Atmospheric Air Sampling System
Team Space Donkeys

April Slawson, Delaney Mosier, Jonathan Ramirez, Robert Whitley
Pikes Peak Community College
Faculty Advisor: Rob Gilchrist
Rob.Gilchrist@ppcc.edu
April 10, 2017
Abstract

Collecting data readings of different compounds in the air at high altitudes can be complicated and expensive to obtain. A cost-efficient air sampling system built into a payload launched on a weather balloon that utilizes the rate of descent to fill a Tedlar bag is a solution to keep those data readings accurate and the project's budget low. Due to the tumultuous environment a payload experiences as it rises to approximately 100,000 feet, the sensors may return inaccurate readings. Collecting an air sample midflight allows for on the ground tests that can be far more controlled and the readings are predicted to be far more accurate than midflight tests. Reducing the weight of the launched payloads is crucial. In-flight air sampling using pumps has been done by previous teams. By instead constructing the payload to harness the air flow caused by the rate of descent, the overall payload can be much lighter.

1. Introduction

1.1 Air Sampling Systems

Traditionally, basic weather balloon payloads are designed around a core Arduino or Raspberry Pi, with sensors incorporated for data collection. In addition to sensors that report readings related to atmospheric conditions, such as temperature and pressure, some payloads include gas detection sensors. Carbon dioxide, methane, and ozone sensors, among others, provide information about the composition of the atmosphere. This information may be utilized for environmental studies or comparisons of data collected at varying altitudes. Sensitive gas detection sensors, while useful, can be difficult to obtain, causing students and researchers to consider alternative methods of data collection.

Consecutive BalloonSat teams from the Community College of Denver (CCD) incorporated air sampling systems into their payloads and listed collecting air during flight as one of their primary objectives. However, the teams in summer of 2013 and fall of 2014 were unsuccessful due to power supply errors. In spring of 2015, CCD’s team successfully collected air, though no data was analyzed or reported from the sample. All systems designed by CCD included air pumps as a means of filling Tedlar bags at high altitudes. Similarly, two scientists from the Environmental Measurements Laboratory collected numerous air samples, to study perfluorocarbon tracers, using air pumps. Their sampling system alone weighed 275 grams.

1.2 Our Approach and Mission Objectives

Based on this information, our team decided to redesign the air sampling system used by other teams and approach our project as a working concept. Rather than an air pump, which can be heavy and costly, we wanted to utilize the rapid descent of our payload after balloon burst to fill our Tedlar Bag. We chose this approach because of weight restrictions. Including the bag, solenoid valve, funnel, and tubing, our sampling system weighs 200 grams.
Additionally, we hope to prove that the ground lab testing conducted on our air sample will provide more sensitive and accurate information than the sensor midflight. To show proof of this, we wanted to purchase various gas sensors and compare the results to those from several ground tests. However, the CO2 and O3 sensors were on back order and would not have arrived within. We ended up purchasing a methane sensor, but this experience solidified our opinion that collecting an air sample is more efficient than attempting to measure the constituent components of the air with individual sensors.

Thus, our primary mission objective is to show that retrieving air samples during flight and performing ground tests to collect data provides more benefits than conducting the same tests midflight. Our secondary objective is to collect balloon shield and methane data to provide us with information about near space conditions. We would like our unique method and design to be easily replicable for future project teams, who can potentially integrate additional bags and valves into the system.

2. System Design

2.1 Physical Systems

2.1.1 Air Sampling System

Our initial design concept for our air sampling system consisted of multiple components of varying complexity. It included a flow meter to control the amount of air though the system and send a signal to the solenoid to close, a solenoid valve which will enable air flow to the bag, and potentially to route to multiple bags depending on the signal it receives, and an air pump to push air through the system. Since the choice of these components would drive the size of our hose and bag, we opted to delay those decisions.

At this point, the team was advised to start at the simplest design level, then add complexity as each level was completed. For this reason, the flow meter and pump were initially removed. To replace the flow meter, we chose to use time, the limitation of the bag size, and taking a sample on the descent to control the size of our sample. We calculated, using the ideal gas law, that the size of the sample would be approximately 10% of its original size when the payload landed. To make sure the bag did not explode, we opted to sample on descent. Since the predicted rate of descent was 1000 feet per minute, we could use the airspeed velocity of the un-laden payload to fill the bag instead of the pump. We wanted to include a funnel to increase the amount of air we were getting through the tube to the bag. However, the pilot assisted valve required a minimum pressure of 3 psi to open. Based on Bernoulli’s Principle, the funnel would increase velocity, thereby decreasing pressure. We calculated the pressure at the smaller end of the funnel to be 0.131 psi, much less than the pressure that was needed for the solenoid valve to open.

In the search for a new solenoid, we discovered that we should have used a direct acting or a pinch valve. The weight consideration favored the pinch solenoid. However, due to cost constraints, the direct acting solenoid was the clear choice for our experiment. From here, we chose the appropriate hoses to adapt the size of the funnel to the size of the Tedlar bag. The final product of our sampling system consists of a 3-inch diameter base funnel, a direct acting solenoid, a Tedlar Bag, ½” internal diameter hose, a ½” to ¼” step-down hose adapter, and ¼” internal diameter hose.

2.1.2 Box Design

Our payload design was driven by our air sampling system. Since the Tedlar bag and funnel did not have a temperature requirement, and were large enough to potentially disrupt wiring in the electrical compartment, our team decided to use a two-tiered box with separation between the more physical components and the electrical components. To keep the structure as strong as possible, we cut the box from two different pieces of foam core. One piece consisted of the lid and top-front flap. The main structure was cut in such a way that the rear top flap, bottom front flap, and center divider folded into an s-shape. The side flaps have slots notched out of them to line up with the center
divider to firm up the structure. The width and height of each compartment was based on the size of the Tedlar bag and the funnel in the bottom of the payload. We then compared these requirements to all the electrical components arranged by weight around the flight tube. Since the electrical components did not require any additional size, the final size was determined to be 9” x 10” with a 3 ½” bottom compartment height and a 4 ½” top compartment height. We balanced all the internal components around the internal flight line based on their individual masses. At this point, we decided to use the insulation recommended to us by the Colorado Space Grant Consortium, which was low-temperature polyethylene foam rubber insulation. We also added a Mylar cover on the lid insulation. These measures proved through testing to be more than adequate in keeping the electrical compartment above minimum operating temperatures for all components. To secure the internal components, we lined part of the electrical compartment with foam core so the Velcro would adhere to the sidewalls. Also through testing, we found that if the bottom front panel were to detach in flight, the base would be too weak to hold the flight line in place. We rectified this issue by building a bottom cross brace and attaching it to the outside of the sidewalls. On final recovery, the structure of the payload showed no sign of any additional damage beyond what was sustained in testing.

2.2 Electrical Systems

The electrical system of our payload went through many changes and evolved into a working high altitude air sampling system. The payload has two states: active and off. Once the external switch was turned on for the Arduino, power was delivered to all our sensors and they began to record data to our open log. The methane sensor went through a calibration period, then started to record accurate data. We included an internal temperature sensor, an external temperature sensor (which was wired to be completely exposed to the elements), a pressure sensor, X and Z axis accelerometers, and an MQ-4 Methane sensor (which was also exposed to the elements outside the payload). We used three 9V batteries in series to power our resistance heater. We turned on an external power switch to begin heating our payload. We expected to have a longer period of heating our payload prior to launch. Since it was warm on the ground during launch, we activated our heater only a couple minutes before.

We initially began our design concept by integrating a 9V solenoid. The 9V solenoid was pilot assisted with a minimum of 3 psi to open. Our air pressure at the retrieval for the air sample during the descent of the payload would be less than 3 psi, so we decided to use a 12V direct acting solenoid. The transition from a 9V solenoid to a 12V solenoid changed the requirements for the output from the Arduino. We integrated a step-up to 12V regulator into the circuit directly before the solenoid.

The electrical component’s data sheet stated that the input minimum was 2.5V, but the actual minimum voltage when tested proved to be around 2.7V. The output voltage held steady at 12.05V when the 9V powered the Arduino and the solenoid circuit was powered through the VIN pin from the Arduino. The voltage reaching the step-up regulator varied several voltages throughout our bench testing. Our payload was highly dependent on the 9V lithium batteries’ performance and maintaining enough voltage to power the solenoid for several minutes. The power then went through a part of the circuit that controlled the flow of power, keeping the solenoid safe from backflow of potentially harmful electricity. This part of the

![Figure 2: All components before final assembly](image-url)
circuit that led to the solenoid consisted of a Darlington transistor, a 1k ohm resistor, and a diode rectifier 50V. This took the power from the VIN pin, connected to a ground pin, and connected to the 8th digital output pin.

2.3 Command and Data Handling

2.3.1 Commands for Balloon Shield

Many of our flight sensors were assembled on a board, called the balloon shield, which is directly connected to the Arduino Uno. The sensors measure the payload’s internal/external temperatures, pressure, and velocity. The humidity sensor was originally included, but needed to be discarded due to the limited number of pins on the Arduino Uno. The code was generously provided by the creators of the balloon shield concept. The sensors all have a direct analog-to-digital output. The only necessary additions to the code were the functions to convert the raw data to measurements with desired units, such as Celsius degree, psi, and meters per second.

2.3.2 Commands for Methane Sensor

The methane sensor utilized is an MQ-4 sensor. It also has a direct analog-to-digital output; thus, it facilitates the conversion of retrieved data to a practical graph. During activation, the readings from the MQ-4 sensor are not based on any particular unit of measurement. The resolution for interpreting these numbers is to correlate the smallest number output to a 0% presence of methane in the surrounding environment. Similarly, the greatest number output will indicate 100%. Pure methane was too difficult to find and use so, by examining the properties of the sensor in the datasheets, we noticed that MQ-4 sensors are also sensible to butane, a more accessible gas. We used a cigarette lighter as our source of butane and threshold measurement device. The process of converting the raw data to parts per million (ppm) is conducted after the launch. These readings will then be compared to those from ground lab testing.

2.3.3 Commands for Solenoid Valve

The solenoid’s code is time dependent and directly refers to data from the pressure sensor. We commanded the direct acting solenoid valve to open when two conditions are met: the flight’s time is at least 50 minutes and the pressure is between 1 and 2 psi. Once the conditions are satisfied, the valve is programmed to remain open for 5 minutes. We believe this is an adequate time interval for the bag to collect the maximum amount of air. However, problems have been detected while applying this idea. The sole 9-volt battery connected to the Arduino was giving relatively enormous amounts of power to the solenoid during activation, thus the other sensors were deprived and affected. Due to this, our sensors’ data became corrupted while the valve was opened. This is a concerning issue because the state of the solenoid relies on this data. To fix this, we input the “delay” function in Arduino code. By this approach, the battery will directly power the solenoid’s aperture while the other sensors are temporarily deactivated. This means that we will not gain any atmospheric data in this time window. However, we could have a rough estimate of the atmosphere’s state by analyzing the data immediately before and after the 5-minute interval.

2.3.4 Data Handling for Sensors and Solenoid Valve

All readings from the sensors will be transferred to an 8 GB memory card. The memory card is in the open log, a component
that retrieves readings from the serial monitor of the Arduino Uno and moves them to a memory card. We also commanded the Arduino Uno to write “Solenoid Closed” or “Solenoid Opened” according to the solenoid’s state. This helps us indicate the exact moment the valve activates.

### 2.3.5 Data Handling for Air Sample

The atmospheric air sampling system has the objective of collecting an air sample and storing it in the Tedlar bag. The solenoid’s code is created so that the air sample is taken between 50,000 and 60,000 feet, by referring to these altitudes’ pressures. The bag tightly seals the sample through the manual valve. As previously explained, we will send our sample to a laboratory so it can be analyzed for its methane composition. After the analysis is complete, we will receive methane results in ppm. Then, they will be compared to the readings from the payload’s methane sensor that were taken in flight.

### 3. Test Results

#### 3.1 Structural Tests

Since our modified box design contained two compartments, structural testing was vital to ensure that our electronics and sampling system were protected and immobile during flight and landing. We began with a drop test, using mockups from a third story balcony, in which our payload landed on tile. The result from our first drop test was minor structural damage and a shifting of the mockups. Due to this test, we decided to include additional foam core in the interior of the box to securely attach the components with Velcro. We then conducted a second drop test, in which the box was undamaged and none of the mockups shifted.

Another structural test we conducted was a whip test. Initially, we placed our mockups in the box and whipped it for half a minute. Only one mockup shifted out of place. Our second whip test was conducted with the actual components in the box. None of the components shifted, but the box did sustain slight structural damage. Additionally, we conducted several shake tests, which all indicated that our Velcro and wire connections were secure. Overall, our structural tests instilled us with confidence in our box design and ability to secure components.

#### 3.2 Air Sampling System Tests

We wanted to ensure that the atmospheric air sampling system would be capable to intake air from the bottom of the payload while in descent. We ordered two Tedlar bags, one for testing and another for launch. We performed a fill test in which we drove in a vehicle at various speeds, from 35 to 60 mph, with the payload on the side of the window of the passenger’s seat from the outside. We believe this was a relatively accurate test because we estimated the rate of descent to be around 30-40 mph. The results were very interesting and meaningful. The Tedlar bag took considerable amounts of air after several laps of driving at various speeds. The bag’s exact position within its compartment of the payload is the most crucial element to the success of the fill test. While the bag is opened, the air flows through a very small aperture which is found to be easily closed when pushed against a wall. We amended the issue by properly positioning the valve upward and taping one of the bag’s sides.

#### 3.3 Functionality Tests

Tests were performed to test the circuit that contains the solenoid. We tested continuity through each individual part of the circuit, each wire, and each additional electrical component. During this procedure, we discovered that the 12V step-up regulator no longer worked, and we ordered another one that day. While testing the continuity of the circuits, several wires were replaced. The result gave us a completely working electrical circuit that opened the 12V solenoid when the Arduino provided voltage to the VIN pin.

We tested the resistance heater twice. We used three new 9V batteries and a LabQuest temperature probe. The heater heated the inside of the payload to 49.3° C during our first functionality test. For the second test, we used the same 9V batteries that were then producing around 8.5V each. The inside of the payload
reached 41.9° C during the second test, showing that as the power was discharged from the batteries, the heater would not work as efficiently. The coldest temperature the interior of the payload reached during flight was 19.89 °C; the warmest temperature that the payload reached was 62.90° C. The warmest temperature recorded was after the payload had landed and was sitting in the sun.

We performed many tests in a freezer that maintained a -70° C temperature. During our second test, we reached our minimum temperature of -5 °C after 34 minutes in the freezer. The temperature, accelerometer, and the methane sensor shared pins on the Arduino. This caused the readings to show unexplained changes in data. During our last test, we reached our minimum temperature of -5 °C after 72 minutes in the freezer, showing that we had fixed several complications and were functioning at a higher efficiency. The other sensors’ data, including the accelerometers, no longer showed unexplainable outliers. We used the freezer tests to test the functionality of our payload under the most extreme possible temperature variables. The tests helped us to construct our completely operational air sampling system.

4. Flight Results

The data we extracted from the payload proved the flight to be entirely successful. The data collected in open log shows the solenoid valve opening at around 60,000 feet, indicated by a pressure reading of 1 psi. This occurred 4660 seconds into flight. Our Tedlar bag, based on appearance, contains 0.03 liters of air. Also, our balloon shield data is consistent with our expectations for the conditions in near space. Our methane data was successfully retrieved and will soon be compared against lab results from our air sample.

The Arduino remained powered on for over 150 minutes, and the heater remained functional for approximately 30 additional minutes afterward. We tested the batteries with a multimeter after flight and found that the three 9V batteries used for our resistance heater were still producing 8.33V. The battery powering the Arduino and the solenoid circuit was producing 8.26V. The batteries did not drain as much as we anticipated.

5. Conclusion

As previously mentioned, our project was intended to be a proof of concept. Therefore, we hope that future teams participating in similar programs will be able to take our system design and improve upon it, based on the data we have collected and analyzed. Throughout the course of the project, we altered numerous components of our system due to design and software requirements. The changes we have made over time have taught us valuable lessons that we want to share with other teams in our position, so that they may learn from our experiences.

In the future, if this project is replicated, there are several suggested changes to the process. Firstly, we recommend carefully handling electrical components to avoid ESD, which disables them, as well as testing the continuity of all parts and wires prior to soldering them into circuits. Also, we advise thoroughly investigating specifications and component requirements before ordering parts. Although the fill test provided us with vital information regarding where the Tedlar bag should be placed in the payload to ensure adequate air intake, we did not conduct any impact tests with a full bag or drop a full bag off
a building to examine the effects, which may have provided us with more information on how the sampling system functions. One final recommendation is to increase the size of the Tedlar bag from 0.5 liters to 1 liter because the change in pressure during descent reduces the volume of the sample to 10% of the bag’s full capacity. It should be noted that this alteration would require a change to the dimensions of the box.

In conclusion, our project was highly successful. We accomplished both our primary and secondary objectives. Our balloon shield data provides information on near space conditions and the effectiveness of our insulation and heating system. Also, our unique system successfully collected an air sample. Future mission objectives utilizing our sampling system include examinations of the composition of the atmosphere and organisms present. Air samples from Mars, for example, could be collected, analyzed, and preserved for future studies in later years.

6. References

