Splish Splash

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Team First Assignment

MCEN 5151: Flow Visualization

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1 Introduction

After a muddy camping trip in Moab, Utah, I used my backyard hose to wash off all of my camping gear. While spraying down my tent rain fly, I noticed pools of foaming, stagnant water in the valleys of the tarp; this gave me the idea for this image. The photograph in this document is intended to aid in the visualization of current and small waves. This image was taken using techniques discussed in MCEN 5151: Flow Visualization, fulfilling the requirements of the Team First assignment. This experiment used a rain fly and standard garden hose to produce current over a false terrain. Rohan Malhotra assisted in setting up the tarp and adjusting the hose flow rate, and Konstantinos Stathopulos operated the hose as I shot this image. The final image captured fingering of a fluid ridge line, air bubbles entrapped in turbulent flow, and aesthetic appeal.

2 Flow Phenomena

Two of the most notable flow phenomena depicted in this visualization are the 'fingering' of the surface of the water, and the air bubbles entrapped underneath the surface.

To analyze the fingering of the surface of the fluid, we shall consider the water as a film, or thin layer, of fluid moving over the surface of the tarp. As this film ascends the ridge of the tarp, it is subjected to viscous forces, gravity, water pressure, and surface tension. The combination of these forces produces the fingering structure as seen in this visualization. As the film approaches the ridge, there are small-amplitude perturbations in the terrain. This leads to thicker regions of the film, which experience less viscous drag and faster velocity compared to the thinner regions of film, thereby amplifying said perturbations. This results in instability within the fluid, as well as the fingering in this image (Gounley, J., et al. 2016). When understanding the motion and shape of the water, a relevant value to consider is the Capillary number; this is a dimensionless quantity that describes the ratio of viscous forces to surface tension. This number can be mathematically described as follows.

$$Ca = \frac{\mu^{\text{ext}}\,\dot{\epsilon}\,a}{\gamma}$$

Where: μ^{ext} is the viscosity of the ambient surface, $\dot{\epsilon}$ is the shear rate, a is the initial droplet radius, and γ is the resistance of surface tension between the two surfaces (Gounley 2016). In the context of this experiment, μ^{ext} is estimated as 1E-3 Pa, γ is estimated as 7.28E-2 N/m (Engineeringtoolbox 2024). Then, $\dot{\epsilon} * a$ can be estimated as the characteristic velocity of the fluid. The flow rate of a standard residential spigot is $\frac{L}{min}$, or 1.67E-4 $\frac{m^3}{sec}$. Considering a film area of 0.5m wide by 0.005m thick, this velocity is estimated as 0.0668 $\frac{m}{s}$. The capillary number is then estimated as:

$$Ca = \frac{(1E-3) * 0.0068}{7.28E-2} = 9.18E-4$$

Viscous force dominating the surface tension is represented through a higher Capillary number. This is generally representative of an irregular fluid shape, such as the fingers in this image. Although there are no comparative Capillary numbers for this image, we can figure that the fingering is due to the viscous forces out competing the surface tension.

The surface of the water has trapped air bubbles; the source of these bubbles is the point of contact between the flow from the hose and the tarp. When the water hits the surface, it crests like a wave and traps pockets of air when it folds over itself. Additionally, the uneven terrain allows for the entrapment of more air pockets. These pockets remain trapped underneath the water due to surface tension. As the turbulent flow continues to move irregularly, the pockets are then broken into the smaller bubbles from this photo (Na, Byoungjoon, et al. 2016). The air bubbles beneath the surface of the water are highly indicative of turbulent flow.

3 Visualization Technique

The passage of water over the irregular terrain of a water-resistant rain fly generated the splash pattern captured by this visualization. In preparation for the experiment, the tarp was arranged with an irregular surface on an area of grass as seen in the image below; this simulated terrain peaks and valleys. The water source was a garden hose attached to a fully open residential spigot. Iterations of this experiment involved manually obstructing the flow by the operator's thumb to increase water pressure and velocity, but this specific image was generated with unobstructed laminar flow from the hose. There was a three-foot spacing between the surface of the tarp and the opening of the hose, and eight to twelve inches between the flow's point of contact and the ridge seen in this image. The flow was directed toward the base of a ridge, which it ascended and collapsed upon itself.

Figure 1: Visualization setup

The experiment was conducted outside around four o'clock in the afternoon, and natural sunlight was used as the primary light source. Since direct mid-day sunlight is typically uneven, the set-up was placed within the shadow of a tree to prevent uneven shadows on the tarp. Although indirect, this lighting was found to be adequate for the exposure of this image series.

