Abstract
The goal of this mission was to test the speed of sound at different altitudes and ultimately at a maximum height of 100,000 feet during a total solar eclipse. In conjunction with this testing, environmental parameters including temperature, pressure, and humidity are measured and used to calculate the speed of sound to compare to the measured results. The first balloon launch of payload Dorothy was conducted in NASA CSBF on May 16, 2017. The improved payload “Dorothy Z” was launched successfully in Carbondale, IL on Aug. 21, 2017. Data are analyzed and further improvement plan is discussed.

Background
The measurements of speed of sound profiles were conducted in the 1960's when measurements were conducted in New York City, New York, both in the Summer and Winter seasons, as shown in the figure to the right [1]. The measurements were in a much wider range (0 to 120 km). For the altitude range of 0 to 30 km, it can be seen in the figure that the speed of sound decreases as it reaches 10 km and then increases again as it reaches the 30 km altitude.

The speed of sound can be calculated using measured temperature, humidity, and pressure data from an empirical formula studied by E.A. Dean

\[ c = 20.06 + 0.64\sqrt{T} \]  

where \( T \) is the absolute sound temperature that includes the effects of humidity and pressure [2]. The speed of sound on a normal day is roughly 340 m/s under one standard atmospheric pressure on the surface of the earth.

The physical measurement of the speed of sound can be done by timing how long a sound wave reaches a target at a fixed distance. In the balloon payload Dorothy, the speed of sound is measured by timing an ultrasonic sonar pulse reflecting off a purely reflective mirror. In the meantime, temperature, pressure, and humidity are measured and applied to the empirical formula (1) to calculate the speed of sound. The measured and calculated results are compared.

Payload Design

Electrical Design

The payload needs to be able to conduct all environmental testing as well as measuring the time from the ultrasonic sonar module. To do this without losing resolution in the data and not receiving false readouts from the sonar module itself, an Arduino Due is used. Such a microcontroller has a clock speed of 87 MHz which can read the timing of the sonar down to the microsecond level and can read the data from all available components in a timely manner or around 3.14 seconds a reading.

Software Design

The software runs off a main loop that runs infinitely. An interrupt was designed to allow for safe system initiation and shutdown and also safe data acquisition in the form of an SD card. The program records the data from all sensors within 3.14 seconds. Another loop within the main loop takes about 10 readings from the sonar in around 3 seconds to give an average reading in the post flight analysis. The program also has an initial startup check sequence and LED notification located on the Arduino shield for visible notification to the operator.

Results

The environmental data measured in the launch at NASA CSBF on May 16 agree reasonably well with the data measured by Dalkis weather station which is about 122 miles north from the CSBF. The sonar stopped working at temperatures lower than -40°C (readings are all zeros). In addition, the acquired speed of sound data are quite noisy.

Conclusion

The results from the Aug. 21st were as expected for the conditions that had taken place during the eclipse. Environmental readings showed improved reliability in its data compared to the first launch. The sonar experienced icing on the transmitter/receiver causing the data to give fake readings. Overall, the launch was a success and the data can be used to in conjunction with future launches.

References