Water and Food Coloring on a Vibrating Plate

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Introduction and Purpose

This video and paper are for the second team assignment in the Flow Visualization course taught at the University of Colorado at Boulder. This assignment allowed for graduate and undergraduate engineering and art students to work together to generate and capture complex flow phenomenon. Unfortunately, due to time constraints and schedule conflicts, our team was not able to work together. We met for several hours, but could not observe a desired phenomenon and so decided to work individually on this project and save the phenomenon for the final team project. The specific intent of this project was to visualize water streamlines on a vibrating plate. When a fluid interacts with a vibrating plate, waves are formed within the fluid. Within these waves, it is difficult to visualize the motion of the fluid in terms of individual particles or streamlines since the motion is very random. Initially, I intended to take a picture of the water on a vibrating plate, however after attempting this, it became apparent that a video would demonstrate the physics better. With a video, several experiments could be shown that involved different water and dye application methods. I would like to thank Michal Menert, Adam Deitch, and Borahm Lee for the use of their song in the video.

Flow Generation

A 1 [ft] by 1 [ft] by 0.02 [in] aluminum square sheet was used as the vibrating plate. A PSW10 subwoofer was used to amplify the vibrations. The subwoofer was oriented on a stand such that the speaker cone faced upwards. The aluminum sheet was placed directly onto the speaker cone. Using an online tone generator [1], a 50 [Hz] frequency sine wave was sent from a laptop to the subwoofer. At this point, the subwoofer was set to an amplitude of zero such that nothing was vibrating. A thin layer of roughly 10 [cc] of water was injected onto the plate using a syringe. The water was either injected such that the entire field of view was covered or injected in a ring shape. When the entire field of view was covered with water, food coloring was added and was either dropped into the liquid from above or injected gently onto the top of the liquid. The amplitude of the subwoofer was then slowly adjusted up and back down to generate the vibrations.

A DSLR (digital single-lens reflex) camera that was mounted on a tripod was used to record the video. The tripod was set up such that two legs were vertical and resting on the subwoofer and the third leg was extended longer and prevented the camera from tipping backwards. A black backdrop was placed in front of the subwoofer and mostly acted to remove color reflections from the water and the aluminum plate. The subwoofer was placed under three 60 [Watt] florescent light bulbs. With this amount of lighting, a higher frame rate could be used to produce a smooth video. Because this video was not taken with an actual video camera, this was important. The experimental setup is shown in Figure 1 below.

