Flow Visualization
Team Project 1
Vortex Rings in Laser Sheet

Benjamin Britton, Yevgeniy Fedotov

The purpose of this project was to capture the dynamic details of a vortex ring as it passes through a sheet of laser light. Unlike visualizing a regular smoke ring in normal lighting, our intent was to photograph a vortex ring as it passes a sheet of laser light in a pitch black room. The laser light illuminates the details of the vortex ring and creates a snap shot of the sectional area of a vortex ring. The curl and vorticity of a vortex ring can be seen by only looking at a thin sheet of the ring, which breaks down the smoke into a small finite area.

In order to achieve our goal of capturing the intricate details of a vortex ring we needed to figure out how to create a sheet of laser light, produce consistent smoke rings, and capture the vortex ring with a camera. A laser sheet is created by using a 5mW (legal limit on commercial laser power) and shining the laser light through a cylindrical rod. We chose to use a green 5mW laser and a chemistry stirring rod that is approximately 5 mm in diameter to create our laser sheet.

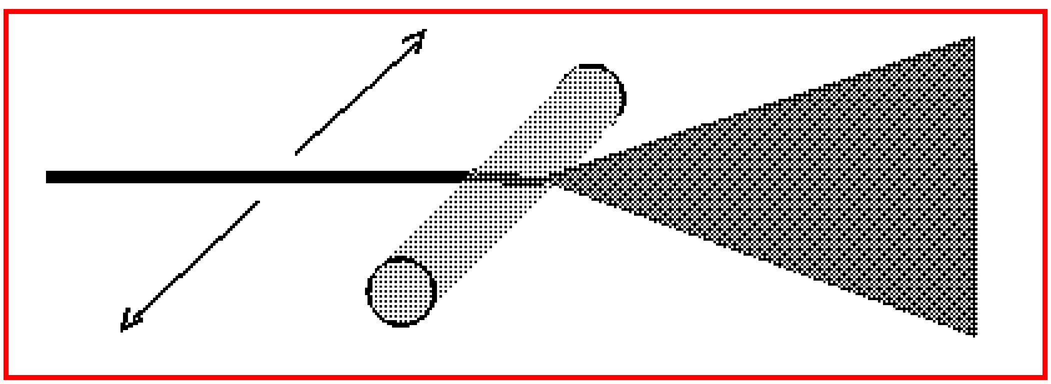
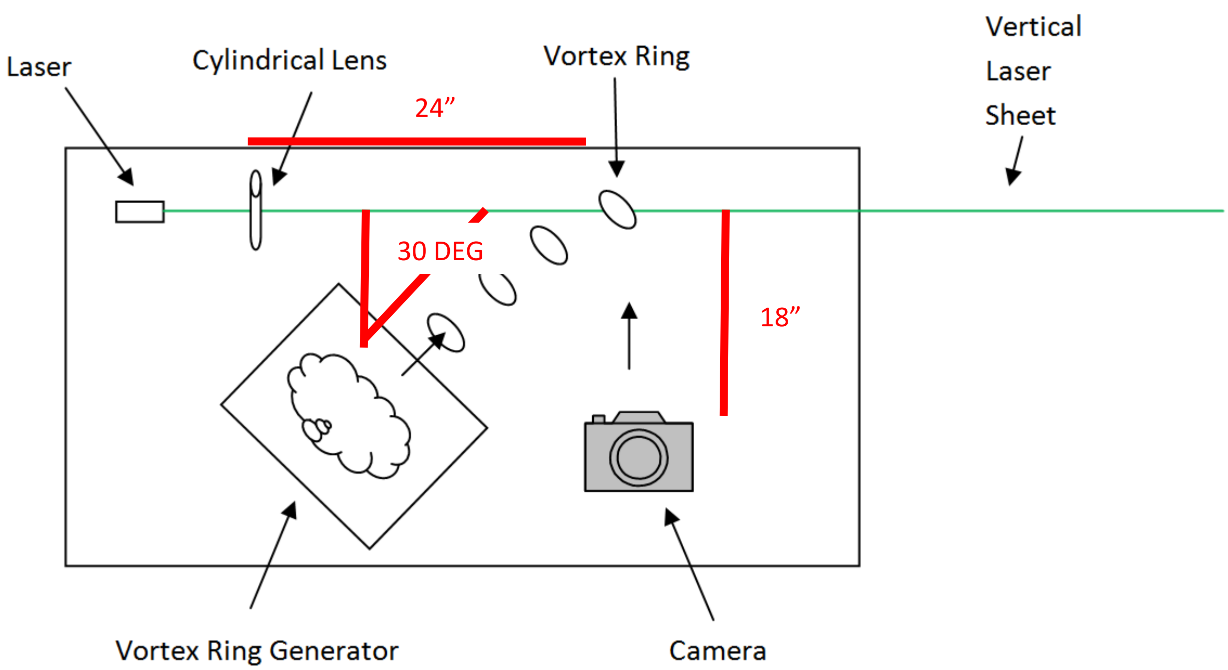


