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MCEN 4151: Flow Visualization

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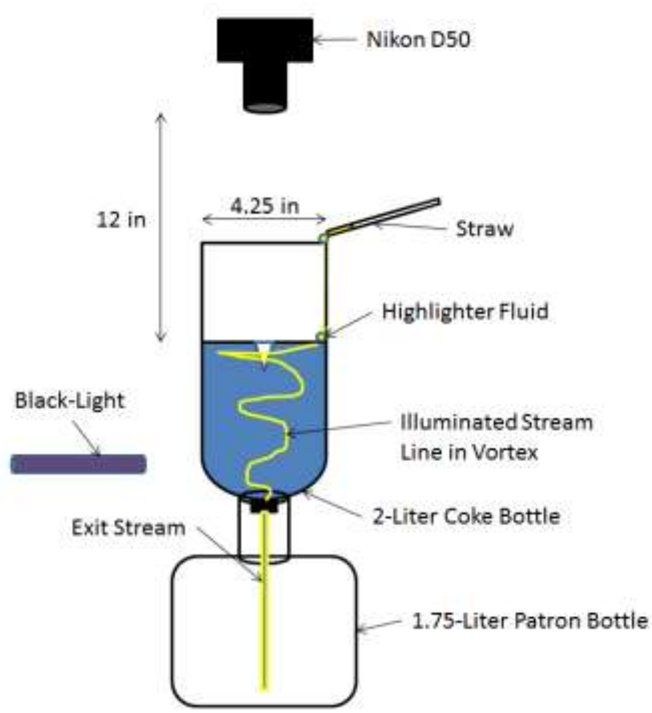
Get Wet Report: The Highlighter Vortex

The purpose of this assignment was to allow beginner photography students to make a first attempt (i.e. “Get” their feet “Wet”) in creating an image of a flow that is both beautiful and physically informative. The goal of this particular image was to capture a vortex formed in water. This was captured using highlighter fluid and black-lights to illuminate the flow. Prior knowledge that highlighter fluid glows particularly beautifully under a black-light and that vortexes form under draining conditions served as inspiration for this photograph.

To create this image it was first necessary to remove the label from an empty 2-Liter Coke bottle and cut off the bottom section of the bottle using scissors. A 1/8” bit was then used in a hand held drill to create a hole in the center of the bottle’s cap. The Coke bottle was then turned upside-down and balanced in a 1.75 Liter Patron bottle. A Nikon D50 DSLR camera was then set up on a tripod with the lens approximately 12 inches from where the surface of the water would soon be. Approximately 1.5 Liters of water was then put into the modified Coke bottle, allowing a vortex to form. The field of view of the image is approximately 4.25 inches (the diameter of the 2-Liter bottle). The set-up is illustrated in the following figure.



The highlighter fluid at first mixed turbulently at the edges upon striking the water, but then settled into many streamlines that turned into laminar flow as the vortex pulled the fluid from the surface of the water. Assuming that the highlighter fluid has zero kinetic energy at the surface, and setting the datum of gravitational potential at the hole in the cap, we can use conservation of energy to estimate the velocity of the highlighter fluid when it leaves the Coke bottle. Since we are neglecting viscous effects and assuming that the pressure at the surface and exit are the same, this is equivalent to using Bernoulli's equation for a streamline.

$$PE_{surface} = KE_{exit}$$

$$mgz_{surface} = \frac{1}{2} * mV_{exit}^2$$

$$V_{exit} = \sqrt{2gz_{surface}} \approx 1.4\, m/s$$

Assuming that the flow starts from rest (Re=0) at the surface, and that gravity accelerates the fluid while it funnels down to a flow the diameter of the hole in the cap where it is traveling at 1.4 m/s, we can calculate the range of Reynolds number for the flow based upon the flow diameter.

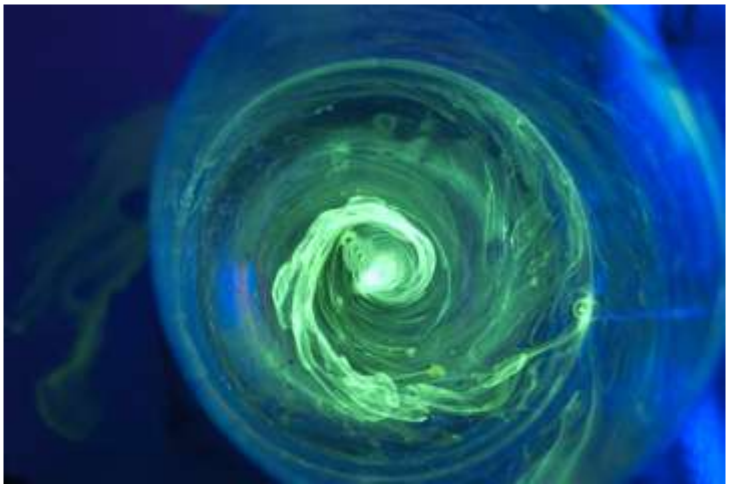
$$Re = \frac{VD}{\upsilon} = \frac{\left(1.4\frac{m}{s}\right)(.00318\, m)}{1.004 * 10^{-6}\frac{m^2}{s}} = 4400$$