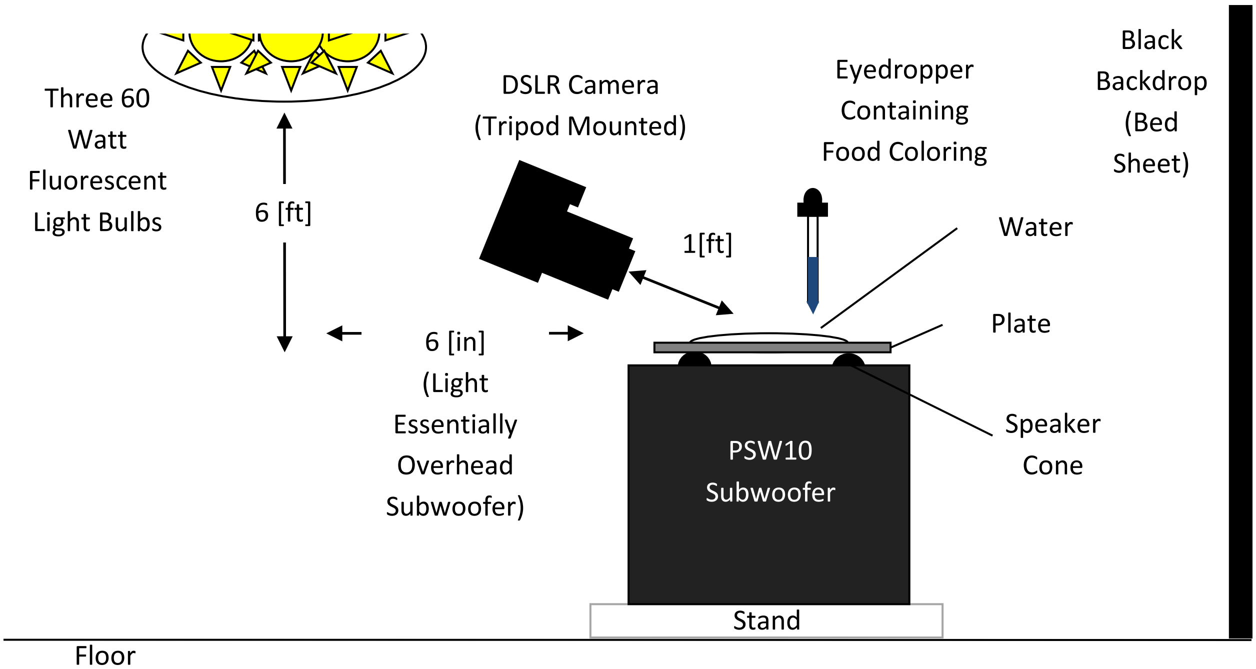

Figure 1: Experimental Setup

Fluid Physics

Agitating a thin fluid via a vibrating plate is similar to another experimental setup known as a Chladni plate. A Chladni plate is a horizontal vibrating plate that holds solid particles (such as sand). When the plate is vibrated at a constant resonant frequency, standing waves are set up throughout the plate [2]. These two dimensional standing waves contain nodes where the plate is not vibrating at all. The sand on the plate is agitated toward the nodes and when the sand reaches the node, it remains there. This is because the nodes act as regions of lowest potential energy.

The Chladni plate is similar to the experiment here because the water on the plate travels to areas of lowest potential. However, the plate was not vibrating at a resonant frequency and so no standing waves were setup in the plate. This means that the lowest potential lines travel along the plate and drive the motion of the water waves. As the water moves throughout the plate, the surface tension effects influence the shape of the water. This means that not all the water moves to the areas of the plate that are at lowest potential. Overall though, the water is attempting to minimize its potential energy both on the vibrating plate and through surface tension interactions.

It is likely possible to repeat this experiment to attempt to achieve a resonant frequency in the plate where standing waves exist. If the plate was vibrated at a resonant frequency, then the water would likely achieve a steady state configuration pattern since the lines of lowest potential energy would not be moving. From the research on Chladni plates, these frequencies exist between 500[Hz] and 5000[Hz] and are most prominent in the 2000[Hz] to 3000[Hz] range [3]. The subwoofer used can only achieve frequencies up to 160[Hz] with the low pass filter turned to the maximum setting. In order to reach the resonant frequencies of the plate, a new vibrating mechanism would need to be implemented.

Because the dye traces the streamlines within the flow field, it is possible to estimate the Reynolds number of the fluid. Since this is a video, estimating the velocity of the dye is very easy because the distance the dye travels in any interval of time is known. The flow appears to be moving in an orderly way so it is assumed that the flow is laminar everywhere. To test this hypothesis, the largest Reynolds number is analyzed. This Reynolds number corresponds to the least laminar portion of flow and also represents the portion of dye that is moving the fastest [4]. The fastest moving portion of dye is easy to trace since it breaks off from the dye injection point first is clearly visible.

Taking measurements from the field of view of the video, it was observed that a dye streak moved roughly 3 [in] in 5 [s] (from red dye and video time 3:10-3:15). This gives a velocity of 0.6 [in/s]. The width of the streak was approximately 0.125 [in] and this is taken as the characteristic velocity. These measurements are only from one time slot in one experiment; however they should give a rough estimate of the upper bound of all the Reynolds numbers throughout all the experiments. Because the flow is approximately two dimensional, it is assumed that the water and dye exist without slip from each other. This means that the dye tracks the water movement perfectly even though the fluid properties are different between the two. When calculating the Reynolds number, the viscosity and density of the water will be used such that the Reynolds number reflects the physics of the water. The kinematic viscosity of water at room temperature is 1.74E-3 [in^2/s] [5]. The Reynolds number is then:

$$\mathrm{Re} = \frac{\mathrm{VL}}{\nu} = \frac{\left(0.6\left[\frac{\mathrm{in}}{\mathrm{s}}\right]\right) * (0.125[\mathrm{in}])}{1.74 * 10^{-3}\left[\frac{\mathrm{in}^2}{\mathrm{s}}\right]} \approx 43$$

