HASP - University of Colorado Boulder

2023

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Submit Date: April 16th, 2024

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1. Introduction and Mission Statements

WhenBuffsFly aims to help the Great Lunar Expedition for Everyone (GLEE)'s mission to raise their technology readiness level (TRL) to level 5 from level 6. To accomplish this, we took the LunaSats to a near-space environment and tested them for twelve hours. We tested all of the sensors onboard the LunaSat including temperature, magnetometer, accelerometer, capacitive, and thermopile sensors. One LunaSat gained power from the sun using its solar arrays, and the others used the power from the High-Altitude Student Platform (HASP) platform. Our mission is to improve the Technology Readiness Level (TRL) of LunaSats by testing their capabilities, survivability, and accuracy in a near-space environment in early September, launching from Ft. Sumner, New Mexico, as part of the HASP platform. Our approach to testing the LunaSats on the HASP platform includes manufacturing the payload to include an angled top face to test the solar panel at the optimal solar angle. We planned on receiving at least 6 hours of data but were prepared to receive upwards of 12-24 hours of data. Throughout the flight we observed the temperature changes onboard the lunaSats through serial data downlink as well as saving all data on SD cards onboard the payload, which we analyzed after the recovery of the payload.

2. Payload Performance

Our payload successfully performed all mission objectives in both integration and flight. We were confident about our payloads ability to gain flight data since we tested our payload in thermal and pressure cycles three times and gained flight certification. We completed our mission objectives obtaining more than six hours of data, running all sensors simultaneously for six hours, performing successful RF communication, receiving similar temperature data compared to that of the HASP platform. With the help of the HASP organizers we were able to have a successful integration, which helped us prepare for flight. Although we had to make final adjustments to the payload after integration, we worked hard to build a fully functional, optimized payload. Our work started last year in the fall of 2022 when members of our HASP team joined a program called WARP SPEED that is part of the NASA Colorado Space Grant. As a group we learned how to solder, code with an arduino, build a demoSat payload, and complete this year’s HASP from its inception to flight and data analysis. For our DemoSat project, we were separated into groups to make payloads that would go on a weather balloon, providing us with our introduction to balloon payloads.

After this learning opportunity, WARP SPEED gave us the decision between three projects, HASP, RASCAL, and Micro-g Next. Four of us chose HASP while other members of WARP SPEED chose RASCAL or MICRO Gen X. However due to the deadline of MICRO Gen X, HASP gained more members to assist in this project. Most of us were freshman and we were excited for this new opportunity. Our advisors brought up the idea of using GLEE's LunaSats on our payload to test them in a near space environment, which we eventually adopted for our science design. GLEE is a NASA-funded, technology and community engagement project that consists of small solar-powered sensing PCBs programmed by students from around the globe, that shall land on the moon to conduct distributed science and technology missions while engaging the world's next generation of space explorers in local lunar science. We agreed immediately and went on to choose our leadership. After choosing our leadership, management had the team members choose which subteams that they wanted to be a part of, as well as, tasking them with learning how the LunaSats operated and familiarizing themselves with its technology . As we began HASP, we created a Notice of Intent and proposal which was accepted to the excitement of our team. After it was accepted, we started right away making an internal (Conceptual Design Review) CoDR to explain our preliminary design and gain insight from the other members of the staff team from the NASA Colorado Space Grant as well as some members of the GLEE team.

After the CoDR, we started assembling preliminary designs for our payload. We started with cardboard structures and placed sticky notes where the LunaSats would be located for testing. We conducted material studies for our (Preliminary Design Review) PDR, which helped the structures subteam finalize their initial design. Before the PDR, we hired team members with coding experience to help us with our software design. On April 22, 2023 we presented our design at the Space Grant Symposium where we showcased our prototype. At the end of the spring 2023 semester we lost the majority of our avionics subteam as well as members across other subteams due to other summer work opportunities. Before our team members departed for the summer, we submitted our Preliminary HASP Payload Specification and Integration Plan(PSIP) and gained comments from the HASP organizers on how to improve. On June 5th 2023, we conducted our internal (Critical Design Review) CDR and worked on building the final flight version of the payload. After our first iteration of the flight payload we tested it in a TVAC bell jar chamber on the University of Colorado Boulder's campus called JANA.

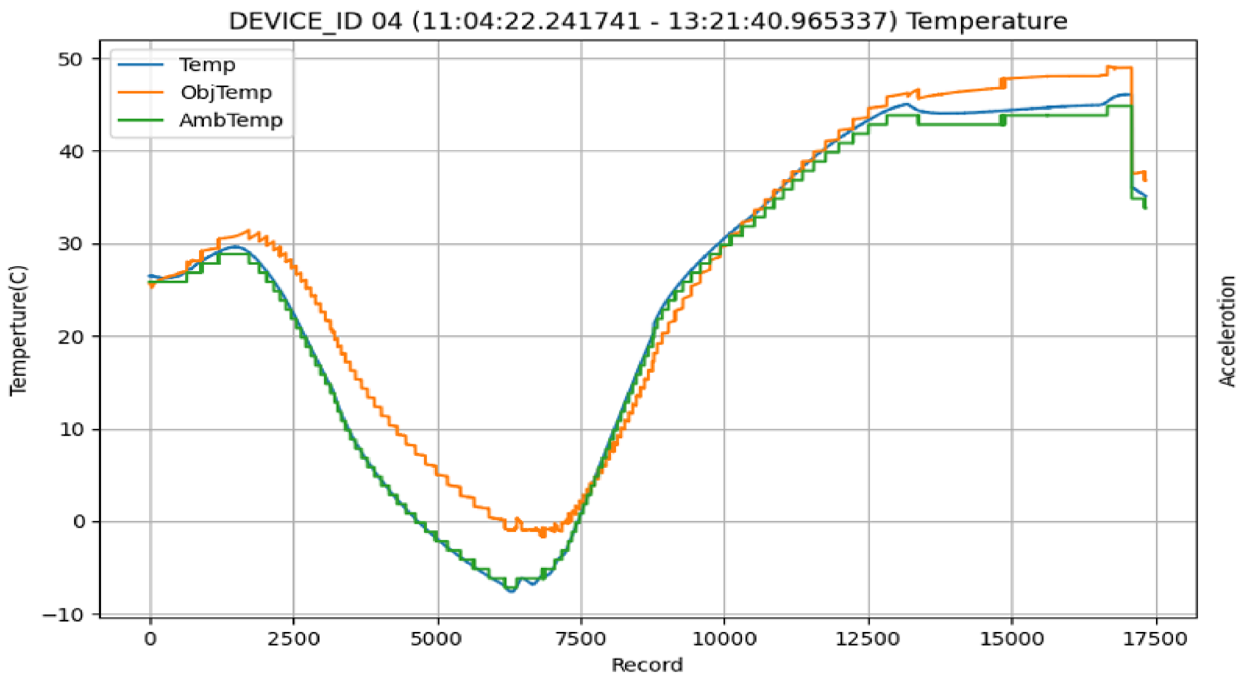


Figure 1: Graph of LunaSat four's temperature during TVAC test

We saw encouraging results in our TVAC test with successful data collection and downlink, similar temperature readings, with extreme temperatures and pressures not affecting the performance of payload. These results can be seen in Figure 1.

We wrote our Final Flight Operation Plan (FLOP) leading up to integration in Texas, describing how our payload operated for flight day. During integration and testing at CSBF for integration we conducted two thermal and vacuum tests. The layout for the test on Friday is shown in Figure 4 below.

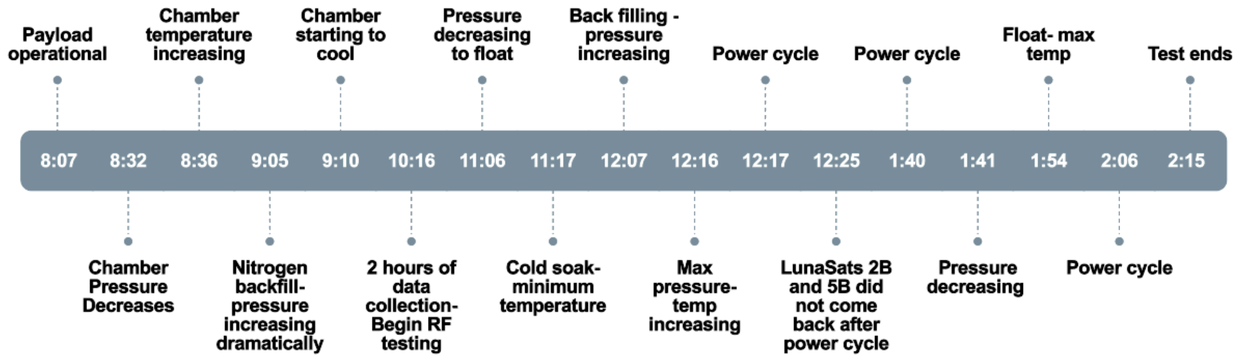


Figure 2: Test Layout for integration on July 28th in local time

We found our test to be successful during the first test because we acquired real time data through downlink, acquired SD card data, low and high temperature and pressure seemed to not affect the performance of payload, we had RF communication, did not see software issues, and had successful power cycling that even restored our LunaSats when they stopped downlinking. We participated in the TVAC test on Friday to verify our findings shown in figures 5 and 6.

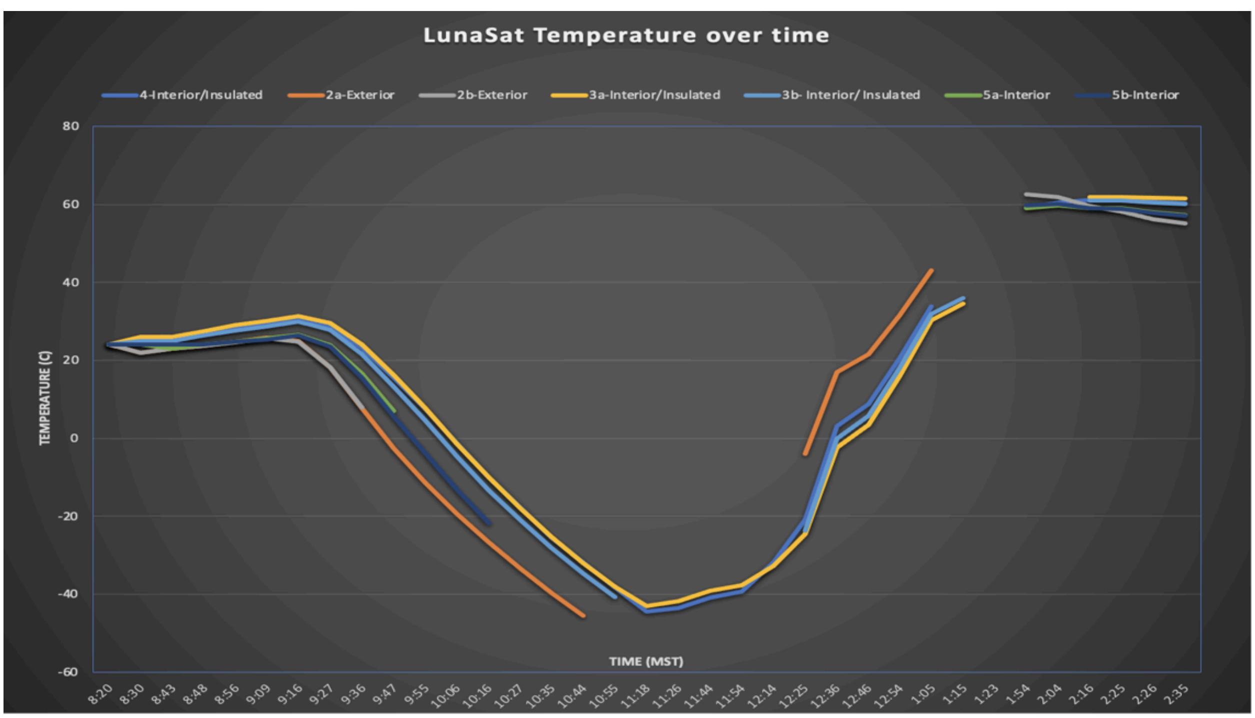


Figure 3: (Graph of LunaSats for Friday integration test)

This graph shows all the LunaSats' temperature sensors working throughout the test. Our most reliable LunaSat turned out to be LunaSat 4 which was inside the payload, mounted below the top face.

The breaks in the timestamps of the LunaSats show where we power cycles that happened during our experiment. We found thermal and vacuum testing was successful both days during integration because we collected data from all LunaSats, we survived multiple thermal cycles so we became flight certified! We made a presentation on this and presented it to the GLEE team and NASA Colorado Space Grant's management team. We also did our own version of the Flight Readiness Review checklist.

The team worked hard at the Columbia Scientific Balloon Facility from July 23 to July 29th and got flight certified. We had a NASA article named "Student-Focused Scientific Balloon Mission Inspires Future Generation" written about us! Here is the link: https://www.nasa.gov/learning-resources/student-focused-scientific-balloon-mission-inspires-future-generation/ .

We will go more in depth about our flight results in the Science/ Technical Results section. For the flight we decided to monitor the data from Colorado this is because we could not stay at Fort Sumner New Mexico for the entire week and were unsure when the flight would take place. Based on our team member's schedule, we created a primary and secondary flight monitor for any given time in flight. The primary monitor viewed the downlink data and commands while the secondary monitor watched the video stream of the platform and observed the environmental data to make sure we were receiving correct current and power. The primary would write which LunaSats were working as well as flight conditions for every downlink data in flight. After the flight we started our analysis. We also did a presentation at Geological Society of America Connects 2023 on Wednesday October 18th on what we were completing with HASP as shown in Appendix II.

3.Problems Encountered

I. Structures

We found that welding was not a viable option at (Critical Design Review) CDR and had to come up with a different way to build the payload. We had some payload sizing issues while balancing the weight requirements, as well as issues positioning the raspberry pi in the payload. There were issues finding insulation within HASP requirements because of cost, however, we found some leftover Aerogel at the Colorado Space Grant so we used that. There were some issues on determining how much aluminum we were going to purchase, Specifically how much extra materials we should plan for. With the size of our electrical system being larger than expected, we increased the footprint of the payload from 10x10x20 cm to 13x13x25 cm.

II. Avionics

Before integration, we only had theoretical knowledge about the downlink and commanding abilities of the payload, but no real applications set in place. This became an issue when we were doing our practice TVAC and had to conduct the test by downlinking with wifi. We overcame this issue and found a way to downlink the data effectively through the DB9 port and were fortunate enough to receive an EDAC power cable from the HASP organizers to test the power systems of our payload. Prior to integration we had multiple buck converter failures, mostly due to incorrect wiring and too high of supplied voltage.. During the first day of integration, our real time clock broke and our LunaSats were failing unexpectedly at random times. We found that two LunaSats were running data on the same I2C line, causing LunaSats to override data from the previous LunaSat. So instead of 8 LunaSats per Raspberry Pi, we changed it to two LunaSats per Raspberry Pi. After hiring our new software team member, we found that we didn't have to add multiple Raspberry Pi's, but instead needed more USB ports. This meant we had to redesign our electrical system, create new schematics, and test to ensure we remained under the current limit of 0.5 A. At the beginning of the project we had issues with choosing a buck converter or linear regulator, but with HASP's advice and the same research of our own we chose the buck converter.

III. Management

One of our biggest issues was the loss of personnel after summer started as well as one of our subteam leads not engaging fully to the project during the summer. Our system engineer mainly took over until we gained new membership until we promoted new team members to subteam lead positions. When the summer started we had to hire new personnel and build our structure which was a tight squeeze. With losing our entire electrical side of the avionics subteam, it was difficult to maximize our electrical design, but we found a may to may the system work with our limit resources and experience.

4.Lessons Learned

Over the course of our project cycle, we learned valuable lessons that can be applied to future payloads and experiments. When looking back throughout this project there are multiple ideas for changes, including taking more photos during presentations, how we manufactured the structure, starting presentations earlier, payload manufacturing timeline, and improved data acquisition and analysis.

