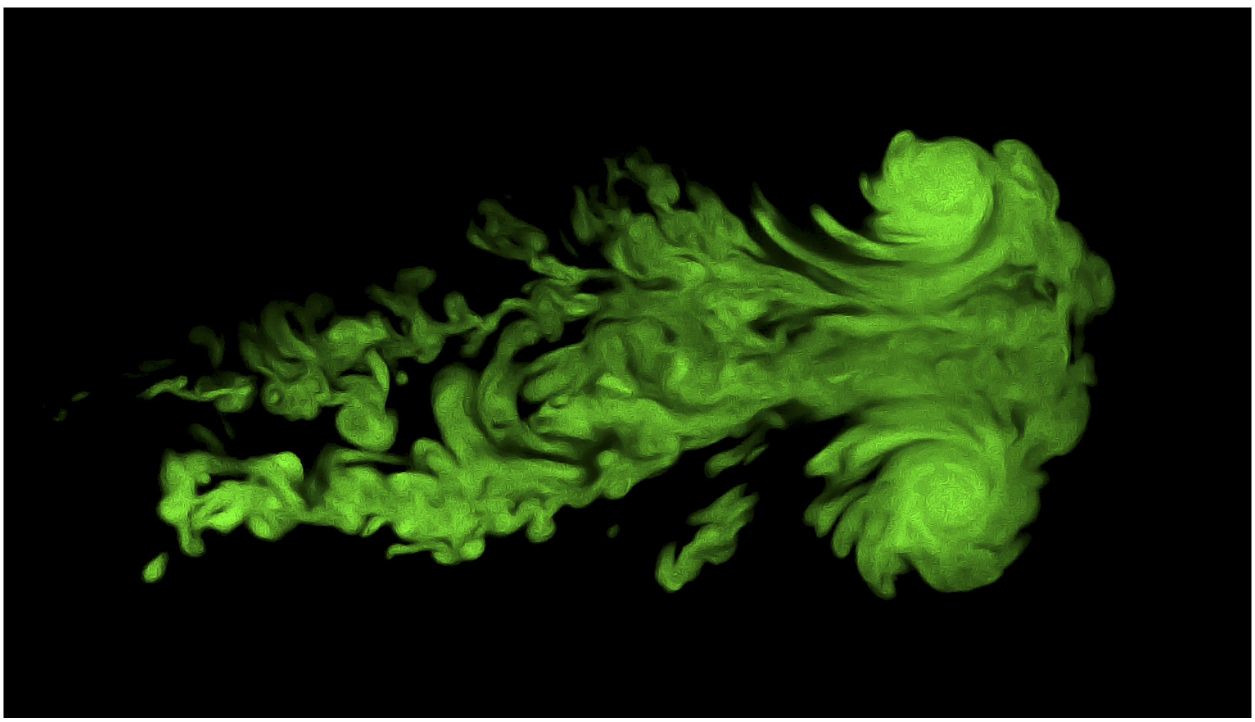
Mechanical Engineering
UNIVERSITY OF COLORADO **BOULDER**

Laser Sheet Vortex Rings



Alexander B. Meyer
Mechanical Engineering

I. Background

This project was the final team assignment of our Flow Visualization class at the University of Colorado at Boulder. The goal of the project was to capture a vortex ring formation in a sheet of pulsing laser light, with the intent of clearly visualizing both the vortices, as well as the turbulent wake that follows. This image was captured with the assistance of Jeffrey Pilkington. Thanks to Professor Jean Hertzberg for allowing us to use her lab and equipment for this project.

II. Flow Mechanics

The primary flow medium used to visualize the vortex ring was standard stage fog. The fog was first concentrated in a "vortex ring generator", essentially a hollow cylinder 12 inches in diameter and length with a six inch diameter hole in one end where the fog inside is forced outward using a piston. The formation of the vortex ring can be seen in Figure 1, where the piston initiating the vortex ring begins to recede back into the cylinder at approximately 1.6 seconds. After this point a secondary vortex is created that mirrors the flow of the primary vortex. In the frame of the final image, the secondary vortex is left behind as the primary vortex propagates away from the cylinder, leaving behind a turbulent wake.

