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Team Project 1 Report

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Flow Visualization
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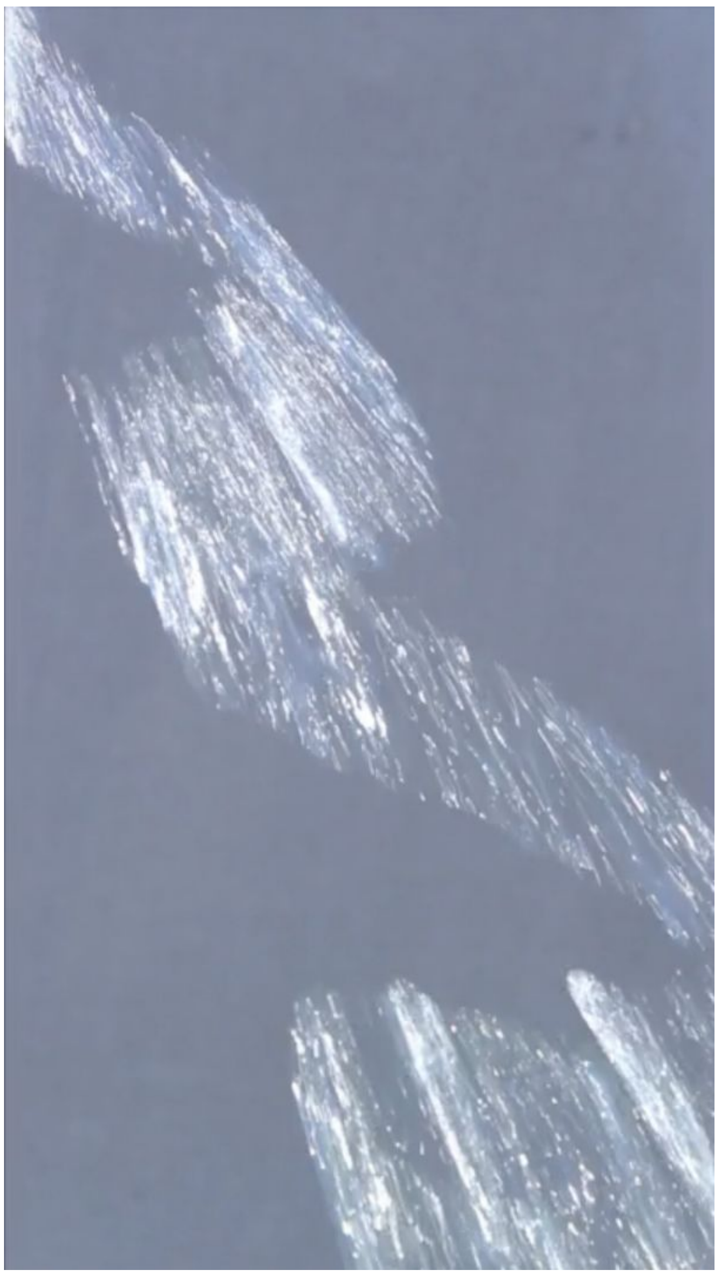

Motivation

This video was created for the first team assignment in a course called Flow Visualization, taught by Dr. Jean Hertzberg at The University of Colorado, Boulder. The ultimate goal of this work was to create an aesthetically pleasing video of a dynamic fluid. A fluid is any substance that continuously deforms under shear stress [1]. Dynamic implies that the fluid is moving, as opposed to being still. The video was taken and edited by John Zeldes, and the setup was built by John Zeldes, Brock Derby, and Rachel Grosskrueger. The video shows water flowing from a hose which is being vibrated at a frequency of at, and around 24 Hz. The volume, or intensity of the vibration, is also varied. In order to see this wave phenomenon, film must be taken at 24 frames/second, as in this video.

Background

The apparatus used to create this flow can be seen in figure 1 below.