I. Structural

The structural subsystem was the most straightforward subsystem of our payload, with the largest time being spent on manufacturing the aluminum structure, attaching the LunaSats, and insulating the upper compartment. The design phase consisted of multiple CAD iterations and cardboard prototyping, while manufacturing spanned the summer months with payload assembly. The initial plan was to weld the structure together, but the combination of the lack of expertise and equipment, as well as past flight examples, suggested that bolt assembly would be more efficient. The payload's preliminary base footprint was 10x10 cm, but was later changed to 13x13 cm due to the electrical system's demand for space in the insulated compartment. This change was prompted by the addition of the raspberry pi USB hub hats, which took up significantly more space than just the raspberry pi zero.

The summer phase of the project was the busiest time for the structures subteam, with the manufacturing of the structure. Towards the end of the summer when it came time to integrate the subsystems together for a fully operational payload, there was a large emphasis placed on the structures subteam to collaborate with the avionics subteam for wiring management and electrical component spacing. Our team found that it was most effective to run the wires along the walls of the interior-insulated compartment of the payload so that there was more space for the USB-mini USB connectors, as well as the USB hub hat and raspberry pi zero.

During the design phase, the team thought that it would be possible to add a locking mechanism to the payload’s door so that the team could access the electrical components during testing and integration, while also designing for flight. There were multiple discussions on how to achieve this design, with the team eventually deciding on using a simplified bolt-and-nut interface between the door and interior structure.

With the project being completed, we gained valuable insight into payload manufacturing and the time it takes to design, manufacture, and test the full subsystem. In the future there will be a larger emphasis on subteam collaboration so that there are no surprises in design changes. This also requires the need for a longer and more detailed testing phase, which was accelerated due to delays in manufacturing. With our knowledge gained from this year's structure, we look to apply that knowledge to future flights when it comes to manufacturing and integration.

II. Electrical and Software

The avionics subteam, which consisted of the electrical and software subsystems, proved to be the most time consuming and demanding task in the entire payload. Our largest problems stemmed from PCB design and software personnel. At the start of the electrical design phase we planned on designing a PCB that would consist of most of our electrical components, such as out buck regulators, additional temperature sensor, and wiring junctions. With the lack of technical experience and the departure of our electrical team over the summer, we were unable to design and implement a PCB into our electrical system. That required us to seek other avenues for our electrical system such as through hole protoboards and breadboards. We experimented with protoboards over the summer, soldering our electrical components to the board and using the solder to “bridge” across the holes of the board to establish an electrical connection. We ran into issues with the protoboard, between the combination of the lack of knowledge and failed components, which led us to use a breadboard design all the way up to integration in Palestine, Texas.

After the testing of our full scale system at integration, we observed that our improvised design of a breadboard with temporary wire connections caused there to be a larger probability for testing failures, specifically with LunaSats not being powered. The LunaSats had power and ground lines that were connected to the breadboard and would occasionally “pop out” of the breadboards rails causing the power of the LunaSats to be interrupted. We also found that in extreme temperatures, the breadboard's rails could expand causing the electrical connection of the wire and the breadboard to be unsuccessful. With this observation, we removed the breadboard from our design and proceeded to run the electrical system through the buck converters, and the wires directly into each component. This change of design allowed us to solder the connections of our electrical system and prevent failures related to faulty electrical connections.

Before integration we tested our electrical systems with jumper wires, bypassing the EDAC power connection because we didn’t have an EDAC cable to power our payload with. At integration we were able to secure an EDAC connector/cable from the HASP organizers that aided us in testing the power system more realistically before flight. With this cable, we will be able to power future HASP payloads before integration to conduct more extensive power testing. In the future, we plan to ask for assistance early on if we have any gaps in knowledge so that we can make the best decisions possible for the electrical systems, even if our team isn’t comfortable with more advanced electronics.

III. Management and Personnel

Throughout the design phase of the project we found that we were having difficulties with work being completed across sub-teams, due to differing work hours and variability in schedules. To counteract this problem, we implemented weekly and daily action items so that team members and subteams overall knew what needed to get done and when so that the project would stay on track. These action items were determined by the subteam lead and then reviewed by the systems engineer so that the management team could monitor sub-team progress.

With the lack of crossover between subteams, outside of our general meeting time, we added an additional work time for our team which emphasized cross-team collaboration so that each subsystem could be seen by all team members. We also implemented cross training over the summer for our team members attending integration so that they would be able to deal with any technical issues that arose, regardless of whether or not they worked on that system.

Documentation across all subteams could be improved so that weekly and daily tasks are defined and clear so that there is a clear path in developing a fully operational payload. We found that adding an action item document, which laid out weekly and daily tasks for team members to be an effective strategy for optimizing work time. This not only made the subteam accomplish more per hour worked, but also helped other team members monitor what was happening across the entire project. We plan to decompose tasks and goals earlier on in the project cycle so that we can optimize our work hours and make more progress earlier on, leading to more time for testing and payload adjustments.

5. Science/ Technical Results

I. Final Payload Structure and Design

Each LunaSat contains a temperature sensor, thermopile, capacitive sensor, 3-axis accelerometer, and magnetometer. The primary purpose of the WhenBuffsFly payload was to determine whether the LunaSat spacecraft can function in a near-space environment. To this end, we ran the sensors in various configurations throughout the flight, recording data continuously, to verify their functionality and accuracy. In addition to the sensors, we evaluate the functionality of the LunaSat's RF systems by sending a temperature value from one LunaSat (transmitter) to another (receiver). In order to simplify the RF testing, we noted how many messages we sent and how many messages were received on the LunaSat. There were three control zones in which the

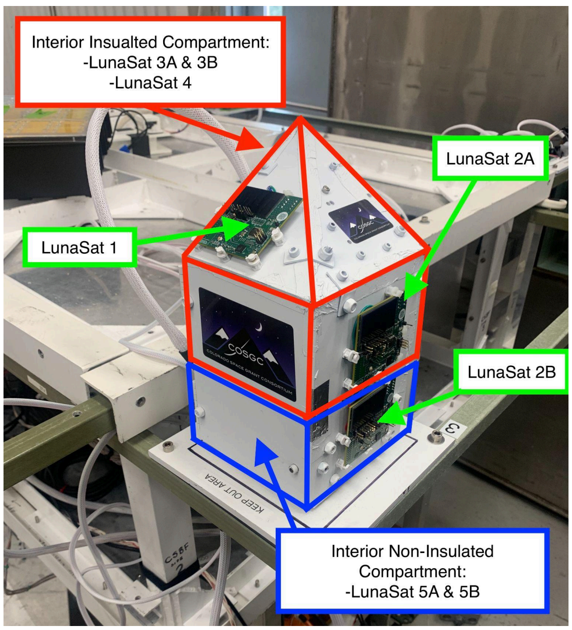


Figure 4: Final Payload Structure

LunaSats were located: an interior insulated compartment, an interior non-insulated compartment, and the exterior of the payload. Each of the LunaSat's locations is described in the image below. The goal of the three control zones was to test the LunaSat in three different temperature regions to see how it would affect their operability.

For our flight success criteria, we had success in every characteristic, with the temperature accuracy correlating to an exterior indicator (platform data), our testing duration reaching 6 hours, determined which temperatures caused failures, and achieved individual communication between LunaSats. For the duration of testing, we lost data from every LunaSat at variable times, which prevented us from reaching level 2 success. We believe that the loss of data from the LunaSats observed in flight were due to wiring issues with the PCB's signal integrity and not the temperature because the failures occurred at different temperature conditions. The operability characteristic of our flight had similar results, which we believe is also potentially caused by the PCB's signal integrity. (Note: the PCB is the physical structure that makes up the LunaSat board, which includes all of the components, and wiring path). Our temperature sensor (TMP117) trends correlated closely with the hanging ambient J5 temperature sensor on the HASP platform, giving us a level 2 success in that characteristic. We found that the RF capabilities of the version of LunaSat that we were flying had limited transmitting ability, restricting the science design to only account for individual communication between the LunaSats. The results from the radio frequency tests are described in the sections below.

II. Timestamp reading

The graphs in this section display the timestamp vs. time of the day to help visualize how long each LunaSat operated for before experiencing an unexpected failure. You'll notice that the data below looks like a series of lines, increasing linearly in the northeast direction. The longer the LunaSat runs for, the higher the value the timestamp will be. LunaSats that operated for a short period of time will have a shorter length than a LunaSat that operated for a long time. The vertical red lines indicate that a power cycle was run, which restarts all LunaSats at the same time, which is different than an unexpected failure, which looks like the line stopping without a red line at its head. LunaSat 1 has a different graph than the rest of the LunaSats because it was restarting every 3.5 seconds, causing the timestamp readings to look peculiar, as seen in Appendix A.

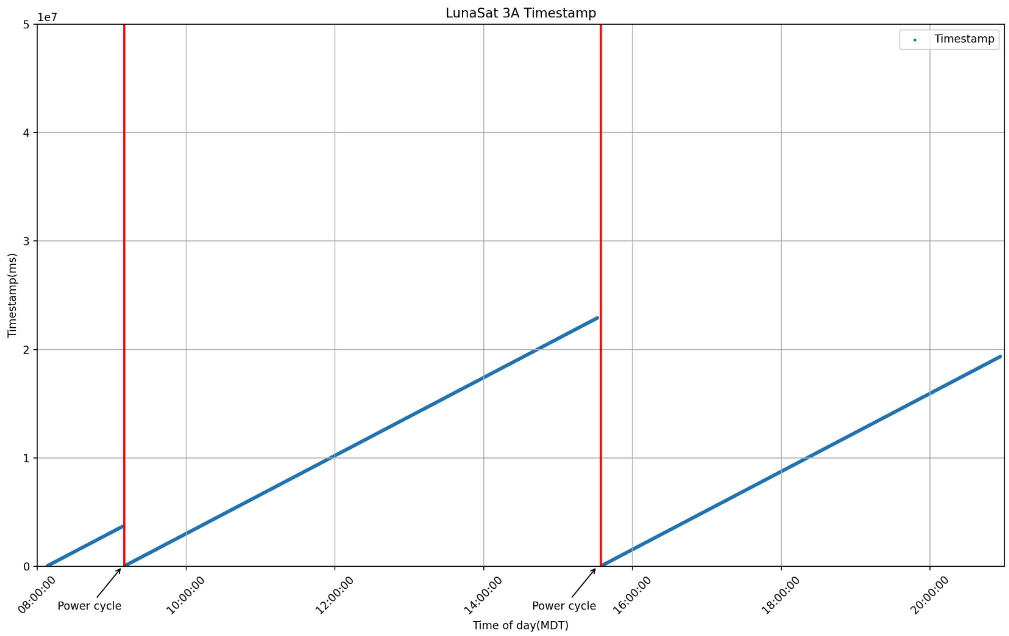


Figure 5: LunaSat 3A Timestamp Data

LunaSat 3A experienced the most consistent readings, with zero unexpected failures.

III. RF Message Reading Results

For the RF testing, each LunaSat in pairs 2, 3, and 5 had to be running for 2 hours prior to testing for the RF test to be successful. This delay was built into the code of our RF test so that we would clear all ground communications and reach float altitude before conducting any RF tests. This delay was tricky, because if we initiated a power cycle it would restart the code and start the 2 hour timer over again, making us wait 2 hours after each power cycle before RF tests began. If any of the LunaSats in each pair were to fail before the 2 hour mark, the RF test would not be successful, which can be seen with LunaSats 2A and 2B in Appendix A. The most successful RF transmission rate occurred between LunaSats 5A and 5B shown below.

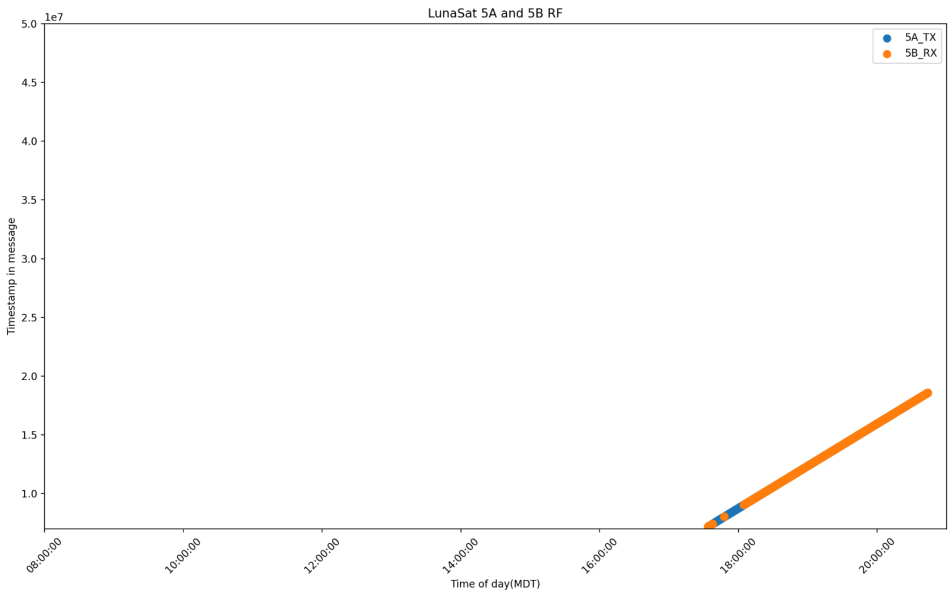


Figure 6: LunaSat 5A and 5B Radio Frequency Testing Results

LunaSat 5A successfully transmitted 5,700 messages after the second power cycle, 5B received 4,881 messages, which resulted in a 85.63% message completion rate.

IV. Temperature Reading Results

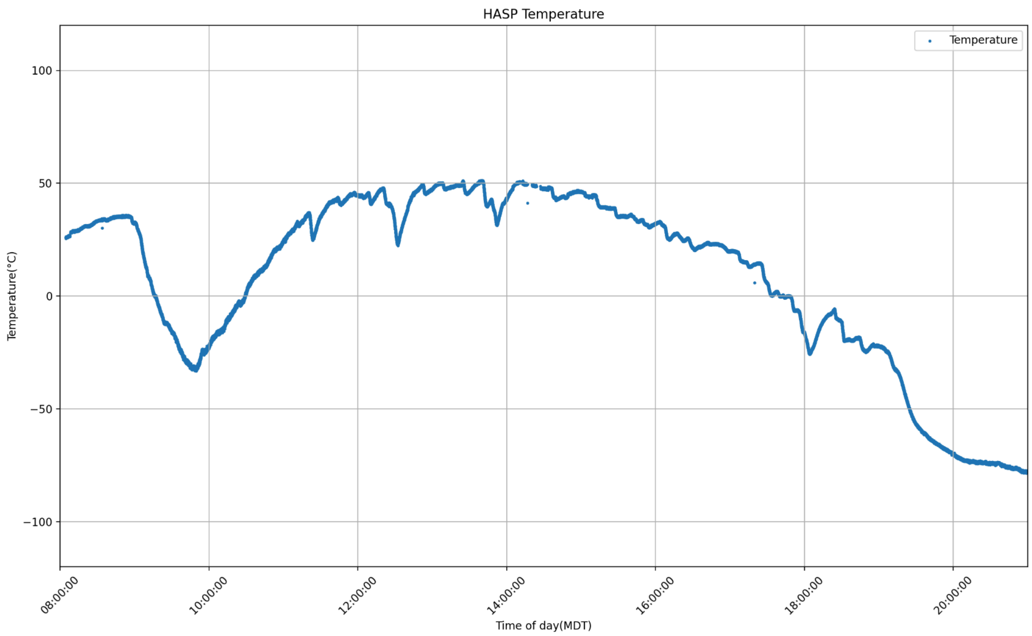


Figure 7: Temperature Data from the HASP Hanging Ambient J5 Sensor

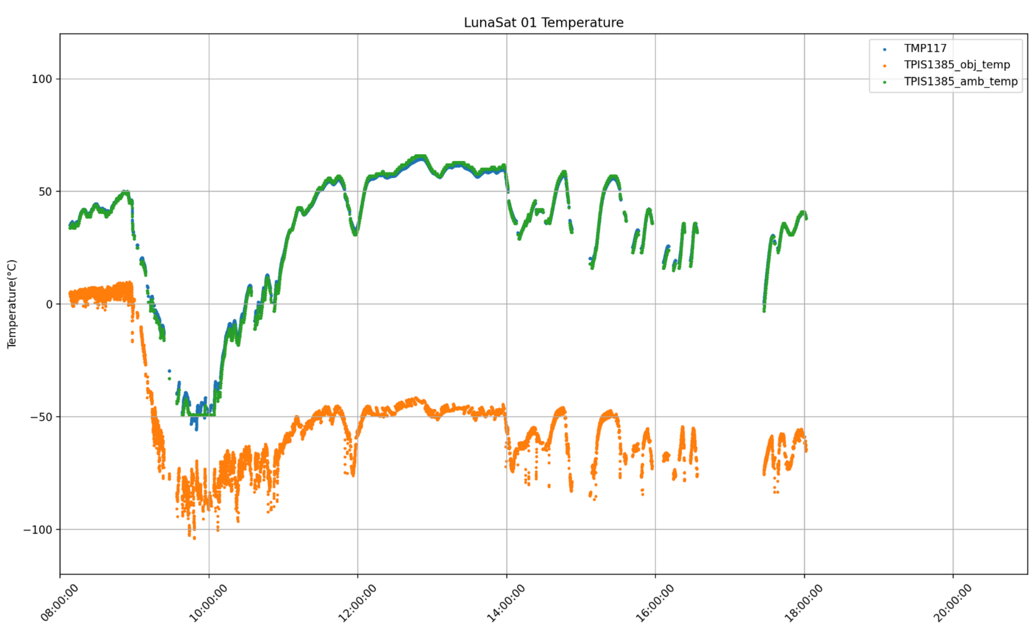


Figure 8: LunaSat 01 Temperature Data

LunaSat 01 experienced temperature data slightly higher than the HASP hanging ambient J5 sensor, likely due to the fact that we designed the payload's top face for LunaSat 1 to receive direct sunlight. With more direct sunlight, it makes sense that the temperature readings would be higher than that of the J5 sensor on the HASP platform.