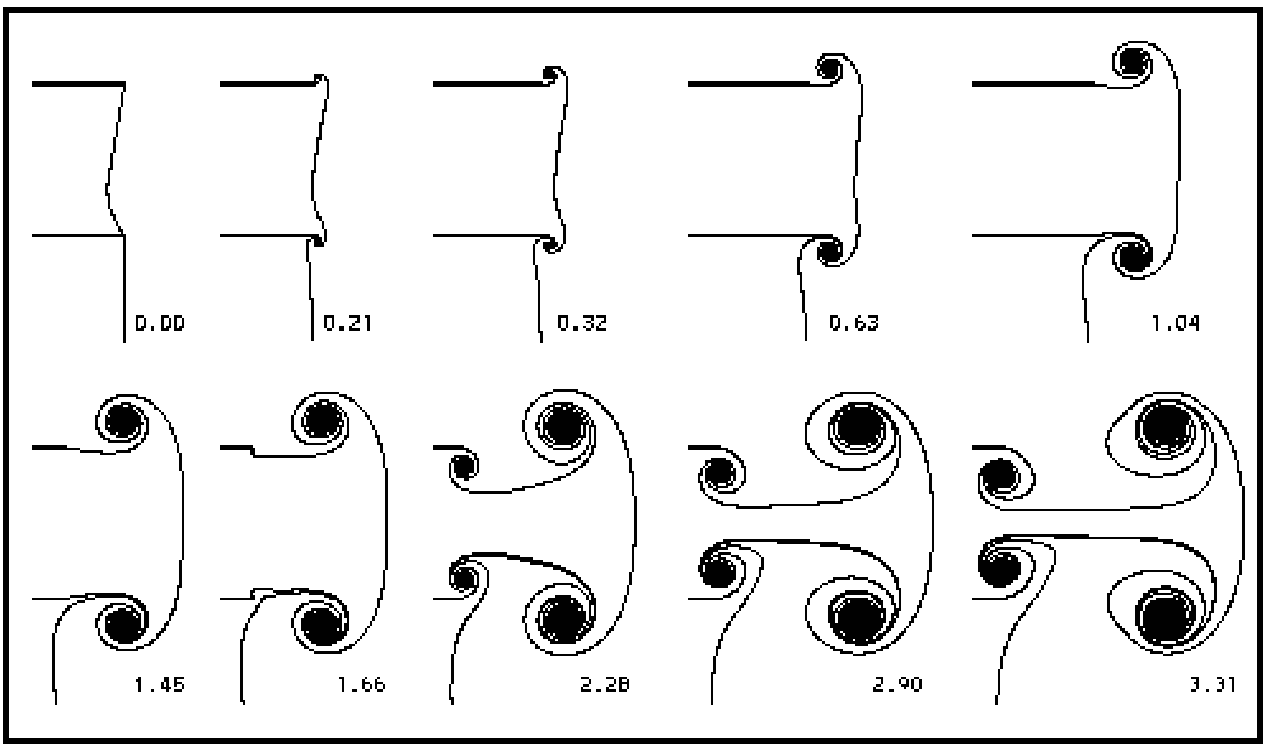


FIGURE 1: Formation of a vortex ring in a piston-cylinder system ("Vortex Ring Formation" 2013)

Video footage of the vortex ring allows the velocity of the vortex propagation to be estimated, which is approximately 0.75 m/s. The hydraulic diameter of the flow is the approximate diameter of the vortex ring generator opening, which was found to be about 0.15m.

To determine the characteristics of the fluid flow, the Reynolds number can be approximated with the following equation given the estimated flow properties and the kinematic viscosity of the stage fog ("Air-absolute and kinematic" 2013):

$$\mathrm{Re} = \frac{ud}{\upsilon} = \frac{(0.75\frac{m}{s})(0.15m)}{(15.68\times 10^{-6} m^2/s)} \approx 7{,}175 \quad (1)$$

The high Reynolds number calculated in Equation 1 indicates that the fluid flow is within the turbulent regime, which confirms the fluid behavior seen in the wake of the vortex ring.

III. Materials and Lighting

This project was carried out in Professor Hertzberg's lab, using standard stage fog illuminated by a pulsing Nd:YAG laser (neodymium-doped yttrium aluminum garnet). The solid-state laser induces fluorescence in the fog, allowing the flow of the vortex ring to be visualized (*Nd-yag laser*). Using a -15mm cylindrical lens, we were able to produce a sheet of laser light that bisected the vortex ring. In order to use the laser safely, a light trap was set up to prevent scattering and reflection of the laser that could be harmful to the eye. The laser was also operated at its low power setting to reduce the intensity of the fluorescence to levels suitable for photographing.

