Get Wet: Capturing a Hydraulic Jump Associate with a Broad Crested Weir

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February 16, 2018

1 Introduction

The purpose of the "Get Wet" assignment was to capture fluid physics phenomena in an artful manner by taking a picture. I chose to capture a hydraulic jump, demonstrating the Bernouli principle. The picture was taken using the water flume in Colorado State University Boulder's Integrated Teaching and Learning Laboratory. A water flume is a similar concept to wind tunnel–scaled devices can be tested with realistic fluid-structure interactions.

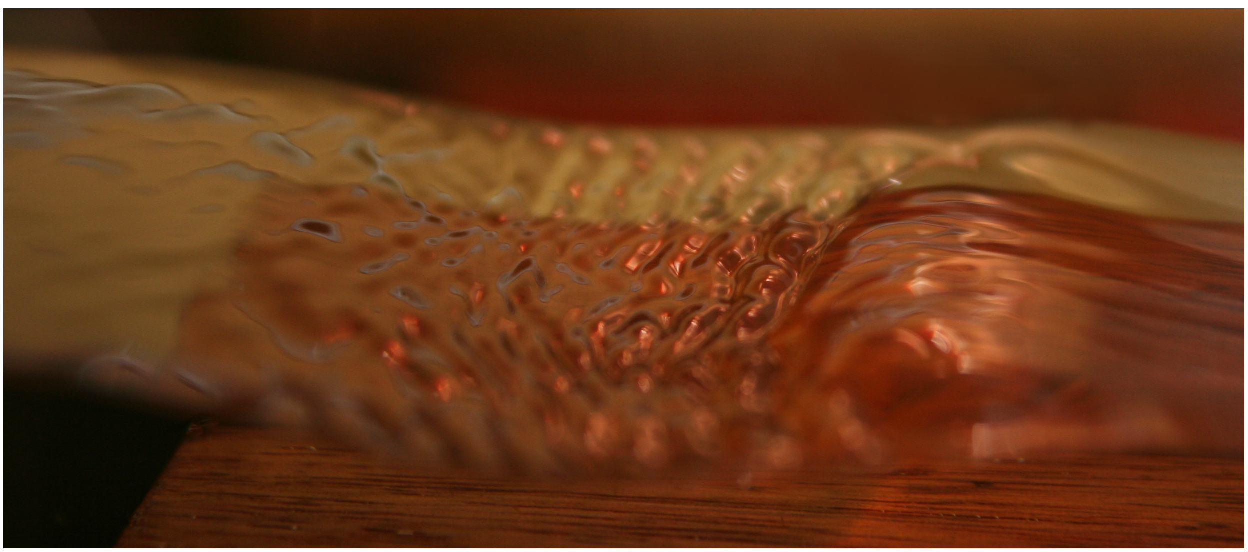

Figure 1: Image submitted to "Get Wet" assignment. A hydraulic jump occurs over the weir. Capillary waves create "folds" in the water surface.

A broad-crested weir was used to displace the flowing water, causing the hydraulic jump. Weirs allow engineers to gauge and control water depth. A sharp-crested weir usually has an angled top (sometime taking the form of a V-notch), causing the hydraulic jump to occur after the weir. Conversely, broad-crested weirs usually have flat tops and cause the hydraulic jump to occur over the weir. [1]

I chose to capture the hydraulic jump phenomena because I think it displays a strange property of fluids. When I first learned about hydraulic jumps, I found the concept confusing and had to see it for myself before understanding. So, I wanted to capture the effect to teach other students about this interesting everyday phenomena.

2 Relevant Physics

The hydraulic jump can be explained using the Bernoulli energy conservation equation 1 [1]. This is a simplification of the true nonlinear physics, but it captures energy trade-offs in bulk flows like those in pipes or flumes. It states that the energy in water is exchanged (not created or destroyed) between kinetic energy via the velocity of the water, potential energy via the water's elevation, and energy stored in pressure. This neglects energy losses like friction.

$$\frac{P}{\rho g} + \frac{V^2}{2} + gz = constant, \tag{1}$$

where P is pressure, ρ is density, g is gravity, V is velocity, g is gravity, and z is elevation.

