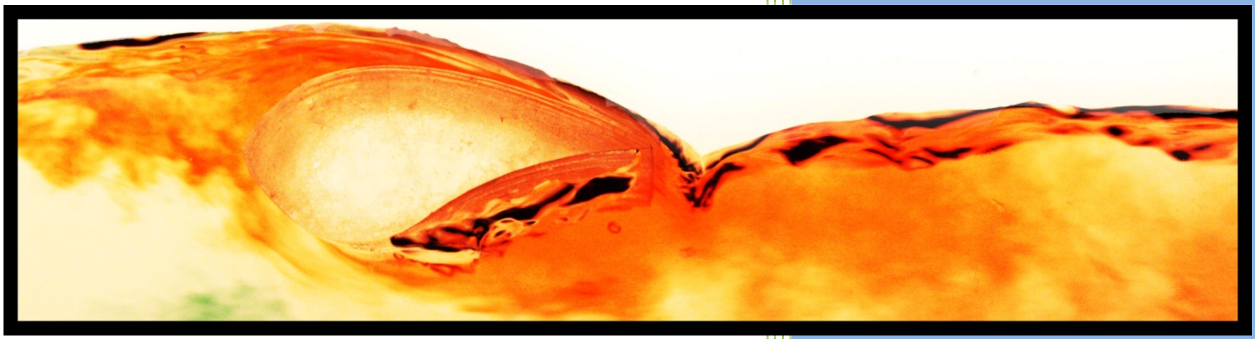
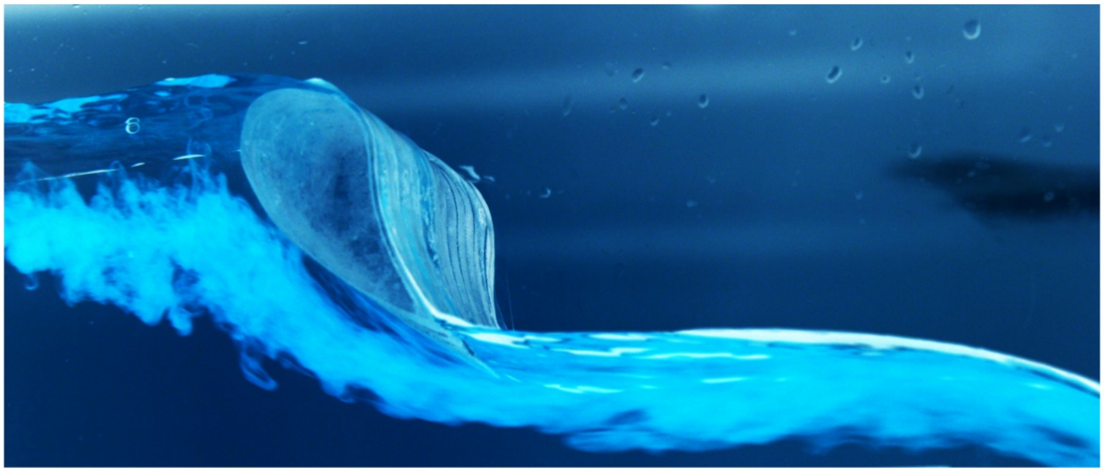
Flow around a hydrofoil





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Context

These images represent the first group project for the course flow visualization at the University of Colorado-Boulder. The purpose of this assignment is to meet with our group members, explore different flow ideas, and capture three images of unique flow phenomena. The group aspect of the project encourages communication and team work. The idea behind these images is capturing water flowing around a hydrofoil to see how it acts above, below, and behind the hydrofoil. The apparatus used to visualize this flow was the flume located in the second basement level of the ITLL. Originally, all sorts of shapes and objects were put into the flume and hundreds of pictures were taken. Different colored dyes were used to visualize the flow of water around the hydrofoil. Of all the images taken, these three were chosen because of the flow phenomena, the colors, and the overall beauty of the images. Each of the pictures was cropped to show the desired aspect of the image, and all three images were processed in Photoshop to enhance the contrast and colors.

Apparatus

The apparatus used to create these images was the flume located in the ITLL of the engineering center at CU-Boulder. A simple overview of the device is shown in figure 1 below. The flume is a rectangular box which allows for channeled flow of water in between the clear plastic walls. According to the figure, the water flows from left to right down the length of the flume which is approximately 95” long, 10” high, and 3” inches wide. Flow rates can be adjusted with the nozzle on the water circulation pipe to increase or decrease the amount of water flowing through the flume. The water flows from the beginning of the flume which is represented as the top left side of the diagram. Then, the water flows through the flume, pools in the water tank and recycle section before the pump circulates the water through the pipe back up to the beginning of the flume.

