The Speed of Sound as a Function of Altitude, UNC DemoSat

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ABSTRACT

We made an attempt to determine how the speed of sound changes as a function of altitude. A balloon payload carrying the necessary apparatus ascended approximately 19 miles above sea level as the relevant data was taken. An altimeter was used to measure the altitude. An ultrasonic sensor emitted a sound wave, which was reflected off of a barrier located a specified distance away, and then returned to the sensor. The time it takes the sound wave to complete one period was measured, and this time was used to determine the speed of sound. Temperature, pressure, and humidity also impact how sound waves propagate, and since these variables change with altitude, they were taken into consideration. We used additional sensors to measure how these quantities fluctuate as the balloon moved upward. After measuring these factors, we believe we can accurately determine how the speed of sound changes as a function of altitude. As expected, the speed of sound does decrease with altitude for the most part.

BACKGROUND

The speed of sound as a function of altitude is generally difficult to represent analytically. We considered temperature, pressure, and humidity as the main factors affecting the speed of sound in our experiment. There are well-known models which relate the speed of sound to temperature and pressure. However, it has been a challenge to find a simple explanation for humidity's influence.

The model chosen for determining how temperature and pressure relate to the speed of sound is as follows:

$$C_s = \sqrt{\gamma R T}$$

Here, Cs is the speed of sound, γ is the ratio of specific heats, R is the gas constant, and T is the temperature of the medium--in our case the atmosphere. The pressure is related to the temperature through the ideal gas law for the range of temperatures expected for our project, γ changes minimally[1]. So, we anticipated the temperature to have the greatest influence of the factors mentioned above.

As far as the effect of humidity, room temperature tests have shown that it has minimal impact on the speed of sound[2]. We have yet to explore how humidity plays a role at different temperature.

OBJECTIVES

- to accurately measure altitude, temperature, pressure, and humidity in order to investigate a correlation to the speed of sound
- to create a lightweight, energy efficient payload capable of measuring all variables needed
- to obtain practical research experience

METHODS

- We used two ultrasonic sensors in our experiment. The internal sensor is in a controlled environment at a quasi-constant temperature. The external sensor experiences the changes that occur in temperature, pressure, and humidity outside of the payload. The measurements taken by the control and external sensors can be compared.
- One of the biggest concerns and constraints for this research is keeping the temperature of the payload warm. For example, the circuit board for the external sensor has a tendency to get cold and fail. So, as seen in Figure 1, the heater was placed near the external ultrasonic sensor in hopes of keeping its electrical components in working order.
- We used a 3D printed skeleton for mechanical sturdiness; however, not shown in Figure 1 is the insulation. We used a thick, rigid insulation with a high R value that was beneficial both thermally and mechanically.

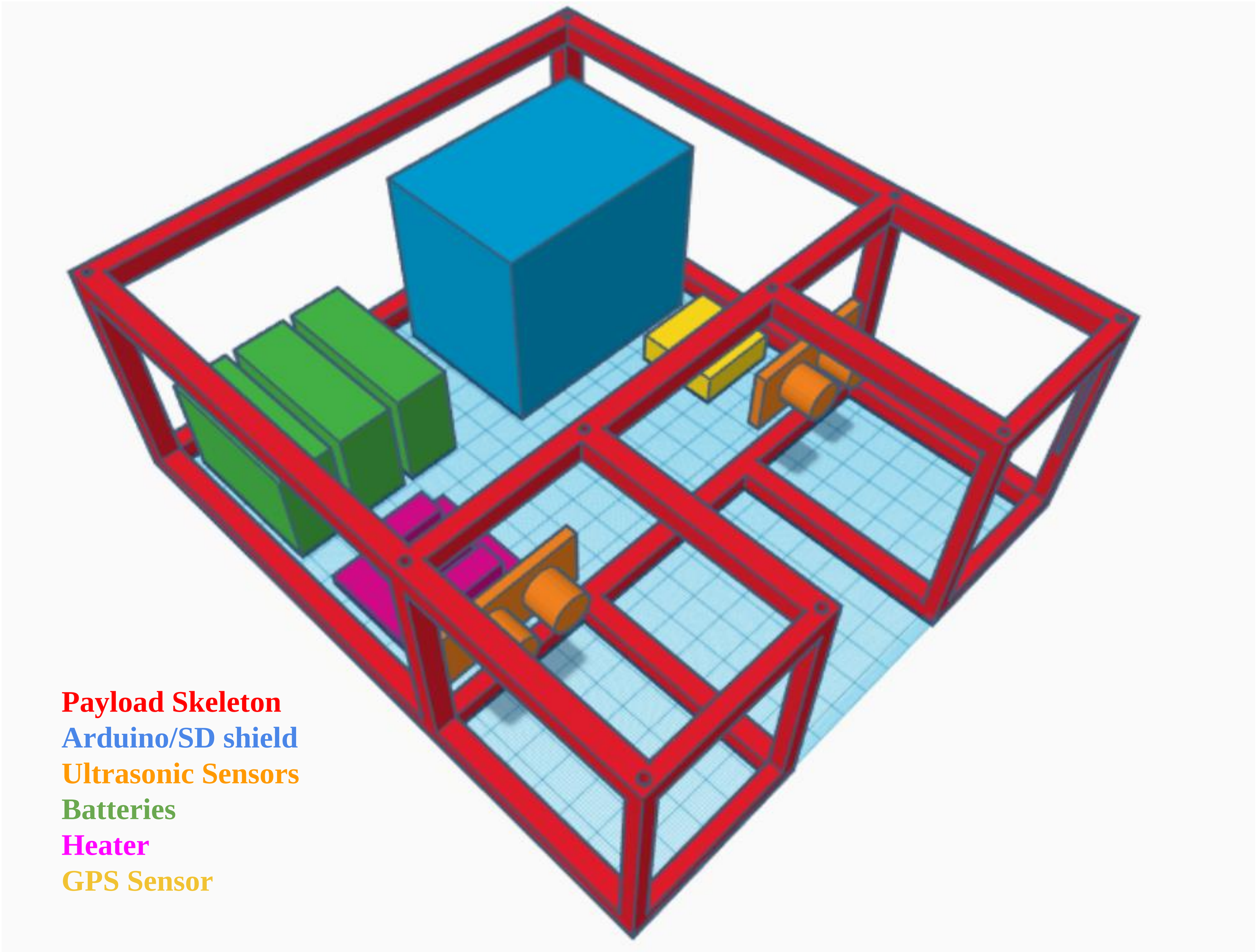

Figure 1: This is a representation of the payload showing hardware placement. The heater was placed nearest to the batteries and external sensor in order to keep them warm and in working order.

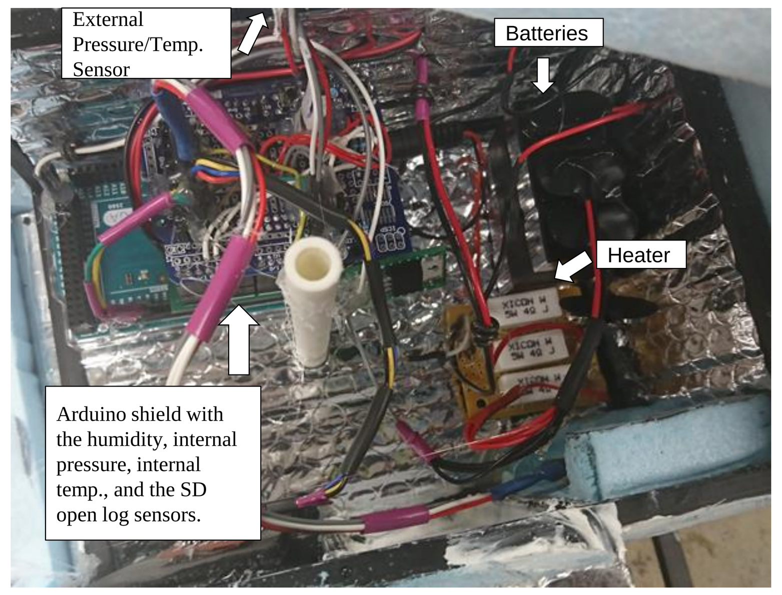

Figure 2: The payload is shown here with all the sensors, heater, batteries and Arduino microcontroller in place.

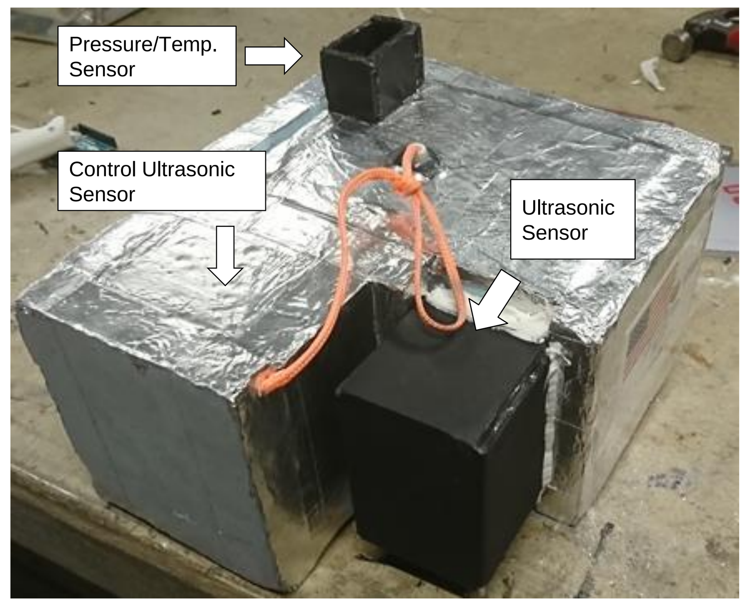

Figure 3: Here the completed payload is shown, with all sensors in their appropriate location and insulated.

References
[1]Hall, Nancy. "Speed of Sound." *NASA*, NASA, 23 Mar. 2018, www.grc.nasa.gov/www/k-12/airplane/sound.html.
[2]Brennan, John. "How Does Humidity Affect Speed of Sound?" *Sciencing*, Leaf Group Ltd, 9 Mar. 2018, sciencing.com/humidity-affect-speed-sound-22777.html.
[3]"Speed of Sound." *Wikipedia*, Wikimedia Foundation, 22 Mar. 2018, en.wikipedia.org/wiki/Speed_of_sound.

LAUNCH DATA

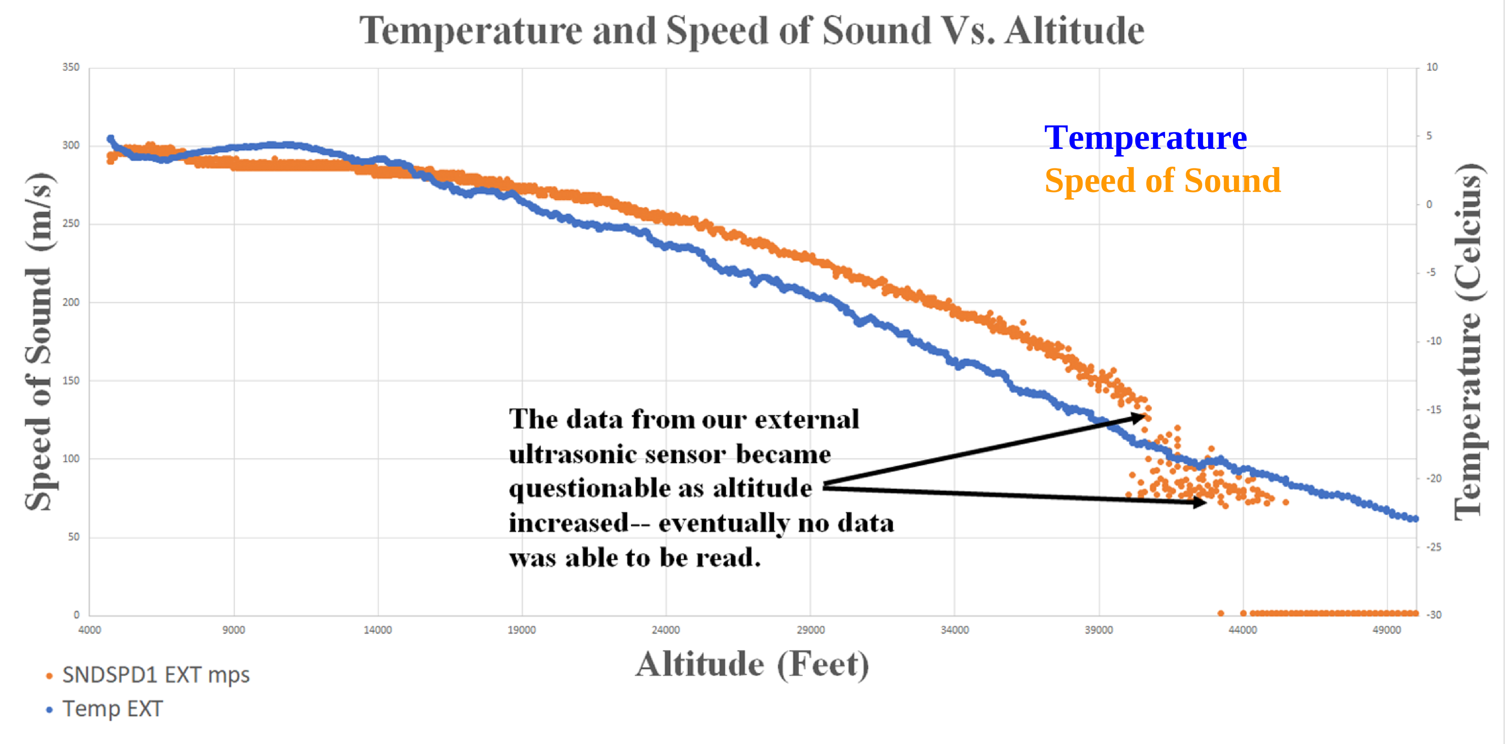

Figure 4

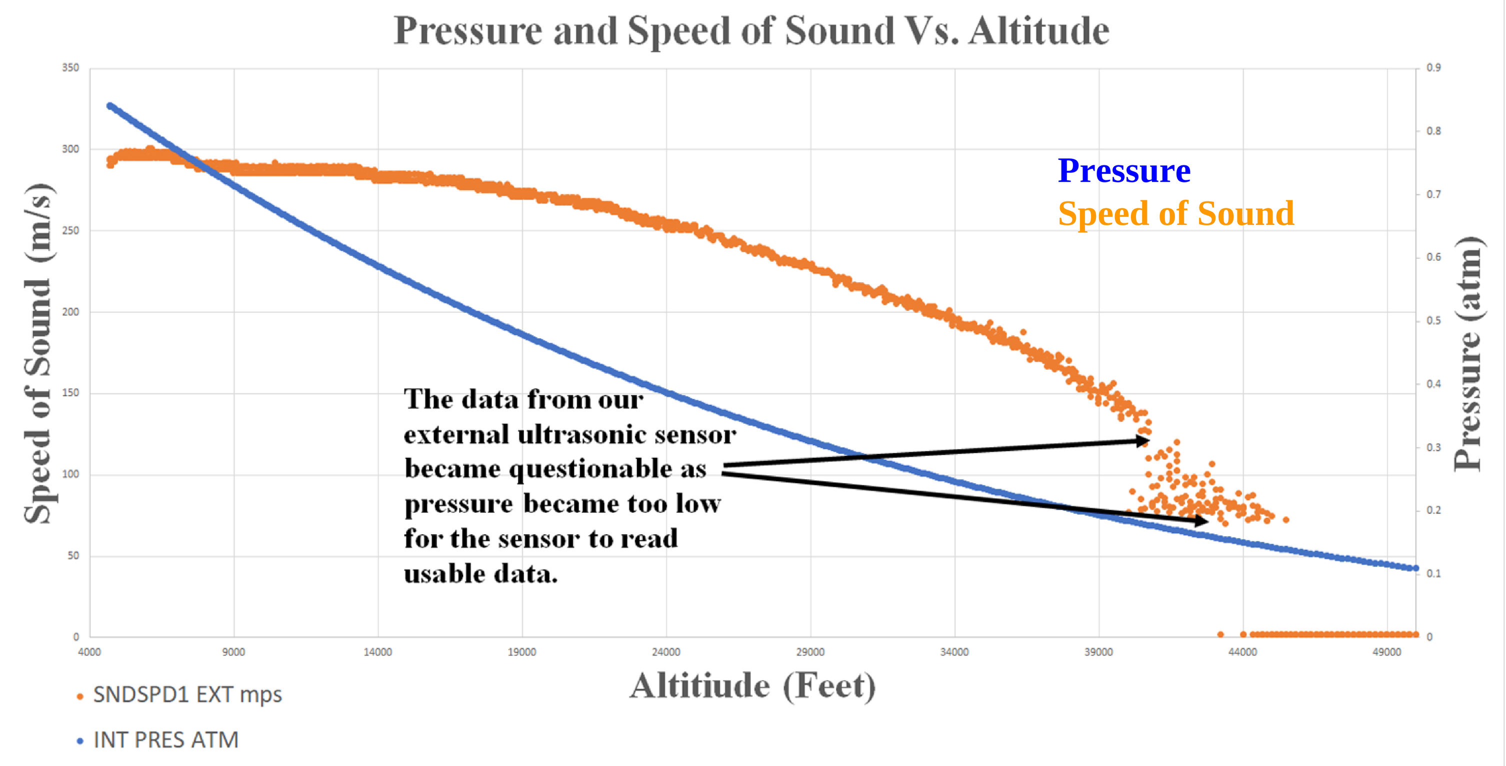

Figure 5

Figures 4 & 5: Figure 4 shows a correlation between temperature and the speed of sound. The temperature and speed of sound data follow each other with a similar rate of change. Figure 5 indicates some relationship between pressure and the speed of sound – more study is required to better understand this relationship. Also, Figure 5 shows at which point our ultrasonic sensor data becomes questionable (around 0.2 atm) and where it stops being recorded (around 0.15 atm).

SUMMARY

We were able to successfully show that the speed of sound changes as a function of altitude — specifically, the temperature and the speed of sound have a general positive correlation. Our ultrasonic sensor data was only usable to about 40,000 feet, at which point it stopped being read. We hope to do more on-ground testing to understand this problem. We believe finding the correlation between humidity and the speed of sound will take a further analysis of our data. Indeed, we hope to be able to quantify any variations in the speed of sound due to humidity, temperature, and pressure changes.

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