Vortex Rings

QuickTime™ and a
decompressor
are needed to see this picture.

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Introduction

The purpose of this experiment was to capture the graceful behaviors of vortex rings when moving through air and when they are colliding with objects. Vortex rings can be found everywhere. In nature we can find vortex rings emerging from volcanoes with circular outlets. Nuclear bombs will form a giant vortex ring referred to as the mushroom cloud. Animals like beluga whales, humpback whales, and dolphins have been observed to make under-water vortex rings for pure entertainment. There are several youtube videos of these animals generating these vortices and playing with them. Even humans like to blow smoke rings while enjoying some sort of tobacco.

Vortex Physics

Vorticity is defined as the rotation of a fluid around its own middle. Vorticity has magnitude and direction, defined by the fluid velocity and its direction is determined using the right hand rule. In the special case of a perfect vortex, the net vorticity is zero since when adding up all the vorticity vectors the sum will equal zero. This is demonstrated in figure 1, where the orange arrows represent the vorticity vectors.

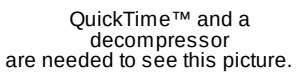

Figure 1: Irrotational (non-vortical) fluid

Vortex rings are self-inducing and propel themselves forward by the nature of the fluid flow. Every part of the fluid in the ring tries to rotate around the rest of the ring, which results in a net forward velocity. The curvature of the ring dictates its overall velocity. Smaller rings move faster than larger ones [1]. A basic representation of particle motion is shown in figure 2, with a net upward motion and equal and opposite vorticity on both sides.

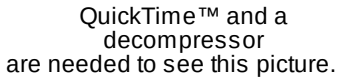

Figure 2: Particle motion

The vortex rings in the experiments were formed when forcing smoke through a circular cutout. When the fluid moves through the cutout, the fluid velocity at the boundary of the cutout and fluid is zero due to the non-slip condition. The fluid velocity in the center of the circle is greatest. Due to the different velocities of the fluid coming out of the opening, a vortex ring is formed shortly after exiting the opening.

Experimental Setup

This experiment was conducted in the Durning lab of the engineering building on Friday March 1st, 2013. The team uses a portable projector screen as a background, 500-Watt construction-lights for lighting, a smoke machine for smoke generation, and a modified five-gallon bucked as the vortex-generator. The top of the five-gallon bucket was taped over, and shut close, with duct tape to form a membrane. The bottom of the bucket was completely cut out and then covered with cardboard with a hole cut out in the center. The bucked was filled with smoke through the opening in the cardboard. After gently tapping the duct tape membrane, smoke was pushed out through the cardboard opening and a smoke ring was formed. One bucket full of smoke could generate up to 100 smoke rings. Very gentle tapping of the membrane was required to get a none-turbulent flow through the cardboard opening. The smoke rings were shot parallel to the dark backside of the projector screen. The velocity of the smoke rings were regulated by the vortex-generator operator and by slightly increasing the velocity from the first vortex ring to the next, a collision of two vortex rings could be staged.

Imaging Techniques

The final media submitted was actually a short movie with several sets of pictures taken in consecutive order. These pictures were imported to iPhoto, then opened in iMovie, converted to grey scale, and finally put in the desired order to make the final movie. The images were taken with a CASIO EX-ZR 100 camera with a shutter speed of 1/30 sec, focal length of 4.2 mm, F-stop f/3.0, and ISO of 800. All images had pixel dimensions of 3648 by 2736 pixels.

Conclusion

The final movie demonstrated the behaviors of smoke-vortex rings nicely while also being visually pleasing. Smoke rings are fun to watch since they slowly move through the air and one can clearly see the fluid rotating around itself. During the experiment some interesting observations, about the interaction of two smoke rings colliding, were made. After the collision, the smoke rings reformed and traveled at their previous speeds, and they reshaped each other to form a more symmetric geometry. Vortex generators can be easily made using common everyday materials and provide entertainment for many hours.

References

[1] Vortex dynamics
http://www.colorado.edu/MCEN/flowvis/course/Lecture2013/11.Vorticity-Resolution1.pdf