TEAM FIRST REPORT

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UNIVERSITY OF COLORADO - BOULDER
MCEN 4151: Flow Visualization

When tasked with taking our first team photo, the team immediately gravitated towards Professor Hertzberg's fluid visualization desk toys. Needless to say, the team was not expecting to have a laser diffraction device and a couple fog machines at our disposal. The team's primary objective in the first team photo was to capture turbulent fluid flow in a more unique way than the traditional Venturi pipe flow, using liquid. For those who are unaware, the Venturi pipe flow experiment is basically a pipe with a constricted center used to measure the pressure and speed differences of a liquid along the pipe. This effect is now used today to give humans the ability of flight.

In the scope of our first team photo, our goal was to use the high pressure fog coming from the fog machines and illuminate the fog's flow using a green laser diffraction machine. The high pressure fluid, as in Venturi's experiment, naturally becomes turbulent and creates a random fluid pattern that is also visually pleasing when illuminated. Conceptually, the two fog machines were aimed to eject stage fog at a high rate of speed into a green, conical laser beam, thus illuminating the fog's fluid trajectory and resulting in a visual representation of turbulent flow. In Figure 3, found on page __ , a top view of the experimental setup is crudely shown. Elaborating on Figure 3, the experiment was constructed in a very dark room, with no windows able to shed any natural light, with both fog machines set up at a rough angle of 45° measured from the tip of the fog machines to the horizontal plane of the laser diffraction device. We needed to setup this experiment in a very dark room because of the weak illuminating nature lasers possess when interacting with clearer mediums, such as the stage fog we had available. Therefore, in order to see the most details of the fog's flow using only the light emitted from the laser, we had to use a dark room and still find creative ways to eliminate any ambient light from the adjacent hallways. I decided to position the fog machines at a 45° angle to the laser diffraction device because of the laser device's cylindrical frame and the vertically emitted, conically shaped, laser emission. This design choice allowed the fog to enter into the laser device, interact with the laser upon entry, and echo off of the frame in order to maximize the amount of fog interacting with the slim laser light. For metric purposes, I would estimate the green laser light to emit a beam no more than 1/8" thick and radiate as much as a two foot tall "lava lamp-like" conical column when interacting with the stage fog.

The most difficult part of capturing this turbulent fog flow was controlling the numerous variables in such a way that the fluid flow could be illuminated to show turbulent flow phenomena like eddy currents, streamlines, and vortices. Turbulent flow is defined as being naturally chaotic and dissipative, making clear visual representations difficult to come by. Having background knowledge of varying fluid flows and their respective characteristics was crucial in translating the turbulent fog into a visually stunning picture. According to Bakker's website, with contributions from Tennekes' and Lumley's *A First Course in Turbulence*, "Turbulent flows always occur at high Reynolds numbers" (Bakker (2003), 2). From my previous courses in fluid dynamics, I know that turbulence in fluids do occur at high Reyniolds numbers, and in fact fluids start experiencing turbulent characteristics at Reynolds numbers above 4000. So what is the Reynolds number and how can we manipulate our fog to become turbulent? Well, the Reynolds number equation is stated below and you can see that the Reynolds number is a function of the specific fluid's density, the velocity at which it is ejected, its dynamic viscosity, and the length at which the fluid travels.

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

For our team's experimental set up, we could not specifically identify the exact parameters of the fog machine's fluid and excitation velocity so I have chosen to estimate the Reynolds number using a 50-50 mixture of glycerol and water to determine if our flow was indeed turbulent or not. The terms of the Reynolds number I used came from using this 50-50 fluid mixture and the specifications of a fog machine that closely resembles the ones we used. The length the fog traveled was estimated from our setup to be around 2 feet. These parameters are as follows:

- Density, $\rho = 1142.0 \ \frac{kg}{m^3}$ (Andreas (2010))
- Excitation Velocity, $V = 0.98094 \ \frac{m}{s}$ (Fog Machine)
- Length, $L = 0.60969 \ m$
- Dynamic Viscosity, $\mu = 0.00837 \ \frac{Ns}{m^2}$ (Andreas (2010))

Inserting these parameters into the Reynolds number equation, we yield:

$$Re = \frac{(1142.0)(0.98094)(0.60969)}{0.00837} = 81{,}601$$

I believe my estimates for all the values used in this equation were fairly accurate and could not have much chance of altering the final Reynolds number too drastically. With this said, my calculations for the fog's Reynolds number solidifies our flow goal and visual inspection of the flow proving that the flow was indeed turbulent. Regardless of the Reynolds number, the fog flow shown in my final image, Figure 1, exhibits clear visual clues showing that the flow was turbulent instead of laminar without even having to calculate the Reynolds number. Referring back to Bakker's .pdf slideshow, "Turbulent flows are rotational… that is, they have a non-zero vorticity" (Bakker (2003), 4). If we examine the image in Figure 1, it is very clear that the fog **does** exhibit a non-zero vorticity, or high vortex-like effects, proving once again that the fog demonstrates vortices, chaotic behavior, and streamlines: just like all other turbulent flows.

