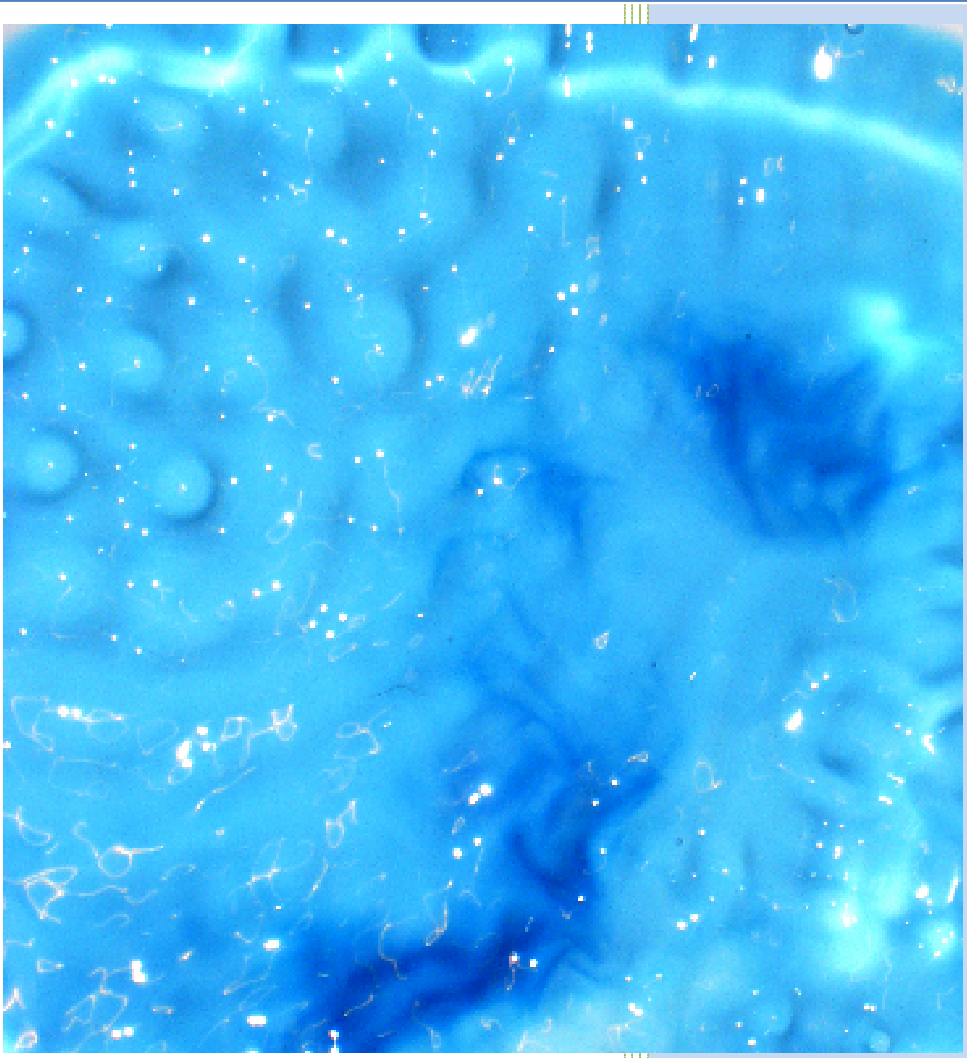
Wave Phenomena in Liquid



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Flow Visualization

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Context

This image is the first individual project entitled, 'Get Wet,' for the course flow visualization at the University of Colorado-Boulder. The purpose of this assignment is to begin experimenting with different flow ideas and techniques in order to capture the flow phenomena. The original idea for this image was to recreate waves in a liquid using sound. The purpose of this image is to show how liquid reacts to an external force of sound waves. The thought originally was that waves would start from a center point and propagate outward in a circular fashion. This image was captured and cropped at the end of the bowl where the waves hit the wall and hit each other causing the phenomenon shown in the image. The waves shown are not typical by any means. The waves in the image are more like protrusions from the liquid caused by the forces and interactions of different waves, the wall, and the vibrations on the bowl.