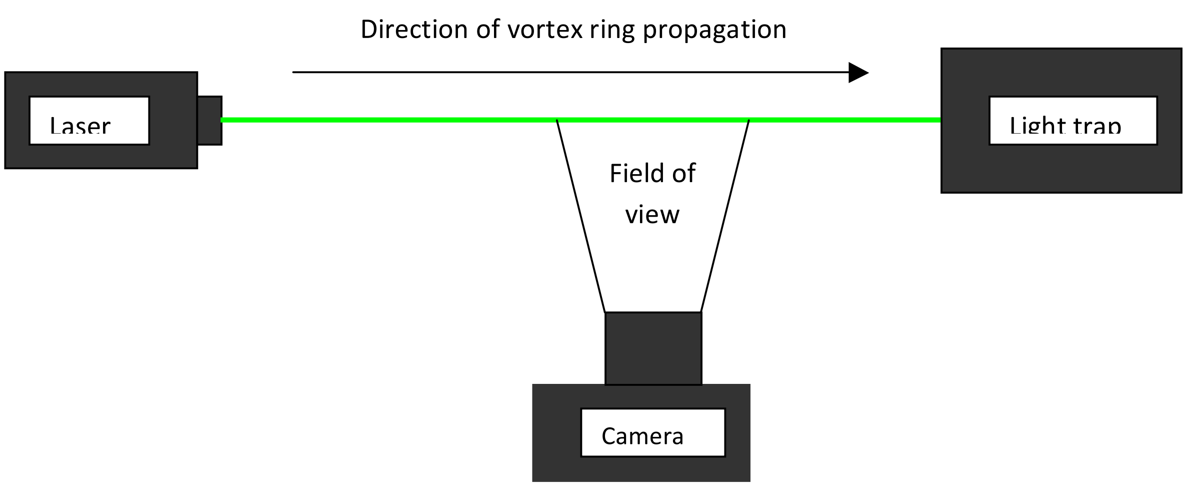


FIGURE 2: Schematic of experimental set up

The vortex ring image was captured at a distance of approximately 1.5 m from lens of the camera in a field of view with dimensions of approximately 64x36 inches. As seen in Figure 2, the camera was set up perpendicular to the direction of vortex ring propagation and the primary axis of the laser. The maximum reflection angle occurs at a 120˚ angle to the laser, but due to the high strength of the laser, the fluorescence of the fog is highly visible at most any angle to the laser. Therefore a perpendicular angle was chosen to capture the entire side profile of the vortex ring.

IV. Camera Settings

The original 5184x3456 image, seen in Figure 3, was captured with a Canon EOS 60D DSLR camera, and an 18-135 mm zoom lens. The camera was set to f/5.0 and ISO 500, with a focal length of 25 mm and a 1/15 second shutter speed. The image was then edited in Adobe Photoshop CS6 by increasing the contrast curve, vibrance and saturation levels, as well as cropping the image and reducing noise. The final image is 1944x1107 in dimension saved in TIFF format.

