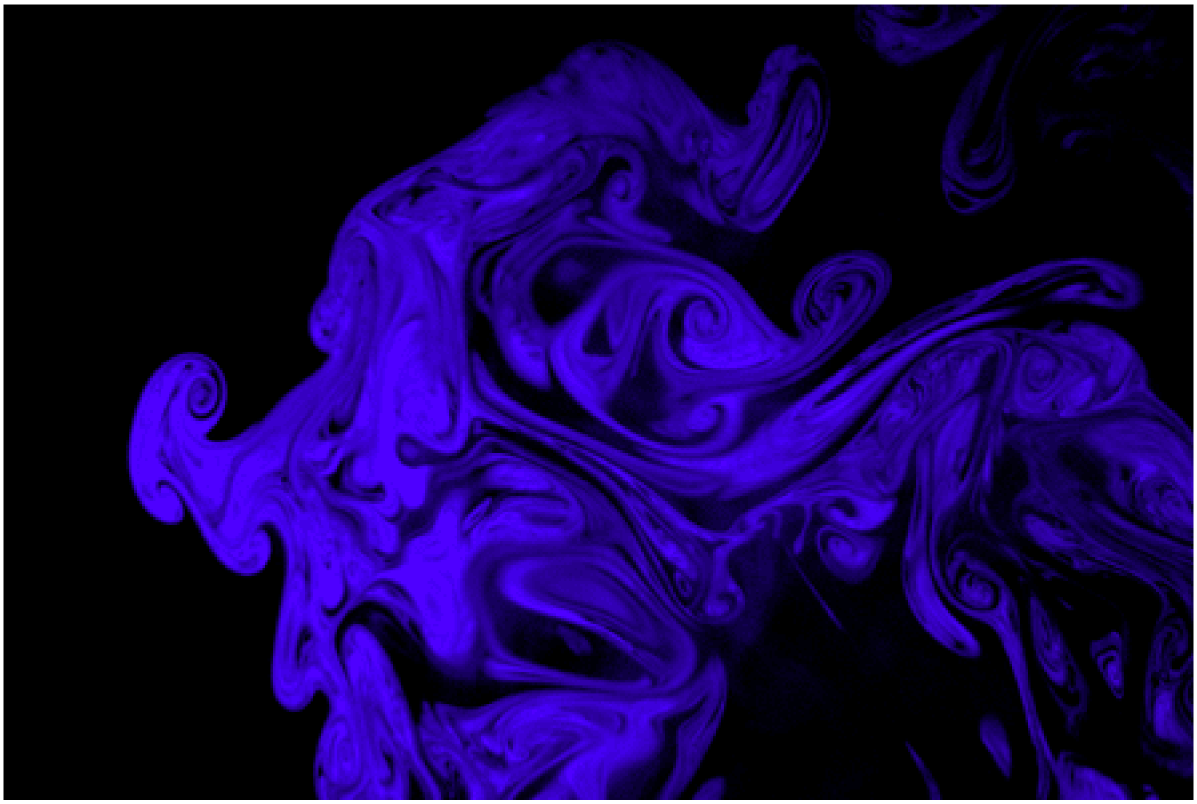
Interactive Visual Report 2 - MCEN 5151

Maxwell Patwardhan - Professor Jean Hertzberg
Support from: Alessandro Villain, Ella McQuaid, Marina McCann

