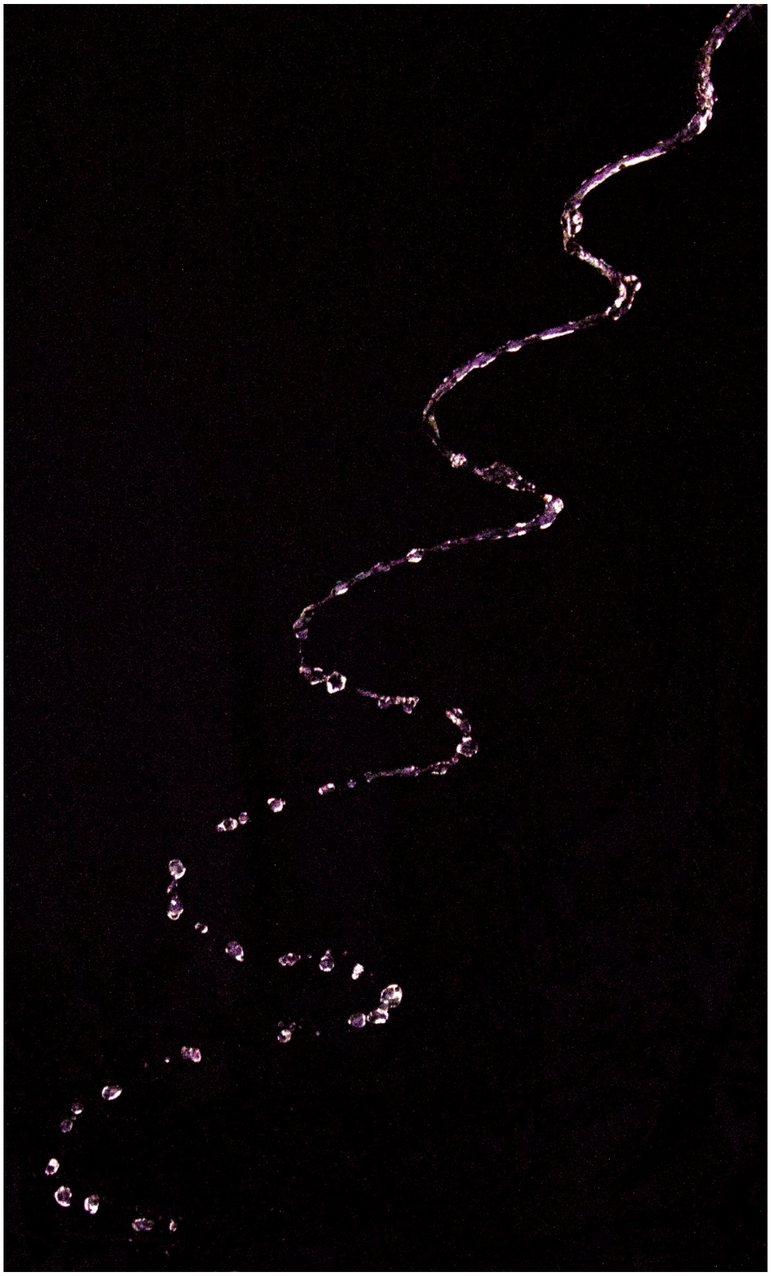
Visualizing Sound in Water



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MCEN 4151

Dec 11 2015

1. Introduction

This image captures the Plateau Rayleigh instability as water flows from a tube connected to a speaker. The speaker produces the oscillations in the flow as the water is ejected from the tubing as an added effect intended to accentuate the effect of this instability. This image was inspired by the video created by Brasspup, listed in the reference section of this report (reference number 5). Essentially, the author was able to capture the temporal aliasing effect when oscillating water through a hose attached to the face of a speaker set at specific frequencies. The key is to match the camera's recording ability to that of the frequency played on the speaker. Due to constraints in the camera used, the exact aliasing effect could not be replicated from Brasspup's video. However, the still image that was taken used the same set up and instead was able to capture the Plateau Rayleigh instability within the motion created by the interaction with the speaker and the water with the help of Brock Derby and John Zeldes. The Plateau Rayleigh instability refers to the behavior of a falling stream of water with relation to surface tension and the air-water boundary layer. A lower energy state occurs within the falling water that separates droplets from the stream of water as seen in the final image. The flow starts out as a continuous stream but as the flow progresses, the flow is perturbed as the droplets separate from the stream due to instability. These varicose perturbations behave in a periodic sinusoidal flow and upon separation, the troughs stretch out until the neck collapses into a small droplet. This separation is due to differences in pressures at each point along the stream. The troughs undergo a higher pressure than the peaks, resulting in pinching along these areas of high pressure and growth in the droplets along the areas with low pressure. The surface tension decreases along the regions with the growing droplets while the surface tension increases within the regions where pinching occurs. This effect is shown as in a progressive manner in the final image.

2. Methods and Discussion

The system used to capture this image consisted of 12 feet of a typical outdoor hose with an inner diameter of 5/8 inch which was connected to the main water source running from a house, two feet of ¼ inch inner diameter (with ½ inch outer diameter) tubing purchased from a general hardware store, a sub-woofer provided by Vincent Staverosky, duct tape, a phone playing the desired frequencies through an online frequency generator, a stool acting as a stand, a black sheet, a drying line, and running water. The tubing was connected to the hose using duct tape and the hose was securely attached to the surface of the speaker using duct tape as well. The hose was hung over the poles of a drying line that was 69 inches high, to reduce tension and pressure that would otherwise interfere with the tubing and speaker connection. The black sheet was used as a backdrop to provide better contrast for the image. The speaker was then placed on top of a twenty nine inch stool to increase the field of operation and view. Please see figures one and two for a visual demonstration of the apparatus setup.

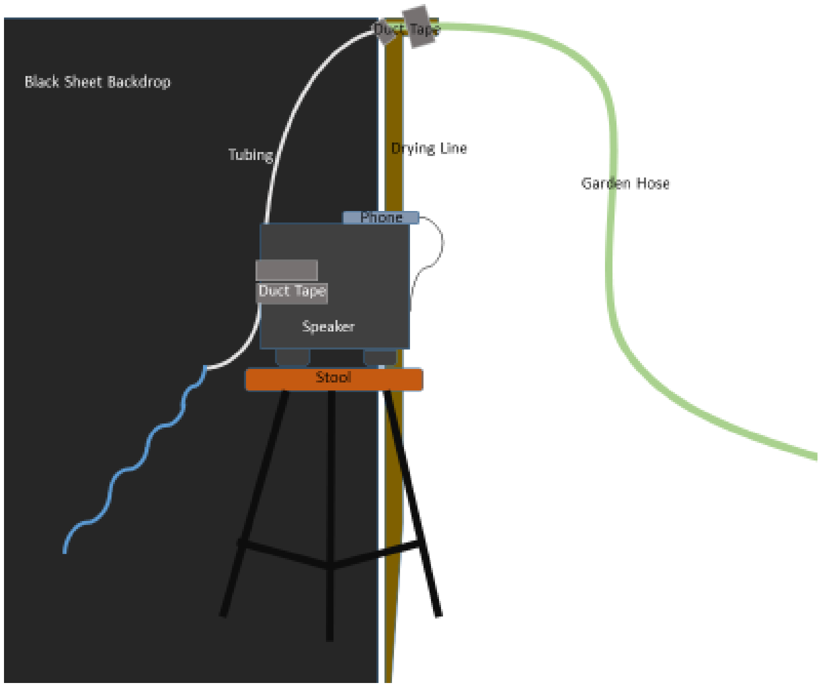

Figure 1: Sketch of Setup

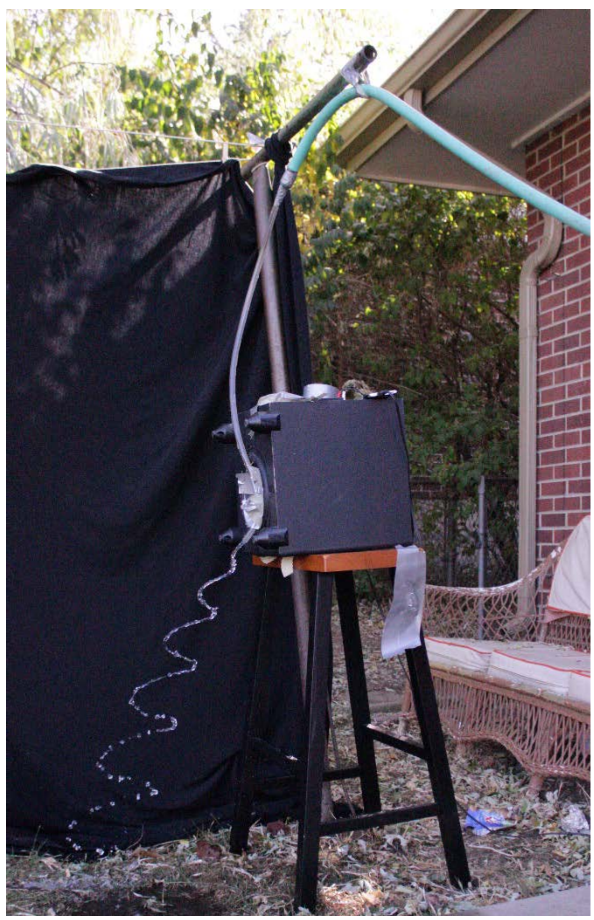
Figure 2: Actual Image of Setup

The water valve connected to the house was turned on to a low speed that would to minimize air bubbles created through the connection between the hose and the tubing. The measured flow rate of the water prior to speaker activation flowed at a steady rate of 4.62 GPM. The volume of the speaker was set to the maximum volume to create the largest impact on the water. Once activated the phone played a 24Hz oscillating frequency through the speaker. The water exiting the tubing was then jettisoned out in a cone shaped behavior expanding to a diameter ranging from two inches to six inches. The water expanded out in a diagonal direction with an estimated trajectory of three feet. This flow can be quantified by finding the Reynolds number through the equation shown below in equation 1.

