Flow Visualization Team Project #3

Ruben's Tube

Jonathan Fritts

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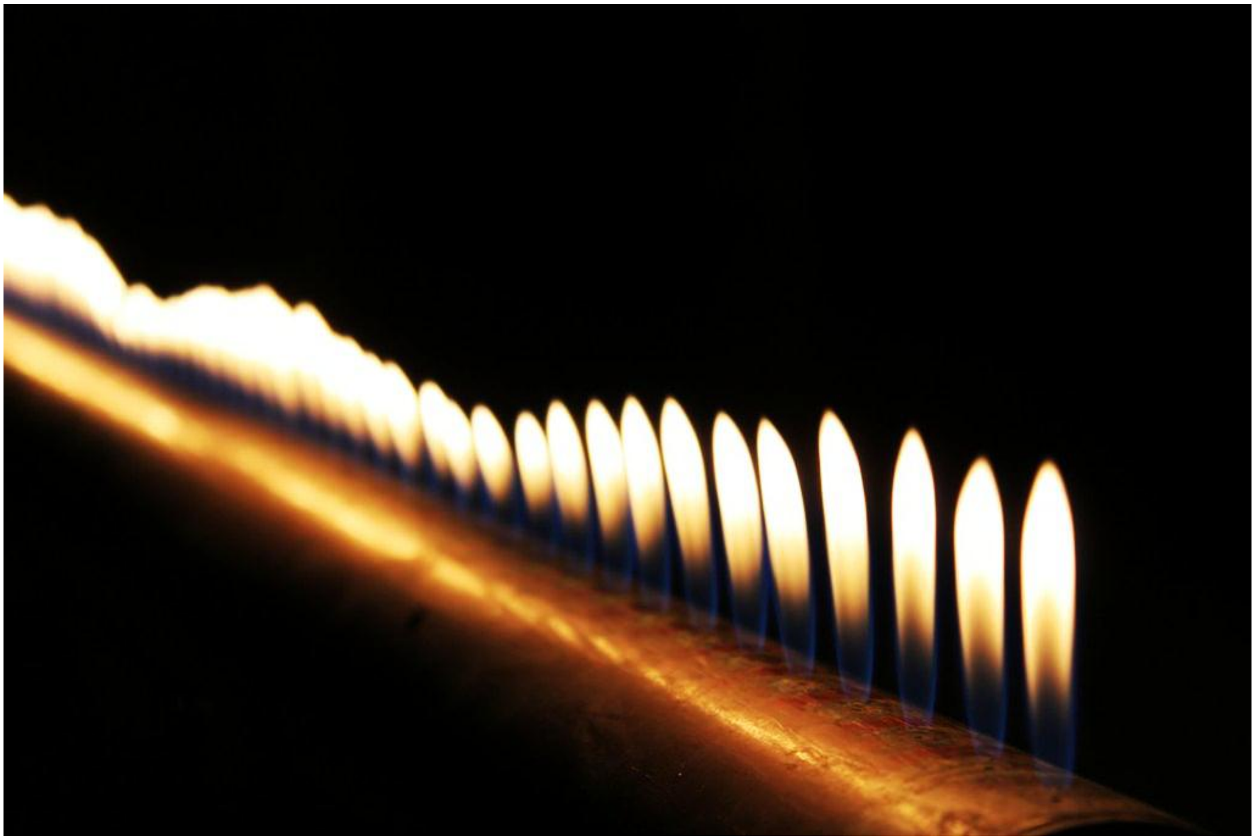


The purpose of this image was to capture a physical phenomenon of a standing wave of flames on what is known as a Ruben's tube. This antique apparatus was invented by Heinrich Rubens in 1905. This device is used primarily in demonstrations for physics educational purposes. It physically shows the relationship between sound waves and sound pressure. The general theory can be simply explained although the detailed explanation of the phenomenon is much more complicated. A long tube is placed horizontally and perforated on top. One end of the tube is sealed off where the other end of the tube has an inlet for flammable gas (propane for most experiments) and an opening for a speaker to fit tightly on the tube. After the cylinder is completely filled with propane, the pin holes can then be individually lit by touching a flame directly to them on the outside of the tube. A constant frequency or music can then be generated through the speaker and the sound causes pressure waves to travel down the tube and reflect back off the closed end of the tube to travel back. This causes nodes and antinodes and the flames appear in the form of a standing wave. The image captured with the help from my teammates;

Anna Gilgur, Daniel Allen and Jeremy Parsons, shows a close up angled view that gives the final product an artistic sensation. More detailed physical explanations of this phenomenon along with the specifications of the experimental setup and photographic techniques used will be discussed in this report.

