Group Project 2

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MCEN 4228: Flow Visualization

"Free Vortex in Water" is an image of a free vortex flowing through a two liter soda bottle. In order to visualize the rotating water, dye was injected into the vortex once it had established itself. The goal of the photo was to visualize the rotating flow with color that was pleasing to the eye, however the final image chosen was one in which the majority of the flow was clear.

To create the flow a 2 liter soda bottle was used. The bottom was cut off and a hole was punctured into the lid. The bottle was then turned upside down and filled with water. A spoon was used to start the rotational motion of the vortex and the water was allowed to flow through the hole in the cap. As the fluid began to flow, the free vortex would form and sustain itself until all of the fluid drained from the system.

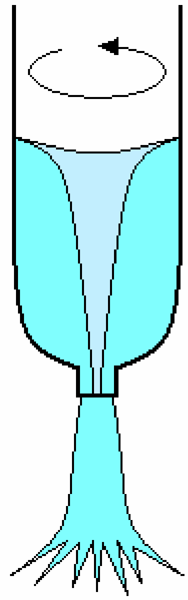

Figure 1: Experimental Set-Up

A vortex is a rapidly rotating body of fluid with closed streamlines. In the case of this set up, the streamlines go from the top of the free surface, spiraling through the vortex, and out through the bottom hole. There are two primary types of vortices, forced and free.

A forced vortex is caused by a mechanical force forcing the fluid to rotate as a whole. In this case, there is no shear in the fluid as all the fluid is rotating. The shape the free surface of the fluid will take during this phenomenon is a parabola. Fluid in a forced vortex is all moving at the same angular velocity, and the tangential velocity can be determined by the following equation:

$$v_t = \omega \times r$$

where ω = angular velocity and r = distance from center of rotation.

This image is of the second type of vortex, a free vortex. The free vortex is caused by the fluid flowing through a sink in the bottom. This vortex is the type commonly seen in a full sink when a vortex is formed or in the toilet when it is flushed. In the case of the free vortex, angular velocity decreases as one moves radially outward from the center of rotation. The tangential velocity of a particle in a free vortex is given by:

$$v_t = \frac{\Gamma}{2 \times \pi \times r}$$

where Γ = circulation and r = distance from center of rotation.

In some instances a vortex can exhibit qualities of both free and forced vortices. On example is a tornado, where the center behaves like a forced vortex with the wind velocities increasing with distance from the center. The outer portion of the tornado, however, behaves like a free vortex in that the wind velocity decreases with distance from the center [1].

By estimating the velocity of the vortex (15 in/s) and the radius at the maximum velocity (3in) the Reynolds number of the flow can be found as 6.5×10^4, which is just on the laminar end of the turbulent/laminar transition. This can be seen in the image in that some of the flow appears smooth (laminar) while flow immediately next to these smooth regions can also appear hazy (turbulent).

To visualize the flow a 60 watt light bulb was used, placed at roughly 180^O from the camera, two feet from the vortex. Blue dye was injected into the flow in an effort to visualize the spiraling nature of the vortex, but the vortex sucked the dye down into its bottom almost instantly. This is why there is the blue dye at the bottom that is circling with the flow. The dye did not diffuse readily into the water, which gave the image the sharp contrast from the clear water on top to the blue dye on bottom. Dilution of the dye was done at a 2:1 ratio of water to dye.

Camera settings for the photograph are given in Table 1.

Table 1: Camera Settings and Properties	
Camera	Nikon D40x
Lens	Nikkor 18-200 mm 1:3.5-5.6
Focal Length	82 mm
Aperture	f/5.3
Resolution	1355 x 2004 pixels
Shutter Speed	1/125 s
ISO	800
Lens Distance	12 in
Field of View	6" x 8"

The final image was altered a great deal in Adobe PhotoShop. The image was first cropped, then drops of water and dirt were removed from the outside of the bottle. Finally, the background was treated with the blur tool to soften the edges where obvious alterations had taken place.

The image is a good demonstration of a free vortex, but it lacks a greater artistic component. It was difficult to balance the light, aperture, and shutter speed to capture the vortex while at the same time letting enough light in so that the image was visible. The final image was a compromise in which the shutter speed was set at a level that the motion blur did not completely dominate the image, but enough light was let in to visualize the flow. In this process, however, the background that was white came out a tan color instead. In order to improve the picture, a stronger light source could be used or a larger vortex could be created. The small nature of the vortex made it difficult to photograph before the water all left the bottle.

References

[1] Crowe, Clayton T. (2005). Engineering Fluid Mechanics.
New Jersey: John Wiley and Sons.