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MCEN 5151
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Assignment 1: Get Wet

1 Introduction

The goal of this assignment was to become familiar with fluid photography by taking a picture that is visually appealing and demonstrates a flow phenomenon. As someone with no experience in photography, I determined that I would begin with a digital photograph and enhance it in Photoshop. My original goal was to observe the frothing of milk that occurs when a circular ring made up of a rotated coil is spun in the liquid; however, after many attempts at capturing a visually appealing image of this process, I determined that the liquid was too opaque to photography from the side, and I could not achieve adequate contrast to photograph from above. Therefore, I began experimenting with creating vortices in water, and adding various amounts of dyes at different times in order to capture the mixing that occurs along the edge of a vortex.

2 Experimental Setup

The experiment consisted of a glass cylinder open at the top, with an inner diameter of 80mm and a height of 145mm (central rectangle in Figure 1) that was filled with water up to 50mm below the top of the glass.

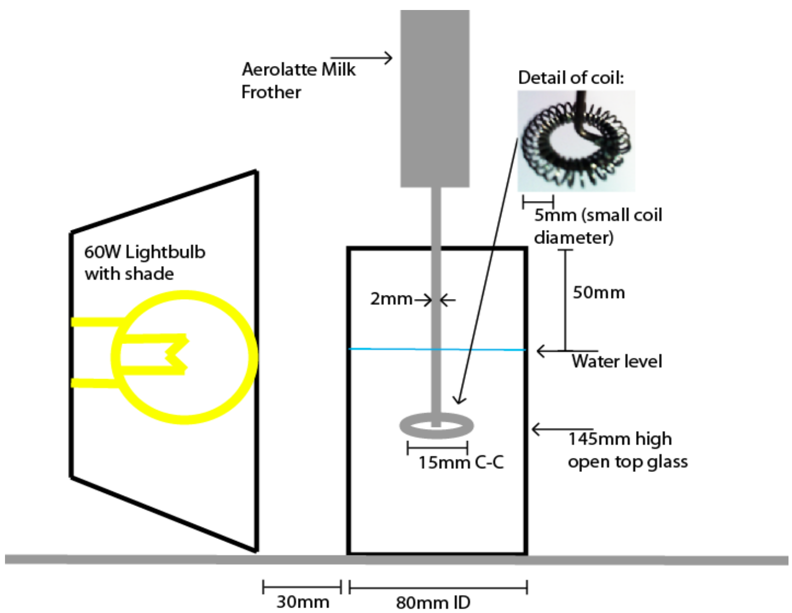

Figure 1: Experimental Setup

A 60-watt desktop lamp with a 150mm diameter shade was oriented against the class as shown in Figure 1, which served to provide backlighting for the photograph. To begin the experiment, the milk-frother was inserted into the water, turned on, and held about 10-15mm above the bottom of the glass until a vortex developed. After the vortex appeared sufficiently developed, the milk-frother was quickly lifted from the liquid and 2-4 drops of food coloring (blue in the final image) were dripped into the vortex. Beginning at exactly that instant, a series of 10-15 photos was taken. The final image was the second in its series.

3 Fluid Analysis

The flow observed in the photograph is a vortex created by a thin rotating cylinder. As a real vortex, it could be approximated by a Rankine vortex containing a core that displays characteristics of solid body rotation and a far field that can be approximated as irrotational [1]. However, as seen in the photograph, the vortex core meets the container wall, indicating that the container is not sufficiently large to achieve a stationary far field condition. Clearly, the wall shear forces play a significant role in the decay of the vortex. The strength of the wall shear force is displayed by the short time that the vortex takes to completely disappear: 15 to 30 seconds.