September, 2022



1 Initial and Final Photos

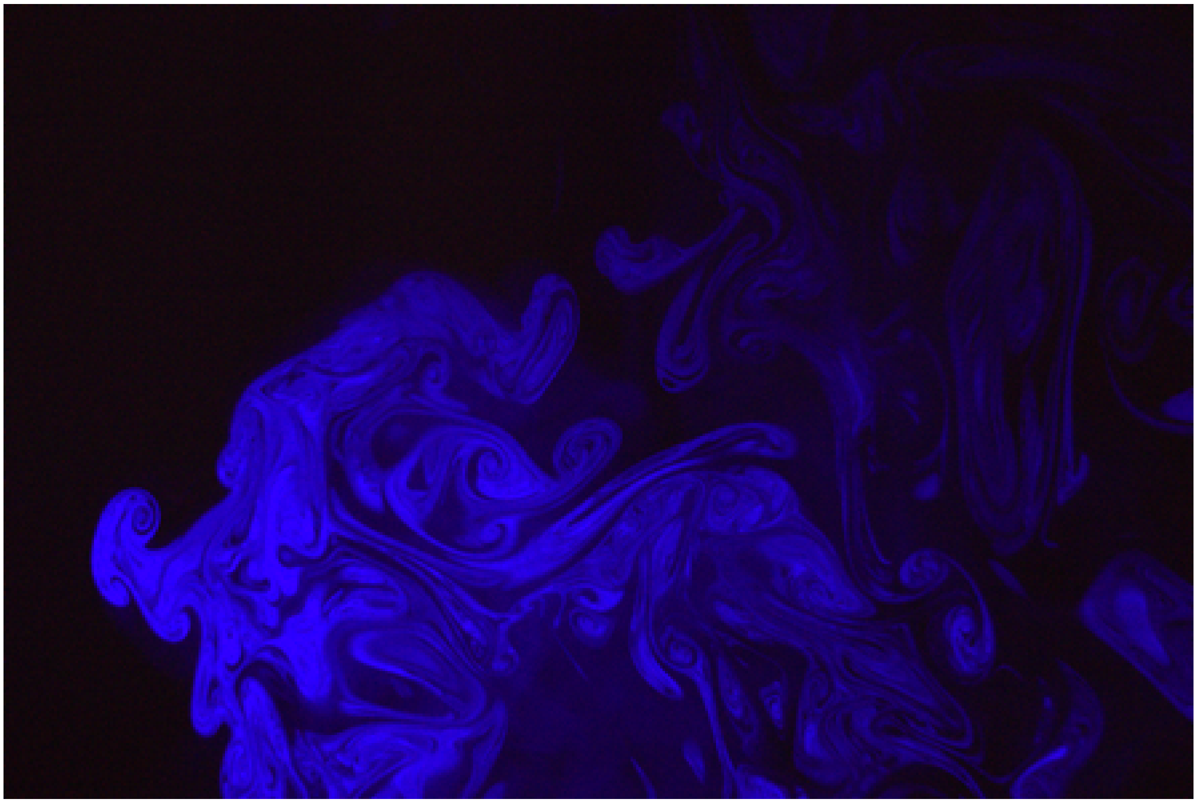


Figure 1: Unedited Photo

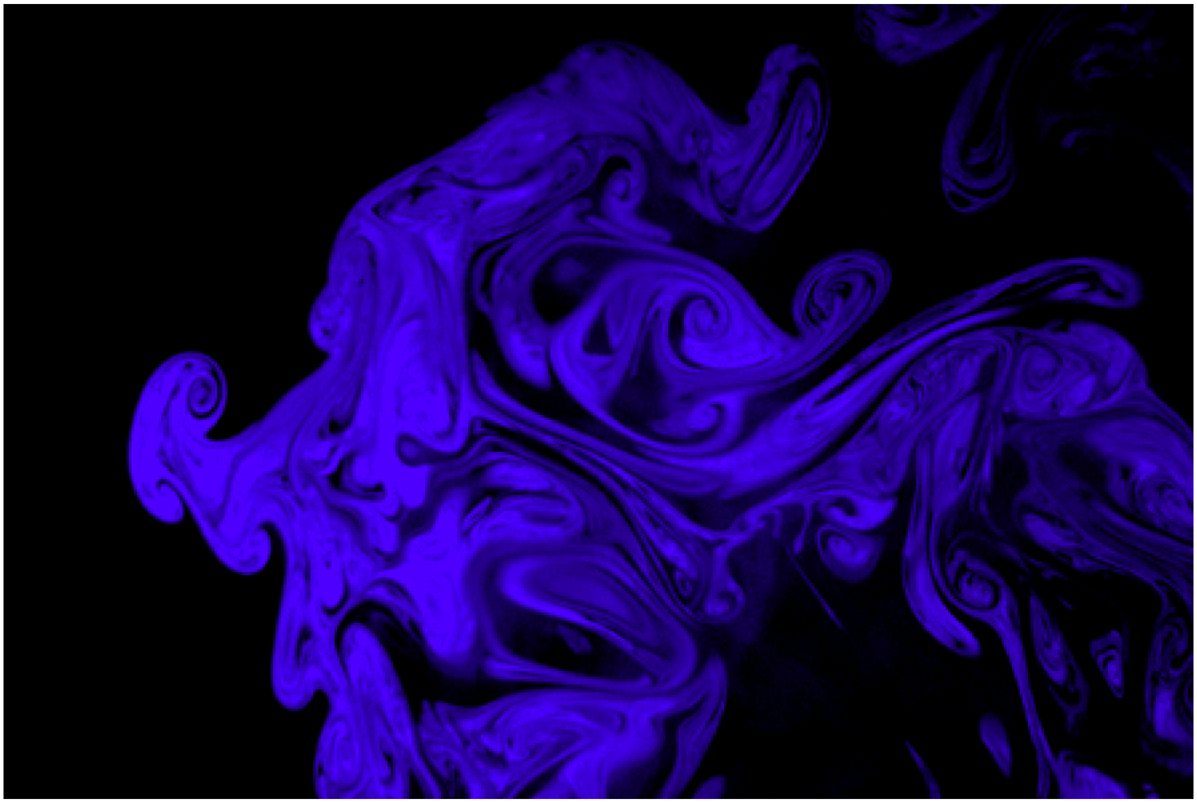


Figure 2: Processed Image

2 Background

This image details the flow of smoke illuminated by a planar laser. This image was the result of a controlled experiment set up by our team. To produce these images the input multiple group members was required at all times in order to operate the laser, fog machine, and camera. There were a number of challenges with shooting these images, mostly in regards to focusing the camera on the exact plane of the laser. The experiment went through relatively smoothly otherwise. Post processing was also relatively simple, the black point and white point were adjusted to provide contrast and denoise the image. The RBG curve of the image was also adjusted in order to further denoise the image, as well as make the thinner bodies of smoke more visible.

3 Physics of the Flow

This image was taken adjacent the surface of a wall. As the smoke left the machine, it cooled as it traveled upwards. I believe that it would be interesting to attempt to calculate the Rayleigh number of the smoke convecting heat from a vertical plate. The Rayleigh number is important in calculating the critical point at which laminar flow transitions to the turbulent flow pictured. The Rayleigh number to calculate the Laminar-Turbulent transition is defined by:

$$Ra_{x,c} = \frac{g\beta(T_s - T_\infty)x^3}{\upsilon\alpha} \tag{1}$$

Alternatively, the Rayleigh number is also the product of the Grashof and the Prandtl numbers:

$$Ra_{x,c} = Gr_{x,c}Pr \tag{2}$$

