Acoustic propagation through a shallow pool of water

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INTRODUCTION

The intent of this photographic experiment was to begin an in depth investigation on the photography of fluid phenomenon. The submitted photograph was for the first image assignment called "Get Wet." Specifically, the objective of this particular image was to capture the movement of sound through shallow water. The phenomenon involves water being shot up into the air in a column as if propelled by a pump. The main driving force of this phenomenon is the pressure wave resulting from the voltage being sent to a speaker situated beneath the water. Many different fluid phenomena could have been photographed for this first image. It was the task of the photographer to create a fluid flow worth imaging. The idea for this image came from working with speaker electronics months previous to the experiment. After wondering which hobbies could be intertwined it became apparent that the effect a sound wave would have on a shallow pool of water would definitely be worth photographing.

FLOW APPARATUS

There were several choices of speakers readily available due to previous work. After deciding that the fluid would be easiest to move on a smaller scale the choice was narrowed down to three options; Orbit USB Lite [1], Philips SPA7210 [2], and Cyber Acoustics CA2002 [3]. The primary difference between these three speakers was their overall shape. The CA2002 was a slimmer model, not capable of producing as much sound as the Orbit USB Lite. The issue with the Philips SPA 7210 was that it was larger, requiring a more complex setup. After weighing these options the Orbit USB Lite was decided upon for the experiment.

The Orbit USB Lite speaker was then connected to a Sony STR-DE698 [4] sound amplifier and home stereo system using speaker wire. Sound signals were then sent from an IPod MP3 player to the stereo where they were amplified and sent on to the speaker as a voltage. This voltage resulted in a response from the speaker in the form of sound waves. Normally these sound waves would propagate through air and reach a listener's eardrum without interruption, but in this case the sound waves first travelled through a pool of water.

The water was pooled on top of the speaker, which naturally has a concave surface. After allowing the water to collect on top of the surface of the speaker music was selected and the volume level was slowly increased. As the volume is increased, the voltages being sent to the speaker increase. Subsequently, the diaphragm of the speaker vibrates, more and more powerfully with an increase in volume. Different volume levels, along with different songs, will produce different shapes of the fluid leaving the speaker.

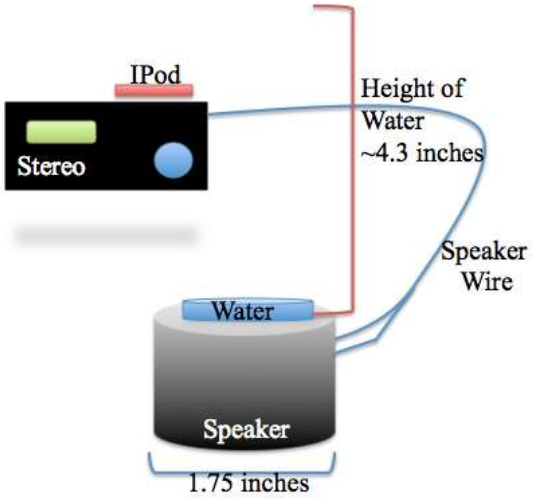

Figure 1: Functional Diagram of Setup

Figure 1 shows the setup of the experiment. There were many variables that could be altered, which would result in different shapes of water columns. Capturing the photo at the right moment though was the truly challenging part. The fact that gravity was constantly acting against the water meant that there was a window of a fraction of a second where the picture could be taken. The camera was setup at many different angles to decide upon the perfect position, but it ended directly in front of the speaker. In the final image the speaker was nearly five inches from the speaker as it was creating jets of water.

FLOW ANALYSIS

There were many forces acting on the water in this design, the most important forces that need to be taken into account though are gravity and pressure from the sound waves. Gravity is constantly acting on the fluid at 9.81 m/s/s, which means that there is always a force bringing it towards the earth's surface. The sound wave propagating from the speaker however, is not constant. A more in-depth analysis is needed to truly understand the reason that these waves propagate as they do.

When sound is moving through a solid structure it travels in groups of oscillating crystals through the lattice. These oscillating crystal groups are referred to as phonons [5, 6]. The force of the sound wave moves the individual crystal atoms out of their equilibrium position and they are then pulled back into place by intermolecular forces. This basic overview of how sound travels through solids can begin to explain the motion of sound through a liquid.

When a sound is propagating through a liquid its waves are not as opposed by intermolecular forces as when they are traveling through a solid material [8]. The atoms within a liquid will move more freely due to the fact that they are not in a solid state. It is the same comparison with liquid to gasses. As sound propagates over time its energy decreases. This occurs more quickly in solids, but slowest in a gas. When a sound wave approaches a liquid it excites the particles and just as in a solid there will be groups of particles moving together through the fluid. This force at the molecular level results in a macroscopic event when music is played through a speaker with water on top of it.

The truly interesting part of this is that the frequency of the sound wave can change everything. After playing various different types of music it was determined that music with a large bass end created the most interesting water columns. The bass end of the speaker ranges from 20 Hertz to approximately 200 Hertz [1]. Hertz is a measurement of cycles per second. This means that as you step lower in frequency from the height of human hearing at nearly 20000 Hertz [7], to the lower end of human hearing at about 20 Hertz, the wavelength is increasing.

A longer wavelength causes the fluid to stay together in columns and propel the water upward, as opposed to at high frequencies where the fluid breaks apart into separate spheres of water. Due to hydrogen bonding, water particles prefer to stay

together, but a higher frequency running through the fluid can force a collection of the water to be pushed away from the crowd and off into its own world. This occurrence can be seen in the top right corner of the submitted image. Judging by the shutter speed, and the original blur of the bead of water, the following equality can be made;

$$0.125\text{in}/(1/200\text{sec}) = 25\ \text{in/sec} \qquad (1)$$

This sphere of water was separated from the main water column and was propelled about two inches above the main fluid column.

