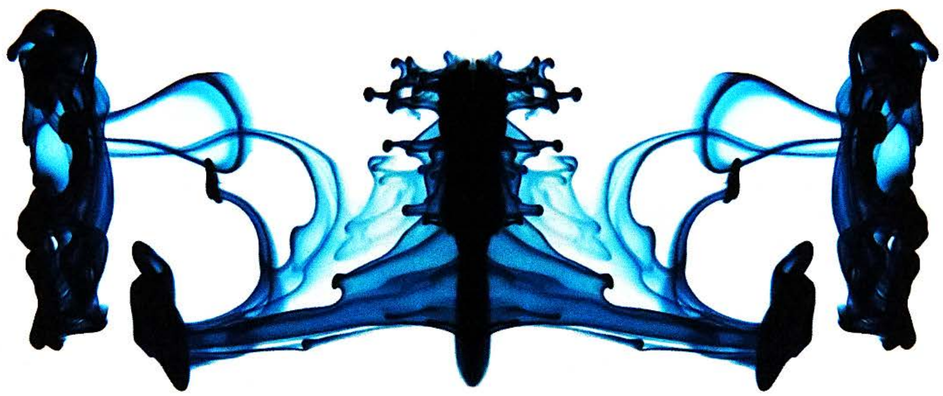
The Rorschach Test



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Get Wet Assignment

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Introduction

The Rorschach Test was created as an introduction project to the Flow Visualization course. This project was not only used to introduce students to the art of photography and image manipulation, but also as an introduction to the physics behind common fluid flow. The original intent of *The Rorschach Test* was to show the interesting and sometimes beautiful effect of Rayleigh-Taylor instabilities through the use of food dye in water, but was then changed into a more unique image due to the commonality of the experiment; especially due to the fact that the original image was taken in a group of two other students (William Derryberry and Stephen Wong), both with similar photographs. This report will not only elaborate on the physics involved in *The Rorschach Test*, but will also detail the setup of the experiment and the post processing of the image.

Description of Flow Physics

The Rorschach Test is a clear example of a fluid dynamic phenomena known as a Rayleigh-Taylor instability. This instability occurs when a fluid of higher density than the medium in which it is placed accelerates through the less dense liquid due to the force of gravity[1]. As the denser fluid progresses, it displaces the less dense fluid causing the overall potential energy of the system to decrease over time. This change in potential energy, however, also causes disturbances to propagate and allow for potential energy to be released. This cycle continues until the denser liquid propagates fully through the less dense liquid, and the potential energy of the system is entirely used.

Rayleigh-Taylor instabilities are largely dependent on two dimensionless numbers: the Reynolds and Atwood numbers. 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[2]; where "U_d" is the velocity of the food dye, "r" is the radius of the drop, and "ν" is the kinematic viscosity of the water. For the purpose of this experiment, both "U_d" and "r" were estimated using a drop height of 2 cm above the water's surface, yielding a velocity of 0.626 m/s and a drop diameter of 5 cm. The viscosity of tap water was assumed to be $4.75*10^{-7}$ m^2/s at an estimated temperature of 60° F (15.56° C).

$$Re_d = \frac{U_d R}{\nu} = \frac{(0.626\frac{m}{s})(5 * 10^{-4}\ m)}{4.75 * 10^{-7} m^2/s} = 659$$

Once calculated, the Reynolds number is shown to be low (under 2300) and greater than 1, and thus fit the instability criterion of laminar, inviscid flow[2].

The Atwood number represents the density ratio of the two fluids, and thus the penetration distance of the heavy fluid's mushroom instabilities into the lighter fluid[3]. The Atwood number, described in the equation below, uses only the densities of the "heavy" and "light" liquids as inputs, represented as ρ_H and ρ_L respectively. These densities were assumed to be 1000 kg/m^3 at room temperature for food dye, and 983.2 kg/m^3 at an estimated temperature of 60° F (15.56° C) for water.

$$A = \frac{\rho_H - \rho_L}{\rho_H + \rho_L} = \frac{1000 - 983.2}{1000 + 983.2} = 8.47 * 10^{-3}$$

Once calculated, the Atwood number is shown to be less than 1, and thus fits the criteria for the formation of rounded, circular cross-section mushroom instabilities.

Experimental Setup

To create *The Rorschach Test* a relatively simple experimental setup was used. First, a large computer monitor was used to create a white, back-lit background. This was done by simply opening a blank file in Microsoft's Windows Paint application, setting the display to full screen, and maximizing the brightness setting of the monitor. All other lights in the room were turned off, and the blinds were closed as to remove all other light sources from the image. Then, a white cardboard box was used to support the tall, cylindrical glass in front of the screen. This glass was filled with cold water, and then cleaned of any bubbles with a Popsicle stick as to not distort the image. A tripod was used to position the camera in front of the glass to ensure stability. The camera was then focused on the contents of the glass by again using the Popsicle stick. Finally, the original food dye bottles were used to drop an individual droplet of dye as close to the waterline as possible. This was done to minimize the force of impact of the dye droplet on the water, and thus remove any extraneous splashing that may occur.