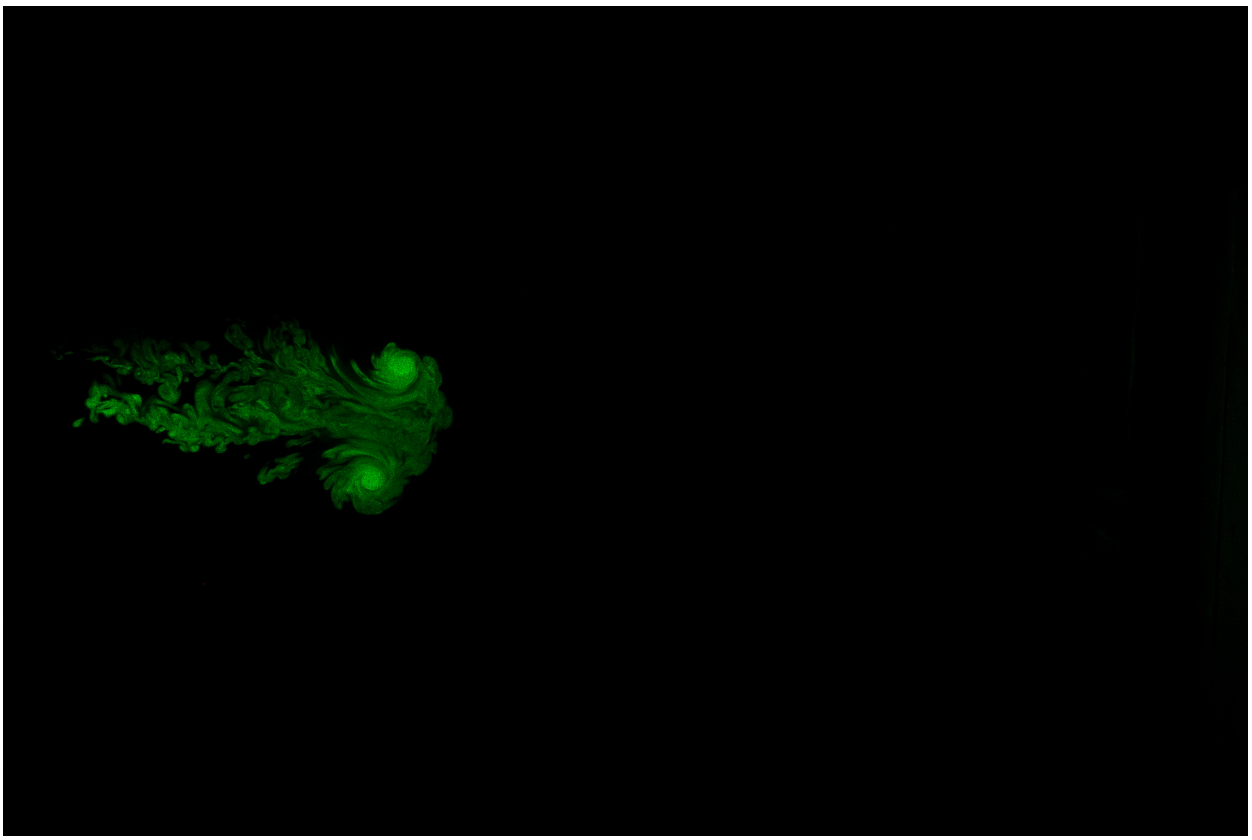


FIGURE 3: Original image of the fluoresced vortex ring

Initially, we attempted to capture video footage of the fluid motion within the vortex ring, but this proved to be somewhat difficult to execute. An oscilloscope was used to measure the pulse frequency of the laser, which we attempted to match with the frame rate of the camera. This provided some clear footage, but the images were often interrupted by a band of darkness caused by the difference in phase between the laser and the camera, despite being at the same frequency. This frequency sync did allow us to capture some nice still images of the vortex rings, which I decided to use to visualize the fluid flow.

V. Conclusion

This image shows detailed fluid flow in a vortex ring. Both the vortices and the turbulent wake are visualized by the fluorescence created by the laser. I also think this image captures the texture of the vortex ring very well. It would have been nice if the original image could have filled the frame of the camera a bit more, which would have reduced the amount of noise reduction required to produce a clean image and preserved more of the detail within the fluid flow. For future projects I would recommend fine tuning the video recording of this process, as the fluid flow is very interesting to watch in real time, or slowed down to see the fluid flow more clearly. This would require a more in-depth set up to achieve the same frequency for the laser and the camera, while syncing the phase of each waveform as well. The use of a continuous laser instead of a pulsing one could also yield some interesting results. There is a lot more that could be learned by further exploring this project in both visualization technique, as well as vortex ring formation.

Air-absolute and kinematic viscosity. (2013, April 30). Retrieved from http://www.engineeringtoolbox.com/air-absolute-kinematic-viscosity-d_601.html

Nd-yag laser. Unpublished raw data, Department of Physics, Davidson College, Davidson,NC, Retrieved from http://www.phy.davidson.edu/stuhome/sethvc/laser-final/ndyag.htm

"Vortex Ring Formation." UM Mathematics. Web. 29 Apr. 2013. <http://www.math.lsa.umich.edu/~krasny/vortex_ring.gif>.