Team First Report

Andrew Mord

Collaborators: Alyxis Ellington, Ellington Smith

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Figure 1. Final image submitted for Team First assignment

Background

This photograph was taken for the second visualization assignment of the Flow Visualization course: Team First. The image depicts four vortices, each in different stages of development. Different vortex development patterns were observed as they were discharged from a vortex cannon. Dry ice pellets and warm water were combined to make the vortices. The LED panel directly below the discharge range made for dazzling photographs.

Fluid Physics

The items used in this experiment include: 16-ounce Disposable Cup, Praxair Dry Ice Pellets, water, balloon, and a 4” x 6” LED panel mounted on a tripod. The items are arranged accordingly as seen below in Figure 2. Note that one end of the balloon was cut and secured over the opening of the cup.

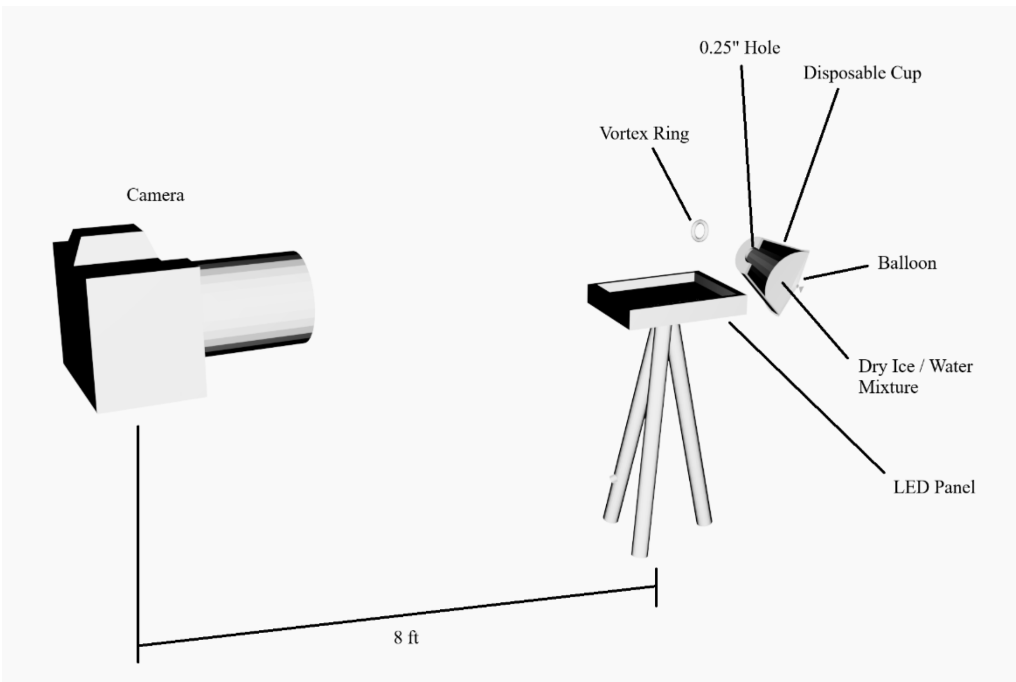

Figure 2. A diagram of the experimental setup used for the Team First project, with approximate dimensions.

The cup was loaded with dry ice pellets and hot water. The balloon membrane could be tapped lightly or forcefully to generate varying strengths of vortex rings. These vortex rings generally ranged from one to two inches in diameter. As the fluid dynamicist Theodore von Kármán once remarked, the vortex has also been “the ultimate symbol of danger to men,” a poetic reminder of the power and universality of rotational flows, from the smallest smoke ring to the largest atmospheric storm [1]. The formation and motion of a vortex ring are governed by a balance of inertial, viscous, and pressure forces acting on the fluid. As fluid is impulsively ejected through an orifice, shear at the boundary layer rolls the jet into a toroidal vortex whose shape is dictated by this interplay: inertia drives the forward motion, viscosity diffuses vorticity into the core, and pressure gradients sustain the circulating structure. Over time, these forces evolve as momentum diffuses outward and the ring stretches as it entrains surrounding fluid, causing its velocity and structure to change. A key dimensionless number to understand this behavior is through the slenderness parameter, α, which relates the ring's toroidal radius to its core radius. The toroidal radius being the distance from the center of the donut hole to the center of the inner ring and the core radius being the distance from the center of the inner ring to the edge of the ring. For a vortex ring like the ones displayed, with a toroidal radius of 0.5" and a core radius of 0.05":

$$\alpha = \frac{L_o}{\delta} = \frac{0.500\ in}{0.0500\ in} = 10 \tag{1}$$

This ratio appears directly in the classic vortex ring propagation equation:

$$U = \frac{\Gamma}{4\pi L_o}\left[\log\left(\frac{8L_o}{\delta}\right) - \frac{1}{4}\right] = \frac{0.00200\ \frac{m^2}{s}}{4\pi * 0.0127\ m}\left[log(8 * 10) - \frac{1}{4}\right] = 0.0518\ m/s \tag{2}$$

where Γ is the circulation, δ is the core radius, and L_o is the toroidal radius. Lord Kelvin published this without proof as an appendix to Hermann von Helmholtz's paper, and the origin of the ¼ term has been of much controversy. Fortunately, it turns out that Kelvin's value is correct [1]. For small, thin vortex rings, circulation is equivalent to $U_{core} * 2\pi\delta$, so for a small core velocity of 0.25 m/s, the circulation is $\Gamma = 0.0020\ m^2/s$ [2]. As the ring becomes more slender (large α), it travels faster and retains coherence over longer distances. In this context, the dimensionless form encapsulates how geometry and circulation together control the conversion of rotational energy into translational motion. The visual evolution of the ring — from a compact torus to a stretched, diffusing structure — reflects the ongoing competition between these forces. One can expect the upper, thinner vortices to propagate further than the lower, thicker vortices in Figure 1. Indeed, this phenomenon was observed while performing the experiment.

Visualization Technique

Initially, many different vortex cannons were used in this experiment, but ultimately the team settled on the cup with the 0.25" hole. The team performed the experiment in a dark room, with plenty of black curtains available to keep out light. The curtains did not reflect the LED, so they served well as a black background. When making the dry ice and water mixture, hotter water gave better results. Approximately 5-6 dry ice pellets (50 grams) with a cup of hot water gave optimal vortex rings. It sublimates the dry ice faster, generating more vapor, giving the vortex rings a clear structure. Timing was essential, as dry ice and water had to be combined efficiently to capture the best-looking vortex rings. Gloves are highly recommended when handling the dry ice pellets, as they can be inserted into the 0.25" hole on the cup.

The LED panel had a temperature setting of about 4000K, illuminating the vortices with a cooler light. No flash was used. The team took turns discharging the vortex cannon into the light. When it came to photographic intent, I wanted to capture as many vortices in one instance as possible. This led to taking hundreds of photos and hundreds of barrages of vortex rings. Patience must be exercised, as the image shown is the only one with four vortex rings.

Photographic Technique

Digital manipulations were used in the final product, the primary one being contrast equalization. Mid-range contrast was increased to get thin, smoky tendrils along the edges of the rings to pop out. A denoise modifier was added to decrease the graininess associated with the increase in contrast. Finally, the photo was cropped to remove the disposable cup in the corner since its red color distracted from the rings.

Figure 3. Original image with no manipulations

I wanted to have the two middle vortex rings in focus, while the edges be out of focus. This led to a lower F-stop and a large focal length zooming in heavily on the dynamics. Camera specifications are outlined in the table below.

Table 1: Camera Specifications

Camera Make & Model	Canon EOS Rebel T7 1500D
Shutter Speed	1/400
ISO	6400
Focal Length	300 mm
Aperture	f/5.6
Original Image Size	6000 x 4000 pixels
Final Image Size	4810 x 3848 pixels

Conclusion

The image reveals the diversity in vortex rings as the propagate forward. Some are thin and highly coherent, while others are plump and have trailing wisps. I like how clearly the slenderness parameter can be seen, and at the same time, the propagation of more slender rings. I dislike that the image cannot fully capture the circulating motion of the rings. I also wish there were more dry-ice vapor in the shot, I think it could help fill it in. The fluid physics are shown convincingly, but I am left wondering how sensitive the observed patterns are to container geometry and balloon elasticity. My original intent to capture the beauty of thin-core vortex rings in a simple, table-top setup was fulfilled, though the image could be improved with a slightly larger depth of field to resolve the rings towards the edge. Moving forward, I could develop this idea further by experimenting with different containers to see how they shift the vortex ring patterns.

References

[1] Shariff, K., Leonard, A., and Ferziger, J. H., “Dynamics of a Class of Vortex Rings,” 1989.

[2] Saffman, P., “Vortex Dynamics,” 1993. Retrieved 3 October 2025. https://doi.org/10.1017/CBO9780511624063