Apparatus

The apparatus used to create the image is shown in Figure 1 below. The black rectangle represents the subwoofer and the gray circular shape represents the speaker of the subwoofer that produces the sound. The square shaped bowl was placed on the center of the speaker. The blue liquid, representing a mixture of milk and blue food coloring, is shown in the white bowl in the overhead view. Two drops of blue food coloring was gently mixed into the milk before sound started interacting with the mixture. A bass heavy song played through the speaker as the bowl sat on top. Dozens of pictures were taken of the phenomena shown in the final image. This image was chosen amongst the others because it shows a unique blend of colors and displays the most interesting waves formed in the milk mixture.

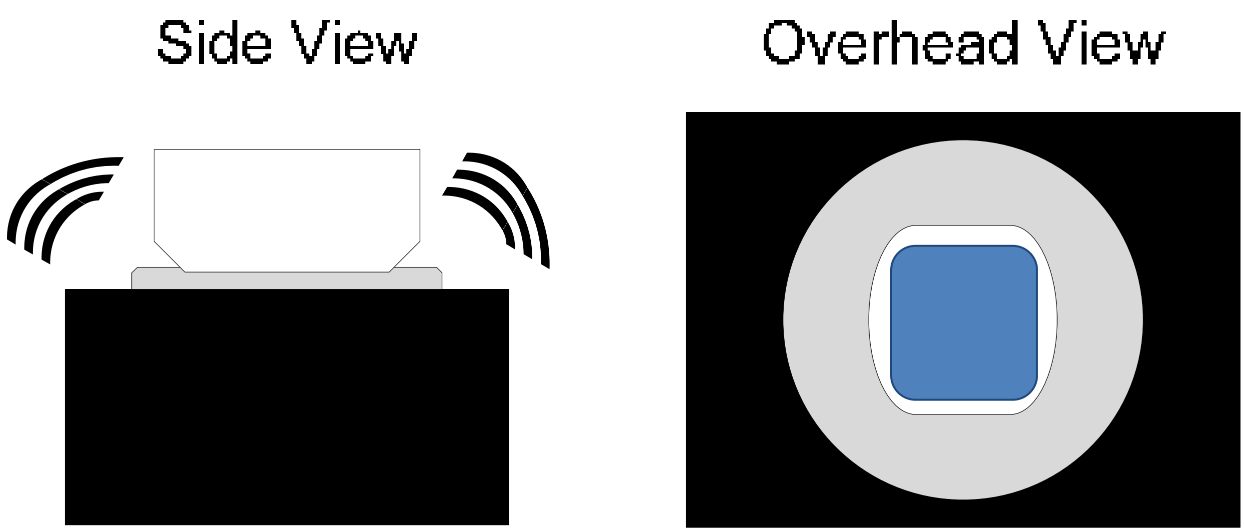

Figure 1-Experimental apparatus from side view and overhead view

The dimensions of the subwoofer are 6" tall x 11" long x 9" wide. The bowl containing the liquid has dimensions of 2.5" high x 4" long x 4" wide. By viewing from above, the maximum amplitude of the waves formed in the bowl appeared to be approximately one quarter to one half inch.

Flow Phenomena

The phenomenon of propagating waves in liquid has been observed and studied for centuries. Physicists and scientists through years of experimentation have found and promulgated to society both linear and nonlinear wave equations.[1],[2] The study of waves and wave phenomena is required learning in all college level physics courses throughout the nation. Waves are a part of nearly every aspect of the universe including sound, light, oceans, earthquakes, all types of transmission signals, and many others.

This image attempts to capture a unique image of waves being created from sound. Typical mathematical waves begin from a point source, propagate away from that source, and diminish over time based on their speed and amplitude. This type of wave is described by the mathematical function of $\varepsilon = f(x - vt)$ where epsilon (ε), or the wave size, is a function of position (x), velocity (v), and time (t).[3] This type of wave is known commonly as the traveling wave and can easily be seen by throwing a stone into a large body of water and watching the waves ripple outward away from the impact.

