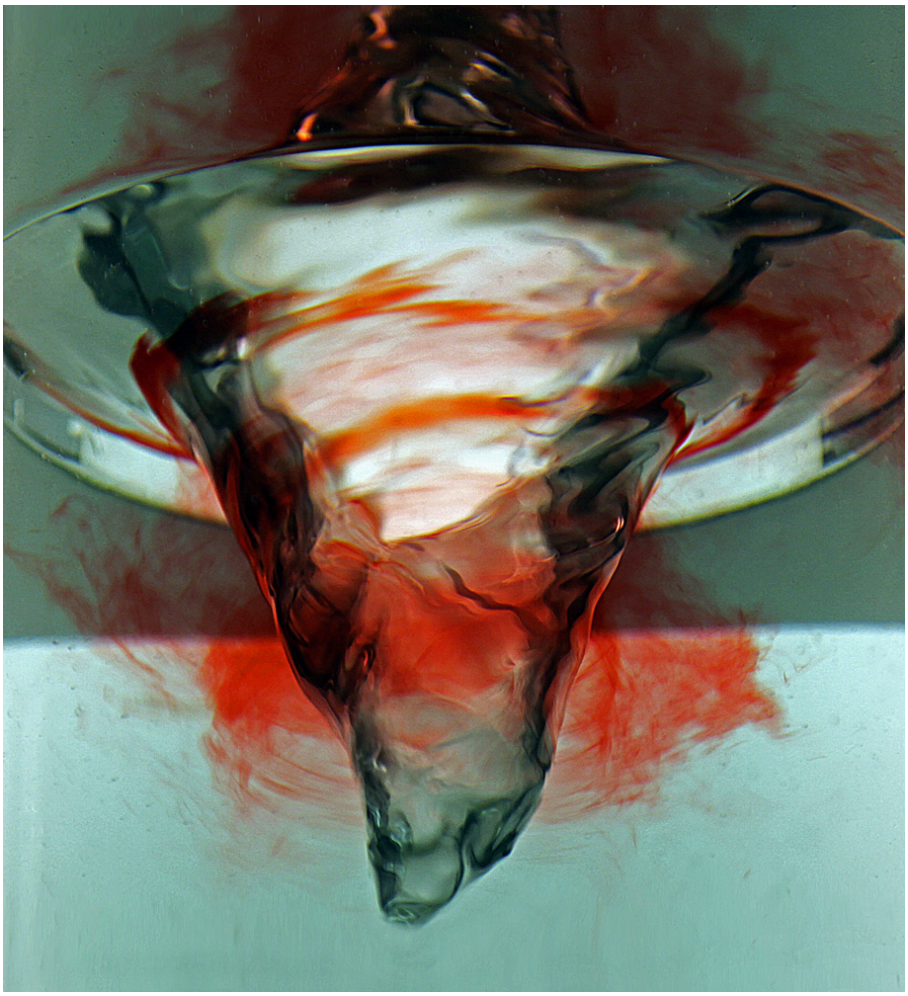
Porco Rosso



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MCEN 5151 – Flow Visualization

Group Assignment 2

4/1/2014

University of Colorado, Boulder

Introduction

Porco Rosso was created as the second team project for the Flow Visualization course. This project was not only used to again promote students to create and photograph more complex and intriguing fluid phenomena than they would on their own, but also to reinforce the importance of proper group dynamics in a team project setting. The original intent of *Porco Rosso* was to capture a vortex in water, as it is a great personal interest of mine, but was then added upon, using different vortex speeds and food dye, to allow each group member (William Derryberry, Lael Siler, and Mark Voll) to add a personal distinction to their image. This report will not only elaborate on the physics involved in *Porco Rosso*, but will also detail the setup of the experiment and the post processing of the image.

Description of Flow Physics

Porco Rosso is a clear example of a fluid dynamic phenomenon known as a vortex, more commonly referred to as a whirlpool when present in liquid water. This phenomenon simply occurs when a fluid flow is rotated about an imaginary vertical axis, whether by natural or unnatural rotational forces[1]. For a fully developed funnel to occur, however, a specific balance of forces must be achieved. Mainly, the angular velocity of the water must exceed the force of gravity acting on the water, causing a hole to be created as water is pulled away from the axis of rotation. This hole would continue to the bottom of the liquid, if it were not for the proportional increase of pressure obtained from the increase in depth below the waterline, causing the hole to narrow proportionally with depth.

