Get Wet!

Joseph Eisinger
Flow Visualization Assignment 1

February 8, 2010

The purpose of this assignment was to introduce myself to the art and science of flow visualization. I was not constrained any further than to produce an image involving a fluid of some kind. My intention for this assignment was to explore what types of flows or fluid phenomena can be produced, and with what techniques. I also wanted to start to familiarize myself with photographing flows, and the difficulties therein. After seeing what other students have produced in the past, I wanted to contribute something unique. I am pleased with the image and the flow physics apparent in it.

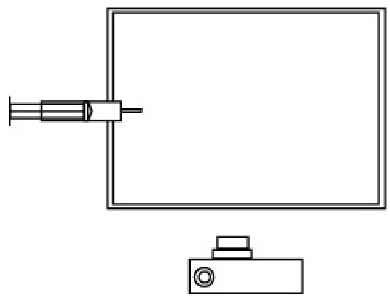

Figure 0.1: Sketch of flow apparatus.

The flow shown in my image is that of a free jet of dye being ejected from a syringe into a tub of water as seen in Figure 0.1. The syringe used had an exit hole of approximately 1 mm^2. The dye was ejected at a speed of about 25 cm/s and the length scale of the image is about 10 cm. Based on the size of the syringe exit hole, the Reynolds number of the flow, defined as:

$$Re = \frac{V \cdot L}{\nu}$$

just at the exit is approximately 250. The basin of water in which the flow was photographed was about 30 cm by 20 cm. The jet of dye is water with food coloring, so the properties of both fluids can be considered the same. The flow phenomena seen are due to the difference in velocities of the fluids. As I pushed on the syringe, I added pressure to the flow of dye which moved down the pressure gradient to the basin just outside of the syringe. Once the dyed water has exited the syringe, there is no longer a pressure gradient and the flow continues due to its momentum. The flow is eventually slowed down due to the friction of the water through which it is moving, which is a function of its viscosity. In the image one can see the transition from laminar flow just outside of the syringe to turbulent flow in the plume of dye. The turbulent flow does not seem to be due a high Reynold's number since it is so small in this flow, but rather because the flow breaks down from laminar to turbulent due to instabilities at the boundaries of the flow.

Also apparent in the photograph is the vorticity at the boundaries of the two fluids and the jet-column instability. The initial oscillatory behavior seen in the jet of fluid is due to the instability of the flow. This shear layer instability is caused by the shear stress on the fluid particles at the boundary due to the difference in velocity between the fluids[4]. The frequency of the vortex shedding seen is a function of the Strouhal number, and is defined as

$$S = \frac{n \cdot d}{V}$$

where n is the frequency, d is the diameter of the flow, and V is the velocity of the flow[1]. I calculated the frequency in the flow to be 1.25 Hz which gives a Strouhal number of 0.005. This is characterizes the flow and the oscillations seen as due to the rapid buildup and discharge of vortices[7]. The instability seen further down in the flow, at the boundary between the two flows, is known as Kelvin-Helmholtz instability [3]. Although Kelvin-Helmholtz instability is commonly observed at the boundary of stratified, different-density flows, this is not a requirement of Kelvin-Helmholtz instability [2]. This instability is observed under certain conditions, which can be predicted using the Richardson number [6]. The Richardson number describes the ratio of buoyancy forces to inertial forces and is written as:

$$Ri = \frac{g \cdot L}{V^2}$$

where g is acceleration due to gravity, L is a length scale, and V is the velocity of the flow [5]. The flow is guaranteed to be stable if the Richardson number is greater than 0.25 everywhere in the flow, but is not necessarily unstable for $Ri < 0.25$ [1]. The Richardson number for the flow in my picture is approximately 0.15, which corresponds to the instability seen in the flow.

The visualization technique that I used for this photograph was a red dye. The dye that I used was food coloring, three drops per 25 mL water. The syringe that I used was designed for cleaning one's mouth after having teeth pulled; it had a very small exit hole. The lighting in the photo is natural lighting. I was outside in the shade of a tree when the picture was taken, to maximize light, but minimize glare on the surface of the water. The light coming to the lens of the camera came from the image which was recorded. This light in turn originated from the sun, and after a series of interaction with matter, made it to the camera. The white background in the image is seen in the way it is because light was incident on the surface of the water, was refracted at the interface, was transmitted through the water to the white paper at the bottom of the water basin. At this junction, some light was absorbed, and some was reflected diffusely and continued to be transmitted through the water, was refracted again at the interface of the water and air, and then was transmitted through the air to the camera. Similarly, the red seen in the image travels the same path as the white, but instead of all of the light being reflected off of the white background, all but the red light is absorbed by the red dye, while the red light is diffusely reflected back towards the camera. Of course some of the red light is absorbed, and some is reflected onto other red particles before eventually heading out of the water toward the camera.

The photographic technique that I used was very simple and straight forward. I took the picture outside so that I would have the most light that I could. I took the picture in the shade so that I would minimize glare on the surface of the water. The size of the field of view of the original image was approximately 200 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 1180 x 702 pixels. The exposure specifications were shutter speed of 1/200 seconds, ISO 100, and F number 2.8. I processed the image slightly in Photoshop, cropping the image and then increasing contrast and red hue.

This image reveals the flow physics of a free jet into a similar medium as the jet. I am very pleased with the phenomena seen, I intended to capture an image showing some sort of instability and/or vorticity. I am not as pleased with the quality of the photograph, I had a very hard time getting the image in focus, and getting enough light so that the image was crisp. I had a hard time getting the right exposure, and am disappointed that the image looks so grainy when cropped to size. In the future, I would like to improve on my photographic technique, and be sure to have enough light. 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] Danforth, Charles. "Kelvin-Helmholtz Instability." CASA. University of Colorado at Boulder, 24 Mar. 1999. Web. 25 Jan. 2010. <http://casa.colorado.edu/~danforth/science/cloudshock/node5.html>.

[3] "Kelvin–Helmholtz instability." Wikipedia, the free encyclopedia. Web. 25 Jan. 2010. <http://en.wikipedia.org/wiki/Kelvin%E2%80%93Helmholtz_instability>.

[4] Merzkirch, Wolfgang. Flow visualization. Orlando: Academic, 1987. Print.

[5] "Richardson Number – from Eric Weisstein's World of Physics." ScienceWorld. Web. 25 Jan. 2010. <http://scienceworld.wolfram.com/physics/RichardsonNumber.html>.

[6] "Richardson number." Wikipedia, the free encyclopedia. Web. 25 Jan. 2010. <http://en.wikipedia.org/wiki/Richardson_number>.

[7] "Strouhal Number." Wikipedia, the free encyclopedia. Web. 03 Feb. 2010. <http://en.wikipedia.org/wiki/Strouhal_number>.