In order to analyze the flow, characteristic parameters must be determined. Determining a Reynolds number for the flow is difficult because establishing the correct characteristic length is challenging. Furthermore, the lack of any attempts in the Scientific Journals or Textbooks referenced in this paper to calculate a Reynolds number for a vortex seem to indicate that the Reynolds number is not a suitable characterization of the flow. The most important (and measurable) parameter is the rotational speed of the milk-frother, which at the instant it is removed from the glass, is approximately equal the rotational speed of the vortex at that radius. In solid body rotation, the angular velocity is proportional to the vorticity, making it an appropriate characterization of the vortex [1]. Since no technical data could be found regarding the milk-frother, the following experiment was used to determine the rotational speed: (a) a string was attached to the milk-frother, (b) the milk-frother was turned on for one second, (c) and the length of string rolled up was measured. Due to the high speed of the motor, any longer time frame than one second resulted in the string coiling on itself, which increased the diameter and changed the velocity measurement. Clearly this calculation is crude, but it gives the order of magnitude of the velocity of the flow. The angular velocity of the milk-frother is given by:

$$\frac{510mm}{1\sec} x \frac{1rev}{2\pi mm} = 81.2\frac{rev}{\sec}$$

and the velocity at the edge of the coil, assuming solid body rotation: (15mm center to center main coil, plus 5mm diameter rings centered on main coil = effective diameter 20mm)

$$81.2\frac{rev}{\sec} x .01m = .812 \approx 1\frac{m}{s} \quad \text{(Solid body rotation: } u_\theta = \omega_0 r\text{)}$$

Due to the crude nature of the experiment, an order of magnitude of the velocity at the coil of the milk-frother of 1 m/s will be assumed, giving an initial angular velocity on the order of magnitude of 100 revolutions/second. Furthermore, since the vortex had sufficient time to form and reach a semi-steady state before the milk-frother was removed, it can be assumed that the entire inner surface of the vortex was at a uniform angular velocity, but due to the varying diameter of the vortex, the linear velocity of points at a greater radius from the center (i.e. the top of the vortex) is higher.

The pressure gradients in the vortex can be described by the Bernoulli Equation. The constant pressure contours help demonstrate the “dip” of the center of the vortex below the original surface level, and the vortex shape [2]. These can be seen in Figure 2.

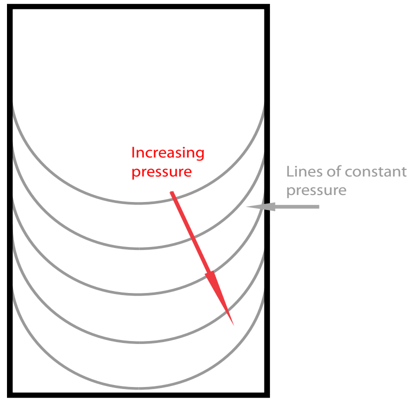

Figure 2: Lines of constant pressure in solid body rotation

Ultimately, I did not choose this image to demonstrate a specific phenomenon, but rather because I think the colors serve to show the complex mixing and rotation that occurs in a vortex. From the clear “whole” in the center of the image, it is evident that the dye drop first rotates with the vortex before it mixes into the water. This motion highlights the speed and surface tension at the vortex surface, as the dye is literally “carried” around the vortex before it is mixed. A sketch of this initial effect is shown in Figure 3 as viewed from above the container. From the viewpoint displayed a “whole” appears from the side view (where the image was taken) between the streaks that are visible from above.

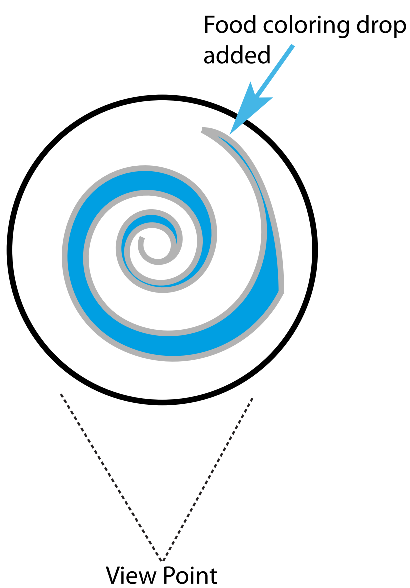

Figure 3: Sketch of food coloring before mixing

The progression from darker, thoroughly mixed sections, to lighter, less mixed sections is clear in the image. Furthermore, the collecting of the slightly denser dye at the bottom of the vortex before it can mix into the water is clearly displayed.

