Good Vibes: Capillary Wave Action

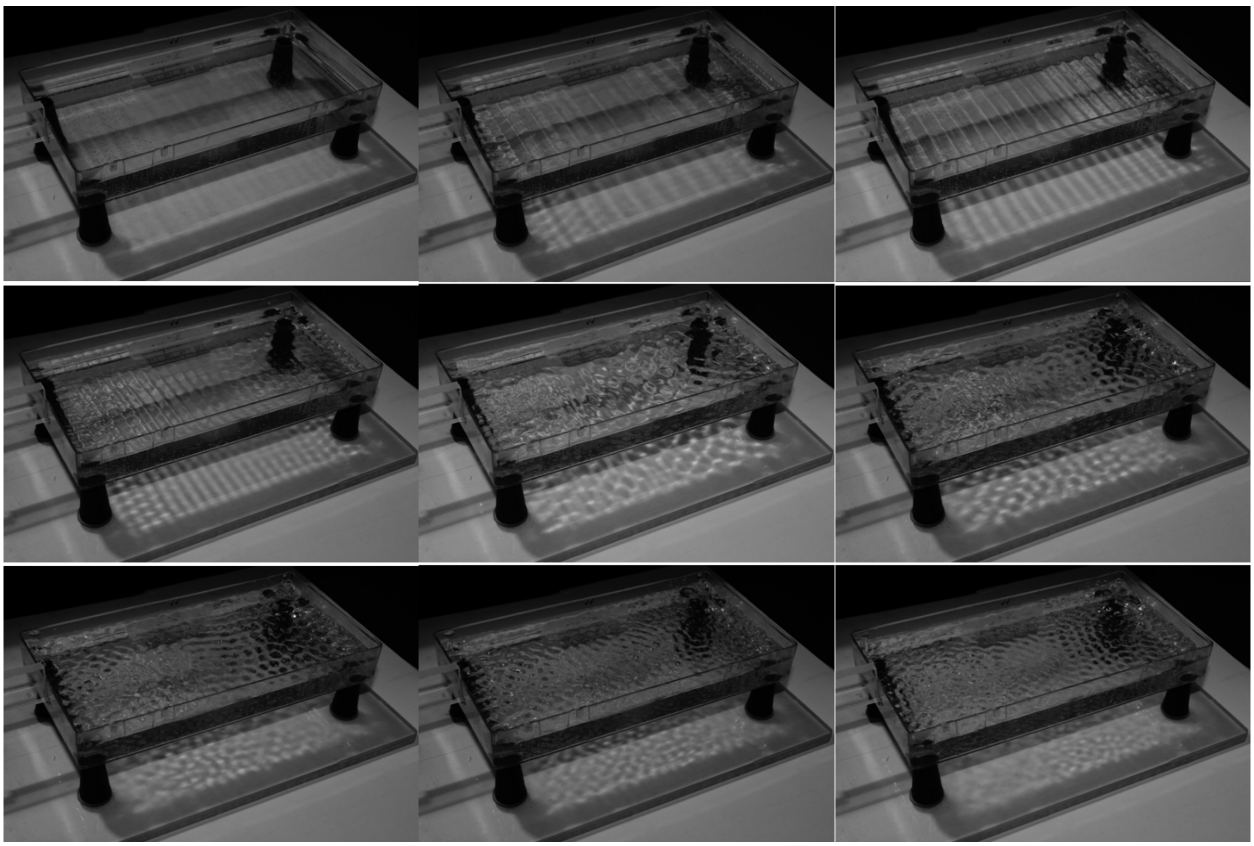

Figure 1: Final, edited images which were excerpted from a GIF

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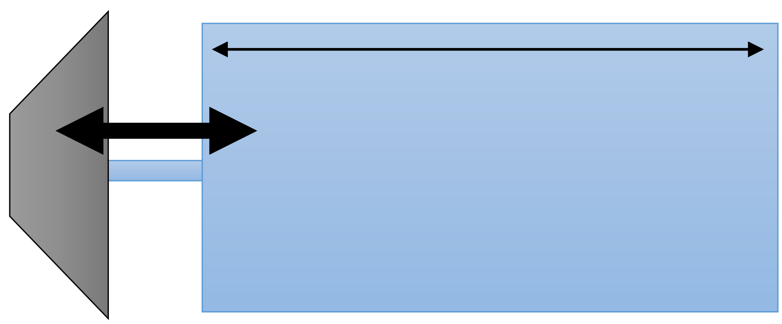
Introduction

This image was produced for the Team First assignment for the Fall 2015 Flow Visualization course offered in the University of Colorado School of Engineering. The objective of the assignment was to produce an aesthetically appealing image that captures a unique physical phenomenon that can later be analyzed. The intent of the experiment behind this image was to examine the dynamics of a Newtonian fluid that has been excited by acoustic waves. In other words, what effect does sound have on the creation of ripples in water?