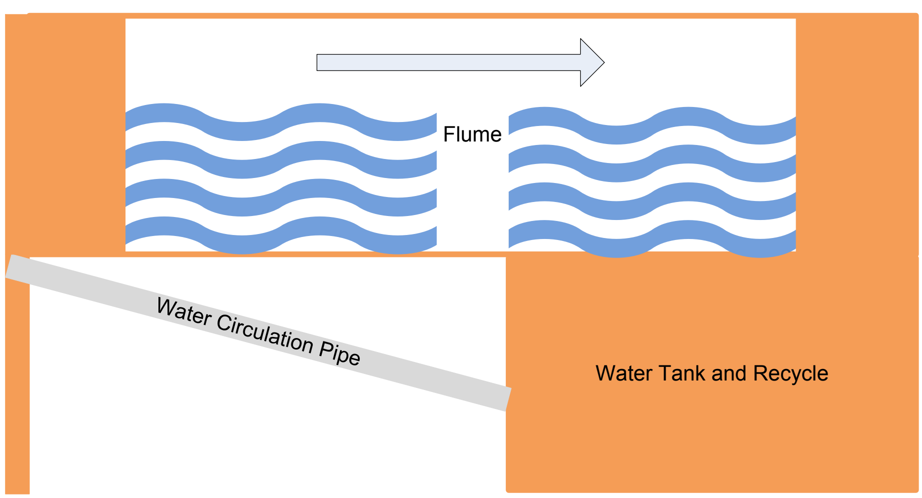

Figure 1-Flume Apparatus Depicting Water Flow

The wing shaped object, hydrofoil, was placed into the flume near the bottom to allow the water to flow around it. The hydrofoil was placed at different angles to divert the flow of the water different ways. The flow rate of the water in the flume was also adjusted in order to get the desired water level. Dyes were inserted from the top of the flume which is open to the air. Once the water became too colored from the increased amount of dye injected into the flume, the tank was emptied and refilled with clean water. Dye is useful in observing the flow phenomena and also in creating better looking images.

Flow Phenomena

The flow of fluids around a hydrofoil has been widely studied and is of the utmost importance in the field of aviation. Airfoils give airplanes the ability to lift off of the ground. They are used at a different angle in racecars to keep the cars on the ground as they reach speeds greater than 200 miles per hour. Hydrofoils are also used on the back of boats and ships in order to steer while moving through the water. Depending on the shape and angle of a hydrofoil, the surrounding fluid either increases or decreases in pressure because of the flow. This is what gives wings lift and keeps car drivers on the road. The intent of these images was to capture unique flows around a wing shaped object placed in the flume.

The Reynolds number was calculated for the flow of water in the flume. The Reynolds number is the velocity of the fluid multiplied by its characteristic diameter divided by the kinematic viscosity of the fluid. The characteristic diameter for flow in a non-circular duct, which describes the flume, is 4 times the cross sectional area divided by the perimeter.[1] The equations shown below were used to determine the turbulence of the flowing water. The fluid velocity was measured at approximately 6 inches per second, the dimensions of the flume described in the apparatus section were used for characteristic diameter, and a value of 1.407 x 10^-5 ft^2/s was used for the kinematic viscosity of water at 50°F.[2] Using these values the Reynolds number was calculated to be 13,681 and rounded to 10,000, indicating the system is well into the turbulent flow regime.[3]

Equation 1-Reynolds Number and Characteristic Diameter for Noncircular Duct

$$D = \frac{4*A_C}{P} = \frac{4*30in^2}{26in} = 4.62in \qquad Re = \frac{V*D}{\nu} = \frac{0.5\frac{ft}{s}*4.62in*\frac{1ft}{12\,in}}{1.407\frac{ft^2}{s}} = 13{,}681 = 10{,}000$$

The images show several different fluid dynamic effects. The images will be referred to in the order they appear on the cover page: Image number one is the red dye with the black border, image number two is the blue image, and image number three is the yellow and red image. In all three images the water is flowing from left to right. Image number one displays the classic hydrofoil flow dynamics. A hydrofoil produces lift because the average velocity of fluid flowing above the wing/foil is greater than the fluid velocity below the wing. This creates lower pressure above and higher pressure below the wing producing lift.[4] The image shows the faster fluid velocity above the hydrofoil by the way the fluid divots as it comes down off of the top. The slower velocity fluid below the wing is causing a wake as it hits the water coming from the top of the wing. The flow of the water is well within the turbulent range and this is why wakes are seen below and behind the hydrofoil.

The second image shows two different phenomena than the first; the Venturi effect and the Coanda effect. The image shows the water being diverted underneath the hydrofoil at a greater velocity. The dye becomes more blurred in the image as the fluid velocity increases. The Venturi effect describes how the pressure and velocity of a fluid change as it flows through different sized openings.[5] On the top of the hydrofoil, the Coanda effect is being seen to some extent. The Coanda effect describes a fluid's tendency to 'stick' or be attracted to a surface.[6] The flow rate in this image should be fast enough to propel the water over the hydrofoil and into the air, but rather the water is attracted to the surface and flows gentle down the backside. Of course this is also due to the effect of gravity on the fluid as it flows over the hydrofoil.

