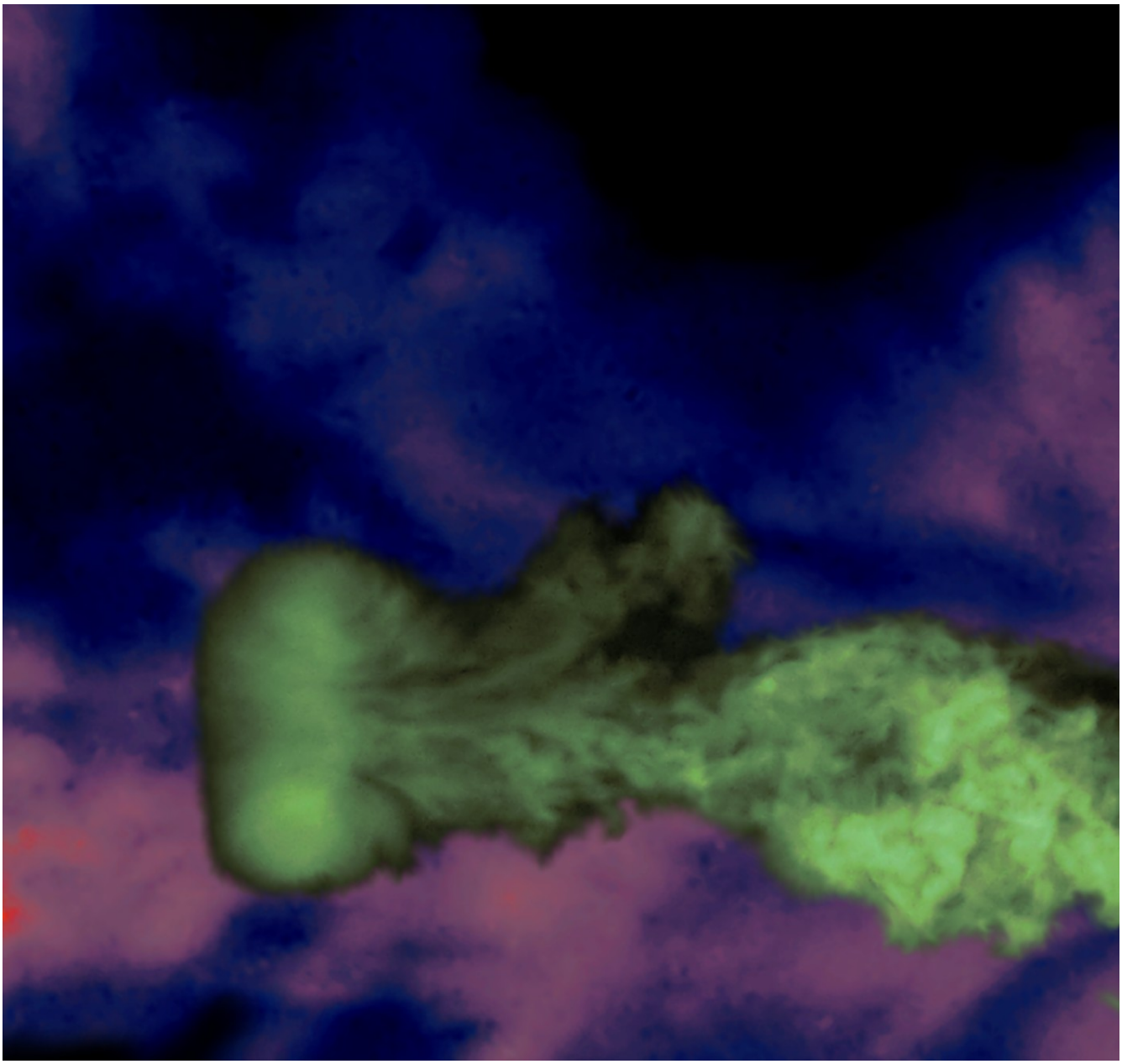
Vortex Rings

MCEN 5151-Group 9, Image #1

Wayne Russell



This picture was taken for the first group image in the Flow Visualization class at the University of Colorado. It was captured with the aide of Lotem Sella, Kelsey Spur, and Paul Sweazey. In order to capture the complex and often beautiful forms of vortex rings, a simple vortex generator was built and filled with smoke. The image was taken in front of a black background, although everything other than the jet of smoke was cropped out of the final image. Heavy post-processing resulted in an otherworldly image.

The vortex generator (shown in Figure 1) was built using a 5-gallon bucket. The top was covered in duct tape and a hole was drilled in the bottom. After initial testing, an attempt was made to enlarge the hole, but the bucket cracked. The entire bottom of the bucket was removed, allowing pieces of cardboard with different hole configurations to be used to create the smoke rings. When the duct tape was tapped, a smoke ring would rush out of the hole in the cardboard.

