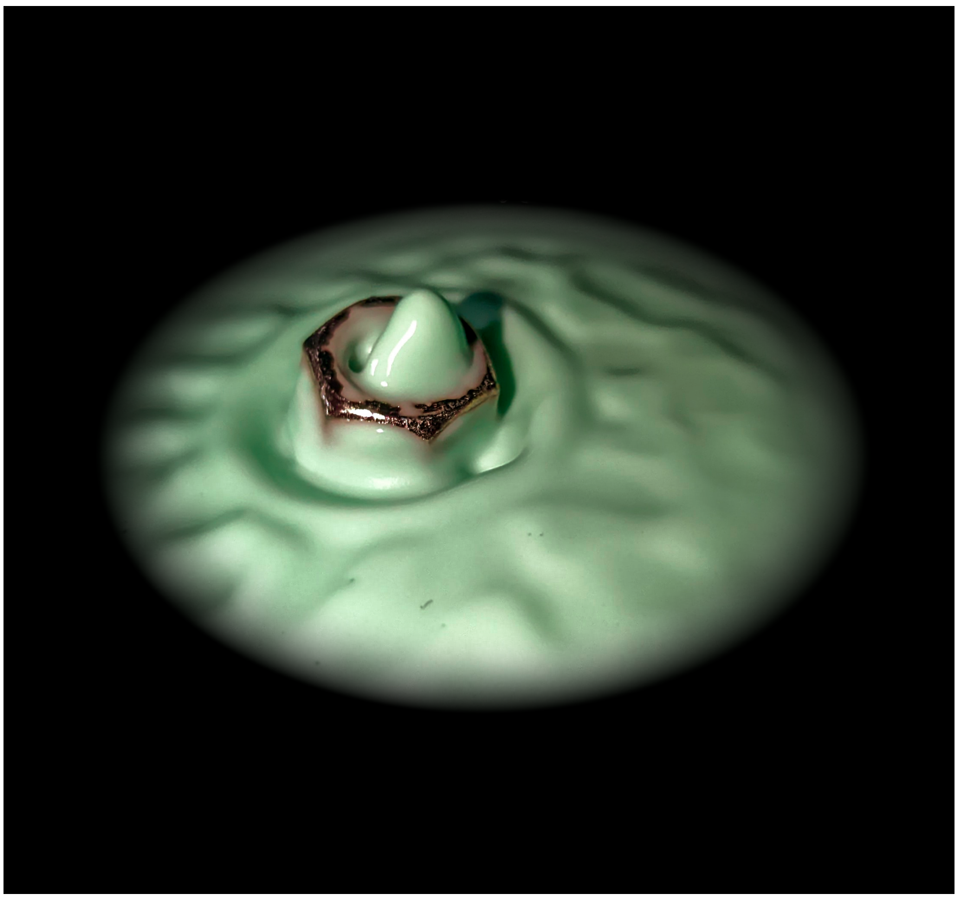
IV 4: Oobleck and Standing Waves



Isaac Martinez in Collaboration with Martin Allsbrook
IV 4 - Team First
MCEN 5228: Flow Visualization
November 14, 2022

Image Purpose and Context

This photo was inspired by some of our classmates using oobleck on the shake table in the ITLL and what my team knew about standing waves that are created in sand that is shaken at certain frequencies. We hoped to see how an object would interact with the surface of oobleck (a non-Newtonian fluid) when its surface is subject to standing waves. The end result was a distinct phenomenon not commonly seen in everyday life.

Image Circumstances

This photo was taken in one of the ITLL study rooms on November 1 at 8pm. We mixed 2 cups of Sprouts Cornstarch, 1 cup of water, and a few drops of green McCormick Food Color and Egg Dye to create our oobleck. After mixing, we poured a few ounces of the mix directly onto the subwoofer on one side of Martin's JBL Charge 4 bluetooth speaker. In order to apply a steady frequency to the speaker and fluid, I downloaded an app called "Frequency Generator" from the Google Play Store. We experimented with what frequency we wanted to use but ultimately settled on 65 Hz since it gave us the amplitudes of waves we wanted in the fluid. After we settled on the fluid behavior, we dropped a small nut from the ITLL consumables closet onto its surface. The experimental setup can be seen below in Figure 1.

