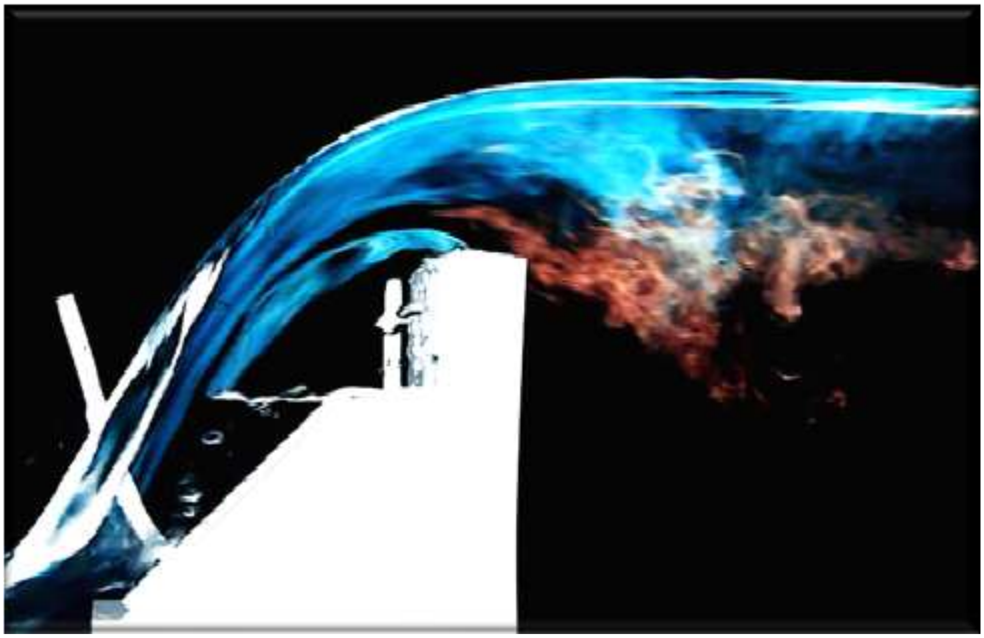
Third Team Project Report



Michael J. Vallejo

MCEN 5151 - Flow Visualization

Spring 2011

University of Colorado at Boulder

Group Members - Team 6:

Daniel Anson

Matthew Feddersen

Bradley Samuels

Kryztopher Tung

I. INTRODUCTION

This reports documents the visualization techniques and physics of water flow in a flume and over a weir for the third of three team projects of the Flow Visualization course at the University of Colorado at Boulder (CU). The goal of this document is to describe the converging fluid flow over a rectangular weir presented on the cover page (p. 1) and photographic techniques used to capture the image. The discharge coefficient of water over the weir and dimensionless fluid ratios will be described in some detail.

II. FLOW APPARATUS

The open-channel flume located in the CU Integrated Teaching and Learning Laboratory (ITLL) was used to capture the image of investigation (see Figure 1). The flume is a transparent channel that circulates room temperature water (around 20 °C) for hydraulics experiments. A blunt, rectangular weir was attached to the bottom of the channel approximately 65 cm from the water inlet. The tiltable flume was set to a horizontal slope (0%) and adjusted to a flow rate of approximately 0.001 m^3/s (see Section III for derivation of flow rate). Additional features of the experimental setup are depicted in Figure 2 including location of the weir, height of flowing water in relation to the flume, head, location of lighting sources, camera position and channel dimensions. A semi-opaque backdrop was attached to the transparent flume in order to reduce glare from ambient lighting. The lighting used was the black and yellow studio lights checked out from the CU Durning lab (unknown wattage). The water in the image was bleached in order remove previous additions of food dye prior to capturing photo and video; this investigation assumes the bleach does not alter the fluid properties of the water.

Figure 1. ITLL Open Channel Flume.