Besides gravity and sound pressure there is a list of other forces causing this fluid to take the shape that it does. Some of these forces are hydrogen bonding, air resistance, air movement, or even other noise sources. It can be seen from the image that the fluid column looks sporadic, and completely random. All of these other forces play a role in causing the odd undulations, which appear to be senseless.

VISUALIZATION TECHNIQUE

The water was distilled water that was purchased from the store. Distilled water was used to avoid any seriously oxidized water that may appear cloudy in a photo. The background used was the reverse side of a painting. The unfortunate disability to working with water like this is that it tends to cover the room in droplets. This muffled the background and toward the end of every shooting trial, of which there were many, the background was completely soaked with droplets that had landed on it, crowding the actual detail of the photo.

Many different lighting techniques were explored in an attempt to really make the water column stand out. After experimenting with lamps in the house, compact fluorescent bulbs, and incandescent bulbs, it was discovered that the flash on the camera with some good background lighting really worked the best. Typically flash would be avoided in a photography project, but the flash lit up the water particles. It is actually possible to see the flash going off in some of the individual beads of water. Not only does this give a nice color effect to the photo, but also it makes the water beads have a very unique appearance if viewed close up.

PHOTOGRAPHIC TECHNIQUE

Due to the speed of the water moving up and down the shutter speed had to be at least 1/200. If it were any slower than this the image would be badly blurred. This shutter speed was then the driving force for the ISO setting of 500. After turning on the camera flash it was possible to reduce the ISO from 1600 to 500. The higher ISO setting was resulting in rather grainy photos, which did not have the desired color balance. Finally the aperture was set to f/9 and the focal length was set to 46mm.

The point of the image was not to get everything in focus; it was to draw attention to the water columns while distracting from the background and speaker. This was well achieved by keeping the plane of focus right at the middle of the speaker where the water columns were. Beyond the plane of focus, everything that is in the photo is what was intended to be there. There was very minimal cropping due to the fact that the main subject is in the middle, and there is not much to distract from the subject. There was not much work done in Photoshop other than increasing the blue levels and removing some background stains.

This photo was taken with a digital Nikon D3000. It provided a (2306x3872) pixel resolution. As previously stated the camera flash was on. The D3000 is a digital single lens reflex camera (DSLR). The advantage to using DSLR cameras is that the image seen in the viewfinder is very similar to the photograph since the image is taken so quickly. That is helpful for situations like this where everything is happening very quickly.

CONCLUSION

This image really reveals a link between two artistic hobbies: music and photography. On top of that it includes a new spark of interest in fluids. Personally I like the fact that there is a loner sphere, and I really like how the columns look like ice after changing the blue balance. I feel as though the physics here are shown very well. It does not characterize one single fluid phenomenon, but a multiplex of them.

Questions I have after this project are, to start with, how in the world do photographers get all of their lighting correct? That was the most challenging part of this project for me. I ended up burning out a 135-Watt bulb trying to get it close to the water. And I am also curious how to get access to better backgrounds besides the Durning lab ones which are rather small. In the future I definitely want to have better backgrounds and lighting.

There was one photo I took at the very beginning of this project that I love. I tried recreating it for hours and did not succeed. The issue with it was that the plane with the water beads in it was out of focus, so the droplets are extremely fuzzy. If I were to work on this more I would definitely try to fix that.

BIBLIOGRAPHY

1. Altec Lansing. "Orbit USB Lite - IML227 - Computer Speakers at Altec Lansing." Altec Lansing Speakers. Altec Lansing, 01 Jan. 2012. Web. 11 Feb. 2012. <http://www.alteclansing.com/ae/us/computer-speakers/orbit-usb-lite-iml227/invt/iml227/>.
2. Philips. "Philips - Multimedia Speakers 2.0 SPA7210/17 - Multimedia Speakers 2.0 - PC Audio - PC Products and Phones." Home - Royal Philips. Philips, 2012. Web. 11 Feb. 2012. <http://www.usa.philips.com/c/pc-audio/spa7210_17/prd/en/>.
3. Acoustics, Cyber. "Speakers: CA-2002 - 2 Piece Amplified Computer Speaker System | By Cyber Acoustics." *Cyber Acoustics - Computer Speakers, Headphones, Headsets, Microphones and More - Official Web Site.* Cyber Acoustics LLC., 2012. Web. 11 Feb. 2012. <http://www.cyberacoustics.com/retail/Speakers/CA-2002>.
4. Sony. "Sony STR DE698." *Sony: Home Audio*. Sony Europe Limited, 2011. Web. 12 Feb. 2012. <http://www.sony.co.uk/product/hfc-amplifier/str-de698>.
5. Speed of Sound through Materials Velocity of Materials, February 13, 2012 <http://www.bamr.co.za/velocity%20of%20materials.shtml >.
6. Chang, Z. P. "Pure Transverse Modes for Elastic Waves in Crystals." *Journal of Applied Physics* 39.12 (1967). Online.
7. Olson, Harry F. *Music, Physics and Engineering*. 1st ed. Vol. 2. New York: Dover Publications, [199. Print.
8. Kiefer, Susan W. "Sound Speed in Liquid-Gas Mixtures: Water-Air and Water-Steam." *Journal of Geophysical Research* 82.20 (1977): 2895-8904. Print.