Figure 1: Final Image

Team First Report

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3/9/2018

MCEN-4151

Flow Visualization: The Physics and Art of Fluid Flow

Background

This image is of water being poured from a pitcher with a curved spout. The shape of the pitcher and velocity of the fluid creates small capillary waves in the surface as the water moves over the lip. This type of wave is often seen as an aftershock of something splashing into a pool of liquid. Capillary waves are purely surface waves with the surface tension as the restoring force. The diamond shapes are due to interference between the capillary waves formed at the edges of the flow.

Experimental Setup and Process

For this image, the only fluid used was water. The water was poured from a pitcher with a curved edge as a spout, fig. 2, and a top diameter of 4 in. The geometry of the pitcher is what created the waves in the water as it was poured out. The final setup can be seen in fig. 3. Finding a lighting angle that would highlight the waves was difficult and took much experimentation. The lighting for the final image consisted of light from a window and desk lamp below and to the left of the water. Behind the water, white paper was placed on a music stand to reflect the light back through the water and proved a clear background. It was a dreary day, so the light from the window was not sufficient to correctly illuminate the water.

Figure 2: Pitcher used in this experiment.

The water was poured from behind the backdrop into a bucket on the floor. The bucket was only semi successful in catching the water, which resulted in a very flooded kitchen. Since the lip of the pitcher needed to be below the top of the paper, the angle of the pitcher was quite high. The amount of water per pour was relatively low to achieve the correct flow velocity with this high pitcher angle. Around 50 pours were attempted before the correct velocity, angle, and focus to capture the wave phenomenon were found.

The image was captured using a Canon EOS Rebel XSi with an 18-55mm lens. To focus the image correctly, a focal length of 48mm, and exposure of 1/50, and F29 were used. The ISO was set to 800. The distance between the camera and the water was approximately 5 in.

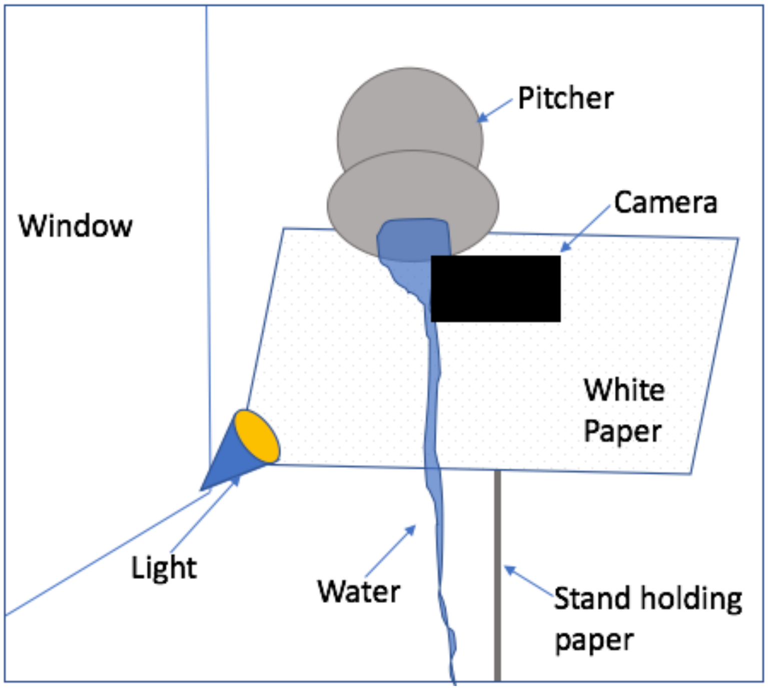

Figure 3: Experimental setup.

Post Processing

The original image can be seen in fig. 4. From here, the image was cropped, and adjusted using Adobe Photoshop. The adjustments done are pictured in fig. 5 for the curves. The color balance for the midtones was moved to +20 blue, with the other colors remaining at 0. No other post processing or editing was done to the image.


Figure 4: Original image.

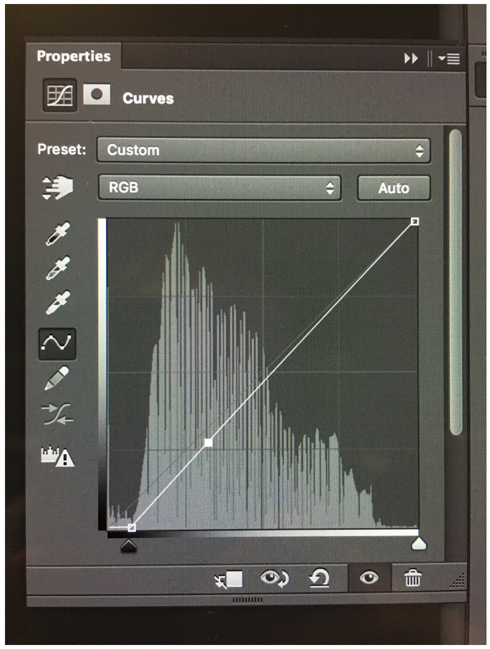

Figure 5: Curves adjustment in post processing.

Fluid Physics

The flow is a product of gravity, and is facilitated by tilting the pitcher until the surface of the water is higher than the neck of the pitcher. When this occurs, the water readily flows out over the lip of the pitcher. When the water flows over the lip, small capillary waves are formed due to a disturbance in the surface tension of the water. The surface tension of water in contact with air is roughly $7 \times 10^{-2}\ \frac{N}{m}$, and is the restoring force for these waves [1]. Larger waves are driven by gravity not surface tension. Since the surface tension is a relatively constant force, capillary waves can only occur when the wavelength is less than 1.76 cm [2]. Surface tension may vary with impurities in the water, slightly changing this critical wavelength. Even with the waves, this flow is laminar. As can be seen in fig. 1, the waves from either side of the water interfere to create a diamond shaped pattern

These waves are purely surface waves, and do not propagate beneath the surface. Therefore, the dispersion relation is different than that of gravity waves in shallow water. The dispersion coefficient for shallow water can be seen in eq. (1), where g is the acceleration due to gravity, h_0 is the water depth, and k the wave number.

$$\omega = \sqrt{g h_0} k \tag{1}$$

When surface tension plays a role in the wave and its propagation, the dispersion equation changes to include not gravity, but the effective acceleration of gravity. The new dispersion equation becomes eq. 2, where γ is the surface tension, and ρ the density of the fluid. When the second term under the square root becomes the dominant term, the waves becomes a capillary wave [3].

$$\omega = \sqrt{gk + \frac{\gamma k^3}{\rho}} \tag{2}$$

Conclusion

Fluid dynamics and physics are everywhere, surrounding us in so different many ways. Nothing fancy was done to achieve this image and observe this phenomenon. These diamond shaped waves were first observed when created by a restaurant water pitcher and recreated for this project. It is fascinating to look closer at everyday occurrences and discover the physics that create these interesting phenomena

References

[1] Britannica, The Editors of Encyclopaedia. “Capillary Wave.” *Encyclopædia Britannica*, Encyclopædia Britannica, Inc., 4 Jan. 2011, www.britannica.com/science/capillary-wave.

[2] Fitzpatrick, R. “Capillary Waves.” *Oscillations & Waves*., 4 Aug. 2013, http://farside.ph.utexas.edu/teaching/315/Waves/node71.html.

[3] Blandford, R., and Thorne, K. “Waves.” *Applications of Classical Physics,* Ch. 16. 16 Sep. 2011, http://www.pmaweb.caltech.edu/Courses/ph136/yr2012/1216.1.K.pdf.