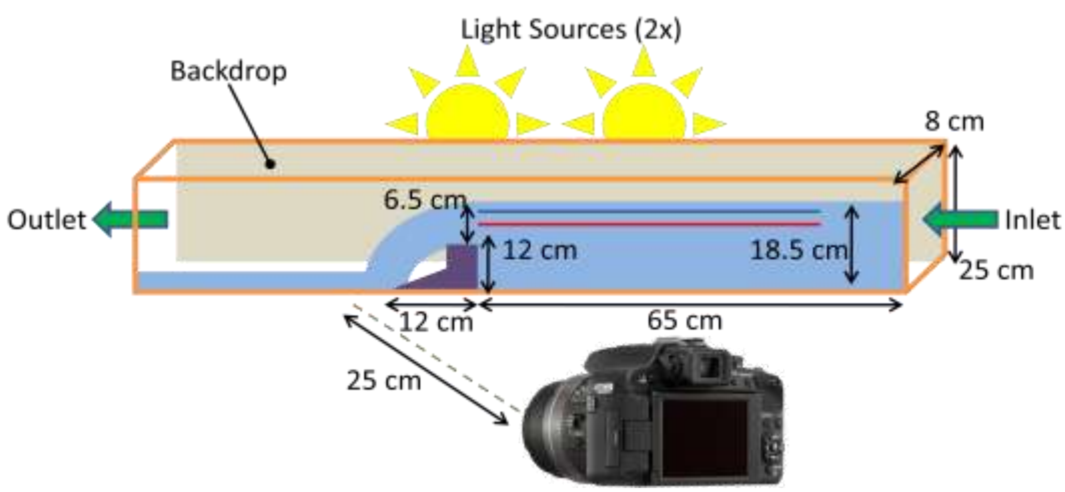


Figure 2. Flow apparatus including camera location, flume (orange), weir (purple), light sources and backdrop (FZ100 camera image courtesy of Panasonic[1]).

III. DESCRIPTION OF FLOW

Weirs are important tools used in hydraulic engineering to measure flow rates of bodies of water such as dams and streams. The flume flow rate upstream, or that of the water before it comes in contact with the weir, was roughly measured using the food dye used for visualization. A drop of dye was placed into the flowing water 65 cm from the weir and timed with a stop watch; the drop of dye traveled 65 cm in 9 seconds, resulting in an upstream velocity V_u of 0.072 m/s. For reference, the flume flow rate upstream Q_u can be calculated using the width of the flume *b* and height of the water upstream *h* as

$$Q_u = V_u bh = \left(0.072\ \frac{m}{s}\right)(0.080\ m)(0.185\ m) = \ 0.001\ m^3/s$$

The velocity downstream of the weir V_d can be approximated based on the flow rate over the top of the weir Q_d using the following equation based on the Bernoulli equation for a rectangular weir[2]

$$Q_d = \frac{2}{3} Cb\sqrt{2g}H^{3/2}$$

where *g* is the acceleration from gravity (9.81 m/s^2), *H* is the head height or difference between rectangular weir height and upstream water height and *C* is the discharge coefficient. While flow over a weir can roughly be calculated solely proportional to head height, the discharge coefficient includes factors such as surface tension and inertia effects that alter the velocity distribution of the downstream water fall. In order to calculate inertia and surface tension of the flow, the Weber number *We* and Reynolds number *Re* and are calculated respectively. The upstream Weber number of the water before it comes in contact with the weir is based on the density of the water ρ (998.2 kg/m^3), surface tension σ (0.0728 N/m), flume width and upstream velocity as follows

$$We = \frac{\rho V_u^2 b}{\sigma} = \frac{\left(998.2\ \frac{kg}{m^3}\right)\left(0.072\ \frac{m}{s}\right)^2 (0.080\ m)}{0.0728\ kg \cdot \frac{m}{s^2}/m} = 5.7$$

The downstream Reynolds number suggested by Aydin, Altan-Sakarya and Sisman[3] can be calculated based on the dimensions of the weir and head, gravity and the kinematic viscosity ν of water (1.004E-6 m^2/s)

$$Re = \frac{\sqrt{2gH}\sqrt{bH}}{\nu} = \frac{\sqrt{2(9.81\ m/s^2)(0.065\ m)}\sqrt{(0.080\ m)(0.065\ m)}}{1.004E-6\ m^2/s} = 81110$$

suggesting that the flow over the weir is laminar. Munson, Young an Okiishi[2] suggest that for small Weber and Reynolds number effects, the following correlation for the discharge coefficient as a function of head and rectangular weir height *P* is appropriate

$$C = \ 0.611 + 0.075\left(\frac{H}{P}\right) = 0.611 + 0.075\left(\frac{0.065\ m}{0.120\ m}\right) = 0.651$$

Inserting *C* into the downstream equation yields the following flow rate for the water falling from the weir

$$Q_d = \frac{2}{3}(0.651)(0.080\ m)\sqrt{2\left(9.81\frac{m}{s^2}\right)}(0.065\ m)^{\frac{3}{2}} = 0.003\ m^3/s$$

It should be noted that this flow rate falls within the experimentally determined values determined by [3] for a 0.08 m wide weir.

IV. VISUALIZATION TECHNIQUES

As described in Section III, the goal for visualization was to capture the effect of the changing velocity and flow rate of the water flowing over the weir. To do this, two different colors of food dye (blue and red) were dropped into the flowing water using eyedroppers near the inlet to the flume. The dye highlights both convergence near the fluid stagnation point at the weir and streamlines that show the constricting flow cross section as the water overcomes the top of the obstacle. As will be described in the next section, color inversion of the image was used to darken the background and create a "flame" effect from the converging blue dye particles.

