DYE-FLOW VISUALIZATION IN A WATER CHANNEL

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ABSTRACT

In this lab we performed experiments in a water tunnel to visually record the behavior and development of flow structures with high clarity and contrast through the method of dye visualization. Dye visualization is a cheap and less time-consuming method that can produce three-dimensional test results that accurately predicts the real-world performance of an object through a fluid. Thus, in this lab we used a neutrally buoyant dye, that is a dye that faithfully follows the flow dynamics of a fluid, to capture the behavior of a fluid as it interacts with a solid body.

INTRODUCTION

Flow visualization, is an experimental technique utilized widely in fluid dynamics to make flow patterns visible, in order to obtain qualitative information on them, namely defining the effectiveness of specific shapes in shifting the flow of a free-stream fluid. Typical applications include airfoils, auto-body shapes and correction points between pipes. Determining the exact reaction through of a particular shape is not easily defined through expository and analytical techniques, hence testing specific shapes under explicit conditions creates opportunities for subsistence scaling. The conditions are not consistently scalable, so a dimensionless similarity parameter, known as the Reynolds number, is introduced, which is the ration of the inertial to viscous forces.

$$Re = \frac{\rho V L}{\mu} = \frac{VL}{\nu} \tag{1}$$

Where ρ is the density $\left(\frac{kg}{m^3}\right)$, V is the velocity (m/s), μ is the dynamic viscosity $\left(\frac{kg}{m\,.\,s}\right)$, ν is the kinematic viscosity $\left(\frac{m^2}{s}\right)$ of the fluid, and L is the characteristic length of the body (m). The characteristic length, L, for an airfoil is taken to be the chord length, c, and for a cylinder and sphere the characteristic length is taken to be the diameter, D. Determining Reynold number is particularly important because it effectively defines the flow parameters under which different patterns of flow exist.

In Laminar flow, these patterns could usually be characterized using streamlines, streak-lines and pathlines. Streamlines are lines whose tangents are ubiquitously parallel to the velocity vector, a streak-line is a line traced out by a neutrally buoyant marker fluid that is continuously introduced into a flow field at a fixed point in space, and a pathline is a line that traced out in time by a given particle as it flows. Notably, in steady flow, the position of streamline, streak-line and pathline coincide. To visualize the flow patterns in the water tunnel, a neutrally buoyant (specific gravity $\approx$ 1) colored-dye marker fluid is introduced into the flow through dye injection ports, creating streak-lines that are then disturbed by the shape of the bluff body. In addition, it is essential for the fluid marker to be neutrally buoyant to ensure the marker does not disturb the flow with its own gravity driven motion.

The colored-dye marker fluid is introduced into the flow of the water tunnel using a gravity-fed dye system conforming to Bernoulli's equations as follows:

$$P_1 + \frac{1}{2}\rho V_1^2 + \rho g h_1 = P_2 + \frac{1}{2}\rho V_2^2 + \rho g h_2 \tag{2}$$

Where P is the pressure and h is the depth of the water. The dye-reservoirs are held at a height above the flow channel, meaning that there is a potential difference between the top and the bottom of the dye tubes. Also, the pressure of the flow near the exit of the dye injection location depends on the freestream velocity, the depth of the water and the relative location of the port with respect to the body. While infusing the colored-dye marker fluid in the flow, it is impossible to match the exact velocity of the flow in every location where the dye is introduced. Therefore, the difference in velocity between the infused dye marker and the flow generates jets, which implies the presence of faster fluid velocity within the flow. The velocity gradient within the flow generates shear stress, which in turn contributes to the vorticity.

$$\tau_{xy} = \mu \frac{\partial u}{\partial y} \tag{3}$$

$$\overrightarrow{\omega} = \overrightarrow{\nabla} \times \overrightarrow{u} \tag{4}$$

METHOD

We conducted our experiments in a closed-circuit water channel (see figure 1) with an acrylic test section of 15.24 *cm* x 30.48 *cm* (see figure 2). The test section suspends different shaped foils by a circular panel on the rear of the face channel. The pump connected near the bottom of the channel controls the fluid flow, and the gravity-feed dye system attached to the top of the channel (see figure 3) feeds dye to mark the streak-lines around the body.

