Flow in a Flume

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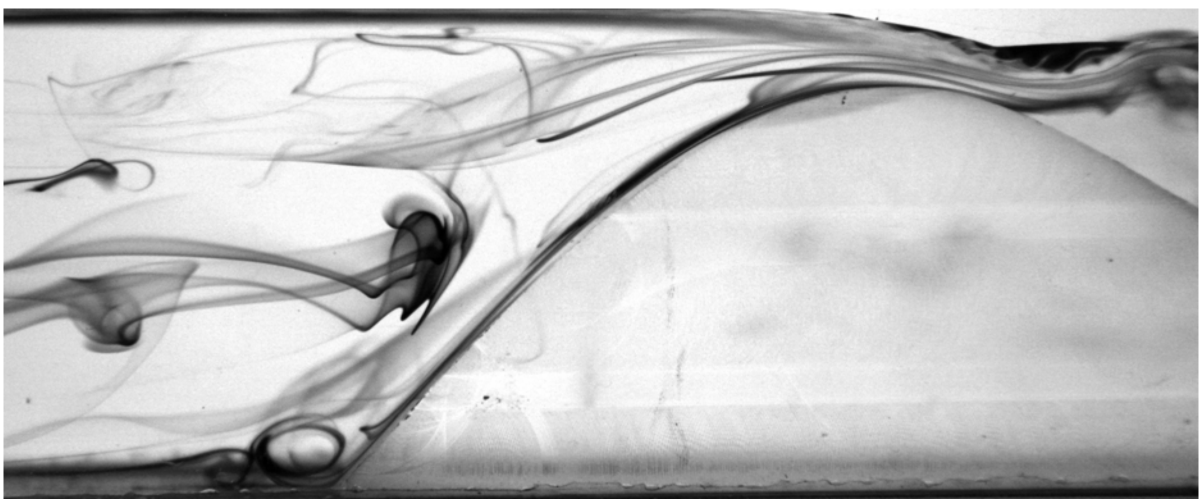

04-05-06

MCEN 4228
Professor Hertzberg and Professor Sweetman

The laminar flow field in a channel is relatively uniform and uninteresting; the velocity vectors are all unidirectional and only gradually vary in magnitude. The flow becomes more interesting when a blockage is introduced into the geometry. With a blockage present, the fluid has to find ways to go around it. The streamlines of the flow are bent around the object and create regions of high and low pressure. The fluid exhibits phenomena such as vortices and boundary layer separation. Prediction of how the fluid will flow is important in engineering and enables the design of such applications as airplanes and aerodynamic bodies on automobiles. For the second group project, group 4 decided to photograph fluid flows in the flume. The original intent of the image was to use food coloring to visualize common flow features such as the recirculation off a backward facing step. We found that the food coloring did not behave as planned and instead would diffuse before the desired phenomena could be seen. Through experimentation we found geometries that produced flows that were beautiful and exhibited some interesting flow characteristics.

The photographs were of fluid flow in the flume. The flume is a 2.5m x 76mm x 250mm rectangular channel.

