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MCEN 4151
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Get Wet – Spring 2018

Figure 1: Final Image

Context:

The Get Wet assignment is an introduction into flow visualization, I chose to replicate vortex rings and other fluid instabilities using food coloring to visualize the phenomenon. Observed in Figure 1 is the azimuthal instability on the vortex ring, and the umbrella instability in the upper left of the image. Many pictures were taken in to get multiple desired instabilities to occur in a single picture. At first, I attempted to simply photograph a vortex ring, but the image appeared too plain and I opted for something a little more eye-grabbing. The resulting image makes use of the dark green and blue drops of food dye spaced closely together to contrast with the white background.

Apparatus:

Moving on to the physics, the type of instabilities seen are mostly from the Rayleigh Taylor suspension drop phenomenon. Vortex rings are formed by ejecting fluid from a circular nozzle, and often an Azimuthal instability develops as the ring translates in space [1]. Seen in the bottom right of figure 1, the vortex ring has many waves around its perimeter because it is unstable to sinusoidal displacements of the vortex filament [3]. This ring appears to be an azimuthal instability of n = 7. The weber number is an important part in the formation of a vortex ring. The relation is between the surface energy and the convective energy of a surface and is important for this application. The objective was to set conditions to produce a weber number that is below the critical value, which determines if the drop is a jet or vortex ring. A small weber number will produce a vortex ring [2]. From the setup, the weber number is:

$$We = U\left(\frac{\rho D}{T}\right)^{\frac{1}{2}} = 0.70\left(\frac{m}{s}\right)\left(\frac{998.21\left(\frac{kg}{m^3}\right)0.00625(m)}{0.0728\left(\frac{N}{m}\right)}\right)^{\frac{1}{2}} = 6.5$$

The velocity was calculated assuming the droplet can be approximated as a sphere with diameter d = ¼” and the drop conserves energy when dropped from a height of 1”, and assuming the coloring is mostly composed of water (not viscous). The density of water is 998.21 kg/m^3 and the surface tension is 0.0728(N/m) at room temperature. The resulting weber number is of the correct magnitude to create a vortex ring. Judging by the green and blue droplet wisps in the rest of the image, the flow is somewhat turbulent, indictive of a moderately high Reynolds number. This is an important condition for Widnall’s conclusion [3].

In my apparatus, I used a large glass salad bowl with an upper diameter of 10.5”, a base diameter of 5”, and a height of 5.5”. To produce this image, I filled up the bowl to a little over half full until the water line sat at 3.5” and let sit for 2 minutes to calm the stirring flow. Figure 2 below outlines the setup.

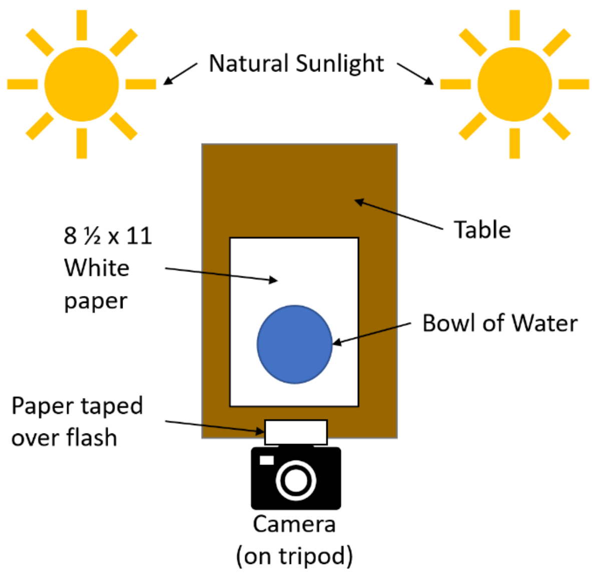

Figure 2: Setup Schematic

The food dye bottles had round nozzles and produced droplets with of approximately ¼” in diameter. The coloring was dropped at a height of 1” above the waters’ surface. The camera was set up on a tripod 3” above the top of the bowl and 6” away. The backdrop in the image an 8 ½” x 11” white piece of paper.