V. PHOTOGRAPHIC TECHNIQUES

a). Camera Settings

A 14.1 megapixel Panasonic Lumix DMC-FZ100 digital camera was used for the image. The image is a screenshot of a high definition video shot at 30 frames per second at 1280 x 720 widescreen pixel resolution. The screenshot was captured by running the video in Apple QuickTime Pro and using the print screen key on the keyboard. The screen capture was then pasted into Microsoft PowerPoint and saved as image files (tiff and jpeg formats).

Still shots of water flowing in the flume were also taken which include image data stored by the camera. The video of the fluid flow was taken with the camera lens 25 cm from the front of the flume as depicted in Figure 2. The camera was placed on a tripod while filming. A focal length *f* of 10 mm was used in order to zoom in on the weir. The field of view was approximately twice the length and height of the weir at 25 cm x 25 cm. For the exposure, a shutter speed of 1/125 s and an f-stop (relating to aperture size) of *f*/3.36 was used. The shutter speed and aperture diameters were chosen to balance the incoming light into the camera lens with a relatively quick exposure time in order to capture the rapidly changing dynamics of the fluid flow. ISO data was not captured but the sensitivity setting is estimated to be 400.

b). Image Post Processing

Adobe Photoshop CS5 was used for post processing of the image. The original 960 x 720 pixel JPEG image was imported into Photoshop to begin post processing. The image was then cropped to 740 x 477 pixels in order to remove unwanted details around the weir and the widescreen video bands. The colors of the image were then inverted to create the black background and a flame-like effect from the water and food dye impacting the weir. The contrast was adjusted to 100 to deepen the tones and colors of the image. Finally, the RGB curve in Photoshop was adjusted to further darken the background and dye highlights. The original image and post processed image are shown side-by-side in the figure below.

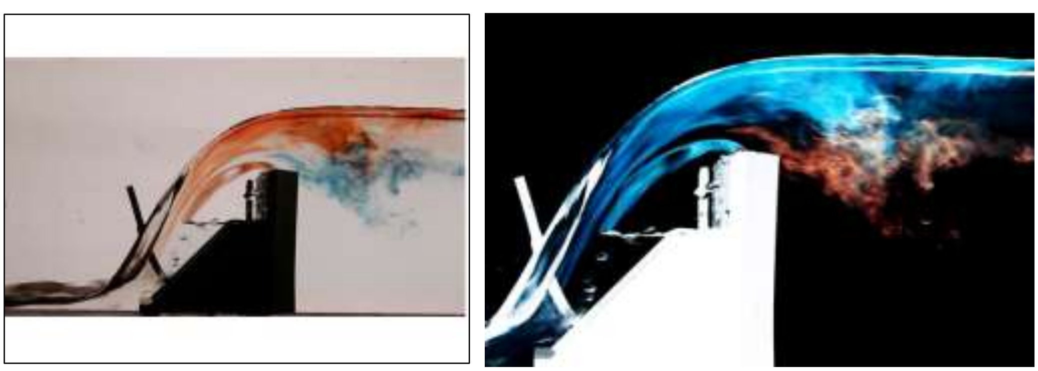


Figure 3. Original screenshot (left) and image following post processing (right).

VI. IMAGE ANALYSIS AND CONCLUSIONS

The image clearly captures the converging effects of water flow over a rectangular weir. The physics of the falling water and stagnation effects are shown well. Several areas for further investigation can be made regarding the fluid flow including detailed calculation of vortices around the weir, pressure and velocity distribution curves and fluid statics of the water just below the falling water stream. The visualization can also be improved in a number of ways. The resolution of the image is small and can be improved by either extracting an image from the video using video editing software (rather than a screen shot) or snapping a photo directly.

VII. REFERENCES

[1]Panasonic. "DMC-FZ100K - Lumix Digital Cameras." Panasonic Digital Cameras. 2009. Accessed 9 February, 2011. <http://www2.panasonic.com/consumer-electronics/shop/Cameras-Camcorders/Digital-Cameras/Lumix- Digital-Cameras/model.DMC-FZ100K.S_11002_7000000000000005702#tabsection>.

[2]Munson, Bruce, Donald F. Young and Theodore H. Okiishi. Fundamentals of Fluid Mechanics. New York: Wiley and Sons, 2002.

[3]Aydin, Ismail, Altan-Sakarya, A. Burcu and Sisman, Cigdem. "Discharge formula for rectangular sharp-crested weirs." Flow Measurement and Instrumentation 22 (2011): 144-151.