Jennie Jorgenson

Group Assignment #1

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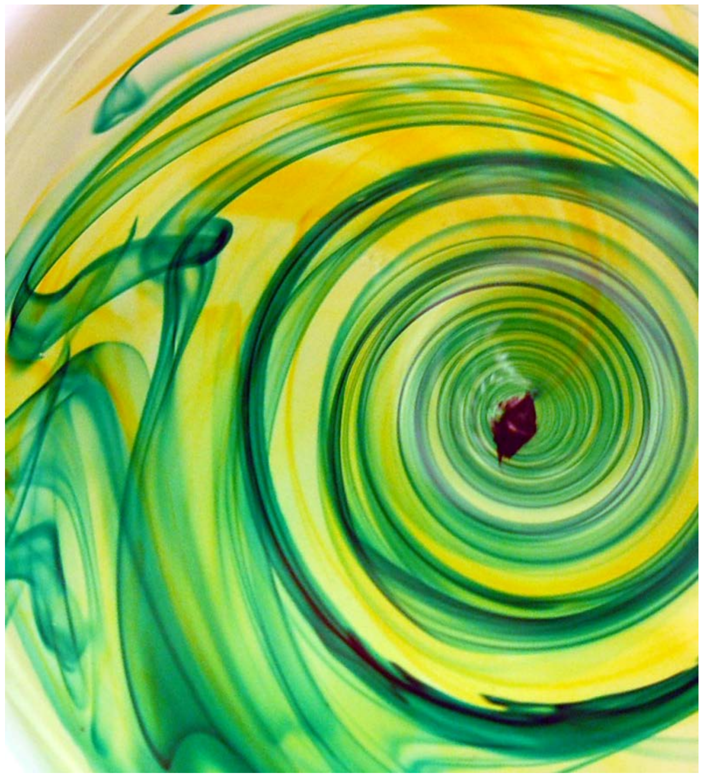

Context & Purpose

Originally, our group planned to capture the flow of microbes in pond water using lasers. However, due to the resourceful and evasive nature of microbes, we were only able to capture one sufficient image (for details, see Joshua Smith's report). As such, our group had to get a little creative for the rest of our images, using only the resources we had on hand. Inspired by some of the fluorescent pictures of vortices that were captured by students during the Get Wet assignment, I

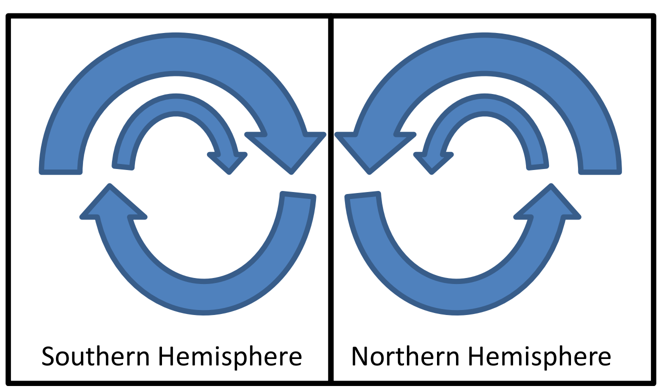

Figure 1: Does the Coriolis effect cause differences in draining direction?

grabbed a plastic drink container and got to work. My goal was to capture the natural and impeccable symmetry of a bathtub vortex, while also providing some commentary on the dynamicity of the situation.

The Physics of Bathtubs

One question about vortices has been asked since antiquity: which direction will my bathtub, sink, or toilet drain? In order to answer this question, we must first address a more basic question: does the rotation of the earth cause vortex direction to differ in the south and north hemispheres? The basis of this question arises from the observed Coriolis effect [3]. The Coriolis effect is the deflection of moving objects observed in a rotating reference frame [3]. The Coriolis effect has been demonstrated to have an effect on determining the spinning direction for hurricanes, but it seems to be a bit far-fetched to say that it will affect which way the toilet spins. In fact, experiments in the bathtubs of the northern hemisphere indicate that it may [2], [1]. However, these experiments are conducted in a highly idealized situation without edge effects and where the water has been allowed to “settle” for at least twenty-four hours. An important dimensionless parameter has been defined to gauge the effects of rotation [4]:

$$Rossby\ number = \frac{U}{2L\omega}$$

Where U = fluid velocity, L = vortex length scale, and ω = angular frequency of planetary rotation. The estimated fluid velocity is 7.5 m/s (see section below), the vortex length scale is about 0.1 m, and the angular frequency of planetary rotation is 1 revolution/day, or 7.3 x 10^-8/sec. Thus, our Rossby number is on the order of 10^9. A large Rossby number indicates that inertial and centrifugal forces dominate over the Coriolis effect [4]. It is important to note that the Rossby number applies to the surface of the vortex rather than to the jet, even though the jet velocity was used for the calculation. This is probably a fair assumption here, since the Rossby number is very high. Even if the velocity at the vortex were an order of magnitude or two smaller, the Rossby number would still be high. If the Rossby number were closer to unity, this assumption would have to be revisited.