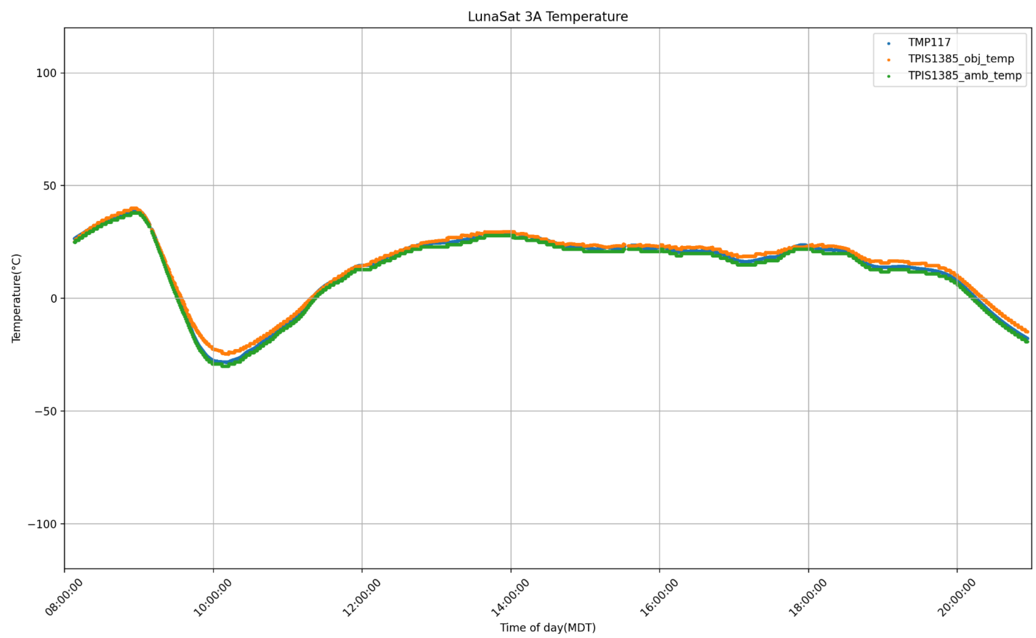


Figure 9: LunaSat 3A Temperature Data

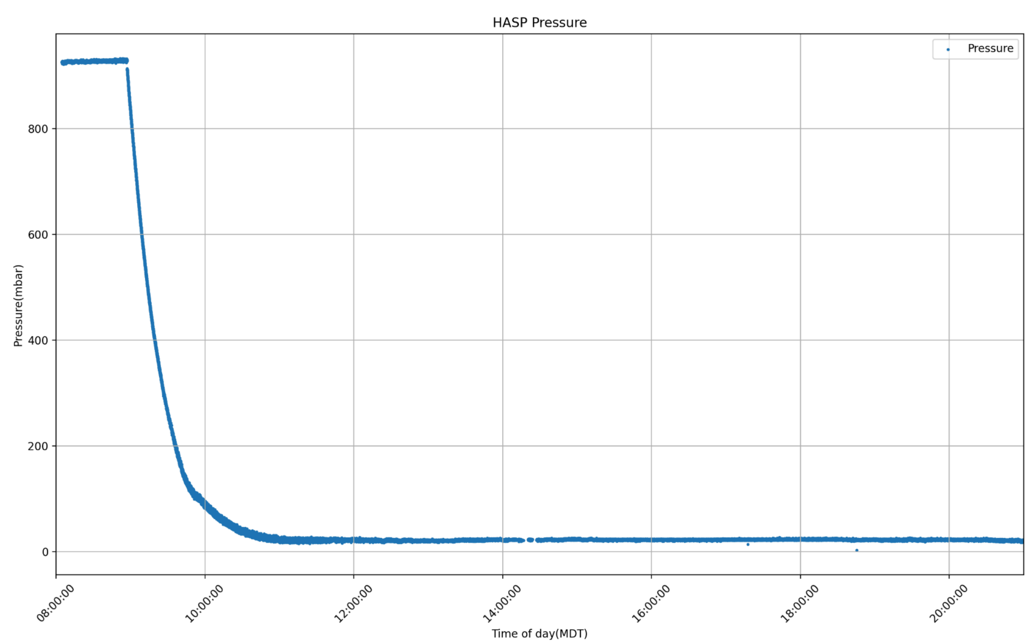


Figure 10: Pressure from the HASP Environmental Data Readings

With the failures of the LunaSats coming at both atmospheric pressure and vacuum, we concluded that the failures were not related to pressure changes sustained in flight.

Data collected from the other sensors onboard the LunaSat, including magnetometer, accelerometer, and capacitive sensors are included in the appendix at the end of this report. We excluded those values from the body of the report because those sensors have since been replaced on the current version of the LunaSat, and we only ran those sensors from an operability standpoint, not accuracy.

6.Conclusions

Our conclusions for this project are that thermal and vacuum testing was successful for both tests. We collected data from all LunaSats. We have conducted our flight data analysis, but when we were monitoring the data, we found that most of our LunaSats were working as expected. We also gained RF data during our thermal and vacuum testing.

Since we utilized the HASP platform, we could do a system test in a near-space environment; because we find this to be a beneficial test, we are creating another payload for another test on the HASP platform!

After collecting the data that we obtained from flight, we determined that our science design was completely successful, with each of our mission objectives being met. Sensors onboard the LunaSats ran for over 6 hours total, RF communication was successful between LunaSats, the LunaSat survived temperature changes sustained in flight, and the temperature sensor of the LunaSat coincided with that data from the HASP environmental readings.

Aside from all of the mission objectives being met, we gained a better understanding of how the LunaSats operate in near space conditions. With the successful tests of our flight, we were able to raise the technology readiness level of the LunaSats to level 6 (system prototype demonstration in a space environment). This was a huge accomplishment for the GLEE mission, which will have impacts on future technology development and access to funding.

While looking at the data from the LunaSats, we not only wanted to display which aspects of the flight were successful, but also identify why other aspects of the flight failed. Based on our data, we were not able to make a conclusion on the operation of the LunSats based on temperature and pressure, but we hypothesize that failures of the LunaSats in flight were due to multiple factors such as incorrect impedance matching of the RF antenna, messy wiring of the LunaSats, specifically the lack of a continuous ground plane on the PCB, and inaccurate sensors. The incorrect impedance matching of the antenna is most likely the reason why we were seeing such low sent-to-received RF data messages, which will be changed in the next version of the LunaSat. The lack of a continuous ground plane, as well as the overall poor signal integrity of the LunaSat's circuit, is what we believe caused the failures of the LunaSat. The failures were not related to temperature or pressure differences because the failures occurred at variable conditions, that is, not at minimum or maximum value of pressures or temperatures. As the circuit runs, there are reflections in the current that "bounce" back in the opposite direction of the current flow. With poor signal integrity, these reflections can build up over time, causing a failure in the traces of the PCB. We hypothesize that the failures observed in flight were due to the build up of reflections, which can explain why the power cycles turned the LunaSats back on after purging the circuit and restarting the current flow, and therefore the reflections. In the next version of the LunaSat, there will be a completely required PCB with the addition of a continuous ground plane.

There have been many updates since the LunaSat that we flew, including a new magnetometer, capacitive sensor, and RF antenna, improved PCB wiring, and onboard memory storage through an EEPROM. These new components were selected to improve the operation of the LunaSats, especially with the concerns from above, and we plan to test the new version of the LunaSats on the next HASP platform.

8. Appendix I

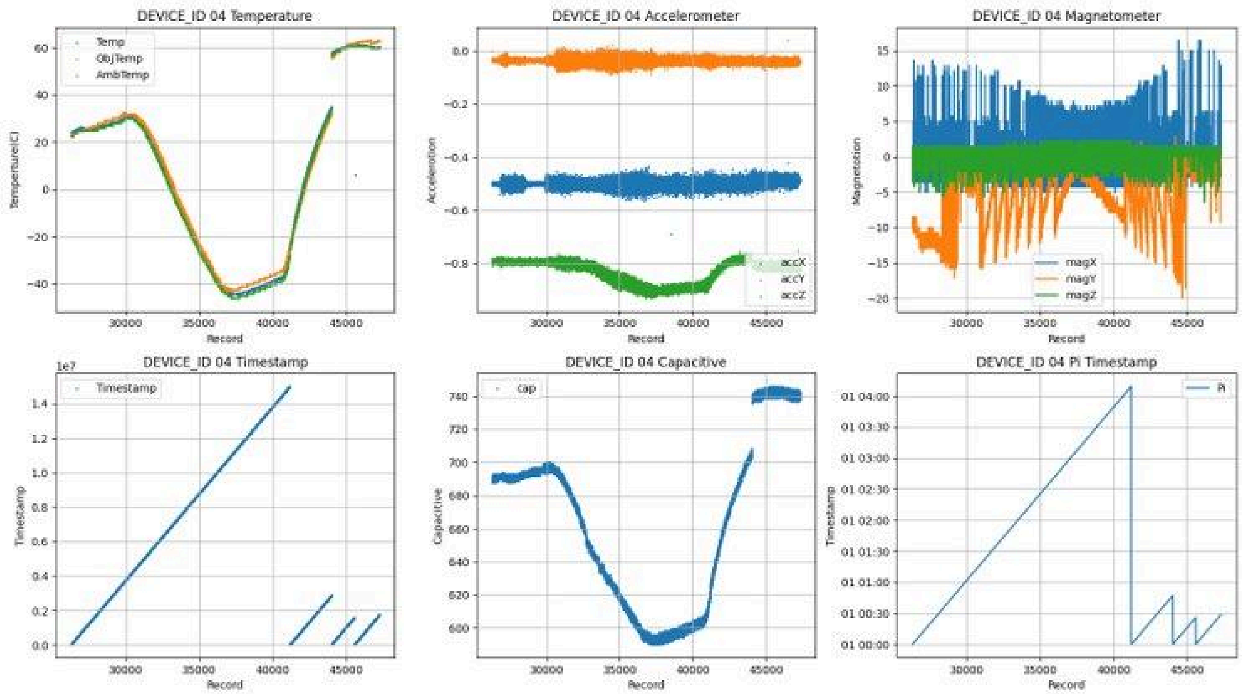


Figure 11: (Results from LunaSat 4 from each sensor from Friday's integration test)

Team Organization, Roles, and Demographics

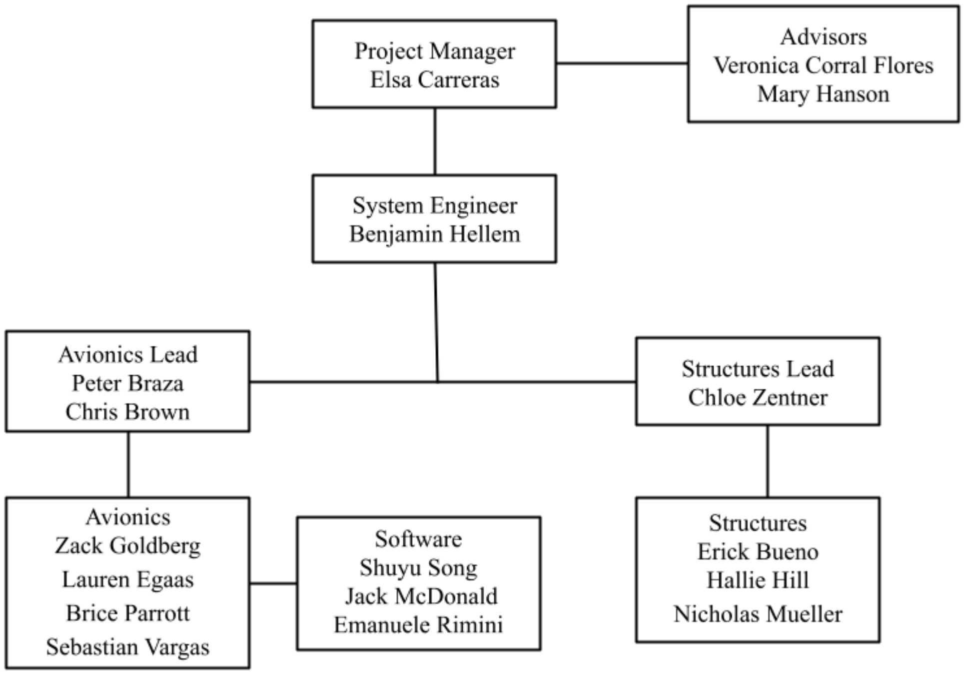


Figure 12: Team Organization

Figure 31 shows our team organization and roles throughout the whole project. We had multiple changes without the projects with people pursuing new adventures and changes in subteam leads.

Table 2 reflects all team members that participated throughout the course of the project, from Sept. 2022 to Dec. 2023 and their join date as well as their roles, student status, race, ethnicity, and gender.

Table 1: Payload Success Criteria

LunaSat Subsystem	Characteristic	Level 1	Level 2
Sensors	Duration of tests	Obtain 6 hours of data	Obtain data throughout flight (4 pairs)
	Operability	Determine which temperature causes sensors to fail	Non-Solar powered LunaSats will run the entire flight
	Temperature accuracy	Determine level of accuracy	Sensor temperature correlates to exterior indicator
Radio Frequency (RF)	Form of communication	Individual communication	Array communication

I. Additional Timestamp Data

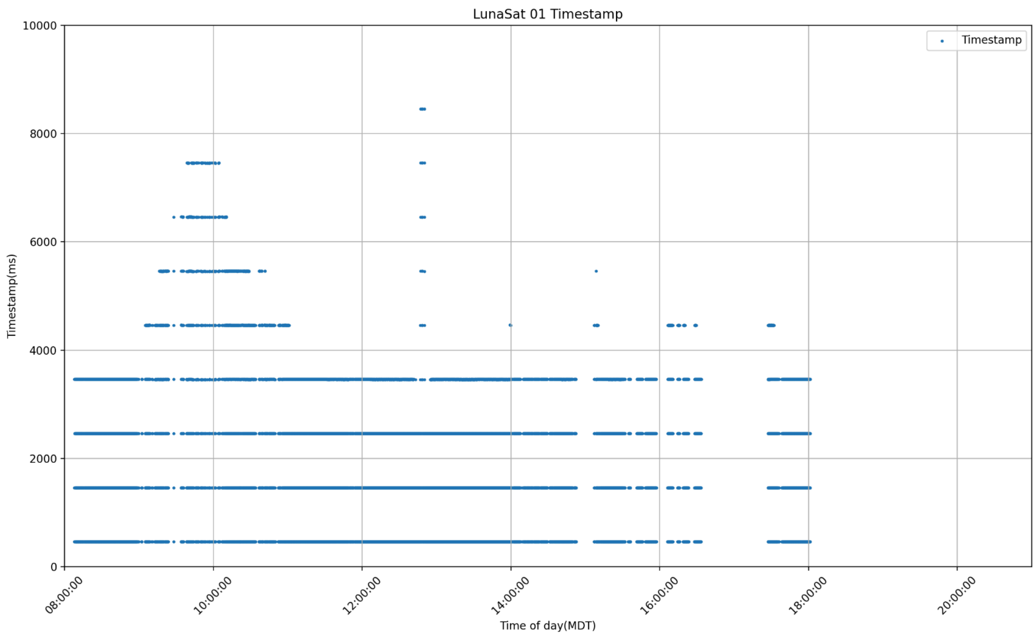


Figure 13: LunaSat 01 Timestamp Data

LunaSat 01 restarts approximately every 3.5 seconds, with the longest duration being 8.4 seconds. With the LunaSat restarting every 3.5 seconds, the graph looks much different from the other timestamps, as the other LunaSats didn't experience the same frequency of restarts. Also, it’s important to note that this LunaSat was running off of solar power, which is why it stopped working later on in the flight when the sun wasn’t visible.

