Project 1: "Get Wet"

MCEN 5151 – Flow Visualization
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1.0 Introduction

At the beginning of the MCEN 5151 – Flow Visualization (Flow Vis), Spring 2013, "Get Wet" project, it was described as being a project where the photographer was to submit a "picture of fluids that both demonstrates the phenomenon being observed and is a good picture".[1] I decided purpose number 2 should be the focus of my efforts, as my knowledge of the field of photography was sparse at best and being practicing techniques in a controlled environment seemed an excellent way to learn. From the previous years of Flow Vis "Get Wet" projects, a number of seemingly basic ideas were picked as subjects of focus.

In the end, however, the simple motion of food-coloring through water captivated me the most; the final result of which is shown on the front cover and in Figure 3. Photo-editing for white balance, color, and image cropping was completed in the freely distributed software program GIMP *(www.gimp.org)*. Fellow Flow Vis colleague Blake Buchannan assisted with final re-touches in Adobe Photoshop CS5, including adding better contrast to the background and sharpening the red food-coloring edges.

2.0 Flow Physics

Section 3.0 discusses the photograph's detailed information, but it is prudent to discuss the flow of the apparatus, shown in Figure 1. The red food-coloring fell from approximately six inches from the surface of the water in the chalice (at center); the chalice's pool was 3" x 2.5"-3.5" in diameter. Upon hitting the water, the surface tension of the food-coloring was overcome by gravity and the lower density of the water, breaking from drop form and beginning to expand. No obstacles were present in the path of the food-coloring, and the water in the chalice was allowed to settle as much as possible prior to test-taking.

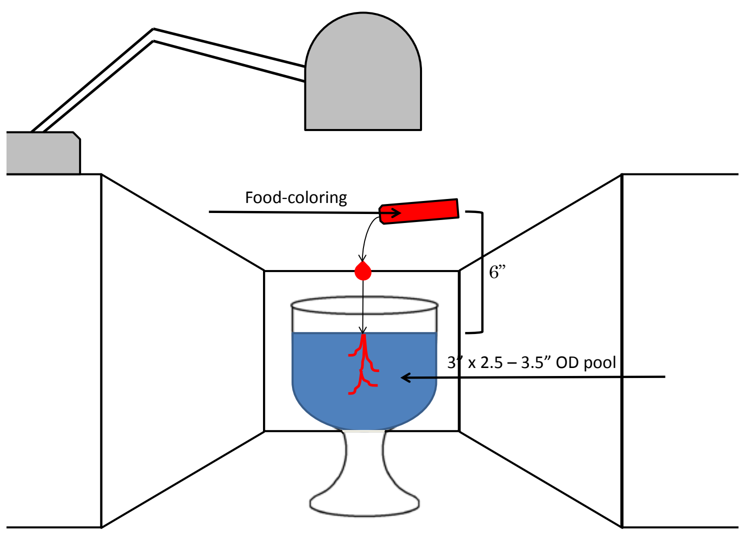

Figure 1: Flow of Apparatus

The motion of the food-coloring in the water is due change in Reynolds values. The Reynolds number is a dimensionless way to determine general fluid flow in a system; low

[1]Hertzberg, Jean. "Initial Assignments." *Flow Visualization: A Course in the Physics & Art of Fluid Flow*. N.p., n.d. Print. 31 Jan 2013.

Reynolds numbers represent viscous, laminar flow[2]. Equations governing the motion of the food-coloring are[2,3]

$$Re = {}^{\rho V l}/_{\mu} = {}^{V l}/_{\nu} \tag{1}$$

$$V = {}^{(\rho_d - \rho_w) R^2 g}/_{\rho_w \nu} \tag{2}$$

where Re is Reynolds number, V is velocity (terminal), ρ_d is density of the food-coloring, ρ_w is the density of water, v is kinematic viscosity of water, and l, R both represent drop radius.

For Reynolds numbers Re<1, flows are highly viscous and laminar,[2] which causes the food-coloring to retain its spherical shape.[3] Upon impact, the Reynolds number increases to Re>1.[3] With the increase in Reynolds number, the food-coloring loses its spherical shape and starts to disperse in the less-dense water. This is called the Rayleigh-Taylor instability, which occurs at the plane interface of different-density fluids accelerating towards one another[4].