This type of wave phenomena can be modeled in either two dimensions or three dimensions. To fully understand the effects of the wave in liquid it is usually best to model in three dimensions. Some experimental groups have used Euler equations in two dimensions for inviscid flow, or simplifying with the assumption that the liquid has no viscosity.[4] Other groups have found ways to incorporate a compressible multiphase Euler flow solver to model this type of system in three dimensions.[4]

The apparatus as described earlier was used in an attempt to cause traveling waves that would propagate towards the sides of the bowl, away from the center. The image captured does not exactly show this particular phenomenon. Rather, the image shows some waves going in different directions and protrusions of liquid in the top left corner. The main reasons for these abnormal waves is the shape of the bowl, the differing amplitudes of sound coming from the speaker at different times, interactions of different waves, and vibrations on the bowl from the speaker. This image captures a unique look at how a liquid reacts to all of these different forces simultaneously.

Visualization Technique

The technique used is the application of food coloring to dye the liquid and create a more dramatic coloring effect and more contrast. The waves and liquid protrusions are more easily seen when dye is used as opposed to using white milk alone. Only two drops of blue food coloring are necessary. This way the mixture is not entirely dark blue, but rather a mix of white and many shades of blue. The lighting used is the standard flash of the camera along with my room’s ceiling light (60 W) and my desk lamp (40 W) from three feet above. I used several sources of lighting because I not only wanted to show the wave phenomena in the image but also the reflection of some light off of the liquid. There are several areas in the image that show the reflection of the light from above.

Photographic Technique

The original image was much larger than the final cropped image chosen. The original image was zoomed in far enough to only see the entire bowl. The most interesting and colorful section of the image was cropped to produce this final image. The camera was approximately two and a half feet above the bowl at the time the picture was taken.

The image was taken with a digital *Canon Powershot* SD870 IS. The original image size is 3264 pixels wide x 2448 pixels high while the cropped image size is 2136 pixels wide x 2292 pixels high. The camera exposure specifications for the photograph were; an aperture equal to 5.8, the shutter speed at 1/60 s, and ISO speed setting at 250. The focal length was 17.3 mm. The image was processed in Photoshop. The only changes made to the image in Photoshop were cropping the desired section of the image and adjusting the contrast using the 'Curves' feature. The darker colors were made slightly darker and the lighter colors were made slightly brighter.

Revelations

The image reveals the unpredictable effects that multiple external forces will have on liquids. Each of the pictures taken with this set up was different in its own way. They all displayed waves and had similar qualities, but only this one showed the unique blend of colors along with very interesting wave dynamics. The intent of the image was fulfilled. Once the set up was created and many pictures were taken, the general idea of how the liquid would look under these external forces was known. This image shows how the liquid was reacting better than any of the others. One aspect that could be improved is the lighting technique. There are some reflections off the surface of the liquid that add to the beauty and effect of the image, but there may be too many reflections. The reflections may become distracting and take away from the overall image. To develop this idea further, one may experiment with a higher quality camera, more images, and different dye colors. Changing any one of these things may result in a very different image that may be more effective.

References

[1] *Linear Wave Equations.* EqWorld. Online. http://eqworld.ipmnet.ru/en/solutions/lpde/wave-toc.pdf. Copyright 2004-2005.

[2] *Nonlinear Wave Equations*. EqWorld. Online. http://eqworld.ipmnet.ru/en/solutions/npde/npde-toc2.pdf. Copyright 2004-2005.

[3] Lane, William C. *The Wave Equation and Its Solutions*. Physnet. Michigan State Unversity. 2002.

[4] Chen, H. and Liang, S.M. *Flow Visualization of Shock/Water Column Interactions*. Shock Waves. 17:309-321. 2008.