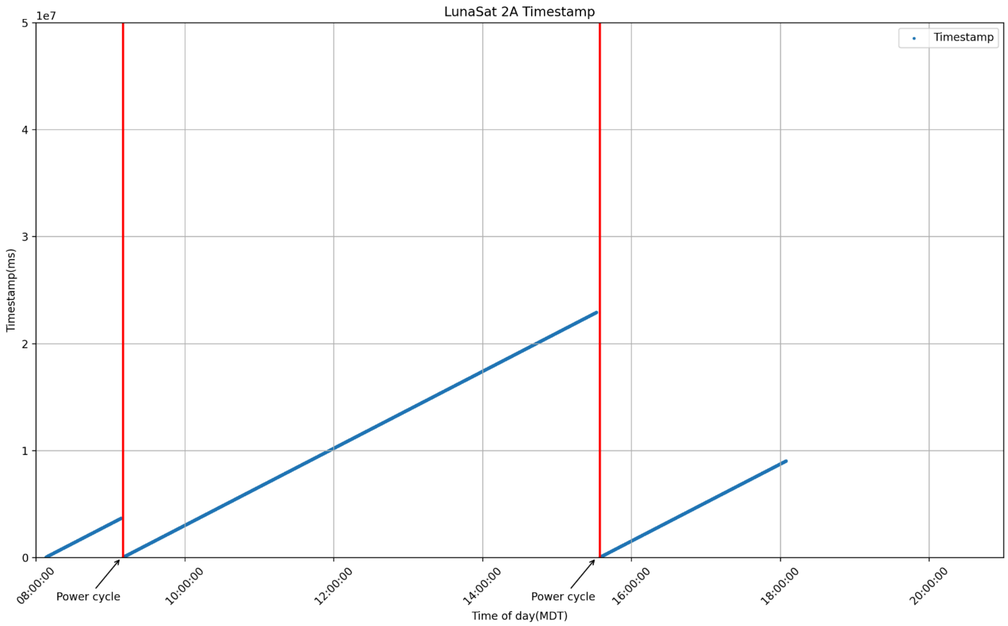


Figure 14: LunaSat 2A Timestamp Data

LunaSat 2A from the beginning of flight until 18:04:28, when it failed to read. This LunaSat only experienced 1 unexpected failure, towards the end of flight, with the other timestamp resets occurring from our initiated time cycles.

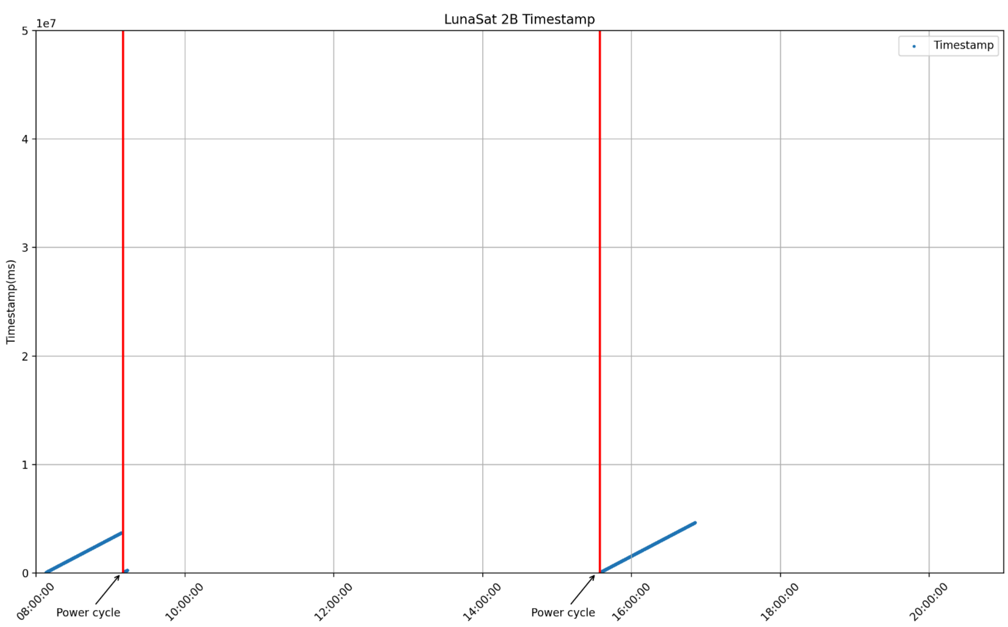


Figure 15: LunaSat 2B Timestamp Data

LunaSat 2B experienced a long period of lost readings , with 2 unexpected failures shortly after 9:00 and 17:00 MDT. The largest period of lost reading lasted about 7 hours between 9:00-16:00 MDT.

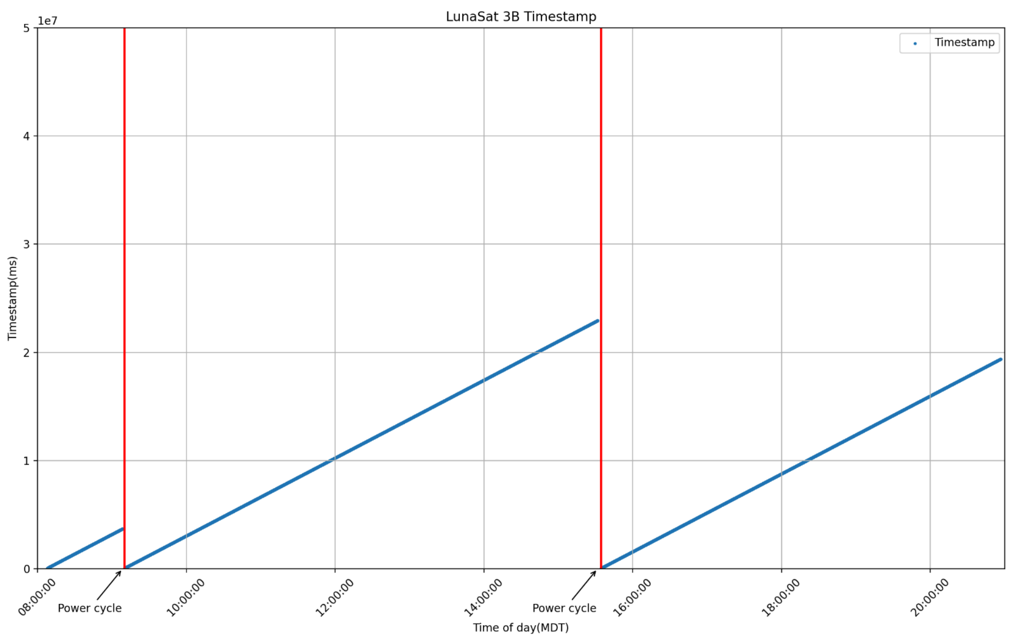


Figure 16: LunaSat 3B Timestamp Data

Similar to LunaSat 3A, 3B had zero unexpected failures.

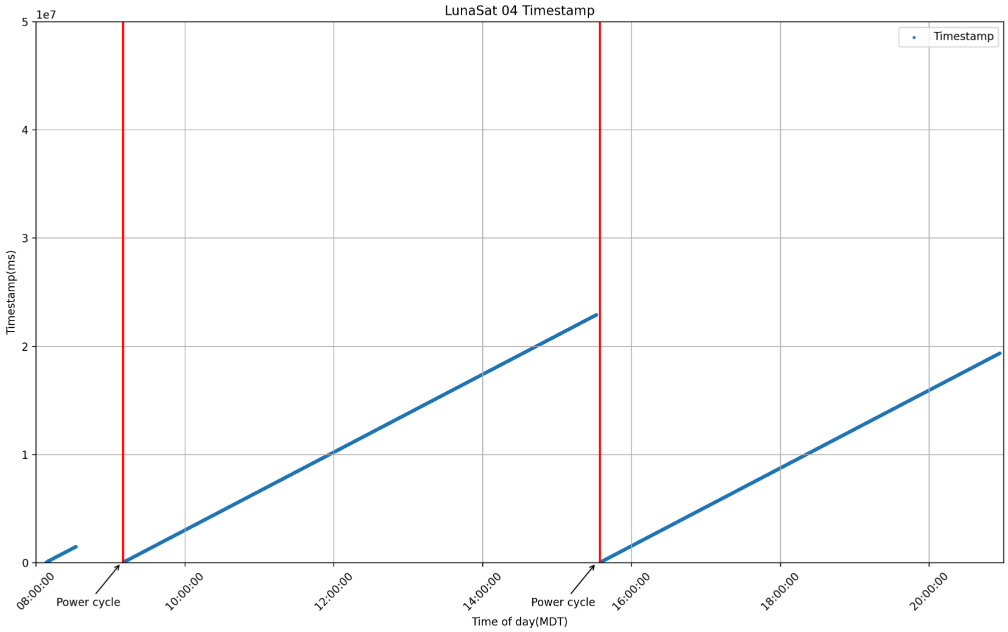


Figure 17: LunaSat 04 Timestamp Data

LunaSat 04 experienced a short period of time lost reading before the first power cycle after launch. 08:50 lost reading, 08:53 requested power cycle.

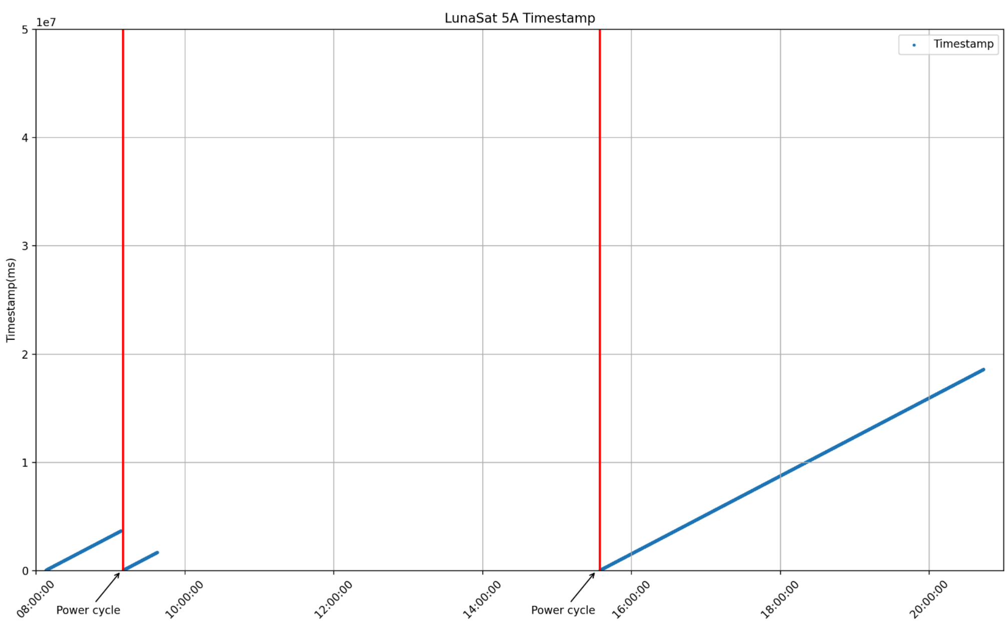


Figure 18: LunaSat 5A Timestamp Data

LunaSat 5A experienced a long period of time lost reading after the first power cycle, but was recovered after the second power cycle.

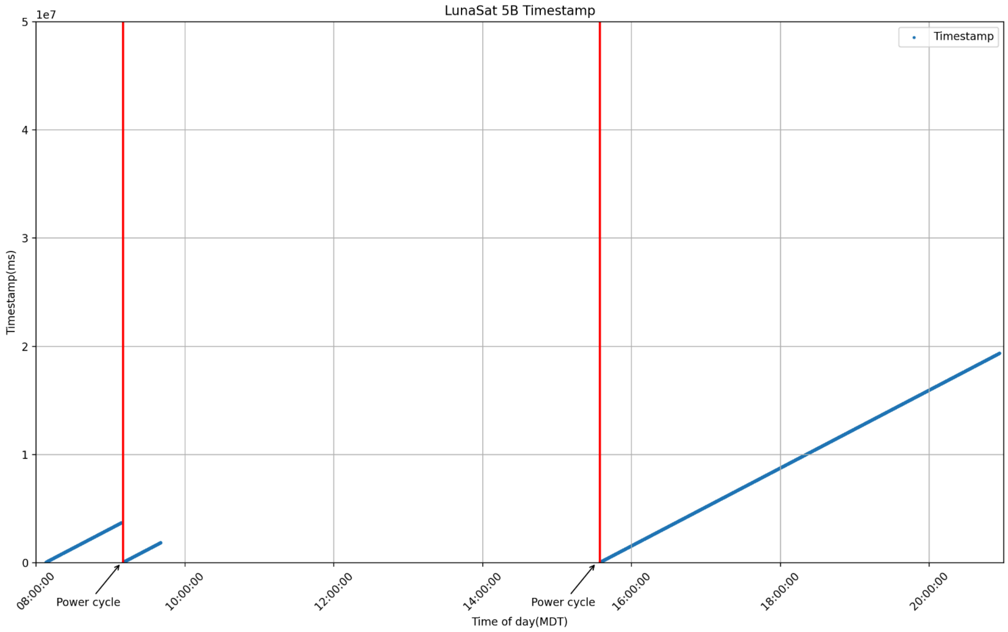


Figure 19: LunaSat 5B Timestamp Data

LunaSat 5B experienced a long period of lost data after the first power cycle, and was recovered after the second power cycle.

II. Additional RF Message Reading Data

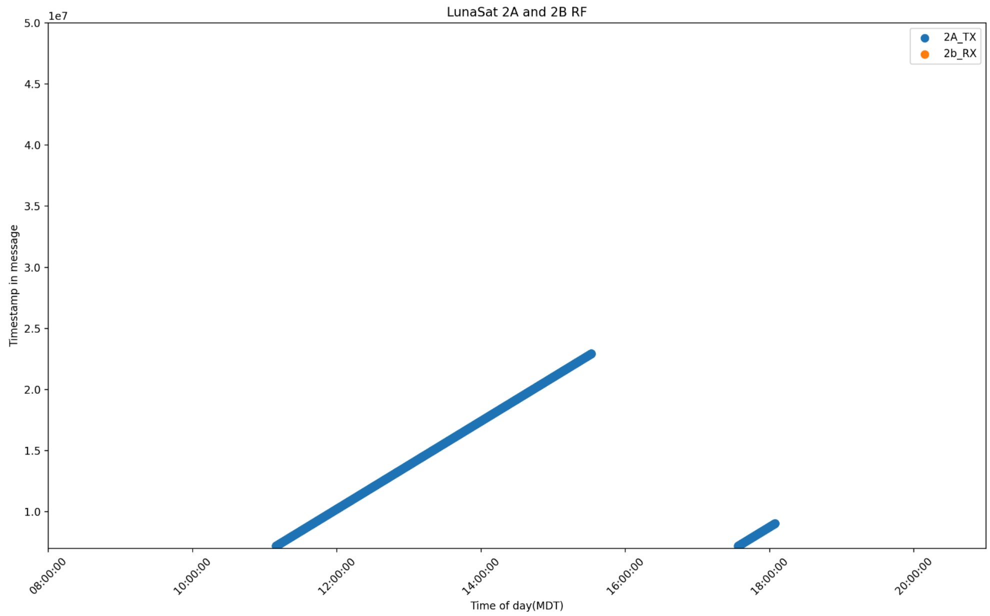


Figure 20: LunaSat 2A and 2B Radio Frequency Testing Results

LunaSat 2B was not able to run for more than 2 hours, so only 2A was transmitting, which resulted in LunaSat 2B receiving no data.