Figure 1: Closed Circuit Water Channel

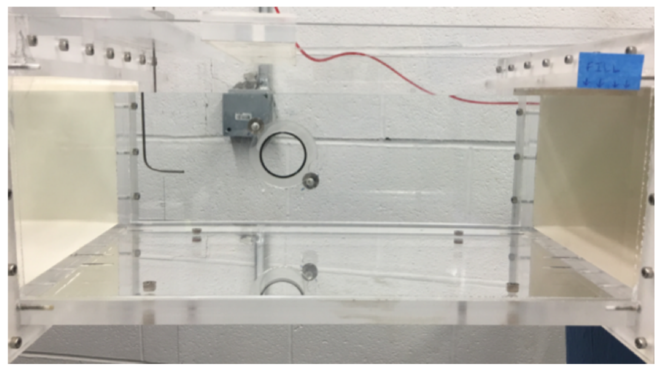

Figure 2: Acrylic test section

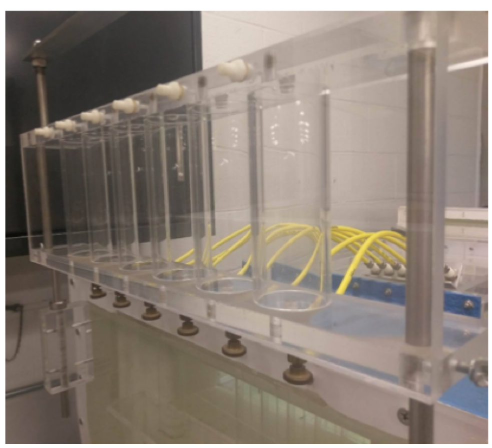

Figure 3: Dye Reservoirs Of The Gravity System

Preparing the closed circuit water channel

1. A plug always has to be installed into the rear of the acrylic test section before filling the test section.
2. Begin by removing the acrylic plug and install the airfoil. **BE CAREFUL WITH THE ACRYLIC WING, IT CHIPS VERY EASILY. MAKE SURE THAT IT DOES NOT HIT THE TEST SECTION AS YOU INSTALL IT.**
3. To prevent leaks, ensure that the o-ring seal has been fully engaged and the peg on the end of the wing is situated properly.
4. Once the model is set up, you can adjust the angle of attack. The leading edge should be opposed to the direction of flow.

Filing the flow channel with water

1. To fill the flow channel, first ensure that the large red valve leading to the drain is closed and the valve near the pump where the hose connects to the channel is open (see figure 4).
2. Next find the water filter mounted on the wall and open the blue valve next to it to begin filling.
3. Fill the channel as close to the fill line as possible.

Powering the channel

Refer to the figure below, it is self-explanatory.

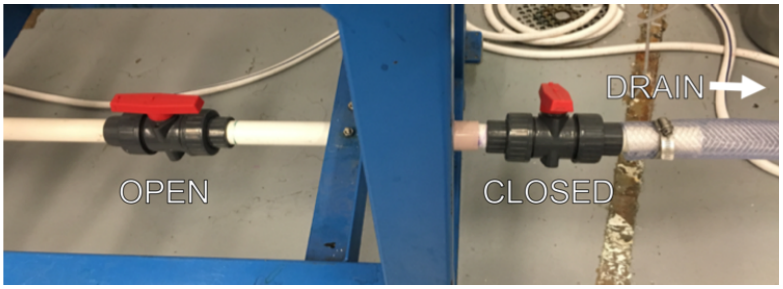

Figure 4: Water Channel Valve Schematic

1. **DO NOT TURN ON THE PUMP WITHOUT WATER IN THE SYSTEM**

2. Ensure both the electrical plugs for the flow channel are plugged in, click on the power strip on the top o the flow channel, and turn the "MAIN POWER" switch, located on the water channel under the test section, clockwise to "on" (see figure below for clarification).

