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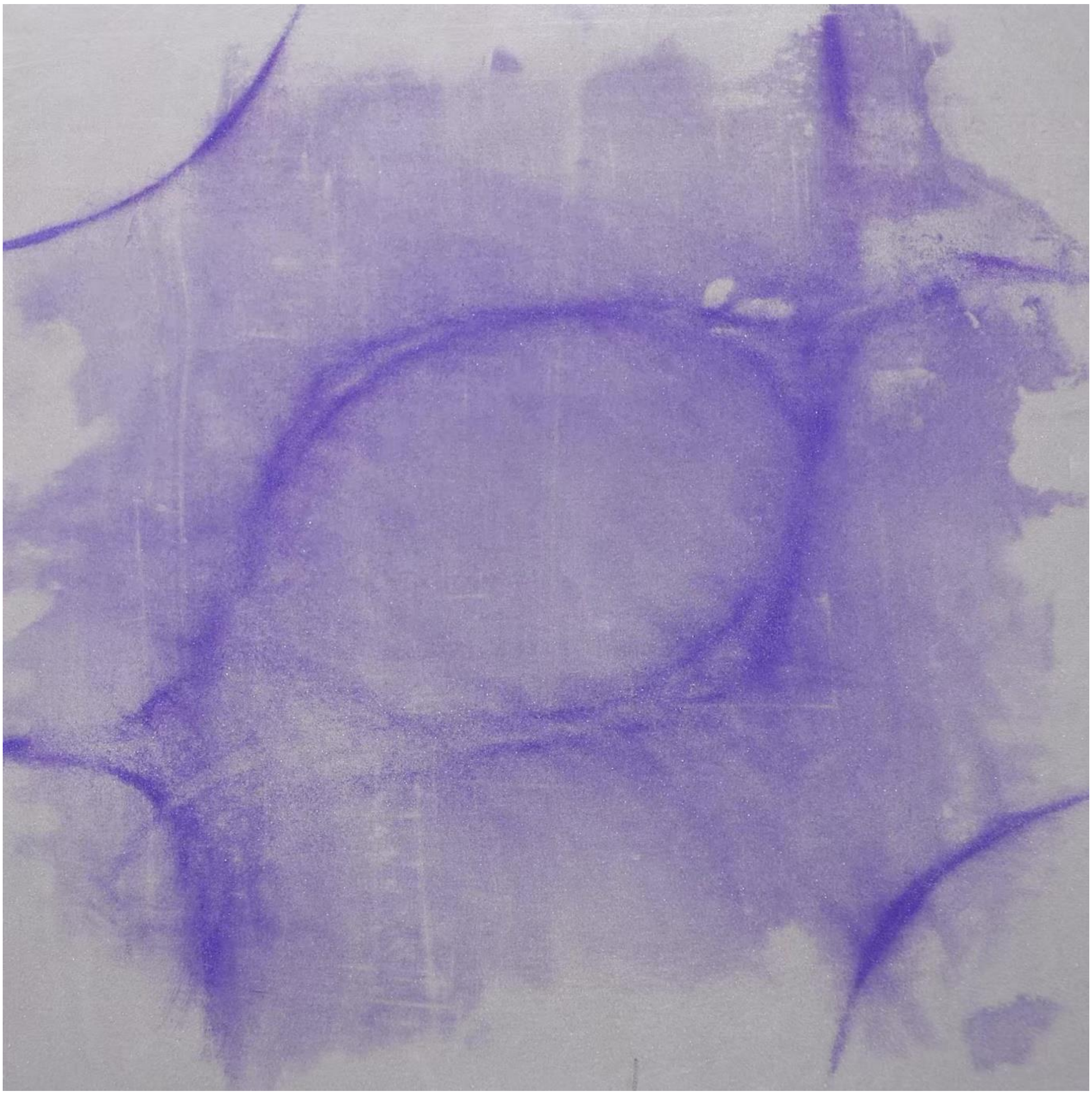
MCEN 5151 Flow Visualization