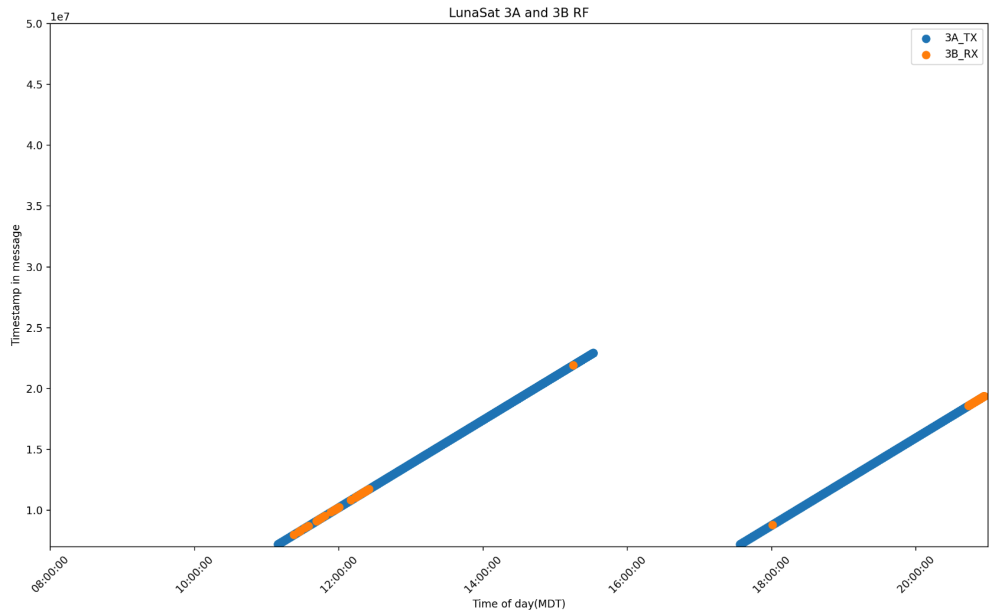


Figure 21: LunaSat 3A and 3B Radio Frequency Testing Results

LunaSat 3A successfully transmitted 13953 messages, 3B received 486 messages, which resulted in a 3.48% message completion rate. The low message completion rate could be attributed to the number of electrical components surrounding the LunaSats in the interior compartment, which could interfere with RF data transmission.

III. Additional Temperature Data

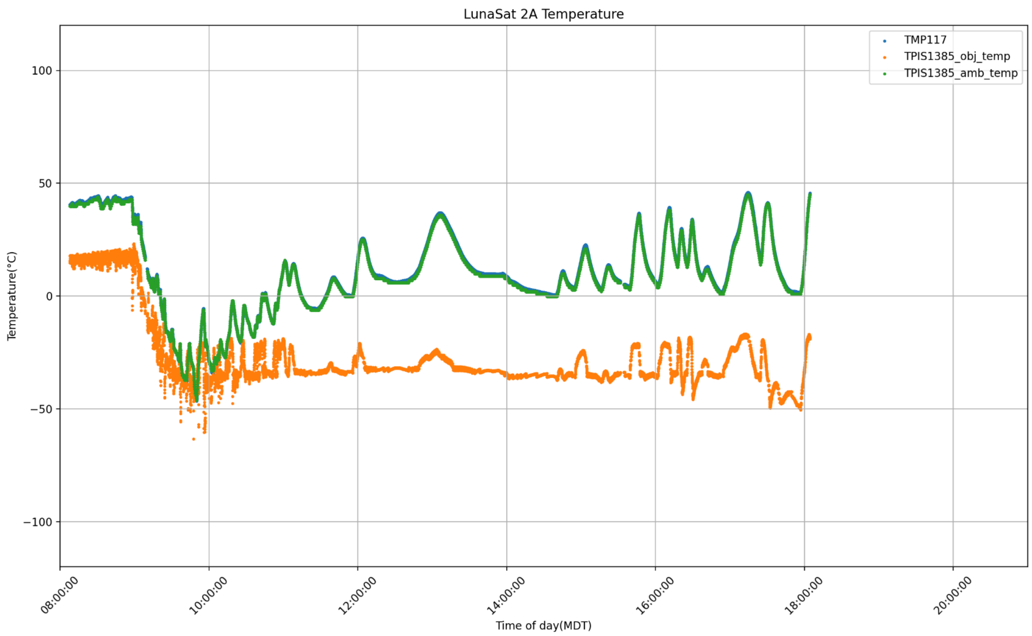


Figure 22: LunaSat 2A Temperature Data

LunaSat 2A experiences temperatures lower than that of LunaSat 01 because LunaSat 2A was located on the side of the payload, receiving less direct sunlight.

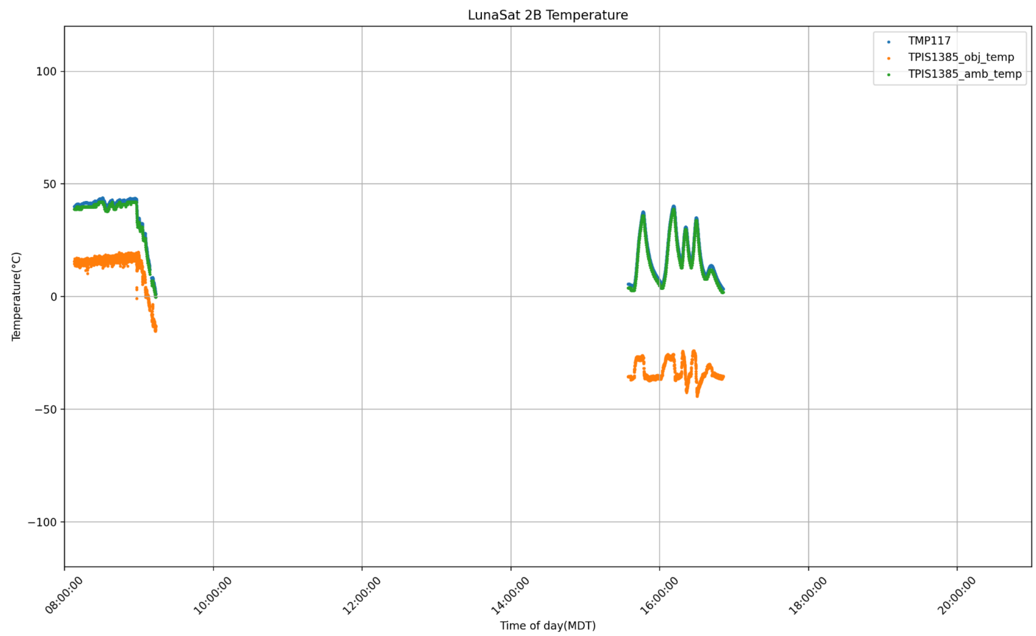


Figure 23: LunaSat 2B Temperature Data

The temperature data for LunaSat 2B frequently experienced reading losses, which correlate to the timestamp graph shown in Figure 11. Similar to LunaSat 2A, the temperature readings were lower than that of LunaSat 01 because it received less direct sunlight.

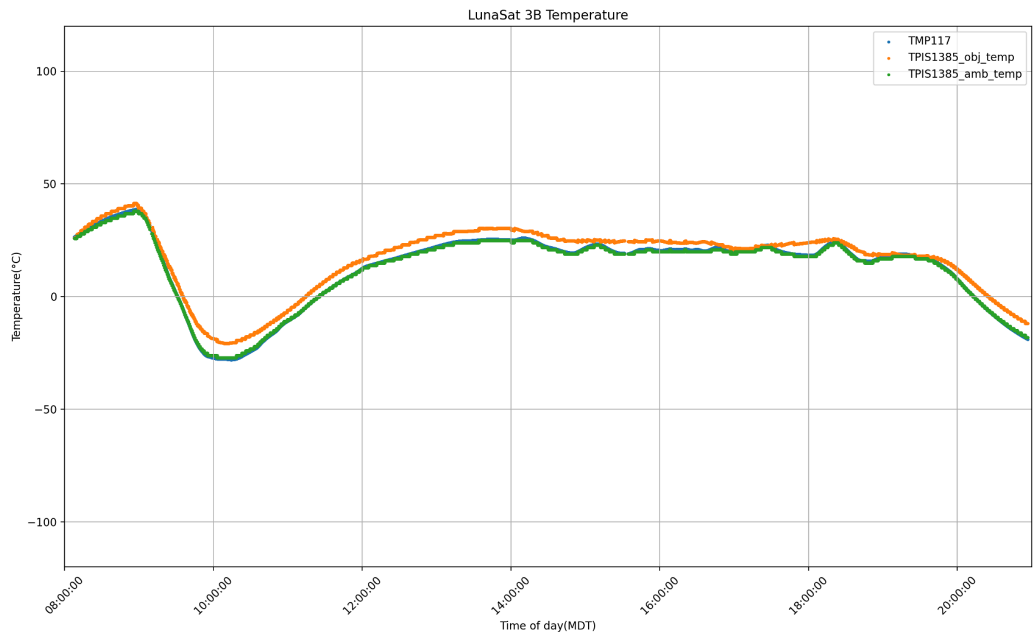


Figure 24: LunaSat 3B Temperature Data

LunaSat 3A and 3B experienced temperatures that were more constant than that of the previous LunaSats because the devices were located in the interior compartment of the payload, which wasn't exposed to such extreme temperature fluctuations.

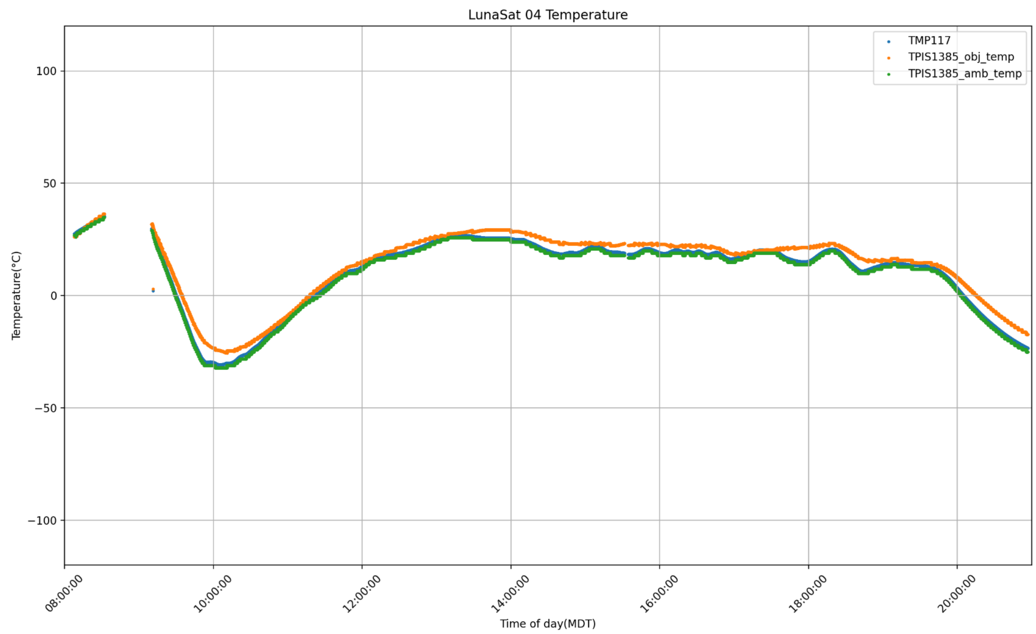


Figure 25: LunaSat 04 Temperature Data

LunaSat 04 was located in the insulated compartment with LunaSats 3A and 3B, yielding similar results. The only difference was that LunaSat 4 lost readings for a brief period of time at the beginning of flight, during maximum temperatures.

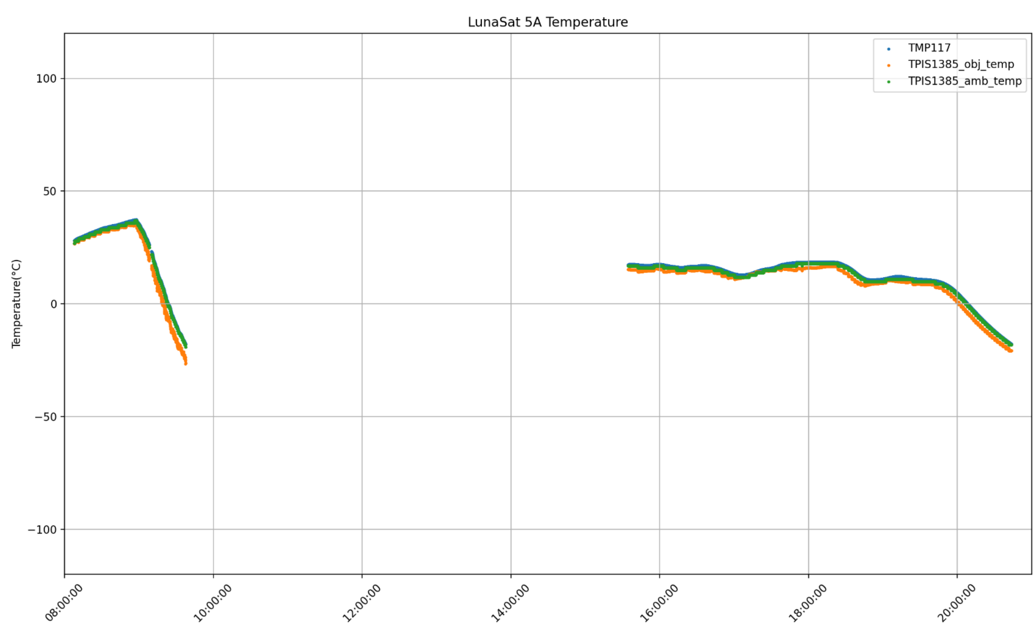


Figure 26: LunaSat 5A Temperature Data

After the first power cycle, LunaSat 5A lost readings, but turned back on after the second power cycle. For the readings that were reported, the temperatures corresponded to those of the interior compartment. LunaSat 5B experienced similar results as shown in Figure 29.