Figure 5: Power Sources

Priming the dye lines.

The dye system is a gravity fed system, meaning that it builds more pressure the higher the reservoirs are located. The air in the lines, however, wants to rise up creating an opposing pressure. If there are air bubbles in the lines, they will hamper the dye from flowing smoothly. Therefore, we need to remove the air from the lines. To that end:

1. Fill a small syringe with water from the water channel and insert the syringe into the bottom of the line. Plunge the syringe so that water flows up the lines, expelling the air bubbles, until you see water beginning to flow in the reservoir; then clamp the line with a hose clamp as close to the syringe as you can (this prevents the water flowing back out).
2. You should repeat step 1 for one more dye reservoir, and also purge the internal channels in the models.

Changing Models

Once you have completed your experiment and wishes to switch models, drain the water channel so that the water line is below the hole for the model mount.

Remove the wing model (**CAREFULLY**), then insert the cylinder model. Make sure that the peg seats properly in the hole, then seal the hole, and fill the test section.

Preparing Dye

Neutrally buoyant dye consists of three components: milk, isopropyl alcohol (IPA), and Food coloring. Milk provides opacity to the color and allows the mixture to bond. This bond produces a more comprehensive structure that diffuses slowly in water rather than food coloring alone; food coloring on the other hand allows for better visualization of the flow; and isopropyl alcohol (IPA) maintains the neutral buoyancy of the mixture on average. Notably, we determined the correct mixture of these three fluids using a dye mixture calculator provided to us.

Conducting Test

The water channel is controlled with a controller mounted on its side. The input is the frequency of the motor, and the second display, on the right, indicates the volumetric rate in Gal/min (see figure 6).

Figure 6: Pump Frequency Controller (Left) And Volume Flow Display (Right)

Procedures

1. Using a calculator, enter your measured water height and adjust the flow speed cell until you get an appropriate corresponding Reynolds number.
2. To get a desired flow rate, adjust the pump frequency.
3. Use the flow rate from the meter to record the Reynolds number for each test.

4. To adjust the Ange of attack, loosen the two screws holding the model and then rotate it.
5. Open dye valve at the bottom of the reservoir slightly, and insure that the dye doesn't jet.
6. When using the dye rake, be sure to adjust to the height and angle of the rakes as necessary.
7. Record the data by capturing a 10-20 seconds video for each case.
8. Turn off the valve below the reservoir before setting up for the next case.

RESULTS

The following images displays different flow characteristics and features.

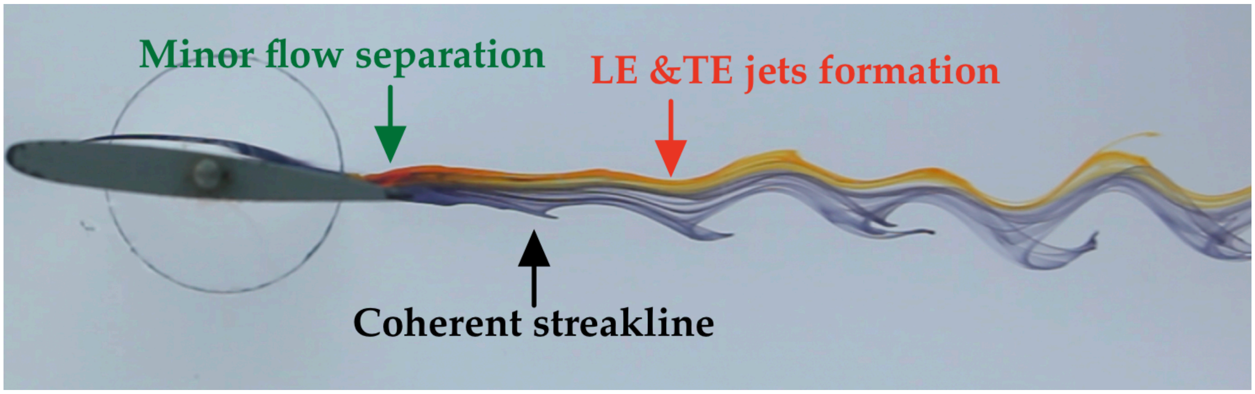

Figure 7: Flow over a low angle airfoil at Re>800 and the different flow characteristics on display.

