Space Owls

To detect muon radiation in the upper atmosphere while gathering auxiliary sensor data to better understand the performance of our design.

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1.0 Mission Statement

Our mission is to detect the frequency of muons as a function of altitude. Secondarily, we are collecting accelerometer data to track the orientation of our payload through the flight. We intend to use this data to create a three dimensional representation of the payloads orientation from launch to landing.

Muon detection is accomplished via scintillation in combination with a SiPM. The signals from the SiPMs are digitized by a CAEN A1702 front end board and saved to a CERN Root file as well as displayed through a GUI. In order to correlate detections with altitude, the payload includes an accelerometer to track orientation and when approximate zero acceleration is reached. This data when combined with radar ranging from Wallops Flight Facility should enable a correlation of detection frequency to altitude.

2.0 Mission Requirements and Description

The mission was defined as being successful if muons were detected during the flight and a comprehensive success was defined as correlating those detections with altitude. The payload was designed to meet the comprehensive success criteria and provide a reasonable level of redundancy in the event of a subsystem failure. Deliverable dates were also set forth to ensure early completion of task and a problem free integration of the payload to the launch vehicle.

To ensure that muons were detected, appropriate scintillating blocks and correctly paired SiPMs able to detect the photon counts produced were required. A data acquisition system and a computer with necessary processing power that could fit within the payload dimensions were needed. Power requirements also needed to be met as well as auxiliary sensors chosen that could perform in the mission environment.

A means of running the experiment automatically at power on of the payload was also a requirement. This entailed choosing an operating system for the computer compatible with the front end board and which provided a means of automatic function.

Wallops flight facility had several requirements for payloads which must be met before the payload was allowed to fly. These requirements as applicable to our payload are listed below:

- Payload must be contained within provided RockSat-C canister
- Payload must have a center of gravity lying within 1 cubic inch of the centroid of the canister
- Payload must be connected to canister by at least 4 bulkheads on either the top or bottom of the payload
- Canister with payload(s) must have a mass of 20 +/- .02 lbs
- Payloads sharing a canister must have a maximum height of 5 inches and have clearance between both payloads
- There can be no voltage on the canister (electrical isolation of payload)
● Payload must have a Teflon coated activation wire of at least 4 feet in length
● Early activation current must be below 1 Ampere
● Batteries must be of approved type

3.0 Payload Design

The design of our payload was mainly dictated by the components used by the previous RockSat team at our university. The 2018 team was attempting the same experiment and had completed preliminary work and fielded a partially functioning system which was launched as a RockSat-X payload. However, their experimental setup was fundamentally flawed due to a lack of understanding of the underlying physics. The 2019 payload was redesigned to address the failures of the 2018 payload and to meet the RockSat-C programs specific requirements.

Muons are particles with properties similar to electrons but having a much greater mass. They are produced as a result of collisions of cosmic rays with the atmosphere. When a cosmic ray strikes a particle in the atmosphere, a shower of secondary particles, which include muons, is generated.

To detect muons our payload used plastic scintillator blocks paired with a SiPMs (silicon photomultiplier). When muons strike the plastic scintillator sometimes one is stopped and releases a burst of photons proportional to its energy. These photons are detected by the SiPM which outputs a voltage to the front end board. The front end board amplifies and digitizes the signal. Software running on the computer displays these signals graphically and saves the data to memory for later analysis. Additionally, the payload has a three axis accelerometer onboard which is used to record the orientation of the detector and detect when the payload reaches its maximum altitude. Maximum altitude should coincide with an acceleration reading of approximately zero. The accelerometer data is saved in a text file.

The following diagram shows the flow of power and data within the system:
The key element in the experiment is the particle detector composed of the scintillating blocks and the SiPMs. The front end board is configured to make detections in coincidence mode. This means that an event is registers only when there is a signal withi
Our payload followed the Wallops 1.SYS.1 activation scheme. This method was chosen because we wanted to assure that the system booted and began recording data well before the rocket launched. During development of the payload it was discovered that current on the activation exceeded Wallops maximum allowable metric. To overcome this issue, an attempt to lower power consumption of the subsystems was made however this proved not to be possible. Instead, the problem was solved by isolating the payloads main power from the activation line by using a solid state relay. The relay required a very low current and voltage to operate which dropped the subsequent current reading on the activation line to a level lower than the test multimeter could read.

The chassis section of the payload had to meet the weight, space, and mounting requirements set forth by the program. Our payload was underweight after all essential pieces were installed. To rectify the weight issue, steel plates were mounted to the payload as ballast. The payload chassis was composed of two sheets of ¼” inch thick acrylic separated by aluminum standoffs and secured with various nuts and bolts. The bulkheads connecting the payload to the canister were custom made derilin approximately. These materials were primarily chosen because they were known to have been successfully used in previous payloads built by Temple University. Secondarily, it was thought that the derilin bulkheads would provide additional shock protection over using metal bulkheads. These were not used in previous payloads. Construction of the payload chassis began very early in the design process as we had old components in the lab that were available to test mount as the chassis was perfected. These used examples allowed parallel development of the prototype chassis and the rest of the payload simultaneously. Creating the final version of the
payload was then trivial when all new components arrived. Final 3D models of the payload are shown below:
4.0 Student Involvement
David Horowitz - Electrical Engineering:

Team leader, primary engineer, test engineer, programmer, and assembler.

Idris Sadiq - Computer Engineering:

Presentations and accelerometer testing

Tyrel Cherry - Computer Engineering:

Presentations and front end board testing

Zacharia Ismael - Mechanical Engineering:

Presentations and vibration testing
5.0 Testing Results

A. Integrated Subsystem Testing Results

Chassis Vibration Testing

The chassis was vibration tested using a soil vibration machine that was available in the civil engineering department of Temple University. The test was used to confirm that no payload components would break or come loose. After vibration testing the payload was undamaged. This test, along with the knowledge of materials used in previous successful payloads, indicates that our payload should pass testing at Wallops and survive the flight.

Electrical System Testing

The power regulator was tested to confirm that the needed voltage and current levels required for operation of the Udoo computer and the Front End Board were met and that these levels code be maintained for the duration of the mission.

![Image of power regulator testing](image)

**Fig. 7: Power regulator testing using benchtop supply as input**

Figure 9 above shows the output of the power regulator on an oscilloscope when a supply voltage is provided by a benchtop power supply. Using a temporary setup the system was successfully run for at least 30 minutes without incident.
Software Testing

The Udoo computer was tested to confirm that it could autoboot and start necessary programs using a shell script.

The testing revealed that our BIOS settings and shell script accomplished the auto-starting procedures necessary to accomplish our mission.

Sensing Testing
The Front End Board and associated software were tested for basic functionality.

![Fig. 10: Front End Board readout software is tested](image1)

![Fig. 11: ROOT browser data analysis software is tested with files saved from Front End Board](image2)

**NOTE:** Further subsystem integration testing information can be found in the STR report presented on 2/13/19.

### B. Full Mission Simulation Results

**NOTE:** The following mission simulation results are those that were carefully documented for the purpose of the LRR. Numerous partial simulations were run testing specific components of the
system during development but were not recorded. Please see the FMSR report present on 5/1/19 for more information.

**FMSR 1**  
**Date:** 4/25/19  
**Duration:** 10 minutes  
**Payload Status:** Initial

**Power Source:** LiPo battery

The payload successfully detected particles (as far as we can tell without in depth analysis) and performed as expected with two exceptions:

1. Current on T-3 Wallops activation wire was greater than 1 Ampere.
2. FEB data was not able to be opened due to corruption

To resolve the current issue, a solid state relay was added to the payload which separates the activation line and the payload. Now the activation line is only connected physically to the relay and a 9 volt alkaline battery. This resolved the over current problem.

The source of corruption in the data was not discovered. Sometimes data is corrupted and sometimes it is not. We do not know why this is the case. To circumvent this issue, a screen recording program was installed on the payload to capture a video recording of the FEB GUI during the experiment.

![Image](image_url)

Fig. 12: Vertical and horizontal payload orientation results show detection of particles is successful because of rate change between the two orientations.

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**FMSR 2**  
**Date:** 5/21/19  
**Duration:** 15 minutes  
**Payload Status:** Finalized

**Power Source:** LiPo battery
The second mission simulation with the finalized payload performed as expected. The payload again detected particles as before. Current on the T-3 Wallops activation line was recorded as 2.31 mA, well below the threshold allowed. Screen recording software performed as intended. Data corruption did not occur during this test and saved data was recovered.

Fig. 13: Saved data viewed after test showing no corruption
6.0 Mission Results

The payload was activated at T - 3 and approximately 30 seconds later began capturing data. Data failed to record without corruption in the CERN root file format. However, screen capture software was running as a redundant means of capturing the data via the output of the front end board GUI. The screen capture software successfully recorded detection data and using the computer desktop clock which was configured to display time in seconds, captured data can be correlated with the timestamped altitude measurements provided by Wallops radar.

The desktop clock displays the time 5:27:21 when it begins capturing data. Since the payload was activated at T - 3 and boot takes approximately 60 seconds, this means data recording began at T - 2. Launch then corresponds to approximately the desktop clock reading 5:29:21.

A large spike in detection occurs at desktop time 5:29:38 or T + 17 seconds. A second spike is detected at 5:29:44 or T + 23 seconds. A final large spike occurs at 5:29:52 or T + 31 seconds. After the third spike, no further large detections are recorded for the remainder of the flight. Using the Wallops radar data, these times indicate the spikes occurred at altitudes of 8785 meters, 14148 meters, and 22530 meters respectively. These results are summarized in the following table:

<table>
<thead>
<tr>
<th>T + time in seconds</th>
<th>Altitude (m)</th>
<th>Altitude (km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>17</td>
<td>8785</td>
<td>8.79</td>
</tr>
<tr>
<td>23</td>
<td>14148</td>
<td>14.15</td>
</tr>
<tr>
<td>31</td>
<td>22530</td>
<td>22.5</td>
</tr>
</tbody>
</table>

We note that these altitudes and times are approximations as boot time for the system can vary by several seconds. An average of boot times would be needed to better fit detection to altitude. However, we are confident that the altitude readings displayed in Table 1 would likely only vary by +/- 2 kilometers.

Because the accelerometer did not function as expected and maxed out at 16 Gs, orientation of the detector can not be determined to any useful degree. The method used to capture the accelerometer data is sound, however a higher G rated component is needed. Before and after the accelerometer maxes out and then returns to its operating range, the data does correspond to that of a parabolic flight path as would be expected.

The design of the payload proved to be a majority success as all of the systems did function and data was able to be retrieved on return. Additionally, the entire system was still perfectly functioning when powered on after the flight with one exception. The LiPo battery, because it ran until depletion will waiting to be retrieved from the ocean, was unable to be recharged again. This is the expected behavior of LiPo batteries in this situation. A low power cut off circuit could be utilized in order to save the battery, however, this is not a major concern as the system can be
partially powered from a wall transformer to retrieve flight data. In fact, a low power cut off circuit was considered during the design process but was decided to be unnecessary.

The redundant desktop recording software proved a key component of the design as without its presence, no useful data would have been collected. The GUI readout from the flight overlayed with calculated altitudes is displayed below:

In table 1, note the start up noise displayed on the event rate graph. This behavior was observed in some testing of the payload but was thought to have been dealt with by having the GUI reset itself after initial startup. Clearly, this procedure was not reliable. There were many issues and bugs associated with the software provided by the front end board manufacturer. If this issue had not been present during the flight, more resolution could have been obtained for the detection spikes and a comparison between each spike may have been possible as is illustrated by figure 12 on page 12. Despite this, the spikes themselves do reveal interesting results.
The major failure of the payload was a software issue that caused the CERN root file to be recorded with corruption. It is difficult to determine whether this fault was due to poor scripting on our part or the software itself containing bugs. Extensive testing and use of the software leads us to suspect the latter. Examination of the source code for the GUI reveals almost completely uncommented code. Inconsistent behavior from the software was present throughout the testing of the payload. If the corruption had not occurred, data on the magnitude of the detections could have been collected and analyzed and combined with the accelerometer orientation data, more illuminating conclusion may have been able to be drawn.

As for the chassis and physical construction of the payload, there were no issues found after the flight. The chassis withstood the stresses of the flight extremely well and no damage was sustained.

7.0 Conclusions

The data collected suggests that previous research that indicated peak muon detection frequency occurring at around 15 km is accurate. If our data collected is at least somewhat accurate, it appears that detection rates have distinct peaks within the altitude of approximately 8.5 to 22.5 km. Our expected results were that we would see a rising curve of detection rates and then a falling curve. Instead we have these separate peaks of activity within a period of overall high activity.

It is difficult to speculate on the meaning of the results as there are many unknowns. However, one reason that may account for the distinct peaks in the data is differing composition of the atmosphere at these points. Any cosmic rays traveling through the atmosphere are of course more likely to be absorbed in areas of denser atmospheric composition and release secondary particles in these regions. It is possible that the payload was passing through a striated region of the atmosphere, very likely regions with and without clouds. We must note that this is highly speculative.

8.0 Potential Follow-on Work

To continue the experiment, the issues with the CERN root file format would need to be corrected if true analysis of the data is desired. The accelerometer on the payload would also need to be switched to the high G rated external accelerometer rather than using the onboard module in the Udoo computer.

I do not feel it is worth continuing with this mission, at least not aboard a sounding rocket. It would be of greater benefit to conduct the experiment perhaps on a high altitude balloon or aircraft. The sounding rocket, while unique in that it reaches much greater altitudes than a balloon, moves too quickly to gather enough muon data to make a sound conclusion.

9.0 Benefits to the Scientific Community

The primary benefit to the scientific community provided by this experiment is the validation of the concept that it is possible to conduct high energy physics research using a small apparatus constructed with commercial-off-the-shelf components. The small front end board and single
board Udoo computer have been shown to provide the processing power needed for complex particle research while requiring relatively little power. Such a design could be used to deploy many detectors that run autonomously in remote locations and in harsh environments.

The secondary benefit to the scientific community gained from our mission is a possible new question to be investigated regarding muons at high altitudes. Namely, the distinct peaks of detection rates, while within the expected altitudes for peak detection, are not a smoothly rising curve as expected. This may be, and likely is, experimental error and flawed design on our part. However, there is a possibility that the results are legitimate and worthy of further investigation.
10.0 Lessons Learned

The key lesson learned from this project was to find teammates who are reliable and invested in the work. While the team appeared enthusiastic and willing to put time into the project when the group was formed, by the launch week, only one team member was present. Despite clearly assigned roles and documented expectations for the team members set by the team lead, the vast majority of work and effort was undertaken and completed by the team lead. Despite this failure on the part of the team as a whole, the payload was a success thanks to a highly dedicated individual.

Another important lesson is to make sure you understand the fundamental science behind the experiment you are conducting. Key changes to the payload were required from the previous teams design. The 2018 team made serious errors in their design which made it an impossibility for them to make any accurate detection of particles. Mainly, the detector housing they constructed was not light-tight and the scintillators were not oriented parallel to each other. A light tight detector is an absolute necessity in this detection method because any photons produced in the scintillators will be completely drowned out by incident light from any source, including LEDs present on the front end board and computer. Secondly, the orientation of the detectors made it so it was extremely unlikely muons would pass through both scintillators thus negating the possibility of coincidence detection. These are catastrophic design flaws that would have been avoided if proper research had been done. Luckily, these flaws were discovered early in our own design process and changed.

Another lesson is to make sure that any components used in a design are rated for the environment and there is a margin of error. The onboard accelerometer on our payload maxed out at 16 Gs making it not useful for a portion of the flight. There were initially two accelerometers and one of them would have worked but to simplify the design it was decided to rely on the internal unit in the main computer. The datasheet was checked and it while the unit was supposedly rated for 25 Gs, it did not perform at this level. If the other accelerometer had been utilized it likely would have function as expected because it had a higher maximum G rating.

Finally, and possibly most importantly, it was learned that working on an experiment you personally have little interest in makes for an unpleasant experience. While it is still possible to succeed when carrying another team’s experiment forward, it is much more enjoyable to work on something for which you have passion.