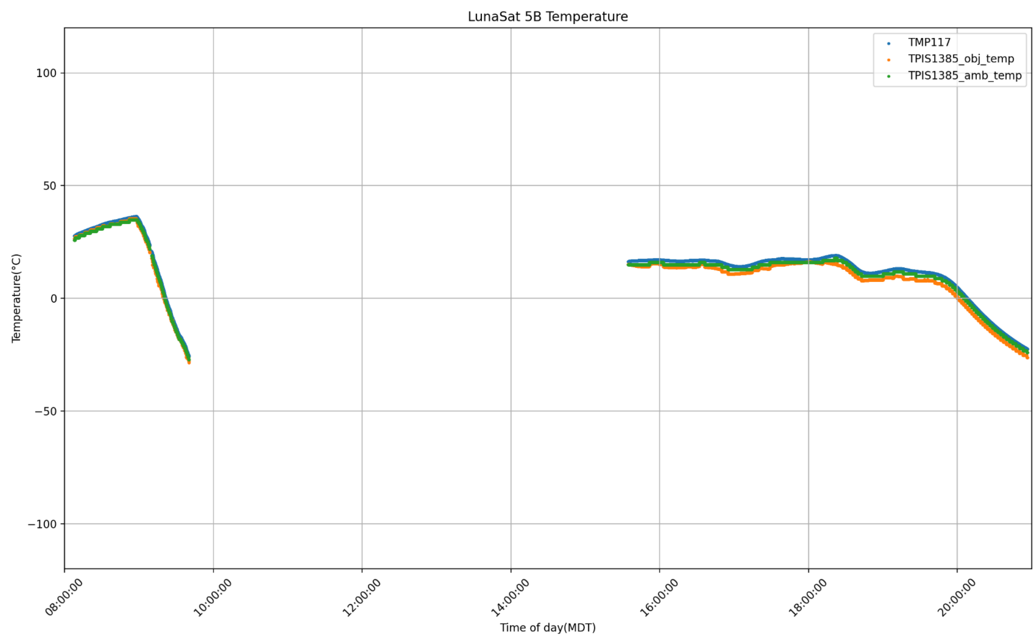
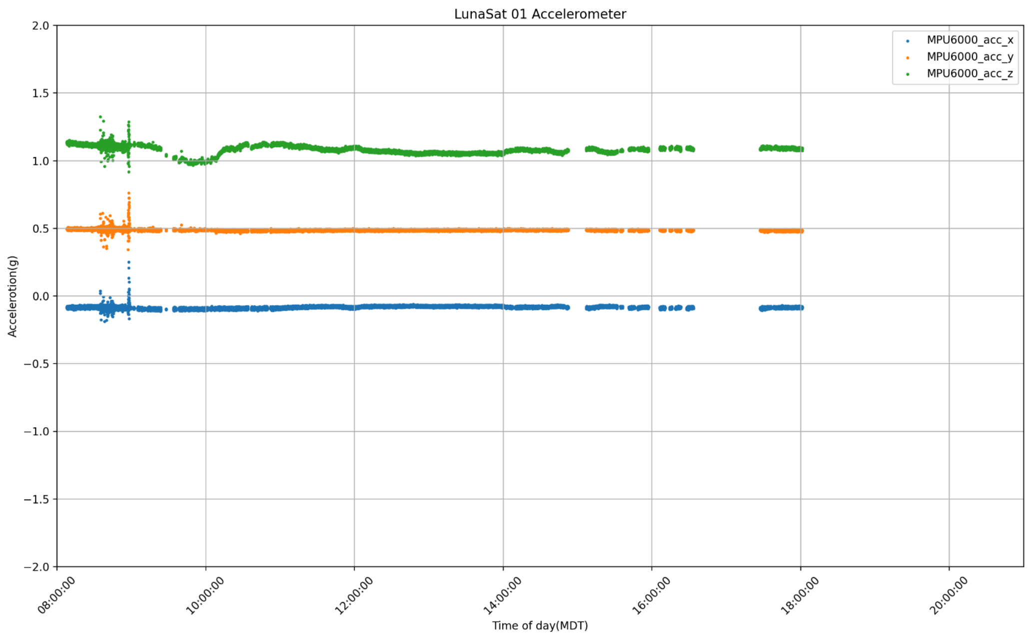
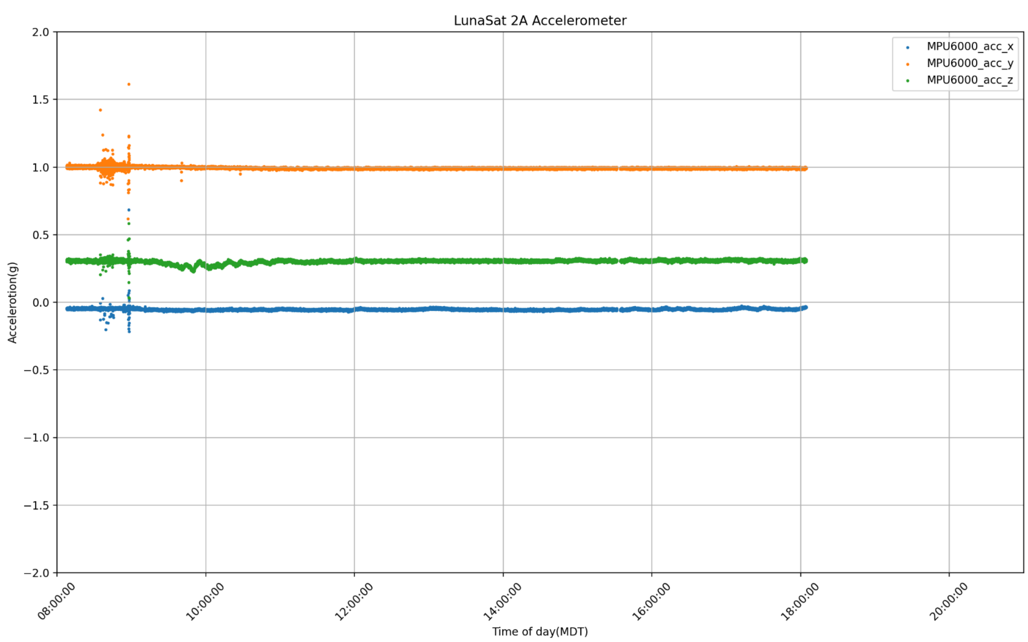
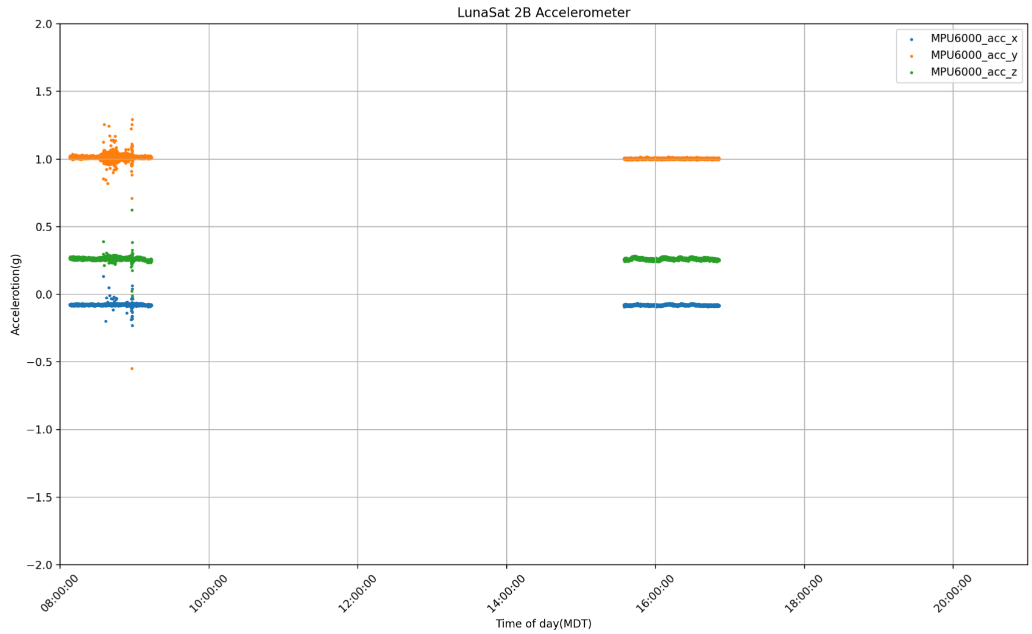


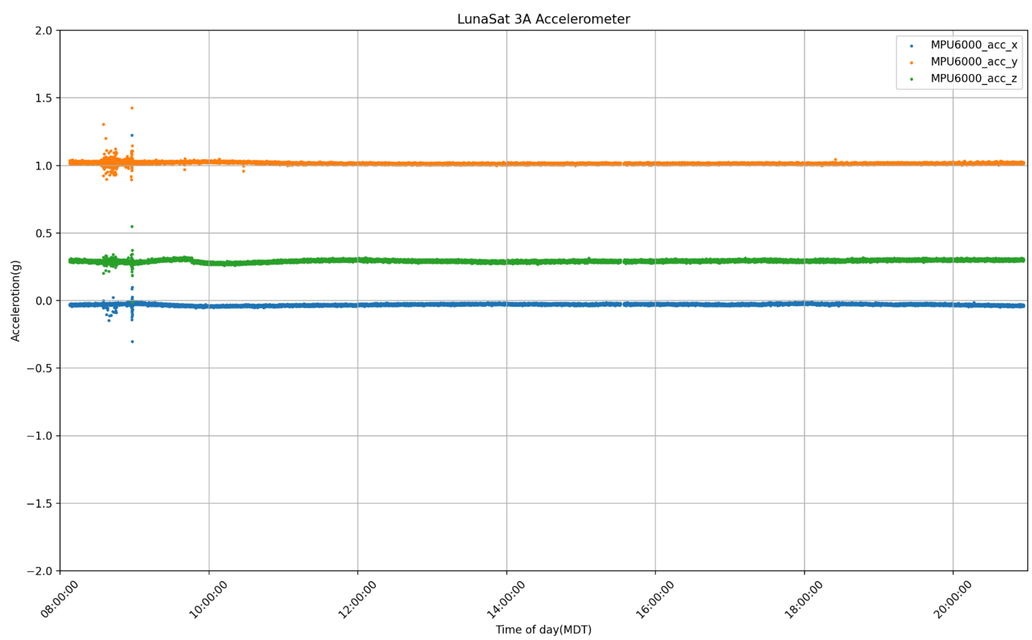
Figure 27: LunaSat 5B Temperature Data

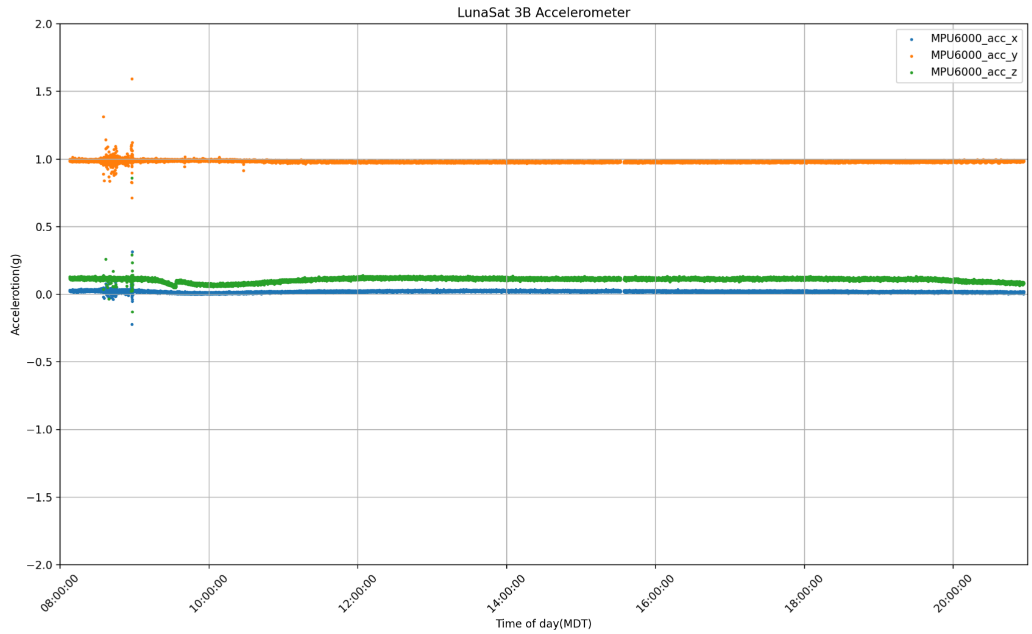
IV. Accelerometer readings

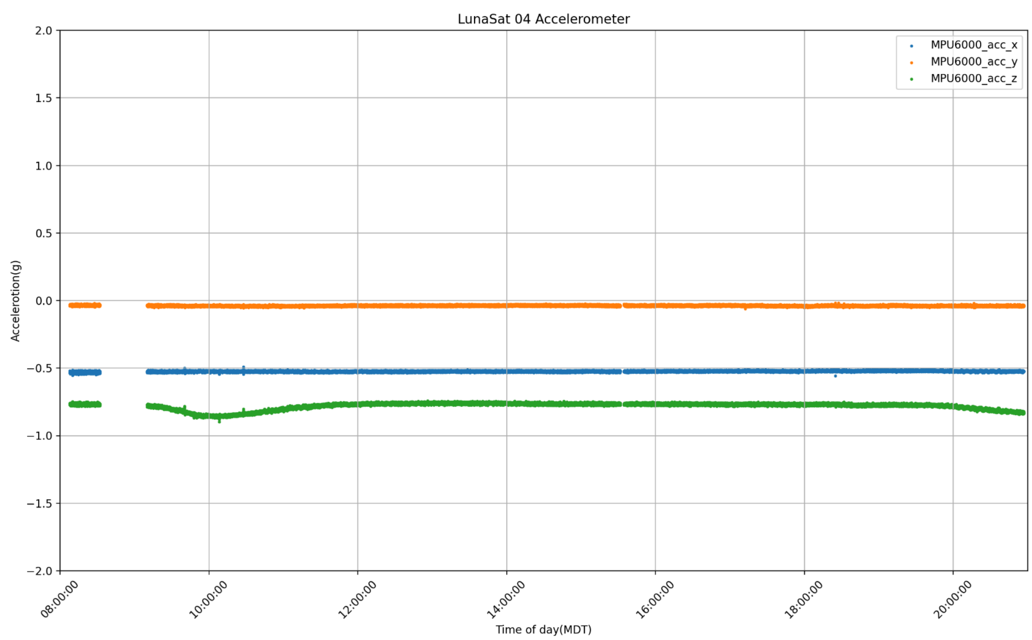


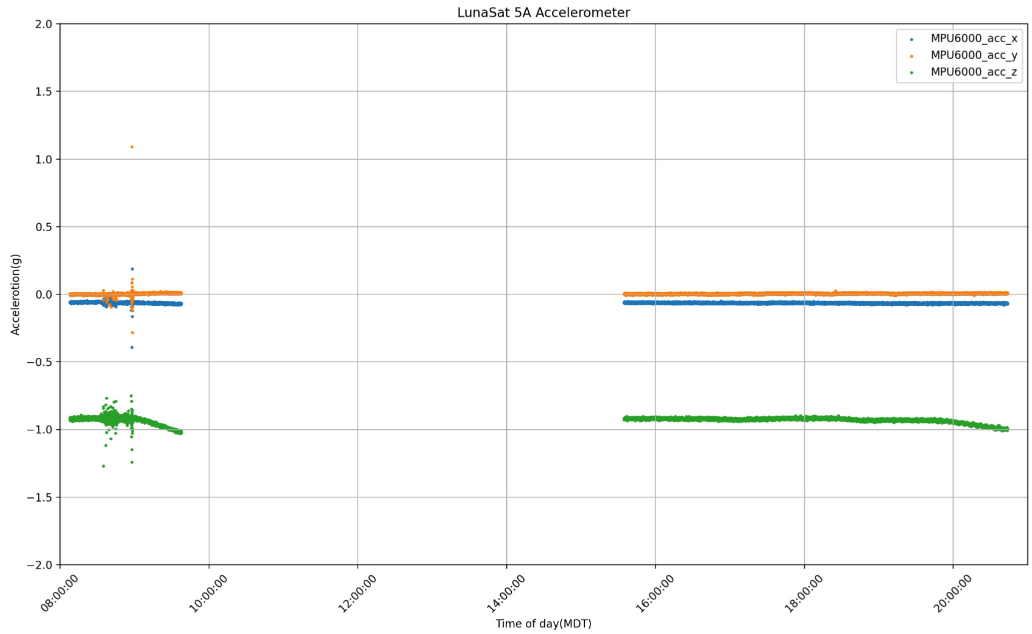


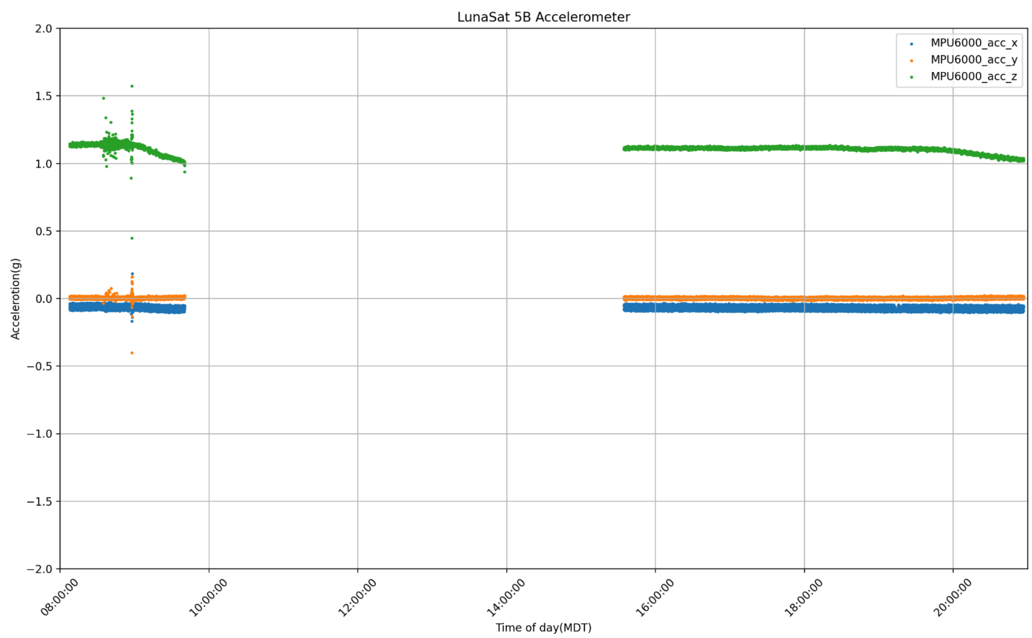

LunaSat 2B Accelerometer
MPU6000_acc_x
MPU6000_acc_y
MPU6000_acc_z
Accelerotion(g)
Time of day(MDT)
2.0
1.5
1.0
0.5
0.0
−0.5
−1.0
−1.5
−2.0
08:00:00
10:00:00
12:00:00
14:00:00
16:00:00
18:00:00
20:00:00


