Report #4 – Team Second Assignment Fall 2018

William Tse

MCEN 4151-001: Flow Visualization

Professor Jean Hertzberg

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1 ABSTRACT

The Team Second assignment was the second creative challenge that teams took on in MCEN 4151-004: Flow Visualization. The intent of the assignment was to build from the first team assignment and apply what was learned from the first assignment into the second. In our case, we took on a new visualization in vortex smoke rings.

1 Physics Revealed

The phenomena studied in this report focuses a puff of smoke suddenly being injected into air, through a narrow opening. This narrow opening happened to be through the mouth of group 5's member, Christopher McFadden. The exterior, still air contacts the outer edges of the puff and slows this contact point in the poloidal direction (in the direction of the poles) to form its donut-like shape.

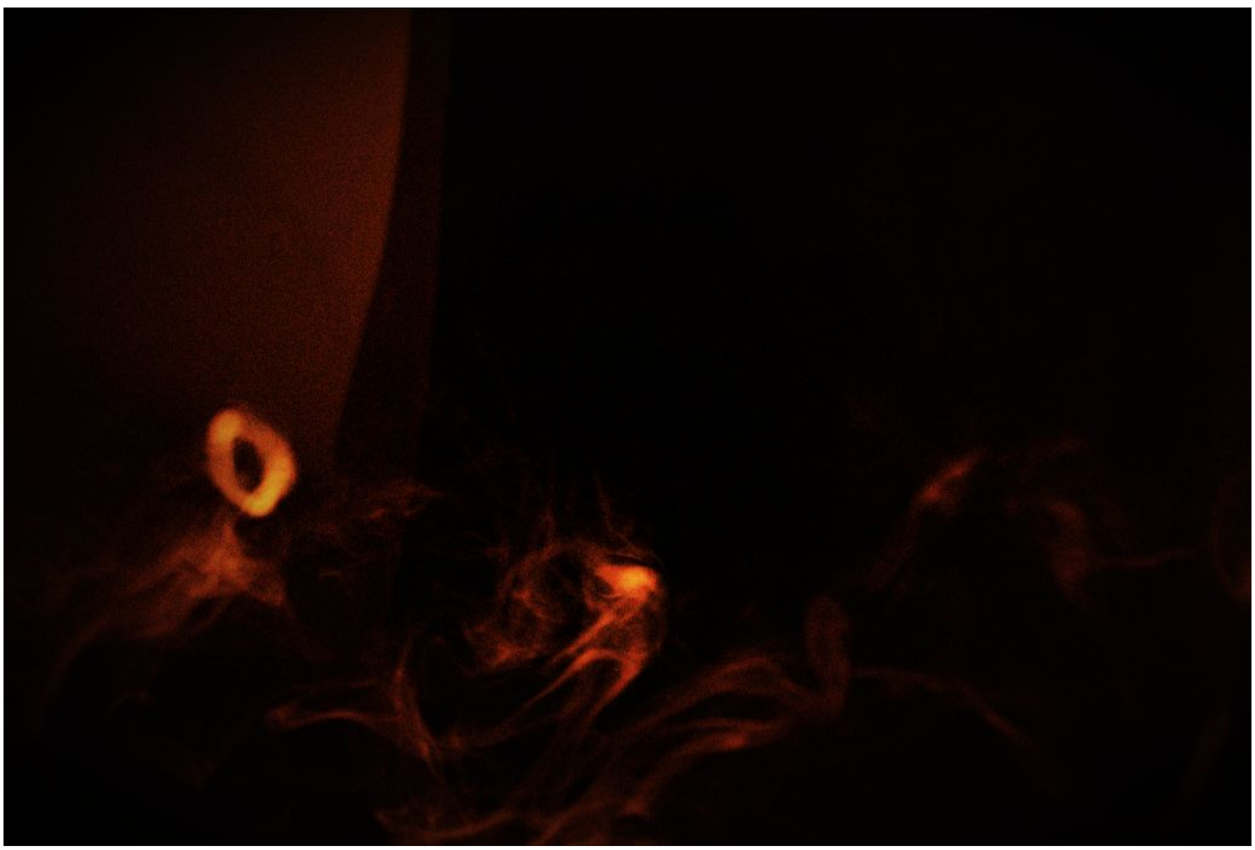

Figure 1: Edited Team Second picture of O-rings blown from team member Christopher McFadden as wisps from preceding rings fade.

