Mechanical Engineering
University of Colorado Boulder

Team First Report

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1 Background

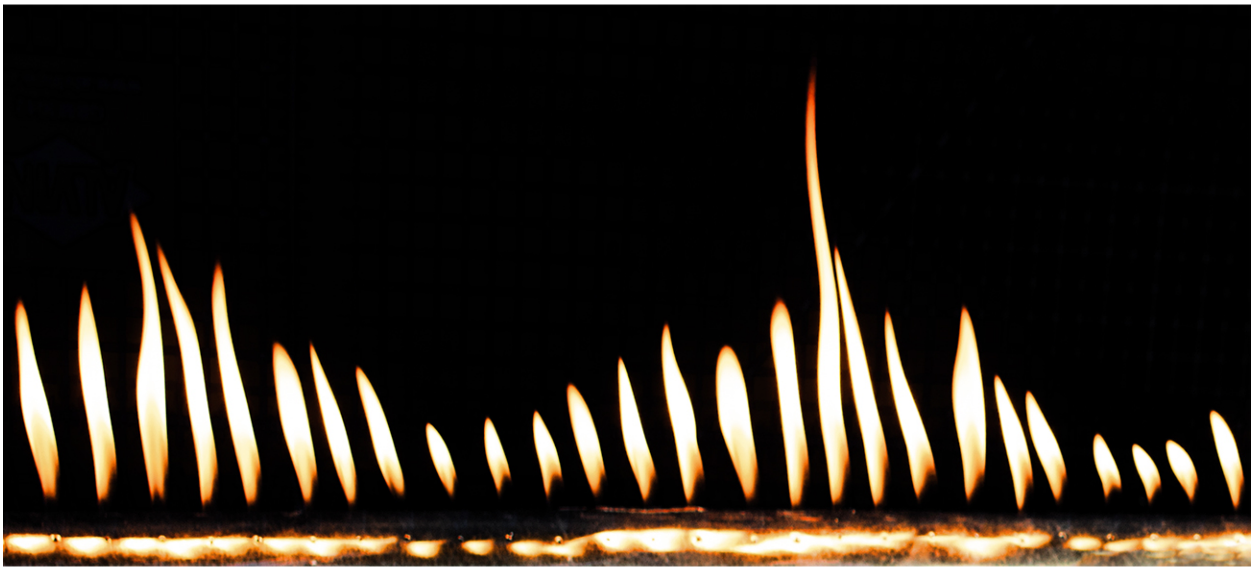

Figure 1: Team First Submission.

The figure above is the final image that I submitted for the Team First assignment. I set out to capture standing waves in the flames produced by sound waves inside the Rubens' Tube. My team for this project consisted of Aaron, Evan, Robbie, and Max. Every member of our team collaborated in setting-up the location for this photograph. And we all contributed to building the Rubens' tube.

2 Flow Apparatus and Flow Description

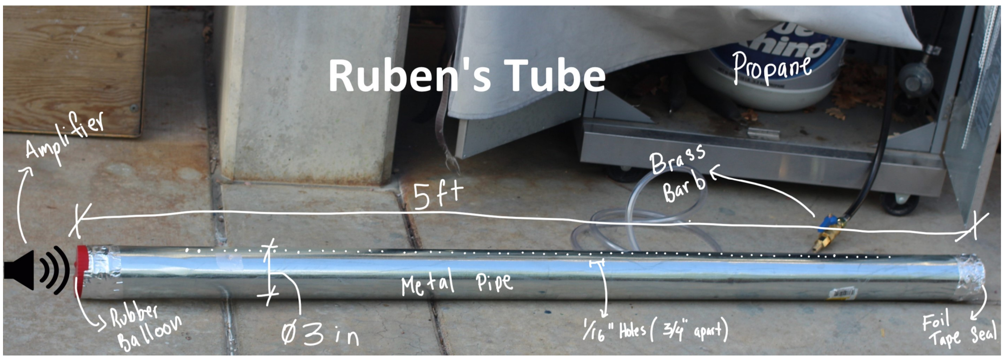

Figure 2: Rubens' Tube Layout.

Our Rubens' Tube consisted of a five-foot long, three inch diameter metal pipe. Along the length of the pipe we drilled sixty-two one-sixteenth inch diameter holes. We spaced each hole to be three-fourths of an inch apart. We sealed one end of the pipe with several layers of foil tape. This was an important step to ensure proper reflection of the sound waves inside the tube. We sealed the other end of the pipe with a rubber balloon. The sound waves are able to pass through the rubber surface without interference. In front of the rubber end, we placed a guitar amplifier. Finally, we drilled a one-inch diameter hole at the center of the pipe to connect the the brass adapter barb. This is the mechanism that we used to fill the Rubens' tube with propane gas.

The Rubens' tube was the creation of Heinrich Rubens, a German physicist born in 1865.[4] Rubens worked with Max Plank on some of the ground work in quantum physics. Yet, he is better recognized for his flame tube. His original tube contained 200 evenly-spaced holes along the length of a four-meter pipe. With both ends sealed, he pumped flammable gas into the pipe. The pressure inside the pipe builds as gas fills the inside of the tube. When the pressure inside the tube is greater than the pressure outside, the holes allow gas to escape upwards. This phenomenon equalizes the pressure inside with the pressure outside. The gas will continue to escape until the pressures are equal. Figure 3 shows the relationship between the inside and outside pressures. P_t is the pressure inside the tube and P_0 is atmospheric pressure. He then lit the escaping gas to find that that they formed evenly-sized flames. Finally, he introduced sound waves through one of the ends. He found that specific frequencies produced standing waves in the flames. The standing wave is a result of a series of nodes and antinodes along the length of the pipe[1].