Visualization technique:

To get the effect visualized in Figure 1, the droplets of water being propelled into the fluid needed to be seeded with dye. The food dye used was a Kroger brand, bought at King Soopers. Luckily, the food dye nozzle could produce droplets in the range of Reynolds numbers needed to see the vortex ring phenomenon. The drops did not need to be diluted, as they are approximately the similar viscosity as water. The blue and green dye showed up best against the white backdrop and were used to create a crisper image. The lighting was natural afternoon sunlight in a dining room, approximately 4 feet away from the windows, and additional lighting from the flash of the camera diffused by a piece of paper folded over the light.

Photographic Technique:

The original photo shown in figure is 4000 pixels x 3000 pixels. The camera used is a Canon PowerShot SX50 HS. The camera was placed on a tripod, about 8" away from the bowl, and facing downward at about 30 degrees from horizontal. The camera specifications are an ISO-4000, an aperture of f/5 and a shutter speed of 1/160 s. The focal length is set at 17mm, and the field of view is approximately 5 inches across. The image was cropped to dimensions of 2982x2106 pixels in Adobe Photoshop to put emphasis on the instabilities flowing across the diagonal of the image and to crop out the bottom edge of the bowl. Brightness and contrast was increased slightly to brighten up the darkness of the blue green interaction.

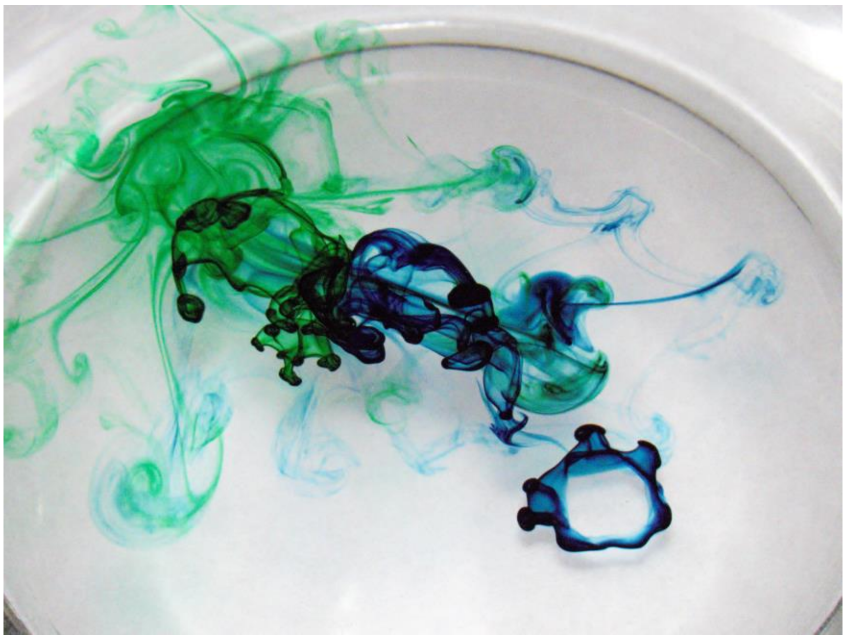

Figure 3: Original Image

Critique:

The image reveals several fluid flow phenomena that are dependent upon parameters like the Reynolds number and the Weber number. I would like to learn more about the Widnall instability and why the vortex ring dissipates with varying sinusoidal nodes, displayed in the image. Something I would change is the ISO and measuring the parameters for the dimensionless variables. This being the introductory assignment for the course, and having little experience with photography the final cropped section of the photo turned out to be a little granular, which subtracts from the quality of the image. I did not notice until cropping in post processing. If there were more light projected behind the setup, I believe this could mitigate that effect and provide a clearer image. However, the physics are displayed well and the composition of the image is aesthetically pleasing. It would be interesting to attempt to recreate the observed fluid phenomenon with a variety of different liquids, playing around with viscosity and the fluid properties to create similar Weber and Reynolds numbers and determine if the same fluid flow will occur.

References:

[1] Feng, Hualong, et al. “Azimuthal Instability of a Vortex Ring Computed by a Vortex Sheet Panel Method.” *Fluid Dynamics Research*, 2009, doi:10.1088/0169-5983/41/5/051405.

[2] Hsiao, Mingying, et al. “The Critical Weber Number for Vortex and Jet Formation for Drops Impinging on a Liquid Pool.” *Physics of Fluids*, 1988, doi:10.1063/1.866872.

[3] Idnall, Sheila E. W., and J. P. Sullivan. *On the Stability of Vortex Rings*. Vol. 332, 1973, pp. 335–53.