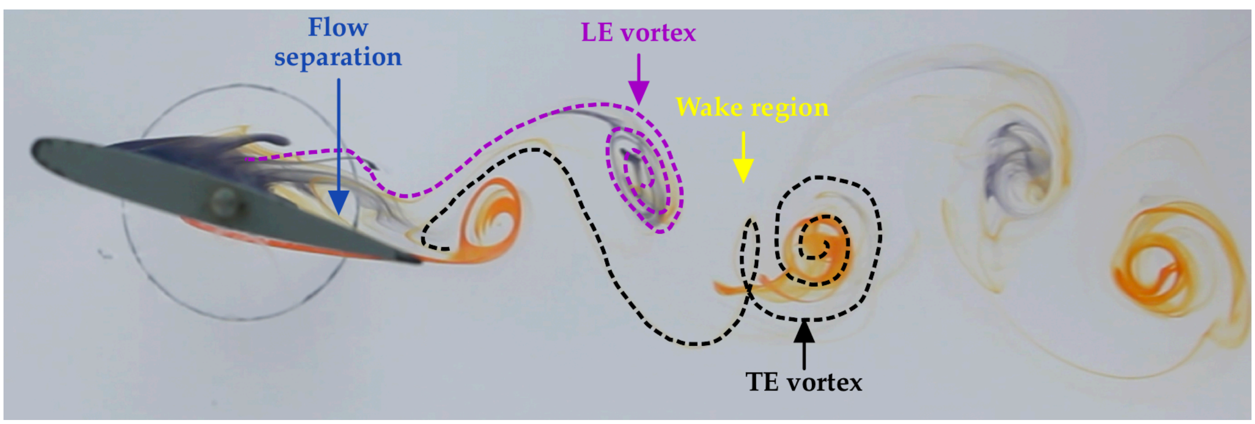

Figure 8: Flow over an airfoil at a high angle of attack and the different flow characteristics on display