11/10/2023

Team Second Report: Sand Resonance



I. Context & Purpose

Flow visualization is an observing technique that makes transparent fluid flow patterns more visible by using adjuncts like optical methods or dye tracers. Therefore, flow visualization is not only widely used in scientific analysis, but also important in the artistic field. In the Team Second Assignment, Team Snap Peas considered exploring a special physical phenomenon called sand-resonance: Prepare a board and attach an audio exciter to the bottom side of the board. Then sprinkle sand evenly on the board. When the audio exciter is activated, it transmits vibrations throughout the board, and the sand resonates as it forms different patterns under the influence of these vibrations. Even though sand is a solid, a large amount of sand particle can flow to form visible, unique visual patterns. I decided to record video with my camera to record the movement of the sand at different frequencies and waveforms, and the beautiful patterns formed. I'd like to thank my teammates, Abhishek Raut and Alexandr Vassilyev. I acknowledge that they provided a lot of help and suggestions during the recording: Abhishek Raut offers excellent equipment and operation, and Alexandr Vassilyev provided wonderful ideas about the purpose of this assignment.

II. Flow Apparatus

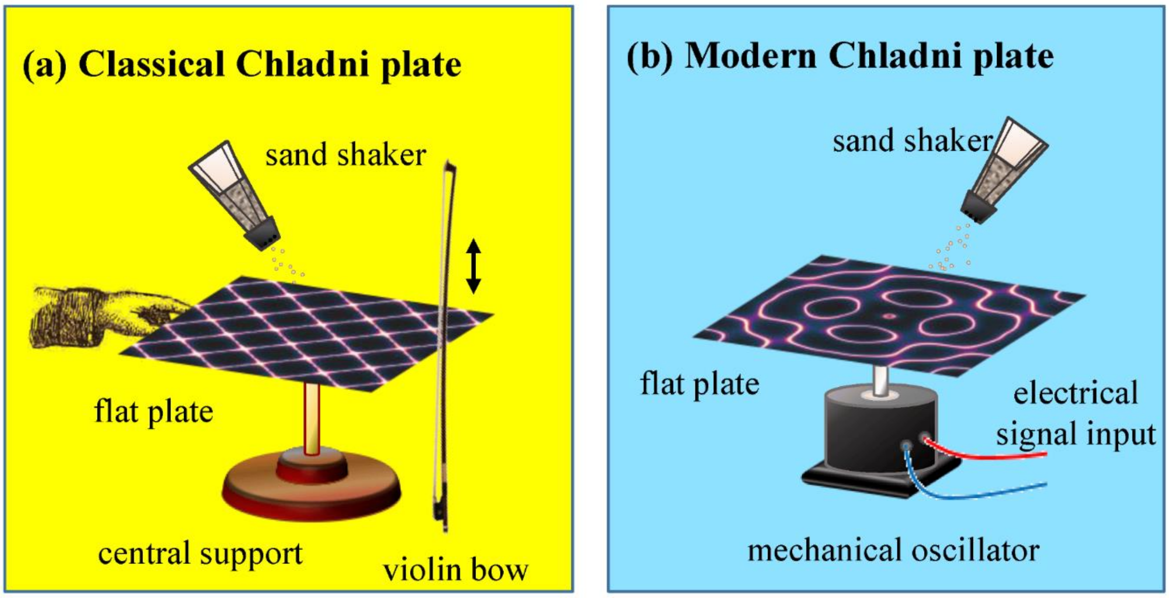


Figure 1. Sketch of devices used before and now[1]

Ernst Chladni was a great acoustician and physicist. In the late 18th and early 19th centuries, he researched the various modes of vibration of rigid surfaces and exhibited them to the public. Thus, the similar device used in the experiment was called the Chladni plate, and the pattern formed by the resonance was called the Chladni figure. At that time, Chladni used a thin metal plate, sprinkled sand particles on it, then rubbed the edges of the plate with a violin bow, causing it to vibrate as if playing a violin. In resonance, the vibrations push the sand particles into a specific pattern[2]. In modern times, it's common to use a mechanical oscillator to vibrate the plate instead of a violin bow. In principle, there is no difference between the two methods shown in Figure 1. It's important to note that modern technology provides a great convenience for the study of Chladni patterns, as the oscillator's vibration pattern can be artificially and intuitively controlled.

