Flow Visualization of Open Channel Flow in a Flume

Author/Photographer: **Ryan Wells**
Collaborators: **Kelsie Kerr, Maridith Stading, Will Dietz**
Assignment: **Image/Visual 3**
Course: **MCEN 5151, Flow Visualization**
Date: **November 7, 2022**

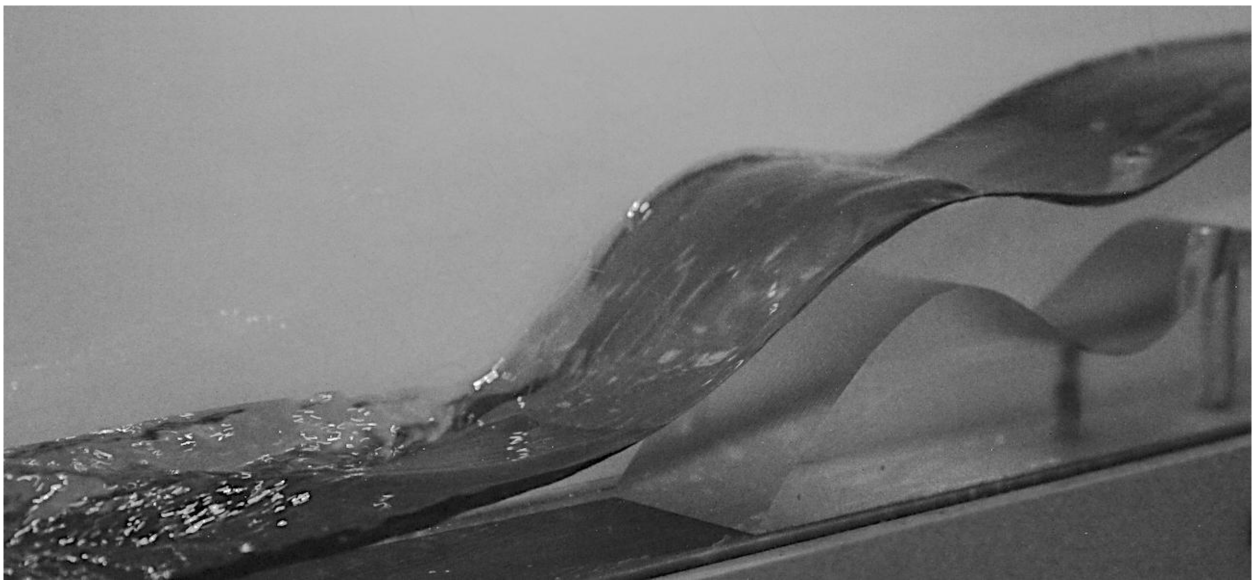

Figure 1, Depiction of the Flow Phenomenon of water in open channel flow over two hydraulic jumps, flowing from right to left

Introduction

The image above in Figure 1, was taken for the third Image/Visual project in the MCEN 5151, Flow Visualization course at the University of Colorado, Boulder in the Fall 2022 semester. The purpose of Flow Visualization is to capture and observe fluid phenomena while exploring the interface between art and science [3]. The image in Figure 1 depicts the phenomenon caused by open channel flow over a hydraulic jump. A hydraulic jump is a sudden transition from a laminar open channel flow into a "subcritical flow motion" [2]. Subcritical flow motion is a general term for when flow is subject to new conditions that alter the flow. In Figure 1, there is laminar (normal/organized) open channel flow until it hits the hydraulic jumps. The effects of the hydraulic jumps are depicted, showing the flow following the curves and then turning into turbulent flow after the jumps. This experiment was conducted indoors in the ITLL of University of Colorado, Boulder using a flume, a device for open channel flow depicted in Figure 2 below.

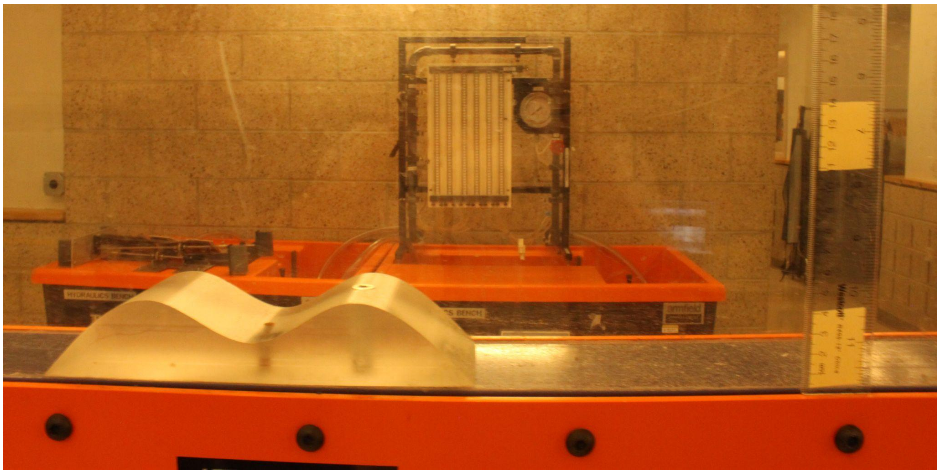

Figure 2, the flume and experiment setup depicted in the ITLL of University of Colorado, Boulder in the Engineering Center. The two hydraulic jumps are depicted with no water flow as well as a ruler for size comparison.

Fluid Physics

The flow apparatus used in this experiment was a flume, an open channel water simulator. Using the equation for the open channel Reynolds number below, the flow before and after the hydraulic jumps can be classified as turbulent, transient, or laminar.

$$Re = \frac{\rho V R_h}{\mu} \text{ [1]}$$

Where:

$$\rho = water\ density = 997\ kg/m^3 \text{ [1]}$$

$$V = fluid\ velocity = Volumetric\ Flow/Cross\ Sectional\ Area = Q/A \text{ [1]}$$

$$R_h = hydraulic\ radius = Cross\ Sectional\ Area/Wetted\ Perimeter = A/P \text{ [1]}$$

$$\mu = water\ viscosity = 0.001\ Pa * s \text{ [2]}$$

The volumetric flow rate, Q, was measured to be approximately 1.36 liters per second or 0.00136 meters cubed per second (m3/s), and height and width of the flow was measured to be 8 cm by 9 cm, respectively. This height and width is for the flow before the hydraulic jumps. The flow after the hydraulic jumps is measured at a height and width of 3 cm by 9 cm, respectively. With these measurements the Reynolds number for before and after the hydraulic jumps are able to be calculated. Due to the theory behind hydraulic jumps, the Reynolds Number does not need to be calculated as it is known that the flow is transitional or subcritical flow [2].

$$V_{before} = \frac{0.00136\ m^3/s}{(0.08m*0.09m)} = 0.19\ m/s$$

$$V_{after} = \frac{0.00136\ m^3/s}{(0.03m*0.09m)} = 0.50\ m/s$$

$$R_{h_{before}} = \frac{(0.08m*0.09m)}{(0.08m+0.09m+0.08m)} = 0.029m$$

$$R_{h_{after}} = \frac{(0.03m*0.09m)}{(0.03m+0.09m+0.03m)} = 0.018m$$

$$Re_{before} = \frac{(997kg/m^3)(0.19m/s)(0.029m)}{0.001Pa*s} = 5500$$

$$Re_{after} = \frac{(997kg/m^3)(0.50m/s)(0.018m)}{0.001Pa*s} = 9000$$

Open Channel Flow is Turbulent if $Re \geq 2000$

As shown in the calculations above, the flow before and after the hydraulic jumps is turbulent. All of the flow is turbulent because in almost all cases of open channel flow, the Reynolds number will show that it is turbulent. However, it is shown that the flow after the hydraulic jumps is more turbulent than the flow before, about 64% more turbulent. This effect of more turbulence is caused by the momentum change in the flow. As the water flows over the hydraulic jumps it gains momentum down the slopes and increases velocity. The momentum change is due to the height differences in the flow, specifically the difference in the upstream vs downstream levels causing an increase in velocity (and turbulence) as the flow moves downstream over the hydraulic jumps.

Visualization Technique

The visualization techniques used in this experiment to take the photograph in Figure 1 were very controlled and quite simple with the use of the flume. This photo was taken indoors on a flume in the Engineering Center at University of Colorado, Boulder on the bottom basement floor. Due to this there was no natural light and the room lighting was used. In the future, extra lighting would increase the quality of this experiment and photo. The room lighting was quite dim through photos which were corrected in post-processing, but can be seen in the original photo below in Figure 3. The hose was secured in place but no tripod was used, however a tripod would be highly recommended for repeating this experiment. There were no particles added to the water and white construction paper was used as the background. Other colors of paper were tested however white paper gave the best results. The camera was about 6 inches from the close edge of the flume at an angle down of about 10 degrees. The goal of this image was to capture the turbulent flow right after the hydraulic jumps in best focus and clarity. The flum was running at about 75% maximum volumetric flow rate.

Figure 3, the original photo taken pre-editing to the photo in Figure 1

Photographic Technique

The image was taken with many different photographic techniques that complimented the experiment well. The distance from the center of the flow in focus to the lens was about 7 inches with a field of view of about 24 inches. The lens used was a Canon zoom lens with a 18-55mm focal length, 1:3.5-5.6 aperture and a thread diameter of 58mm. The digital camera used with this lens was a Canon EOS Rebel T1i. For the image taken in Figure 1, the aperture was f/5.0, the exposure is 1/400, a focal length of 46mm, and a 1600 ISO. The original image had a pixel size of 4752px width by 3168px height. This was then cropped down to 4030px width by 1846px height to allow the flow to become the main subject of the photo and crop out the flume framing. The post-processing of this image was very important to bring this flow to life. First, the exposure was increased to increase the brightness of the image due to poor lighting. Then, the RGB curve was adjusted into an S curve to highlight and brighten the image as well. Contrast, highlights, and shadows were adjusted for better clarity and overall definition of the image. Next, the sharpness was increased to bring out details of the flow and some of the light reflections in the flow. Finally, the monochromatic effect was added. This may be the most important post-processing effect as it allows for the focus of the viewer to be drawn to the flow and reflections rather than the flume. The flume was orange on the exterior and blue on the interior, distracting from the amazing fluid phenomenon. Monochrome enhanced this picture very well as it compliments water flow well due to water having no color (along with the white background). The cropping was chosen to include the hydraulic jumps and turbulent outflow for a comprehensive view of the experiment and to have a diagonal line of flow from top right to bottom left and properly show how the fluid is flowing.

Image Conclusions

The image taken in this experiment in Figure 1 captured an interesting but natural phenomenon that occurs everyday in the open channel water around the world. Using a controlled environment like a flume and focusing on the little details within an overall flow can produce some magnificent photos. In the future, it would be very interesting to explore the effects that this flow has on dye entering the stream. Also, different flow rates and different types of hydraulic jumps may produce an even more intriguing flow to capture. From an artistic standpoint, a great improvement to this experiment would be to add colorful lighting or many different types of lighting such as from below or capturing images below the surface of the water. This experiment showed the curiosity and beauty in an open channel flow, hopefully it will open a viewer's eyes to more fluid phenomena in the world.

References

[1] Bengston, Harlan. “CE-089 Manning Equation for Open Channels.” *PDH Star*, PDH Star, https://pdhstar.com/wp-content/uploads/2019/06/CE-089-Manning-Equation-for-Open-Channels.pdf.

[2] Chanson, Hubert. “Current Knowledge in Hydraulic Jumps and Related Phenomena. A Survey of Experimental Results.” *European Journal of Mechanics B/Fluids*, University of Queensland, 1 July 2008, https://www.sciencedirect.com/journal/european-journal-of-mechanics-b-fluids.

[3] Hertzberg, Jean. “SYLLABUS MCEN 4151/5151/ FILM 4200/ ARTF 5200/ ATLS 4151/5151 Flow Visualization: The Physics and Art of Fluid Flow Fall 2022.” *FLOW VISUALIZATION A Course in the Physics and Art of Fluid Flow*, 18 Aug. 2022, https://www.flowvis.org/wp-content/uploads/2022/08/syllabusF22.pdf.