The third image also shows the Coanda effect. The water flows down the backside of the hydrofoil rather than propelling into the air. This image actually shows the Coanda effect better than the second image since the hydrofoil is at a steeper angle. This image also shows the turbulent wakes formed as the water flows past the hydrofoil. The Reynolds number is well within the turbulent regime, so it was expected that these turbulent wakes would form. Of all the images, this one shows the most turbulence in flow behind the hydrofoil. This is due to the angle at which the hydrofoil is placed. In this set up, the hydrofoil acts like a cylinder to the water flowing underneath it. Cylinders are widely studied for their effects on creating wakes in turbulent flow.[7]

Visualization Technique

The technique used in taking these images was the application of food coloring and a unique shape in the flume. The food coloring is used to create a more dramatic effect in the picture than just clear water flowing around the hydrofoil. Food coloring helps enhance the contrast of the image so that the fluid phenomena can clearly be seen. It also has the effect of making the image more beautiful and interesting to look at in the end. The hydrofoil was used along with several other shapes in order to visualize the water flow in the flume. The shape of the hydrofoil at different angles produced the most beautiful, the most interesting, and the most significant images of all those taken. The lighting in the images was provided from behind through a half inch thick white screen. The flash of the camera was not necessary with the amount of light present.

Photographic Technique

The original images were larger than the cropped final images shown. These images were cropped down in Photoshop in order to see the desired aspect of the fluid flow. The camera was approximately one and a half feet away from the subject when the pictures were taken.

All three images were taken with the Canon EOS Rebel XSI. All three images began with dimensions of 4272 pixels wide x 2848 pixels high when first taken. After cropping, the first image is 4372 x 1159, the second image is 4338 x 1872, and the third image is 4272 x 2672. Some of the camera exposure specifications were identical for all three images. The ISO remained at a constant value of 1600 and the aperture at 13. The first image had a shutter speed of 1/200 s and a focal length of 47 mm. The second image had a shutter speed of 1/320 s and a focal length of 55 mm. The third image had a shutter speed of 1/125 s and a focal length of 39 mm. The flash did not fire for any of the images because there was plenty of light in the background.

Based on the image width, the fluid velocity, and the camera's shutter speed, the motion blur in the images can be estimated using equation 2 shown below. The first image has a shutter speed of 1/200 s and the motion blur was calculated at 2 pixels. This is fairly insignificant since the image is 4272 pixels across. Using the shutter speeds given above, the motion blur in the second and third images was calculated at 2 pixels and 4 pixels respectively. The very high quality camera used provides limited motion blur in the images.

Equation 2-Motion Blur Calculation

$$Motion\ blur = Fluid\ Velocity\ (ft/s) * Shutter\ Speed\ (sec) * \frac{970\ pixels}{1\ foot}$$

All images were processed in Photoshop. All images were modified using the basic color, brightness, and contrast features in Photoshop. The main change made was in the second image where the colors were inverted and made into the blue color seen in the image. A border was also placed around all three images.

Revelations

The images reveal the unique phenomena of fluid flowing around a hydrofoil. This phenomenon is not only interesting and beautiful to observe, it is also very useful to humanity. The airfoil makes flight possible. The intent of the images was fulfilled. The original goal was to experiment with the flume, play around with the different settings, and explore different shapes and dyes. These three images turned out to display most interesting fluid phenomena while also being very beautiful. To develop this idea further it would be useful to have multiple hydrofoils, each uniquely different from the other, and experiment with them in the flume.

References

[1] J.P. Holman. Heat Transfer. 10th Edition. McGraw Hill. 2009.

[2] Engineering Tool Box. Online. http://www.engineeringtoolbox.com/water-dynamic-kinematic-viscosity-d_596.html.

[3] Alam, Mahbub, et al. The Ultra Low Reynolds Number Airfoil Wake. Exp. Fluids. 48: 81-103. 2010.

[4] Flow Around an Airfoil. University of Texas. Online. http://www.ae.utexas.edu/~varghesep/class/Irrotational_Flow_Colombini/profilo_e.html.

[5] Baylar, Ahmet et al. Numerical modeling of venturi flows for determining air injection rates using fluent V6.2. Mathematical and Computational Applications. 2009.

[6] Tritton, D.J. Physical Fluid Dynamics. Section 22.7, The Coanda Effect. 1977.

[7] Turbulent Wake Flow Behind a Circular Cylinder. Florida State University. Online. http://www.eng.fsu.edu/~shih/succeed/cylinder/cylinder.htm.