Sreyas Krishnan
Flow Visualization
Team Photo #1

In this photograph, I captured an image of a vortex ring of fog as it exits a square hole. I did this with the help of three other teammates (Aaron Coady, Alyssa Berg and Nick Cote). The main purpose of the image was to portray a common vortex ring in an artistic manner. However, while an isolated vortex ring was an interesting subject matter, I decided that I also wanted to show details in the connecting fog as well because of its intricate detail.

Pictured below is a schematic of the apparatus used to setup the visualization. Objects are not fully to scale.

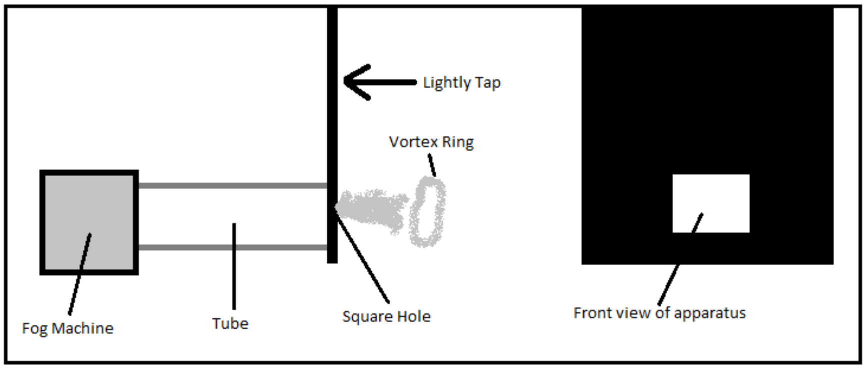

Figure 1

Figure 1 shows the three key components in the flow setup: the fog machine, a connecting tube and a plastic board with a square hole in it. The user has to lightly tap the plastic board after a set amount of fog has been generated and is stored within the tube. This tap causes a small vortex ring of fog to appear and translate away from the hole for a few feet before it diffuses. At first, this is surprising since this phenomenon occurs despite no initial rotational velocity or initial shape *(Karim Shariff)*. However, the scientific explanation for this lies in friction between the fast moving air exiting the hole and the still surrounding air. The chunk of air leaves the hole after the initial tap, which gives it an initial translational velocity. This chunk then causes the surrounding air to move around it in a curvilinear manner *(Karim Shariff)*. This in turn causes the outer layer of the chunk to rotate about itself. The phenomenon is shown below in two dimensions with the red dots representing the fast moving air, the black dots representing the surrounding air, and the arrows indicating the direction of motion of the surrounding air.

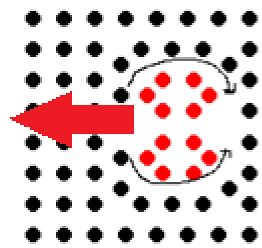

Figure 2 – 2D Vortex Ring Example *(Beaty)*

With this phenomenon occurring in the air, the fog acts as an indicator. The rotational motion caused by friction allows the fog to form the toroidal shape normally associated with a vortex ring. Interestingly, based on further trials, the shape of the hole did not appear to have an effect on this toroidal structure. Whether it's a circular or square hole, a similar looking vortex ring is formed. This would be an interesting study for future flow visualizations.

These vortex rings can be formed with both laminar and turbulent initial flow *(Karim Shariff)*. In the case of this particular flow, the fog trail behind the vortex appears relatively laminar. This can be confirmed by calculating an idealized, 2-dimensional Reynolds number. In order to find Reynolds number, three values are needed: velocity, a characteristic length and the viscosity of air. Using the shutter speed (1/60 sec), the resolution of the image (800 x 861 pixels), the field of view of the image (2.5 x 2.5 inches), the velocity and characteristic length can be estimated. There is no motion blur, meaning that the velocity is no greater than the shutter speed. In the image, the ring travels approximately 2 inches. Hypothetically, if it traveled 2 inches in 1/60 of a second (for the sake of overestimation), that would result in a velocity of 120 in/s or 3.05 m/s. Also, the kinematic viscosity of air at room temperature is about 15.68E-6 m^2/s *(Air - Absolute and Kinematic Viscosity)* and the characteristic length is approximately 1 inch, or 0.025 meters. Using the equation below, the Reynolds number can be determined.

$$Re = \frac{Velocity * Length}{Kinematic\ Viscosity} = \frac{3.05\ m/s * 0.025\ m}{15.68E - 6\ m2/s} = 9725$$

Based on my knowledge from previous courses, this approximation means that this flow is well within the laminar region at and before the instant at which the picture is taken.

The exact type of fog that was used is unknown as many fog machine makers consider the compounds used to produce the fog as proprietary information. However, it is known that this fluid contains a mixture of water and glycerin and is vaporized using a heat exchanger *(Fog Machine)*. The fog itself comes out of the machine cooled and is nothing more than an indicator for the sake of this setup.

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This photograph was taken using a Sony DSLR-A230 at f/9, ISO-400 and 1/60s exposure. The flow itself was about 2 feet away from the lens, which had a focal length of 28 mm. This photograph did require heavy editing. Lots of contrast was added in order to black out the background, and manual brush strokes were used to remove extraneous fog that was not directly connected with the main vortex. Additionally, the picture was cropped to show only the vortex, and rotated to make it appear to be moving upwards. For lighting, a standard fluorescent light was utilized and was pointed at the vortex and away from the camera.

Overall, I think this image turned out wonderfully. I think the fluid physics I described earlier are shown relatively well despite the fact that the proper toroidal structure has not fully developed, and the streaks of fog appear very detailed. If I were to redo this visualization, I would likely attempt to show an even more interesting vortex phenomenon, like ‘leap-frogging.’ Otherwise, I feel satisfied with this one.

Works Cited

1. *Air - Absolute and Kinematic Viscosity*. n.d. 1 April 2012. <http://www.engineeringtoolbox.com/air-absolute-kinematic-viscosity-d_601.html>.

2. Beaty, William. *Why Does Smoke 'Ring?'*. n.d. 1 April 2012. <http://amasci.com/wing/smring.html>.

3. *Fog Machine*. n.d. 1 April 2012. <http://www.crazybuilders.com/item.php?id=000057&type=topic>.

4. Karim Shariff, Anthony Leonard, and Joel Ferziger. *Dyanmics of a Class of Vortex Rings*. December 1989. 1 April 2012. <http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/19900010208_1990010208.pdf>.