ACC DEMOSAT FALL 2018

Foam Hogs
(Muon Detectors)

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1 1.0 Mission Overview
Our mission was to build two detectors that would be able to detect muons and save the data to a SD card to analyze upon payload recovery. For this mission we decided to follow in the footsteps of a project from MIT called CosmicWatch. CosmicWatch has built and tested many iterations of muon detectors to refine their design (Przewłocki & Frankiewicz, 2017). We have based our payload on the 4th version of their muon detector design (Przewłocki & Frankiewicz, 2017). For our mission we decided to run 2 muon detectors in coincidence mode. Coincidence mode is where one detector is the “master” and the other is the “slave”, if a muon passes through the top detector but not the bottom one, then only the top detector will record it (Przewłocki & Frankiewicz, 2017). However, if a muon passes through both the top and bottom detectors then both detectors will record the data. This data would be useful to find out how many muons are coming directly down from Earth's atmosphere.

2 2.0 Requirements Flow Down
● Basic Requirements:
  ○ Do not exceed a budget of $1000.
  ○ Payload needs to be under or at 1000g.
  ○ Structure must be able to survive flight and landing conditions.
    ■ Structure needs to be able withstand a drop up to 10 ft.
    ■ Structure needs to withstand whip test
    ■ Structure needs to withstand high altitude air pressure
    ■ Structure needs to withstand temperatures up to -60c
  ○ Structure must include necessary flight string attachments
● Advanced Requirements:
  ○ Detectors need to detect muons
  ○ Battery needs to maintain operational conditions
    ■ Battery must not go below -40°C
    ■ Battery needs to stay powered for duration of flight
  ○ Detectors need to save data to SD card
  ○ Detectors need to run in coincidence mode

3 3.0 Design
For the mission our design was focused on simplicity to minimize possible errors. Our mission required our payload to withstand a fall of up to ten feet, sub-zero temperatures, low atmospheric pressure, and violent whipping from the wind because we launched it on a weather balloon. We were also required to keep our weight under one kilogram.

With these requirements in mind and basic dimensions of our muon detector known from the CosmicWatch website we were able to put together a preliminary design (Przewłocki & Frankiewicz, 2017). We used a basic cube shape for the construction of the detectors container. The container consists of three/sixteenth inch thick black foam board walls insulated with one half inch thick Low Temperature Polyethylene Foam Rubber Insulation. All of this material was available to us as leftovers from previous payload projects. Hot glue was used as the adhesive.
For the two detectors we followed CosmicWatch’s design for the most parts, improvising when needed. The major components are an Arduino Nano, a plastic scintillator, a silicon photomultiplier, a digital display, temperature sensor, and a SD card reader. We also used a LED signal and an assortment of capacitors and resistors. As you can see in fig. 1, the Arduino and the plastic scintillator/photomultiplier are located on the top of the board with the temperature sensor and most of the resistors and capacitors. The SD card reader is located on the bottom. We soldered all the components ourselves using onboard and pinhole soldering techniques for both detectors.

**Figure 1. One of our finished detectors.**

**Design: FBD**

![Functional Block Diagram for our detector operations](image)

**Figure 2. Functional Block Diagram for our detector operations**

After we finished soldering the detectors we fixed them into the container by making two housing units from layers of one half inch thick Low Temperature Polyethylene Foam Rubber Insulation that we glued together with a square hole cut so that the detectors fit in very snugly. We counterbalanced the weight of the detectors with the power source using more foam and hot glue to make a simple housing unit to hold the power source on the opposite end of the container.
Using the foam for the majority of our building material lent a “bend but not break” aspect to our payload as well as insulating it very well. These characteristics helped us do very well in our drop test, whip test, and cold test and ultimately ensured that our payload survived the entire mission with no structural damage.

4.0 Management
For our project there were only two active participants for most of the year. Because of the lack of members, Brandon and Caleb both had to do a bit of everything. We were slightly behind our original schedule due to the lack of active members on the team. Despite the lack of membership, due to our good communication and ability to follow through, the team of two was able to complete all progress reports on time and effectively launched a completed payload on our launch date.

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<td>5th Start soldering PCB</td>
<td>2nd finished detector and assembled payload</td>
<td>4th finish final report</td>
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Figure 3. Inside of our payload with detectors mounted.
<table>
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<th>12th Finish Critical design review</th>
<th>6th finished preliminary test</th>
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<td>19th Critical design review</td>
<td>9th Launch readiness review</td>
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<td>10th Launch</td>
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<td>16th start Final Report</td>
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## 4 5.0 Budget And Weight

**Predicted Weight:**
- Battery: 255g
- Detectors(2): ~200g
- Structure: ~225g
- Total Estimated Weight: ~680g

**Actual Weight:**
- Battery: 255g
- Detectors(2): ~87g each, 174g with both
- Structure and payload housing including tape to hold payload door down: 571g
- Total Weight: 1000g

**Budget:** Below is a picture of our actual final parts list. These are a few key numbers from our budget:
- Total Estimated Cost: $595.18
- Actual Total with Shipping: $799.93
6.0 Test Plan and Results

For our testing we did the standard structure tests, an extreme cold test, a pressure test, and a radiation test.

For our temperature test we used 10 lbs. of dry ice in a cooler, we then put our payload in the container and closed it with temperature probes inside the box. The payload was operating while the test was ongoing. The temperature data on the left figure shows that the temperature inside of our payload got down to about $-25^\circ C$, we suspect that the payload was colder than the air around it because it was in direct contact with the dry ice. Unfortunately, we encountered an issue where our detectors turned off after about 45 minutes of the cold test. We found out that it was because the battery was too cold to operate, it turned off after reaching a certain temperature. To fix this issue we added more foam to the outside of the box claiming the name “foam hogs” and we also used two chemical-based hand warmers inside of the payload to keep everything warm enough to operate.

Figure 4. Spreadsheet of parts list with final totals.
For our drop test, we turned on the detectors and prepared the payload as if it were launching. We used a ladder and Brandon held up the payload above his head and dropped it from a height of 10ft. The drop test was successful, and our payload survived impact with only a minor dent in the foam.

For our vacuum chamber test, we used a vacuum chamber here at ACC and got the chamber to the lowest pressure that the pump could handle. The payload stayed on the entire 5-minute testing time. It was at this point that we learned that one detector did not have enough power draw for our battery to recognize, so after about 6 minutes our battery would shut off. To fix this problem we decided to use both the detectors in coincidence mode so there would be enough power draw for the remainder of the tests.
For our whip test, we prepared the payload as if it were launching and turned on the detectors. We then went outside to a field here at ACC to whip it around. Our test went very well, we whipped it harder than it probably needed, but the results were great. The payload survived with no damage, and nothing inside moved around.

For our radiation test, we used a small amount of yellowcake which is a type of uranium. We had our detectors on and moved the yellowcake close to the detector and observed higher particle count rates since the detector counts the radiation from the yellowcake as charged particles. We were successful in our testing and it helped us test that the detector was working properly.
6 7.0 Expected Results

We expected that as altitude increases, our muon count rate would increase as well. We based our expected data from a previously flown mission by CosmicWatch where they sent up two detectors in coincidence mode up to ~107,000 ft. We expected one of our detectors to run in master mode (the top detector) and the other (the bottom detector) to run in “slave” mode where the bottom detector would only record a signal if it also passed through the top detector. We also expected all of the data to be saved to a SD card on each detector. We expected the “master” detector to have a much higher count rate compared to the “slave” detector.

![Muons Detected As Altitude Increases](image)

Figure 10. This is our expected “Master” muon count rate as altitude increases. (Spencer N. Axani, personal communication, Nov. 8, 2018)

7 8.0 Launch and Recovery

Our balloon launched with Edge of Space Sciences (EOSS). Unfortunately, during launch our payload got tangled at the bottom of the balloon string. This was likely due to a payload being pulled out of another student’s hands causing the rest of our payloads to drag along the ground and ours was tangled upside down.
8 Results, Analysis, and Conclusions

Because our payload was upside down, our data is different than we expected.

Figure 11. Image shows our payload tangled at the bottom with another.

Figure 12. Data from our flight comparing altitude to time in ms (milliseconds)
The fig. 12 & 13 are data from our flight showing the balloon altitude compared to our total count of charged particles in coincidence as time goes on. As time goes on you can see that our slope of the line starts to increase until it levels off after entering the troposphere (23,000 to 65,000 ft.). After exiting the top of the troposphere, it seems that the slope levels off. Then the slope then starts to decrease when it enters the top of the troposphere again. These results are very interesting and will require more analysis. We were expecting a more drastic change in the count rate as the altitude increased, but we believe that this did not happen because our payload was upside down. Because the detector was upside down and the detector can also count some other types of charged particles, we cannot be sure that these counts are all entirely muons.

Fig. 14 & 15 allows us to more clearly see the rate of increase of charged particle counts as altitude increases. We were expecting a higher rate of increase on our graph.
We were also hoping to also have our temperature data from the flight, but after careful analysis of the data it seems that the temperature sensors malfunctioned at some point during the flight.

9 10.0 Ready for Flight

If we were to launch again we would order three new PCBs to build two new detectors and one to replace the current broken SD card PCB. Although our payload was not damaged during flight, during testing we discovered that one of our SD card readers was not functioning because we cut one of the PCBs to close to the board when we were separating them from the other boards and severed a trace. In order to fix this problem, we would only need to order another SD card PCB and be more careful when cutting. For the other two boards we would build a housing and store them in the basic CosmicWatch aluminum casing. The second pair of detectors would stay at ground level for our reference ground data. Since our payload is not sensitive, we will be able to store it in any cabinet that resides in a climate-controlled building. We kept our design fairly simple throughout the project. To activate our payload, you simply need to make sure the battery is charged and plug the micro USB power cord into the sensor.

10 11.0 Conclusions and Lessons Learned

During this project we learned a few skills and techniques that greatly helped us succeed. To solder our PCBs, we used techniques learned on YouTube for surface mount soldering. One such technique is to apply the solder directly to the soldering iron and then touching the solder on the iron to the component we were currently mounting. Another technique we utilized was working as a team to remove solder from tiny components. One person would heat the solder on both ends of the component with two soldering irons while the second person uses the solder sucker to remove the component. We also learned that it is more prudent to error on the side of caution than to strive for perfection from our sliced trace that resulted in one of the SD card readers not functioning. Another major lesson we learned is to take notes of important dates and information that is given out at the beginning of the project,
so we do not have to look them up every time we have a question about them. We learned this from a miscommunication causing us to rip off excess protective foam from our payload to cut weight that we later glued back on when we found out the correct weight limit was 200g higher. Given a chance to go back and do it again we would have taken better notes off of the Colorado Space Grant website so that the information we needed was more readily accessible. We would also give ourselves more leeway when cutting out the PCBs so both our SD readers worked. We also learned to be more careful when ordering parts, so we do not order the wrong part. The fact that our payload was upside down was unfortunate; however, due to our payload being upside down, it gave us a new perspective for our data. Since the payload was inverted, the data we received was from charged particles from up from the Earth’s surface as altitude increases. To our knowledge this data has not been explored before. If our main detector’s SD card board was functional then we would have been able to directly compare the data from the master and the slave data.

11 12.0 Message to Next Year

For future DemoSat participants we have a few suggestions. We hope that they learn from the mistakes we made as far as erring on the side of caution and taking more thorough notes. Another note is to take lots of pictures throughout the entire project not just on launch day. Being organized was probably the biggest reason why we were able to have a successful launch and we would recommend that you try and be as organized as possible, so you can be efficient with your time while working on the project. Our final message to future DemoSat students is that this has been a fantastic experience and we have learned an incredible amount of new knowledge while still having fun!

References: