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MCEN 5151
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Team 3 Report

Introduction

This project was the third team project of the flow visualization course that takes place at CU Boulder during the Spring Semester and is taught by Professor Jean Hertzberg. The purpose of this report is to describe how the phenomenon was visualized and captured by explaining the apparatus, physics, visualization technique and photographic technique used. For this assignment, my team (Jeremy Parsons, Jonathan Fritts, and Daniel Allen) and I decided to capture and document the standing waves that are produced from a Rubens' Tube. The tube was provided by Michael Thomason from the Physics department at CU Boulder. The combustion guidelines presented in the course were carefully followed and observed. Jonathan, Daniel, and I took the images from different angles, while Jeremy was in charge of creating the flow. The final, edited image of the flow can be seen in figure 1, below, and in figure 7 within the Photographic Technique section of the report.

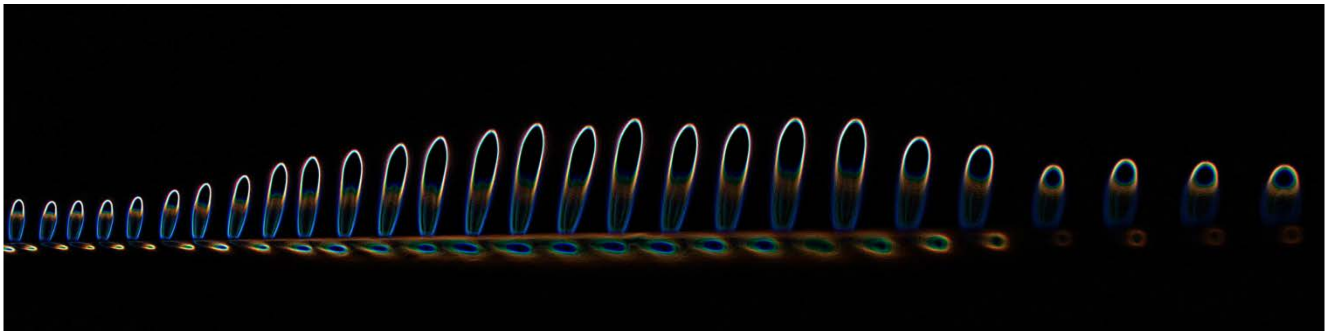

Figure 1 - Final, edited image of phenomenon

Apparatus

The flow apparatus was the same for all images captured. It consisted of a long copper tube – about 7 feet in length – with holes spaced periodically on the top of it. One end of the tube was closed, while the other had a speaker attached to it. The speaker was connected to a frequency generator that was located on a small table and was responsible for creating the oscillating waves. Propane was fed into the tube through a small opening near the speaker. Below and attached to the tube was a much smaller-diameter tube that had water running through it – this was done to cool the main part of the Rubens' Tube. The lighting in the area was kept as dark as possible – as such, no additional lighting was used. The apparatus set-up can be seen in figure 2, below.

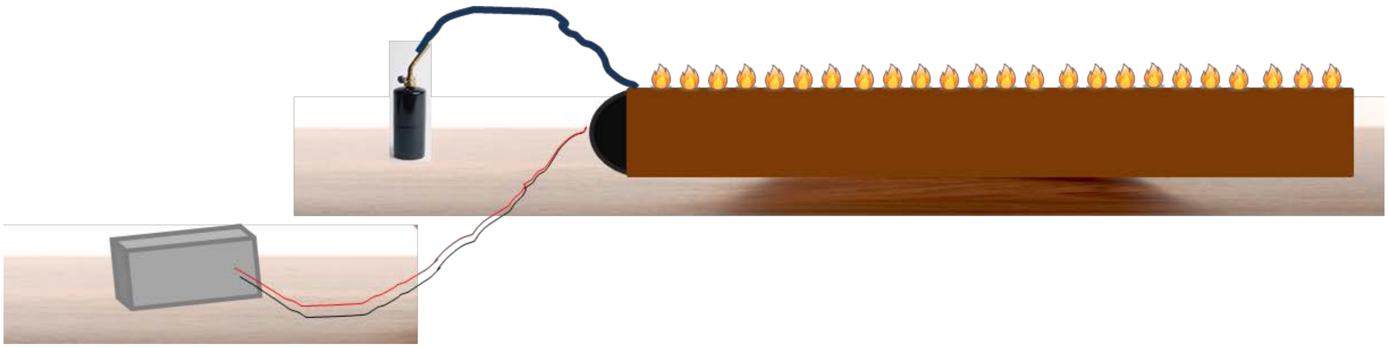

Figure 2 - Apparatus set-up

Physics

A Rubens' tube is a metal tube that has holes drilled into the top of it, a speaker on one end, and a flammable gas supply (typically propane) on the other. The standing waves that are created are due to the frequency of the sound as the gas resonates in the tube. [1] More specifically, as sound travels through the speaker, it vibrates. This vibration results in sound waves that then travel down the tube, bounce off the other end, and come back. This results in the standing wave pattern seen by the Rubens' tube. [1] A visual representation of the steps is seen in figure 3 below.