LunaSat 3A Accelerometer
MPU6000_acc_x
MPU6000_acc_y
MPU6000_acc_z
Accelerotion(g)
Time of day(MDT)
2.0
1.5
1.0
0.5
0.0
−0.5
−1.0
−1.5
−2.0
08:00:00
10:00:00
12:00:00
14:00:00
16:00:00
18:00:00
20:00:00

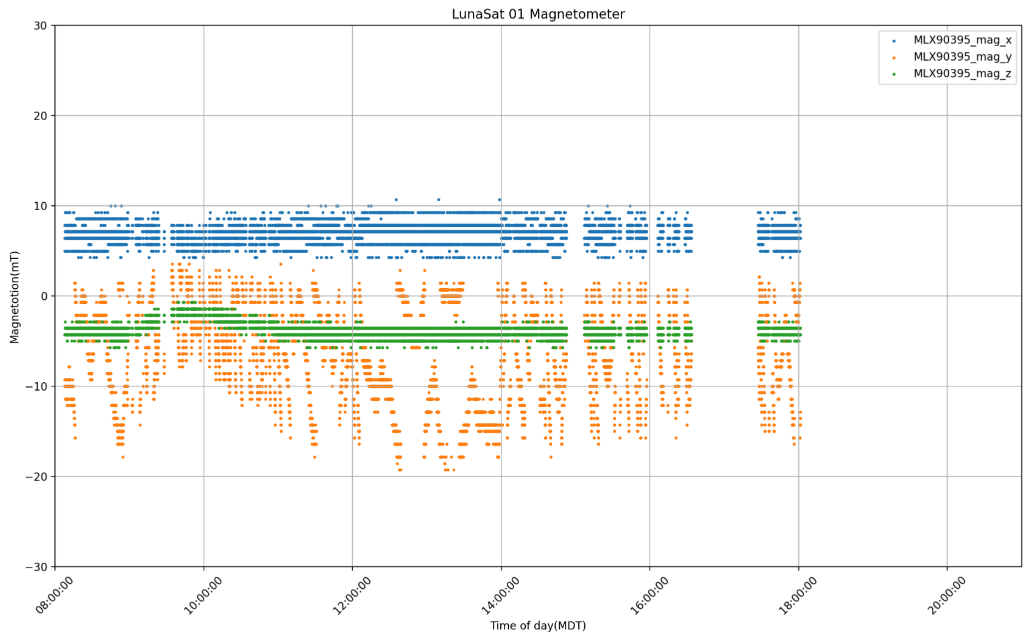

LunaSat 3B Accelerometer
MPU6000_acc_x
MPU6000_acc_y
MPU6000_acc_z
Accelerotion(g)
Time of day(MDT)

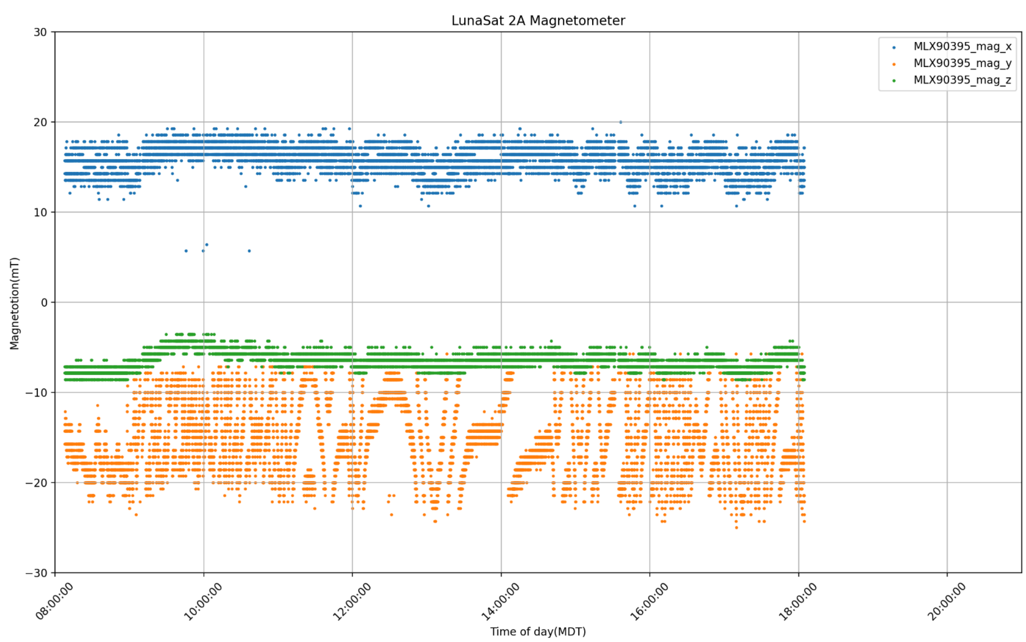

LunaSat 04 Accelerometer
MPU6000_acc_x
MPU6000_acc_y
MPU6000_acc_z
Accelerotion(g)
Time of day(MDT)

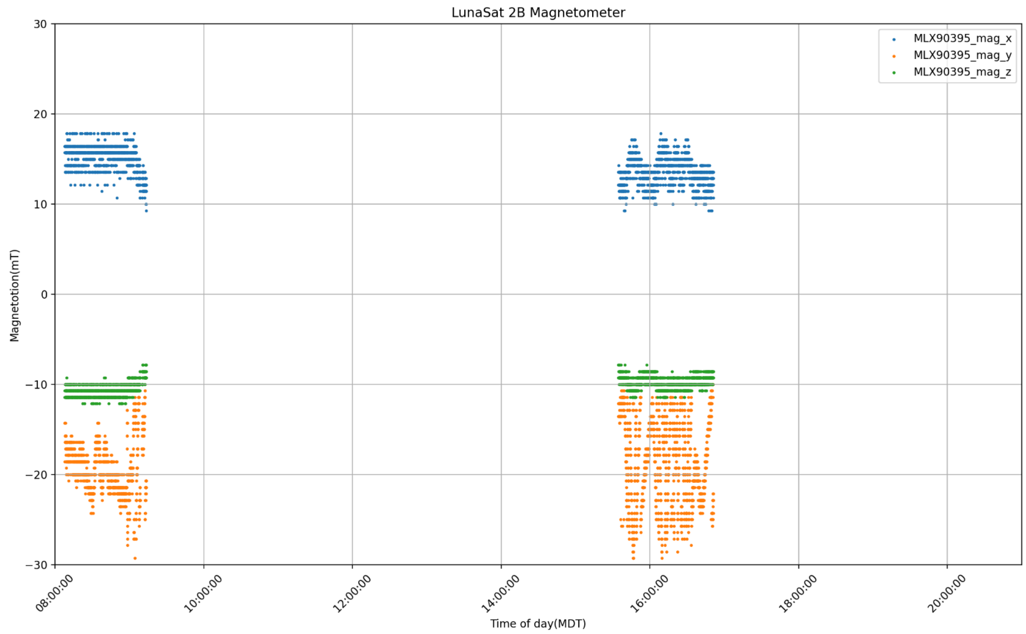

LunaSat 5A Accelerometer
MPU6000_acc_x
MPU6000_acc_y
MPU6000_acc_z
Accelerotion(g)
Time of day(MDT)
2.0
1.5
1.0
0.5
0.0
−0.5
−1.0
−1.5
−2.0
08:00:00
10:00:00
12:00:00
14:00:00
16:00:00
18:00:00
20:00:00

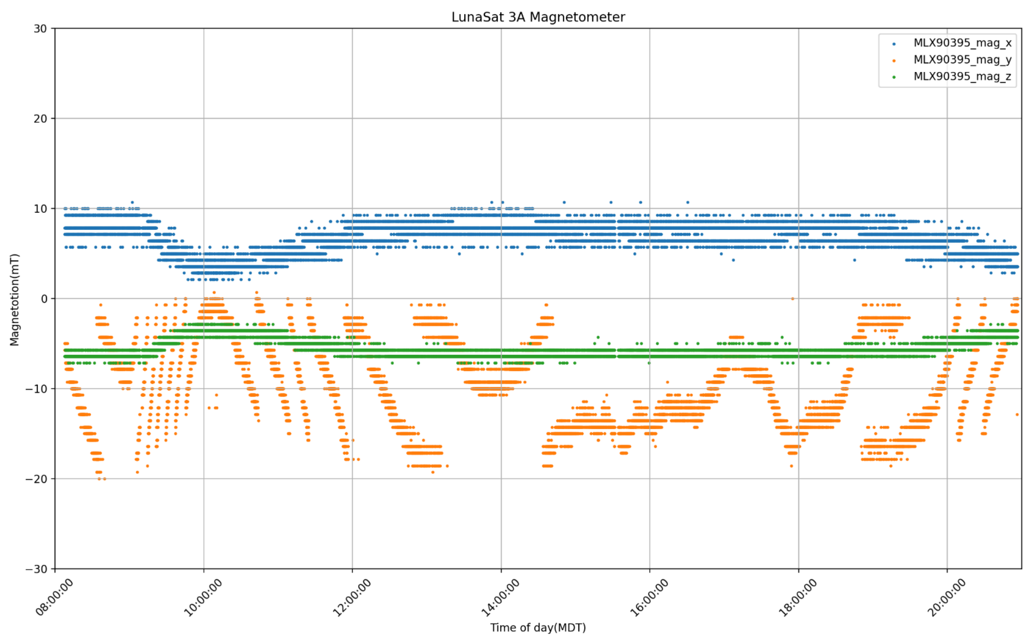

LunaSat 5B Accelerometer
MPU6000_acc_x
MPU6000_acc_y
MPU6000_acc_z
Accelerotion(g)
Time of day(MDT)
2.0
1.5
1.0
0.5
0.0
−0.5
−1.0
−1.5
−2.0
08:00:00
10:00:00
12:00:00
14:00:00
16:00:00
18:00:00
20:00:00

