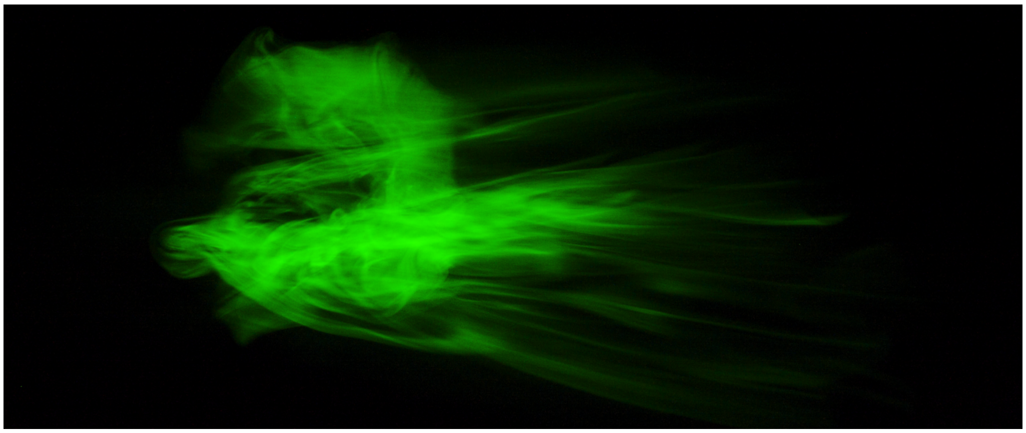
MCEN 5228- Flow Visualization



“Verdant Nebula”

Assignment: Team Project 1
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The celestial bodies have captured human imagination and thought since the beginning of time; their patterns, colors, and movements have pushed human understanding and curiosity to the limit. This picture is not of the heavenly bodies above, but reminds us of the random and beautiful nature of gas and clouds on our planet. This picture was taken for the first team project for Professor Hertzberg's Flow Visualization class for the University of Colorado at Boulder. The intent of the picture was to capture vortex rings crossing a laser sheet and demonstrate how the vortex ring travels at a specific instance in time. Taking this picture was extremely difficult because the team did not have a very powerful laser, but through some advanced photography techniques, we were able to capture enough good images to effectively show an interesting phenomenon. While the rings did not perfectly stay intact, they did demonstrate how the flow moved and separated as it traveled through and past the sheet through this streak photographic image.

In order to create the effect, the team used the Media Shack in the ITLL to take pictures in a dark lit room. The picture had much clearer contrast by eliminating any white/extraneous light from the environment. A 5 mW laser was held by a chemistry stand and pointed through a glass chemistry-stirring rod (held by another chemistry stand) in order to make the laser sheet. The team took pictures at various sheet angles, but finally decided to use a vertical sheet for the final shots. Next, artificial smoke was created by a fog machine and stored in a cardboard box with a 2" diameter circle hole on one of the sides. This served as the vortex ring "generator" and made these rings by simply pressing on the top of the box that then forced air through the hole. The vortex ring generator was positioned at a 20 degree angle to the right offset from perpendicular to the laser sheet. During the experiment, this angle varied, but for this specific picture the box was at a 20 degree offset. The camera was setup 8" perpendicular to the laser sheet, and sat on a tripod. Since the laser did not have a lot of power, the team had to carefully time when to take the shot by having a slow shutter speed and an open aperture (see details at the end of the report). The camera button was pressed, then the vortex ring was released from the cardboard box; the shutter would then close after the ring has passed the sheet. Figure 1 shows the picture setup below.

