Dyson Day Report - Experimental Fluid Dynamics Outreach Activity

Aidan Jones

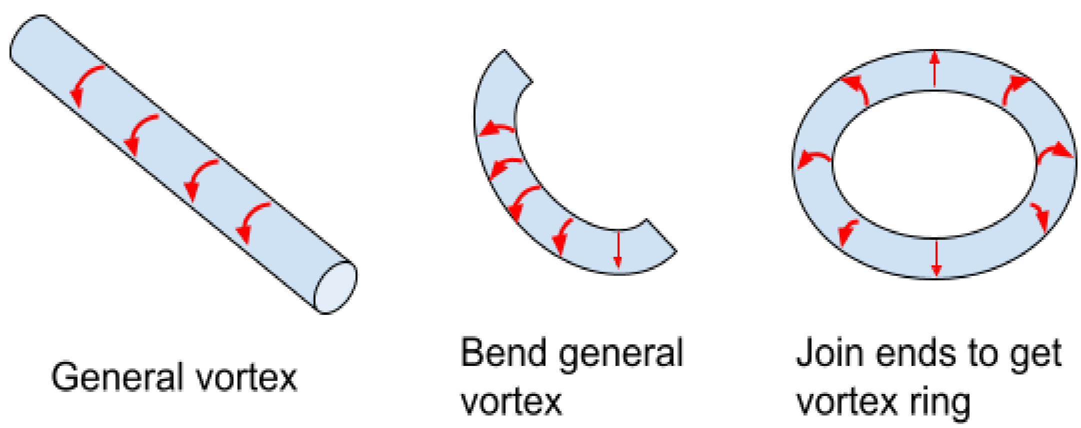
Making a lab based tornado is quite difficult and proved to be a challenge. The field of vortex dynamics (of which tornado physics is a subset) is very broad so for the outreach activity we explored what other types of vortices there are and then we used plastic bottles and a fog machine to experiment with vortex rings. Detailed below is what I went through.

1. **Introduce concept of vortices through tornados**

Tornados, though complex in their true physics, are an excellent introduction to vortex dynamics as they are already familiar to the children and it is quite evident how the air moves around them. I walked the children through the logic I talked through in the other report on a blackboard, asking questions about how they thought the flow field might look as we increased the complexity up to the full tornado. Once that was solid in their heads, we abstracted slightly to the concept of a general vortex looking like a tube of rotating air.

2. **Make link between tornadoes and vortex rings**

Explain that once you have a theoretical tube of rotating air, you can bend and twist and do whatever you please with it and it'll still count as a vortex - i.e. vortices don't need to be straight vertical columns like a tornado. Explain the following manipulation to get from the general vortex tube to a vortex ring:



3. **Make some real vortex rings**

With an understanding of what we're making, we can then start modifying bottles to make some vortex rings.
Easiest possible way to do this is as follows:

- Remove lid from (empty) plastic bottle. Any size works, ones with a smooth neck are great. We used 1 litre/2 litre lemonade bottles and some 250ml water bottles.
- Fill a bottle with fog from a fog machine. Alternative sources of smoke work fine too such as incense sticks/flavourless vape/ other smoke but the fog machine produces loads of smoke on demand which is great.

- Hold it pointing away from you and tap gently on the side of the bottle. Some students found that squashing the bottle around half way then giving it a short, gentle squeeze worked even better. The key here is a very brief puff of air leaving the neck of the bottle. A prolonged squeeze results in a turbulent jet (interesting in its own right but harder to understand).

