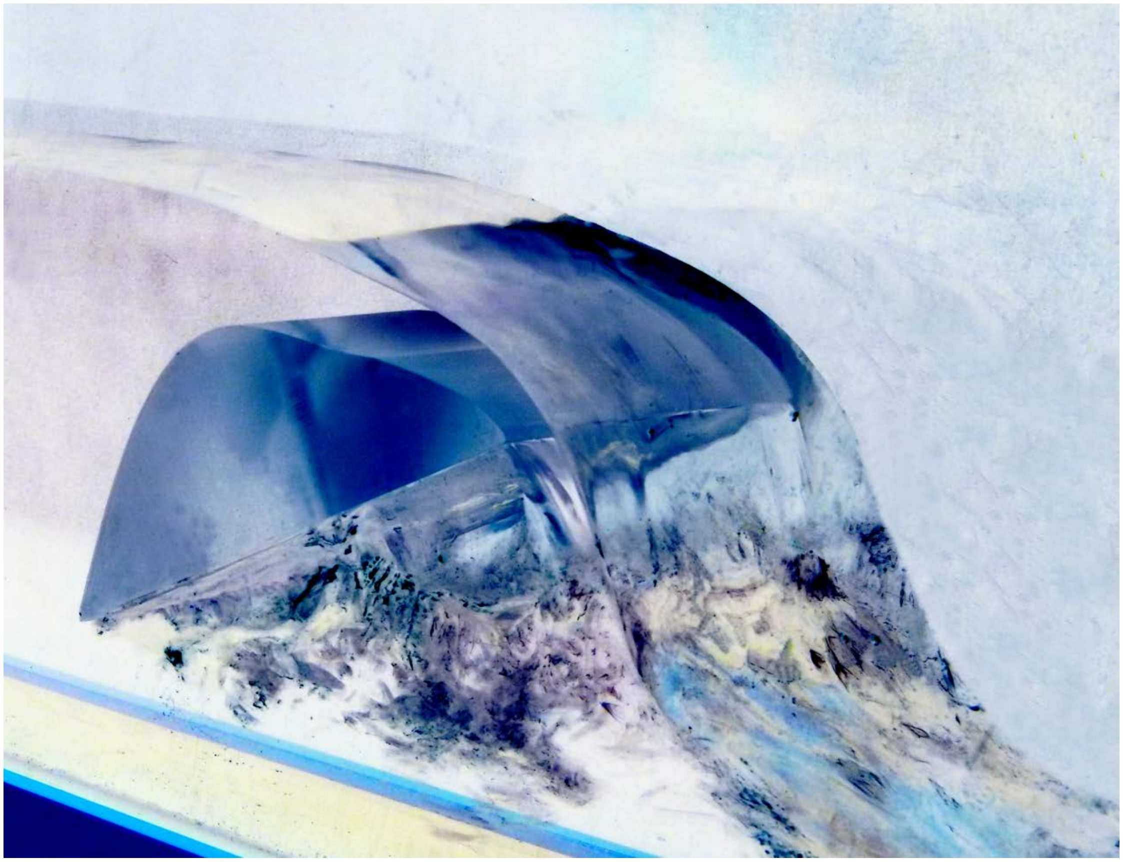
Flow around a submerged object in an open-channel flume



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Flow Visualization
Team 1 Assignment
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Purpose

This image was created as the first team assignment for the flow visualization course offered at the University of Colorado Boulder. The purpose of the assigned teams was to not only broaden the experience level among several people, but also help bring to life more challenging images that would be difficult to achieve individually. Instead of trying to do our own images, we collaborated on a few ideas that we could all get some images from and then we could put our unique spin on them with post processing. For this first assignment we decided to use the open channel flume in the Integrated Teaching and Learning Laboratory (ITLL). This would allow us to have a sensible amount of control on the fluid dynamics we were creating. We would also be able to change the flow by implementing different weirs into the channel. The intent was to see various flows around objects as well as impending vortexes that may form. We tried using pearl-ex to enhance the visibility but this ended up being non beneficial.

Approach

The apparatus we used to visualize the flow is an open-channel flume which can be seen below in figure (1). The flume has a flow bed that is 76 mm wide, 250 mm tall, and 2.5 m long. There is an adjustable jacking lever that allows for a slope change from -1 to 3%, and the water level in the working section is controlled by an overshot weir arrangement at the exit [1]. There also is a lever that allows you to control the rate at which the water flows through the channel.

Figure 1: Open-Channel Flume

So from the image we can see two obvious things occurring, one is the laminar flow created by the flume before the water hits the submerged object. The flow is smooth and uniform and the viscous affects and the inertial effects are of the same magnitude, producing a low Reynolds number, which can be seen by equation (1-a). The other fluid dynamic occurring is the turbulent flow created in the pocket of air beneath the submerged object. This is created from the overflowing laminar flow as well as a jet of water coming through a cylindrical hole running through the object. This shows that the inertial forces are much higher than the viscous forces which can be seen in equation (1-b) for the turbulent values.

$$Re = \frac{inertial\ forces}{viscous\ forces} = \frac{\rho VL}{\mu} = \frac{VL}{\upsilon} \quad (1)$$

$$Re = \frac{\left(.02\frac{m}{s}\right)(.1\ m)}{(1.307x10^{-6}\frac{m^2}{s})} = 1530 \quad (a)$$

$$Re = \frac{\left(.1\frac{m}{s}\right)(.1\ m)}{(1.307x10^{-6}\frac{m^2}{s})} = 7651 \quad (b)$$

As you can see the water was not going too fast. We had it set on a pretty low speed so that we could see the dynamics a little better. These are rough estimates, of course, and an assumption that the water was about 10 degrees Celsius. The turbulent flow creates little waves that translate to the right, but after a short distance the water becomes relatively laminar again. Using submerged objects in experiments like using the flume really allows us to highlight certain attributes of flow and control them so that we can better understand what is occurring.

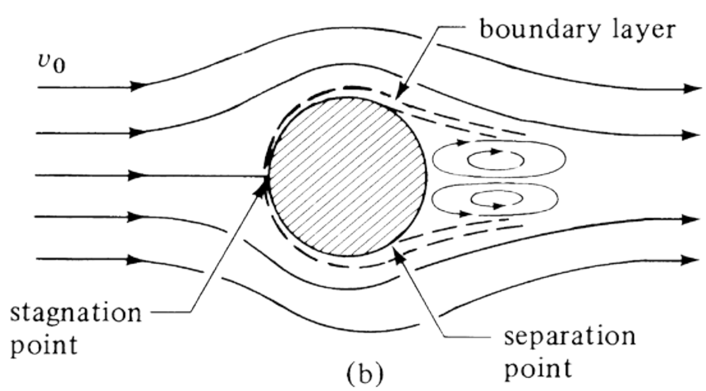

Figure 2 : Flow around an object [2]

Even though our object was a weir, the figure above, Figure (2), illustrates some key areas of flow around an object. The stagnation point is where the flow impacts the object and has a velocity of zero. The separation point is when the flow breaks off from the outline of the object and begins its turbulent regime. The boundary layer shows where the turbulent and laminar flow is separated. For our submerged object, we had it at an angle which created a small air pocket below the object as well as the impinging jet which altered some of the dynamics. We must also look at some of the forces acting on the submerged object. The most common forces are the pressure and frictional drag forces. This equation can be seen below in equation (2).

$$D = \int_A p \sin\theta dA + \int_A \tau_0 \cos\theta dA \qquad (2)$$

The first integral is the effect of the pressure drag and the second integral is the effect due to frictional drag [3]. Since our object was submerged at roughly 45 degrees there is both pressure and frictional drag present. The object was very smooth so the frictional drag will be small, and since the curved portion was facing the flow it will also reduce the pressure drag. The setup of the part in the flume can be visualized below in figure (3) which illustrates a top view and a side view.

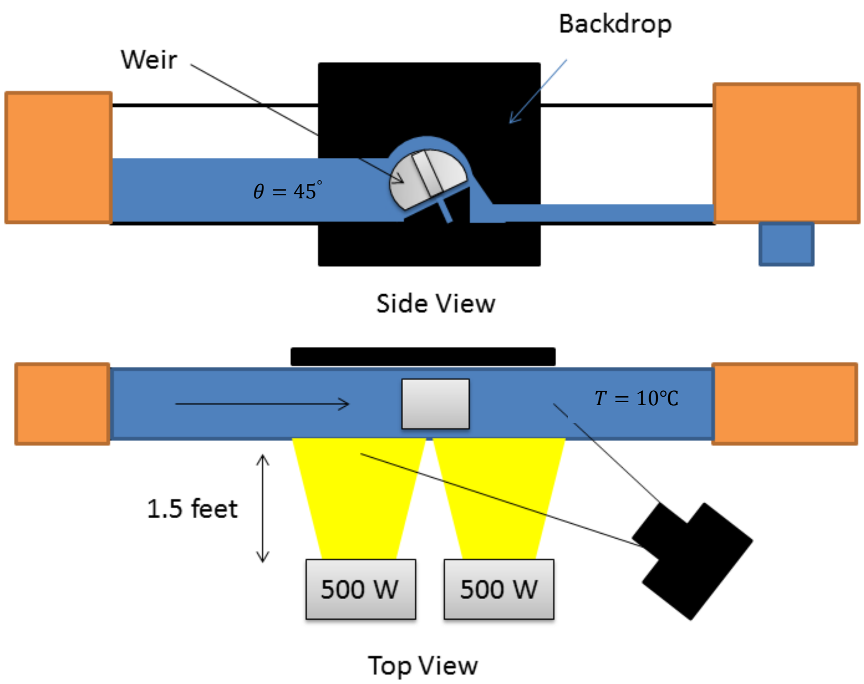

Figure 3: Imaging Setup

So the biggest question is why is any of this truly important? Studying these fluid behaviors around objects helps us expand our knowledge of fluid dynamics and hence we can apply this knowledge to real world problems. One example is improving habitats for fish in streams and rivers. We can do this by implementing natural rocks in key locations. These rocks deflect water and produce wakes which provide shelter and refuge for fish, allowing them to thrive. The physical habitat simulation program (PHABSIM) developed by the U. S. Geological Survey is a worldwide accepted tool for the prediction of microhabitat (depth, velocities, and channel substrate) conditions in rivers as a function of stream flow, and the relative suitability of those conditions to aquatic life [4]. This is just one example of how understanding flow hydraulics around submerged objects can help us create better living environments, not only for us, but for the creatures around us as well.

Visualization Technique

The visualization technique used was flow around a submerged object using plain water in an open-channel flume. The flume creates a uniform flow at an adjusted speed and the submerged object, or weir, highlights the characteristics of how the fluid moves around the object. Blue and yellow Pearl-ex was implemented in the flowing water but overall did not have much impact in the visualization, although it did make the water a little more glistening. For the lighting we used a yellow work lamp that had two individual lamps each at 500 Watts and it was positioned approximately 1.5 feet away from the flume channel. There was no flash on the camera. Since it was shot in the ITLL there was also so fluorescent overhead lighting approximately 4 feet above the flume. The weir helped create the fluid dynamics, but it wasn't until the colors were inversed and adjusted in Photoshop that you could fully see the dynamics of the water's motion.

Photographic Technique

For this photo I used the Nikon Coolpix L105 12.1 MP super-zoom digital camera. The original image was 4000 pixels wide and 3000 pixels high, and the photo shopped image came out to be 3476 pixels wide by 2664 pixels high. The field of view of was about 15 inches wide by 10 inches tall. The object was approximately 1 foot away from the lens when the picture was taken. The F-stop was 4.5 and the shutter speed was 1/16 sec, and the ISO was 200. The max aperture was 3.6 and the focal length was 15 mm, and the exposure had 0 bias. The original image can be seen below in figure (3).

Figure 4: Original Image

I used Adobe Photoshop CS5 for post-processing. I inverted the colors to bring out the turbulent flow underneath object and I adjusted the contrast and brightness to get the right tones. I used the clone stamp to eliminate all of the bubbles which took quite a bit of time; because I felt they were distracting. Finally, I cropped it to just get the important part of the flow.

Conclusion

Overall, I believe it is a powerful image, but there is a lot more capabilities of the flume we were yet to explore. The image reveals turbulent flow being created in an air pocket under a submerged object and laminar flow going over the object. I like the simplicity of the dynamics and physics occurring but the impact and artistic nature of the image is lacking. I did reach my intent of trying to capture some unique flow in the flume, but I wish it had been able to capture a more beautiful and artistic photo. One of the limitations was the lack of various objects we could submerge, if there were a few more shapes I might have been able to get something I was really proud of. To improve this idea more I would try using more various shapes as well as using a higher speed camera to catch a more clear and beautiful photo. All in all it turned out pretty nice, and I got to use the flume which I have never done before so I got to experience something new.

[1] http://itll.colorado.edu/index.php/test_measurement_equipment/hydraulic_equipment/
[2] The University of Texas at Austin. “Flow around Immersed Objects.” PowerPoint presentation. <*capsicum.me.utexas.edu/ChE354/files/.../ChE354_**Immersed**.ppt*>
[3] http://www.tvrl.lth.se/fileadmin/tvrl/files/vvr090/lecture4_drag1.pdf
[4] M. Sadeque, N. Rajaratnam, M . Loewenn. “Flow around cylinders in open channels.” Journal of Engineering Mechanics; Jan2008, Vol. 134 Issue 1, p60-71, 12p, 7 Diagrams, 1 Chart, 8 Graphs <http://rpucolo.colorado.edu/ebsco-web/ehost/pdfviewer/pdfviewer?sid=d4df173d-d55f-4812-9cd4-61a995ca3eb8%40sessionmgr10&vid=4&hid=111>