In this setup, the duct tape acts as a piston, pushing air down a cylinder. As air is forced out of the hole in the bottom, viscous forces cause the outside edges of the ejected air to move slower than the inside[1]. This causes the air to circulate around an imaginary circle as shown in Figure 2, forming the ring.

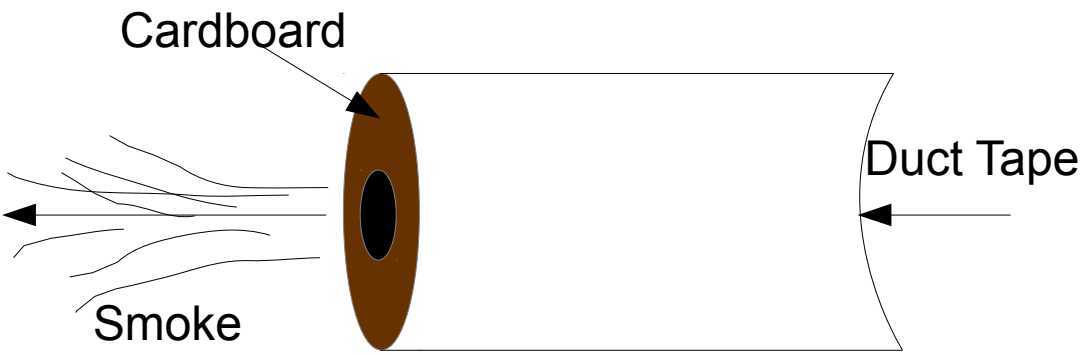
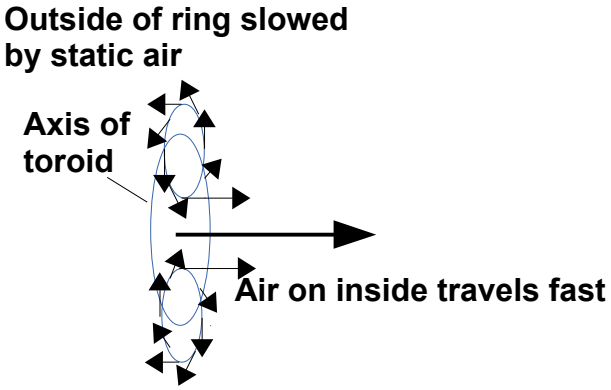


Figure 1: Duct tape depressed on the top of the bucket shoots a vortex out of a hole in the bottom of the bucket.

Had more care been taken while generating the vortex rings, or further measurements made, it would have been possible to estimate several of the smoke rings' characteristics. For instance, a plunger were used instead of duct tape to force the air out of the bucket and its speed measured, the circulation, energy, and impulse could be calculated[2]:



$$\Gamma = \frac{1}{2} L U_P \qquad (1)$$

$$E = \frac{1}{8} \pi D^2 \rho L U_P^2 \qquad (2)$$

$$I = \frac{1}{4} \pi D^2 \rho L U_P \qquad (3)$$

where Γ is the circulation, L is the length of the bucket, U_P is the speed of the plunger, E is the energy

of the vortex ring, D is the diameter of the bucket, and ρ is the density of air. Additionally, video or a series of timed pictures with a length scale could be used to estimate the radius of the ring, its formation time, and its propagation velocity. These measurements could have given further insight into the vortex rings being generated[3].

To generate the smoke rings, the bucket was filled with smoke from a stage fog machine. Illumination was provided by a 500 W work light shining onto a black backdrop slightly below the smoke ring, providing even lighting. The bucket and backdrop were cropped out of the final image, however, to avoid distracting elements.

A Casio Ex-ZR100 high-speed digital camera was used to capture the image. The ISO was set to 800 with a 1/100 s shutter speed. The focal length was 4.2 mm with an aperture of F/3. No flash was used. The original image was 3,648 x 2,736 pixels, cropped to 1,417 x 1,340 in the edited image. The backdrop and bucket were cropped out of the final image. The hue was adjusted to bring out details and give the smoke a green color. Additionally, a larger view of part of the smoke ring was rotated and the hue adjusted to have a blue-violet color; this view is used as the background in the final image.

Artistically, this image takes something with a lot going on and transforms it into a unique, psychedelic picture. Details of the flow could be calculated and estimated had more care been taken while creating the image. Additionally, lighting the smoke from below would have given a stronger contrast without any harsh reflections, minimizing the amount of editing that would be needed to give a visually appealing result.

References

[1] Maxworthy, T. *The Structure and Stability of Vortex Rings*, 1971. J Fluid Mech., vol. 51, pp 15-32.

[2] Shusser, M. and Gharib, M. *Energy and Velocity of a Forming Vortex Ring,* 2000.Phys. Fluids **12**, 618.

[3] Gharib, M., Rambod, E., Shariff, K. *A Universal Time Scale for Vortex Ring Formation*, 1998. J Fluid Mech, vol 360, pp121-140.