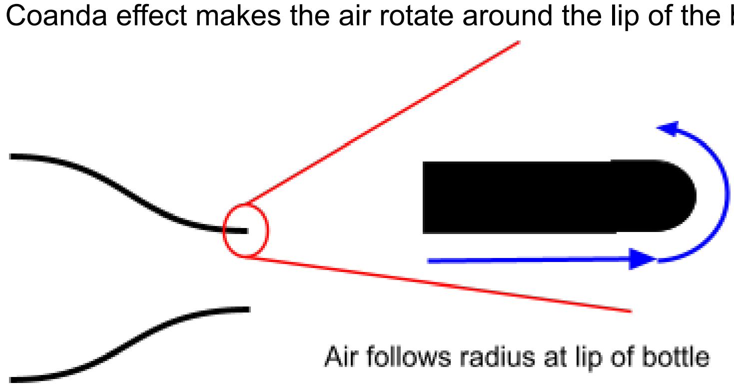
4. **Ask an interesting question and experiment.**

I encouraged the kids to ask an interesting question about the vortex rings and modify their bottles to try to answer the question. Some tried drilling holes into the lid to see if a sharp lip made a difference. Others tried multiple holes. Others tried a non-circular hole using a square file to adjust the hole shape. This is to help them get comfortable using experimentation to find answers to things that are on the edge of human understanding - a good proportion of their questions I had not seen tackled in public academic literature.

5. **Regroup and understand why we're getting vortex rings**

It's really not obvious at first glance why squeezing a bottle should result in a donut shaped vortex tube. I started by drawing a simple outline of the neck of a bottle on the blackboard and we started discussing theories as to what might be going on here to give us such unusual behaviour. Goal here is to get kids to make links between phenomena they are familiar with and understand and this new phenomenon that they don't and see which links work and which don't. Some of the ideas presented were very interesting:

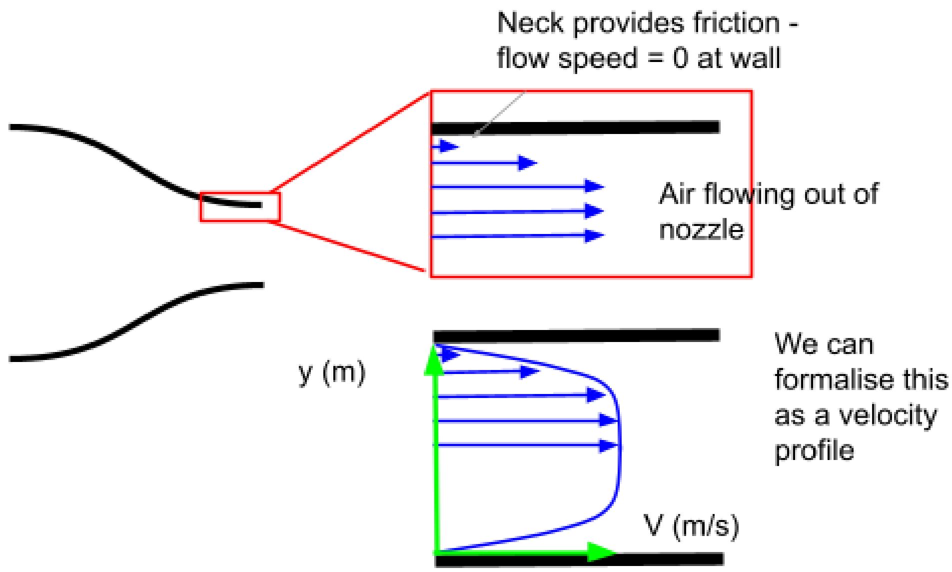
- What if the air gets compressed as it enters the neck then the sudden expansion as it leaves the neck causes the ring to form? (A: Air is broadly incompressible at flow speeds below 0.3x speed of sound so this isn't the right mechanism.)
- What if the Coanda effect makes the air rotate around the lip of the bottle?