Vortices are a major component of turbulent flow, and thus are largely dependent on the Reynolds number[2]. The Reynolds number is a measure of the ratio of inertia force on an element of fluid to the viscous force on an element, and is defined by the equation below[3]; where "ω" is the angular velocity of the vortex, "D" is the diameter of the agitator, and "ν" is the kinematic viscosity of the water. For the purpose of this experiment, "ω" was estimated using videos of the experiment for reference, yielding an angular velocity of 20 rad/s. The diameter of the agitator, in this case the length of the stir rod, was measured to be about 7 cm. The viscosity of water was assumed to be $1.16*10^{-6}$ m^2/s at an estimated temperature of 60° F (15.55° C).

$$Re = \frac{\omega D^2}{\nu} = \frac{(20\frac{rad}{s})(7 * 10^{-2}\ m)^2}{1.16 * 10^{-6}\ m^2/s} = 84482$$

Once calculated, the Reynolds number is shown to be very high (much greater than 2300) and greater than 1, and thus confirming turbulent, inviscid flow[3].

Experimental Setup

To create *Porco Rosso* a relatively simple setup was used. First, a large, rectangular fish tank was filled with cool water, and then cleaned of any bubbles with a Popsicle stick as to not distort the image. Next, this tank was placed on top of a stir-plate with the help of two support tubs to help distribute the weight of the tank. Finally, the cylindrical vortex-generating tank, also filled with cool water and cleaned of any bubbles, was placed within the larger, rectangular tank and prepared with a magnetic stir-rod, which could be controlled to produce varying vortex speeds using the left dial of the stir-plate. This duel tank setup was used to not only allow for a far more simple experimental reset, as only the small tank would need to be drained and refilled with new, clean water, but to also reduce complicated glare and blur that can occur when trying to take a picture of a cylindrical container. To light the experiment, all lights within the room were shut off except the white cabinet lights above the table on which the experiment occurred. Although this seems like a short-handed lighting system, it was the result of much experimentation with various other lighting combinations. Furthermore, although the walls behind the image created a plain, white background on their own, poster-board was used to assure there were no background shadow gradients within the image. To ensure the stability of the camera, but to also allow for the camera to be positioned at complicated angles in relation to the experiment, a monopod was used.

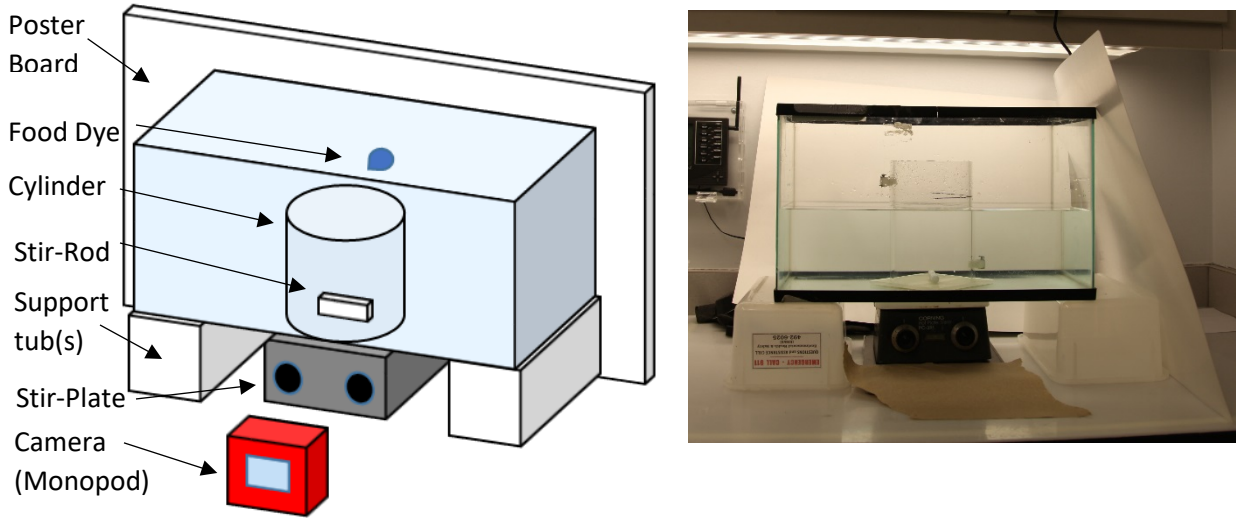

Figure 1: Animated experimental setup (Left), Realistic experimental setup (right)