4 Visualization and Photographic Techniques

As previously mentioned, the primary method implored to visualize the flow was the addition of a dye. In the final image this was blue food coloring, added drop by drop for a total of three drops. Tap water was used, and the experiment was performed indoors with the predominant light source being a 60-watt bulb directly behind the container.

The field of view of the final image is roughly 80 by 100mm. The original image contained the container edge and more of the empty space above the fluid level, which I though detracted from the image. A digital Canon Rebel XSi with a 55-250mm lens was used, and the focal length was 1.46m. The exposure used was 1/1600, and the original image size was 4272 x 2848 pixels.

In Photoshop, the curves were first altered. Only the red and blue were adjusted in order to enhance the light and dark blues and the purple tones, which were not visible in the original. Additionally, the brightness was reduced to 45%, the contrast increased to 100%, and the sharpness raised 500% with a four-pixel radius via the "unsharpen mask." The image was then cropped to focus on the vortex. Finally, the clone tool was used in the lower right corner to remove a piece of the container still present in the image.

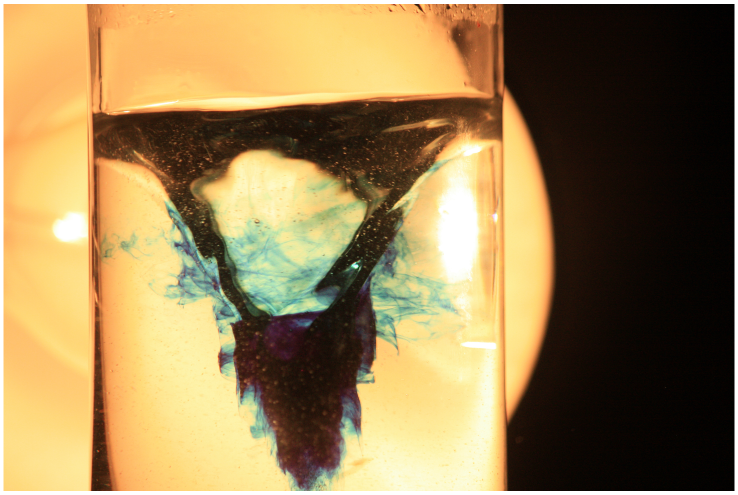

Figure 4: Original Image

5 Conclusions

I am pleasantly surprised with how well the image turned out, and I especially like the way the food coloring highlights the mixing and the motion of the vortex. I would however like to better understand the flow, as it seems that there are many flow patterns shown and not shown by the dye. I think that by understanding the fluid physics I could better determine how well they are represented in this image.