The photos shown on the previous page in Figure 1 were taken during the afternoon of October 19th using a capillary wave generator provided by Scott Kittelman (alan.kittelman@colorado.edu) and in cooperation with Yasmin Mazloom, who provided the location, lighting, and scenery for the photo shoot. The final product was a continuously looping GIF file composed of nearly 20 images, of which a representative sample has been provided in Figure 1.

Experimental Methodology and Observations

The setup for this experiment involved a relatively simple setup of the capillary wave generator (see Figure 2). The generator consisted of a small tray, sized 20 x 10 x 2 cm, that was positioned atop four rubber stoppers. A Plexiglas beam, seen in the left-hand side of the frame, was attached from the tray to a four-inch speaker driver. The speaker was powered by the combination of a frequency generator and amplifier and forced the tray to vibrate with it via the beam, imparting energy into the fluid. The system was photographed at a range of frequencies, from 10 – 100 Hz at 5 Hz intervals.



The basic phenomenon being observed is that of capillary waves, i.e. small, free-surface waves with short wavelengths (< 1.73 cm) such that the dominant restoring force of the fluid is its surface tension.[1] As can be seen in Figure 3, even the longest waves, which were produced at 10 Hz, have a wavelength shorter than this maximum. As is to be expected, the higher frequencies resulted in shorter wavelengths. While the speaker is forcing energy into the system and creating the ripples, the surface tension of the water is dampening those oscillations to produce the observed patterns.

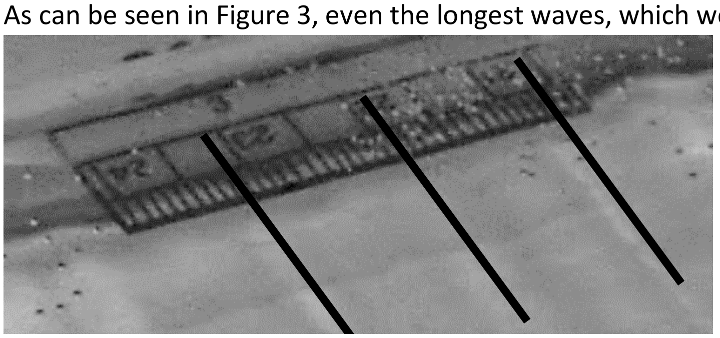


Figure 3: Close up view of the fluid at 10 Hz, with corresponding length scale defined in centimeters. The black lines emphasize wave troughs

Capillary waves can be defined with the help of the following equation[2]:

Equation 1: Dispersion relation for capillary waves

$$\omega^2 = \frac{\sigma}{\rho + \rho'} |k|^3, \quad \lambda = \frac{2\pi}{k}.$$

Where ω represents the angular frequency of the wave, σ is the surface tension, ρ is the density of the water, ρ' is the density of the air, and k is the wavenumber. A rough estimation of the angular frequency can be achieved by making the following assumptions at room temperature: σ = 0.072 N/m, ρ = 1000 kg/m^3, ρ' = 1 kg/m^3, and λ = 0.0125 m (from Figure 3).[3] The angular frequency of the fluid, then, is approximately 96 Hz when it is being driven at 10 Hz.

More specifically, the waves can be considered Faraday waves, defined as the nonlinear standing waves that appear on liquids enclosed by a vibrating receptacle.[4] Mr. Faraday's experiments involved a tray of fluid placed atop a speaker that vibrated vertically, however as this experiment demonstrates, the horizontal arrangement produces similar dynamics with a few unique characteristics. The most notable difference is the existence of stable, linearly arranged ripples that eventually transform into the unstable, seemingly random arrangement of wave patterns at higher frequencies. The breakdown in stability occurred between the 40 Hz and 50 Hz forcing frequencies, corresponding to angular frequencies of roughly 287 Hz and 645 Hz, respectively. Further research and more rigorous data analysis would be needed to narrow this range to a particular frequency and also to explain the reason behind the loss of stability.

Visualization Technique

The water used in this experiment was simply taken from a tap and was not modified in any way. The setup was placed in a photography light box without a top and a black felt mat was placed in the box and a white piece of cardboard was placed on top. The capillary wave generator was then placed on the cardboard. Two large tungsten lamps were used to light the scene from above so that the corners of the shadow aligned with the corners of the Plexiglas baseplate.

