2011

On Fire!

Rubens Tube

Flow visualization and Rubens Tube by Bailey Leppek, Paul Mountford, Daniela Molina-Piper, Shane Schabow, Scott Schollenberger.

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Objectives

My inspirations for this flow visualization were the beauty of fire and the deep emotional power of music. A Rubens Tube is a mesmerizing combination of the two, where music moves fire as well as moving us. The music heard in the video is the exact same music that was played through the speaker, so we can see the effect that the tone and volume of the music have on the flame height.

Set Up

The Rubens Tube was made from a five foot long, four inch diameter copper pipe with 1/16 inch holes drilled along the top spaced every half inch. Two inches near either end of the tube were left without holes to keep flames away from the speaker and the propane inlet.

One end of the tube was capped with a four inch diameter PVC cap. The cap was glued on to prevent leakage of propane. A hole was drilled in the middle of the PVC cap to allow for a fuel inlet. A large propane tank typical for home gas barbeque grills was used as a fuel source. A typical regulator for gas grills lead from the propane tank into the hole in the middle of the PVC cap.

To prevent propane from flowing out the other end of the tube, a silicone swim cap was cut into a circle and stretched over the open end. Electrical tape was used to hold the cap on and also to line the rim of the copper pipe beneath the swim cap so that the somewhat jagged edge would not rip the silicone. The swim cap was used because the silicone material was thick and sturdy but also flexible. The flexibility allowed it to act as a drum for the speaker. A simple 4 inch diameter speaker was attached to the end of the tube over the swim cap plug with electrical tape. The speaker was hooked up with speaker wire to a transceiver intended for a home stereo system, which was plugged into a laptop to play music.

When the regulator was opened, the propane flowed from the tank into the tube and out through each of the holes drilled in the top of the tube. The propane emerging from the holes was lit, so that each hole had a flame issuing from it. For safety reasons, the Rubens Tube was set up outside. To create standing waves, an online frequency generator was used to play different frequencies of sound through the speaker at the end of the tube. Then different songs were played through the speaker. The sound waves generated by the speaker caused the varying flame heights along the tube.

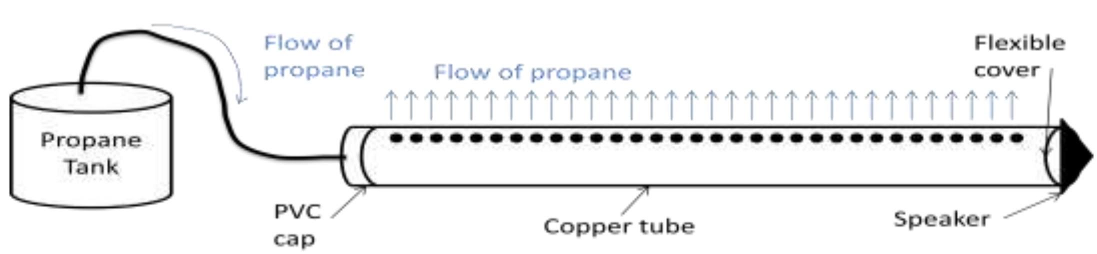

Figure 1: Rubens Tube setup

Physical Analysis

When the regulator was initially opened, it took several minutes to be able to light the Rubens Tube. The density of propane is 1.882 kg/m^3 at 20℃ ; it is denser than that of air, which has a density of 1.205 kg/m^3 at 20℃ [1]. Because of the difference in densities, the propane filled the bottom of the tube first, displacing air by pushing the air up through the holes in the top. Once the tube was filled, propane was pushed out of the holes. The flame height was originally very low. This is likely because the maximum flow rate of regulator was not enough to force sufficient propane through all the holes. When the Rubens Tube was set on a slight incline, the flame height was greater at the end that was lower because the propane is denser than air and settles at the bottom of the tube. Some of the flickering of the flames is due to the wind, as the tube was located outside.

One of the interesting effects observed was the tube's ability to light itself. Some of the flames would die out at times and would then be lit by the flames around it. This was shown in the middle of the video. Only a few flames were lit at the right end of the tube. When the sound changed and the propane flow rate increased, the flame at the right became large enough to light the jet of propane to its left, and so on down the tube in a domino-like effect.

Once the tube is filled with propane, it can be assumed that the gas is mostly propane immediately at the exit of each hole. However, as the propane diffuses in air, the fuel is allowed to mix with the oxygen. In order to burn, the fuel/oxidizer ratio must be within the right range. The blue color in the flame is the result of better fuel/air mixing. Because the combustion is incomplete, unburned hydrocarbons from the propane are left over. These unburned hydrocarbons, known as soot, are excited by the very high temperatures within the flame[2]. At normal temperatures, these particles will only emit infrared radiation, heat; however, at high temperatures, they emit blackbody radiation in the visible spectrum[3]. We see the result as the orange glow.

The most interesting part of a Rubens Tube is, of course, its response to sound. The sound waves moving though the tube create different pressures. The height of the flame above the tube is a response to that pressure.

Playing certain constant sound frequencies created standing waves. The frequency, f, and the wavelength, λ, are related to the speed of sound, v, by Equation 1:

$$f = \frac{v}{\lambda} \qquad \text{(Equation 1)}$$

The speed of sound in propane is about 235 m/s [4]. The distance between the peaks of the standing waves is the wavelength of the standing wave. In order to generate four peaks on the 60 inch long Rubens Tube, the wavelength would have to be 15 inches or 0.382 meters. The frequency needed to generate four peaks can be calculated by Equation 1 as 615 Hz. Using a sound frequency generator, frequencies of 615 Hz actually did create four standing waves. According to Equation 1, increasing the frequency of sound should decrease the wavelength and make more standing waves along the tube. This was also observed experimentally.

Flow Visualization and Photographic Techniques

The still photos shown throughout the video were taken with a Canon Rebel XSi EOS 12.2 megapixel digital camera. They are each 3072 by 2304 pixels. The depth of field for these photos was between ten inches and 1.5 feet. Because many of the shots show a view down the length of the tube, only some of the flames are in focus. The focal length, f-stop, and shutter speed values of some of the photos are shown in Figures 2-5 below. The video clips were filmed with an HD Flip Camera. The frame dimensions are 1280 by 720. The videos had a greater depth of field of several feet, enough to keep the entire Rubens Tube in focus when viewed from the end. All the photography was done on 4/12/11.

Figure 2: Shutter speed 1/20 s, f/ 2.8, focal length 7.7 mm

Figure 4: Shutter speed 1/30 s, f/ 4.5, focal length 18.8 mm

Figure 3: Shutter speed 1/160 s, f/ 7.1, focal length 9.0 mm

Figure 5: Shutter speed 1/20 s, f/ 4.9, focal length 23.1 mm

Video Editing

The video was edited using iMovie. I made no brightness, contrast or color manipulations to any of the videos or photos.

In the real time clips in the movie, the music played in the video is exactly synced with the music that was being played through the speaker at the end of the Rubens Tube. The sound was recorded in the video, but was poor quality. I dubbed over the original sound for each clip with the same song. I used trial and error to make sure that the music in iMovie was exactly synced with the music in the actual video clip. Then I muted the sound in the original clips. This also edited out the sounds of the group talking.

For the clips of the standing wave in fast motion, I increased the frame rate to over twice the original rate. For these clips, I did not edit out the original sound. I think that hearing the constant frequency tones faintly in the background helps the understanding of the physics of standing waves. I think that the sound also helps to distinguish the standing waves generated by constant frequencies from the fluctuations generated by music.

Discussion

I am very fond of this video. I think that the high energy music works very well for demonstrating the beauty of the Rubens Tube. I would really like to try to get the tube to work with higher volume propane regulator. I think this might increase the flame height and cause the flames to stay lit better. Aside from being a "cool" internet fad, I think that the Rubens Tube is an excellent display of fluid dynamics as well as a work of art. Music is very moving; I find that its ability to move flame just as it moves us it profound.

Works Cited

[1] Gases, Densities. (2011). In *Engineering Toolbox.* Retrieved from http://www.engineeringtoolbox.com/gas-density-d_158.html

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[3] Cengel, Y., and Ghajar, A. (2007). *Heat and Mass Transfer, Fourth Edition*. Mc-Graw Hill.

[4] Wiimote Rubens Tube. (2007). *Instructables.* Retrieved from http://www.instructables.com/id/Wiimote-Rubens-Tube%3a-Control-Fire-With-Sound!-And/