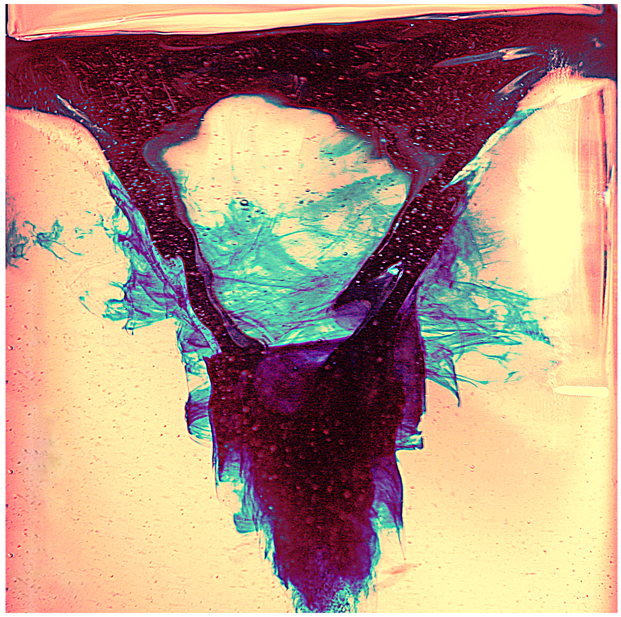

Figure 5: Final Image

6 References

[1] Ide, Kayo, and Michael Ghil. "Extended Kalman Filteing for Vortex Systems. Part II: Rankine Vortices and Observing System Design." *Dynamics of Atmospheres and Oceans* 27 (1997): 333-50. Page 336.

[2] Brillant, Paul, Jean-Marc Chomaz, and Patrick Huerre. "Experimental Study of Vortex Breakdown in Swirling Jets." *Journal of Fluid Mechanics* 376 (1998): 183-219. *Cambridge University Press*.

Image Assessment Form

Flow Visualization

Spring 2010

Name(s) Joshua Smith

Assignment: Get Wet 1 Date: 7 February 2012

Scale: +, ! = excellent √ = meets expectations; good. ~ = Ok, could be better. X = needs work. NA = not applicable

Art	Your assessment	Comments
Intent was realized	~	Could find a way to achieve with milk
Effective	√	Vortex is well displayed
Impact	~	
Interesting	~	
Beautiful	√	I like it
Dramatic	~	The dye makes it look more dramatic, but a vortex is not too dramatic I guess
Feel/texture	!	
No distracting elements	√	
Framing/cropping enhances image	!	

Flow	Your assessment	Comments
Clearly illustrates phenomena	!	I think it does—especially the mixing
Flow is understandable	!	
Physics revealed	!	Looks like a lot is

		happening
Details visible	√	
Flow is reproducible	~	Would be difficult
Flow is controlled	√	Received similar results for many trials
Creative flow or technique	~	Maybe not as good as some on website
Publishable quality	~	I like it, but I'm not an expert

Photographic technique	Your assessment	Comments
Exposure: highlights detailed	!	Very bright and easy to see
Exposure: shadows detailed	~	Not as many shadows
Full contrast range	√	Way more colors than original
Focus	~	Think it could be a bit crisper
Depth of field	X	Looks pretty 2D
Time resolved	√	I'm happy with the timing of this image
Spatially resolved	X	Had some trouble with the orientation of the image
Clean, no spots	X	Had to do some editing

Report		Your assessment	Comments
Describes intent	Artistic	!	
	Scientific	~	Needs more exact physical/fluids analysis
Describes fluid phenomena			
Estimates appropriate scales	Reynolds number etc.	√	As best as possible
Calculation of time resolution etc.	How far did flow move during exposure?	~	Quickly!
References:	Web level	none	
	Refereed journal level	!	Only used referenced journals
Clearly written		!	
Information is organized		!	Follows structure
Good spelling and grammar		√	Seems understandable
Professional language (publishable)		!	
Provides information needed for reproducing flow	Fluid data, flow rates	√	If same device is used
	geometry	!	
	timing	!	
Provides information needed for reproducing vis technique	Method	!	
	dilution	~	Addition of dye pretty approximate
	injection speed	~	
	settings	~	Not too familiar with camera so I

			may be missing some things
lighting type	(strobe/tungsten, watts, number)	!	
	light position, distance	!	
Provides information for reproducing image	Camera type and model	!	
	Camera-subject distance	!	
	Field of view	!	
	Focal length	!	
	aperture	X	Not sure where to find this
	shutter speed	!	
	film type and speed or ISO setting	!	
	# pixels (width X ht)	!	
	Photoshop techniques	!	
	Print details	?	Not sure what this means
	"before" Photoshop image	!	Provided