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Flow Visualization
Team Project #1
3/22/12

The flow phenomenon our group wanted to capture in our first group project was the creation and flow of smoke rings. The intent of my particular image was to capture a smoke ring image that was in the later stages of flow after the tailings of smoke have dissipated and all that is left is a complete circular ring of smoke. It was increasing difficult to find the correct speed the smoke ring could travel to allow the ring to remain intact after traveling enough distance to allow the tailings to dissipate. Having the smoke ring travel at higher velocities caused the ring to break apart quicker and create more smoke tailings. However, having the smoke ring travel at slowest possible velocities the smoke ring would have a smaller diameter by the time it reached the end of the given space provided to capture the image. It was found that the most effective way to create an almost uniform smoke ring was to use a velocity that allowed the smoke ring to dissipate the smoke tailings and allow enough time to pass for the smoke ring to expand to a larger diameter.

This particular image, provided in Figure 5, consists of a near uniform smoke ring with an outer diameter of 6 inches and an approximate ring thickness of 1 inch. To begin to describe the physics behind the creation of smoke rings it is important to describe the apparatus itself that is utilized to create smoke rings. The apparatus used consists of a square cardboard box with the dimensions of 1.5 ft. by 1.5 ft. The box was placed on its side with the top of the box, where the flaps come together, on the right side and the bottom of the box on the left side. A 3 in. diameter hole was then cut into center of the front of the box. Duct tape was used to enclose the top of the boxes flaps to allow the top to fluctuate. The fluctuation is used to force smoke and air out of the hole cut into the front of the box. This forcing of smoke and air out of the hole is important in the creation of smoke rings and will be described in further detail later on. The apparatus can be seen in Figure 1. This apparatus described was then filled with water vapor from a fog machine that was provided in the Integrated Teaching & Learning Program and Laboratory, ITLL. The apparatus was placed in front of the fog machine forcing water vapor into the 3 inch hole in the front of the box. Once the box was considered filled with enough water vapor, it was ready to be used to create smoke rings by applying a force to the fluctuating side of the box. The variation in the force applied to the fluctuating side determined at what velocity the water vapor and air would exit the hole in the front of the box.

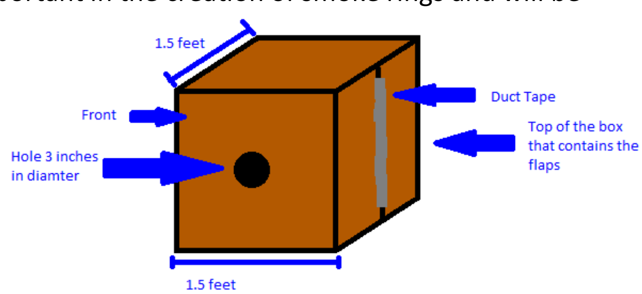

Figure 1

Smoke rings are actually just an example of the flow phenomenon known was vortex rings. The vortex rings created from this apparatus are created by the fluctuating side asserting a force onto the air particles forcing the particles to exit the hole cut in the front of the box. The air is travels at a higher velocity in the center of the hole and the air near the edge of the hole travels at a lower speed due to the drag caused by the surface of the hole. The air from the edge of the hole is then forced into the center of the ring and then picks up velocity. This creates a rotational motion of air in which air travels faster through the center of the ring and air from outside edge of the ring is then sucked into the center of the ring. This rotational movement of air is what allows the ring-shape of water vapor to be maintained.[1] Figure 2[2] demonstrates the rotational motion of air around the vortex ring. 'U' is the air in the center of the ring moving at a high velocity and '2a' is the air that is in the rotational motion.

