MCEN 5151: Flow Visualization

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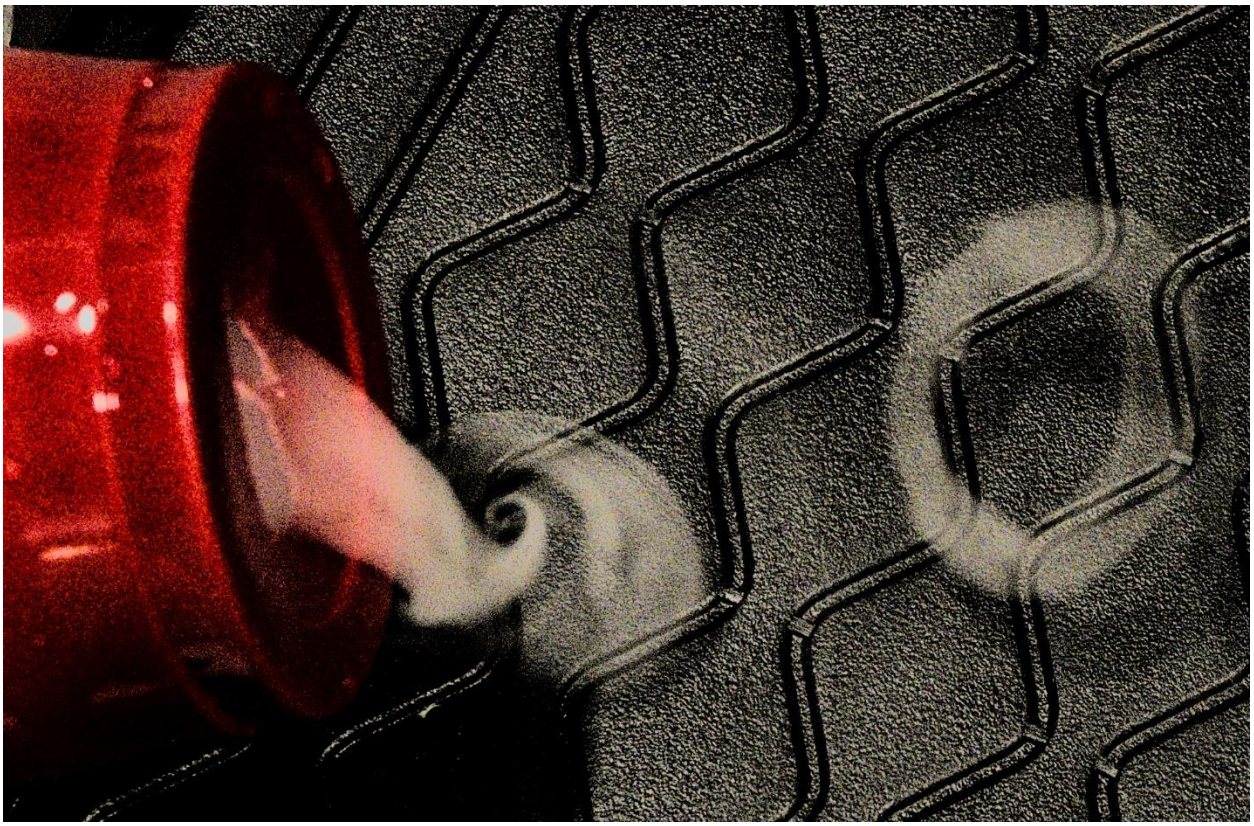

Flow Visualization 2nd Assignment

Purpose

The motivation for this image was to try to create and photograph a vortex ring. I have previously studied vortex rings in fluids classes, but I have not had the opportunity to see their physical manifestations. Therefore, for this assignment I decided work with dry ice to create my own vortex rings. The report attempts to describe how this picture could be recreated.

Visualization Techniques:

Materials:

- Dry Ice Chips from Boulder General Air Store
- Warm Tap
- Red Solo Cup
- Rubber Band
- Black Rubber Shoe Mat

Imaging Technique:

Camera: Nikon Z6

Image Size: 6064 x 4040

Focal Length	Exposure	f/	ISO
65 mm	1/60	10	20000

To take the picture I held the camera by hand. Since the shutter speed was relatively fast this mean I could get a decently clear image. The initial image was clear but I wanted to make the contrast between the dry ice vapor and the background stronger. I had some success in achieving this by playing with the RGB curve using darktable editing software.

Flow Apparatus:

The image was taken inside with the source of light coming from behind the camera (my phone flashlight). I first cut a small hole in the bottom of a red solo cup (about 1 cm in diameter). Then I took a plastic sandwich bag and placed it over the top of the solo cup. Using a rubber band, I secured the bag so that there was a complete seal (i.e. Stretched the rubber band around the cut with the plastic bag edges between the rubber band and the cup – similar to a drum skin). Then, from the bottom, where I cut the small hole, I filled the cup about a third of the way up with warm water. After that I put in a few dry ice pellets.

