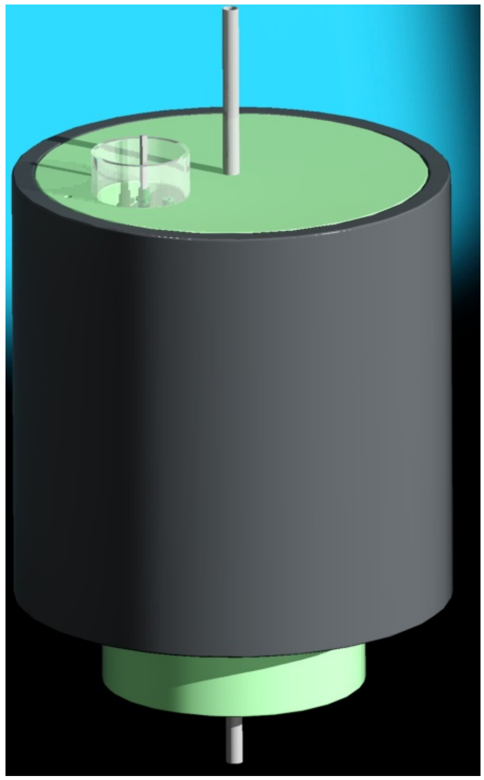
COLORADO STATE UNIVERSITY

Colorado Space Grant Symposium



DemoSat Air Sample Capturing Device

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Contents

Abstract 3

Introduction 3

Design 3

  Analysis 3

Manufacturing 5

  Mechanical 5

  Electrical 7

  Biological 7

Testing 8

  Mechanical 8

  Electrical 8

  Biological 9

Results and Discussion 9

Conclusion 11

Abstract

There is little available information regarding the biological composition of air at altitudes above 50,000 feet. Having the ability to capture an uncontaminated air sample at a distinct altitude can prove to be highly beneficial in understanding what organisms can exist in the extreme conditions of high altitudes and will allow microbiologists to study many uncharted regions within the Earth's atmosphere. The purpose of the project was to design a cost-effective device capable of capturing an air sample from an altitude of 85,000 feet while keeping the air sample entirely isolated from the surroundings. The components were required to operate in low temperatures and pressures, as well as meet the mass and design requirements set by the DemoSAT program. The design was subjected to severe environmental and structural tests, in addition to tests regarding the functionality and biological aspects of the device. Although the payload did not capture a sample due to unforeseen damage during flight, the design could be tested further to determine if the sampling system is effective.

Introduction

Recently, there has been a surge of interest in finding life in extreme conditions on earth, in order to find limits of where living things can exist. If life exists on Earth in there conditions, then it is possible to find life on a different planet in similar conditions. There extreme conditions include high and low temperatures, pressures, as well as varying oxygen, nitrogen and other gas levels. One of these extreme environments is the upper atmosphere where the air is thin and the pressures and temperatures are low. *The mission of the 2012 CSU DemoSat team is to build a cost effective way to collect an air sample at high altitudes for the purpose of testing air quality, particulates, and culturing microorganisms.*

Design

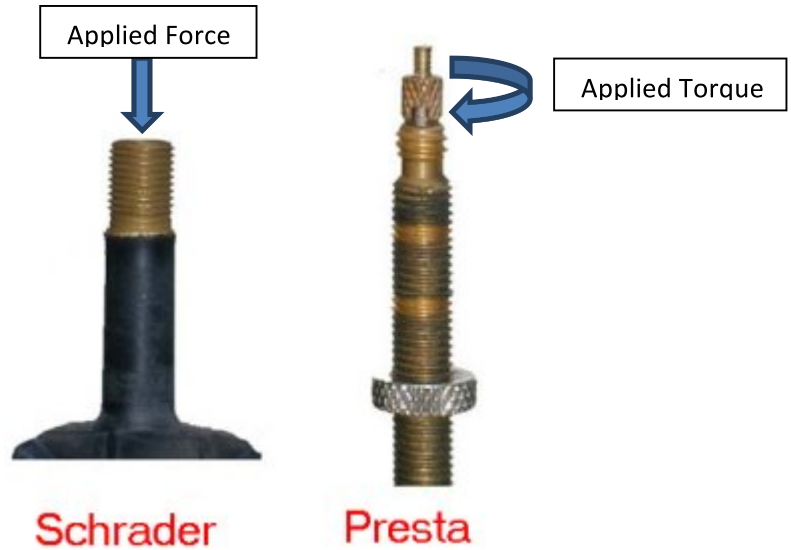
Analysis

The two primary concerns of the project were to ensure that the payload would be able to capture an air sample at 85,000 feet, and to make sure the air capturing system remained sterile until collecting a volume of air at the predetermined altitude. In order to minimize the complexity of the system while still meeting the requirements, the air sampling system was designed to have only a single moving part.

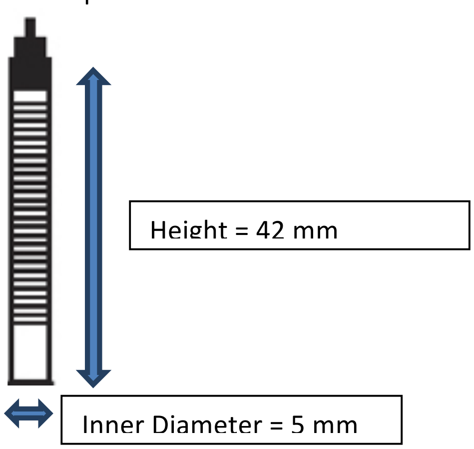
A 60 mL biological syringe was chosen as the device to store the air sample because it could be put in the autoclave for sterilization, it was cheap and because it is used in industrial application, so it is air tight when sealed.

The next challenge was to add an attachment to the end of the syringe that could be opened and sealed in the middle of the flight to capture the air sample and seal the container to prevent contamination. A variety of used bicycle valves were obtained from bicycle stores around Fort Collins and then a Presta valve was chosen and epoxied onto the end of the syringe. All of the materials chosen were suited for the autoclave, and the Presta valve was chosen over a Schrader valve for a variety of reasons. First, the

Presta valve involves turning a nut attached to a threaded pin. Once the nut is loosened, the pin slides down into the valve, which allows air to flow though the valve. Thus circulation can occur through a Presta valve without any applied force. A Schrader valve involves axially pushing a rod, which compresses a spring and opens the valve, while a Presta valve requires a torque in order to open the valve. Having the ability to apply a torque instead of an axial force created more opportunities for the layout of the project and allowed the project to be condensed into a relatively small space. A sprocket was then attached to the nut on the Presta valve and another was attached to the motor, and a chain was used to connect the two. This allowed for even more flexibility in the design as links could be removed from or added to the chain to bridge the motor to the air capturing device.



Once the air sampling device was constructed, a plan needed to be devised in order to capture the air sample. The goal was to see if the syringe could be pre-drawn and then clamped into place, to minimize the amount of moving parts. The dimensions of the Presta valve were measured, and the syringe with the agar inside, was compressed fully. The height of the Presta valve was 42 mm and the inside diameter was equal to 4.5 mm.



The volume of air inside the Presta valve was found from the measured dimensions using the equation $\pi r^2 h$.

$$Volume\ inside\ Presta\ valve = \pi(0.0025\ m)^2(0.042\ m) = \mathbf{8.247\ x\ 10^{-7}\ m^3}$$

The valve was then sealed and the syringe was fully drawn. The new volume was found by adding the initial volume to 60mL because of the volume of the syringe.

$$Volume\ of\ system\ with\ syringe\ drawn = \pi(0.0025\ m)^2(0.042\ m) + 60mL\left(\frac{1\ x\ 10^{-6}m^3}{mL}\right)$$
$$= \mathbf{6.08247\ x\ 10^{-5}\ m^3}$$

Using the ideal gas law equation, $PV = nRT$, and knowing all of the initial values and assuming that the system is isolated such that variables n and R are constant, and the temperature is negligible, the equation was reduced to $P_1V_1 = P_2V_2$.

$$P_{ATM@5000ft}V_{valve} = P_{system}V_{system}$$
$$(84300\ Pa)(8.247\ x\ 10^{-7}\ m^3) = (P_{system})(6.08247\ x\ 10^{-5}\ m^3)$$
$$\mathbf{P_{system} = 1142.95\ Pa}$$

The final pressure was then compared with data tables for the pressure at an altitude of 85,000 feet.

$$\mathbf{P_{ATM@85{,}000ft} \approx 2200\ Pa}$$
$$\mathbf{P_{system} < P_{ATM@85{,}000ft}}$$

As the calculated pressure was less than the theoretical value from the tables, air flowed into the device at the pressure associated with an altitude of 85,000 feet. This calculation confirmed that the internal pressure would be sufficiently low to draw air into the device at 85,000 feet, thus the device could be pre-loaded and clamped before the launch. Holes were then drilled into the plunger of the syringe at the proper locations and metal clamps were machined so the plunger could be held fully drawn.

Manufacturing

Mechanical

One objective was to make the payload with inexpensive materials. However, it also needed to be able to withstand the impact of landing in a worst case scenario. For this reason, most of the components were made out of high density foam, Foamular250 (an insulator used in housing), aluminum, and carbon fiber. Figure 1 shows a cross sectional view of the payload. The high density foam provided most of the impact resistance. The Foamular250 also helped with the impact, but more importantly acted as an insulator for the electrical components.

Carbon

Aluminum plates
3 Foamular 250
rings and discs

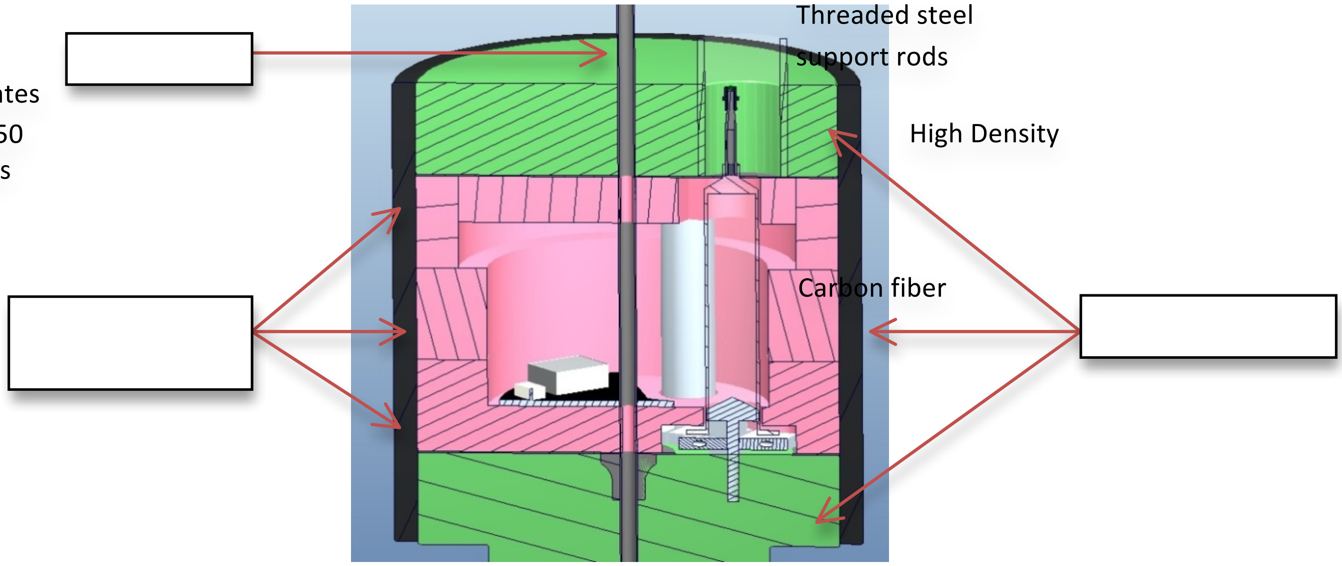


Figure 1: Cross Sectional View

The main structural components were made from aluminum plates that held the Foamular250 in place, which were fastened by 4 steel threaded rods. Figure 2 shows how these components fit together without the high density foam and Foamular250.

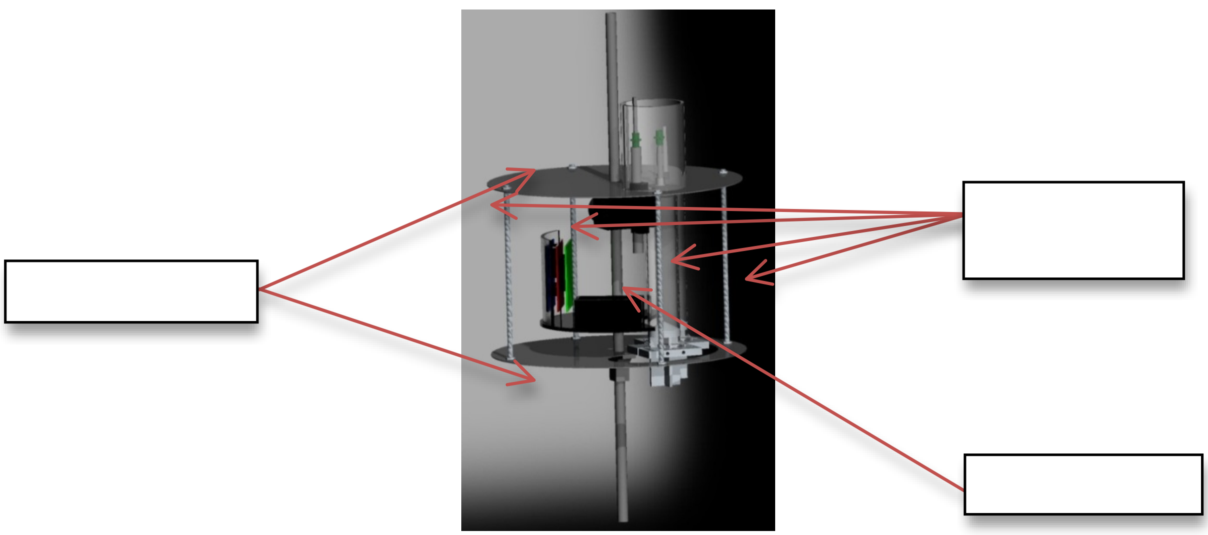


Figure 2: Structural Support

A 60 ml syringe with a Presta valve attachment was used to capture the air sample. A DC motor turned a sprocket and chain mechanism to open the Presta valve. Figure 3 shows the basic set up.

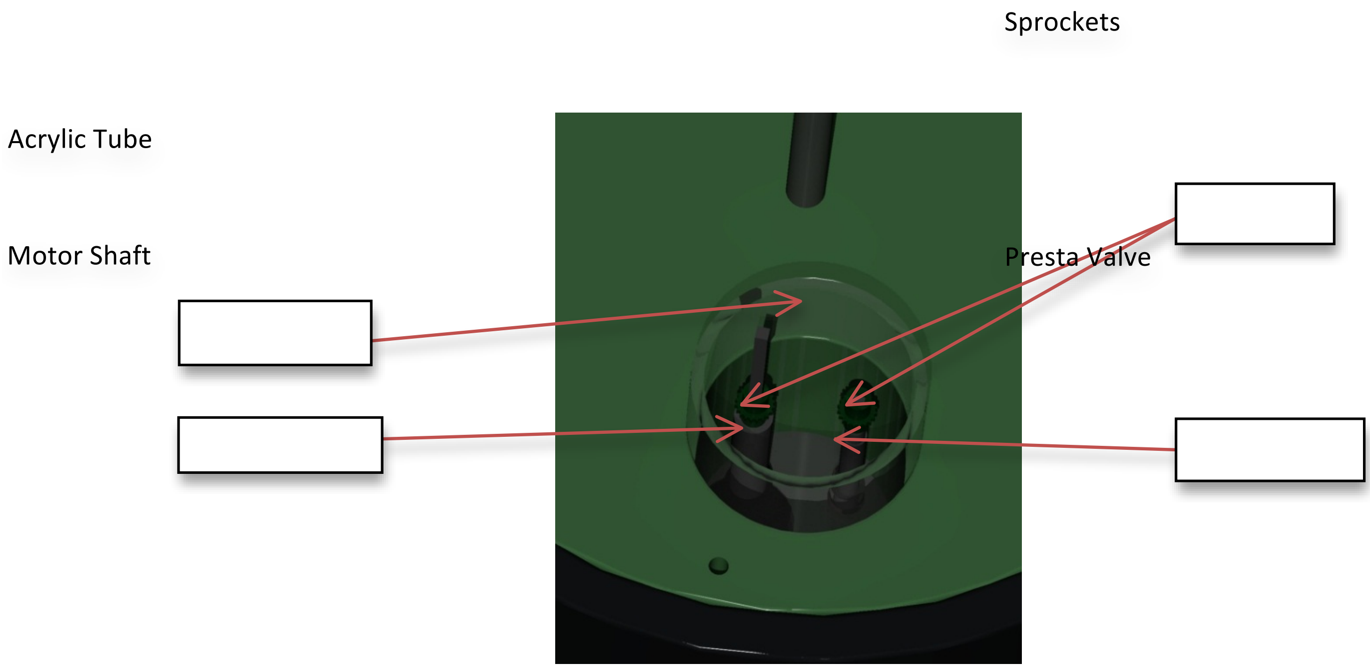


Figure 3: Sample Collection Area

Electrical

The electronics were designed to measure barometric pressure, IR levels, Dust level, humidity in addition to the temperatures inside and outside of the payload and then store the data on a microSD card. The electronic system was also designed to active the sample collection system with data from the barometric sensor or from a timer. An Arduino Uno was used to control everything. The Arduino Uno and other electronics were chosen for their user friendly interfaces, custom ability and online resources. Two programs were used; the preflight program and flight program. The preflight program reset the fuses, checked to see if the memory card was in place, and inspected to see if the electronics were in place and functioning. The flight program primarily ran in a loop where the program read the sensors and recorded the data. The flight program also checked if the barometric pressure was at the set point. If the program read that the barometric pressure was at the set point, the program then looked to see if the fuse has been blown. If the barometric pressure was at the set point and the fuse had not been blown, the program activated the sample collection system.

Biological

The most important consideration that had to be taken was accuracy. First, the sampling has to be done inside of a closed system. Also, all components involved in sampling needed to be sterile to begin with, or able to be sterilized in an autoclave. These considerations were tested by various sterile tests. Testing indicated that whatever was cultured out of sampling system will be from the desired altitude.

To minimize cost of lab analysis, a culture medium was placed inside of sampling system. This provided the payload with an exaggerated and easily identifiable method to determine the quantity of microorganisms.

Due to the anticipated temperature gradient, culture medium effectiveness was tested in various temperatures. Testing indicated that the culture medium would retain the ability to culture microorganisms throughout the expected temperature gradient.

The sampling system environmental and chemical conditions had to be within tolerable ranges for microorganisms to remain viable. Study of scientific literature supported that the conditions experienced inside the sampling system were within tolerable ranges for expected microbes.

The cost of project remained under $500 to satisfy budget projections. This was achieved by using cheap and accessible materials for the sampling system.

The presence of microorganisms at this extremely high altitude was also considered. Multiple pieces of scientific literature were obtained and used to support expectation of microbes at 85,000 feet.

Testing

Mechanical

Whip Test — The purpose of the whip test was to simulate the event that the flight string got caught in a tree or another obstacle and the payload experienced a whip as a result. This was done by tying the flight string to a rail and dropping it from the edge of the balcony. The payload survived the whip test.

Drop Test — The purpose of the drop test was to simulate a high speed impact in the event that the parachute did not open. This was done by dropping the payload from a second story balcony with the structure completely assembled including electronics, syringes, and batteries. The payload survived the test with all of the components functioning.

Stair Pitch Test — The stair pitch test simulated the event that the payload was dragged along the flight string if the parachute was blown by the wind. This is done by rolling the payload down a flight of stairs. The payload successfully completed the test without damage and remained collecting data at the end of the test.

Electrical

Subsystem Function Tests— Each subsystem was built and programmed and then tested for functionality and ability to work with the other subsystems. The payload survived all of the function tests.

Flat Sat Test— Once all of the sub systems were assembled, the whole system was left alone to run for three hours. This test was designed to test if the electrical components and programs were stable. This test also gauged how much memory and how many batteries were needed. The device successfully performed all of the desired tasks during this test.

Cold Test— The payload was placed in a cooler with liquid nitrogen to see if there was sufficient heating inside of the payload for the batteries to remain functional. This simulated the cold temperatures the payload experienced during the flight. The electronics remained functional throughout the cold test.

Vacuum chamber Test— The payload was placed and a Bell jar vacuum chamber to see if the barometric pressure sensor would trigger the sample collection system at the pressure corresponding to an altitude of 85,000 feet. The motor was activated at the correct pressure and an air sample was collected.

Biological

Sterile Capsule Test— The purpose was to ensure device was in fact a closed system. The test was performed by sterilizing system and letting sit for four days. After the four day time period, analysis confirmed system was closed.

Agar Environment Test— The purpose of this test was to test culture medium (agar) efficacy at extreme altitude conditions. Testing confirmed medium culturing ability was unhindered in the conditions expected at target altitude.

Air Volume Test— The purpose of this test was to conduct actual DEMOSAT experiment at ground level to ensure sampling system efficacy when integrated into device. Testing confirmed that sampling system effectively samples bacteria at desired time.

Results and Discussion

The results of the launch were inconclusive. The payload was able to collect a good amount of data through its sensors. The results are shown in the following graphs. The barometric pressure sensor malfunctioned.

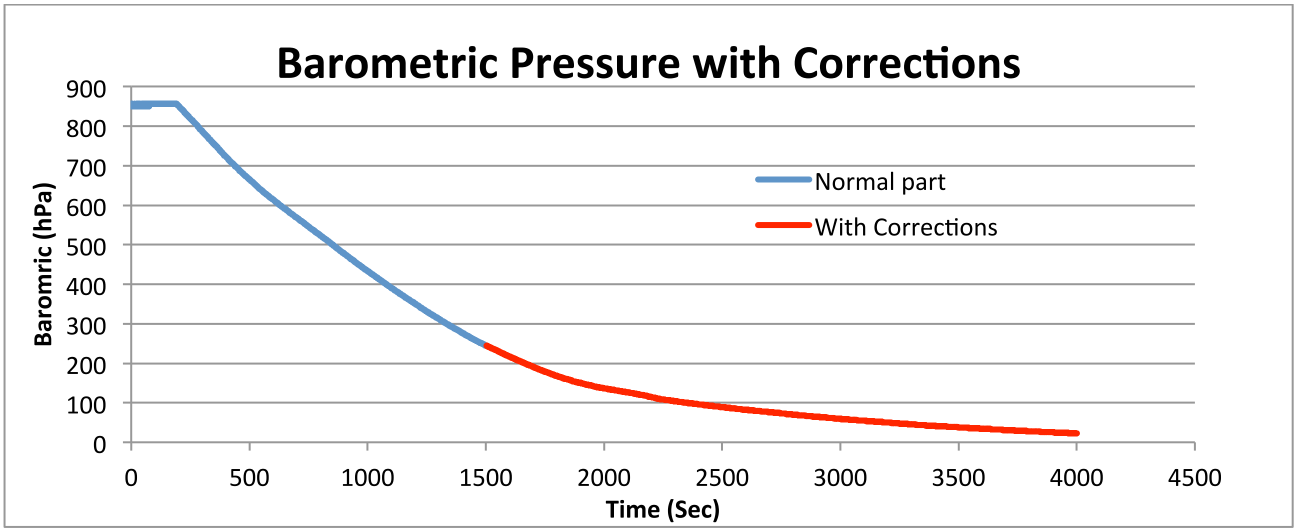


Figure 4: Temperature

Figure 4 displays the values from the barometric sensor. At about 1500 seconds into the flight, the barometric sensor began to malfunction and gave off-scale readings, so a correction factor had to be applied to that portion of the data. As the sensor was reading off scale values at the altitude of 85,000 feet, the device failed to capture an air sample.

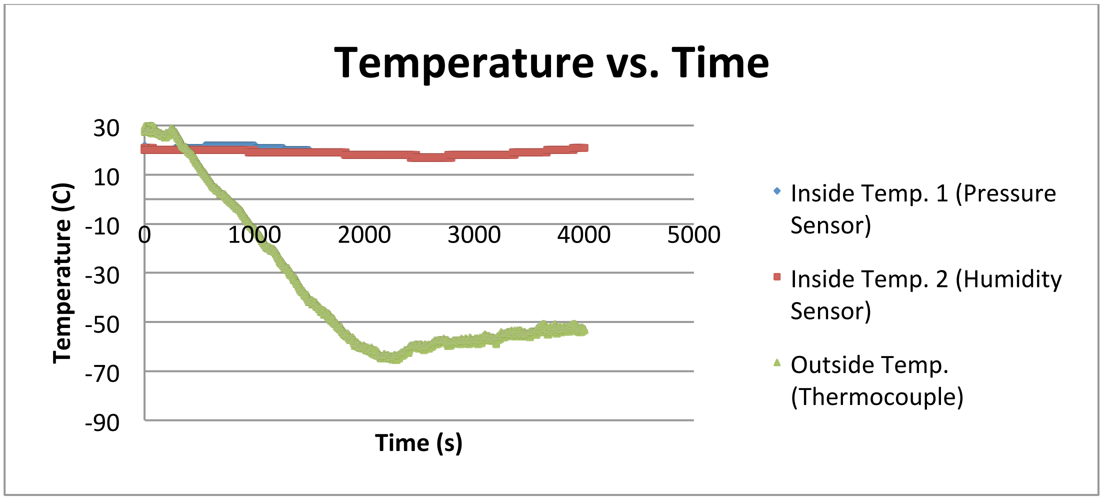


Figure 5: Temperature

Figure 5 shows that the insulation and heating systems were successful. The payload experienced temperatures of -90 degrees Celsius, while the sensors inside experienced little change in temperature.

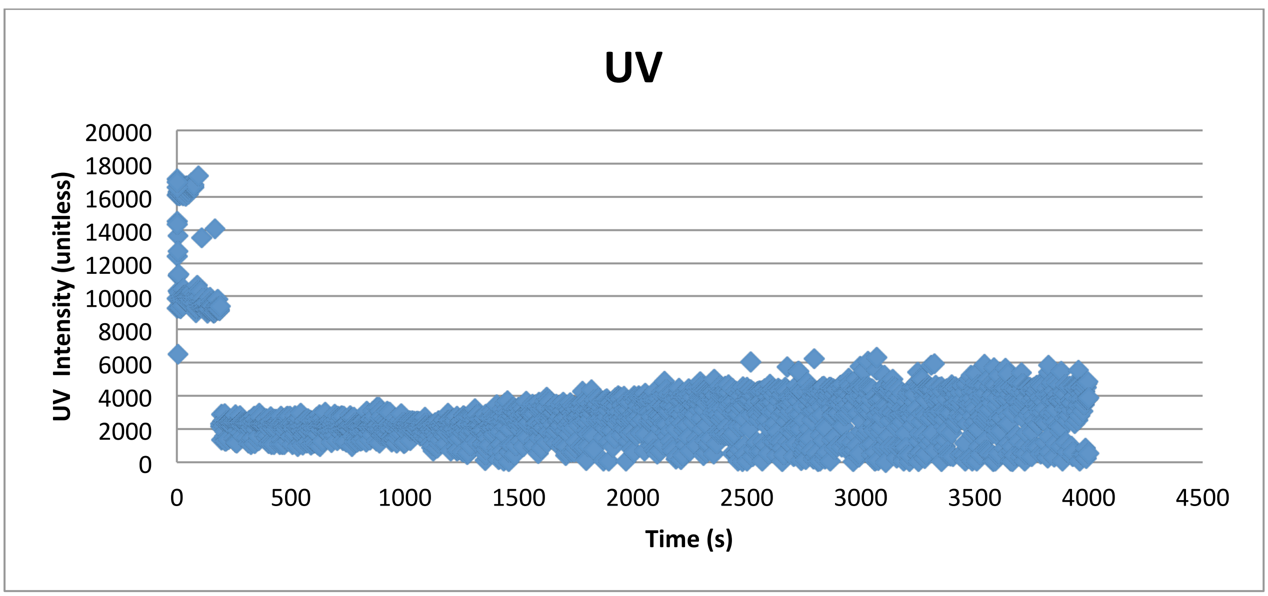


Figure 6: UV Intensity

Figure 6 shows that the UV intensity is relatively unchanged by the altitude. The sensor picked up a wider range of intensity at higher altitudes.

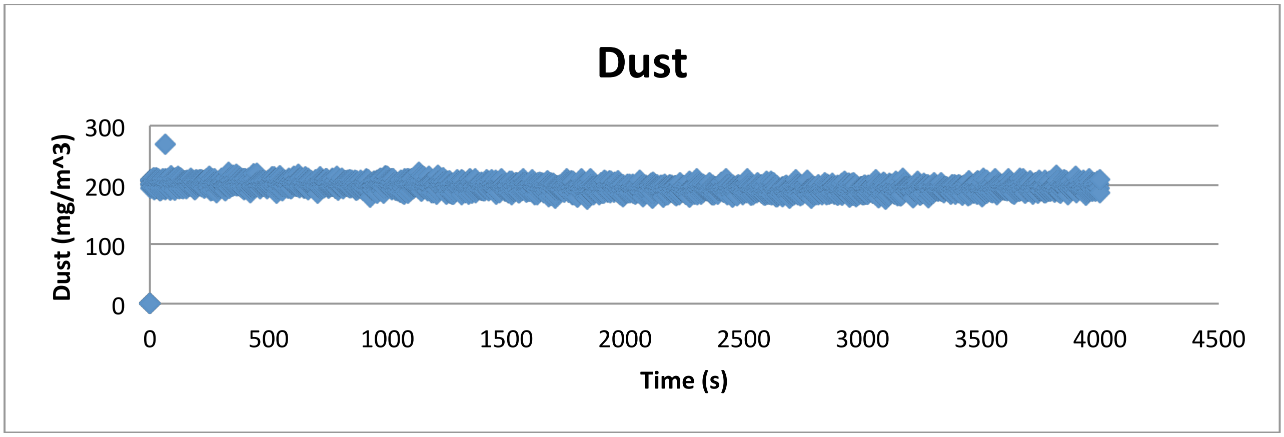


Figure 7: Dust Sensor

Figure 7 shows the values of the dust sensor in mg/m^2. There was no appreciable difference in the amount of dust at higher altitudes.

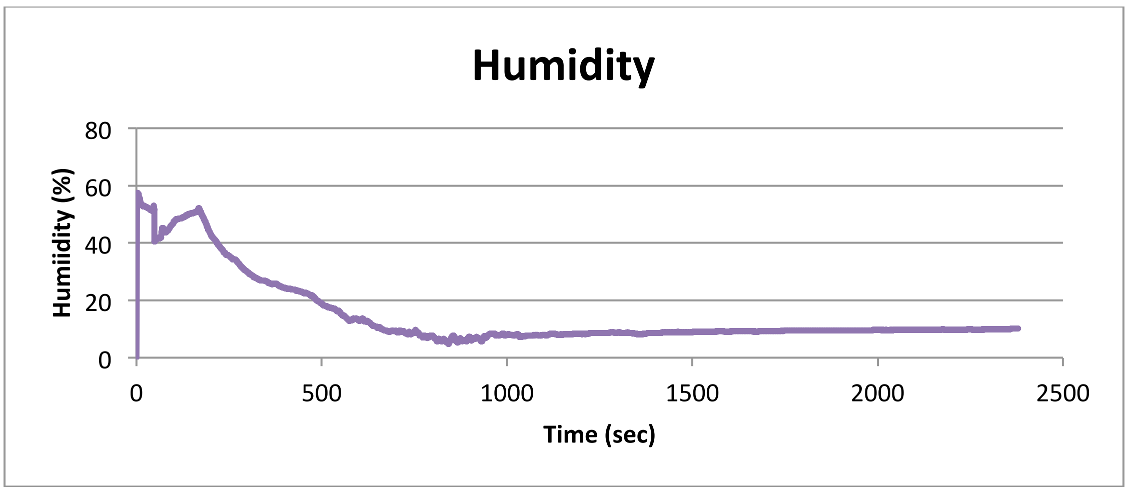


Figure 8: Humidity Sensor

Figure 8 shows the relative humidity as measured by the humidity sensor. The launch was completed early in the morning, so the high initial humidity resulted from the morning dew. The humidity then decreased indicating that the climate at high altitudes is very dry.

Conclusion

Due to the malfunction of the pressure sensor and an unknown complication during the flight, no sample was collected. However, the collected data shows that this method would be effective for future tests in this field. The mechanical design of the payload was both inexpensive and durable. This design is perfect for small sample sizes of air samples that can be used for biological research and air quality testing. The payload protects the electronics and the sample from the cold temperatures and the low pressures experienced from high altitudes as well as from its reentry and pick up.