Get Wet

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I. Introduction

This report documents the techniques used to create Rayleigh-Taylor instabilities and the physics behind it. It will also describe the photographic techniques used to capture the flow. This project and image was designed and captured for the Flow Visualization course at the University of Colorado at Boulder in the spring of 2012.

II. Flow Apparatus

The Raleigh-Taylor instability was created using food coloring droplets into a water bowl. This instability occurs when food coloring, primarily propylene glycol, is dropped into water from above. The propylene glycol has a slightly higher density than water [1]. Once the propylene glycol is dropped on the surface of the water, gravity takes over and begins to pull the fluid to the floor of the water filled apparatus. Calculating a Froud number gives a dimensionless ratio of the food coloring's resistance to the water as gravity pulls it downwards. Below the Froud number is calculated and it is expected that the fluid with a greater resistance (propylene glycol), will likely cause deformation as it flows through the less dense fluid (water).

$$Fr = \frac{U_d}{\sqrt{gR}} = \frac{0.045\,{}^{m}\!/_{s}}{\sqrt{(9.8\,{}^{m}\!/_{s^2})(0.5_{cm})}} = .203$$

Where U_d is the velocity of the dye, g is the gravitational force, and R is the radius of the droplet. Using logical engineering assumptions the dye was dropped into the water approximately .5cm above the surface giving it velocity of about $0.045_{m/s}$. The diameter of each drop was around 1cm giving a radius of 0.5cm. As the propylene glycol begins to sink, the water is also pushing back against gravity, and the propylene glycol droplet begins to widen outwards creating a vortex ring. This energy continues throughout the interaction creating an umbrella appearance. Eventually the dense liquid reaches the bottom of the container and fluids begin to mix.

Calculating the Reynolds number for this flow, the Raleigh-Taylor instability is to be expected when the above experimental conditions are applied. The Reynolds number is the dimensionless ratio of inertial forces to the viscous forces and can be calculated using the following formula.

$$\mathrm{Re}_d = \frac{U_d R}{\nu} = \frac{(0.045\,{}^{m}\!/_{s})(0.5_{mm})}{1.307x10^{-6}\,{}^{m^2}\!/_{s}} = 172$$

Where U_d is the velocity of the dye, R is the radius of the droplet and ν is the kinematic viscosity of the water. The velocity and radius assumptions, used in the Froud calculation above, were used. The viscosity of tap water is $1.037x10^{-3}$ N $_{s/m^2}$ at an estimated temperature of 10°C [2].

A low Reynolds number, number has the greatest influence in this experiment and gives the flow the umbrella appearance [3,4]. Since each of the propylene glycol colors have slightly different densities their, Reynolds number also change very slightly and reflect their slight differences in appearance.

III. Visualization Technique

In order to get the desired lighting for this photo a light box was built (Figure 1). This was accomplished using a card board box, 12”x12”, and cutting out three of the sides. The sides were then covered with tissue paper and a piece of white poster board was inserted to cover the bottom and the back of the box. This gave the photo a smooth even light and minimized glare. Next, a fish bowl was filled with water and placed inside the light box (Figure 2). The only light source was provided from a flexible neck desk lamp fitted with a 100W bulb, the rest of the room was dark. The light source was placed on the right side of the light box as seen in figure 3.

Figure 1- Light box

Figure 2- Fish bowl in light box

Figure 3- Light box and Fish bowl showing light source placement

The camera was then placed on a tripod in the standard horizontal position, and the lens was placed 0.5cm away from the fishbowl surface. An eyedropper was inserted into the water in the center of the bowl and the camera was manually adjusted to focus on the dropper as a reference point. This is not a necessary step but useful and was performed to minimize any focusing that would need to be done while flow was developing. The three food colorings were then dropped into the water, all within 1cm of each other from an approximate height of 0.5cm. The space was chosen to keep the colors next to each other but also minimize any mixing that might occur, the height was chosen to minimize any additional gravitational forces on the droplets before reaching the water (Figure 4). Once the fluid was dropped into the water a series of pictures were taken to capture the fluid as it developed downwards. This flow developed for approximately 15 seconds and 10 pictures were taken during the length of the experiment. This experiment was recreated several times until the final techniques described in this report were determined and the final photograph was created.