Tilting the cup sideways and using the plastic bag like a diaphragm, I pushed a small puff of vapor out of the cup. After a few minutes of practice, I was successfully able to produce vortex rings. Then I photographed the results

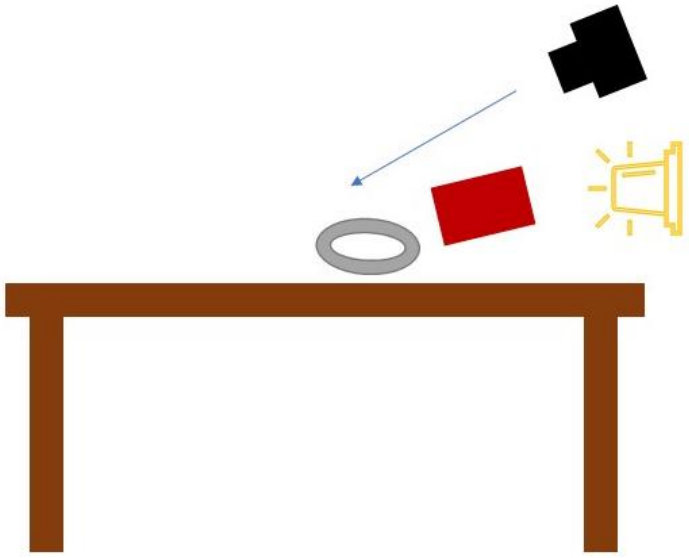

Figure 1

Flow Dynamics:

The phenomenon demonstrated in the image is related vortex dynamics. The reason a vortex ring is formed in this experiment is because air flowing out the center of the hole is moving faster than the air flowing out near the edges[1]. A vortex ring is a closed vortex filament – a line which fluid circulates around (a vortex ring analogous to a tourus for electricity and magnetism). Once the vortex ring is created, its behavior is modeled using the Biot-Savart Law.

$$\boldsymbol{u} = \frac{1}{4\pi}\int_{\Omega} \frac{\omega \times (x - x_s)}{|x - x_s|^3} d\Omega$$

Here u is the induced velocity at a location some position with coordinates x by the vortex filament located at x_s [2]. It can be simplified to the following equation:

$$\boldsymbol{u} = \frac{\boldsymbol{\Gamma}}{\boldsymbol{2\pi h}}$$

Here $\boldsymbol{\Gamma}$ is the circulation strength of the vortex and h is the distance between the center of the vortex and the location of induced velocity. Since the ring is moving towards the

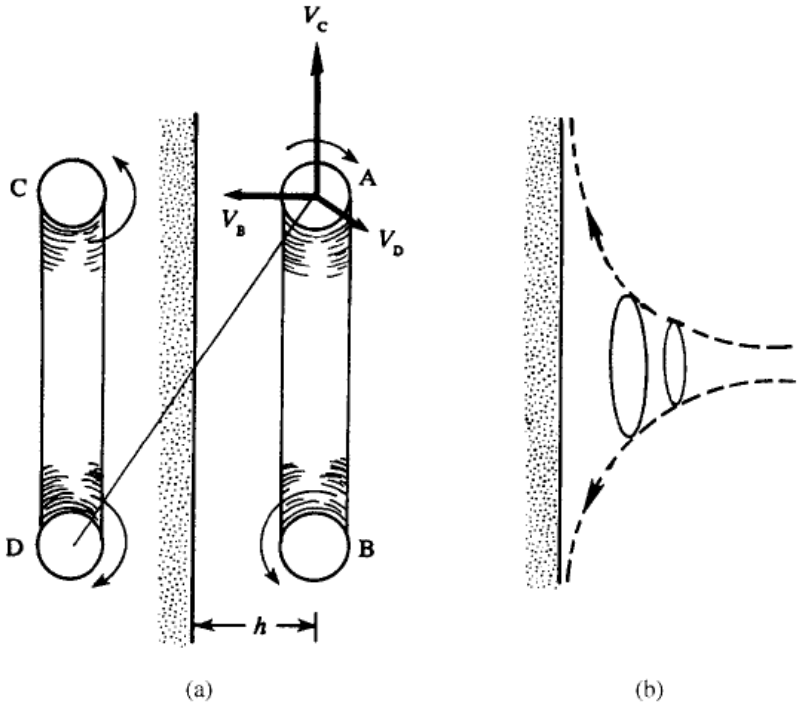

Figure 2

table, we can use the method of images to determine the behavior. With the method of images an imaginary vortex ring is placed on symmetrically on the other side of the table. Each vortex ring, the real and the imaginary one, will induce a velocity on the other. In this case we see the vortex ring stretching out to a wider diameter as is

approaches the table[4]. This can be seen the figure above. Based on some observations we can estimate the circulation along the vortex ring. The vortex ring moved approximately 0.5 cm/s at a distance of about 1 cm away from the table (2 cm away from its image).

$$\Gamma = u2\pi h = (5 * 10^{-3})(2\pi)(2 * 10^{-2}) = 6.3 * 10^{-4} \frac{m^2}{s}$$

It is notable that this model assumes an inviscid fluid which isn't correct. Air is viscous fluid and this model breaks down[3]. This is evident given by the fact that vortex rings do not propagate infinitely in real life.

Results of Final Image and Revelations:

I was happy with the results of this image. I think in the end the choice of colors worked out well: there was enough contrast so that the vortex ring was visible. I think that it could have been a stronger image if I used a background that didn't have as much texture and didn't have as much glare on it. However, I think despite the extra glare, the pattern of the shoe mat is interesting. My favorite part of this assignment was that I was successfully able to produce vortex rings and see that they have similar behavior to the theoretical solutions I have worked with in my classes.

Works Cited

1. “Dry Ice Smoke Ring Launcher - Sick Science: Science Experiment.” Steve Spangler Science, 23 Apr. 2019, https://www.stevespanglerscience.com/lab/experiments/dry-ice-smoke-ring-launcher/.
2. Ye, Qu-Yuan, and C. K. Chu. “Unsteady Evolutions of Vortex Rings.” AIP Publishing, American Institute of PhysicsAIP, 1 Apr. 1995, https://aip.scitation.org/doi/citedby/10.1063/1.868602.
3. Sano, Osamu. (2015). Behavior of Vortex Rings. Forma. 30. S77-S80. 10.5047/forma.2015.s013.
4. Kundu, Pijush K., et al. Fluid Mechanics. Elsevier, 2016.