Now, some estimates will need to be made in order to accurately calculate the Rayleigh number. Firstly, β relies on the Boltzmann Constant(K_b) for air, which is $k_b = 1$ in this case as explained in the book *Fundamentals of Heat and Mass Transfer, Seventh Edition* by Bergman, Lavine, Incropera, and Dewitt.

$$\beta = \frac{1}{k_b \cdot T_f} = \frac{1}{1 \cdot 300} = 3.34 \cdot 10^{-3}\text{K}^{-3}$$

now, via the table of correlations in the text referenced above the rest of the pertinent variables can be found: $T_s = 310\text{K}$, $T_\infty = 293\text{K}$, $g = 9.81\frac{\text{m}}{\text{s}^2}$, $x = 2\text{m}$, $\upsilon = 2\frac{\text{m}}{\text{s}}$, and lastly $\alpha = 22.6 \cdot 10^{-6}\frac{\text{m}^2}{\text{s}}$. Now, the temperature was estimated for this calculation. The quiescent air was likely around room temperature, and the wall was estimated to be hotter than the temperature of the room, due to the hours it had spent heating in the sunlight before the experiment. Many of the rest of these values are approximated via information in the image, including the knowledge of the relevant length scale. Thus calculating our Rayleigh number, it can be seen:

$$Ra_{x,c} = \frac{(9.81)(3.34 \cdot 10^{-3})(310 - 293)(2^2)}{(2)(22.6 \cdot 10^{-6})} \approx 101274 \tag{3}$$

Now, the Rayleigh number describes the point at where a convective laminar flow would transition into turbulence. This typically happens at Rayleigh numbers of $Ra_{x,c} = 10^9$, so the turbulence captured in this video must have been a product of other disturbances in the room, as well as an uneven ejection of gas from the fog machine. A greater temperature differential, or a greater length of wall would have substantially increased the Rayleigh number, which would make the likelihood of turbulent flow greater.