Photographic Technique

To take the original JPEG image of *Porco Rosso* a 21.1 megapixel Canon EOS 5D Mark II digital camera was used. A Canon EF 24 – 105 mm f/4L IS lens was also used to compliment this camera, and allowed for greater resolution at moderately close distances. The camera was not

placed a specific distance from the tank, but was rather shot by hand with the aid of a monopod to experiment with various angles and distances to maximize image quality. The camera was manually focused and adjusted using customized exposure specifications during the experiment, as the vortex could be run indefinitely before the dye was added. Specifically, a relatively fast shutter speed of 1/100 seconds and an aperture of f/4 were used to ensure the capture of the quick flowing fluid with minimal motion blur, while still allowing for a good depth of field and resolution. A mid-ranged ISO of 250 was also used to compliment this shutter speed and aperture size as experimental lighting was not very bright.

For the post processing of the image, Adobe Photoshop CS5 was used. First, the image was cropped from 5616 x 3744 pixels to 2958 x 3240 pixels. This was to reduce the field of view of the image from about 25 cm x 17 cm to around 14 cm x 9 cm, thus removing all the blank space from around the cylindrical tank, as well as the cylindrical tank itself from the image. Then, the Clone Stamp tool was used to add a little space below the vortex, removing the table from the bottom of the image while still allowing for compliance with the rule of thirds. Finally, the sharpness, highlights and shadows, contrast, and color levels of the image were all adjusted to allow for more visible fluid flow, and a generally more appealing image.

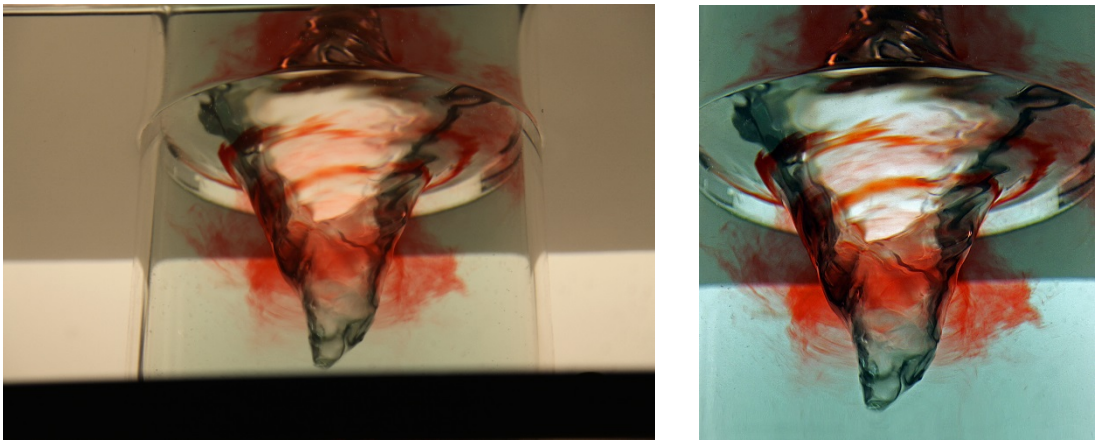

Figure 2: Pre-processed image (Left), Post-processed image (right)

Conclusion

Porco Rosso not only clearly displays a vortex in water, but also clearly displays particle rotation of any object being sucked down by the downdraft of a whirlpool. Overall, I am relatively happy with the final outcome of this image. When researching similar images online, it seemed like getting a perfectly glass-like appearance was easier than it seemed, which resulted in a little disappointment with the final appearance of the image. Furthermore, there was little creative post editing to be with this photo in comparison to my previous work, which I have come to enjoy very much. However, this experiment was very enjoyable for me, as I love whirlpools, and the very low resolution high-speed video from this experiment was extremely mesmerizing to watch (if only we could submit it).

References

[1] Faber, T. E. (1995). *Fluid Dynamics for Physicists.* Cambridge, UK: Cambridge University Press

[2] McWilliams, J. C. (1984). *The Emergence of Isolated Coherent Vorticies in Turbulent Flow*. National Center for Atmospheric Research, Boulder, Colorado

[3] D. F. Young, B. R. Munson, T. H. Okiishi, W. W. Huebsch (2007). *A Brief Introduction to Fluid Mechanics, Fourth Edition.* Hoboken, NJ: John Wiley & Sons, Inc.