Here we assume that the rotational velocity is negligible compared to the vertical velocity, and that the highlighter fluid has the same viscosity as water at 25 degrees Celsius. Reynolds number varies from 0 (laminar flow) to 4400 (turbulent flow) from the surface of the water to the exit of the cap. It is notable that the rotational velocity was probably not negligible, and so the Reynolds number is probably larger at the exit than we have calculated here. This was to be expected, as turbulence is characteristic of vortices [1].

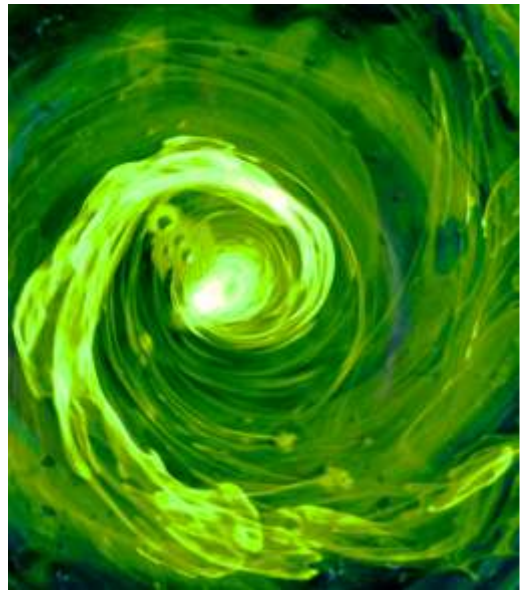
The lights in the windowless bathroom were turned off, and four 36 inch long commercial black-lights (bought from Spencer's Gifts) lining the bathtub containing the set-up were turned on. Undiluted highlighter fluid, which had been extracted from yellow Sharpie highlighters, was then dripped close to the side of the bottle using a plastic straw approximately 4 inches above the surface of the water.

The camera used to capture this image was a Nikon D50 DSLR. The lens was capable of varying its focal length between 18 and 55 mm. An exposure time of 1/25 second with f/5.6 and an ISO of 1600 were used to capture the image. This shutter speed allowed for the laminar section of the flow to be seen vividly, while the ISO allowed for an acceptable amount of pixel saturation in low-light conditions and the f number achieved an acceptable depth of field. In the turbulent section, where the flow is moving at about 1.4 m/s, there is blurring because each individual particle has moved at least .056 meters (about 2.2 inches) over the course of the exposure. In the raw (.NEF) image the field of view is approximately 4.3 by 6.4 inches (2000 by 3008 pixels). As stated earlier, the distance from the surface of the water to the lens was approximately 12 inches.

Photoshop was used to create the final image. First the raw image was cropped to 1244 by 1084 pixels to remove the glare of the black-light on the Coke bottle, and remove the edge of the Coke bottle in order to focus the viewer on the flow. The contrast was enhanced to separate the highlighter fluid from the background, and the color temperature was adjusted to further accentuate the warm colors in the photo. Also, the blue pixel intensity was decreased while the green was enhanced.



Raw "Before" Image



Post-Photoshop "Final" Image

The image does an excellent job at showing the stream lines in the vortex as viewed from above. I like the green and that it is not excessively photo-shopped from the raw image. The laminar-to-turbulent streamline effect seen in the vortex is also interesting, and what I had intended to capture using the highlighter fluid. Although I tried to keep bubbles from forming over the vortex I was not capable of doing so, and was incapable of capturing the entire vortex as a result. If a way to prevent these bubbles is possible then it would further improve the image. Otherwise there is nothing to distract the viewer from the flow itself. I do still wonder what the deciding factor is in which way the vortex spins, since during the iterations of this procedure the vortex spun in both the clockwise and counterclockwise directions. This idea could be developed further by introducing obstacles into the flow and seeing what effects they might have on the stream lines.

Citations:

[1] *Vorticity*. (n.d.). Retrieved from http://en.wikipedia.org/wiki/Vorticity