# Visualization of a Turbulent Jet with Stage Fog and Laser Sheet

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**Figure 1:** Final image submitted for the second team project.

For the second team project assignment a goal was set out to photograph a turbulent jet. The inspiration for this image came out of the turbulent flows chapter in van Dyke's *An Album of Fluid Motion* [1]. The intent in creating this image would be to visualize the different scales of turbulent structures. By using a high powered laser a sheet of light was used to illuminate a jet of stage fog resulting in the final image as seen in figure 1. Different turbulent scales can be seen here in the many eddies that were located in the plane of the laser sheet.

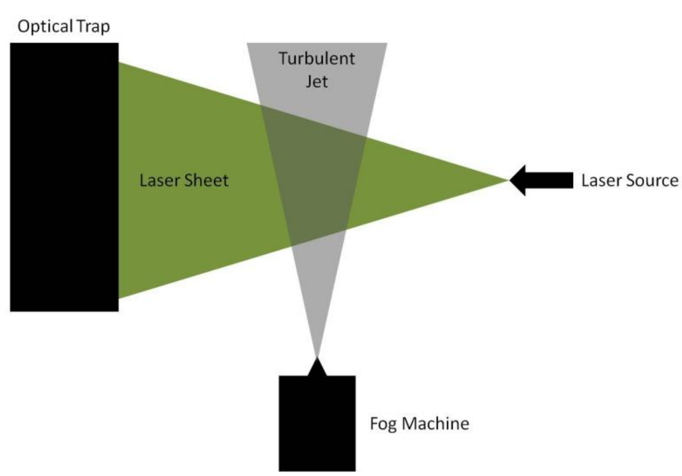


**Figure 2:** Schematic of the setup used to visualize the turbulent jet for this project.

As mentioned before in order to create the image of the turbulent jet a high power pulse laser was used in conjunction with a stage fog machine. Special lenses were used to focus the laser beam into a plane sheet. The fog would serve as a tracer particle to illustrate the turbulence involved in a round jet. A schematic of the setup used to capture the image for this project can be seen in figure 2. A very important aspect to the setup for this project was that since the laser was high powered much care would need to be taken to ensure that it would be controlled and not cause harm to anyone involved with the project. An optical trap was setup to capture any excess light produced by the laser that would pass through the turbulent jet. It was decided that the turbulent jet be shot perpendicular to the laser light so that the fog particulates would not damage the optical equipment on the laser. With this it would then be possible to illuminate a plane of the round turbulent jet created by the stage fog machine. The scale of this flow would be on the order of a meter.

The physics of the turbulent jet has been extensively investigated and is very well documented. Round turbulent jets have been shown to be axi-symmetric [2]. With this in mind it was desired that the laser sheet be placed in such a way that the plane would pass through the center of the turbulent jet in order to visualize this phenomenon. Additionally in the study of turbulence it has been observed that one of the key aspects is the level of scales. This can be seen with different sizes of eddies within the flow. Many times large scale eddies will contain smaller and smaller eddies within them. The large scale eddies contain the most energy in the system and the smaller eddies feed off of this through a dissipation process [3]. This dissipation process continues down to smaller and smaller scales of eddies until the eddies are the size of the Kolmogorov length scale where viscous diffusion becomes the dominant force and diffuses the eddies away [3].

The Reynolds number can also have a large impact on what the turbulent jet will look like. In a study done by Dahm and Dimotakis a visualization of a turbulent jet was made with a planar laser-induced fluorescence method for different Reynolds numbers [4]. It was shown that for lower Reynolds number larger scales were more visible, and for higher Reynolds numbers the flow showed smaller scale turbulence [4]. Controlling the Reynolds number would be a key aspect to illustrate different types of turbulent jets, however since a stage fog machine was used this would be hard to control. After the image was taken the Reynolds number could be estimated by comparing the image captured to that of other photographs where the Reynolds number was known. In doing this analysis it can be estimated that the Reynolds number seen in the image for this report is between 1500 and 5000 when compared to the images documented in [4]. This analysis is very qualitative however given that the fog machine provides little control for the flow speed it is the best estimate that can be done.

In visualizing the turbulent jet stage fog was used to seed the flow. This fog is composed mainly of water and glycerin. This was provided to the group through Professor Jean Hertzberg's lab at the University of Colorado at Boulder. This solution would be turned into fog using a stage fog machine. The machine would then eject the fog in a flow that would develop into a turbulent jet. The laser used in this project to illuminate the turbulent jet was a Solo PIV class IV pulse laser manufactured by New Wave Research. The frequency of the pulse laser was set to the highest setting to increase the chance that the camera would capture the flow while the laser was on. With this the camera shutter speed would need to be adjusted accordingly so that it would capture one pulse of the laser. If the shutter speed was too long the image would capture several pulses showing the flow at different times. This would result in a poorly time resolved flow image.

In photographing the image for this project the field of view required was what would be illuminated by the laser sheet of the turbulent jet. As mentioned earlier this was on the order of a meter. The distance between the laser sheet and the lens was about two and a half meters. The focal length used in the lens was 70 mm. A digital image was taken with the original pixel dimensions of 3088 high by 2056 wide. This was then cropped down to 2051 pixels high by 1271 pixels wide. The camera used for this project was a Canon EOS 10D. The exposure settings used for the image consisted of an aperture f-stop of f/4, an shutter speed of 1/500 seconds, and a 400 ISO. With all of this the image was then transferred to a computer where it was first converted to a tiff file format. The next step in post processing was to crop the image down to size to highlight the turbulent jet that was captured. The next step involved adjusting the contrast using the Curves feature in GIMP. This was done by adding more contrast for the red and green values while keeping the blue values fixed. Finally GIMP's sharpen tool was used to make the image look slightly crisper.

This image shows that the visualization of a turbulent jet reveals the different levels of scales that occur in turbulence. Not only does the image show these scales but also illustrates some neat curves that draws the viewer in. The image does lack a variety of colors as the dark room provided no background to the image and the sole lighting used was the green light from the laser. It would be interesting to further investigate the flow to determine the Kolmogorov length scale for the small scale turbulence. It would also be interesting to develop a way to control the fluid flow in order to visualize the turbulent jet at different Reynolds numbers.

## References:


[1] M. Van Dyke, “Turbulence”, *An Album of Fluid Motion*, 12th ed. The Parabolic Press, Stanford, CA, 1982, ch. 6, pp. 88-103.

[2] P. Dimotakis, R. Lye, D. Papantoniou. Structure and dynamics of round turbulent jets. *Physics of Fluids* 1983 **26**: pp. 3185-3192.

[3] S. Pope, “Free shear flows”, *Turbulent Flows*, 1st ed. Cambridge University Press, Cambridge, NY, 2000, ch. 5, sec. 5.1, pp. 96-110.

[4] W. Dahm, P. Dimotakis. Mixing at large Schmidt number in the self-similar far field of turbulent jets. *Journal of Fluid Mechanics* 1990 **217**: pp. 299-330.