Vortex Cannon

Demonstration

Build a device that releases ring shaped air vortices and visualize them using smoke to show the wonders of fluids

Number of Participants: 2-15

Audience: High (14+) and up

Duration: 10-20 mins

Difficulty: Level 2

Materials Required:

- Large, round trash bin
- Plastic shower curtain liner or equivalent plastic sheet
- Bungee cords
- Box cutter
- File (Optional)
- Duct Tape or equivalent
- Fog machine (smoke also works)

Setup:

1. On the bottom of the trash bin, cut out a circle that is 8-14 cm in diameter using a box cutter
2. Use a file or cutting tool to smooth down any rough areas on the circular hole.
3. Flip the trash can over so it is right side up and take the plastic sheet and cut out a piece that is 4 times larger than the top of the bin (twice as wide)
4. Lay the plastic sheet on top of the trash bin opening and make sure it is centered.
5. Use the bungee cords to secure the plastic sheet in place by stretching them around the top of the bin carefully.
6. Gently pull on the edges of the sheet from underneath the bungee cords to make sure that the layer across the opening of the bin is taut.
7. Lay down the excess edges of the sheet as flat as possible and tape them to the side of the bin. An air tight seal is ideal.
8. Use the fog machine to fill the bin with fog/smoke through the small hole on the bottom until the bin is full.

Presenter Brief:

Be familiar with how vortices are formed and Bernoulli’s principle.

Vocabulary:

- Vortex ring– Spinning flow of air in a torus shape, where fluid spins around an imaginary axis forming a closed loop.[1]
- Torus – A surface revolution created by revolving a small circle along a line made by a big circle as shown in figure 1[2].
- Bernoulli's Principle – A behavior of fluids saying that as the flow velocity of a fluid increases the pressure exerted by that fluid decreases.

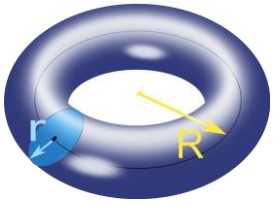

Figure 1. Torus shape

Physics & Explanation:

Highschool (ages 14+):

It's often hard to visualize the motion of fluids. As air is a fluid, fog or smoke can be used to examine localized regions of material motion. In this case, smoke rings are created due to a fluid dynamics phenomenon known as a vortex. Vortices are regions of spinning flows of air around an axis line within the volume enclosed by the radius *r*, as shown in Figure 1. Bernoulli's principle states that as the speed of moving air increases, the pressure within this region of air decreases. The air inside a vortex moves faster than the air outside which means that the pressure outside of the vortex is higher.[3] That high pressure is the force that hold the smoke ring together. Over time, friction mixing causes the vortex to dissipate but the ring shape will coherently travel long distances.

> To display this, hold the vortex cannon sideways so the small hole faces away and give the center of the plastic sheet on the back a light tap. If only smoke comes out with no rings, try changing the force of the strike. Note: if performing this experiment outside, locate a region will little or no wind.

When the sheet is struck, the force sends the smoky air inside the trash bin racing outward. The outer region of the air puff is slowed down by the edge of the hole relative to the air in the center thus creating a poloidal (twisting donut-like) flow pattern. Dynamics will vary with hole size, but lighter taps will tend to create more visually appealing smoke rings. Results can vary.

One amazing behavior of vortices is their ability to travel long distances. There is no force exerted on the surrounding air which means that the air is not moving forward, yet somehow, the ring is able to travel through air. Well, one property of vortex lines is that they cannot start or stop in a fluid with constant density. They can either start and stop at a surface or they can form continuous loops such as rings. This property is similar to how an electric current cannot suddenly stop or start in the middle of a wire.[4] The current is either bound by surfaces on both ends of the wire, or it goes around in loops. Since a smoke ring has this continuous looping motion, when it is introduced to the still surrounding air, the ring is able to "roll" using friction

with surrounding air particles to get across a room. This looping motion can be seen in figures 2 and 3.[5]

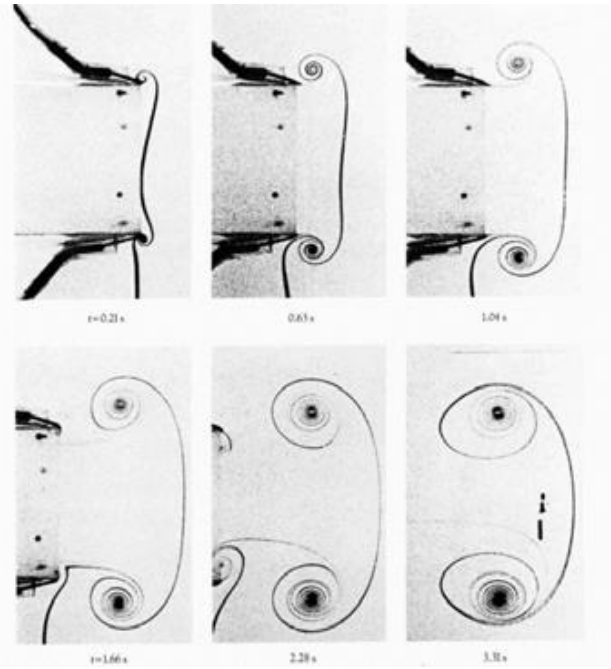

Figure 2. Formation of a vortex ring from a nozzle ejecting water

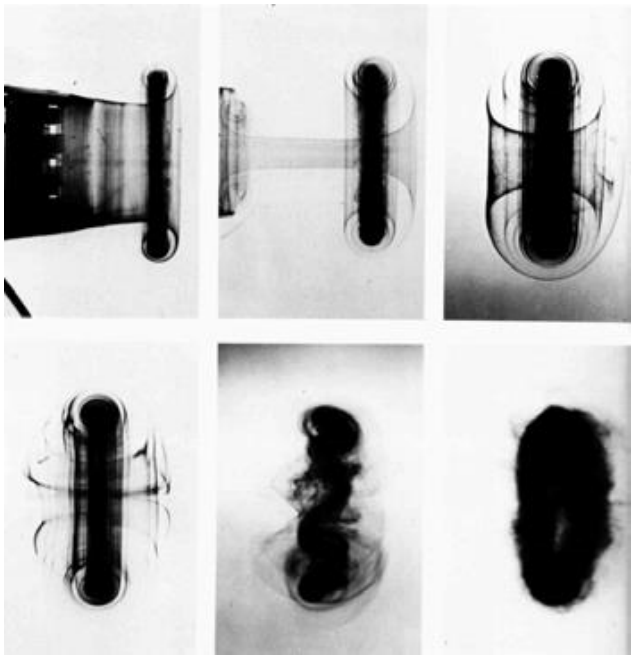

Figure 3. Step-by-step formation of a vortex ring from the moment the fluid is ejected to the formation of the ring

Smoke is able to highlight this occurrence without significantly disturbing the flow by simply being carried along inside the ring.[4] Every time particles of air in the ring move forward, particles of the still air around move backward[1]. As the ring makes its way through the air, it experiences friction with the surrounding air which causes the ring to lose energy slowly until it can't keep its shape anymore.

> 👉 Pushing the air out of a small hole causes the air that came in contact with the edge of the hole to slow down and bend backward, creating a vortex ring.

Additional Resources:

- Animation of vortex ring moving through surrounding air. Why Does Smoke 'Ring'?, Science Hobbyist http://www.amasci.com/wing/smring.html
- Alternative design. The Vortex Cannon, The Physics Teacher : https://aapt.scitation.org/doi/10.1119/1.880411

References:

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