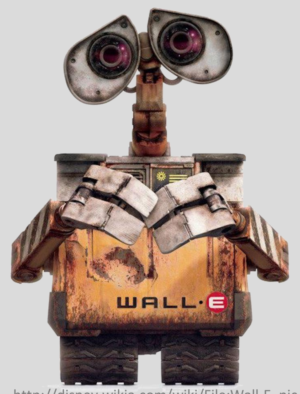

http://disney.wikia.com/wiki/File:Wall-E_pic.png

High Altitude Ballooning: Designing a Payload for Muon Detection

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Mission Statement

Team Wall-E's *Enterprise* Mission, executed in cooperation with the Colorado Space Grant Consortium through the Gateway to Space class at the University of Colorado Boulder, designed, built, and launched a BalloonSat to an altitude of 30 kilometers. The team collected data on atmospheric temperature, pressure, and humidity, as well as used a CosmicWatch detector to measure muon count as a function of altitude.

Introduction

What are cosmic rays?

Cosmic rays are high energy atomic nuclei originating from the sun and outer space. They travel at **nearly the speed of light** and are impossible to detect from inside the atmosphere. When cosmic rays interact with the atmosphere, they break down into unstable subatomic particles, among which are **MUONS**.

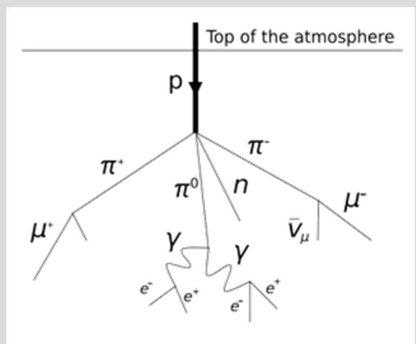


Figure 1. Muons, denoted e- and e+, are byproducts of cosmic rays colliding with the atmosphere.
http://hardhack.org.au/cosmic_rays

Why are muons important?

Since cosmic rays come from outside our solar system, gathering information about their byproducts can tell us about where they came from and what is happening far from Earth!

Muons...

- Can be detected due to special relativity and its effects
- About 207 times the mass of electrons [1].
- Average lifespan of ~2.2 microseconds [1].
- Make up much of the radiation that reaches the Earth's surface.

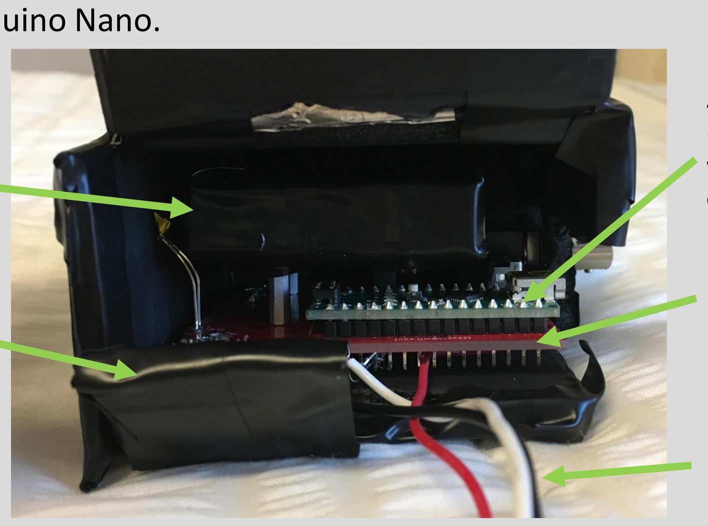
This means that their detection can be used in a technique known as **muon tomography**, where scientists use scintillators to detect muons and map structures like volcanoes [1]. This technique is similar to having a very large x-ray. One issue with this technique is that the detectors used must withstand some extreme conditions, and it is important to know how those conditions affect muon detection. Studying muon generation can aid in the understanding of how to use muons for these imaging techniques and the limitations that can be expected.

What is a CosmicWatch?

A **CosmicWatch** [2] is a low-cost muon detector that was developed by Spencer Axani at MIT. It weighs 68 grams. The detector was meant as an educational tool and an introduction into radiation research for students. The detector includes a plastic scintillator, and when muons pass through this scintillator, they emit a flash of light. This flash can be detected and amplified by a silicon photo multiplier (SiPM), and then recorded on an Arduino Nano.

Plastic Scintillator (wrapped in vacuum foil and electrical tape to make sure it wouldn't have a light leak that would affect our data)

Case (built from foam core, vacuum foil and electrical tape, this case was built to block alpha and beta particles from activating the sensor)



Arduino Nano (microcontroller board which ran our script to collect and record data)

Printed Circuit Board (PCB) (the location of our circuit for the system.)

Connects to our OpenLog (recorded data)

Figure 2. The CosmicWatch detector built and used by Team Wall-E. The case was built with foam core, aluminum tape, and electrical tape.

Concept of Operations

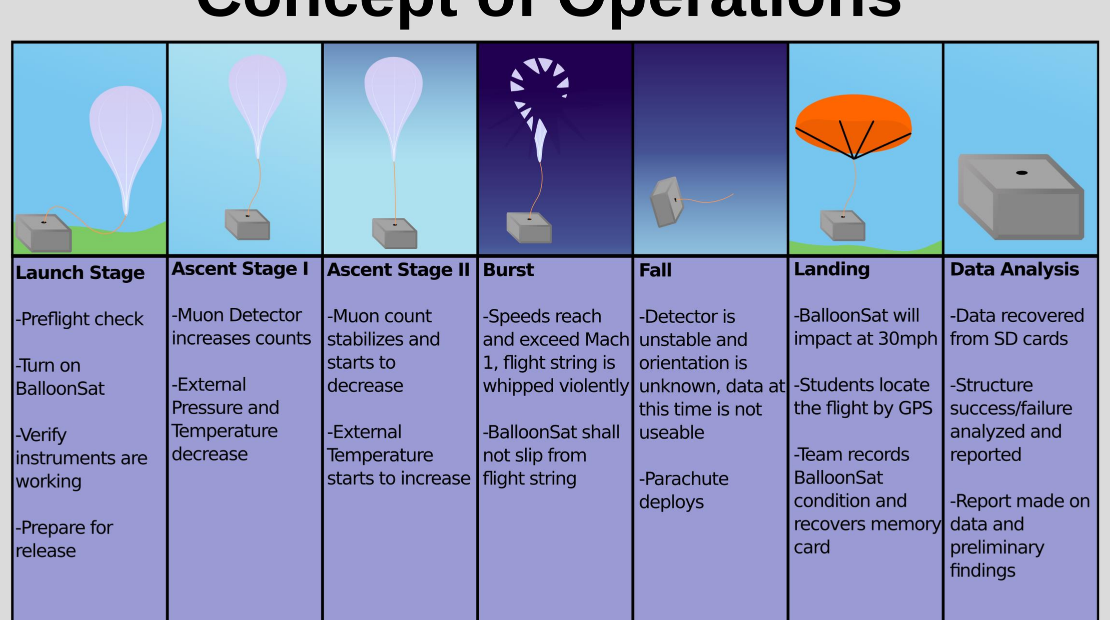
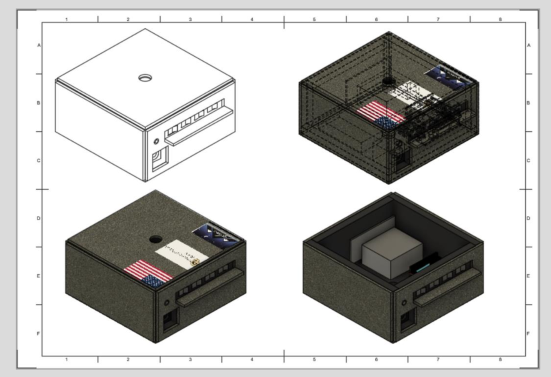
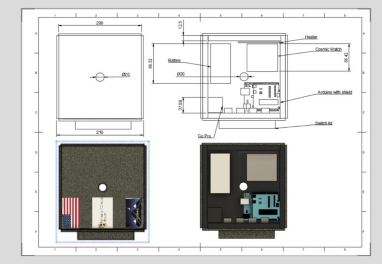


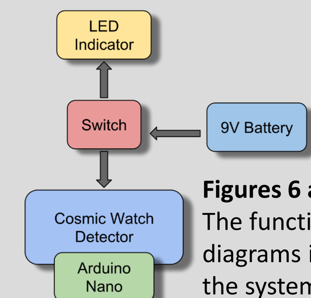
Figure 3. The Concept of Operations for Mission Enterprise.

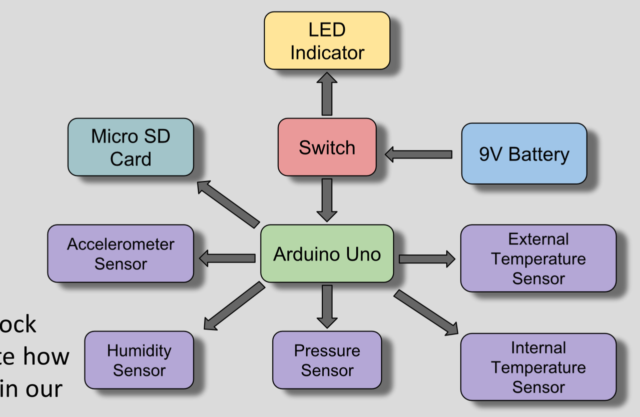
Unless otherwise stated, all figures were made by Team Wall-E

Design and Testing

Figures 4 and 5. The CAD Drawings of our payload design.





Figures 6 and 7. The functional block diagrams illustrate how the systems within our payload operate.

The team completed many tests on Project Enterprise before launch. The purpose of these tests was to ensure the structural integrity of the BalloonSat, confirm the successful data recording and collection of our flight sensors and CosmicWatch, and make sure it would be able to withstand the extreme conditions of flight and a near-space environment.

Figure 8. Whip Test

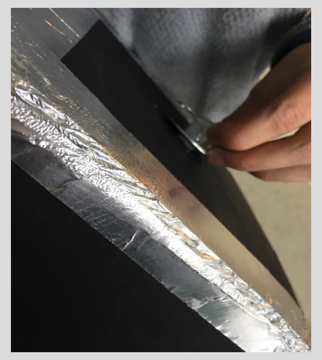


Figure 9. Whip Test Result

Completed Tests:

- Structural (drop, whip, and stair)
- Sensor (accelerometers, temperature, humidity, and pressure)
- GoPro
- CosmicWatch (duration and radiation)
- Mission Simulation
- Cold

Cosmic Watch Results

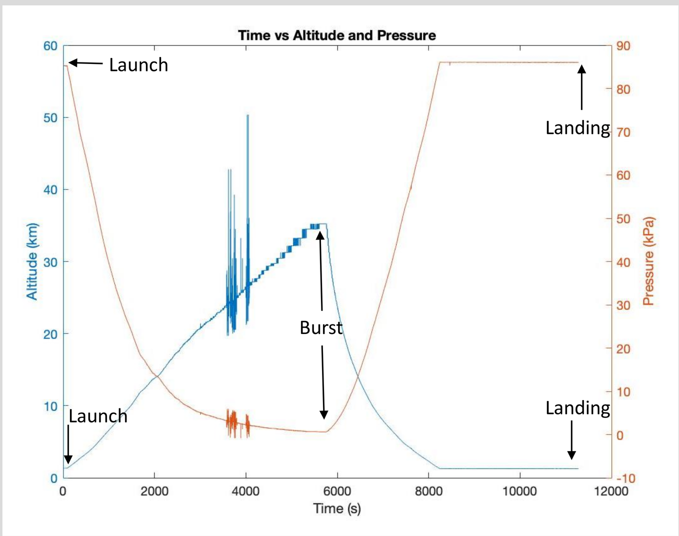


Figure 10. Recorded pressure in kPa and altitude in km. Note that the altitude was calculated using pressure and temperature using the hypsometric formula.

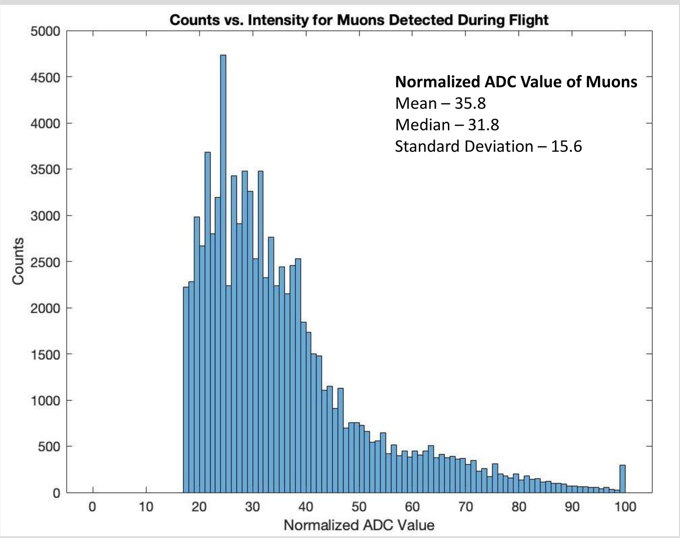


Figure 11. The normalized distribution of muon intensity using ADC values. It follows roughly a normal distribution. Events with a measured SiPM voltage of below 30mV have been removed.

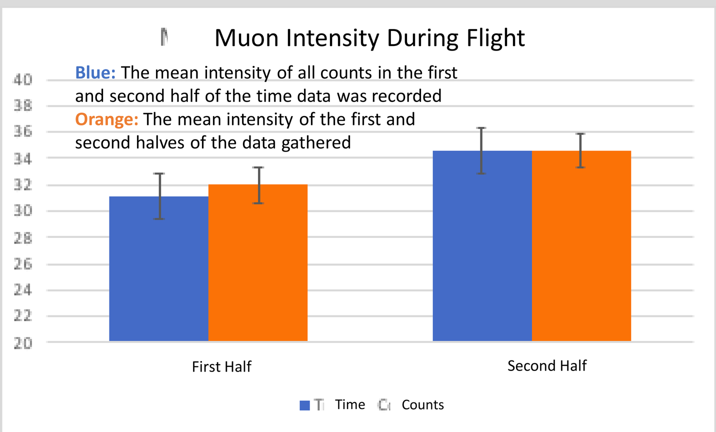


Figure 12. The average intensity of the muon pulses detected over the course of the flight. The graph shows the mean intensity of pulses increases by 3%, thus the later muons are more energetic. The error bars show the standard deviation.

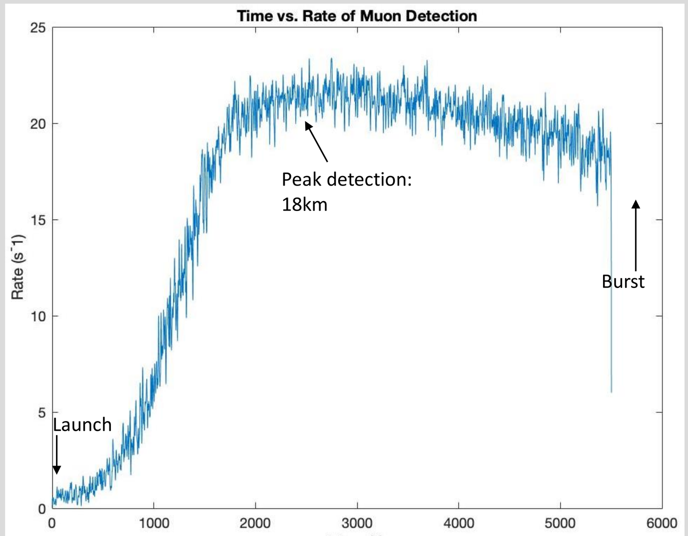


Figure 13. The average of 100 instant count rates around the time. The changing rate shows a peak detection rate at around 2700 seconds, calculated to be 18km.

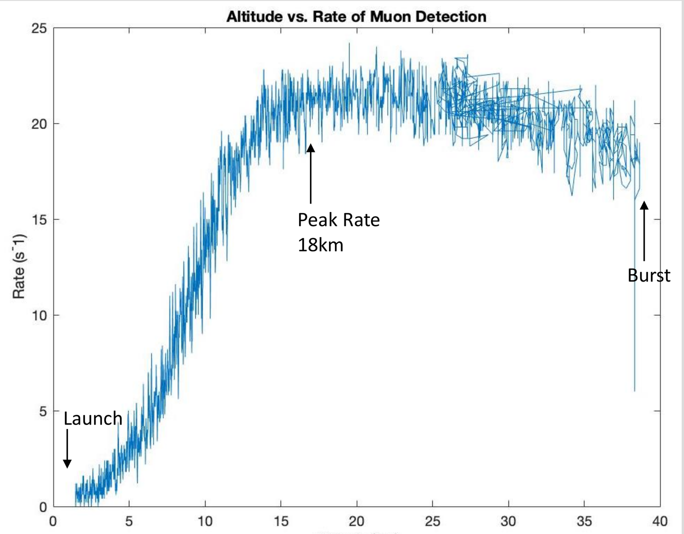


Figure 14. The count rate against calculated altitude. The peak occurs at 18km.

GoPro


Figures 15 and 16. Images captured by our onboard GoPro at an altitude of about 30 km.

Flight Data

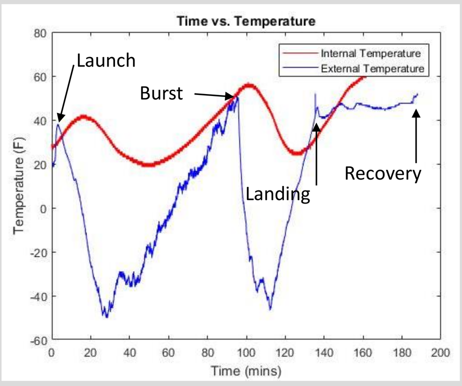


Figure 17. Flight Data for Internal and External Temperature.

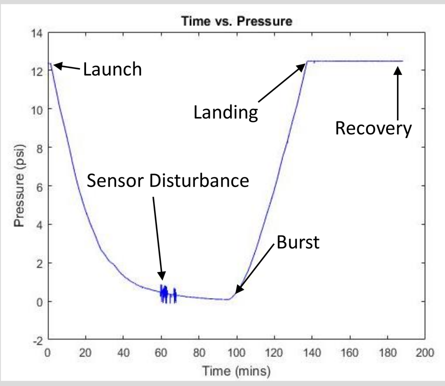


Figure 18. Flight Data for Pressure

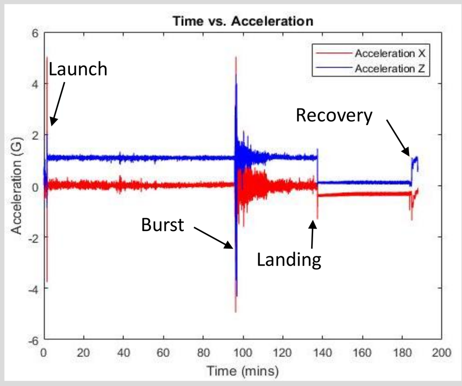


Figure 19. Flight Data for Acceleration

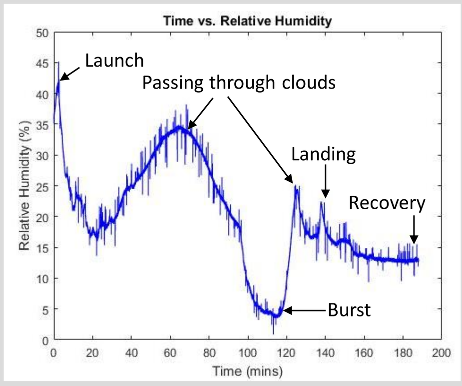


Figure 20. Flight Data for Relative Humidity

The flight data recorded was as expected. All sensors worked throughout flight, and the Arduino Uno and OpenLog recorded data throughout the entire flight.

Discussion

The data Team Wall-E collected during flight is very similar to the expected results. One point of contention lies between Figure 14 and Figure 22, both showing rate against altitude. Figure 21 only has data up to an altitude of 10km [3]. The leveling of rate that Team Wall-E experienced is not accounted for in this model. On the other hand, Figure 10 and Figure 21 match quite well. Both show data of 15 counts/s at 10km.

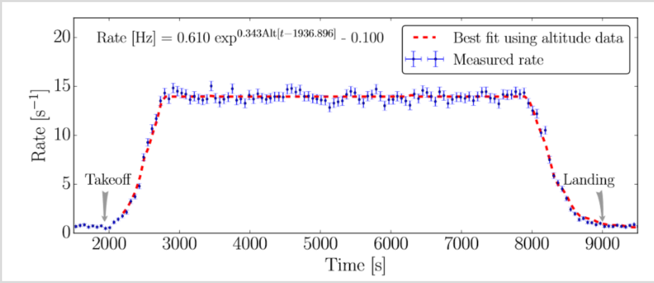


Figure 21. The graph shows counts measured on a commercial flight as a function of time.
S. Axani, et. al., *American Journal of Physics* ***85*** (2017)

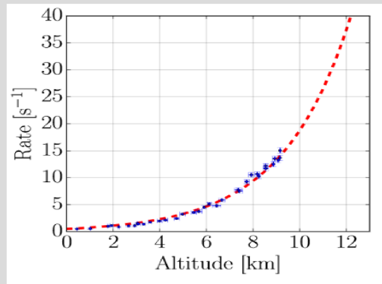


Figure 22. The graph shows counts measured on a commercial flight as a function of altitude.
S. Axani, et. al., *American Journal of Physics* ***85*** (2017)

The team expected Figure 13 to more closely match Figure 23, specifically how quickly the rate drops from its max at 15km. This drop off did not occur to the same degree and did not happen until 18km. This is likely due to atmospheric conditions and the detector not being set in coincidence mode, which ensures the pulses are only muons and not pions, gamma rays, or other high energy particles [4]. However, the trend of both graphs still match.

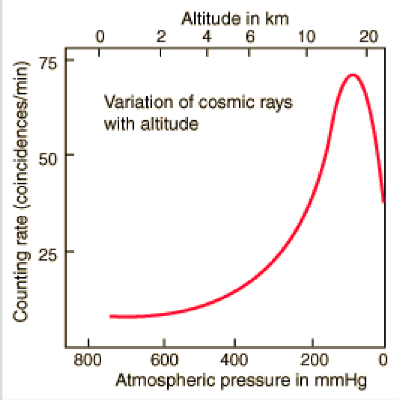


Figure 23. The graph shows the correlation between Muon count and altitude.
http://hyperphysics.phy-astr.gsu.edu/hbase/Astro/cosmic.html

Applications

Muon Topography

- Can be used as a technique for detecting well shielded nuclear contraband [5]
- The denser the material, the more a muon's path is deflected and the more energy it can absorb from particles.
- Physicists can track how often muons of different energies reach detectors placed around a target and compare that with the expected rate without an obstacle, to build up a 3D profile of the density of the interior of an object. [6]
- Volcanoes can also be mapped using this technique. Since lava channels absorb less energy from muons than the denser surrounding rock, this could one day help to predict eruptions. [6]
- In December 2015, physicist Kunihiro Morishima of Nagoya University, Japan, and his colleagues used muography (muon mapping) to reveal a large, previously unidentified chamber inside the 4,500-year-old Great Pyramid in Giza, Egypt. [6,7]

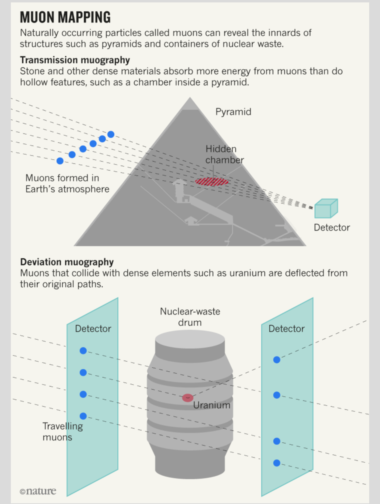


Figure 24. The graphic shows how the penetrating power of muons makes them perfect for imaging large, dense objects nondestructively.
https://www.scientificamerican.com/article/muons-the-little-known-particles-helping-to-probe-the-impenetrable/

Conclusion

In conclusion, Team Wall-E's Project *Enterprise* demonstrated the usefulness of using a low-cost muon detector for determining changes in muon flux through the atmosphere. It is practical to use the CosmicWatch to study muons in the atmosphere, as it is a relatively lightweight, low-cost and robust system. The experiment replicated and verified current models for the relationships between muon flux and altitude and muon intensity and altitude. The team estimates an altitude of 18km is ideal for maximum muon generation. This estimate could be used to determine the placement of detectors for practices like volcano mapping.

References

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Background obtained from: https://i.pinimg.com/originals/83/79/31/8379311ad450fd8d47347ac17cbc65f0.jpg