Now that our flow is known, I was still left with the task of artistically capturing the turbulent flow phenomena of the fog while also conveying to individuals the underlying physics. To successfully do this, I made the decision to photograph the conical light-tower as physically close as I could and limit the amount of zoom necessary on my Sony DSC-HX300 camera. By reducing the zoom on my camera, the image would be more focused and illustrate the finer details of the flow more clearly. I also wanted to capture the fog tower at a such an angle as to give my viewers the perspective they were observing the flow as if it were at eye level. I thought that taking the picture with this perspective would also bring out the finer details of the vortices and exasperate the differences between the dark backdrop and focus of my image, the bright glow of the fog. By using the dark room as a backdrop, I also believed even the smallest of flow details would easily seen by everybody. However, by using a pitch black back drop while also needing to capture a swiftly moving flow, it was necessary to set my camera's aperture setting to a large value and maintain a faster shutter speed. By fixing the aperture setting on my camera to a high value, f/3.2, my image has a shallow depth of field allowing only small amounts of light enter the camera and focus only the items that are physically closer. This is another reason why I wanted to be as close as possible to illuminated fog. By using a relatively narrow aperture setting, my shutter speed was forced to be faster to ensure sufficient light exposure. The shutter speed I used to take the images seen in Figures 1 and 2 was 1/25, or 0.04 seconds. Furthermore, my camera also used a focal length of 7.65 in conjunction with my chosen aperture level and shutter speed. All of my specific camera settings used to capture my Team First image can be found in Table 1, below.

Table 1: Camera Settings

Camera Setting/Information	Figure 2 (raw)	Figure 1 (edited)
Dimensions	2272 x 3256	2920 x 5184
Focal Length	7.65	--
F number	3.2	--
Exposure Program	1	--
Exposure Time	1/25	--

As seen in Table 1, the only difference between Figure 1 and Figure 2 is the size of the image itself. After capturing what I thought was a clear image of the flow phenomena, I realized I still needed to post-process my image to highlight more flow details, emphasize the fundamental physics causing the flow, and also boost the artistic quality of my image. I used iPhoto on my MacBook Air to edit my original image and started off by cropping the image down to a portion of the glowing fog where there were more interesting turbulent flow characteristics. After cropping, I wanted to accentuate the unique conical shape of the flow and touched up the image to eliminate all residual fog outside of the cone and some around key flow locations that was still being lit from the laser's beam. This residual fog was dimly lit and was not a focus of my eye when I looked at the image; however, the minute flow details were too important to me and I felt I needed to take the extra time for touch ups. After the residual fog in my image was removed, I ever so slightly boosted the contrast in order to centralize individual's focus on the brighter, more detailed, areas of my image. The final post-processing step I took to enhance my image was to faintly boost the colors in my image. With the increased contrast, the image only needed a small boost of color for my satisfaction. Personally, the most important part of the post-image processing was to maintain the natural beauty of the flow characteristics and merely accentuate the details. At times, I altered the original image too much and the image looked and felt made, rather than captured.

When reflecting on the final image, I am very happy with how it turned out. The swirls of green light entrapped within the fog secrete a mystique similar to a Medieval witch's cauldron full of potion. For some reason, I am drawn to this mystique and this image certainly satisfied my intent during this project. While reviewing the comments left on the FlowVis.org website, my peers had all around good things to say about the image and also gave great advice for future products. My biggest takeaway, that my peers so keenly pointed out, was the slight granular effect seen in my final image. I did not notice this when I was taking the image or during post-processing, but I believe if I lower my ISO a bit then the inadvertent granular texture would not detract so much from the flow physics I was originally aiming for. I now see what my peers are talking about and in the future I will consider my ISO settings more so than I did for this image in order to produce a better image.