Photographic Technique

The field of view was intended to capture the entirety of the water tray as well as the shadow produced below. The photo was captured using a 55mm diameter lens with a focal length of 45mm and has an image size of 4592 x 3056 pixels. At a distance of approximately two feet from the setup in order to achieve the appropriate field of view, the field of view is roughly 30 cm wide by 20 cm high. It was captured using a Sony DSLR-A290 which was adjusted to the following settings: aperture = f/16, exposure time = 1/100 sec, ISO speed = ISO-100, exposure bias = 0 step. These settings were chosen, respectively, to increase the field of focus, to freeze the motion of the waves, and to increase the contrast and purity of the raw image. The raw image is shown on the next page in Figure 4 (left).

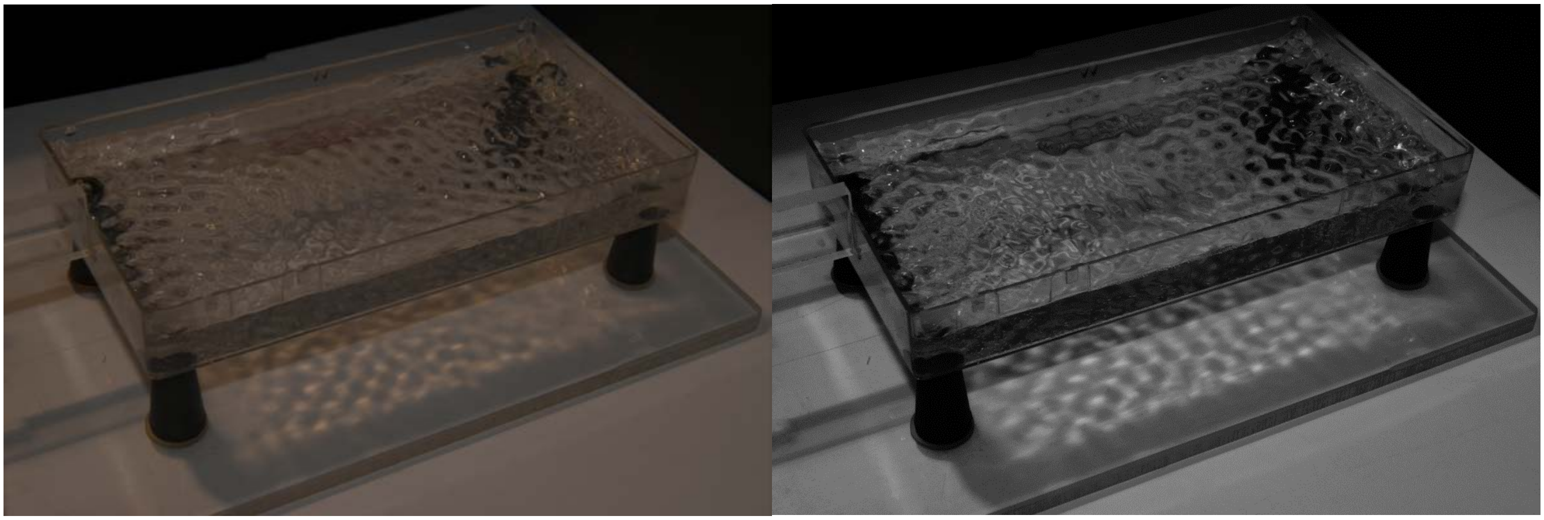


Figure 4: Comparison of before editing (left) and after (right)

Figure 4 also shows the corresponding final image (right), after processing. A series of edits were made to improve the aesthetics of the image and the ability to visualize the flow. After the addition of a black/white filter, the blacks were made blacker and the whites, whiter to increase contrast. Additionally, the exposure of the image was reduced slightly and the effect of the shadows was dramatically increased. One last touch was to increase the mid-tone contrast of the image. Overall, the intent was to make the ripples and their shadows more dramatic.

Critique

Ultimately, this piece effectively captures a number of interesting flow characteristics. The black and white filter, along with the contrast processing, really help accentuate the clarity of the fluid dynaimcs. After putting this report together it is clear that a single still image would not have been nearly as interesting or informative as the full collection and completed GIF, which unfortunately cannot be displayed in this document. That final product certainly fulfills the intent of this project.

Unfortunately, since the images were taken based upon a more aesthetic impression, they are lacking in data resolution which is necessary for more precise analysis. In order to further investigate these phenomena, the experiment could be repeated with a variety standardized of camera angles to enhance the amount of information that can be obtained. Macro imaging could potentially provide very useful data as well. Additionally, the use of a single, collimated light source would help sharpen the image, particularly in the shadows, and help reduce ambiguity during analysis. It would be very interesting to eventually understand the physics behind the instability of the water.

Bibliography

[1] http://www.britannica.com/science/capillary-wave

[2] https://en.wikipedia.org/wiki/Capillary_wave

[3] http://hyperphysics.phy-astr.gsu.edu/hbase/surten.html

[4] https://en.wikipedia.org/wiki/Faraday_wave