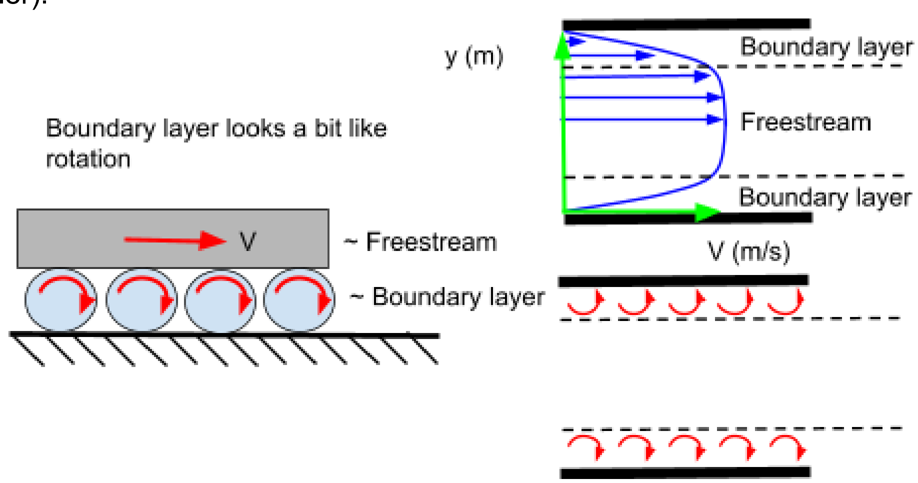
A: This is a brilliant idea which I loved but the air can't follow that tight of a curve for long.

The true reason is as follows:

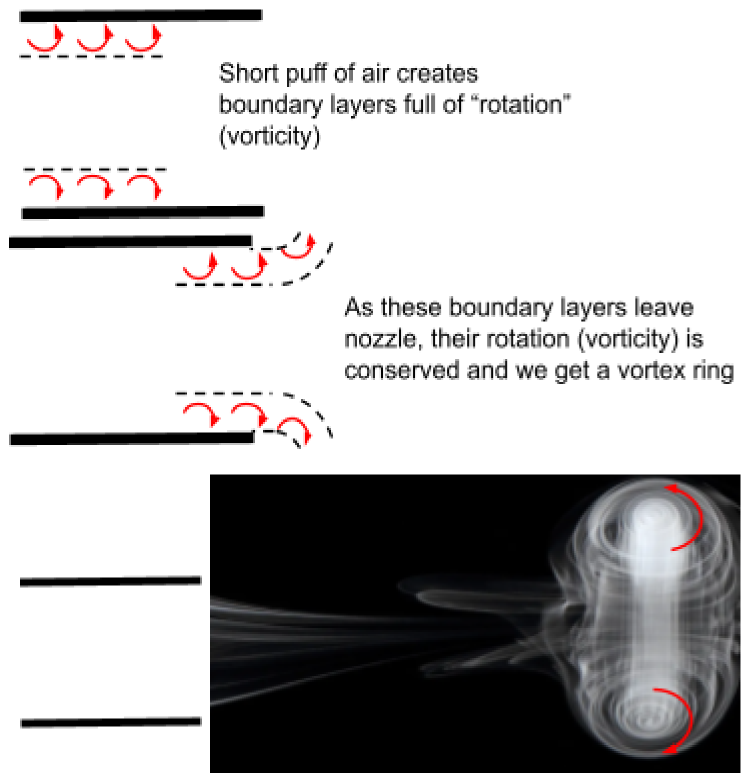
The neck of the bottle is microscopically rough so it provides friction against the air moving out of the neck. This gives us a velocity profile across the neck - zero velocity at the walls, high velocity in the middle.



We can see that there's a flat section to the velocity profile in the middle referred to as the freestream and near the walls there's thin layers where the velocity rises from zero to the central velocity. These are called boundary layers. (Similar concept as the tornado boundary layer but much simpler).



You can imagine putting a set of rollers between a moving plate and a stationary ground - they'd rotate. This looks a lot like our boundary layer, where the block represents the fast moving freestream and the ground represents the neck of the bottle where the air is stationary. Air is a little more complex as it's not obvious how big the "rollers" should be, but the idea that the boundary layer looks like the perfect breeding ground for rotation is the key. (Strictly in fluids "vorticity" is the term we use to avoid this confusion, and solid body rotation like the rollers and shear flow like the boundary layer are mathematically identical).



6. **Discuss extensions of this thinking**

We had some spare time so we started digging into harder questions that lead on from this:

- What happens if you do a long squeeze rather than a short one - why doesn't this make a vortex ring too?
  → Natural lead into the idea of turbulence (thousands of tiny vortex tubes in close proximity)