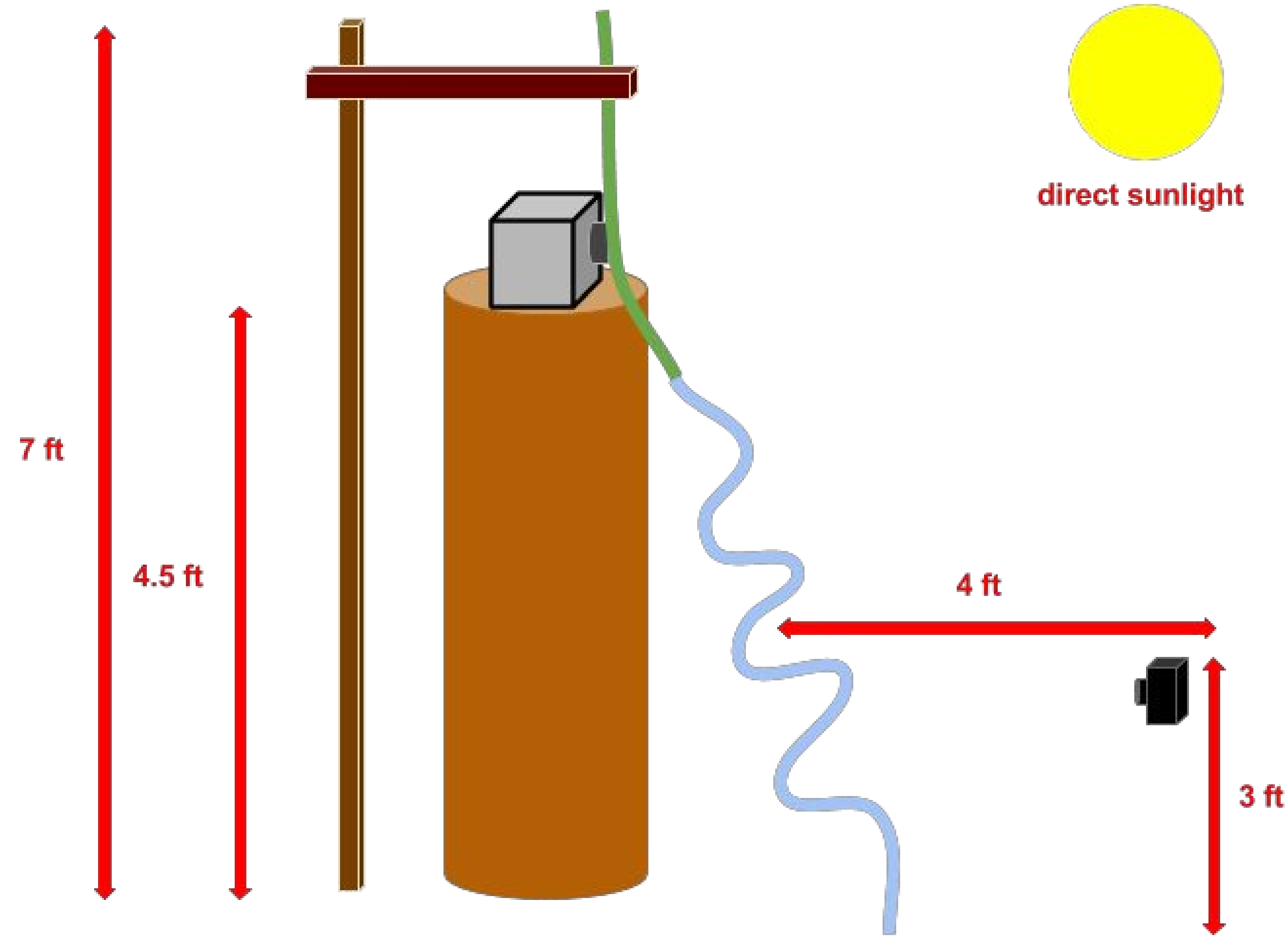

Fig. 1 Flow Apparatus and approximate camera location

The flow was created and filmed outdoors and in direct sunlight. The ambient air temperature was approximately sixty degrees. The water was from a hose, and was colder than the ambient air. The hose reached a maximum height of seven feet, and the water stream started about four feet off the ground. The end of the hose was firmly taped to a sub woofer, which was playing a 24 Hz sine wave using an auxillary input from an iPhone. The wave was generated using a mobile app waveform generator. The camera was approximately four feet from the flow.

The important forces acting on the fluid are gravity, the reaction force from the vibrating hose, and the Rayleigh instability effect. Gravity is responsible for the downward direction and acceleration of the flow. The Rayleigh instability effect is responsible for the reason why the stream is broken up into smaller packets. The reaction force causes the appearance of a wavy stream, which is why the water appears to flow in a zigzag pattern.

25 Hz creates a forward moving wave pattern, while 23 Hz creates a backwards moving wave pattern. It is important to understand what forces cause the flow to appear to change direction. There is not a force in direction of propagation that causes the forward or backward moving wave pattern; the pattern is caused by the reaction forces between the hose and the stream of water. The speed at which the water appears to be flowing at can be calculated as follows: One twenty fourth is equal to .0417, and one twenty fifth equals .04, which is 96% of .0417. This means when the hose is vibrating at 25 Hz, the water appears to be flowing at 4% of its actual speed. This causes the forward slow motion effect in the video. The flow is changing with time. This is related to the displacement caused by the vibrating hose. The hose is moving slightly back and fourth, 24 times per second. This, combined with the film being shot at 24 frames per second, creates the phenomenon shown in the video.

