Flow Visualization

Assignment 1: Get Wet




Jason Brownstein

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Purpose:

The purpose of this time-lapse flow sequence was to visualize the instabilities that form when two fluids of different densities collide. This is the first in a series of photos and movies that will be made for this class. Being that this is the first assignment the visualized fluid flow is relatively simple as is the experimental set up. Initially an experiment using champagne and a flute glass was going to be used to visualize the eddies that are formed by the champagne bubbles. After experimentation this result was quite hard to produce given the time scales of the champagne bubbles and the contours of the glass. This false start led to the shown experiment in this report. A simple food coloring drop dropped in water experiment.

Flow Set-Up:

In order to achieve the desired picture the experiment had to be set up. Studio lights that provide constant intensity light were used to eliminate all shadows in the image and ensure that it would be possible to capture the flow in high detail with the cameras available settings. Placing one light on either side of the set up eliminated the shadow produced by the opposing light on the vase, see Figure 1. To house the fluid a 5” W x 7” H x 4” D square flower vase was used. It was important to use a square vase instead of a cylindrical one in order to achieve a consistent plane of focus throughout the image. As well a flat piece of glass aids in reducing any refraction abnormalities when shooting an image through glass. A white piece of poster board was placed behind the flower vase to ensure a flat background that would provide good contrast to the colors in the image and not distract the viewer’s eye from the fluid flow. Finally the camera was placed on a tripod approximately 10” away from the vase.

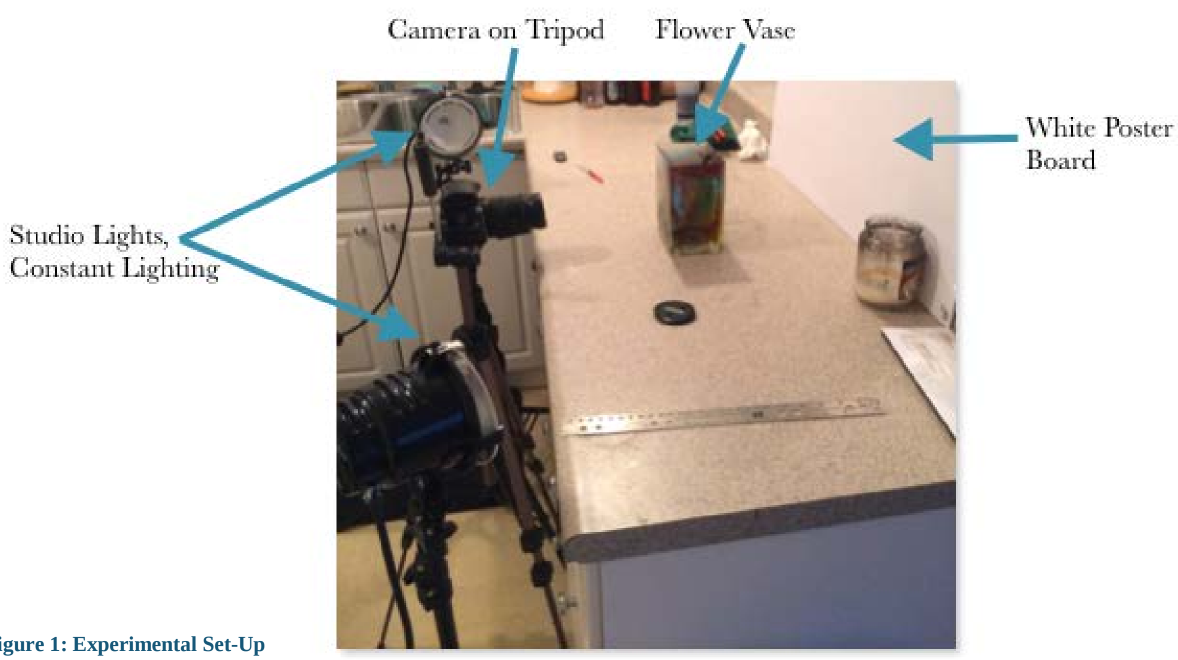

Figure 1: Experimental Set-Up

Once the experimental set-up was complete the flower vase was filled with water. The vase was filled till the water was about to flow over the sides of the vase. This water level made the image a bit more appealing because the edge line of the flower vase was minimized, due to blending with the water. With the studio lights on and the camera settings complete food dye was then dropped into the flower vase. To achieve constant drops the provided food dye container was used. First three drops of blue food coloring was dropped into the flower vase. After approximately two and half minutes three drops of red food dye were dropped into the flower vase. Then after two minutes three drops of yellow food dye were dropped into the flower vase. Finally after another minute the green food dye was dropped into the flower vase. The relative times between dropping was determined visually by how much the dye had diffused into the system.

Flow Physics:

When each drop of food dye is dropped into the water several flow phenomena occur. As evident in the time lapse a Rayleigh-Taylor instability is formed and several vortex rings appear. The Rayleigh-Taylor instability occurs when there is an interaction between two different density fluids. The interaction is visualized in what appear to be fingers, this is due to the less dense fluid pushing on the more dense fluid[1]. To understand the transition into this instability and how it occurs the Reynolds number is needed to characterize the flow of the food dye. The flow can be either laminar or turbulent[2].

$$Re = U_d R/v \quad 1)$$

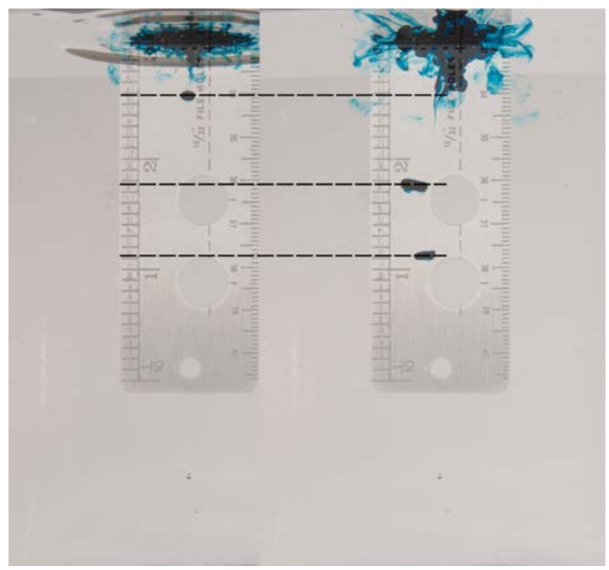

Figure 2: Overlay Technique

Where U_d is the velocity of the drop, R is the radius of the drop, and v is the kinematic viscosity of the food dye. The velocity of the fluid can be approximated by using an overlay technique with the time lapse still images. Shown in Figure 2, the fluid is initially entering the water, then in the next frame is has fallen to a certain depth within the fluid. Using the ruler that has been overlaid on the image it can be seen that the distance travelled is 3.7 cm after one second. Thus the velocity of the drop was .037 m/s. The drop size is approximated to be .0015 m. The kinematic viscosity of food dye is close to propylene glycol which is, $v = 8.9e\text{-}7\ m^2/s$.[3] This number is then calculated to be Re = 62.35.

There is a strong dependence on the Reynolds number of the fluid and the way that the drop will eventually break up in the denser fluid. Initially with a Re >1 there is a stronger influence by inertial forces on the drop. This causes the initial vortex ring to form and the drop to appear as though it is still intact. Then as the Reynolds number begins to decrease viscous forces take over and the resulting instability starts to form. As this initial Reynolds number

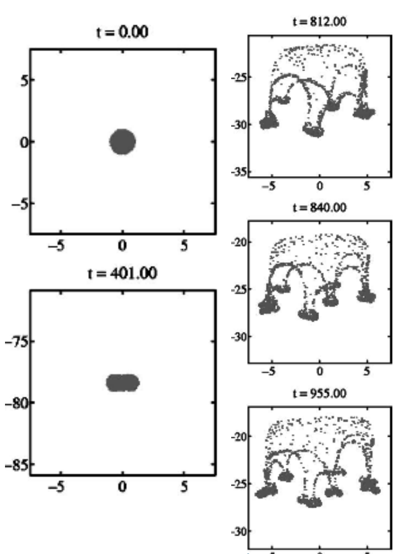

Figure 3Drop Separation[4]

increases the number of parts that break off from the initial drop are increased; Figure 3 illustrates this well. As the time increases the drop begins to separate as is evident in the time lapse; this is mimicked in the numerical model of Bosse et. al.[4] As the time lapse continues more of these instabilities form as more food dye drops are added to the water and they eventually disperse enough to diffuse into the water and change the overall system color.

It can be mentioned that there is a sort of whirlpool that is shown at the beginning of the time lapse and this does not have any sort of explanation because of the drops of dye being added. It is simply a visualization of existing water currents in the flower vase after being filled up from a faucet. The result adds an added turbulent mixing element to the flow but is not a result of adding food dye.

Photographic Technique:

To capture this series of images a Nikon D500 was used with a lens of focal length 18mm - 55mm. In each image a shutter speed of 1/320 of a second was used with a corresponding aperture of *f* 10.0. This combination provided a depth of field that would put the entire image in focus and leave the detail of the white background out of focus. The use of the studio lights allowed the ISO of this image to be 400 which reduced the amount of grain in the image.

At 10 inches away from the flower vase and the focal length of the camera set to 52mm a field of view which encompassed nearly the entire flower vase was achieved, 3.75" W x 5" H. This field of view is then transferred into a image that is 2596 pixels wide by 3423 pixels high. All of these settings remained constant for every image in the time lapse series. To make a time lapse of this fluid flow the camera was set to take a photo every second until the camera was shut

Figure 4: Edit Comparison

off or the memory card was full. To capture the entirety of the this fluid event 271 images were captured each at a second apart. This means that the total flow experiment lasted for roughly 4 minutes. When these images are then assembled into a video it will look choppy if the true duration of the experiment is represented, so the video is sped up by a factor of 8 to make a video that is now roughly 30 seconds long. This action was done in iMovie.

Before assembly of the video each image was batch edited. From the camera each image is a RAW file that can store the most amount of data in comparison to any of the other image capturing file types. When opened into Adobe Photoshop, the camera raw tool was used to alter the images exposure and contrast slightly and to crop the image. Figure 4. Illustrates the editing comparison.

Conclusion:

As a first image for the class this was a successful experiment. It was not the initial intention of the experiment but still proved to be a valuable lesson in the art of flow visualization. The time that must be taken to achieve the exact image in mind is far greater than initially thought. But in the end the time spent is directly related to the quality of the image and its corresponding flow. If this experiment was to be done again it has been suggested to use film instead of a time lapse to capture the flow phenomena. This is a great suggestion considering the time scales in which this fluid is moving. A cleaner more detailed flow could be observed if the frames were shot at a higher rate. With that in mind this time lapse series still does an adequate job of illustrating the flow and the several phases that occur as time increases. Regarding the flow itself the use of several colors helped and hurt the image at the same time, it illustrated the effect of changing density of the fluid and its effect on the diffusion of the food dye but it also made for a loss of contrast and an overall icky image. Next time a different way of altering the overall fluid density without changing its color would be valued.

Bibliography:

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