In this experiment, the Ruben's tube was setup in the Duane physics lab at the University of Colorado. As discussed before, one end of the tube is sealed off completely and the other end has a small inlet for the gas to enter and a suitable, covered speaker fits tightly in the opening. As the valve is opened to the liquid propane, gaseous propane completely fills the tube which slightly raises the internal pressure above atmospheric pressure. As the tube is lit, the flames rise to a height that is naturally related to the flow rate of the gas. If assumptions of an inviscid and incompressible flow are made, the flow out of one hole can be modeled by Bernoulli's equation. Another simplification that the change in height of the fluid is negligible will yield the following equation [1]:

$$\frac{\rho V^2}{2} = P_T - P_0$$

where:

ρ = density of the fluid (propane)

V = velocity of the gas

P_T = pressure inside tube

P_0 = atmospheric pressure

Therefore, the velocity of the gas is proportional to the square root of the difference between the pressure inside the tube and the atmospheric pressure. This can be summarized again in figure 1 [3].

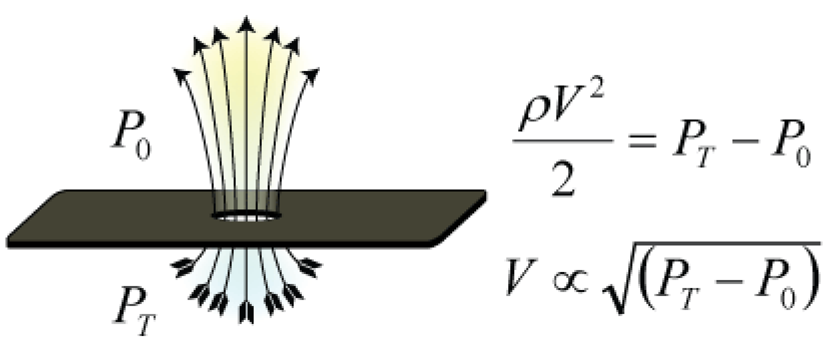


Figure 1 - Inviscid flow through a hole

The sound introduced into the tube through the speaker was a constant sine wave frequency generated by a function generator. This causes pressure waves that travel down the tube, reflect off the end and travel back towards the speaker. At certain points along the tube, a high pressure peak leaving the speaker will meet with a low pressure trough from the feedback returning from the other end of the tube. The magnitudes of these pressures are equal and the sum of them therefore is simply P_T [1]. These locations are referred to as nodes. Alternatively, there are other locations in the tube where high pressure peaks combine and low pressure troughs from the feedback combine and create what is known as antinodes. These antinodes are seen as the maximum height or peaks of the flames on the tube. The summation of these pressure waves results in the standing wave that is seen in any Ruben's tube demonstration. A representation of the flames responding to the nodes and antinodes derived from the interfering waves can be seen in figure 2 [1].

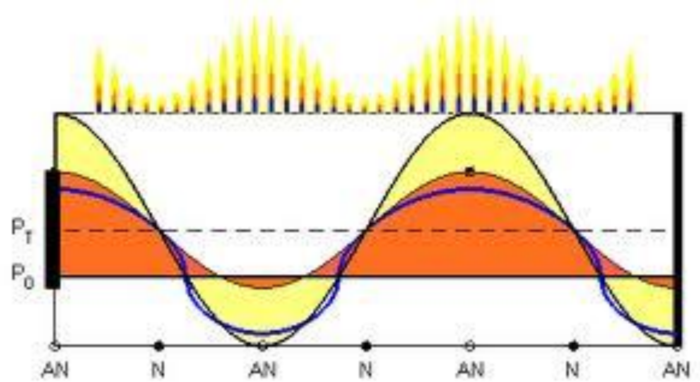


Figure 2 - Flame height corresponding to nodes

The standing wave should have a wavelength equivalent to that of the sound being played. The wavelength can be found theoretically by:

$$\lambda = \frac{v}{f} = \frac{258\ m/s}{300\ Hz} = 0.86\ m = 2.82\ ft$$

where:

λ = wavelength

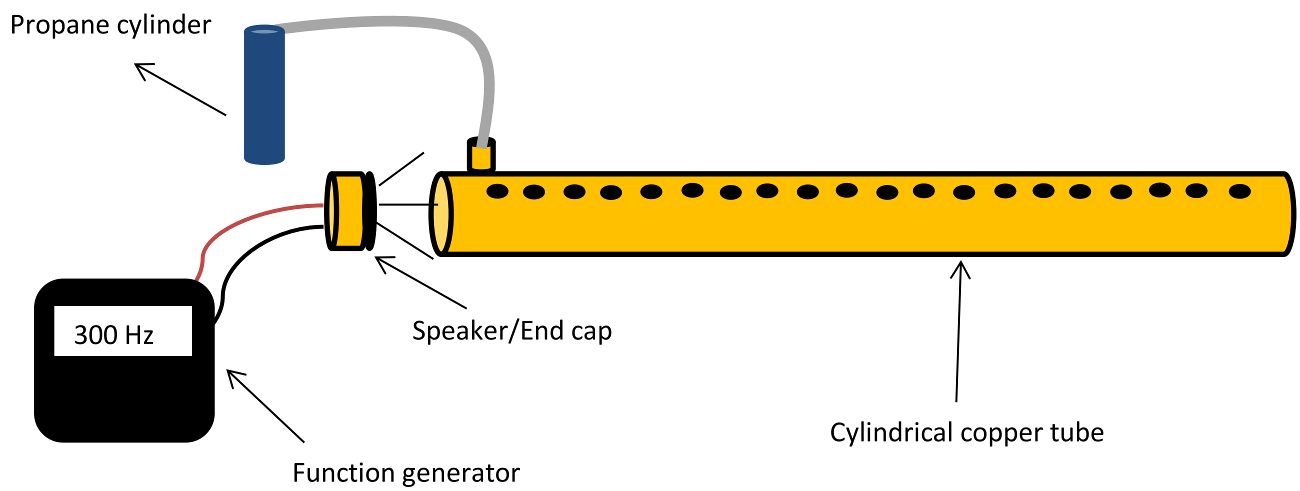
v = speed of sound through gas = 258 m/s [2]

f = frequency generated = 300 Hz

The experimental wavelength can simply be measured physically from peak to peak. The measurement observed from using a tape measure during the experiment was approximately 2.75 ft. The experimental wavelength therefore agrees with the theoretical wavelength.

The physics behind the Ruben's tube is more complicated than the general theory presented in this paper. For example, the harmonics in the tube are altered by the presence of the pin holes, which act as Helmholtz resonators and shift the location of peaks [4]. Additionally, some of the sound returning to the speaker will reflect back into the tube and some will be absorbed or reflected to the surroundings outside of the tube. In fact, the entire theory of the Ruben's tube is not completely settled [4].

The setup of the experiment was relatively simple. The cylindrical copper tube was placed horizontally on a counter with the perforated holes facing upward. The speaker was placed in the open end of the tube that also acted as a cap to the cylinder. The wires of the speaker were connected with cables to the function generator. A range of frequencies was experimented with on the generator, but the output was 300 Hz for the picture seen in this report. A plastic tube was then placed over a nozzle on the copper tube and attached to the regulator of the propane tank. The valve of the propane tank was then opened and the Rubens tube filled with gas for approximately 30 seconds. A lighter was then used to ignite the perforated edge of the tube. The basic setup can be seen in the diagram below:



There was no direct or indirect lighting used to capture the picture. All the lights in the room were turned off and the group attempted to block any other light from entering the room. This allowed the group to capture the brightness of the flames and give a dark background that did not distract the viewers. No flash was used to snap the picture either.