The stream breaks up into smaller packets because of a phenomenon known as the Rayleigh instability effect. This was discovered by Joseph Plateau and Lord Rayleigh in their study of instability of cylindrical fluid jets bound by surface tension. Surface tension is the driving force behind this effect. Due to the water's surface tension, the water wants to minimize its surface area [2]. The packets of water "ball up" because a sphere is the geometry with the least amount of surface area per volume . The Rayleigh instability effect is responsible for the pinch-off effect seen in a relatively small stream from a faucet, shown on the following page.

Fig. 2 The Rayleigh instability effect as seen in a water thread falling under the influence of gravity. The initial jet diameter is approximately 3 mm [2].

The phenomenon cannot be seen by the naked eye. This is because the subwoofer is moving so fast the human eye just sees a blur. At 24 frames per second, the water appears to be in a wave pattern or almost floating in mid air, because all that is being displayed are screenshots of reality where the water is almost in exactly the same location as the previous frame [3]. This means the flow doesn't "actually" look like that in midair. At one point, the stream comes together to form a normal, fairly laminar flow like that out of a sink, and then forms the wave again. This was created by decreasing the subwoofer volume slowly and then increasing it again combined with the Rayleigh instability effect. The phenomenon of vibrating a hose at 24 Hz and filming water flowing from it at 24 frames/second is known as the wagon wheel effect, named after wheels in Western movies being perceived as rotating backwards.

Visualization Technique

There were no particles or other fluids (i.e. smoke, dye, flakes) mixed with the water in order to visualize the flow. The water used in this project was “city water”, which typically contains trace amounts of chlorine and fluoride, although this is probably not necessary for the phenomenon to occur. The key aspect to visualizing the flow in the case is light. The water is clear, but distorts and reflects light, enabling the flow to be visible. For this reason, a large amount of light was used directly on the flow. In this case, direct sunlight from a clear day was used. The project was filmed at approximately 5,500 ft above sea level, which may intensify natural light due to the fact that the atmosphere is thinner at elevation. The sunlight was not scattered or redirected in any way. In order to create contrast, a black sheet was used in the background. This was also subjected to direct sunlight, although if the experiment is to be repeated, the flow may look better if the black fabric background is in the shade, while the flow is still in sunlight. This will make for a less distracting background, as a black sheet in direct sunlight can be seen moving in the wind. No flash or other light altering equipment was used in conjunction with the camera.

Photographic Technique

The size of the field of view was approximately 4.5 ft by 2 ft. The distance from the object to the lens was about 4 ft. A Canon Rebel T3i EOS camera was used to film the flow, with a basic 18-55mm lens. The lens focal length was set to 18mm while filming. The camera is only capable of shooting in automatic exposure mode, where the user has no control over exposure settings. This was the reason for the motion blur, as it was not possible to control shutter speed. The video was set up in various light conditions in order to try and minimize the motion blur, but it was not possible. There was no editing done to the raw footage during post processing, iMovie was used to add a title and soft transitions. The original audio was dominated by the shaking of the subwoofer, so an iMovie rain sample was overlaid in to order to eliminate the distracting noise.

Conclusion

The video reveals some of the physics associated with vibrating a flow, specifically the effects of varying frequency and intensity. This can only be seen when the frequency of the vibration is similar to the recording rate (frames/second). The physical phenomenon being observed is fascinating, but a lot of the interesting effect was lost due to the motion blur. If done properly, droplets appear to be floating seperate from eachother, instead of the broken up streams observed in this film. This project could be developed further by investigating the effect of wave form on the flow. A sine wave was used to make this video, but while experimenting with the setup, the team discovered interesting patterns from changing the wave generator to a triangle waveform.

References

[1] Munson, Bruce R., and Donald F. Young. "Introduction." *Fundamentals of Fluid Mechanics*. 6th ed. Don Fowley, 2009. 3. Print.

[2] "LECTURE 5: Fluid Jets." *mit.edu*. Massachusetts Institution of Technology, 19 Jan. 2007. Web. 14 Dec. 2015. <http://web.mit.edu/1.63/www/Lec-notes/Surfacetension/Lecture5.pdf>.

[3] Luntz, Stephen. "Sound, Water and Camera Make A Zigzag of Awesome." *IFLSCIENCE!* www.iflscience.com, 20 May 2014. Web. 9 Nov. 2015. <http://www.iflscience.com/physics/sound-water-and-camera-make-zigzag-awesome>.