Vortex Ring

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Figure 1: Vortex Ring Above LED Panel

Project Background

A vortex ring drifts over an LED patch light. The ring is composed of water vapor and carbon dioxide produced by dry ice sublimation in hot water. This image aims to capture vortex ring propagation.

Methods and Discussion

Flow Apparatus

To generate the vortex captured in Fig. 1, we placed dry ice in a small cup with water. We covered the large opening of the cup with a stretched balloon and drilled a small hole in the opposite end. My team mates tapped the balloon end of the cup to propel the cooled water vapor and carbon dioxide outwards forming a vortex ring. The cup was positioned just below the LED light as seen in Fig.2.

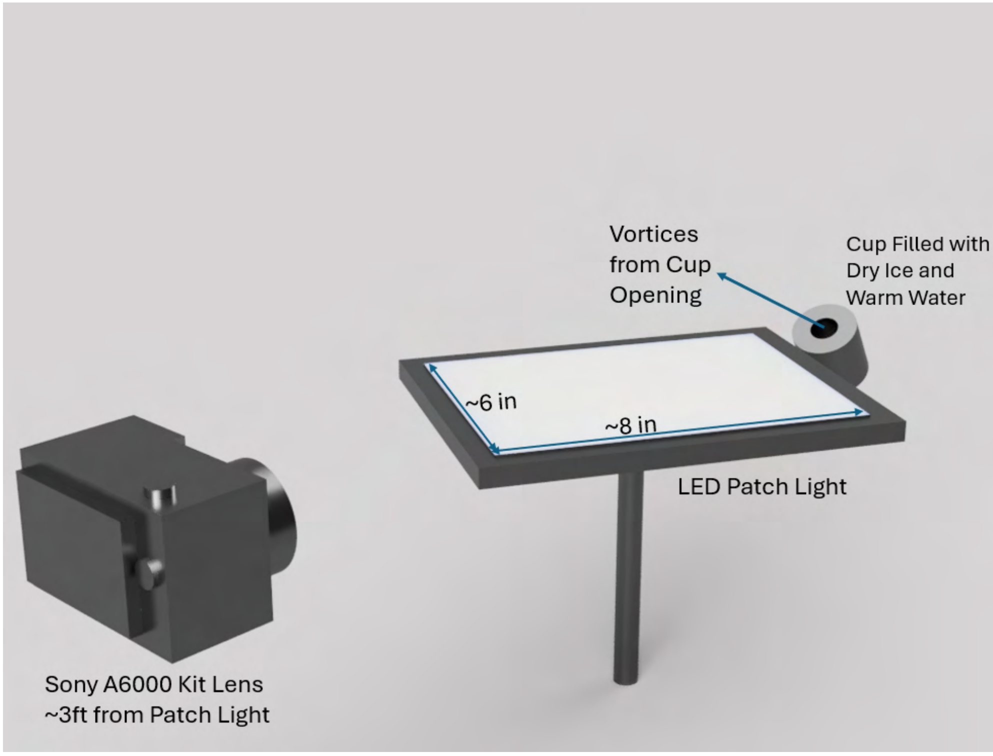

Figure 2: Imaging and Flow Set Up

After tapping the cup, the vortex rings fell traveled upward and fell across the LED light.

Nondimensional Estimates

The vortex ring Reynolds number is estimated using the translational speed U, the ring diameter D as the characteristic length, and the kinematic viscosity ν. For the kinematic viscosity, the fog mixture is assumed to be cold humid air.

$$Re = \frac{U\,D}{\nu}$$

Based on the image, the ring diameter is estimated to be $D \approx 4\,\text{in} = 0.1016\,\text{m}$ with a speed range of $U \approx 0.3\,\text{m/s}$ to $1.0\,\text{m/s}$. The kinematic viscosity is taken at 10° C which gives $\nu \approx 1.4 \times 10^{-5}\,\text{m}^2/\text{s}$ (The Engineering Toolbox). With these assumptions, the Reynold's number range is:

$$Re_{\min} \approx \frac{(0.3\,\text{m/s})(0.1016\,\text{m})}{1.4 \times 10^{-5}\,\text{m}^2/\text{s}} \approx 2.2 \times 10^3, \qquad Re_{\max} \approx \frac{(1.0\,\text{m/s})(0.1016\,\text{m})}{1.4 \times 10^{-5}\,\text{m}^2/\text{s}} \approx 7.3 \times 10^3.$$

$$\boxed{Re \sim (2\text{–}7) \times 10^3}$$

This range places the vortex ring in a relatively high Reynold's number regime. For a more accurate Reynold's number calculation we could also consider the density of the vortex ring.