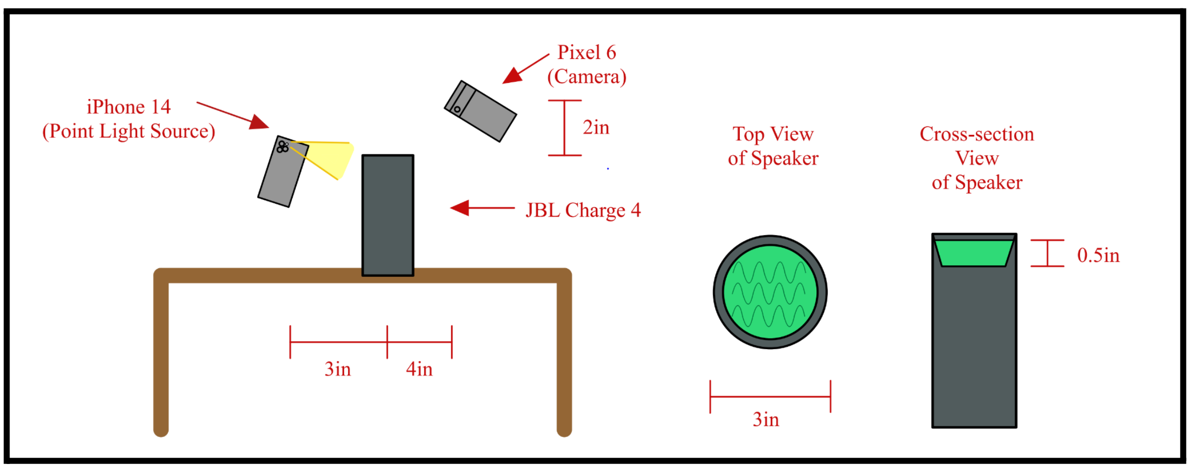


Figure 1: Experimental photography setup of oobleck on speaker.

In 1831, Michael Faraday observed standing capillary waves at the free surface of fluids on plates subjected to period vertical oscillation. He remarked the characteristic frequency of the emerging patterns of the fluid's surface was half of the driving frequency of the imposed vibration [I]. The basic equation governing the behavior of a layer of fluid in a vertically vibrating system is that of the parametric oscillator[II]. The parametric oscillator equation for infinitely small fraction of a the fluid surface is provided below:

$$z'' + 2\mu z' + \omega_0^2[1 + \alpha(t)]z = 0$$

Where z is the vertical position of the infinitesimal fraction of the surface of the surface, μ is the damping rate associated with the viscosity of the fluid, ω_0 is the frequency of oscillation of the fraction of the surface, and α(t) is the dimensionless oscillating parameter function. This is similar to the damped harmonic oscillator[III]:

$$g(t) = g + A\omega^2 cos(\omega t)$$

Where g is gravity, A is the amplitude of the vibrations of the shaker, and $\omega=2\pi f$ with f being the frequency of the driving force. Because of this, Faraday waves are sometimes referred to as "standing gravity waves". Different wave amplitudes and numbers occur are directly influenced by the frequency and intensity of waves applied to them. At higher frequencies, the unstable wave "tongues" tend to clump together and increase in number with the amplitudes being translated directly from wave intensity. For the sake of visual clarity, I have also added a link to a video from the "Interesting Clips" YouTube channel to show how the shapes of Faraday waves change based on increasing the frequency of the waves vibrating the surface of the fluid, below[IV]: Faraday waves and water .

Not much is known about exactly how the Faraday instability applies to non-Newtonian fluids, but it has been seen that the instability threshold is higher than the Newtonian case. This suggests that as the driving frequency increases, the viscosity of the solution conversely decreases. We did see this as we increased the frequency. Initially, the fluid did not want to pulsate at all, but once we approached 50 Hz, we were able to see more dramatic changes in the waveforms on the fluid's surface at smaller increased intervals of frequency. In other words, it was more "open to change" at higher frequencies.

<u>Visualization Technique</u>

This photo was taken with the back camera of my Pixel 6, since it performed better than my Canon Power SX10IS 10MP camera at capturing macro photos of the Faraday waves. The photo was taken in the evening with no lights on in the study room. The only light source came from the same level as the fluid to create shadows on the surface to better accentuate the waves with Martin's iPhone 14 4W flashlight. The raw, unedited photo can be seen in Figure 2.

Figure 2: Unedited photo of Faraday waves on oobleck

Photographic Technique

This photo was taken with the 9.1 MP back camera of my Pixel 6. The initial image had a resolution of 2268x 4032 pixels from 4 inches away (slightly higher than the horizon of the with a 3 inch field of view). The camera was zoomed in with the following settings applied:

- Aperture: f/1.9
- Exposure: 1/639
- Focal Length: 6.81 mm
- Focus Distance: 0.1 m
- ISO: 402

In DarkTable, I performed heavy edits to the image in order to remove the distracting background and speaker elements in order to bring the focus to the Faraday waves and the nut on its surface. I started by cropping the image to 2220 x 2075 pixels. I put a mask around the fluid, along the circular edge of the speaker surrounding the fluid and decreased the brightness of the background until it became black. To soften the boundary between the fluid and black edge of the mask, I added a vignette with a softening radius, so the boundary was not distracting. Once the fluid was isolated I adjusted the RGB curve to increase the color vibrancy and to cover the full dynamic range. The green-magenta balance was also increased and a low strength velvia to better contrast the color differences between the nut and fluid that were initially washed out by the phone light.