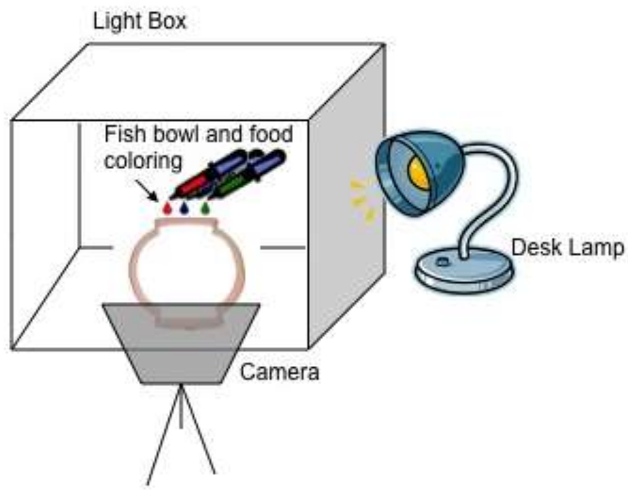

Figure 4- Animation of the experiment set-up

IV. Photographic Technique

An 18.1-mega pixel DSLR camera was used and captured an image of 5184 x 3456 pixels. The camera used was a Canon EOS Rebel T2i 18.1 mega pixel body, used with a Canon EFS 18-55mm f/3.5-5.6 IS II lens [5]. The lens was also fitted with a 42x HD Super Wide Angle Panoramic Macro Fisheye Lens Adapter. The macro fisheye lens adapter was added for three reasons. First the macro capabilities, this allowed the camera to get much closer to the flow and the surface of the bowl than the camera would normally allow with the supplied 18-55mm lens. The fisheye lens also gave a wide-angle view, giving the image a spherical distortion, which seemed to compliment the similar shape of the fish bowl as well. The adapter naturally provided the unique rounded cropping that you see in the image, this also helps to block out any edges from the bowl and draws the viewers attention to the beautiful flow phenomenon in the center of the image. The light box and light source as described in the visual technique section above, were also key techniques used to capture the image.

The camera was focused manually and custom exposure settings were used including shutter speed, aperture, and ISO. A relatively fast shutter speed of 1/30s and an aperture value of f/5.6 were chosen to quickly capture the moving flow, minimizing distortion that maybe caused when photographing moving objects. The ISO was used to compliment the shutter and aperture values and due to the ample amount of light that was provided. The image field of view was approximately 140 degrees with the wide angle fisheye lens placed 0.5cm from the bowl surface. These settings balanced the light coming into the camera's sensor and produced the RAW image you see below (Figure 5).

Figure 5- RAW image. Size: 5184 x 3456 pixels

Post processing was then done using Adobe Photoshop CS5 and adjustments were performed to enhance subtle qualities and produce the final image. Minor cropping was done to the left and right sides to give a more uniform shape and to remove some non-uniform distortion, primarily seen on the right side of the image. The tonal ranges were adjusted (figure 6) to bring out certain qualities by brightening the white background, and enhance the colors of the propylene glycol. The brightness was brought down, after the tonal curves were adjusted, to -10 and the contrast increased to 6. The final image can be seen in figure 7.

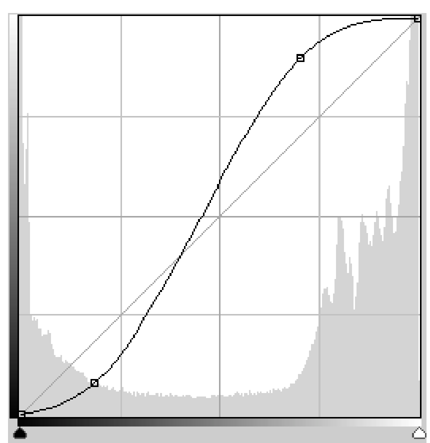

Figure 6- Tonal curves

Figure 7- Final Image, Size: 4120 X 3456

V. Image analysis

The image accurately and artistically displays the Raleigh- Taylor instability as propylene glycol falls through water. The unique shapes of the three combined falling propylene glycol flows accurately display this instability and me a unique understanding of this phenomenon. I really enjoy the colors and the shape of the flows, they are very vibrant and seem to pop out right out of the photo. I would like to make some more adjustments in post processing to remove some distortion around the black edges of the photo and also bring back some of the shading that was lost from the RAW image. I would also like to perform more accurate temperature readings of the room and water used to improve the accuracy of the engineering calculations.

VI. References

[1] Dow Chemical Company. “Dow Propylene Glycol USP/EP.” Technical Data Sheet- Propylene glycol. 2010. Accessed 15 February, 2012. <http://msdssearch.dow.com/PublishedLiteratureDOWCOM/dh_0048/0901b80380048696.pdf?filepath=propyleneglycol/pdfs/noreg/117-01619.pdf&fromPage=GetDoc>

[2] Engineering Toolbox. “Water - Dynamic and Kinematic Viscosity." Engineering ToolBox. Web. Accessed 15 Feb. 2012. <http://www.engineeringtoolbox.com/water-dynamic-kinematic-viscosity-d_596.html>.

[3] Bosse T, Kleiser L, Härtel C, Meiburg E. Numerical simulation of finite Reynolds number suspension drops settling under gravity. Physics Of Fluids [serial online]. March 2005;17(3):037101. Accessed February 16, 2012.

[4] Bayareh M, Mortazavi S. Three-dimensional numerical simulation of drops suspended in simple shear flow at finite Reynolds numbers. International Journal Of Multiphase Flow [serial online]. December 2011;37(10):1315-1330. Accessed February 16, 2012.

[5] Canon U.S.A. “Consumer & Home Office.” EOS Rebel T2i EF-S 18-55IS II Kit. Web. Accessed 16 Feb. 2012. <http://usa.canon.com/cusa/consumer/products/cameras/slr_cameras/eos_rebel_t2i_ef_s_18_55is_ii_kit>.