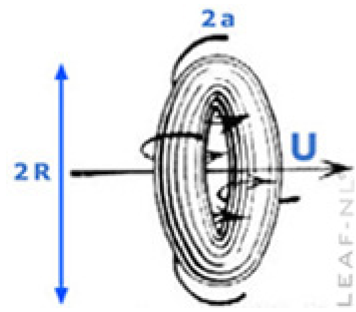

Figure 2

This particular smoke ring, seen in Figure 5, can have an estimated Reynolds Number calculated to determine if the smoke ring is experiencing Laminar or Turbulent flow. For this calculation the properties of the air, not the water vapor, is the focus of this calculation since it is the fluid caught in the rotational motion. The Reynolds Number equation can be seen below:

$$Re = \frac{UD}{v}$$

'U' is the velocity of the air and can was estimated to be 3 ft/s and 'D' is the diameter of the smoke ring which was measured to be approximately 6 inches uniformly. 'v' is the kinematic viscosity of the air and this was found using air property tables, for air at a temperature of 70°F. The kinematic viscosity is therefore 1.64×10^{-4} ft^2/s.[3] Using these numbers the Reynolds Number is calculated to be 9,146.34 which would make this particular smoke ring to experience Laminar flow. [4] Another useful number in classifying a vortex ring is the formation number and this formation number is the time at which the vortex ring reaches maximum circulation. This means the vortex ring's circulation will no longer be effected by the column of air forced from the apparatus, which the equation for the formation number can be seen below:

$$T = \frac{L}{D}$$

'T' is the formation number, 'L' is the length of the column of air, and 'D' is again the diameter of the smoke ring. The length of the column of air depends on the size of the apparatus and for the apparatus

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1 "Ring-shaped Vortices." *CAELESTIA: A Research Initiative for Unidentified Aerial Phenomena*. Caelestia. Web. 22 Mar. 2012. <http://www.caelestia.be/ringvortex.html>.

2 "LAB FOR ADVANCED STUDIES IN NON LINEAR PHENOMENA." *LAB FOR ADVANCED STUDIES IN NON LINEAR PHENOMENA*. University of Chile Department of Physics and Mathematics. Web. 22 Mar. 2012. <http://www.leafnl.uchile.cl/rings.html>.

3 http://www.engineeringtoolbox.com/air-absolute-kinematic-viscosity-d_601.html

4 Giezer, Ari. "The Formation of Vortex Rings." *Scitation.aip.org*. University of Arizona Department of Aerospace and Mechanical Engineering, 24 Aug. 1988. Web. 22 Aug. 2012. <http://scitation.aip.org/getpdf/servlet/GetPDFServlet?filetype=pdf&id=PFLDAS000031000012003532000001&idtype=cvips&doi=10.1063/1.866920&prog=normal>.

used the column of air is at a length of 1.5 ft. Again the diameter of the smoke ring was measured to be approximately 6 inches uniformly. This makes the formation number to be 3.

One of the materials utilized in this to capture this flow visualization technique was the use of a cardboard box apparatus which was previously described. The smoke was created by using a fog machine provided by the ITLL and a 3ft by 3ft black poster board provided by group member Guy Casavan. The apparatus sat on one table approximately 1 foot from the black poster board on an adjacent table of equal height. The experiment itself was conducted in flow visualization storage room on the bottom floor of the ITLL. The light source that was utilized is just the room overhead lights that are located approximately 10 feet and 11 feet from where the smoke ring was formed. The smoke ring picture was taken as the smoke ring was 3 ft from the apparatus and in front of the black poster board. To location and distances of all of these materials are provided in Figure 3.

