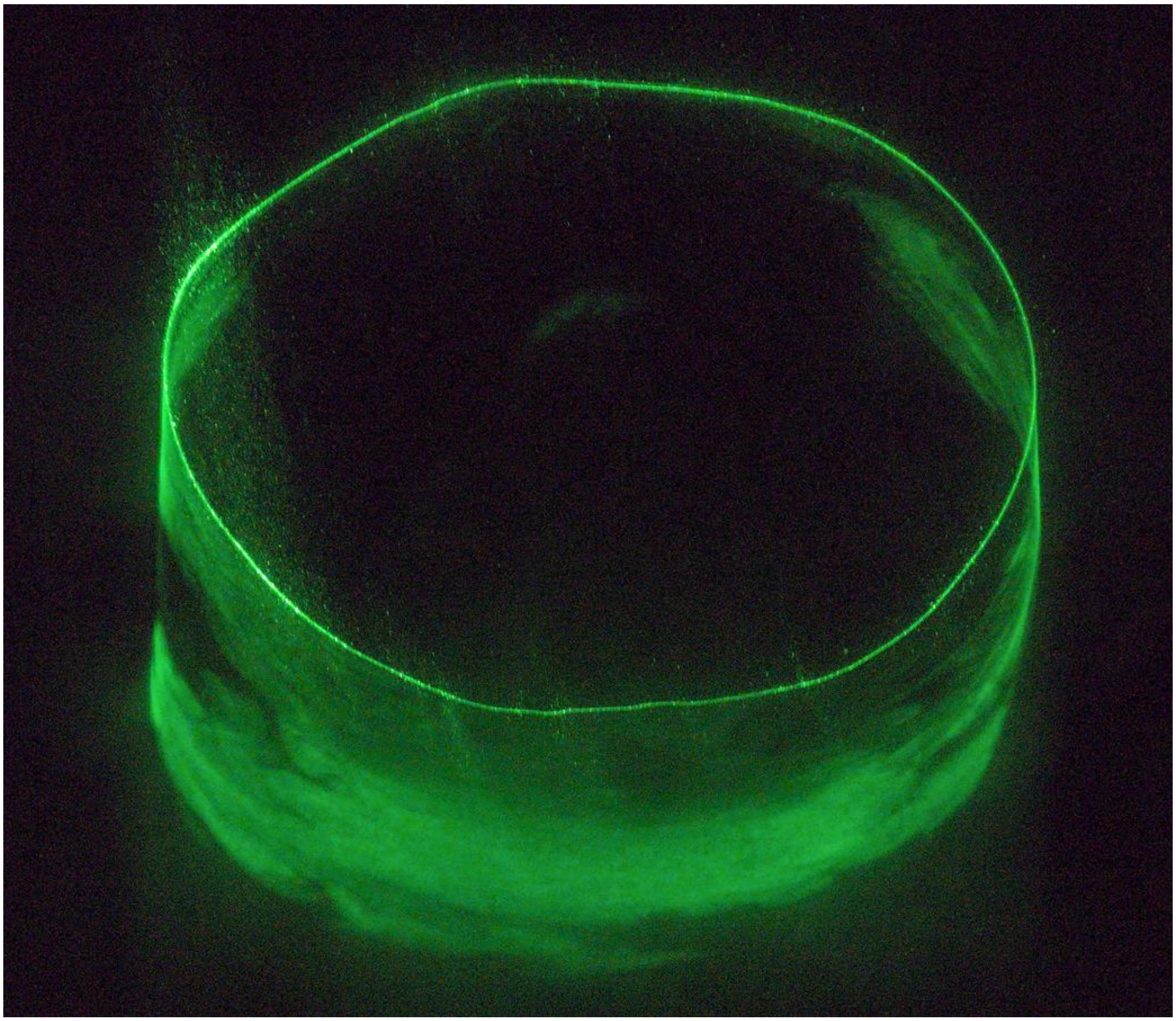

Figure 1, front view of turbulent airflow generated by a smoke machine interacting with a green laser beam.