Now we can answer the question: does the Coriolis effect therefore determine the direction of the spin in this case? Likely not, since the Rossby number is large, and photograph clearly depicts a clockwise spinning vortex. So, if the earth's revolutions are not causing the spin a vortex, what is? The simple answer is gravity [5]. The opening at the bottom of the container is smaller than the container itself. The hydrostatic pressure forces the fluid downwards, but only a small amount of fluid can pass through the hole itself, meaning that the other fluid must find somewhere else to go – around [5]. Thus, a spinning motion has been induced, and centrifugal force pushes the fluid to the walls of the container, leaving a tornado-shaped opening in the middle, commonly known as a whirlpool [5].

Visualization Technique

In order to capture this image, I used the top portion of a 24 fl oz plastic drink bottle. Using a box cutter I removed the top third of the container. However, I needed an opaque, homogenous background. To achieve this, I took off the bottle cap and used a covering of white paper and a white paper cup to block the flow from the tapered end of the bottle where the vortex would form. I taped the white paper to the bottle with electrical tape. The paper and cup were not waterproof, which would have been a problem if I hadn't gotten the image on the first try. The bottle, when inverted, held approximately 150 mL of water. The water took approximately 30 seconds to drain, leading to an overall flow rate of 5 mL/sec (note that the hole was about 2 mm by 2 mm, which leads to a velocity of 7.5 m/s). I added the food coloring after about five seconds when a steady vortex had formed. The drops of food coloring were added near the edges of the bottle at approximately the same time.

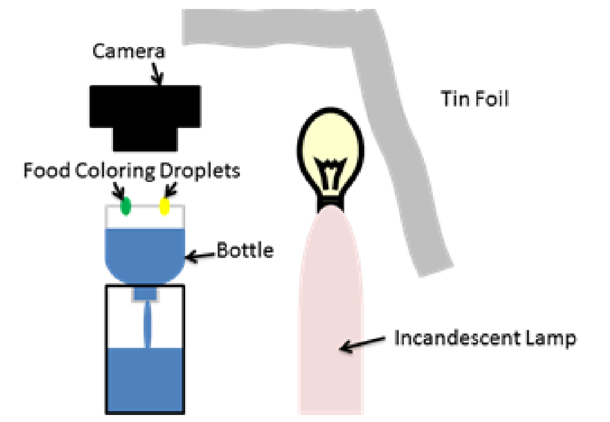

Figure 2: Setup used to capture image.

The picture was taken from above. Light was diffuse, from several windows in a daylight room. To improve luminosity, I used a bare incandescent bulb with aluminum foil to direct the glow. See **Figure 2** for the side-view of the setup.

Photographic Technique

This image was captured using a Nikon D40 DSLR. The approximate size of the field of view is 5 cm by 3 cm. The distance from the lens to the object was about 10 cm. The final pixel size is 1012 x 1120. The shutter speed was 1/60 sec, and the F-Stop value was f/5.6. The ISO was at 560, and the focal length was 55 mm. The original image is seen in **Figure 3** above. Manipulation of the image was conducted in Photoshop. The image of the background detracted from the overall image, so the photo was highly cropped. Additionally, the contrast was increased to bring out the yellow dye against the white background and to further contrast the two dye colors.

Impact of Image

Overall, I think this image captures the dynamicity of vortices. This phenomenon is very common – you have likely seen it in draining a sink or bathtub. However, the addition of the dye allows the viewer to see the distinct vortex "layers" as they circle through the container. We can also see that diffusion is no match for the force of a vortex; the dye colors remain distinct. I also like that the genesis of the vortex is visible near the left side of the cup. However, one question still remains. Near the "genesis" of the vortex, diffusion is beginning to take place. With the progression of the dye through the vortex, the diffusion almost seems to reverse itself (ie, the dye seems to collect into parcels of color rather than continuing to spread throughout the cup). The answer to this question is not apparent to me, and will require deeper research. Despite the lingering question, I did fulfill my intent to capture the bathtub vortex phenomenon. If I could retake this photo, I would like to maybe add a third color, just to enhance the effect. Additionally, the vortex container was relatively small (only a few inches across), so I would like to investigate the vortex effect in a container where edge effects are negligible. Overall, I enjoyed taking this image and my interest in vortex dynamics has been piqued – I will never look at a draining sink the same way again.

References:

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[2] Binnie, A. M. “Some experiments on the bath-tub vortex,” *Journal of Mechanical Engineering Science* 6(3), pp 256-257. 1964.

[3] Feinstein, M. R. “Which way will my bathtub drain?” *Physics FAQ*. 1996. Accessed: 22 Mar 2012. <http://math.ucr.edu/home/baez/physics/General/bathtub.html>.

[4] Gedney, L. “The Bathtub Vortex, Article #523,” *The Alaska Science Forum*. 19 Mar 1982. Accessed 22 Mar 2012. <http://www2.gi.alaska.edu/ScienceForum/ASF5/523.html>.

[5] “Wind, Whirlpools, and Waves.” *British Broadcasting Company*. March 2004. Accessed 22 Mar 2012. <http://www.bbc.co.uk/nature/blueplanet/infobursts/whirlpools_waves_bg.shtml>