Flow Visualization

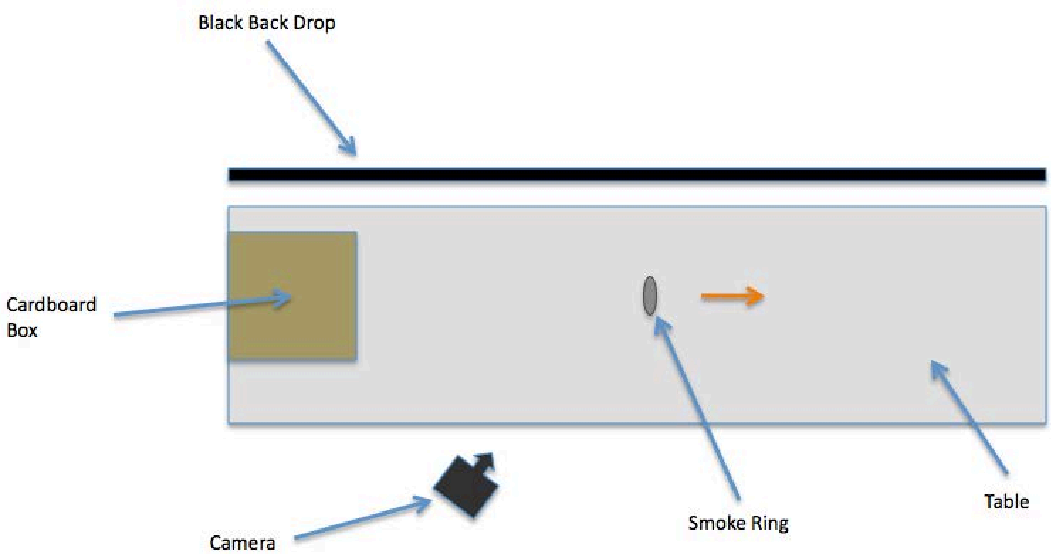
"Smoke Ring"

March 12, 2014

By:
Mark Voll
Kristopher Tierney, Lael Siler, and William Derryberry

This image captures a vortex ring of smoke moving from left to right horizontally across the frame. The intention was to illustrate how the fluid within the smoke ring moved. A video would have given a better sense of speed but a single image gives the viewer much more opportunity to study the detail. One example of this is the jellyfish like trail coming off of the back of the smoke ring.

This image was captured from a distance of approximately five feet. The diameter of the smoke ring was similar to that of the hole in the box, this was measured to be three inches. The box was able to enclose a cubic foot of smoke; this enabled us to generate multiple rings before refilling the box with smoke. The rings were generated by squeezing the side of the box. This changed the volume of the box and increased the pressure inside. The smoke had no where to go but out the small hole in the front. The source of the smoke was a commercial fog machine. We let the fog flow into the box for 20 seconds so we new the air was saturated. The camera was hand held in order to track along with the ring as it moved to the right. The set up we used is displayed below.



Vorticity is defined as the rotation of a fluid element around its own middle. This is what occurs in a vortex ring. The fluid on the edges is orbiting the center while the fluid in the center is rotating about itself. The closer you get to the middle the faster this rotation occurs. The fluid on the edges that is orbiting the center can easily be identified in this image, which is why I chose it. Vortices are an extremely interesting phenomenon and can be observed in water, air, volcanic plumes, and also fire under the right circumstances.

The smoke ring possessed a Reynolds number of 1515. This number helps show that the ring was not completely stable. Vortex rings have been observed to be stable at Reynolds numbers below one thousand. Rings with higher Reynolds numbers become unstable over time and begin to oscillate[1]. I observed this phenomenon after around ten seconds. The Reynolds number calculation is shown below using the diameter of the ring, speed of the ring, and kinematic viscosity of air[2].

$$\mathbf{Re} = \frac{UD}{\nu} = \frac{(1\ ft/s)\ (.25\ ft)}{1.65*10^{-4}\ \frac{ft^2}{s}} = 1515$$

The smoke ring was lit by the natural sunlight shinning through big windows parallel to our set up. It was a very cloudy day so this evened out some of the glare that could have resulted from direct sunlight. This made it easy because we didn't have to set up artificial lighting. We planned for the fact that smoke is hard to detect because of its light grey color by using a black background. The black background allowed for the best contrast that could be achieved with the light colored smoke. The post processing improved this contrast further. I adjusted the light levels to make the smoke stand out even more from the background. The original raw image from the camera is shown below.

The camera I used was a Canon EOS Digital Rebel with a 50 mm non zoom lens. I used the automatic focus and shot in sports mode. This gave me a quick shutter speed that allowed all the fluid movement to be in focus. The camera specifics are listed below.

Dimensions:	2571 x 1526
Device make:	Canon
Device model:	Canon EOS DIGITAL REBEL
Color space:	RGB
Color profile:	Camera RGB Profile
Focal length:	50
Alpha channel:	No
Red eye:	No
F number:	1.8
Exposure time:	1/250

This image is very unique in the way that you can see the smoke spinning off the edges of the ring. It really paints a picture of the physics occurring with the smoke leaving the ring and then hanging temporarily in the air to for the tail section. The tail of the smoke ring also helps make the smoke ring look like a comet streaking through the air. I am proud that this image was able to capture my initial intent of showing the inner physics of a vortex ring.

References

1) http://books.google.com/books?id=7KJpEiB1DQgC&pg=PA104&lpg=PA104&dq=stable+vs+unstable+reynolds+number+vortex+ring&source=bl&ots=UwA4Zs5LaB&sig=GwKV-f0reGgFRmxybIbHoplOZdU&hl=en&sa=X&ei=GYsmU9r5D4SfyQGF-4GQBg&ved=0CC0Q6AEwAg#v=onepage&q=stable%20vs%20unstable%20reynolds%20number%20vortex%20ring&f=false

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