Introduction

The image in figure 1 was captured for the Team First assignment for MCEN 5151. This is a Flow Visualization course at the University of Colorado Boulder. The goal of this course is to focus on making the physics of fluid flow more visible to the human eye [1]. The intent of this image was to use smoke from a smoke machine in the air, to photograph turbulent airflow that was generated by the smoke machine. A green laser was used for better flow visualization. This image was shot with the help of Team Kohlrabi (Hannah DelGuercio, Sam Lippincott, Kenneth Olavarria). In the following report, I will discuss the phenomena and techniques used to capture this image.

Fluid Physics

Below in figure 2 is a diagram of the flow visualization apparatus used for this photo.

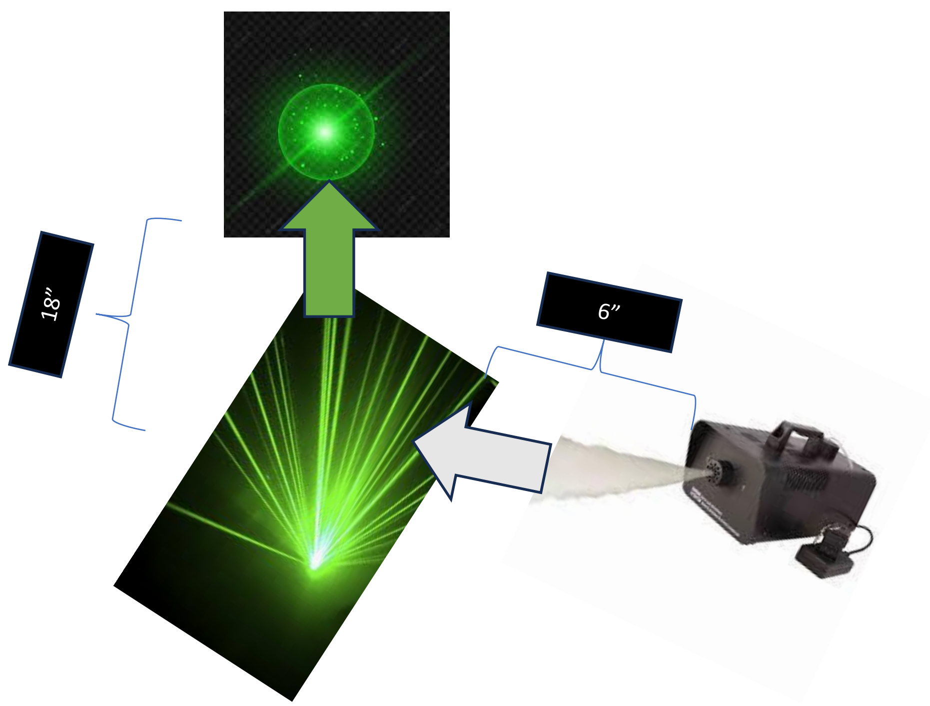

Figure 2, diagram of flow visualization appartus

As seen above, the fog machine was used to project fog towards our green shining laser. We used a dark room so that our only light source was from the laser. We predicted that the smoke generated would rapidly become turbulent after leaving the machine. This is due to the free stream air in the room being substantial. “The airflow field in indoor environment is normally characterized by high turbulent level and unsteady flow due to the relatively low air velocities from diffusers, thermal plumes of heat sources and unsteady perturbation of occupants’ behavior” [2]. Our team sought to calculate the physics behind the free stream in the air with respect to the output from the fog machine. Through a deep dive in the physics occurring, I found that the circular pattern mimics that of a Karman vortex street. “They concluded that at Rec = 5.5 × 10^4 the vortices appeared to form a pattern in the wake region … were similar to a Karman vortex street” [3]. However, Karman vortex streets occur because of vortex shedding. This is when a fluid or water flows past a bluff body, which creates alternating low-pressure vortices on the downstream side of the object. In our experiment, there was no bluff body present to cause this. What is more likely occurring is the concept of Brownian motion. “Brownian motion is the irregular and perpetual agitation of small particles suspended in a liquid or gas” [4]. This causes the turbulence seen in our image. Other factors like airflow patterns, fog machine nozzle design, and room design can influence the rotating motion that mimics that of the Karman vortex streets. Below I calculate the Brownian motion equation to understand the agitation of the small particles from the fog machine. I also calculate the Reynolds number to describe the flow. The Reynolds number provides insight into the flow conditions within a room and how they influence the behavior of fog particles. It’s useful to consider this alongside Brownian motion when analyzing the dispersion of fog in the room.