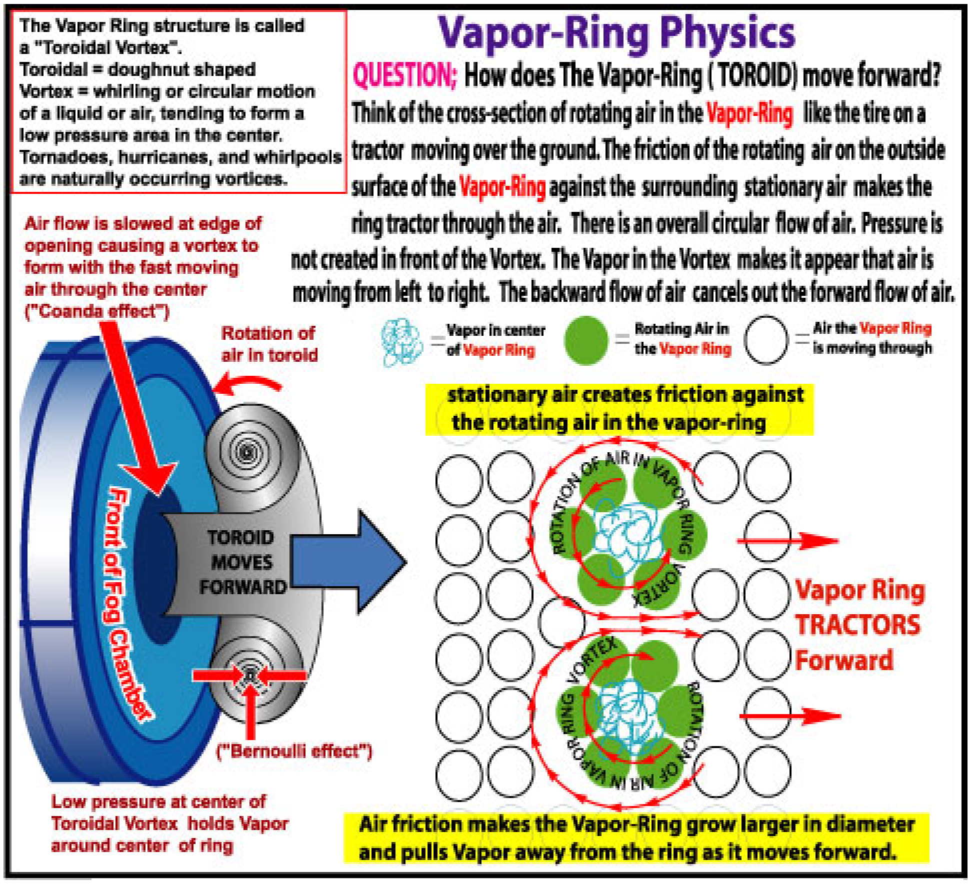
Figure 1. Laser Sheet. Laser Sheet. http://folk.uio.no/walmann/Publications/Master/node14.html

To clearly visualize the vortex rings for these photographs we used a combination of laser light and stage fog. A cardboard box was filled with smoke from a standard portable fog machine. The box was then place into position for photography. A five milliwatt green laser was then turned on and pointed at the side of a glass stir rod 5mm in diameter. The photons from the laser hit the cylindrical surface of the glass rod and scatter to create a laser sheet. The smaller the diameter of the glass rod, the wider the sheet is. We chose a 5mm rod because it was similar to the diameter of the light beam produced from the laser, creating a uniform widespread sheet. At this point, the cardboard box was tapped to create vortex rings. These rings shot across the table and through the laser sheet, providing a single planar view. All lights in the room were shut off and a black background was used to create a uniform background.



A vortex ring is formed from a varying velocity profile. The change in velocity within the profile creates rotation and translation of particles. The center of the ring has a constant velocity profile creating a low pressure zone that moves the ring forward. The pressure wave created from tapping the cardboard box shoots air out of the hole with a higher velocity than the surrounding fluid. The friction between fluids creates the curling effect and produces toroidal (doughnut) geometry. Vortex rings will only dissipate due to friction between fluids, which is why they can travel great distances while maintaining laminar flow. Using an online tool ‘efunda’, the Reynolds number was calculated to be

3200, which would indicate a transitional flow from laminar to turbulent. This could be seen in the images as the fog did not produce a perfectly toroidal shape and the vortex ring began to dissipate to frictional losses. Below is an illustration borrowed from Zero Toys, which graphically depicts the physics of vortex rings.



http://www.zerotoys.com/shtml/science.shtml

Figure 2. Zero Launcher Vortex Ring Physics

Capturing this fluid phenomenon in very low light conditions proved to be a challenge. Many techniques were attempted but only one method proved successful. A very wide aperture was used to capture as many photons as possible on the camera sensor. Also, a slow shutter speed made the timing of photograph much easier. The shutter was opened prior to the vortex ring entering the laser sheet and maintained open until the vortex ring exited the laser sheet. This produced a time averaged image as the fluid passed through the plane of light. Below are the specific details for both images:

Camera	Canon EOS Digital Rebel XT
Lens	Canon Zoom Lens EF 28-200mm 1 : 3.5 - 5.6 72mm ↔
Date	3/5/2010 @ 5:08PM
Shutter Speed	0.6 sec
Exposure Program	Manual
F-Stop	f/4
Aperture Value	f/4.0
ISO Speed Rating	1600
Focal Length	35mm
Flash	Did not fire
	No Strobe Return Detection (0)
	Compulsory Flash Suppression (2)
	Flash Function Present
	No Red-Eye Reduction
Metering Mode	Average
Pixel Dimensions	2068 x 1224
Orientation	Normal
Resolution	240 dpi
Color Space	65535

This image reveals the physics behind vortex rings. We were pleased that we could capture the details of the vortex rings with such a low-lit environment. This proved to be the most difficult task in photographing this subject. It was very frustrating to see the flow very clearly with our eyes and not be able to translate that into an image. If we could do these images over, we would use an ultra-high powered laser to increase the number of photons present and use a video camera to show the progression of the vortex through the laser sheet.

References

Anonymous. 2010. The zero toys science. Zero toys. Online: <http://www.zerotoys.com/shtml/science.shtml>. Accessed 3/14/10.

Efunda. 2010. Reynolds number calculator. Efunda. Online: <http://www.efunda.com/formulae/fluids/calc_reynolds.cfm#calc>. Accessed 3/14/10.

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