$$\text{Equation 1:} \quad R_e = {ud_h}/{v}$$

In this equation, u is the measured velocity of the flow, d_h is the hydraulic diameter, and v is the kinematic viscosity of water. Velocity was measured using a gallon milk jug and timing how long it took to fill the jug with water at the same pressure and velocity used in the setup and converting that value to GPM to find that the flow rate was 1.875 gallons per minute. This value was then converted to 12.26 feet per second using an online converter. The kinematic viscosity of water at 70 degrees F (temperature outside on day of image) was referenced from the engineering toolbox (reference number 4) and found to be 1.052 x 10^-5 ft^2/s. And finally, the hydraulic diameter d_h can be found using the relationship of the inner radius to the outer radius which was substituted for d_h in equation 2. These values can be used to calculate the Reynolds number of the flow shown below.

$$\text{Equation 2:} \quad R_e = \frac{u*2(r_o - r_i)}{v}$$

$$R_e = \frac{12.3\ ft/s * 2(0.02\ ft - 0.01\ ft)}{1.052 * 10^{-5}\ ft^2/s}$$

$$\boldsymbol{R_e = 23384}$$

This calculated Reynolds number informs on the behavior of the flow during the experiment. Since the Reynolds number is greater than 4000, it can be concluded that the flow was indeed turbulent when exiting the tubing. When the water was jettisoned out from the tubing, it appeared to be turbulent, especially when oscillating on the speaker. Additionally, because of the high Reynolds number it can be concluded that gravity had a minor effect on the behavior of the flow observed. That is, the perturbation was not caused by gravity but by the Plateau Rayleigh instability.

This flow pattern can be further understood by examining the forces acting on it. As described in the previous section, the water undergoes a pressure gradient that causes the separation of the water droplets from the continuous stream. The oscillating waves was a behavior created by the interaction with the speaker. Normally Plateau Rayleigh effect is most commonly observed with water falling in a straight line, but the speaker added the additional component of the oscillations in the flow as it exited the tubing. As the speaker plays a frequency, it oscillates, transmitting kinetic energy to the hose and water that is directly secured to the surface of the speaker. This motion is similar to that of a person holding the hose and moving it back and forth in a continuous motion/frequency. The advantage to controlling the motion through a speaker is that the speaker plays a set frequency moving at a constant, continuous, and predictable rate to create the oscillations which helps prevent motion blur due to the small and precise motion created as well as the containment of the setup itself.

3. Visualization Technique

The materials necessary to duplicate this effect is a camera (cannon T3i was used), a sub-woofer speaker, a computer that can play the desired frequencies through the speaker, flexible clear tubing, duct tape, and a pressurized water source. These materials can be acquired from any source as long as they meet the requirements mentioned in the previous section. Extra materials to help with aesthetics would be a backdrop of some sort (in this image a black sheet purchased from target was used) and a stand of any height that will not interfere with the flow (in this case a household stool was used). The lighting used was direct sun light without the use of any external lighting sources. A strobe light can be used to visualize this effect in person with the naked eye if desired, but is not necessary for imaging. The best way to duplicate this effect is to make adjustments to the setup and to the camera settings until the desired result is achieved.

4. Photographic Technique

The photographic technique was intended to decrease motion blur and focus on the detail of the water droplets as the separated from the stream due to the Plateau Rayleigh instability as they were oscillating toward the ground as well as decrease the brightness in the image to allow more contrast. Thus, to achieve this, the camera settings of the Cannon EOS REBEL T3i were adjusted to be at an F-stop of f/5.6, exposure time of 1/4000 second, an ISO of 6400, a focal length of 55mm, and the maximum aperture of 5 with the original dimensions of 5184 x 3456 pixels. The photo was enhanced in Photoshop to further support the intent of the image. The original image had a distracting background which was adjusted using the clone stamp to remove the creases in the sheet, remove the stool, and remove the grass from the image. The intent was to bring all the focus to the flow of the water rather than have these elements present to distract from the information. The background was darkened and the detail in the flow was brought out through the adjustments made in the levels of black set at 13, grey at 1.09, white and 240, an unsharp mask applied at an amount of 168% with a radius of 243.8 pixels, and a threshold of 32 levels, with vibrance settings at +48, saturation at +17, and a final photo filter of 73% using the warming filter 85. The final adjustment was to crop the image to just show the flow of the water. The original image can be seen below in figure 3.

Figure 3: Original Uncropped Image

This photo was taken at a distance approximately three feet from the setup at an angle level to the center of the flow. The field of view is three feet high by two feet wide.

Conclusion

This image does a great job of capturing the progression of the Plateau Rayleigh instability as the flow is lengthened through the oscillations of the water. It provides a gradual progression that is easy to follow for this instability and provides a dramatic comparison of the flow as it leaves the tubing to the flow near the ground. This image also really highlights the differences in the pressure areas along the instability through enhancements made the post processing phase. To further develop the understanding of the phenomena, wider tubing could be used and set at a higher elevation to provide a magnified example of this instability. Close up shots could also further highlight the surface tension of the droplets as they separate and provide a more detailed and up close example of this phenomena.

5. References

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