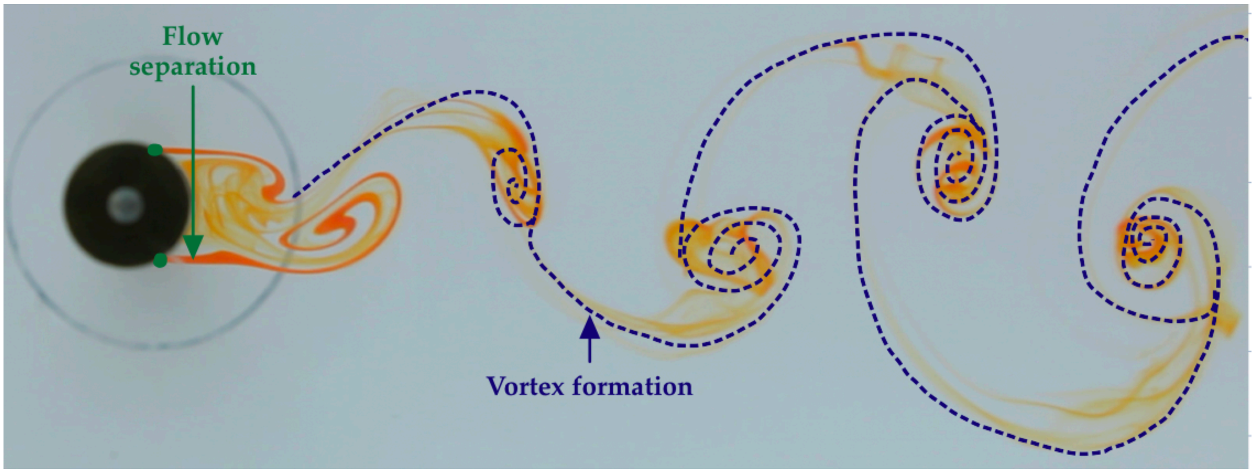

Figure 9: Flow over a cylinder and the different flow characteristics on display

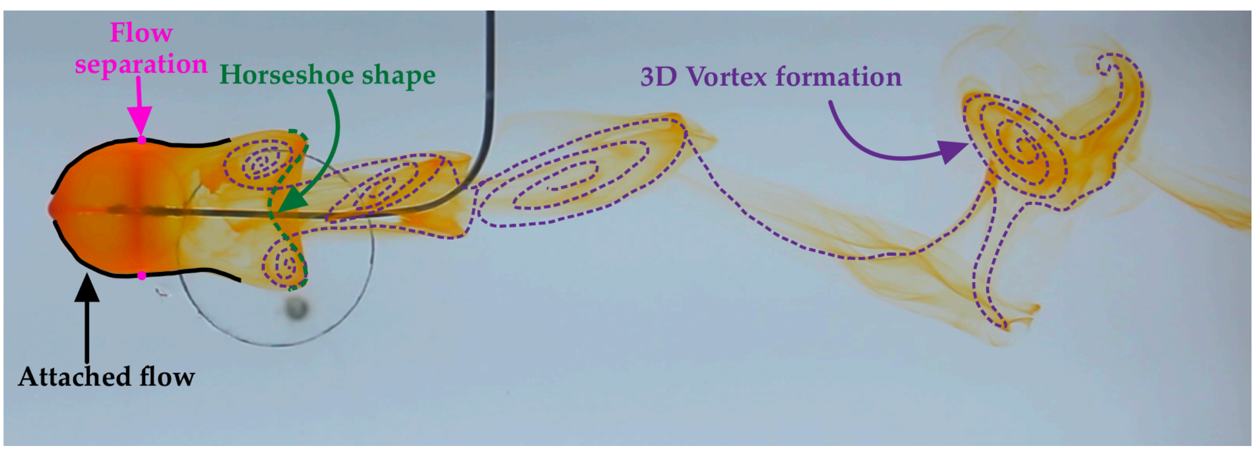

Figure 10: Flow over a sphere and the different flow characteristics on display

DISCUSSION

1. ***Airfoil***

   From figure 7, we observe that our airfoil doesn't seem to be deflecting the flow very much, evident by the almost non-existent flow separation occurring behind the airfoil. Also, as we increase the Reynolds number to Re>800, we can see the streak-line becoming more coherent and more jets subsequently forming down the flow. The two directions of the jets give us lift and drag.

   From figure 8, we observe that as we increase the angle of attack of the airfoil the flow separation increases which in turn leads to the formation of oscillating vortices in the wake region of the airfoil, which marks a greater generation of lift.

2. ***Cylinder***

   From figure 9, due to boundary flow separation which is brought about by the viscous effect within the boundary layer, we can observe oscillating vortices being shed off the trailing edge of the cylinder generating drag. Also, the average velocity of the flow is directly upstream.

3. ***Sphere***

   From figure 10, we can observe the formation of a full 3D ring forming all around the sphere, and this rings eventually grows until it reaches a size that the sphere can no longer feed, then the sphere ejects the ring similar to the vortices shading on the cylinder. Also, we can see that when the ring it is ejected, next ring starts to form and the moment where two rings seem to be touching is that horseshoe shape, from which the rings are connected continuously into a chain. Henceforth, we are witnessing the process of three-dimensional vortex shading, where we have vortices forming all around the body. In addition, the force on the body will follow the vortices which for a 3D shape will end up moving all around the body, which explains why 3D object cannot travel straight in a fluid.

CONCLUSION

Dye visualization is an important technique that aids engineers envision the characteristics and effects of fluid passing through a solid body. Therefore, in this experiment we were able to visualize the flow with great success, which gave us great insight on the importance of the Reynolds number and the Angle of Attack of a body moving past a fluid. It also gave us an insight into the generation of forces such as lift and drag on body traveling in a fluid. Finally, it gave us an intuition and admiration of the vortex shading phenomenon, especially the 3D kind. By and large, this experiment significantly increased our knowledge pertaining to the behavior of fluids.

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