Get Wet

MCEN 4151

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The image described in this report was the first deliverable in the University of Colorado's Flow Visualization class. The assignment was to, "get your feet wet." There were no guidelines or constraints for the image, other than to make an interesting image of an observed fluid phenomenon. The phenomenon intended to be captured in this image was that of a toroidal vortex ring. Many attempts were made to capture a solitary vortex ring with varying techniques. Although this was eventually archived, the actual image chosen proved to be more interesting than just a single vortex alone.

The flow apparatus used for creating the image is depicted in Figure 1. The medium used was a solution of sugar dissolved in water with a ratio of 2 tablespoons sugar per 1 cup water. This produced a fluid with a density of $0.977 g/ml$. The medium was allowed to settle for approximately two minutes in a wine glass so that residual flows in the medium were minimized. A dropper was then filled with 2% milk which has a density of $1.030 g/ml$. Droplets of the dyed milk were then carefully dropped into the medium from a height of approximately $15 mm$ in order to produce vortex rings. The resulting difference in densities ensured that the vortex would propagate downward though the medium.

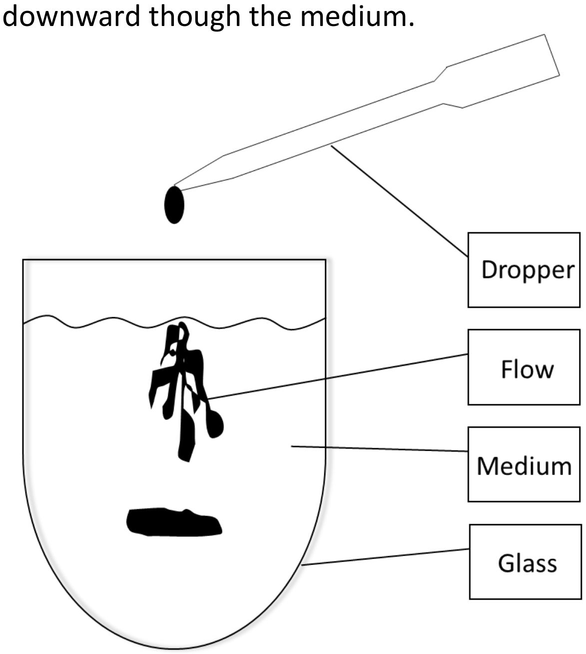

Figure 1: Diagram of flow apparatus.

A vortex ring is a flow phenomenon where a fluid moves in a circular paths perpendicular to a center core region and direction of travel to produce a shape resembling a donut as seen in Figure 2. When a fluid's velocity increases, its pressure is lowered relative to the surrounding medium. This results in a compression effect that stabilizes the vortex. The now spinning fluid drags against the medium at its edges which help to maintain its spinning motion.[1]

[1] www.howitworksdaily.com/science/how-vortex-rings-form/

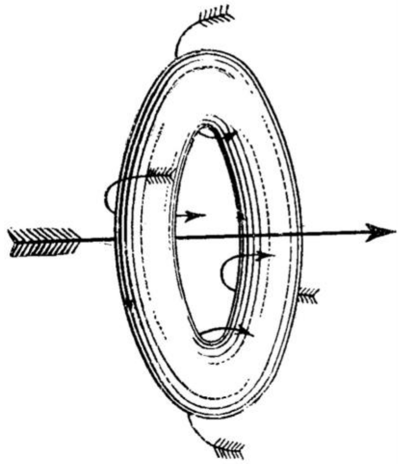

Figure 2: Depiction of a toroidal vortex ring showing the direction of fluid motion and ring vector.[2]

Based on Hamiltonian dynamics, the equations describing a toroidal vortex are:

$$\ddot{r} = \frac{p_\varphi^2}{M^2 r^3} - G\frac{M}{\pi R r}$$
$$\ddot{R} = -G\frac{M}{\pi R^2}\ln\frac{\alpha r}{R} \quad (1)$$

where, r and R are the small and large radii of the torus, M is the total vortex mass, G is the gravitational constant, $\alpha{\sim}1$ is a numeric factor, and $p_\varphi = Mr^2\dot{\varphi} = cons$ is the angular momentum of the matter (φ is the cyclic rotation coordinate at the small radius).[3]

In order to clearly visualize the vortex ring, the fluid had to be contrasted from the medium. To achieve this, the milk was dyed a dark purple by using red and blue food coloring. In addition, the subject was backlight with a 150W incandescent light bulb which was scattered though a single layer of white flannel fabric and a single sheet of white printer paper. The subject was placed approximately 100mm in front of the printer paper to produce an uninterrupted background for the photo.

This photo was taken on a Nikon P7100 10.1 Mega Pixel digital camera. The focal length was 14.5mm with a sensor size of 7.6x5.7mm resulting in a 29.6° horizontal and 22.2° vertical angle of view. This field of view was chosen so that the glass would fall completely inside the paper backdrop when the lens was placed 450mm from the subject. The camera was set to a fixed ISO 800 value to minimize image noise. A relatively small F-Stop of f/4.0 was chosen to allow for a greater density of light to hit the camera sensor and to emphasize the flow phenomenon by defocusing the rest of the image. A shutter speed of 1/200sec was chosen to allow for the maximum quantity of light to reach the camera sensor without blurring the fluid

[2] Image courtesy of vortexdynamics.blogspot.com
[3] Bliokh, K.Yu. "Gravitational Collapse and Equilibrium Conditions of a Toroidal Vortex with Thermal Pressure." n. page. Web. 15 Feb. 2014. <http://arxiv.org/ftp/astro-

motion between pixels insuring a sharp picture. Finally, Photoshop was utilized to alter the image by cropping, increasing contrast, decreasing exposer and increasing color saturation. The original image shown in Figure 3 can be compared to the final.

This image reveals both the incredible stability of a toroidal vortex ring and the turbulent instability caused by its wake. The image is well composed from the pseudo black and white coloring, the framing caused by the glass and the image clarity. However, although the vortex ring was well captured temporally, it would be more interesting to captured the toroidal physics better spatially from different angles as in examples in Figure 4. Additionally, a time laps or video of the development of flow, as in Figure 5, would also be interesting and could be further developed for future work.

Figure 3 – Original image as captured before Photoshop.

Figure 4 – Additional toroidal rings captured from different angles.

Figure 5 – Six images depicting the progression of flow phenomenon captured in creating the final image.