Figure 2. App for controlling audio exciter

A foam board and an intelligent audio exciter were used for this assignment. Foam boards are more portable and accessible than metal plates, and the audio exciter can be conveniently controlled for frequency and waveform using a smartphone. It's difficult to find proper natural sand particles in the Boulder region, so artificially colored art sand was used for this experiment. First, the sand was spread evenly over the foam board. The waveform and frequency of the vibrations were adjusted and recorded on the smartphone app as shown in Figure 2. Then the audio exciter was activated and the movement pattern of the sand particles was recorded with the camera. Finally, the sand was restored to initial state where it was evenly spread across the board, at least without the visible patterns formed in the previous test. And the parameters were changed again for the next test.

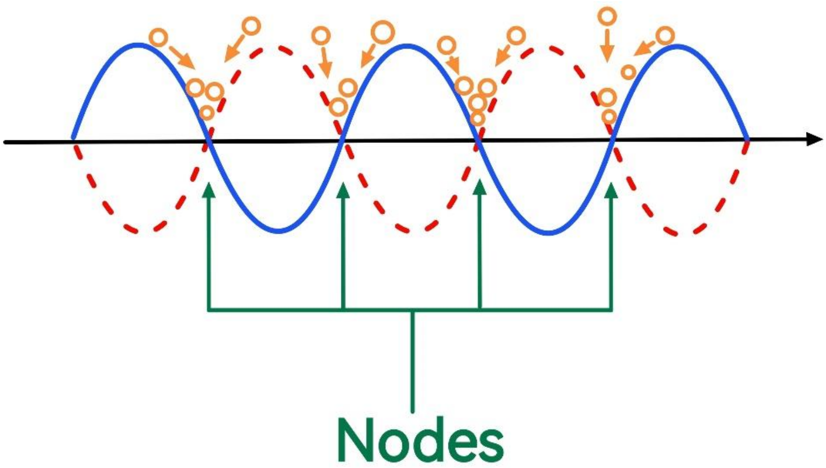
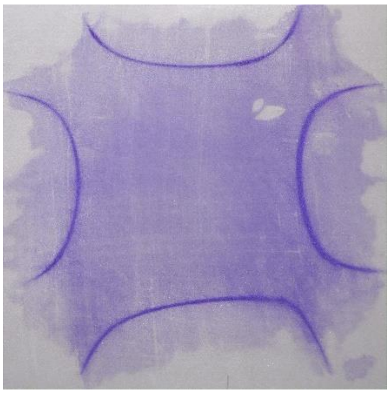


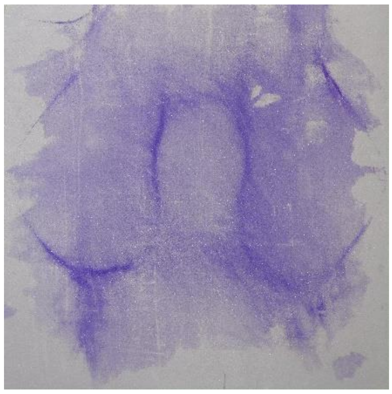
Figure 3. Principle of sand movement

As the audio exciter worked, it transmitted vibrations to the foam board. The vibrating wave were reflected when they reached the edges of the foam board, causing a change in the direction of the waves, and when two vibrating waves in opposite directions touched, they interfered and resonated, creating standing waves. In standing waves, there are some regions of minimum amplitude called "nodes". The light sand particles were moved into these regions by the larger amplitude waves outside the nodes, as shown in Figure 3. This causes the sand to concentrate at the nodes, creating these patterns.