The Froude number is a useful dimensionless quantity used to determined the ratio of the speed of water to the speed of a wave traveling in the water (2). It is used to characterize how much time a flow has to respond to a downstream obstruction. If the Froude number is low, the flow will be impacted by the obstruction far upstream of the obstruction's location, causing it to gradually adjust to the obstruction. Conversely, if the Froude number is high, the flow will have almost no time to respond to the downstream obstruction, causing a violent reaction, refered to as the hydraulic jump. Usually broad crested weirds are designed so that the Froude number is equal to unity at the crest (downstream side) of the weir, which can be used to estimate the volumetric flow rate (Equation 3) [1].

$$Fr = \frac{V}{\sqrt{gy}}, \tag{2}$$

where y is water depth,

$$Q = AV = A\sqrt{gy}, \tag{3}$$

where Q is the volumetric flow rate associated with Fr=1 and A is cross-sectional wetted area.

3 Methodology

The flume was run. The volumetric flow rate was measured to be XXX. The broad-crested weir was placed in the flume and the water height was adjusted to achieve the desired hydraulic jump. The water elevate on the weir crest was measured to be 3.25 inches. A Cannon Rebel XT camera was used to capture the image. The camera operator (Julian Quick) used their hand to block the flash from the camera, creating a warm glow.

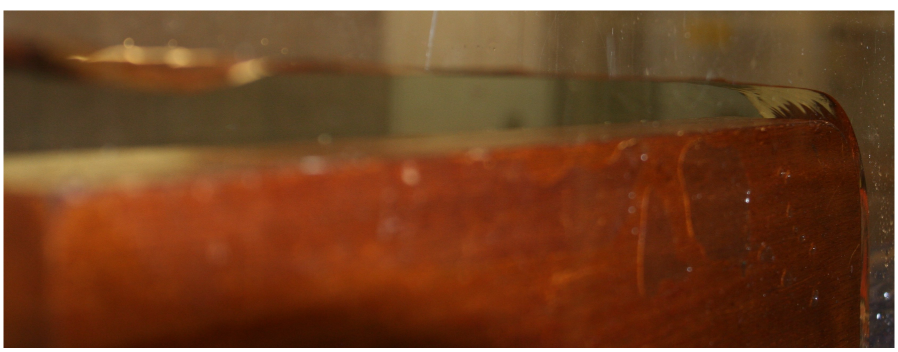

Figure 2: The elevation of the water surface stayed approximately constant after the hydraulic jump

The settings used to take the shot are shown in Figure 3. The focus was manually adjusted to capture the wrinkles on the water surface.

3.1 Edits Made to the Image

The original image captured stray bubbles stuck to the top of the weir and a strange blur in the background. Photoshop's "Magic Stamp" tool was used to remove these undesirable characteristics.

Dimensions:	3456 × 2304
Device make:	Canon
Device model:	Canon EOS DIGITAL REBEL XT
Color space:	RGB
Color profile:	sRGB IEC61966-2.1
Focal length:	55
Alpha channel:	No
Red eye:	No
F number:	5.6
Exposure program:	0
Exposure time:	1/60

Figure 3: The camera settings associated with the submitted photo (Figure 1)

4 Discussion

A hydraulic jump over a broad-crested weir was photographed. This image demonstrates the hydraulic jump fluid phenomena and allows the viewer to estimate the water velocity, given the measured water elevation at the weir crest. Using the measured crest height, equation (2), and assuming that the Froude number is one directly over the weir crest, the speed of the water flow was calculated as approximately 0.9 meters per second or two miles per hour. The wrinkles on the water are interesting–it looks like the water is wrinkling due to the hydraulic jump. Despite my efforts, I was not able to use the information in the photo to make any physical statements.

References

[1] P.J. Pritchard. *Fox and McDonald's Introduction to Fluid Mechanics, 8th Edition.* John Wiley & Sons, 2010.