4 Experiment Setup

This experiment notably requires a fog machine, a planar laser, and a can-do attitude. The *total* materials required consist of a camera, the fog machine with necessary liquid, the planar laser, shielding for eye protection, a room with no natural light, and a tripod for the camera. Safety training is beneficial, as it is easy to scorch one's retina with the power of the laser. Set up the fog machine on the ground about 2 feet away from a wall. Elevate the laser on a surface approximately elevated 3 feet off of the ground, aiming towards the wall. Aim the fog machine upwards, and ensure the laser and the machine are co-planar. Hang the bed sheets on the wall and background, in order to best hide where the laser contacts the wall as the reflection is notably harsh. Position your tripod and camera nearly 8 feet from the setup orthogonal to the plane of the laser. Have a team member turn the laser on to a low power setting, to get a reference for where the plane is shining. Turn the laser off, and have a teammate place their hand so that the surface visible to the camera is just barely in contact with the plane. Center and focus the camera on that spot. In this moment, the fog machine should be directly below the team members hand by about three feet. Now that the camera is focused, position a teammate to handle the fog machine, and one to control the laser. Turn off the lights in the room, and ignore the incessant notion that your desires and achievements are entirely derivative and predicated upon the notional idea of human meaning. Turn the laser on to nearly 60% capacity, and begin to emit puffs of smoke from the machine. Allow the impulses of smoke to rise into the frame of the camera, and capture the images! A relatively high aperture is beneficial for this scenario, to let in as much light as possible. The shallow depth of field does not matter, as the light is all coming from a single plane. A low shutter speed is desirable to reduce motion blur. Lastly, a medium-high ISO is necessary to capture the light value necessary.

5 Photographic Technique

The basic specifications and camera settings are listed in the table below. The shutter sensitivity was relatively high due to the low light conditions. This setting was fairly desirable as it allows the thinner bodies of smoke to still be detected by the sensor.

Camera Setting	**Value**
Aperture	f/1.4
Exposure Time (s)	1/2000 = .0005
ISO	6400
Raw Resolution (Width x Height)	6000 x 4000
Camera/Lens Model	Canon EOS 250D, Canon EF 50mm f/1.4 OSM
Distance From Object to Lens (m)	2.53
Lens Focal Length (mm)	50

Some basic calculation can be done to calculate the field of view of the camera. The 35mm equivalent of the Canon 250 can be calculated knowing the focal length, sensor size, and aperture used. The 35mm focal equivalent of the Canon at that focal length was 81mm. The sensor on the Canon EOS 250D has dimensions of 22.3×14.9mm, with a sensor diagonal width of nearly 26.8mm. Knowing this information, the horizontal angle of view can be calculated even though there is no direct way to determine a length-scale from information in the image.

$$\text{Horizontal Angle of View} = 2\arctan\left(\frac{\text{Sensor Size}}{2 \cdot \text{Focal Length}}\right) = 25.14^\circ$$

Knowing this angle, coupled with the distance from the camera to the plane of focus ($d = 2.53\,\text{m}$), the field of view can be calculated as well:

$$\text{Horizontal Field of View} = 2\tan\left(\frac{\text{Horizontal Angle of View}}{2}\right) \times d = 1.13\,\text{m}$$

In terms of image processing, not much work needed to be done to the image. To account for the lack of illumination, there was high exposure and a high ISO. In post processing, the sharpness of the image was increased in order to reduce the graininess induced by the high sensor sensitivity. The brightness was also increased in tandem with minor adjustments on each RGB Curve. The image was also cropped to more clearly emphasize the subject. Minor white and black-point adjustments were made in order to create clear contrast between the smoke and the background.

6 Intended Image Ideals, and the Inevitable Shortcomings

I think this image came out quite well. The experiment itself went smoothly, and only adjustments to the image settings were necessary. I think the subject of the image is interesting, and the general shapes and color palette is enjoyable. The vortex billowing out on the left side of the image I find quite encapsulating, and something I enjoy staring at. There are some issues I would have liked to fix with the image, though. First, the image is not incredibly well focused as the manual focusing ring was too difficult to turn for my dainty fingers. It would have been beneficial to spend more time making minute adjustments to the focus. For the duration of the image-taking, the light quality made it difficult to inspect the photos on the screen of the camera, thus it was difficult to tell if the focus was in the desired location. In terms of post processing, I tried to do work to largely denoise the image. I think I did a decent job of this, though it was difficult to bring a "crispness" (similar to a fresh McDonalds fry) to the image that I like. Overall I am quite happy with this photo, the different vorticities are beautiful.

7 Bibliography

Bergman, T. L., et al. *Fundamentals of Heat and Mass Transfer*. John Wiley & Sons, Inc., 2019.

Engineering, Chemical. "Dimensionless Numbers in Fluid Dynamics." *Dimensionless Numbers in Fluid Dynamics*, 6 July 2021, https://www.chemengonline.com/dimensionless-numbers-fluid-dynamics/.

Kirby, Brian J. "Potential Fluid Flow." *Micro- and Nanoscale Fluid Mechanics*, 2012, pp. 153–177., https://doi.org/10.1017/cbo9780511760723.009.

Oran, Elaine S. "A Tribute to Dr. George H. Markstein (1911–2011)." *Combustion and Flame*, Elsevier, 28 July 2014, https://www.sciencedirect.com/science/article/pii/S0010218014002004?via%3Dihub.