Brownian Equation & Assumptions [4]

Assumption 1. Steady state and homogenous environment

Assumption 2. Negligible gravitational effects

Assumption 3. Constant temperature and humidity

$$D = \frac{k_B*T}{18.84*n*r}$$

where k_B is the Boltzmann constant, T is absolute temperature, n is the dynamic viscosity of air, and r is the radius of the particle.

k_B	1.3806352*10^-23 J/k [5]
T	298 K
n	2.052 * 10 ^-5 kg/m-s [6]
r	10 * 10^-6 m

Therefor we get a value of 4.88 x 10^-9 m^2/s. For comparison, gas diffusion in air is 10^-5 m^2/s [7]. So, in comparison, the fog particles in this scenario have a moderate diffusion coefficient.

Reynolds Number Equation

$$Re = \frac{\rho vL}{n}$$

where ρ is the density of the fluid, v is the velocity of the fluid, L is the length, and n is the dynamic viscosity of the fluid. Using a density of .05 g/m^3 [7], a velocity of 1 m/s and a length of .1524 m, the Reynolds number can be calculated to be 3.602*10^4. This was the expected value as this falls above the threshold of 4000 to be recognized as turbulent flow.

Experiment Setup

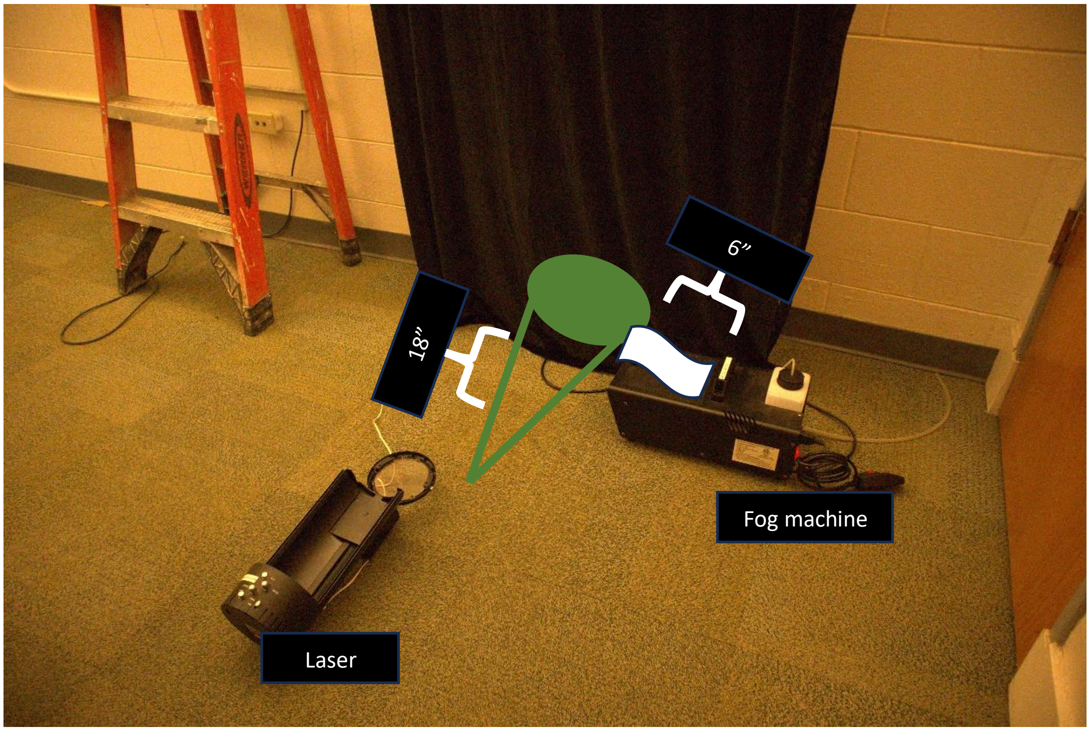

Figure 3, experimental setup.