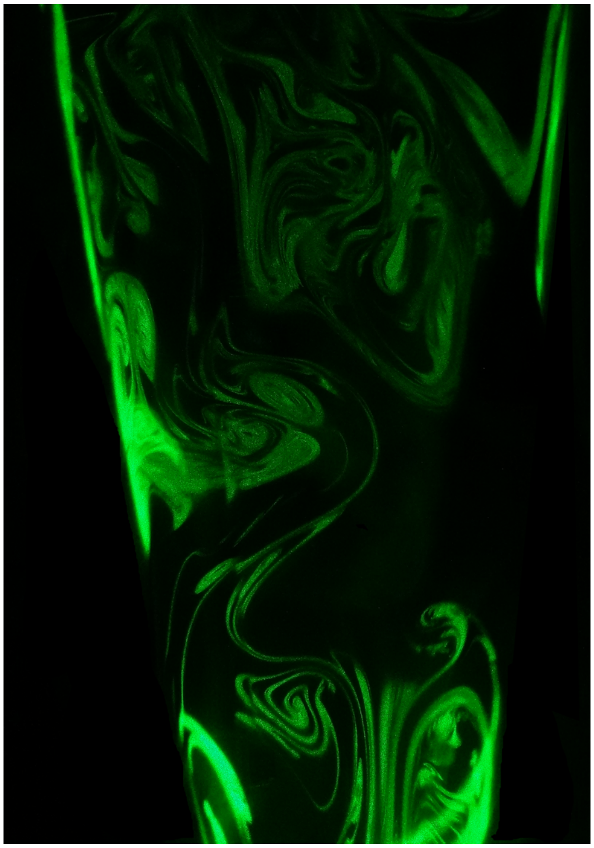


Figure 1: Edited Team First Photo

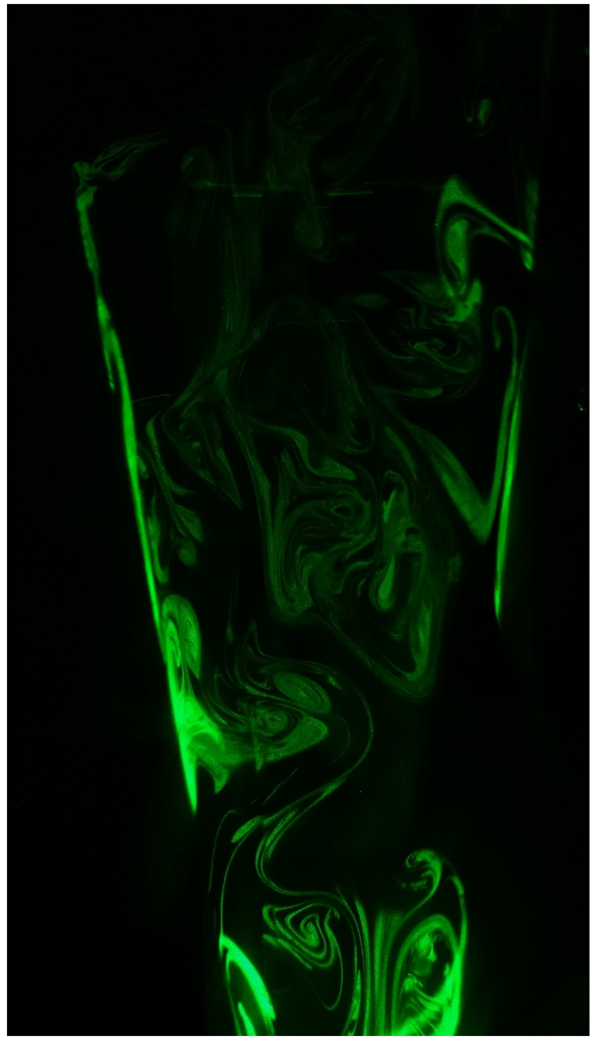
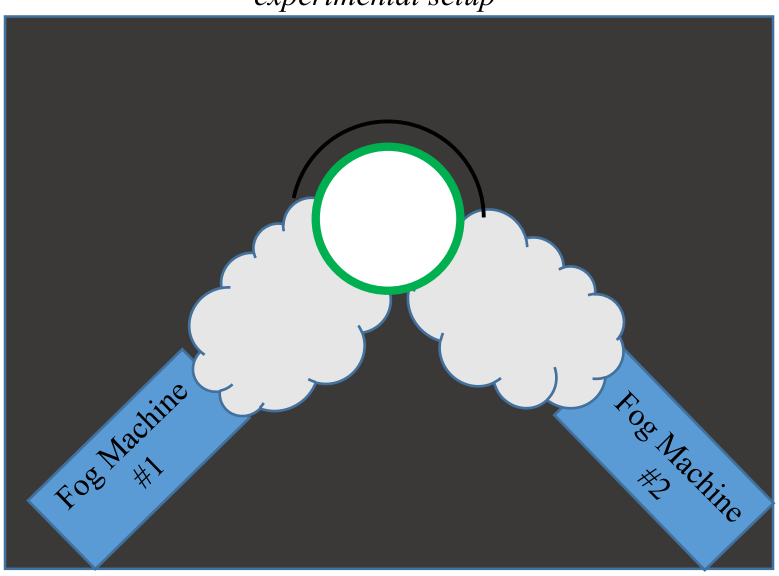


Figure 2: Original, Unedited Team First Photo

Figure 3: Top view of our team's experimental setup



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