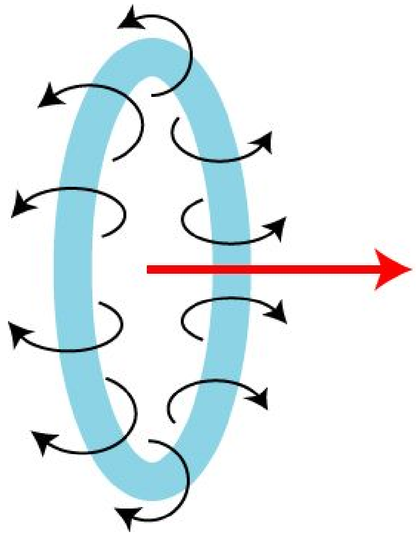

Figure 2: Illustration of poloidal direction of molecules forming as still air makes contact and slows down the edges of the fluid projection.

There are many mathematical models explaining the motion of vortex rings, as air cannot be perfectly still for steady state flow. However, assuming this steady state, axisymmetric rotational flow can be derived from Stokes stream function,

$$u_z = \frac{1}{r}\frac{\partial\psi}{\partial r}, \quad u_r = -\frac{1}{r}\frac{\partial\psi}{\partial z}.$$

This looks into the azimuthal velocity component that develops the rotary motion depicted in figure 2 about the symmetry axis, taking into account the radius r, direction z, and angle phi. Using the mass-conservation equation for an incompressible fluid flow, this flow then becomes:

$$\nabla \cdot \mathbf{u} = \frac{\partial u_z}{\partial z} + \frac{1}{r}\frac{\partial (r u_r)}{\partial r} = 0,$$

The vorticity vector, *w,* becomes important in measuring the rate of rotation, and Navier-Stokes equation is used to model this vector:

$$\omega_\phi = \frac{\partial u_r}{\partial z} - \frac{\partial u_z}{\partial r} = -\frac{1}{r}\left(\frac{\partial^2\psi}{\partial z^2} + \frac{\partial^2\psi}{\partial r^2} - \frac{1}{r}\frac{\partial\psi}{\partial r}\right)$$

There is much more that goes into the formation and dynamics of vortex rings. But in short, the individual elements of each "puff" molecule on the outer edge makes contact with still air in vectors mentioned above. Using the conservation of mass, the direction, magnitude, and shape of the ring can be determined using steady-state assumptions.

2 FLOW APPARATUS

The setup to produce this image was fairly simple. The location that the picture was taken on was on the third floor of the Wolf Law Building in a study room. A black drape was used as a background for many of the produced flows. However, for the picture below the wall of the study room was used with the lights turned off in the room. Two phone lights were placed a foot apart and shining directly on the rings as they passed the light three feet from the study room floor. The smoke vortices were blown from the left side and traveled to the right wall, facing the door of the study room.

3 VISUALIZATION TECHNIQUE

To create the image, the Cannon SL1 was used. The F-stop was set to f/5, exposure time was set to 1/100 seconds, and the ISO was set to 1600. The ending pixel image was 5184 x 3456. The setting of the camera was changed to auto-focus, focused by a finger placed at the approximate location that the smoke ring would be blown to, to capture the smoke ring in focus.

Figure 2 : Raw, unedited version of the photo taken with the visualization technique above. Post processing was simply done in Photo Editor that comes with Windows 10. The contrast was set to +25, warmth +30, saturation +10, tint +15, light +5, these settings were repeated three times, saved and redone to get warmth and contrast of the picture.

4 CONCLUSION

Both the post-processed and raw photos reveals the complex motions of theoretical stable vortex ring flows. Maybe for next time, I could adjust the shutter speed or look more into focusing the image better to reduce the amount of motion blur and grain in the picture as contrast is increased during post-processing. The lighting would also be more controlled if the image was to be redone.

5 REFERENCES

[1] Skullsinthestars (2012, August 28). *Physics Demonstrations: Vortex Cannon!* *https://skullsinthestars.com/2012/08/28/physics-demonstrations-vortex-cannon/*