4 Photographic Technique

Captured using a Nikon D810 paired with a macro-lens, this image demonstrates close-up, high-definition details of the flow. The Nikon D810 is a full frame sensor DSLR, producing an image size of 7380 x 4928 pixels. The lens used was a Nikon macro lens with a fixed focal length of 105mm and maximum aperture of f/2.8. This macro lens was chosen to magnify the fine details of the surface of the water, and blur the background to bring focus to the phenomena. The exposure was set as follows: ISO-640, F-stop f/5, and shutter speed 1/1000 sec. The need to freeze an instantaneous moment of the flow drove the decision to use a fast shutter speed. Because of the fast exposure, the ISO was relatively high compared to the D810's native settings, and the aperture was wide to allow more light on the sensor. The field of view in the original image is roughly seven inches by five inches, and the camera was as close to the flow as possible without being splashed (about two feet). Since the flow was constantly moving, auto-focus was unable to select a steady focal point. Manual focus was used to control the focus because of this, although it proved challenging to consistently change the focus while taking pictures. The final image was developed using Adobe Lightroom, with a final image size of 5162 x 3433 pixels. Contrast was edited to brighten the highlights and dim the shadows, and exposure was brought up. These edits provided better detail and clarity to the flow in the image. The vibrance of the image was increased, primarily for aesthetic appeal, which resulted in added blue-tone to the final image. Cropping was used to fill the frame with the flow through the removal of sections of the tarp and background. The original photo is displayed below for reference.

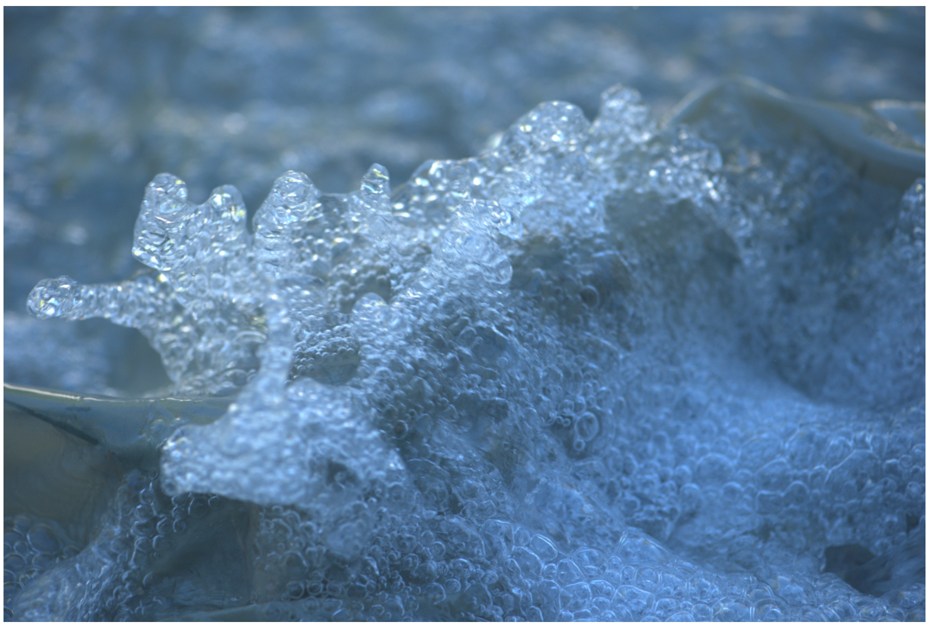

Figure 2: Unedited, original photograph

5 Artists Statement

This photograph is useful in understanding oceanographic current and wave phenomena. Although my initial intent was to capture the foamy, stagnant pools of the fluid, I am much happier with how this turned out. This final image proved to be much more complex, involving unanticipated bubble texture and fluid structure. This detailed image allowed for a deep investigation into the physics of this fluid structure, as well as admiration for beauty found in nature. As an artist, this is my favorite and most impressive work.

6 Citations

Engineeringtoolbox, Editor. "Surface Tension - Water in Contact with Air." Engineering ToolBox, 4 Apr. 2024, www.engineeringtoolbox.com/water-surface-tension-d_597.html.
Gounley, J., et al. "Influence of Surface Viscosity on Droplets in Shear Flow: Journal of Fluid Mechanics." Cambridge Core, Cambridge University Press, 22 Feb. 2016, www.cambridge.org/core/journals/journal-of-fluid-mechanics/article/influence-of-surface-viscosity-on-droplets-in-shear-flow/F6179DAA0126660CA250EAEF7890D1F8.

Na, Byoungjoon, et al. "Turbulent Flow Field and Air Entrainment in Laboratory Plunging Breaking Waves." Advancing Earth and Space Sciences, 6 Apr. 2016, agupubs.onlinelibrary.wiley.com/doi/10.1002/2015JC011377.