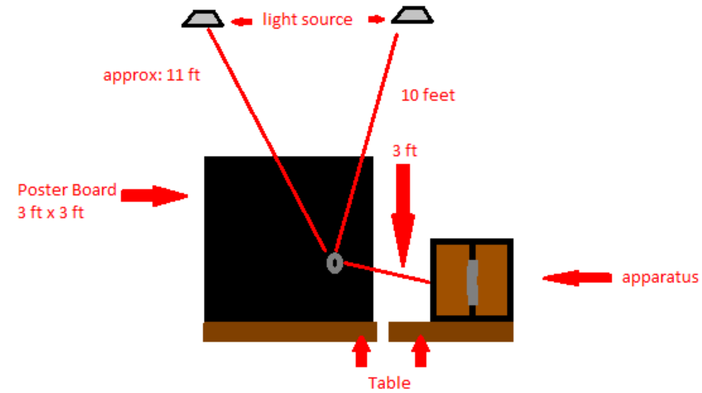

Figure 3

The size of view the photo was taken in was 2 ft. by 2 ft. or an area of 4 ft^2. The photo was also taken from behind the smoke ring at a lens to object distance of 4 ft and an angle of 45°, this can be seen in Figure 4. The camera I used is a Pentax Optio WS80 digital camera with a focal length of 6.2 mm. This picture had a shutter speed value of 1/6 seconds and a Aperture Value of 3.852 secs. The ISO setting used was 800. The final image, Figure 6 was also minimally photoshoped because too much manipulation distorted the image too much. The manipulations that did occur were a basic cropping of some of the poster board caught in the image. The contrast of the image was than increased to make the smoke ring really pop out from the black poster board. This also created an unintentional effect of making the smoke ring appear to be "ghostly" and helped make an ordinary smoke ring image become a more unique image. The original and final images can be seen below:

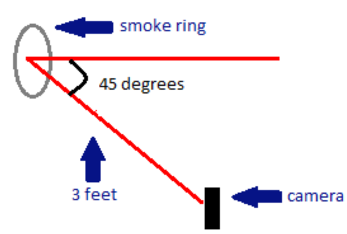

Figure 4

<u>Original Image:</u>

<u>Final Image</u>:

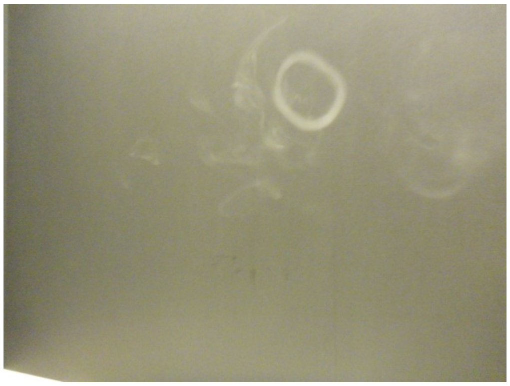

Figure 5

Width: 3648 pixels
Height: 2736 Pixels

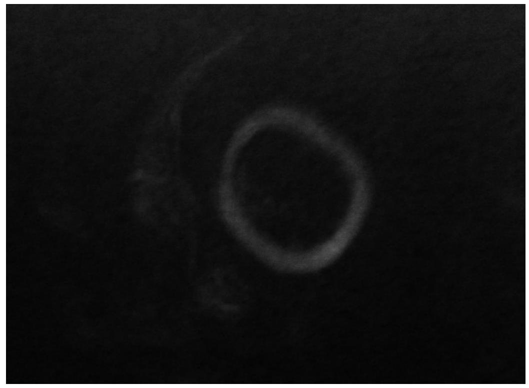

Figure 6

Width: 1764 pixels
Height: 1290 pixels

I like how instead of taking a typical perpendicular image of a smoke ring that this was taken at an angle behind the smoke ring. This really helped demonstrated how the rotational motion of air creates a circular ring of smoke. It captures the effects of this fluid flow phenomenon but does not actually show the circulation of air itself which is generally better seen in images taken perpendicular to the smoke ring. However, in the end I was able to achieve my intention of capturing a smoke ring being seen as a nearly uniform circular ring. To improve this image I would have preferred to use a better camera that allows more of zoom function that won't distort the image. However, team member Guy Casavan did have a DSLR type of camera that allowed that type of zoom and I took a few images with. I found it very difficult to be able to use the zoom function because the smoke rings created from the apparatus would not form in the exact same area each time. This made it difficult to predict the best positioning of the camera to capture the intended image. I wonder if the use of a smoke ring gun would allow less variation in the position of the smoke ring and help better predict the best positioning of the camera? Overall, I was able to achieve the image I intended to capture, but further iteration of this experiment might include the increased use of a DSLR camera and developing a apparatus that has a more predictable smoke ring location.