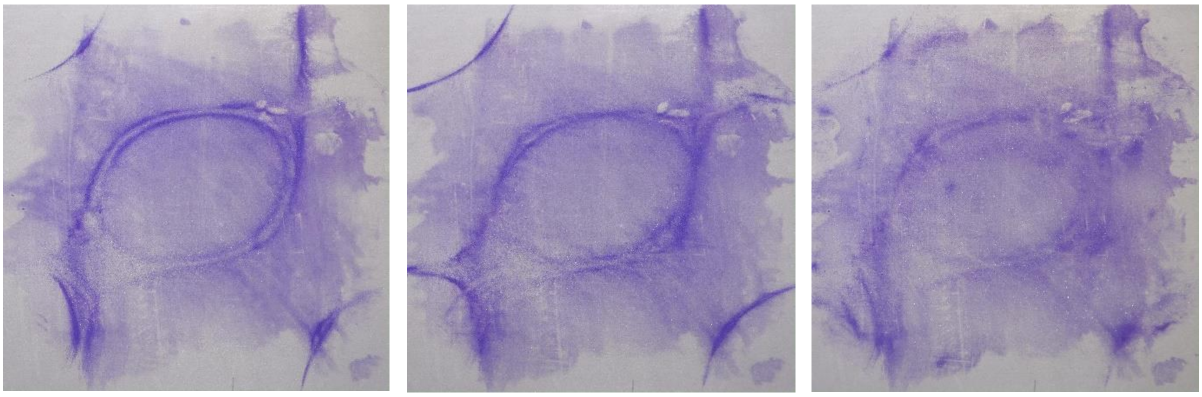
(1) 80Hz Sine wave



(2) 210Hz Sine wave



(3) 360Hz Sine wave



(4) 180Hz Sine wave **(5) 180Hz Triangle wave** **(6) 180Hz Square wave**

Figure 4. Sand patterns at different frequencies and waveforms

Figure 4 shows the pattern formed by several tests with different parameters. Subfigures (1), (2), (3), and (4) show the pattern formed by a sine wave, but at different frequencies. They demonstrate that the location and distribution of the nodes of standing waves are highly dependent on the frequency. Also, subfigures (4), (5), and (6) show the pattern formed by frequency of 180 Hz but different waves: Sine wave, triangle wave, and square wave (Due to the loud noise, the test of square wave continued shorter time, but the tendency of the pattern already appeared). They demonstrate that the location and distribution of the nodes doesn't seem to have much to do with the waveforms.

The computation and simulation of these standing waves and nodes is difficult and complex due to the free boundaries of the plate and the constraints of the boundary conditions[1]. Some additional research has shown that in addition to frequency, the shape of these nodes and the sand pattern are also related to the shape, mass, and material properties (stiffness, Poisson's ratio, etc.) of the plates[1][4]. In addition, at lower frequencies, the sand is more likely to form a symmetrical pattern. And while the frequency increases, the influence of the boundary layer becomes greater[5]. The pattern in subfigure (3) of Figure 4 was consistent with this rule, where the symmetry axis of the pattern decreases at higher frequencies (the patterns in the other subfigures all have two symmetry axes, but the "ω" shape in subfigure (3) has only one symmetry axis). Of course, the position of the vibration source also affects the pattern of the sand, and an eccentric source is more likely to create an asymmetric pattern[5]. Although detailed and specific calculations and simulation are exceptionally difficult, it's still possible to make beautiful patterns by simply adjusting the vibration parameters and material properties.