Looking at the food-coloring/water system, $\rho_w = 995 \frac{kg}{m^3}$,[2] $\rho_d = 1026 \frac{kg}{m^3}$,[5] $\nu = 1.0038e^{-6} \frac{m^2}{s}$,[2] $g = 9.8 \frac{m}{s^2}, and\ R = 0.00150\ m$. All values were taken for 25 ^{0}C and 1 atm. Using equations (1) and (2):

$$Re = {}^{V l}/_{\nu} = \left({}^{(\rho_d - \rho_w) R^2 g}/_{\rho_w \nu} \right) * ({}^{l}/_{\nu})$$

$$= \left({}^{[(1026 - 995)(0.00150)^2 (9.8)]}/_{(995 * 1.0038e^{-6})} \right) * ({}^{0.00150}/_{1.0038e^{-6}}) = 1022.7$$

A Re>1000 denotes a transition into turbulent flow,[2,3] which is exhibited by the multiple streamlines and cloud formations.

Also worth noting is that in the range 1<Re<100, the more-dense fluid forms a detached torus, which eventually disintegrates into smaller segments.[3] While the final picture does not exhibit that particular phenomenon, another picture in the same set does show the

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[2] White, Frank. *Fluid Mechaniccs*. 7th. Ed. New York City: McGraw Hill, 2011. 27. Print.
[3] Bosse, Thorsten, Leonhard Kleiser, and Carlos Hartel. "Numerical simulation of finite Reynolds number suspension drops settling under gravity." *Physics of Fluids*. 17.037101 (2005): 3. Web. 11 Feb. 2013. <http://me.ucsb.edu/~meiburg/pubs/Bosse_et_al_2005.pdf>.
[4] Chandrasekhar, Subrahmanyan. *Hydrodynamic and Hydromagnetic Stability*. Dover Ed. Dover Publications, 1981. 428. Print.
[5] McCormick and Co., . "Material Safety Data Sheet, Red Food Color." . McCormick and Co., 02 May 2010. Web. 11 Feb 2013. <http://www.indstate.edu/nursing/lrc/pdfs/emergency-plans/msds/red-food-color.pdf>.

torus being created, showing a gradual increase in Reynolds number. The torus is shown in Figure 2.

Figure 2: Torus Formation, 1<Re<100 Range

3.0 Photograph Setup

As exhibited on the front cover, the final photograph consists of red food-coloring falling through distilled, undisturbed water in a chalice. Distilled water was chosen to prevent particulates from interfering with the fluid flow, and the chalice was chosen because of the curved nature of its sides; it was hoped the curved sides would provide magnification of the internal fluid flow. Once the water settled and the camera was completely level with the center of the chalice, a single drop of red food-coloring was dropped at approximately six inches from the top of the chalice. A series of pictures were then taken, culminating with the red food-coloring pooling at the bottom of the chalice.

Before any photographs were taken, however, a suitable photograph "white-box" was deemed necessary for white balance. This consisted of three file boxes for the walls and 96-brightness printer paper for the floor of the box. To provide lighting, a high-intensity incandescent 60W soft-white desk lamp was situated directly above the center of the box, with the bulb level with the non-existent white-box lid, or approximately 12 inches from the top of the water level. No flash was used in the final photograph, as previously-taken photographs with the flash had produced a glare on the glass face.

4.0 Photograph Specifics

The final photograph was taken with the Olympus Stylus XZ-2 digital camera. To prevent camera shake and unintended soft-focus, the camera was mounted on a table-top tripod. The field of view measured 6.65 x 4.10 inches; the camera lens was 8.00 inches from the chalice. A 1.0x zoom was used, and the focal length was 6.00 mm (28.0 mm – 35mm equivalent). The shutter speed was 1/400 sec, the aperture size was F2.5, and the ISO was set at 200. These particular camera settings were chosen primarily based on information obtained during the Flow Vis "Introduction to Camera Settings" lecture given on Thursday, January 30th, 2013, by Dr. Jean Hertzberg, and from pointers found in the MAGbook The Ultimate Guide to Digital Photography.[6] The original image was 3968x2232 (196:9 ratio)

[6] Fearon, David. *The Ultimate Guide to Digital Photography*. 4th Ed. 2010. Print.

pixels and taken in .JPEG format. The original photograph is shown in Figure 3. After some post-processing cropping, the final image was 2160x2226 and .TIF format.