We shot a series of photographs in an unoccupied room in the engineering center. This room proved to be dark enough for us to effectively capture the interaction between the smoke and the laser. The smoke machine was placed perpendicular to a laser beam, and the laser beam was projected onto a black velvet tarp hung from a rail. This allowed enough contrast for us to see the laser interacting with the smoke machine.

The following camera settings were used on the Canon EOS M50 Mark II

1/5, f/5.6, 30.0 mm, 12800 iso

1/5 is the shutter speed. This is a slow shutter speed that helped illuminate the dark scene as it helped bring light through the lens. The picture was taken approximately .25 meters from the fog machine. A 30.0 mm zoom lens and 5.6 aperture were used for this specific image. Finally, 12,800 iso was used to create a higher sensitivity to the laser beam.

Image processing

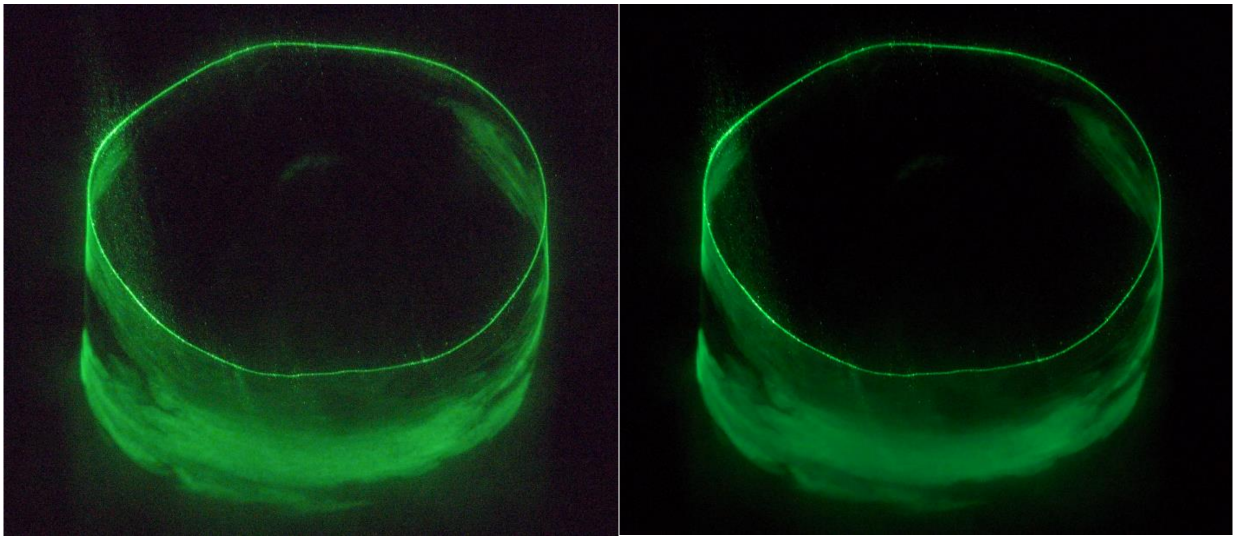

Figure 4, after editing (Left), before editing (Right)

Dark Table was the editing software used to process my original image. Some notable edits to the image were increasing the sharpness. This helped the circular waves stand out more. I also played with the white balance and local contrast to make the fog appear more vivid. Lens correction caused a slight zoom as well that helped capture a “closer” image. I also did some color correction to make the green stand out more.

Conclusion:

Overall, the team was able to capture turbulent airflow through a laser beam. I believe I was able to capture an aesthetically pleasing image, while also showing the physics occurring between the fog and the room air. Another approach to this image could have been adding a bluff body from the exhaust of the fog machine. This could have created strong vortex shedding and we may have been able to see true Karman vortex streets.

References

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