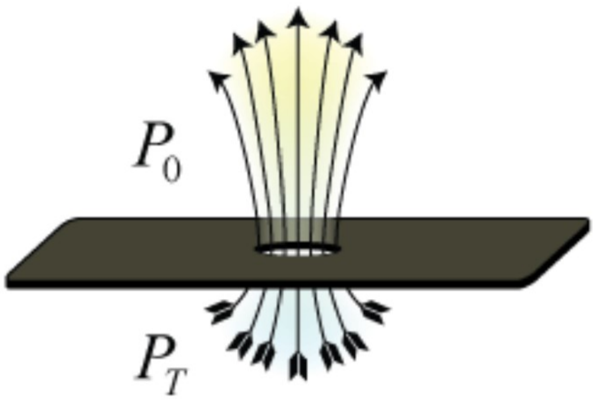

Figure 3: Inviscid flow through a hole.[2]

Unfortunately, the frequency of the sound wave was not recorded prior to taking the photo. Luckily, the theoretical frequency can be calculated using the relationship between frequency, speed of sound, and wavelength. I can calculate the frequency using the following equation:

$$f = \frac{v}{\lambda}$$

where v is the speed of sound through propane gas and λ is the wavelength measured from peak to peak. The speed of sound through propane gas is 258 $\frac{m}{s}$[3]. I measured the wavelength from peak to peak in my image to be 0.346 meters. Using these values, the theoretical frequency is calculated to be following:

$$f = \frac{258\ \frac{m}{s}}{0.346\ m} = 745Hz$$

Finally, I can conclude from the smooth nature of the flames that the fluid flow belongs to laminar flow. The Reynold's number for this flow can be predicted to be less than 2000. Values below this threshold belong to the the laminar flow region of the Reynold's number.

3 Visualization Technique

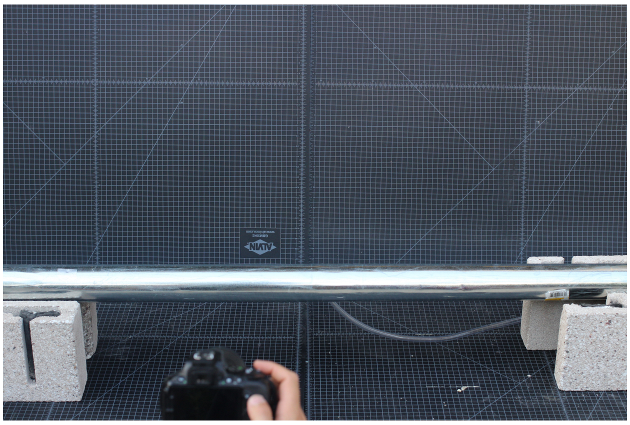

Figure 4: Background.

The technique I used for this assignment was the seeded boundary technique. Our Rubens' sat in front of a black background. This was necessary to ensure that the light emitted from the flame contrasted well with the dark background. My camera was able to capture the bright outline of the flaming standing waves against the dark backdrop. The backdrop we used is a Alvin-GBM Series 30" x 42" Green/Black Professional Self-Healing Cutting Mat that we borrowed from the ITLL. We shot our images outside as a precaution in case there was a gas leak in our tube. There was some wind in the environment and the sky was clear. The wind caused some of the nodes to be bigger than they should be.

We took our photos in the afternoon, as the sun was setting. Flash was not used in my photograph; flash would have caused the photo to be overexposed.

4 Photographic Technique

The field of view of the original image is 5184 x 3456 pixels (45" x 30"). I shot the photo at a distance of 40 inches from the end of the lens to the Rubens' tube. Table 1 breaks down all the properties that I used to capture the original image.

Table 1: Camera Properties

Property	Value
Camera Maker	Canon
Camerica Model	EOS Rebel T6
ISO	ISO-100
F-stop	f/4
Exposure Time	1/125 sec.
Flash Mode	No Flash
Focal Length	40mm

Moreover, I used Photoshop to edit my image. I straightened the photo using the rotate tool. Then, I cropped the image to show only complete flames and, concurrently, I aligned the highest flame to be off-center (using the rule of thirds). To make the background completely black, I used the color replacement tool. I did this by selecting a pixel from the backdrop and replaced the color of every similar pixel with black. Any remaining imperfections were then removed using the clone stamp tool. Figure 4 shows the original image and the post-processed image.

Figure 5: Before and After.

5 Conclusion

In conclusion, the final image that I submitted shows the physics behind sound waves and pressure differences. I am pleased with the aesthetics of the standing wave I captured. I fulfilled my intention for this image, as I was able to capture a standing wave using the Rubens' Tube. Moreover, having captured a standing wave for one frequency, I would like to extend the this experiment to include many frequencies. Future iterations may include video to capture and display a wide range of frequencies.

References

[1] Rubens' flame tube.

[2] The rubens' tube: Soundwaves in fire!, Feb 2018.

[3] Anthony Butterfield. Outreach teaching module, chemical engineering, university of utah.

[4] American Physical Society. The flaming oscilloscope: The physics of rubens' flame tube.