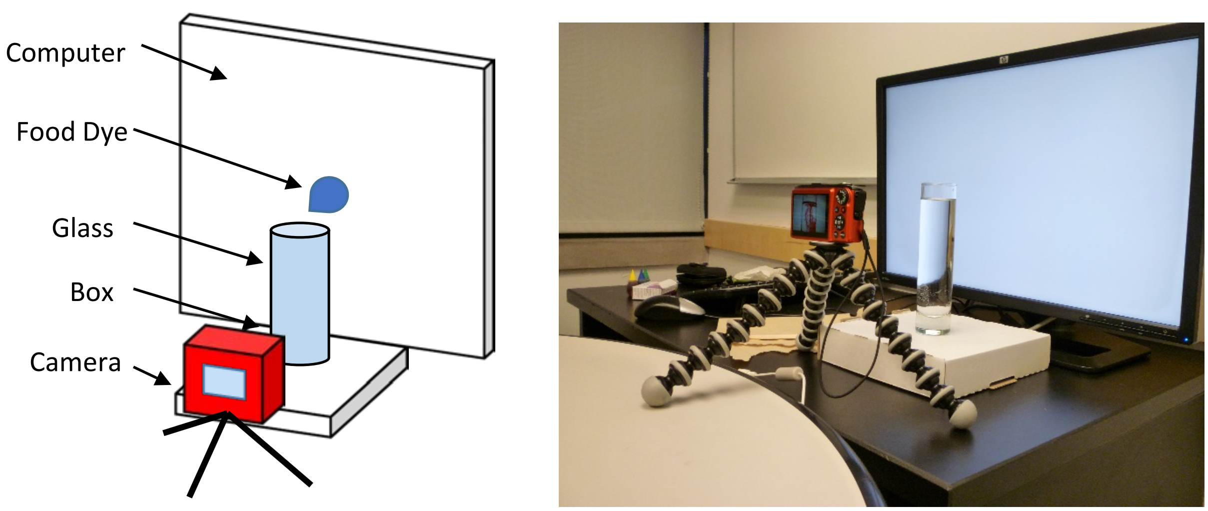

Figure 1: Animated experimental setup (Left), Realistic experimental setup (right)

Photographic Technique

To take the original JPEG image of *The Rorschach Test* a 12.1 megapixel Canon PowerShot SX280 HS Digital Camera was used. As the camera is a simple "point and shoot", the default 4.5 - 90.0 mm focal length with 20x optical zoom and image stabilization lens was used. The camera, with lens extended, was placed 5 cm in front of the glass to maximize the distance from the lens to the glass while still allowing the camera to focus on the dye within. The camera was then manually focused and adjusted using customized exposure specifications. Specifically, a fast shutter speed of 1/2000 seconds and an aperture of f/3.5 were used to ensure the capture of the quick flowing fluid with minimal motion blur. A large ISO of 3200 was also used to compliment this shutter speed and aperture size as ample light was present.

For the post processing of the image, Adobe Photoshop CS5 was used. First, the image was cropped from 4000 x 3000 pixels to 1938 x 1338 pixels. This was to reduce the field of view of the image from about 8 cm x 6 cm to around 6 cm x 4 cm, thus removing all the blank space from around the glass, as well as the glass itself from the image. Then the image was flipped 90^{o} clockwise and mirrored about the waterline to create the Rorschach-like image. Finally, both the contrast and the sharpness of the image were adjusted to allow for more visible fluid flow, and a generally more appealing image. Although these techniques did remove most of the "graininess" from the white area around the fluid, the eraser tool was used for a few minor touchups.


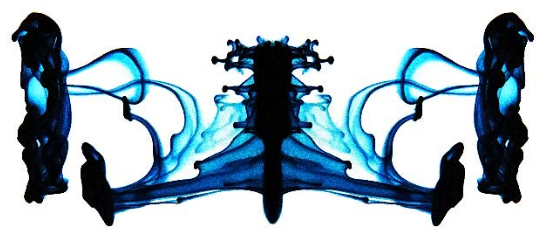

Figure 2: Pre-processed image (Left), Post-processed image (right)

Conclusion

The Rorschach Test not only clearly displays Rayleigh-Taylor instabilities between two liquids of different densities, but allows the viewer's imagination to wonder. Overall, there is little to be done to this image that would make me happier with how it turned out. I very much enjoy both the colors of the image, and the endless pictures it creates. My only wish is that the quality of the original image file was a little crisper and less grainy, but that mainly depends on the type of camera used. The lighting for the image could have also used some improvement, but I was honestly impressed with how well it worked in the first place. I have always had an interest in Rorschach tests (not to question my sanity), and thus would most likely repeat the experiment to yield different, unique results rather than change any major step in the experimental procedure.

References

[1] Drazin, P. G. (2002). *Introduction to Hydrodynamic Stability.* Cambridge, UK: Cambridge University Press

[2] 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.

[3] Sharp, D. H. (1984). *An Overview of Rayleigh-Taylor Instability*. Physica 12D.