A slower shutter speed of 1/50 second was used in the video. Obviously, this time resolution is not appropriate for sand particles moving at high speed under the influence of vibrational waves. However, the focus of this task was not to observe the motion pattern of a single sand particle. Rather, it was to see how the relatively large "clumps" or "streams" of sand would come together to form the final pattern. Considering the size of the sand, the spatial resolution of this video is sufficiently high. It's not difficult to distinguish large numbers of sand particles of about one pixel in size at rest or in motion, not to mention to observe the movement of sand "clumps" and "streams" on a scale of 10-50 pixels.

III. Visualization Technique

Figure 5. Sand

Figure 6. Illumination condition

It's hard to find sand in the Boulder region that is beach or desert-like, non-condensing, and easily flowing. Also, the foam board used in this assignment was a lighter pink color, so the white salt particles are also unsuitable for creating large color contrasts conducive to visualization. Finally, multi-colored artificial sand particles were used, as shown in Figure 5. I chose a darker purple color to create an intuitive color contrast that facilitates visualization and observation of sand movement patterns.

The filming took place in an activity room in the Engineering Center. The lighting conditions were a bit poor. There were only a few chandeliers of moderate brightness on the ceiling of the activity room. The foam panels were too large to use the camera boxes used in previous missions. To avoid shadows from the tripods and cameras on the foam board, filming was done in one corner of the room.

IV. Photographic Technique

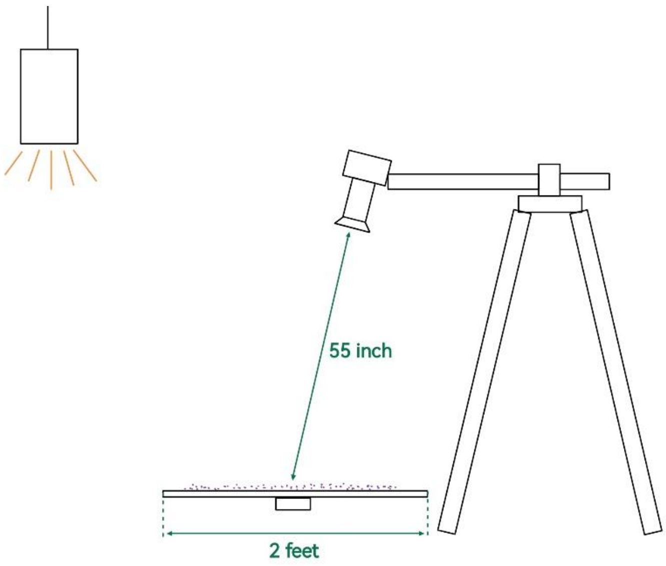


Figure 7. Filming scene

The video was recorded using a tripod that allowed the center column to be placed horizontally to allow filming from above the foam board. The lens was the Tamron 18-300mm F/3.5-6.3 lens, an all-in-one lens that covers a wide range of focal lengths and field of view from wide-angle to ultra-telephoto. The camera used was Sony's ZVE-10 mirrorless digital camera with 4K 30FPS video recording capability, which is 3840 by 2160 pixels.

The filming scene is shown in Figure 7. The lens was approximately 55 inches from the center of the foam board. The foam board was a square with sides about 2 feet long. The focal length of the lens was set to 35mm, and due to the smaller APS-C size of the camera's sensor, it had a 35 mm equivalent focal length of 52.5 mm. The width of the field of view at this point is about 3 feet. This setup allows the height of the field of view to just cover the top and bottom edges of the foam board, thus reducing the work required for post-cutting.

Due to a bit poor illumination, the lens was set to the maximum aperture, f/3.5. In addition, considering that the sand " clumps " and " streams " were not moving very fast, the shutter speed of the camera was set to a relatively slow value, 1/50 second. This shutter speed did not conflict with the frame rate of the video. Larger apertures and slower shutter speeds reduce the effects of low light levels. The ISO was set to 400, which in this case prevents noise from affecting the view.

