Group Project 1: Fluid Flow in a Flume

Shweta Maurya

Supporting Team Members: Alex Meyer, Jeffrey Pilkington, & Dillon Thorse

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Purpose

Flow Visualization, an intersection of art and physics, is also an intersection of ideas. In this report, the product of a collaborative process will be examined in the first group project assignment. The purpose of this experiment is to visualize the flow of fluid over a hydrofoil and analyze the dynamics of this fluid based on its conditions. The intent of this experiment was to see how the speed of the water and angle of the foil affect the point at which flow turned from laminar to chaotic. In order to perform this experiment, the group chose to use a flume and foil, wherein water flowed through the flume and around the foil. The flow was accentuated with the use of dye coloring.

Visualization Technique

This experiment required various materials in order to be executed:

- Flume (ITLL)
- Water (ITLL)
- Acrylic and glue for the hydrofoil (ITLL)
- I.V. Bag (donated)
- White cloth or paper (household)
- Fabric dye (household)
- 2 500W lights (Alex Meyer)
- 1 camera

With the use of the aforementioned items, the experiment can be conducted. The air foil was created by Dillon Thorse with acrylic and glue by using the laser machine in the ITLL basement. Slices of the foil were glued together and dried overnight. On the experimentation day, the flume was turned on to allow for fluid flow. A weir was placed towards the end of the flume to increase the height of the water in the flume and reduce the rate at which it drained from the flume canal. A white cloth was hung up on the back-side of the glass wall of the flume to provide a uniform background for the fluid analysis. The foil was wedged into the flume canal until it was secure and at an appropriate height for the water to flow above and below it. An IV bag was hung from a metal pole above the flume, and an IV needle was used to expel the diluted fabric dye and water mixture into the canal. Team member Jeff Pilkington held the needle in the appropriate location in front of the foil and controlled the flow of the dye. The 2 500 Watt lights were placed on a table on the other side of the flume, and at a height about 1 ft below the flume; these lights were angled to point upwards through the side of the flume so that the light shone through the white cloth and illuminated the flume. Team member Alex Meyer’s camera was set up on a tripod on the other side of the flume, facing the hydrofoil and ready to capture images. Additional lighting was minimized by turning off some of the lights in the ITLL basement and removing the flash on the camera. The figure below shows the experimental set-up from a distance.

Approach

A view of the experiment can be seen in the schematic shown below.

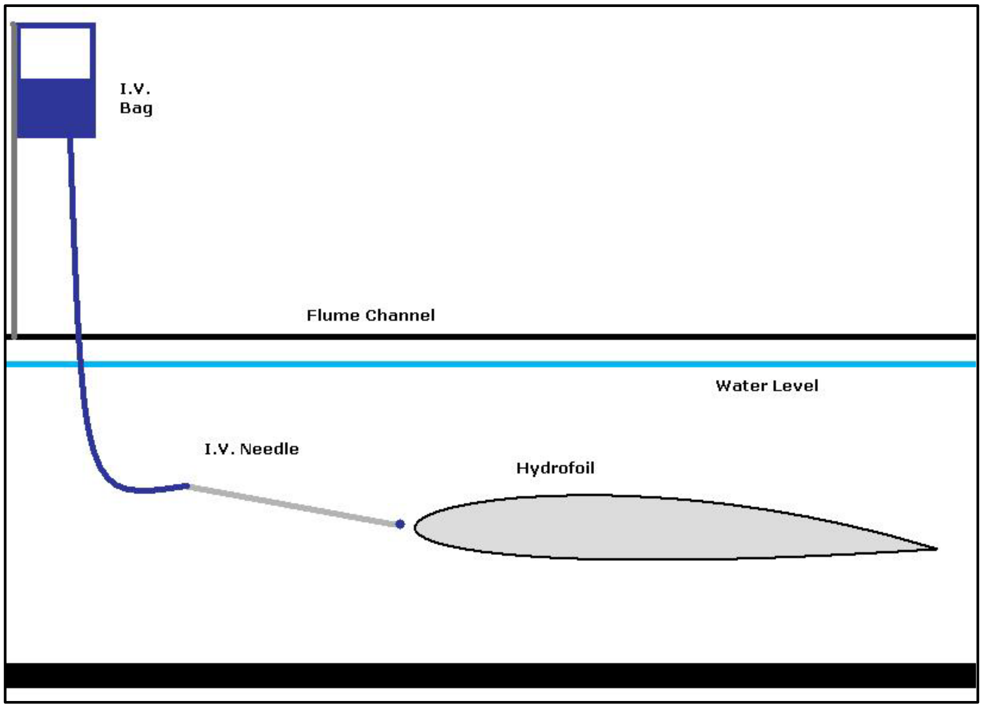

Figure 1. Experimental Schematic

In this experiment, there are some critical components that need to be calculated in order to understand the fluid flow. First, the velocity of the water in the flume channel will be calculated. This can be done by calculating the cross sectional area of the water in the flume and a measurement of the volumetric flow rate of the water. The volumetric flow rate was calculated by draining the container at the end of the flume and timing it while measuring a volume change. As such, the fluid velocity was determined using the following equation:

$$Q = VA$$

The values of Q and A were determined in order to solve for V, the velocity.

