Vortex Rings

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MCEN 5151: Flow Visualization – Team Second

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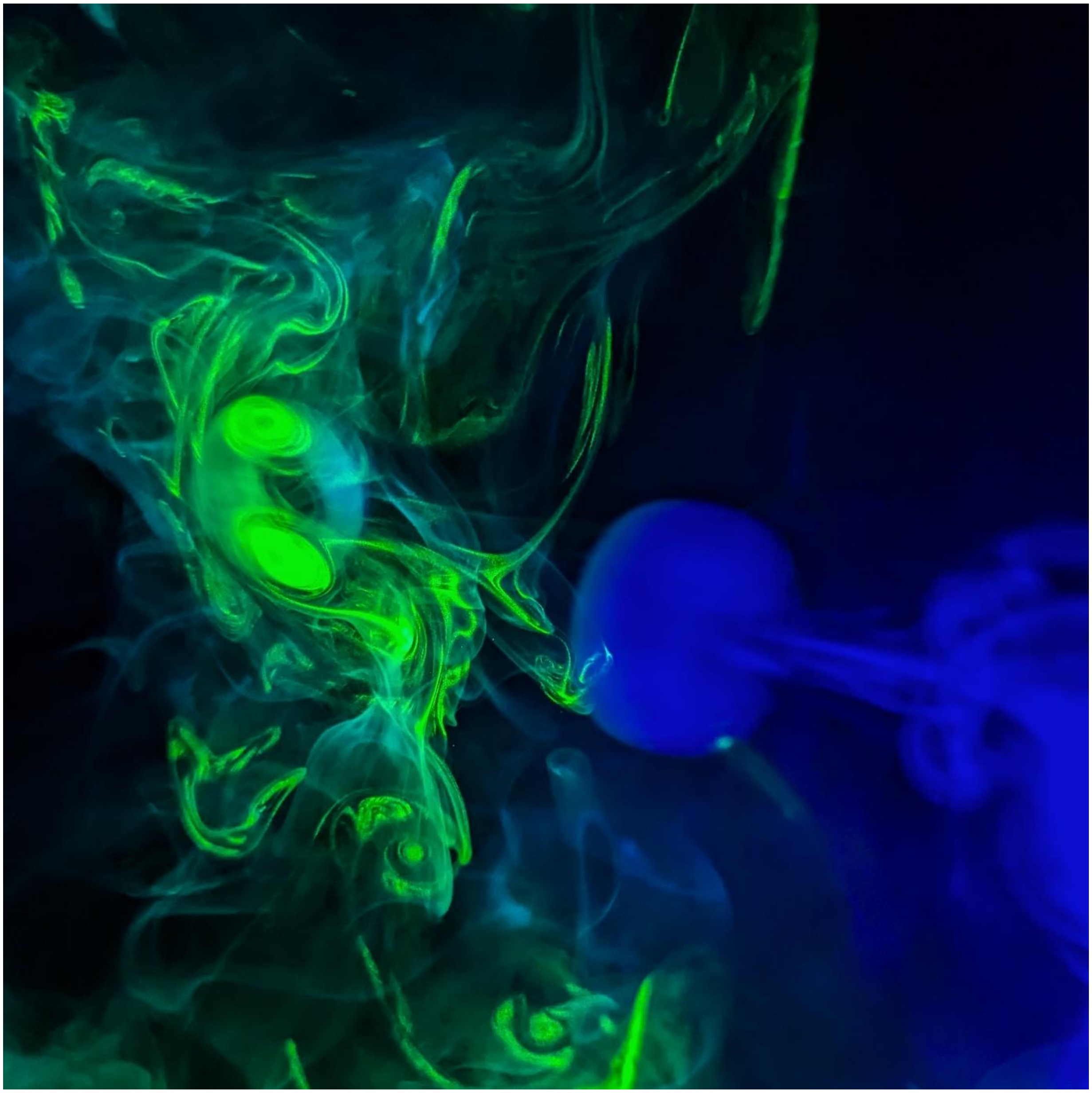

Figure 1: Vortex rings

Introduction

Figure 1 shows several vortex rings, illuminated by a swept laser and an LED. Vortex rings are shot from a gun on the right, and the first one is illuminated in blue. The next one is sliced by the laser, revealing the cross-section of the ring. A few older ones are visible in various places in the laser sheet. The photo was taken without assistance from Lia or Kate due to illness.