The following photographic techniques were used to record the image:

Size of field of view	Approximately 4 feet
Distance from object to lens	12 inches
Focal length	43.0 mm
Type of camera	Canon EOS Rebel T3
Original/Final image width	1024 x 682 pixels
Aperture/ISO	F 5.0/2500
Shutter speed	1/85 sec
Photoshop processing	• Increase contrast slightly using curves • Use brush to get rid of distracting mark

The aperture was used to intentionally focus part of the image closest to the camera, and then blur the image farthest from the camera. This gave the image a very artistic feel as it makes the line of flames look like it goes on forever. The shutter speed and ISO were adjusted as necessary to allow the appropriate amount of exposure. The curves feature was used in Photoshop to slightly increase the contrast by making an “S” shape. This really made the flames stand out and made the background even darker, adding to the artistic, antique feel. The dark, rusty looking tube reflects the flames and appears to be lit similarly to candle light. Additionally, there was a speck of brown in the image away from the tube that was distracting to the viewer (bottom left of original image). Therefore, the brush tool was used and a black paint was brushed over this distracting feature. The comparison of the original image and the final product after editing can be seen in figure 3 below:

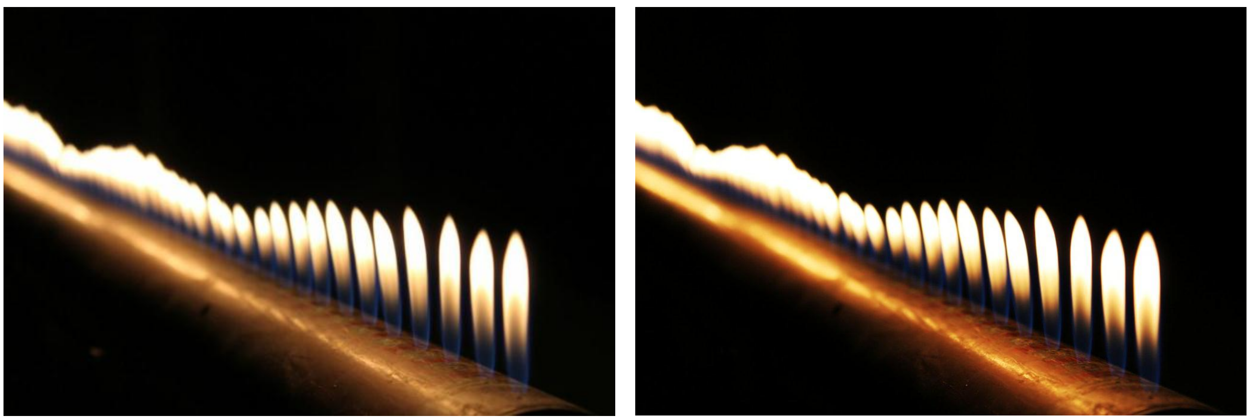


Figure 3 - Image before and after editing

The image captured for my final team project shows a great balance between explaining the physics of a Ruben’s tube and expressing art through an interesting point of view. Many demonstrations of this experiment show a straight on view of the tube to see the standing wave form. While this is helpful for explaining the physics, it does not give a unique perspective. The image here gives an old, ancient feel like an antique lit with candle light. Additionally, the standing wave can still be observed from this perspective. I am very happy with the outcome of this photo and there is nothing significant I dislike about it. I would be very interested in performing the same experiment with using music instead of a constant generated frequency. Our group did not have the resources to connect music to the speaker provided. I believe a video of the tube while music is playing and several frequencies are bouncing around in the tube could be very interesting.

References

1. Ficken, G.W., Stephenson, F.C., Rubens flame-tube demonstration. The Physics Teacher, 17, pp. 306-310 (1979).
2. Zuckerwar, A.J. "Handbook of the Speed of Sound in Real Gases,"(Academic Press, 2002).
3. Gardner, M.D., Gee, K.L., An investigation of Rubens flame tube resonances. Journal of Acoustical Society of America, 125 (3), pp. 1285-1292 (2009).
4. Spanga, G.F., Rubens flame tube demonstration: A closer look at the flames. American Journal of Physics, 51 (9), pp. 848-850 (1983).