Cross-Sectional Area: A = 0.011745 m^2
Volumetric Flow Rate: Q = 0.00268 m^3/s

$$V = \frac{Q}{A} = 0.22818\, m/s$$

The primary equation used to indicate the type of flow occurring is called the Reynold's Number equation. The Reynold's Number is a measure of the amount which a fluid is opposing motion versus the viscosity of the fluid. If this ratio is above 2000, the flow can be characterized as turbulent. The equation is shown below:

$$Re = \frac{\rho V L}{\mu}$$

Where ρ is the density of the dye, V is the velocity of the dye in water, L is the diameter of the initial dye drop, and μ is the dynamic viscosity of the water. All values have been listed below in fluid properties.

Density of diluted dye (approximated to water): $\rho = 1000\ kg/m^3$ [3]
Dynamic viscosity of water: $\mu = 1.002 \times 10^{-3}$ Pa*s
Diameter of the dye drop before release: L = 0.0047625m
Velocity of the dye in water: V = 0.22818 m/s

With these values known, the Reynold's Number can be solved.

$$Re = \frac{\left(1000\frac{kg}{m^3}\right)\left(0.22818\frac{m}{s}\right)(0.0047625m)}{(1.002x10^{-3}Pa\cdot s)} = 1084.538$$

As stated earlier, this value needed to exceed 2000 in order to be characterized as turbulent flow. Because the Reynold's Number is 1084, it the interaction between the food dye and water is laminar.

One of the major intents of this experiment was to show how, when changing the angle at which a foil is oriented (angle of attack), the flow over the foil can change from laminar to chaotic and even show vortices. The point at which this shift occurs is called the separation point. For this particular set-up, the angle of attack was set to be 5˚. In the original image below, the separation point can be seen right after the highest point on the hump of the foil.

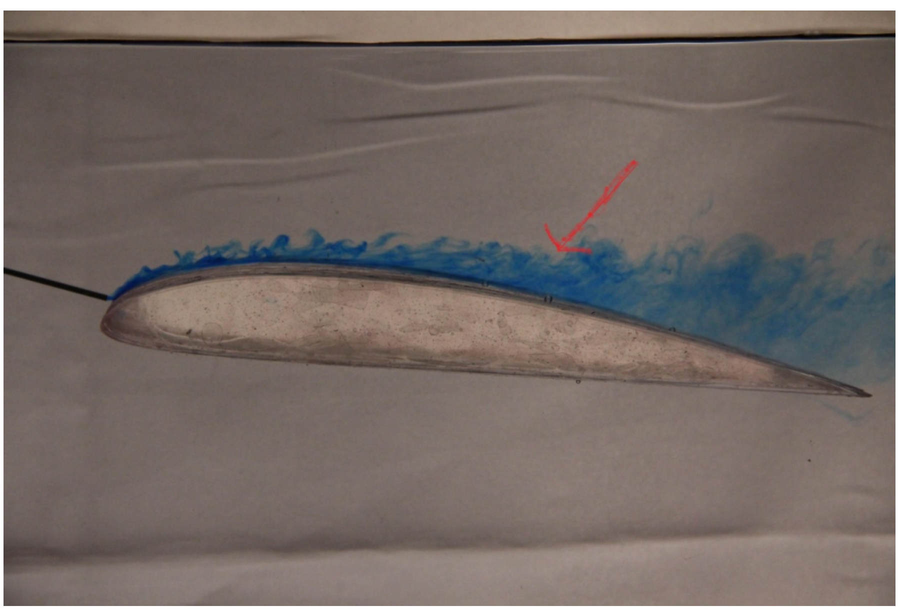

Figure 2. Separation Point

In order to see this separation, it is important for the flow to be laminar, which is accomplished by the experimental design. In a new iteration, it may be interesting to see the foil at a greater angle of attack in order to exaggerate the separation point.

Photographic Technique

The digital camera used in this experiment is a Canon EOS 60D DSLR with EF-S 18-135 zoom lens. The size of the field of view is about 10in wide and 8in tall, while the distance from the camera to the glass wall of the flume is a little more than 1ft. The focal length is 75mm and 118mm in 35mm film. The original pixel dimensions of the image are 5184 x 3456, while the edited and cropped image dimensions are 4708 x 1172 in order to emphasize the focus on the foil rather than its surroundings. Because the final image was capture during the second day of shooting and experimentation, the water at this point was beginning to have slight blue and purple tinges to it due to previous dye used. As a result, the ISO was changed to 2500 in order to bring out the white and color contrast and remove the blue and purple tint in the water. Additionally, it was important to capture the image in time to see the fluid dynamics, since the flow was turbulent, resulting in certain exposure specifications. The exposure time was 0.0005sec, while the aperture and F number are 5.38 and f/6.3 respectively. Once the original image was imported into Picasa, major edits were made. An artistic choice was made to make the fluid flow of dye look like flames of fire. The intention behind the editing was to create a somewhat deceptive and layered image with striking colors. First, the image was cropped in order to focus more narrowly on the foil itself. After this, through trial and error, the photo processing steps were established. The photo was lightened and then the contrast was increased. This made the colors more vivid and boundaries more defined. Finally, the colors were inverted. This final touch allowed the dye flow to look like fire over the hydrofoil. The following histograms show how the color spread changed before and after editing.

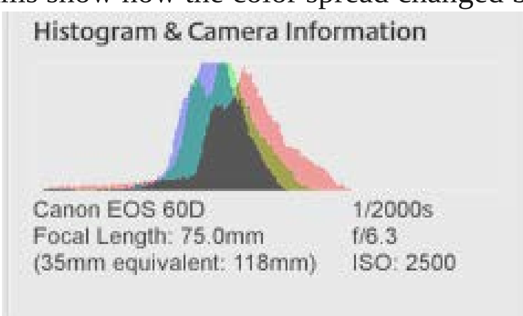

Figure 3. Original Histogram

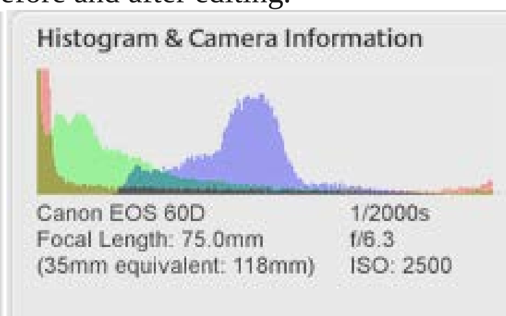

Figure 4. Final Histogram

When the original image was chosen after two days of experimentation and shooting, the original intention was to demonstrate how liquid fluid flow can be physically similar to gaseous fluid flow by editing the dye so that it looked like fire. The images below demonstrate this comparison between the original and edited images.

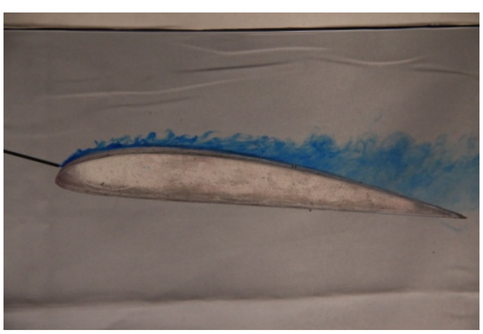

Figure 5. Original Image

Figure 6. Final Image

Conclusion

One of the major feedback points given by peers was that the image looked somewhat pixilated and grainy. Often times, a grainy and textured quality to an image can add to its mood. However, this was not the intention of this image, and thus, the grainy and pixilated quality detracted from the effectiveness of the image. In the future, the editing would be done differently during the contrast step so that the pixilation would not occur so heavily. Some additional comments stipulated that the foil seemed noisy instead of smooth; this is a product of the clear glue used to join the slices of the foil together; as such, a future experiment could utilize a foil of the appropriate thickness so that glue is not necessary. Ultimately, this image is striking and somewhat deceptive due to its editing. Because the original scientific intent was to demonstrate the separation point on a foil and the resulting vortices, this was somewhat demonstrated with the image. Perhaps a slower velocity of water and higher volume of dye could help in demonstrating the phenomenon. The original artistic intent of the project was to produce a deceptive image; the fire-like fluid flow is successful in doing this. Overall, this experiment was useful in observing an important phenomenon seen in different mediums.

Works Referenced

http://edge.rit.edu/content/P12463/public/CFD%20of%20Flow%20Over%20Hydrofoil

http://petroleum.mines.edu/faculty/JFM%202005.pdf

http://quest.nasa.gov/aero/planetary/atmospheric/aerodynamiclift.html

http://web.mit.edu/2.972/www/reports/hydrofoil/hydrofoil.html