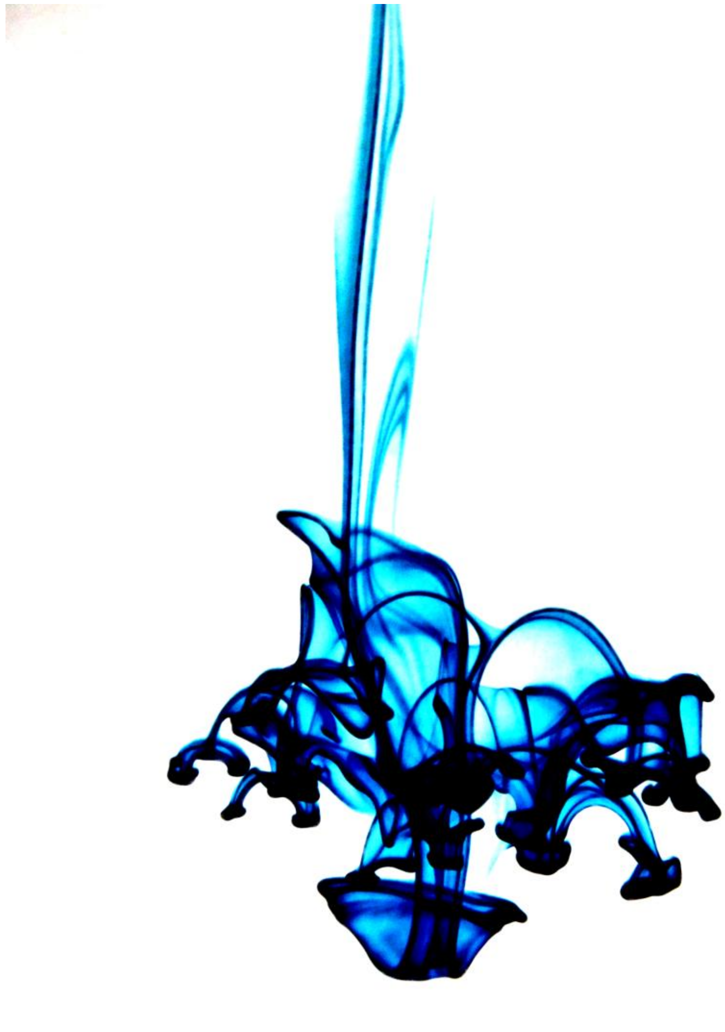
Get Wet Assignment



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MCEN 5151: Flow Visualization

Spring 2012

February 16, 2012

1. Introduction

The purpose of this report is to describe the physics behind a flow phenomena, visualization techniques, and photographic techniques for the initial get wet assignment. For this assignment a Rayleigh-Taylor instability or Umbrella Instability was used as the flow phenomena, and achieved using blue food dye in cold water as seen on the cover of this report. The following text describes the physics behind the Umbrella Instability, how the flow was achieved, and photographic techniques used to achieve the best possible picture. Initially several different colors of food dye were dropped into the water at close to the same time with the thinking that the variety of color would add to the aesthetics of the photograph. This, however, created more chaos in the photograph, and made it harder to visualize the flow of the dye droplets as they broke up, figure 1.1. For the final image one blue drop was used because it gave the clearest image of the flow and the blue created the most contrast with the white background.

Figure 1.1 Initial attempt at Umbrella Instability using Multiple Dye Colors

2.0 Experimental Setup

For this experiment a 6” x 3” x 4” plastic fish tank was used as the apparatus to contain the fluid flow. A round glass was first used, but it was found that the curvature of the glass produced unwanted glare and distortion of the fluid flow and the flat surfaces of the tank produced better photographs. A white piece of construction paper was placed under and behind the tank to help the dye contrast well with the surroundings. Natural light through a window was used because it was found that natural light created less glare off the surface of the tank compared to light from an artificial light source or camera flash. The tank was filled with cold water roughly a 0.5” from the top then place on a piece of white paper. The tank position was then moved forward or backward to reduce the shadow that the tank cast on the white paper behind the tank. This was necessary so that that a shadow would not be seen in the area where a droplet was released. An example of the tank shadow can be seen in figure 1.1. One drop of blue food dye consisting of water, propylene glycol, FD&C Blue 1, and propylparaben, was released from a height of about 0.25” into the water. A camera, roughly 5 inches away from the tank and pre-focused on the small bump on the bottom center of the tank, started taking photographs in burst mode in order to capture the progression of the instability. Figure 2.1 shows a diagram of the experimental setup.

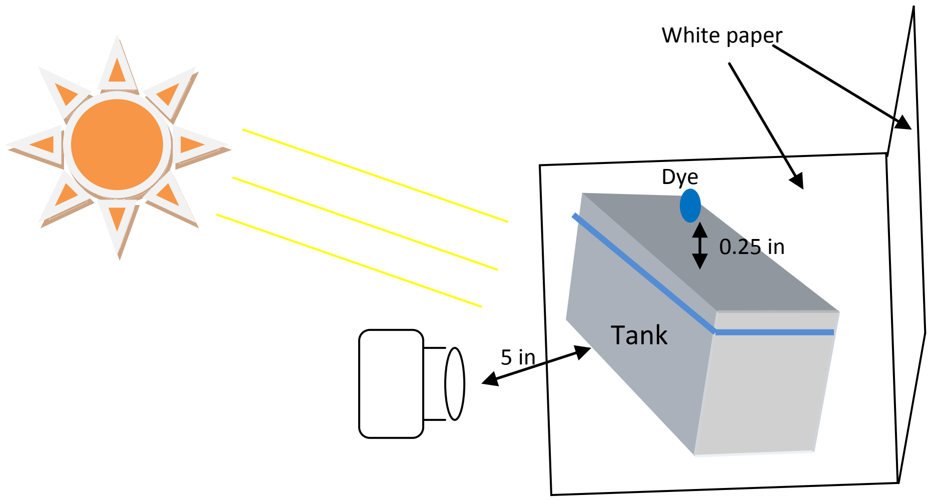

Figure 2.1 Experimental Setup

3.0 Description of Flow Physics

Umbrella instability is observed in liquid drops settling in a fluid of smaller density. The settling occurs under the influence of gravity, and undergoes a complex evolution, including the formation of a torus and the eventual umbrella effects seen in the photograph. The flow transition from the initial drop to the torus to the eventual break up is defined by the Reynolds number of the fluid (eq. 3.1) (Bosse et al. 2005).

$$Re = \frac{U_{drop} * R_{drop}}{\nu_{drop}} \qquad \text{eq. 3.1}$$

For Re<1 the drop will mostly obtain its initial spherical shape while settling, with a few particles shedding off the drop leaving streaks behind the drop, as seen from the relatively straight lines in the photograph. For Re = 1 the drop will form into a torus that grows in diameter while settling. (Bosse et al. 2005). The initial torus can be seen in the bottom of photograph in what looks like an upside-down mushroom. For Re>1 the drop undergoes a complex shape evolution with eventual breakup into a number of secondary blobs. As the drop speeds up due to gravitational forces the Reynolds number increases above 1 and the droplet breaks up into multiple blobs.

The characteristics of the drop instability and cascade, depends on factors such as the initial momentum, viscosity, and density of the fluids (Meng et al. 1998). In this case the initial droplet momentum was small enough to see the trailing particles, along with the transition from the torus to instability. The velocity of the droplet was estimated using a ruler and stopwatch to be about 0.05 m/s when the instability occurred. The radius of drop was about 1mm, and the dynamic viscosity of the dye was taken to be $4.7\text{x}10^{-5}$ m^2/s. The Reynolds number when the drop broke up was then calculated as

$$Re = \frac{0.05\frac{m}{s} * 0.001\ m}{4.7 * 10^{-5} m^2/s} = 1.064$$

This fits with the condition that instability occurs at Re>1. Since the calculated Re is very close to 1 this could explain the smaller number of secondary blobs since the number of instability blobs formed increases with Re (Bosse et al. 2005).

4.0 Photographic Technique

A Nikon D5100 SLR 16.2 MP camera was utilized for this photograph. The 18-52 mm lens was used along with a 52 mm 4xclose-up filter in order to get a clearer close up photograph. The field of view of the photograph was roughly 5" x 4" and the camera was placed roughly 5" from the front of the tank. The focus mode was set to manual with a focal length of 24 mm. Aperture was set to F/22 with the camera exposure mode set to aperture priority. The shutter speed was 1/640s and the ISO was 1600. Figure 4.1 shows the before and after gimp processing photograph. Post processing in gimp included increasing the brightness to 30 and contrast to 80 along with cropping out unwanted area.

Figure 4.1 Pre and Post Processing Photograph

5.0 Conclusion

This image shows the different transitions of the flow of a fluid drop of greater density settling in a fluid of lesser density. All regions of Reynolds number can be observed from the low Re number streaks, the Re=1 torus, and the Re>1 breakup instability. The biggest issue with this assignment was figuring out what settings to use to get the clearest picture. Although the picture is relatively clear I believe this is an area that can be improved on for future assignments that require close-up shots. A picture that showed the different transition points in different colors, i.e. a red drop leaving a trail, a green drop forming a torus, and a blue drop with instabilities would be nice aesthetically and show the different stages separately.

6.0 References

1. T. Bosse, L. Kleiser, C. Hartel, and E. Meiburg, “Numerical simulation of finite Reynolds number suspension drops settling under gravity,” Physics of Fluids 17, 037101 (2005).

2. H. Meng, J. Estevadeordal, S. Gogineni, L. Goss, and W.M. Roquemore, “Holographic Flow Visualization as a Tool for Studying Three-dimensional Coherent Structures and Instabilities,” Journal of Visualization, Vol. 1, No. 2 (1998).