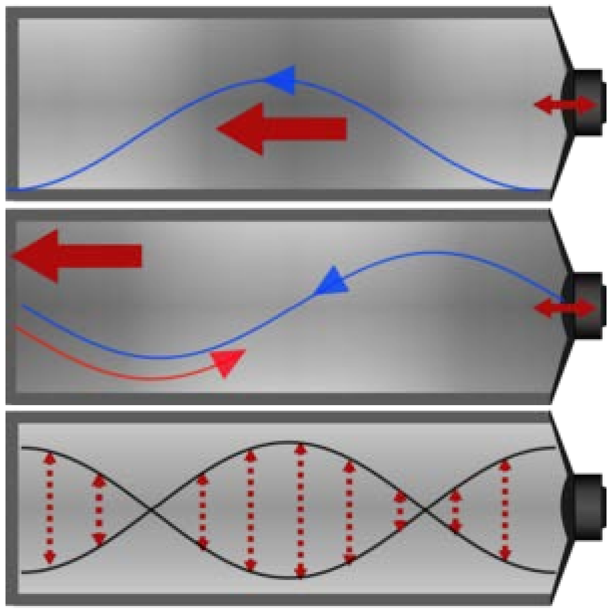

Figure 3 - Visual Representation of creation of waves in Rubens' Tube. Adapted from [1]

When the holes are added to the tube and propane is put into it, the waves can be seen. Unfortunately, it is not possible to predict if the highest flames will occur at the nodes ("normal"), or at the antinodes ("reversal"). When the gas flow/pressure is lower, the highest flames occur at the antinodes, whereas if the gas flow/pressure is higher, the highest flames occur at the nodes. However, the difficulty of prediction of the highest flames occurs at a fixed gas pressure. When the gas pressure/flow is fixed, a high sound intensity results in high flames at the antinodes, while a low sound intensity results in high flames at the nodes. [2] Ficken and Stephenson applied the Bernoulli equation to the gas flow and derived the formula below to attempt to predict where the flames will be highest. [3]

$$F = \rho A v = A\sqrt{((p_g + p_m \sin(\omega t))2\rho)}$$ Equation 1, taken from [3]

In the equation above, F is the mass flow rate, ρ is the density of gas near a hole, p_g is the pressure at the gauge, p_m is the pressure of the sound amplitude, v is the speed of gas going through the hole, A is the hole area, and ω is the angular frequency of the wave. [3] As a final note on the physics of the Rubens' Tube, a pictorial representation of the two possibilities of where the high flames can occur is present in figures 4 and 5, below. [1]

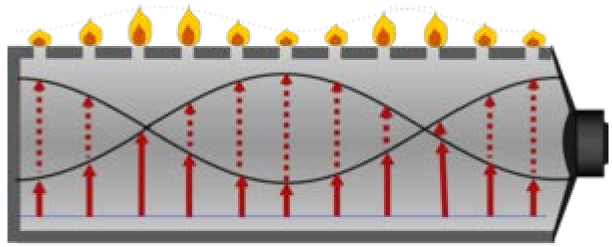

Figure 4 - Tube with highest flames at nodes. Taken from [1]

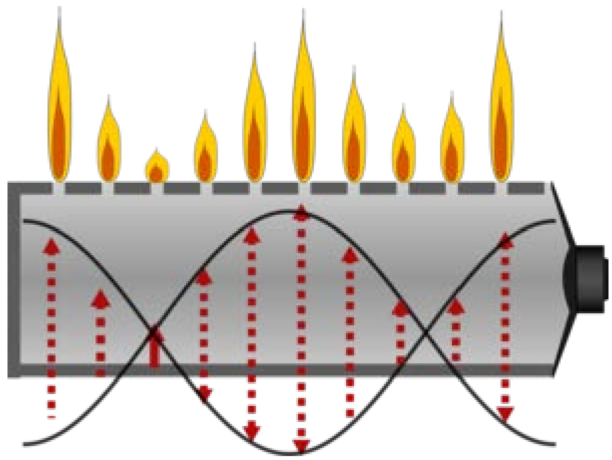

Figure 5 - Tube with highest flames at antinodes. Taken from [1]

Visualization Technique

The fluid used for this visualization was propane in the form of flames. The propane tanks used were 400-gram propane tanks purchased at McGuckin's Hardware. The amount of propane needed to fill the tube and for each image varied and was difficult to quantify. For this experiment, the propane was lit with a lighter. No additional lighting was used because it was not necessary for this image – in fact the area that the image was taken in was kept as dark as possible to produce the best-quality image possible.

Photographic Technique

The camera used to capture this phenomenon was a Canon EOS Rebel T3 DSLR camera. The creative auto setting on the camera was used, with the default settings selected. For this image, the flash did not fire. The size of the field of view of the original, unedited image is approximately 2 feet tall by 3 feet wide. The lens was about 6 inches away from the Rubens' Tube and the creative auto mode on the camera was selected. The shutter speed, f-stop, aperture value, ISO speed, and focal length were 1/60 sec, f/4.5, f/4.6, 2500, and 32.00mm, respectively. The original, unedited, image has pixel dimensions of 4272 pixels wide by 2848 pixels tall, while the final image has pixel dimensions of 3904 pixels wide by 966 pixels tall. Refer to figure 6 for the original image and figure 7 (or figure 1) for the final image.

Adobe Photoshop CS2 was used to edit the original image. The tools used were: crop, clone stamp spot healing, curves, and glowing edges. Glowing edges "identifies the edges of color and adds a neon-like glow to them." [4]These modifications transformed the original image (figure 6) into the final image seen in figure 7.

Figure 6 - Original, unedited image

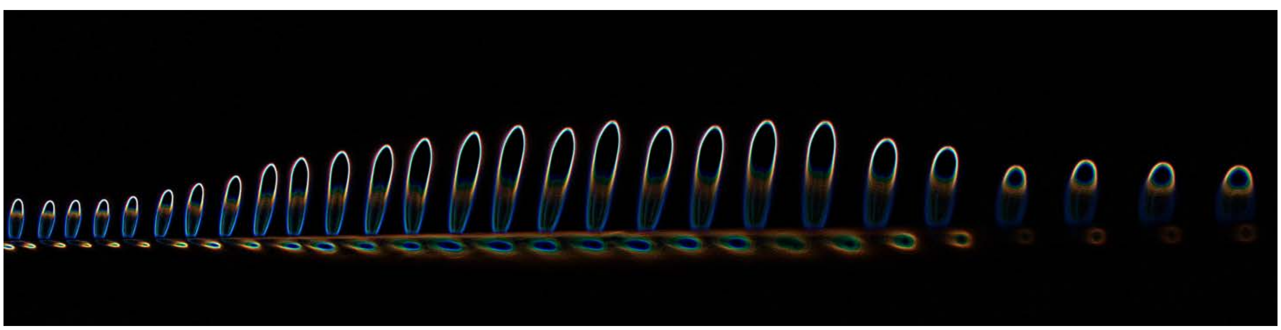

Figure 7 - Final image

Conclusion

This image shows a good representation of a wave on the Rubens' Tube. I like the depth of field, and colors that are present. I feel that the glowing edges effect gives a different effect to the common flames that are seen in images where fire is present. I think that the fluid physics are pretty well defined in this image. I dislike that the flames are smaller on the left-hand side versus the right hand side; however I don't think that it detracts from the image. My intent with taking and presenting this image was to show the flames and waves of a Rubens; tube – that intent was fully realized. To further develop this idea, a video of the Rubens' Tube in action could have been shown. While there is always room for improvement, I am pleased with how this phenomenon was realized and shown.

References

[1] Ansell, Dave. "Rubens' Tube - Waves of Fire." *Rubens' Tube - Waves of Fire - The Naked Scientists*. The Naked Scientists, 21 Apr. 2010. Web. 16 Apr. 2013. <http://www.thenakedscientists.com/HTML/content/kitchenscience/garage-science/exp/rubens-tube/>.

[2] Am. J. Phys. 51, 848 (1983); doi: 10.1119/1.13133

[3] Phys. Teach. 17, 306 (1979); doi: 10.1119/1.2340232

[4] "Photoshop / Filter Effects Reference." *Adobe Photoshop * Filter Effects Reference*. Adobe Photoshop, n.d. Web. 25 Apr. 2013. <http://help.adobe.com/en_US/photoshop/cs/using/WSfd1234e1c4b69f30ea53e41001031ab64-7970a.html>.