Vortex rings have been studied for decades and can be visualized in a multitude of different ways, depending on the goal for the visualization. Walker et. al describes two techniques using dyes (Walker, Smith, Cerra, & Doligalski, 1987). The first method, the simplest, is to dye the fluid that will create the vortex ring. This strategy is good for observing the motion of the vortex ring, though the inner motions are obscured. The second method is to dye a plane in the path of the vortex ring. This method is effective for viewing how the boundary of the ring interacts with the fluid around it. While both these techniques are good for visualizing different behaviors of vortex rings, neither technique well-visualizes the interior. To do this, a laser sheet can be used to illuminate a plane of the vortex ring (Wang, Chen, Deng, & Gao, 2023). Wang et. al describes how laser-induced fluorescence can be used to visualize the interiors of vortex rings. A vortex ring is created with some fluid that fluoresces when hit with a laser beam. By creating a laser sheet and shooting a vortex ring across the sheet, the interior becomes visible.

Experiment Overview

This experiment uses that principle. However, a laser sheet was not available, so a swept laser was used instead. Since the swept laser had a finite speed, the shutter speed needed to remain relatively high to capture enough of the sheet to visualize the vortex ring. The vortex rings were generated with a toy gun that shoots rings made of stage fog. The rings were estimated to move at approximately $0.033\ \frac{\mathrm{m}}{\mathrm{s}}$ and have a diameter of $0.05\ \mathrm{m}$, though their velocity and size were somewhat varied. This gives a Reynolds number of:

$$\mathrm{Re_D} = \frac{\rho V D}{\mu}$$

$$\mathrm{Re_D} = \frac{(1.01)\left(0.033\ \frac{\mathrm{m}}{\mathrm{s}}\right)(0.05\ \mathrm{m})}{1.81 \times 10^{-5}\ \frac{\mathrm{m}^2}{\mathrm{s}}}$$

$$\mathrm{Re_D} \approx 92$$

Visualization Technique

The experiment was conducted in a dark room in front of a black velvet sheet for a backdrop. There were two sources of illumination: the laser sheet, and an LED on the vortex ring gun. The LED was purposely left on to show two different perspectives of vortex rings: the LED illuminates the entire fog and shows the body of the ring, and the laser slices rings and shows their cross-sections.

Photographic Technique

Table 1 lists the camera information and the size of the image.

Table 1: Camera information/settings

Camera model	Google Pixel 6
Focal length	6.8mm
Aperture	f/1.9
Exposure	1/77
ISO	434
Image size	3072 x 4080
Image size (cropped)	2729 x 2729
Field of view	61.26 cmx 80.25 cm

The original image is shown in Figure 2. The image was cropped, and the contrast slightly increased, but otherwise left largely untouched. A cell phone camera was chosen because of the larger aperture and the HDR, which produced much brighter, less noisy results than a traditional camera.

Based on the velocity of the fluid, the vortex ring is estimated to have moved about 0.43 mm (or 2 pixels) during the exposure period, which is negligible.

$$\text{Exposure time} = V \times \Delta t = 0.033\,\frac{\text{m}}{\text{s}} \times \frac{1}{77}\ \text{s} = 0.43\ \text{mm}$$

However, the motion *inside* the ring is much faster, and motion blur can be seen increasing toward the center, where there are higher velocities.

Figure 2: Original unedited image

Conclusion/Recommendations

The final image shown in Figure 1 shows several vortex rings, both as whole rings, and sliced through the center, revealing cross-sections. To produce better images, a true laser sheet could be used to produce better results, as this would allow for further increases in shutter speed. A higher shutter speed would result in greater resolution of the detail inside the ring. However, the current image is still compelling.

References

Walker, J. A., Smith, C. R., Cerra, A. W., & Doligalski, T. L. (1987). The impact of a vortex ring on a wall. *Journal of Fluid Mechanics, 181*, 99-140. doi:10.1017/S0022112087002027

Wang, X., Chen, W.-L., Deng, Z., & Gao, D. (2023). Reynolds number effect on vortex ring colliding with a solid wall. *Journal of Visualization, 26*, 1263–127. doi:https://doi.org/10.1007/s12650-023-00944-0