Group Project 3

Joseph Eisinger
Flow Visualization Group Assignment 3

May 3, 2010

My intention for this assignment was to explore the visualization of different-density flow. Our group could not match our schedules during the last week of school to work together, so I did this project individually. I wanted to produce an image showing a flow of bubbles in water. I am pleased with the image I produced and the flow physics apparent in it.

The phenomena seen in my image is that of air bubbles streaming up through water. To create this, I submerged an effervescent tablet underneath a funnel inside a vase of water, as seen in Figure 0.1. The shutter speed of the camera was long, so the bubbles appear as streaks as they float up through the water. The streaks seen in the picture illustrate path lines, the paths taken of individual fluid particles. The speed of the bubbles in the water is approximately 10 cm/s. I determined this by measuring the distance that one bubble moved, 1150 pixels, in the amount of time that the shutter was open, 0.25 seconds. The straw diameter is 270 pixels, which corresponds to 7 mm. This means the bubble moved 30mm in 0.25 seconds, which is 12 cm/s. I estimated the size of the bubbles to be 0.6 mm in diameter. The Reynolds number of this flow can then be calculated as:

$$Re = \frac{V \cdot L}{\nu} = \frac{0.12(m/s) \cdot 7(mm)}{1.004E-6(m^2/s)} = 830$$

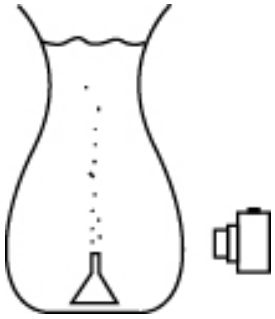

Figure 0.1: Sketch of flow apparatus.

This low Reynolds number suggests that the flow would be moving very steadily and laminar. However, as the photograph shows, the flow stream seems to be moving a bit chaotically. This is due to the fact that the flow is unstable, since a less dense fluid is flowing through a more dense fluid[6]. This is a form of Rayleigh-Taylor instability, though it does not show some of the characteristics of Rayleigh-Taylor instability such as mushroom clouds and well resolved vorticity at the boundaries[4]. The reason for this is the magnitude of buoyancy of the bubbles; they are rising to the surface of the water faster than their paths can be significantly manipulated by

shear stress imposed by the water at the boundary of their path. Also, the bubbles moving up are entraining water and causing it to flow upward as well, decreasing the effect of differential velocities at the boundary[1].

The forces on the bubbles causing them to rise is determined by the difference in density of the two fluids, and the size of the bubbles[5]. The bubbles have three major forces contributing to their vertical motion.

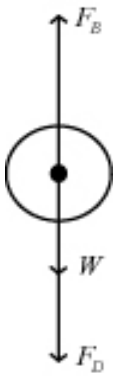

Figure 0.2: Bubble Free Body Diagram.

The buoyancy force is pushing the bubbles up. This is equal to the weight of the water that they displace, $F_B = V_B \rho_w g$. Next, the bubbles' own weight is holding them down, $W = V_B \rho_a g$. Additionally, there is a drag force on the bubbles, $F_D = \frac{1}{2}\rho_w v^2 C_D A$. Summing these forces and solving for the velocity gives [5, 3, 2]:

$$v = \sqrt{\frac{8rg(\rho_a - \rho_w)}{3\rho_w C_D}} = \sqrt{\frac{8 \cdot 0.0003(m) \cdot 9.81(m/s) \cdot (1.189(kg/m^3) - 997(kg/m^3))}{3 \cdot 0.47 \cdot 997(kg/m^3)}} = 13cm/s$$

This is very close to the bubble speed determined photographically.

The visualization of this flow is mostly by refraction and reflection. The lighting in this picture is just ambient indoor lighting. Photons entered the vase from all directions and were reflected off of the bubbles and sent toward the camera. Also, some photons were bent at the air-water interface of the bubbles and directed toward the camera.

The photographic technique that I used was fairly straightforward. The brown color in the background of the picture comes from the hardwood floors that the vase was on when I took the picture. It was difficult to get the image framed correctly and not have reflections or glare on the surface of the vase; I took the photograph with a dark background behind me, to minimize glare. The shutter speed of the camera

was slow, so the bubbles had significant movement during exposure and my image is not well time resolved.

The size of the field of view of this image is approximately 45 cm^2. The distance from the lens to the object was approximately 15 cm, and the focal length was 4.4 mm. The type of camera that I used was a 10 MP digital camera, Panasonic DMC-FX500. The original image file was 3648 x 2736 pixels, and the final image is 2136 x 3295 pixels. The exposure specifications were shutter speed of 0.25 seconds, ISO 100, and F number 2.8. I processed the image slightly in Photoshop, cropping the image and then increasing contrast, and brightness.

This image reveals the flow physics of small air bubbles rising up through water. I am very pleased with the phenomena seen; I intended to capture an image showing bubble flow. I am pleased with the quality of the photograph; I think that the bubbles are in good focus. I like that the image looks hairy, and the contrast with the brown background. Overall, I am pleased that I produced an original flow with some interesting qualities.

Bibliography

[1] Cohen, Ira M., and Pijush K. Kundu. Fluid Mechanics, Fourth Edition. New York: Academic, 2007. Print.

[2] "Density - Wikipedia, the Free Encyclopedia." Main Page - Wikipedia, the Free Encyclopedia. Web. 19 Apr. 2010. <http://en.wikipedia.org/wiki/Density>.

[3] "Drag Coefficient - Wikipedia, the Free Encyclopedia." Main Page - Wikipedia, the Free Encyclopedia. Web. 19 Apr. 2010. <http://en.wikipedia.org/wiki/Drag_coefficient>.

[4] "Rayleigh-Taylor Instability - Wikipedia, the Free Encyclopedia." Main Page - Wikipedia, the Free Encyclopedia. Web. 19 Apr. 2010. <http://en.wikipedia.org/wiki/Rayleigh%E2%80%93Taylor_instability>.

[5] White, Frank. Fluid Mechanics. McGraw-Hill Science Engineering, 2006. Print.

[6] Yang, Wen-Jei. Handbook of Flow Visualization. New York: Taylor & Francis, 2001. Print.