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Team Assignment 1
Flow Visualization
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Departing the Wing

Background:

This image was taken for the first team image in flow visualization. The goal was to use the skills of each team member to design and execute an experimental setup that yielded a good photo of fluid flow. The final goal was to capture fluid flow over an airfoil. The team initially attempted to do this using air moving with a fan and cigarette smoke to mark the fluid streamlines. It was not possible to get the smoke from the cigarettes to make appropriate streamlines so we decided to use the flume in the ITLL. The members who contributed to the image were Dillon Thorse, Alex Meyer, and Shweta Maurya. Each team member had a different role in contributing to the image. Dillon fabricated the airfoil with the ITLL laser cutter. Alex was the primary photographer and brought utility lights. Shweta recorded flow data and I positioned the wing and applied dye streams. Each member equally contributed to the image.

Experiment Setup:

The image was taken in the open channel water flume in the ITLL at the University of Colorado at Boulder. The flume bed is 2.5m x 76mm x 250mm. At the water entrance, a jack system can adjust the slope of the channel between 1%-3%. For this experiment the channel pitch was at 1%. A Clark Y airfoil was made using the laser cutter. Identical wing profiles were cut using the laser cutter and adhered together to create an airfoil that spanned the width of the channel (76 mm). The airfoil was positioned one meter from the inlet tank. A sharp crested weir was used to increase the depth of water in the channel. The weir was placed one meter from the discharge tank. The airfoil was placed a sufficient distance from the inlet tank and the weir so that the flow was not affected. The water enters the inlet tank from the beneath the flume, the tank has marbles to reduce the turbulence of the water in the flume channel. A pump supplies water to the inlet tank, the water flows through the channel to the discharge tank where it is then recycled with the pump. The flow rate of the pump is adjusted using the flow control valve. Food dye is added to the water in the channel approximately 2 ft. before the airfoil. The food dye impacts the airfoil and flows over, the resulting patterns show the fluid flow over the wing.

Important parameters were measured during the experiment. The water height was 0.145m," and the width of channel was 0.076." The flow rate was determined by measuring the time it took to pump 15 L of fluid, which was 6.9s. The velocity of the water is calculated as follows:

$$Q = \frac{V}{t} = \frac{0.015\, m^3}{0.01102\, s} = 0.00217 \frac{m^3}{s}$$

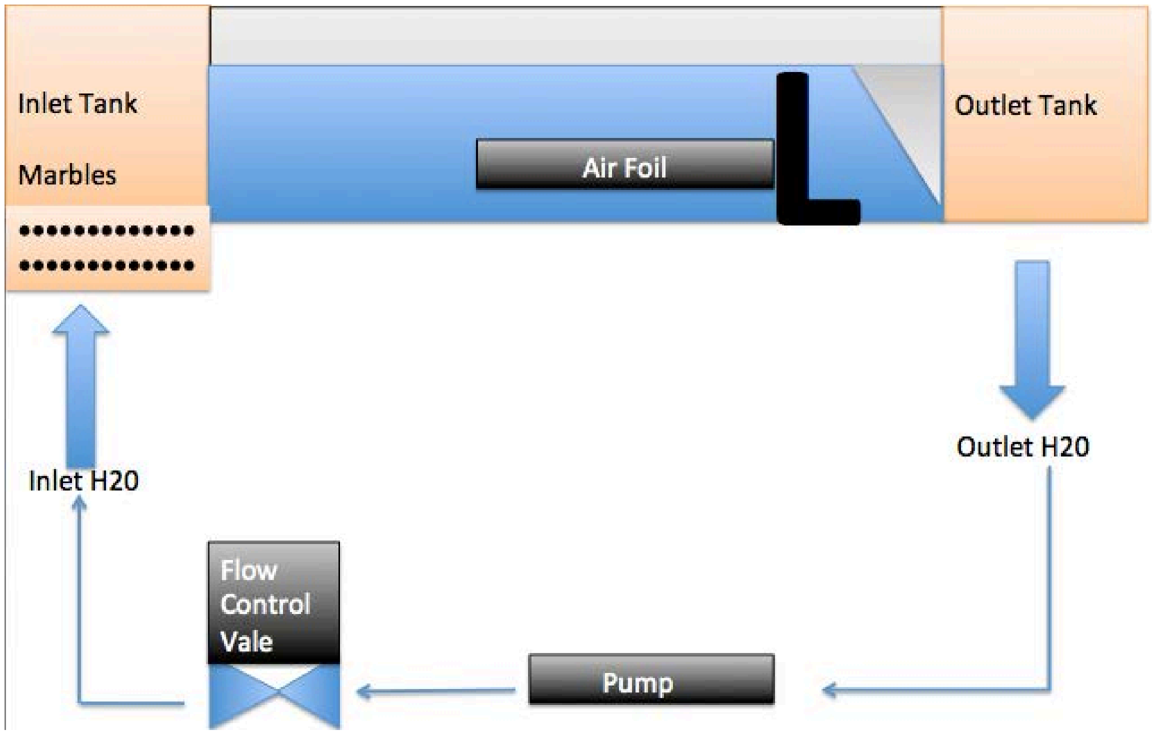
$$A = h * w = 0.145\, m * 0.076\, m = 0.01102\, m^2$$

$$V = \frac{Q}{A} = \frac{0.00212 \frac{m^3}{s}}{0.01102 m^2} = 0.197 \frac{m}{s}$$

The dynamic viscosity of water at room temperature is 0.001013 Ns/m^2, the density of water at room temperature is 998.2 kg/m^3 [1] and the characteristic length for an airfoil is the cord length [2]. For this experiment it can be assumed that the density and viscosity of food dye is equal to the density and viscosity of water. Thus the Reynolds Number Can be computed:

$$Re = \frac{\rho v L}{\mu} = 998.2 \frac{kg}{m^3} * 0.197 \frac{m}{s} * \frac{.17m}{0.001013 \frac{N * s}{m}} = 33000$$

The Reynolds number is the ration of inertial to viscous forces. A Reynolds number of this magnitude means that the inertial forces of the fluid dominate. A Reynolds number of 33000 means that the flow in the flume channel was turbulent which is more chaotic flow. For a Boeing 737 the cruising speed is 780 km/hr,

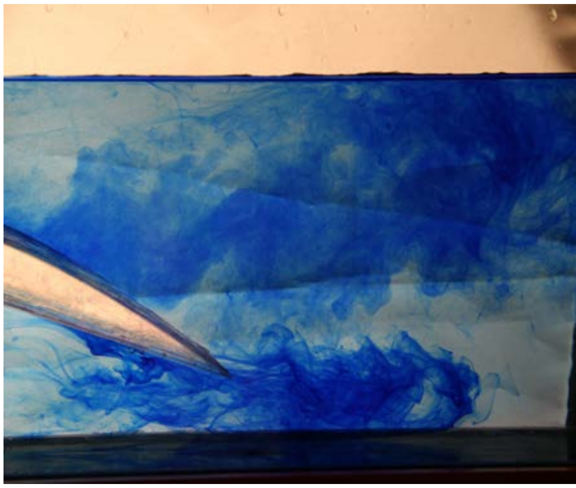


Visualization Technique:

The fluid dynamics were visualized using blue food dye. The dye and flowing water were at room temperature. A white cloth was placed on the backside of the flume to get better contrast between the background and the dye. The ITLL lights surrounding the flume were turned off and the scene was backlit by two work lamps that were approximately 1 ft. below the flume and 2 ft. from the edge of the glass. The photograph was taken from the opposite side of the glass at an angle slightly above the airfoil.

Photographic Technique:

The field of view in the image is approximately .18 m wide by 0.1 m tall. The distance from the object to the lens is about 0.7 m. The lens focal length was 60mm. The camera used was a Canon EOS 60D DSLR with EF-S 18-135 zoom lens. The original photo was 5184 x 3456 pixels. The final image is 5040 x 2424 pixels. The photo settings were a shutter of 1/640, aperture f/6.3 and an ISO of 2500. The photo was cropped to remove the fluid level and the base of the flume. Adjusting the curves in Photoshop increased the contrast. Next the colors were turned to black and white so that the color of the dye and the airfoil are do not distract from the fluid phenomena. The initial and final images are shown in the figure below.

Fluid Physics:

This photo clearly shows how air flows over an airfoil. The Clark Y wing shape is a common shape found in airplanes. The force that makes an airplane fly is a pressure force and is commonly referred to as "lift." The lift can be determined using Bernoulli's principal of fluid flow. The air flowing over the top of the wing moves faster than the air moving beneath the wing. [3] A simplified version of Bernoulli's equation is: $.5 * V_1{}^2 + \frac{P_1}{\rho} = .5 * V_2{}^2 + \frac{P_2}{\rho}$. [3] Since the air on the top of the wing is flowing faster, that means that the fluid pressure on the bottom of the wing is greater than the pressure on the top of the wing. Since Pressure = Force/Area the "lift force" or pressure differential is large enough to overcome the weight of the aircraft and accelerate the plane into the air. Even though it is a still photo it is still very apparent that the fluid over the top of the wing is flowing faster than the fluid beneath the wing. This is known because the concentration of the dye on the top right is much further away from the wing than the concentration in the bottom of the center that is just departing the wing.

Another interesting phenomena to see is the Tollmien-Schlichting instability that can be seen as the fluid departs the airfoil. This instability occurs as the two layers of fluid depart the wing. The two fluid layers are traveling at different velocities (top is at a higher speed than the bottom). As the two layers mix the viscous forces between the layers cause turbulent vortices to form. This phenomenon can be seen in the photo. When the layers mix a turbulent boundary layer is formed much like flow impinging on a flat plate. [4] These layers exist when an inviscid disturbance forces a viscous response, it can exist and be very similar to resonance. [5]

Conclusion:
I really like how you can see the turbulence in the flow as it departs the wing. This is a good representation of how airplanes fly. It shows how the fluid above the wing moves faster than the fluid beneath the wing, thus creating lift. I think that the dye did a good job marking the fluid flow in the chamber. I think the black and white

was an effective photo editing technique which allowed for only the flow to be the focus of the photo instead of the distracting colors. I really enjoyed creating this image.

References:

[1] "Experimental Feature." *Wolfram|Alpha: Computational Knowledge Engine*. N.p., n.d. Web. 10 Mar. 2013. <http://www.wolframalpha.com/>.
[2] NREL, n.d. Web. 11 Mar. 2013. <http://wind.nrel.gov/public/library/3387.pdf>.
[3] IIOP Science, n.d. Web. 9 Mar. 2013. <http://iopscience.iop.org/0031-9120/38/6/001/pdf/pe3_6_001.pdf>.
[4}_"Working Area." *Universität Stuttgart*. N.p., n.d. Web. 11 Mar. 2013. <http://www.iag.uni-stuttgart.de/people/andreas.babucke/work.html>.
[5] Hartford, n.d. Web. 11 Mar. 2013. <http://www.ewp.rpi.edu/hartford/~ernesto/Su2011/EP/MaterialsforStudents/Ferrari/Baines1996.pdf>.