Figure 3: Original Image, Red Food-Coloring in Water

While reviewing taken photographs, it was determined that the white balance was poorly defined, with the incandescent-lit desk lamp providing an extremely yellow version of "white". Using GIMP, the white balance was adjusted using the levels tool for each the R, G, and B values; the final values are listed in Table 1.

Table 1: R,G,B Levels Adjustments

Red	130	1.15	208
Green	80	1.60	165
Blue	35	1.45	75

While adjusting levels did reset the white balance closer to true, the background still retained a purple hue. This was particularly prevalent on the walls, whose original file-box white color was much less pure or bright than the printer paper used for the floor of the white box. Turning to Adobe Photoshop CS5 for fine-tuning, the background walls were re-touched to be on a black/white scale. The floor, however, was left as finished from the levels adjustment phase. The black/white shading was added to help distinguish the containing water in the chalice from the walls. The edges of the red food-coloring were also sharpened to 165%. Finally, minoring editing was necessary to remove some faint blue-green discoloration surrounding the largest bubbles near the left edge of the chalice, which appeared during levels adjustment. The final image was cropped to negate the off-set chalice placement between the white box walls, and is again shown in Figure 4.

Figure 4: Red Food Coloring in Water

5.0 Conclusion

By no means is the final image submitted for the “Get Wet” project complete, but it does mark a very important step for my entry-level photography. During photograph-taking for the project, the importance of aperture, shutter, ISO, distance, focus, and white-balance/lighting was first recognized. The photograph also shows the food-coloring’s transition into turbulence clearly, with the multiple food-coloring cloud structures. Personally, I find the image to be rather striking. The glass is centered and there is an excellent contrast between the background and the water. Also, the red leaps from the image, which is propelled by the black/white background.

However, one less adequate point is the lack of attention to detail with the hand-pick shading tool, which did create overlap on the chalice edge. Another is the remnant of purple hue in on the white floor of the background, which was left because shading between the sides of the stem proved too advanced for my entry-level understanding.

Future work includes fixing the background bottom white balance, and remove the camera, tripod, and block reflections on the chalice. The reflections do not necessary detract from the image, and would prove an extremely difficult challenge to remove, but it would also serve as an excellent step to continue learning about the fine-tuning controls of photo manipulation and processing. Additional future work includes applying the same editing techniques to the set of pictures taken during this particular drop, and stringing them together in a time-lapse sequence. In doing so, one could better visualize the transition of Reynolds number and loss of laminar flow as discussed in Section 2.0 Fl

Since completing the project, I’ve learned no subject can be regarded as simple. It takes far more effort than I initially realized to make any image show what one attempted to capture, but I believe my “Get Wet” photo holds up to critique. I am pleased what skill advancement my photograph represents, and I expect to continue to improve.

6.0 References (Re-listed)

1) Hertzberg, Jean. "Initial Assignments." *Flow Visualization: A Course in the Physics & Art of Fluid Flow*. N.p., n.d. Print. 31 Jan 2013.

2) White, Frank. *Fluid Mechaniccs*. 7th. Ed. New York City: McGraw Hill, 2011. 27. Print.

3) Bosse, Thorsten, Leonhard Kleiser, and Carlos Hartel. "Numerical simulation of finite Reynolds number suspension drops settling under gravity." *Physics of Fluids*. 17.037101 (2005): 3. Web. 11 Feb. 2013. <http://me.ucsb.edu/~meiburg/pubs/Bosse_et_al_2005.pdf>.

4) Chandrasekhar, Subrahmanyan. *Hydrodynamic and Hydromagnetic Stability*. Dover Ed. Dover Publications, 1981. 428. Print.

5) McCormick and Co., . "Material Safety Data Sheet, Red Food Color." . McCormick and Co., 02 May 2010. Web. 11 Feb 2013. <http://www.indstate.edu/nursing/lrc/pdfs/emergency-plans/msds/red-food-color.pdf>.

6) Fearon, David. *The Ultimate Guide to Digital Photography*. 4th Ed. 2010. Print.