Because this Reynolds number is low, it means that the flow remained laminar throughout. This is expected since nothing generated high velocity flow (such as a large pressure difference or a fast moving object). Still though, the Reynolds number is greater than 1 meaning that the flow is not Stokes flow. This also makes sense since water is a relatively low viscosity fluid.

Visualization Method

There were two experimental configurations setup. One configuration relied on filling the entire field of view with water then visualizing the fluid movement with food coloring. The other configuration used the water itself as the primary visualization technique by only partially filling the field of view with a ring of water. The water used in this experiment was normal tap water. The specific food coloring used was McCormick (off the shelf) and the material safety and data sheet can be found in Reference [6]. When the water was excited by the vibrations in the plate, the flow could be seen either via streamlines in the die or by seeing the bulk motion of the water.

This flow was created inside with a single source of light. Three 60[W] fluorescent light bulbs on the ceiling (6[ft] above the subwoofer) provided light for the video. The setup was in a room with mostly white walls. Brown color from the floor and a nearby door were reflecting off of the water, but this color was removed with the use of a black backdrop. This caused the primary colors on the aluminum sheet to be silver (from the aluminum), black (from the backdrop), and white (from the lights).

Video Technique and Post Processing

A Nikon D5000 12.3 effective megapixel DX format DSLR F-mount camera was used to film the video. The field of view is roughly 8[in] wide by 5[in] tall and the camera lens was about 12[in] away from the plate. The aperture was set automatically within the camera and was from an f-stop of about 4.5 (although this value changed between the different videos taken due to changing focal lengths). The focus was manually controlled such that the clearest video could be achieved. Because the camera used is not designed for taking videos, the video was only 640 pixels by 424 pixels. While this is a fairly low spatial resolution, all of the details of the flow are easily visualized since the field of view is so small. Also, since a high frame rate was used (50[fps]), the temporal resolution is very acceptable. The good temporal resolution paired with the fact that this is a video makes it hard to notice any pixilation. The ISO (sensor sensitivity gain) was set to 200 to leave the video as clear and non-grainy as possible. This also helped to not lower the resolution further. A low ISO was acceptable to use because there was so much light. A sample of the original video is shown on the cover page.

Video post processing was completed entirely in AVS video editor. No color alteration effects were preformed to the original video. The primary use of editing was to crop and splice together the six different video clips. All of the audio was removed from the video clips and the song "Electric Touch" by Michal Menert and Break Science was used for the soundtrack. One of the video clips shows how the water on the plate reacts when that song was played through the subwoofer. This video clip is corner inset during the entire video. A title screen with appropriate accreditations was also added using the video editing software. In total, the original video clips totaled to 9 minutes and 30 seconds while the edited version is 4 minutes and 15 seconds.

Conclusion

This was the first video that I made for Flow Visualization. Using a video allowed for multiple experiments to be preformed and displayed and allows for physics to be seen in real time. I have created and edited videos before, but not recently and never with AVS video editor. If I were to perform this experiment again however, I would use a video camera that had a greater spatial resolution. Seeing this phenomenon with a high speed camera could also be revealing. I like how complex the flow looks for being such a simple experiment to setup. The colors are also simple and visually appealing. One of the most challenging parts of this project was keeping the water on the plate and off of the speaker cone. The subwoofer had to be nearly perfectly level to keep the water from running off the plate. The video is a little on the lengthy side, but I wanted to fill up the entire span of the song since the music and the video tie together. Video is a powerful tool for studying fluid physics and making this video was very insightful, however I don't think I will make another for this course. The overall process took a very long time, and I like the simplicity that a photograph captures especially in terms of flow visualization.

References

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