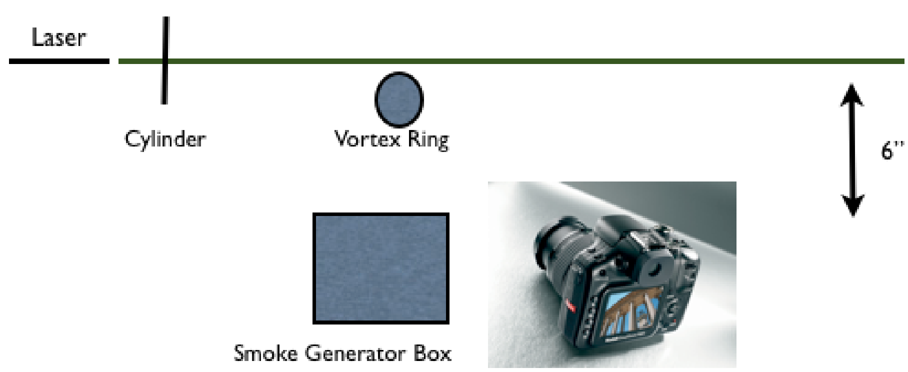

Figure 1: Experimental Setup

The physics of the fluid flow are described by a traveling vortex. A vortex ring is formed when the smoke is forced through the hole in the cardboard box. The fluid near the edge of the box moves slower than the air near the center of the hole due to viscosity and the "no slip" condition. The laminar air flows through the hole, but because the air has some friction caused by the intermolecular interaction (called viscosity) and "sticks" to the side of the hole, the air creates a gradient of air velocity from the edge until it "fully develops" at the center (Kundu et al, 2008). Because of this interaction, the air in the middle is initially moving faster than the air on the outside of the smoke ring. Once the air in the cardboard box hits the outside air, there is a viscous interaction between the moving air and the stationary outside air. The vapor on the edge of the moving flow is slowed down even more by the stationary air, causing it to form a vortex (or circularly flowing air). The outside air reduces the velocity of the ejected air, while the air moving in the inner column keeps moving at the same velocity, thus causing circulation (zerotoys). This air circulation is made on all edges touching the stationary air, thus creating a vortex ring that propels itself forward. The stability of the ring depends on the size of diameter of the vortex ring and also the flow of the moving air (Kundu et al, 2008). The vortex ring will stay together longer if it is in laminar flow with low Reynolds numbers (Shariff et al, 1992). For this experiment, the kinematic viscosity of air is equal to 15.11×10^{-6} m^2/s, moving at .3 m/s at a diameter of 5 cm (engineering toolbox). The Reynolds number is calculated by the following equation below, and is equal to ~993. This Reynolds number indicates that the flow was laminar.

$$RE = VxD/\upsilon$$

The visualization technique used was shedding only specific light on a vortex ring in the form of a laser, so that the phenomenon only scattered specific light for the camera to capture. The artificial smoke only passed the sheet for a brief moment, so it was important to open the shutter for a long time in order to capture the image. The laser was not as powerful as the team had hoped, so most of the images came out a little blurry. However, by photographing the image very close to the phenomenon, the camera was able to receive enough light to yield the picture. This picture uses a technique called "streak photography", where the image's motion is caught at one specific moment in time, but due to the long exposure the film sees the vortex ring's movement. This technique is also known as a "time averaged image" and causes motion blur in the image. The motion blur can be calculated by taking the field of view and the speed of the vortex and the shutter speed. For this picture the motion blur was: (.3m/s)/(1m)*(3/5 sec)*(1)= 18%. This seems high, but for this picture the blur is not as noticeable as in other pictures. The team did not use any flash, or special lighting, other than the green laser. For future teams, we would highly recommend using a stronger laser, as most of our frustrations came from being unable to capture the unique phenomenon were seeing.

As mentioned above, the camera had a very large aperture and slow shutter speed. The field of view was less than 1 m. The photograph was not changed very much from its original image. Some minor changes did include minor cropping of excess black background and increasing the contrast. The camera used was a Canon EOS Digital Rebel XT. Its many functions were very helpful in capturing the image. Table 1 below contains the rest of the data for the camera.

Table 1: Picture Specifications

Make:	Canon
Model:	Canon EOS DIGITAL REBEL XT
Date Time:	3/5/2010 – 4:54:03 PM
Shutter Speed:	3/5 sec
Exposure Program:	Manual
F-Stop:	
Aperture Value:	f/4.0
Max Aperture Value:	
ISO Speed Ratings:	1600
Focal Length:	35 mm
Lens:	
Flash:	Did not fire
	No strobe return detection (0)
	Compulsory flash suppression (2)
	Flash function present
	No red-eye reduction
Metering Mode:	Average

The image is meant to describe the beauty and unique perspective of the fog traveling through the air, yet still shows its inherent chaos. It looks very much like a "Borg" weapon or ship from Star Trek, but this is only a side effect of the laser. This connotation has helped in the naming of the picture, as it reminds people of the hazards and wonders of space and the chaos in stars/gases. It certainly captures the imagination, and allows your mind to play with the shapes to form a unique image. I would have liked to improve the image by having a clearer picture through having more light (more powerful laser) and thus having a faster shutter speed. The picture could be better enhanced by increasing the contrast and turning down the ISO so it looks less grainy. Overall, I am very pleased with the picture. It was very difficult to take, but all the work has yielded tremendous beauty.

References:

Engineering Toolbox. 3/6/2010
http://www.engineeringtoolbox.com/air-properties-d_156.html

Kundu, Cohen. Fluid Mechanics, 4th ed. Academic Press, November 2008.

Shariff, K, Leonard,A. “Vortex Rings” Annual Review of Fluid Mechanics, Vol 24. January 1992.

ZeroToys.com. 3/6/2010
http://www.zerotoys.com/shtml/science.shtml.

Original Shot: