

MCEN 4151: Vis 3 Report

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1 Introduction

For the third team project, my intent was to capture explore the utility of the ITLL water flume in visualizing fluid dynamics. We planned to use the double hydraulic jump from the beginning but played around with the tilt of the flume and the flow rate. I found taking pictures from below the water level really helped to detail the flow and also had really neat lighting effects. This project was assisted by Ryan Wells, Maridith Stading, and Kelsie Kerr.

2 Setup and Procedure

The flume angle was 1 degree. The flow rate was calculated to be 0.73 L/s. Flow rate was kept constant while taking the image and was set well in advance of taking any pictures to guarantee no fluctuations in water levels. The double hydraulic jump used was 23 cm long, 7 cm wide, and approximately 4 cm tall at its peaks. Two pieces of white printer paper were taped to the far side of the flume in order to provide a less distracting background. No lighting was used to supplement the permanent lighting in the ITLL. The camera was held by hand at roughly the same level as the jump at a distance of roughly 0.4 meters. A picture of the setup is shown below in Figure 1.

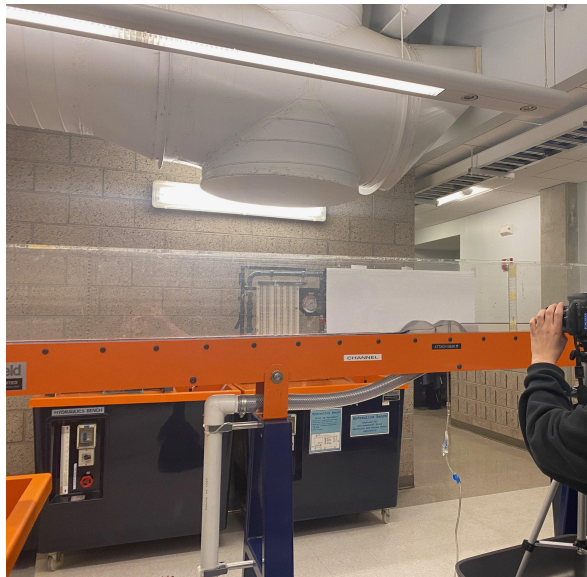


Figure 1: Water Flume used in the ITLL

3 Relevant Physics

The flow appears to be laminar before the jump and turbulent after the jump. This can be checked by calculating the Reynolds number for the flow. The Reynolds number for an open channel flow is given by $Re = \frac{\rho V R_h}{\mu}$, where V is the velocity of the flow, ρ is the density of the fluid, R_h is the hydraulic

radius, and μ is the viscosity of the fluid. For room temperature water, we can assume a density of 997 kg/m^3 and a viscosity of 0.01 Pascal seconds near room temperature. For a rectangular channel such as this one, the hydraulic radius is given as $R_h = \frac{lh}{2h+l}$ where l is the width of the channel, and h is the depth of the flow [1]. We can assume that the width of the channel, l , is constant upstream and downstream of the jump and is 8 cm .

For upstream flow, the flow is approximately 8 cm deep. Firstly, we can find the velocity of the flow from the volumetric flow rate. Keep in mind that a liter of water is 0.001 cubic meters.

$$Q = A \times V \xrightarrow{\text{Solve for } V} V = \frac{Q}{A} = \frac{Q}{l \times h} = \frac{0.73 \times 10^{-3} \text{ m}^3/\text{s}}{0.08 \text{ m} \times 0.08 \text{ m}} = 0.11 \text{ m/s}$$

Next, the hydraulic radius can be easily calculated by the following:

$$R_h = \frac{lh}{2h+l} = \frac{0.08 \text{ m} \times 0.08 \text{ m}}{2 \times 0.08 + 0.08 \text{ m}} = 0.0267 \text{ m}$$

Finally, we can plug these values into our equation for the Reynolds number:

$$Re = \frac{997 \times 0.11 \times 0.0267}{0.01} = \boxed{292.8}$$

Because the Reynolds number is less than 500 , we can confirm that flow upstream from the hydraulic jump is laminar. Following the same steps as above, we can calculate the Reynolds number downstream assuming a depth of 0.75 cm .

$$V = \frac{Q}{A} = \frac{Q}{l \times h} = \frac{0.73 \times 10^{-3} \text{ m}^3/\text{s}}{0.08 \text{ m} \times 0.0075 \text{ m}} = 1.2 \text{ m/s}$$

$$R_h = \frac{lh}{2h+l} = \frac{0.08 \text{ m} \times 0.0075 \text{ m}}{2 \times 0.0075 + 0.08 \text{ m}} = 0.0063 \text{ m}$$

$$Re = \frac{997 \times 1.2 \times 0.0063}{0.01} = \boxed{7621}$$

This Reynolds number is between 500 and 12500 but we can see from the upstream conditions that this flow is likely turbulent.

The drop in the flow depth from before and after the hydraulic jump can partially be explained by volumetric flow as lightly explored above. The flow entering the channel is the same as the flow leaving the channel. Thus, because the velocity of the fluid is moving faster, the cross-sectional area of the flow must be decreased resulting in a lower flow depth. This is also related to the Froude number [2].

4 Photographic Technique and Choices

Camera	Sony ILCE-7M3
Lens	FE 28-70mm F3.5-5.6 OSS
Aperture	f/5.6
Exposure	1/500
Focal Length	70mm
ISO	12800
Px Width x Height (Original)	6000 x 4000
Px Width x Height (Edited)	6000 x 2115

Table 1: Camera and Camera Settings

The field of view of the edited image is approximately 25 cm wide and 8 cm high. ISO and aperture were adjusted in order to maintain brightness while adjusting exposure to try for different motion blur effects. All image editing was done in Darktable. In addition to the cropping edits made, I also used retouch to remove the dark spots visible on the lower left of the hydraulic jump in the original image. Additionally, the image was brightened somewhat using the RGB curve shown in Figure 2. The changes made to the image can be seen in Figure 3

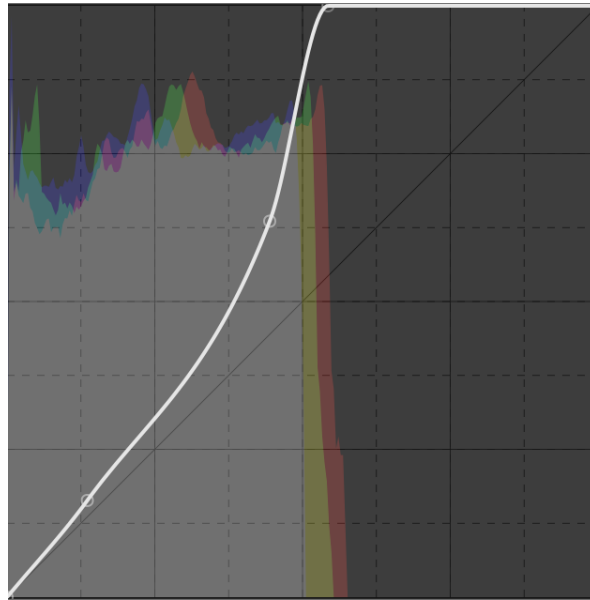
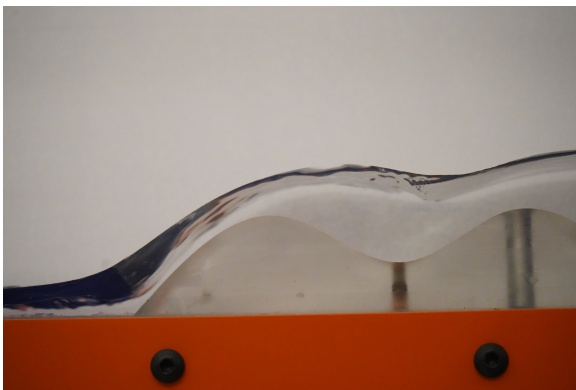
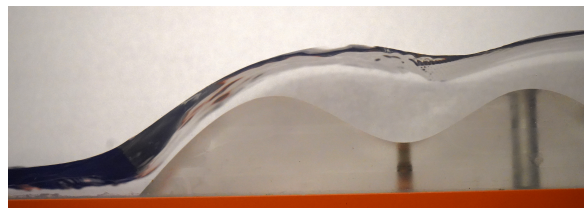


Figure 2: Adjusted RGB Curve From Darktable



(a) Unedited Image



(b) Edited Image

Figure 3: Before and After Edits

5 Further Work

I really enjoyed this project as water flows are very aesthetically appealing and I've never worked with a flume. The Interstellar look of the flow dropping off the jump on the left side of the picture was very detailed and fun to see in different photos. The controllability of the flow made experimentation easy to manipulate. If I were to do this project again, I would want to bring additional lighting since the area is somewhat dark. I would also like to explore the physics of flows that increase again after a hydraulic jump (by using a different piece in the flume) which was explored in [2]. Lastly, adding dye or other seeding could be a neat way to accentuate the details of the flow.

References

- [1] H. Bengtson, "Manning equation for open channels - pdh star." [Online]. Available: <https://pdhstar.com/wp-content/uploads/2019/06/CE-089-Manning-Equation-for-Open-Channels.pdf>
- [2] M. M. El-Seddik, "Hydraulic jump experiment in a rectangular open channel flume," Jun 2017. [Online]. Available: <https://www.heighpubs.org/hjcee/acee-aid1005.php>