Image Reveals

I could not be happier with the outcome of this post processed image. I caught this image at the perfect time where the Faraday wave was disrupted by the nut. The unaffected areas of the wave are visible at the edges of the speaker. It is also very clear how troughs form around the edges of the nut, while the waves have constructive interference in the center of the nut. While there are some small distracting elements left on the fluid's surface (likely metal flake from the nut, pieces of dust, or dirty cornstarch from us touching the nut), I believe the color correction and cropping of the image serve to provide a very clear representation of how Faraday waves form on a non-Newtonian fluid when subject to a constant vibration.

References:

I. *Giulia, B., Giulia Bevilacqua Giulia Bevilacqua MOX, Bevilacqua, G., MOX, G. B., Shao, X., Xingchen Shao Department of Mechanical Engineering, Saylor, J. R., John R. Saylor Department of Mechanical Engineering, Bostwick, J. B., Joshua B. Bostwick Department of Mechanical Engineering, Ciarletta, P., & Pasquale Ciarletta http://orcid.org/0000-0002-1011-5587 MOX. (2020, September 30). Faraday waves in soft elastic solids. Proceedings of the Royal Society A: Mathematical, Physical and Engineering Sciences. Retrieved November 14, 2022, from https://royalsocietypublishing.org/doi/10.1098/rspa.2020.0129*

II. *Westra, M., Binks, D., & Van De Water, W. (2003). Patterns of Faraday waves. Journal of Fluid Mechanics, 496, 1-32. doi:10.1017/S0022112003005895*

III. *Yu Gu, R., Rvachov, T., & Sathananthan, S. (2014). FAR Faraday Waves. University of Toronto. Retrieved November 14, 2022, from https://www.physics.utoronto.ca/~phy326/far/far.pdf*

IV. *YouTube. (2020, June 24). Faraday Waves and Water. YouTube. Retrieved November 14, 2022, from https://www.youtube.com/watch?v=-3jsevcyP9g*

Image Assessment Form
Flow Visualization
Spring 2013

Name(s) Isaac Martinez

Assignment: IV 4 Date: 11/14

Scale: +, ! = excellent √ = meets expectations; good. ~ = Ok, could be better. X = needs work. NA = not applicable

Art	Your assessment	Comments
Intent was realized	√	
Effective	√	
Impact	!	Shows unique interaction with standing wave
Interesting	√	
Beautiful	√	
Dramatic	√	
Feel/texture	√	
No distracting elements	~	Some small particles from nut on fluid
Framing/cropping enhances image	!	Focuses the flow immensely

Flow	Your assessment	Comments
Clearly illustrates phenomena	√	
Flow is understandable	√	
Physics revealed	√	Clear standing waves
Details visible	√	
Flow is reproducible	√	
Flow is controlled	√	Speaker held at 65 Hz
Creative flow or technique	√	Uses Non-Newtonian fluid & vibration
Publishable quality	√	

Photographic/video technique	Your assessment	Comments
Exposure: highlights detailed	√	
Exposure: shadows detailed	√	
Full contrast range	√	
Focus	√	Nice focus throughout surface/nut
Depth of field	√	
Time resolved	√	
Spatially resolved	√	After cropping, yes
Photoshop/ post-processing enhances intent	!	Performs color correction, substantial cropping and good dynamic range
Photoshop/ post-processing does not decrease important information	√	

Report		Your assessment	Comments
Collaborators acknowledged		✓	
Describes intent	Artistic	✓	Standing waves & Non-Newtonian fluid
	Scientific	✓	
Describes fluid phenomena		✓	
Estimates appropriate scales	Reynolds number etc.	~	Stable flow, but struggled to quantify
Calculation of time resolution etc.	How far did flow move during exposure?	✓	
References:	Web level	✓	
	Refereed journal level	✓	Use of new research
Clearly written		✓	
Information is organized		✓	
Good spelling and grammar		✓	
Professional language (publishable)		✓	
Provides information needed for reproducing flow	Fluid data, flow rates	~	Hard to quantify due to fluid "maintenance"
	geometry	✓	
	timing	✓	
Provides information needed for reproducing vis technique	Method	✓	
	dilution	~	Good rough estimates, but mixing
	injection speed	✓	
	settings	✓	
lighting type	(strobe/tungsten, watts, number)	✓	
	light position, distance	✓	
Provides information for reproducing image	Camera type and model	✓	
	Camera-subject distance	✓	
	Field of view	✓	
	Focal length	✓	
	aperture	✓	
	shutter speed	✓	
	Frame rate, playback rate	✓	
	ISO setting	✓	
	# pixels (width X ht)	✓	
	Photoshop and post-processing techniques	✓	
	"before" Photoshop image	✓	