Discussion

Vortex rings form when the thin boundary layer at a nozzle edge separates and rolls up, pulling in nearby fluid (Didden, 1979). In this setup, the cup hole acts as the nozzle. A tap on the balloon creates a short jet then the shear layer at the edge rolls up and the ring moves away. In the Fig. 1, the lighter band near the center of the ring suggests fluid wrapping into the core which is consistent with the Didden. Additionally, this roll up increases the diameter of the ring and its central core size.

The ring also shows a wavy, not perfectly circular edge signs of azimuthal (Widnall) instability (Widnall & Sullivan, 1973). The peaks are not as clear as textbook examples, but the tendency toward a sinusoidal outline is visible.

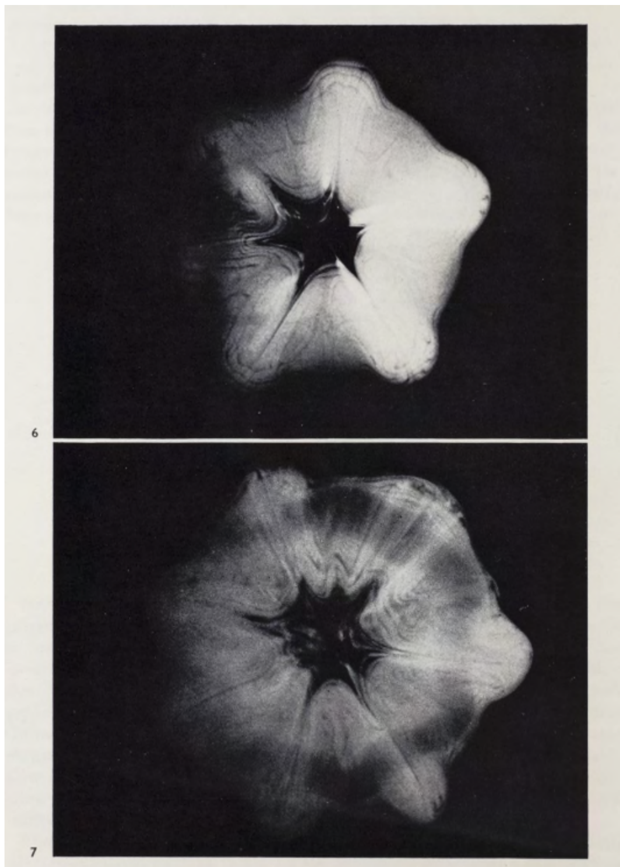

Figure 3: Vortex Ring Instability n=6 and n=7 (Widnall & Sullivan, 1973)

Fig. 3 shows 6 and 7 peaked vortices. The ring in Fig. 1 does not have as clear peaks as those seen in Fig. 3. However, we can see that the vortex is tending toward the Windall instability.

Visualization Technique and Lighting

The only lighting source in this image is the LED patch light shown in Fig. 2. After hundreds of shots, few frames were perfectly focused because small of small air currents in the room. In the final image, the vortex is moving toward the camera before it dissipated on the patch light. As previously mentioned, the vortex ring is made from water vapor and carbon dioxide. To create this mixture, dry ice was placed in a cup with hot water. The hot water caused the dry ice to sublimate and generate a light fog. Dry ice fog was used because the water vapor in the fog captures light easily for imaging.

The image was edited slightly to bring out details and remove unwanted blank space. Fig. 4 shows the unedited version. The following image, Fig. 5 shows the final.

Figure 4: Image Before Processing

Figure 5: Final Image After Processing

All camera settings, specifications, and edits are shown in the following table.

Table 1: Capture and Processing Details

Field of View	$\approx$ 10 in $\times$ 5.8 in
Subject Distance	3 ft
Lens	Sony E PZ 16–50 mm (OSS)
Camera	Sony A6000;
Image Size	Original image: [6020 $\times$ 4024] px Final image: [3659 $\times$ 2139] px
Seetings	Exposure 1/1000, f/5.6, 50mm, ISO 3200
Processing	Crop, increase exposure, sharpen, denoise, and increase contrast

Conclusion

Overall, I am happy with this image. The image reveals vortex instability which is a topic I did not know much about before this analysis. At times, our photography set up made it hard to capture a ring in focus. The small air movements in the room pushed the rings which demanded a higher depth of field. The rings also moved quickly which demanded a faster shutter speed. These factors were difficult to balance. If we were to repeat this experiment, we would fix the location on the vortex cannon and minimize currents in the room. It would also be interesting to capture rings produced by multiple sized vortex cannons and how the ring size impacts its stability.

References

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[3] Widnall, S. E., & Sullivan, J. P. (1973). On the Stability of Vortex Rings. *Proceedings of the Royal Society of London. A. Mathematical and Physical Sciences, 332*(1590), 335–353. `https://doi.org/10.1098/rspa.1973.0029`