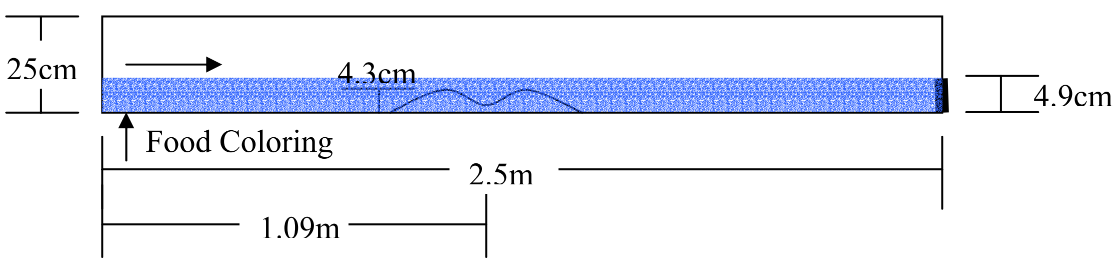

Figure 1: Flume layout

One 4.9cm block was positioned at the end of the flume to increase the depth of the channel and therefore decrease the flow velocity. The double humped piece was inserted into the flume 1.09m from the water inlet. The piece was held in that position by a metal rod at the downstream edge. The effects of the rod on the flow in the front of the picture were assumed negligible. To see the flow, a drop of food coloring was dropped far upstream from the body in the flume. The food coloring was proven denser than water by the fact that the majority of it sank to the bottom of the channel. The food coloring crawled along with the boundary layer of the water until it reached the base of the humped body. As the food coloring climbed the hill it was overcome by gravity and flowed back down. This created vorticity at the base of the body which can be seen in the photograph. Another interesting phenomena that was revealed by the food coloring was the boundary layer separation that occurred after the hump. The Reynolds number, Re, for the flow was calculated using the equation: $Re = \frac{VL}{\nu}$, where V is the velocity, L is the characteristic length, and ν is the kinematic fluid viscosity. The characteristic length for this flow was taken to be approximately 9.5cm, which is from the start of the body, to the point where the flow separates. The velocity was approximately 0.3 m/s, and the kinematic viscosity of water is 9.76×10^{-7} m^2/s (at 22°C). Thus the Reynolds number was 3968, which is right at the boundary of laminar and turbulent flow. The boundary separation point can be clearly seen in the picture, and the flow past that can be seen as turbulent as the water was clearly darker due to the turbulent mixing of the water and food coloring. The Bernoulli principle was demonstrated in that as the channel got shallower, the flow became faster to maintain the consistent flow rate, and thus the pressure dropped as the flow got shallower. The boundary layer separated after the hump in the body, due to the adverse pressure gradient from the Bernoulli effect.[1]

Throughout the process we tried various angles of documenting the dye in the flume, but in the end the best images were from straight on the side of the flume. The flume was 1m away from the camera lens, which had a field of view before cropping of 0.5m. This image was taken with a Canon EOS Digital Rebel and a Canon EF 28-135mm f/3.5-5.6 IS lens. The focal length was at 135mm and since we were using four of the 500W halogen work lights, the flash wasn't necessary. The aperture was at stopped at f/5.6 and the shutter speed was set at 1/1600 sec, which caught the dye sharp enough with minimal motion blur. Considering the estimated velocity, the flow moved 0.19mm while the shutter was open. The camera used produced images that were 3072 pixels wide by 2048 pixels high. The flow only moved across 1 pixel during the

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[1] Ghil, Michael, Jian-Guo Liu, Cheng Wang, and Shouhong Wang. "Boundary-Layer Separation and Adverse Pressure Gradient for 2-D Viscous Incompressible Flow." Elsevier 197 (2004): 149-173.

exposure. Photoshop was used to crop the image and convert it to black and white. The only other thing Photoshop was used for was a slight change in the brightness/contrast.

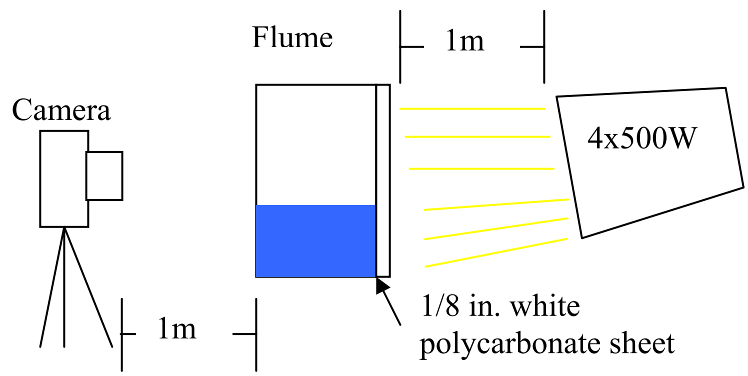

Figure 2: Lighting setup

Although we had slight problems this was a good documentation of how dye reacts to a bluff body while moving through water in the flume. Other images had more distinct flow features, but this is one of few that came out in focus and with enough light. The plastic sheet we used to cover distracting elements in the ITLL diffused too much light, so in most of the images the dye turned out as a solid mass (when it was really more transparent).

The image reveals a range of various fluid phenomena, including Bernoulli's principle, laminar to turbulent flow, boundary layer separation, and recirculation. We definitely like the range of fluid phenomenon going on inside the image, especially the clear boundary layer separation, as well as the recirculation vortex going on at the base of the body. The only thing we really dislike at all was the fact that it was very hard to focus directly onto the food coloring, and thus the image is slightly blurred (however unnoticeable it may seem). Our intent was realized, and actually exceeded, as it not only showed laminar to turbulent flow, but other interesting fluid phenomena. There is not a huge amount that can be done to improve the image, except maybe to use a rheoscopic fluid, to better see the flow lines, and turbulent areas. We are very happy with this image.