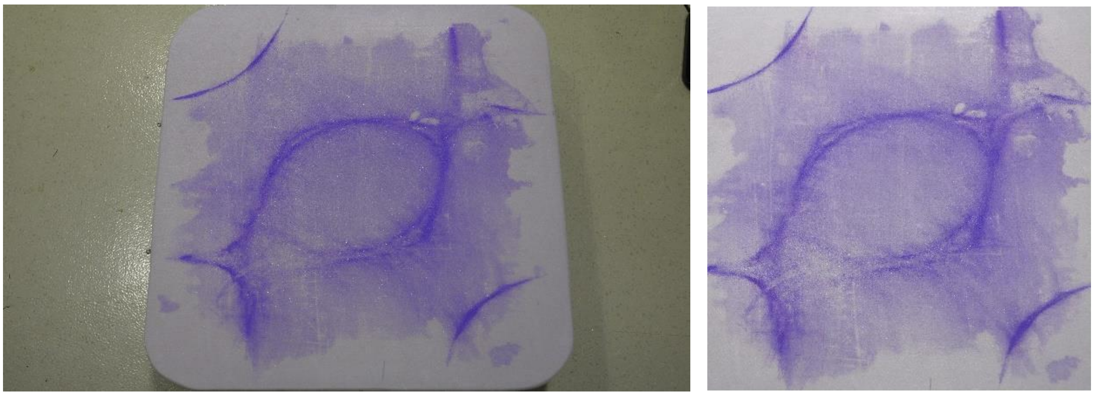


Figure 8. Comparison of video before and after post-processing

To ensure the quality of the video, it was captured at 4K 30FPS with a bit rate of 100 MB/s. In post-processing, the video was cropped to a square 2160 x 2160 pixels wide to eliminate irrelevant elements on both sides of the video. To avoid the shadow of the camera on the foam board, the camera was not directly above the board during filming. Therefore, a perspective correction was necessary to make the view look like it was taken from directly above. Finally, I used the curve to increase the brightness of the video slightly, which improved the look and feel of the video. Video still has over 20 MB/s bit rate when exported. The video now have a great sharpness and nicely display the details of the process of sand moving and shapes forming.

V. Result

In this assignment, several clips of sand motion patterns were recorded. Sand resonance is difficult to calculate and simulate, but it's still easy to create some cool symmetric Chladni figure, such as eye shape, U-shape and ω-shape. These videos clearly show the physical phenomenon of sand resonance and capture the beauty of the shapes of these sand particles. That's what's so endearing about them.

During the filming process, I was worried about our plan to get away from the topic of this course. As everyone knows, sand particles are pure solids, and the topic of the course is the visualization of fluids. I thought that the motion pattern of a large amount of sand particles could be considered a fluid, so I insisted on doing this experiment. The feedback from the audience during the presentation allayed my concerns. The motion pattern of a large amount of sand is indeed somewhat similar to that of a fluid. They also shared some examples of the movement of sand dunes and Cymatics. I'm glad that audiences enjoyed my video and had fun with it.

In the future, I will probably try different shapes of the board, like triangle, circle, etc. And also try different material of the board, like plastic or metal. I believe that these more in-depth experiments have helped me understand more about the science behind this physical phenomenon.

References

[1] Tseng, Yu-Chen, et al. “Exploiting Modern Chladni Plates to Analogously Manifest the Point Interaction.” *MDPI*, Multidisciplinary Digital Publishing Institute, 28 Oct. 2021, www.mdpi.com/2076-3417/11/21/10094.

[2] “Ernst Chladni.” *Wikipedia*, Wikimedia Foundation, 2 Nov. 2023, en.wikipedia.org/wiki/Ernst_Chladni.

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[5] “Chladni Plates.” *Seattle University*, www.seattleu.edu/scieng/physics/physics-demos/waves/chladni-plates/. Accessed 10 Nov. 2023.

The background music for the video is *Ditch Diggin'* by Jingle Punks The music was published by the author on YouTube Audio Library. YouTube Audio Library is a free music library that specializes in providing creators with royalty-free music. Therefore, my using this music for the video does not create a risk of copyright violations.