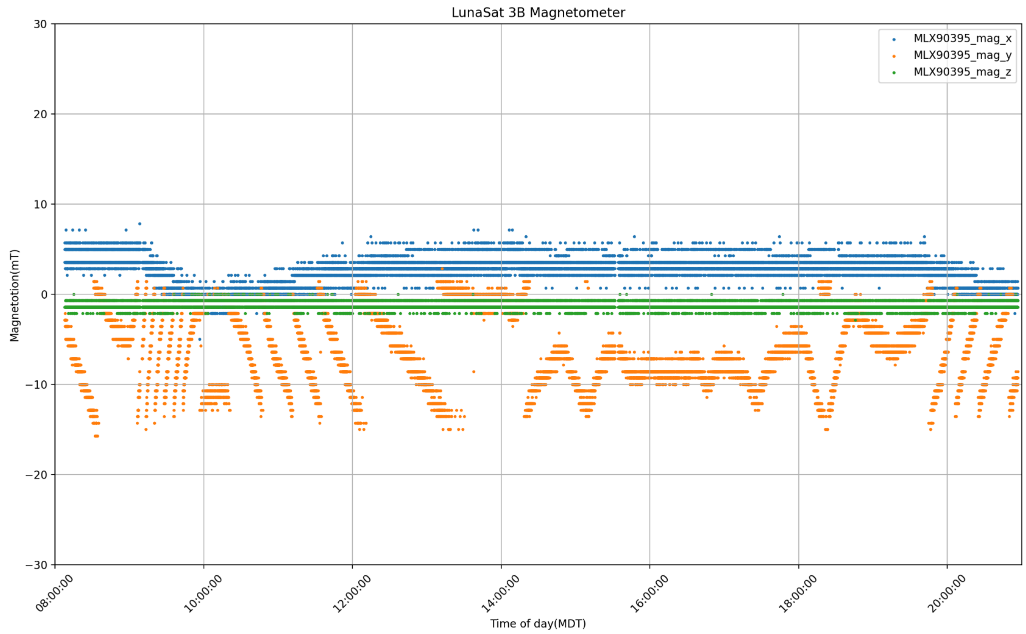
V. Magnetometer readings

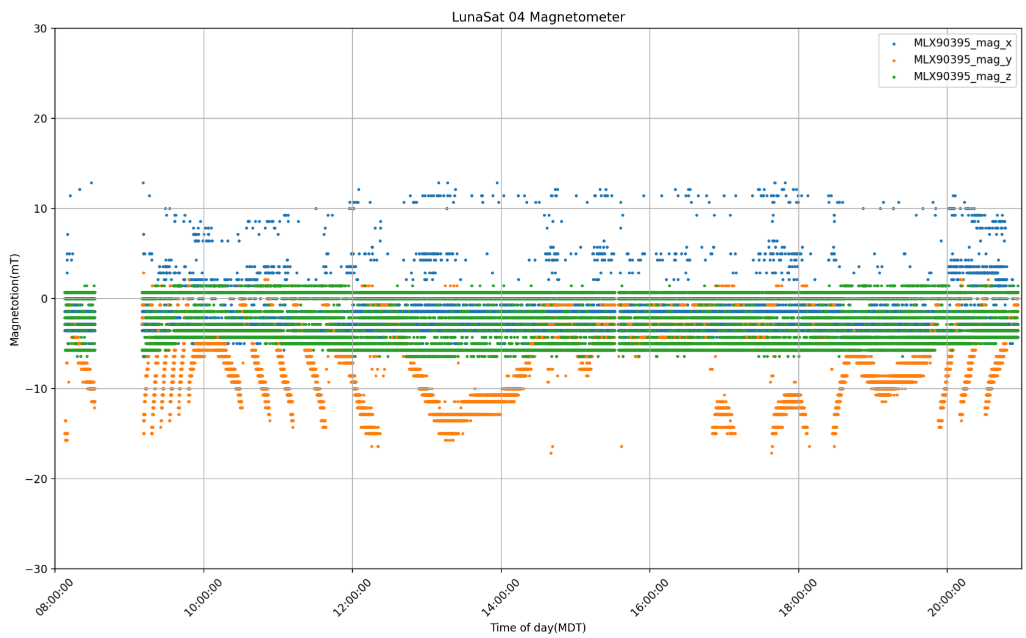


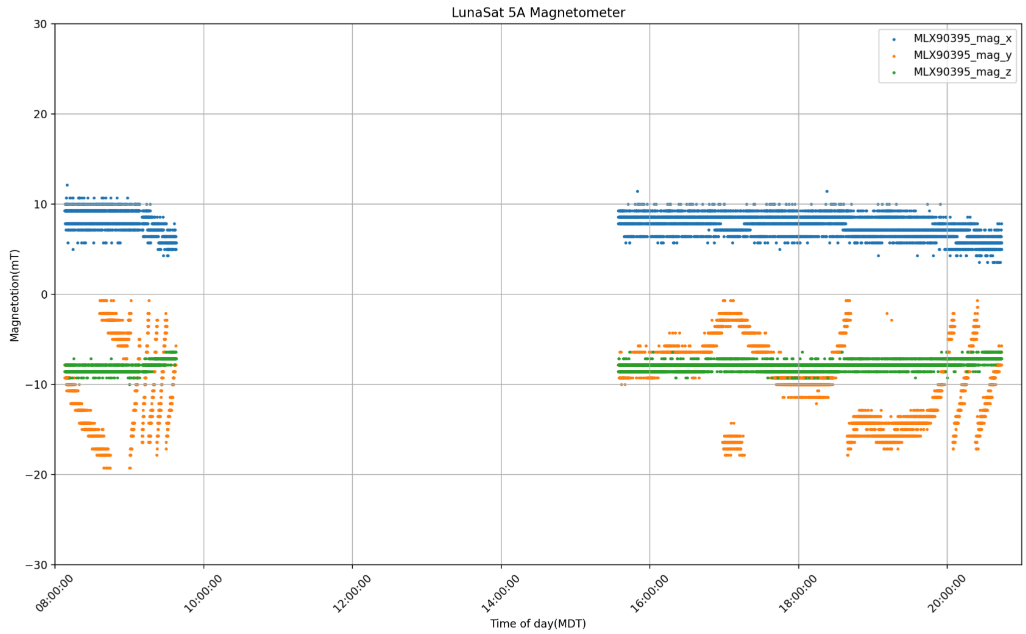


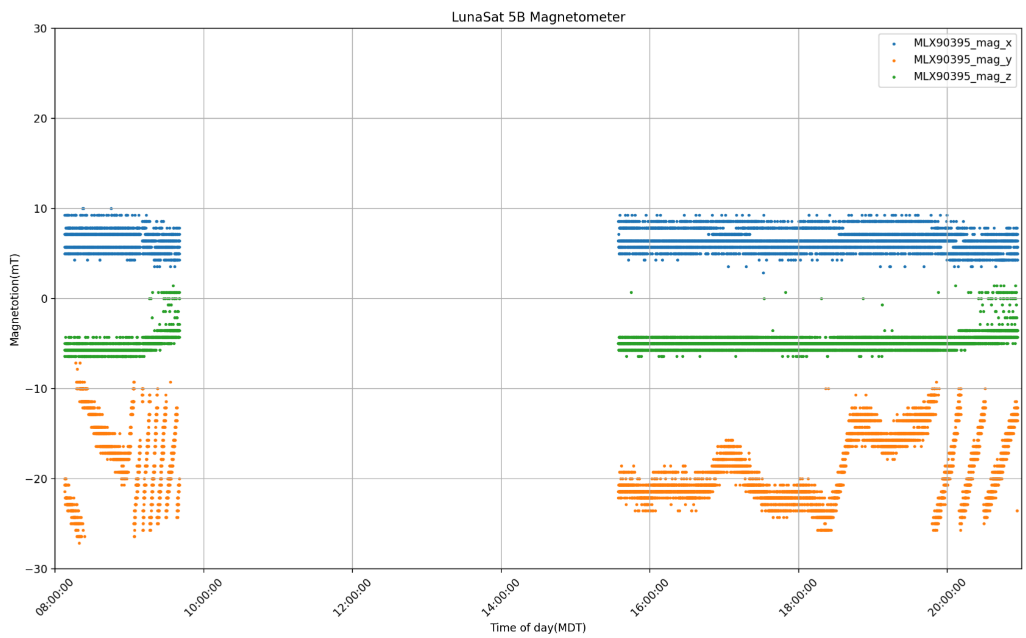

LunaSat 2B Magnetometer
MLX90395_mag_x
MLX90395_mag_y
MLX90395_mag_z
Magnetotion(mT)
Time of day(MDT)
30
20
10
0
−10
−20
−30
08:00:00
10:00:00
12:00:00
14:00:00
16:00:00
18:00:00
20:00:00


LunaSat 3A Magnetometer
MLX90395_mag_x
MLX90395_mag_y
MLX90395_mag_z
Magnetotion(mT)
Time of day(MDT)
30
20
10
0
−10
−20
−30
08:00:00
10:00:00
12:00:00
14:00:00
16:00:00
18:00:00
20:00:00

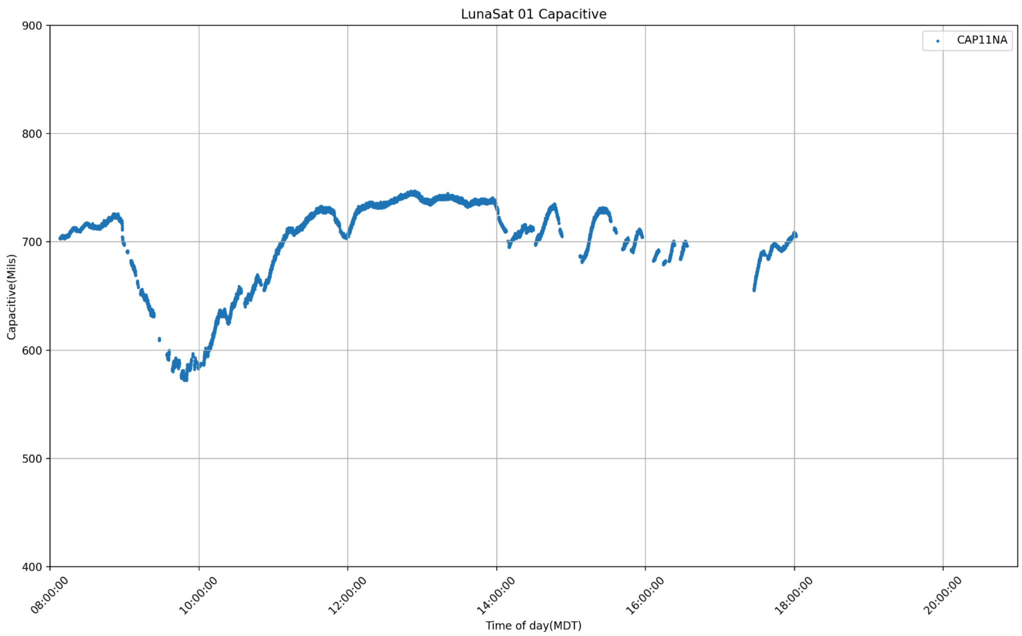

LunaSat 3B Magnetometer
MLX90395_mag_x
MLX90395_mag_y
MLX90395_mag_z
Magnetotion(mT)
Time of day(MDT)
30
20
10
0
−10
−20
−30
08:00:00
10:00:00
12:00:00
14:00:00
16:00:00
18:00:00
20:00:00

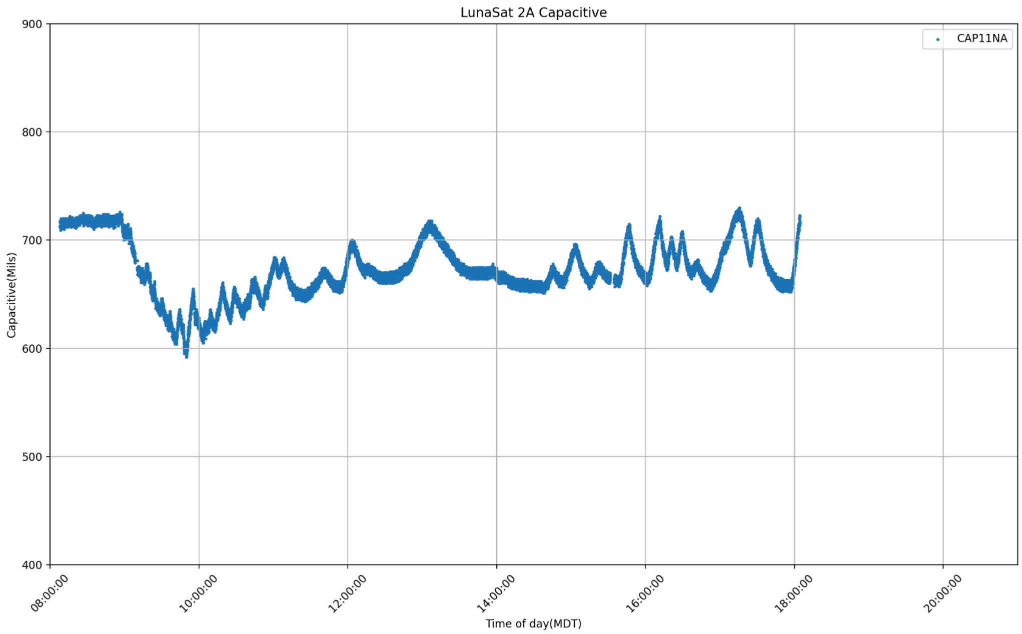

LunaSat 04 Magnetometer
MLX90395_mag_x
MLX90395_mag_y
MLX90395_mag_z
Magnetotion(mT)
Time of day(MDT)
30
20
10
0
−10
−20
−30
08:00:00
10:00:00
12:00:00
14:00:00
16:00:00
18:00:00
20:00:00

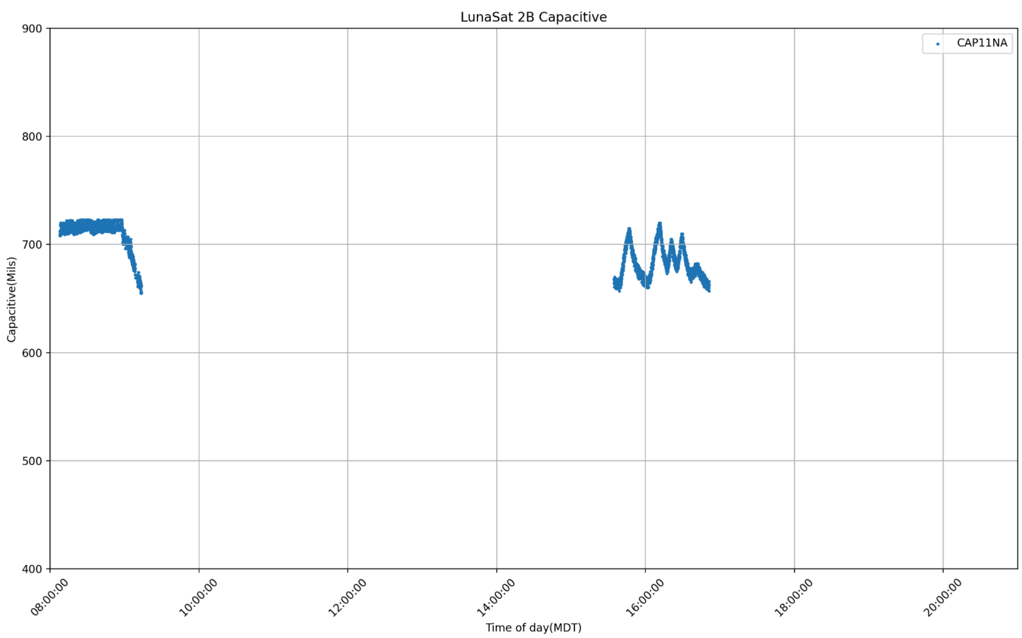

LunaSat 5A Magnetometer
MLX90395_mag_x
MLX90395_mag_y
MLX90395_mag_z
Magnetotion(mT)
Time of day(MDT)
30
20
10
0
−10
−20
−30
08:00:00
10:00:00
12:00:00
14:00:00
16:00:00
18:00:00
20:00:00


LunaSat 5B Magnetometer
MLX90395_mag_x
MLX90395_mag_y
MLX90395_mag_z
Magnetotion(mT)
Time of day(MDT)
30
20
10
0
−10
−20
−30
08:00:00
10:00:00
12:00:00
14:00:00
16:00:00
18:00:00
20:00:00

VI. Capacitive readings




LunaSat 2A Capacitive
CAP11NA
Capacitive(Mils)
900
800
700
600
500
400
08:00:00
10:00:00
12:00:00
14:00:00
16:00:00
18:00:00
20:00:00
Time of day(MDT)


LunaSat 2B Capacitive
CAP11NA
Capacitive(Mils)
900
800
700
600
500
400
08:00:00
10:00:00
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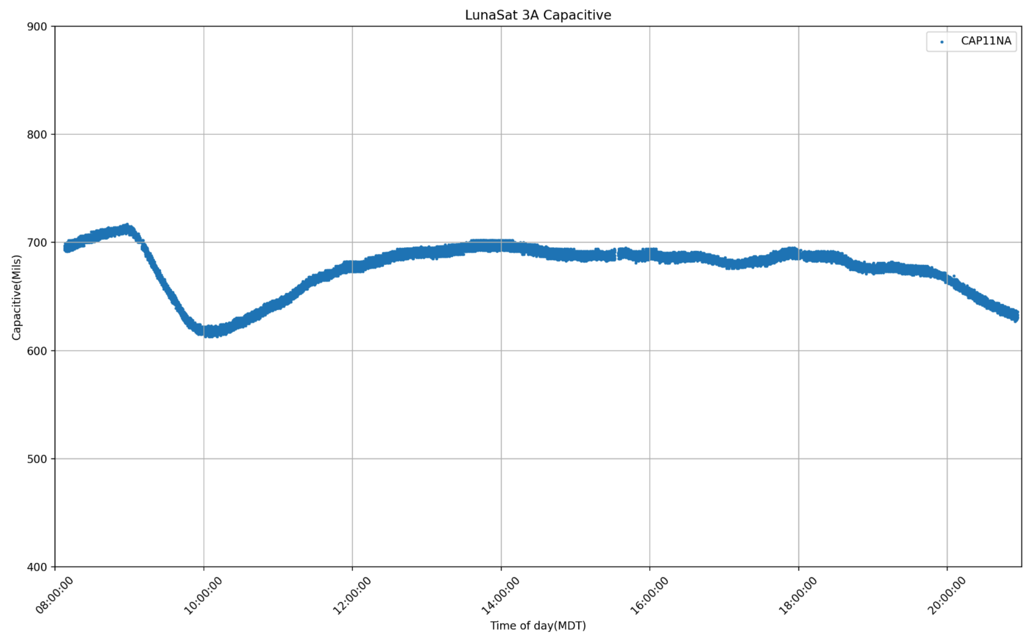
18:00:00
20:00:00
Time of day(MDT)


LunaSat 3A Capacitive
CAP11NA
Capacitive(Mils)
900
800
700
600
500
400
08:00:00
10:00:00
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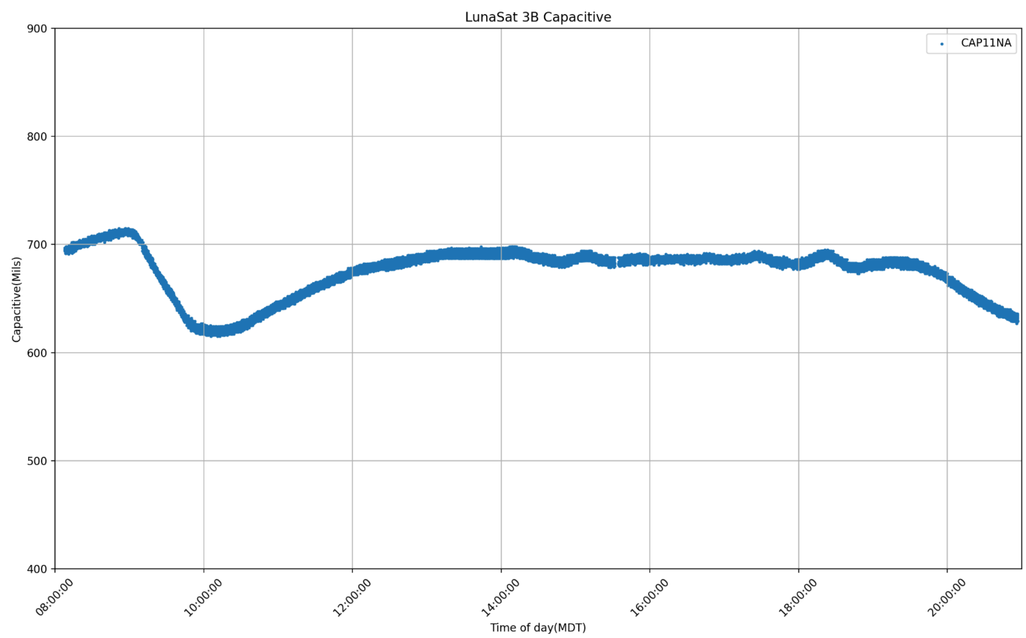
18:00:00
20:00:00
Time of day(MDT)


LunaSat 3B Capacitive
CAP11NA
Capacitive(Mils)
900
800
700
600
500
400
08:00:00
10:00:00
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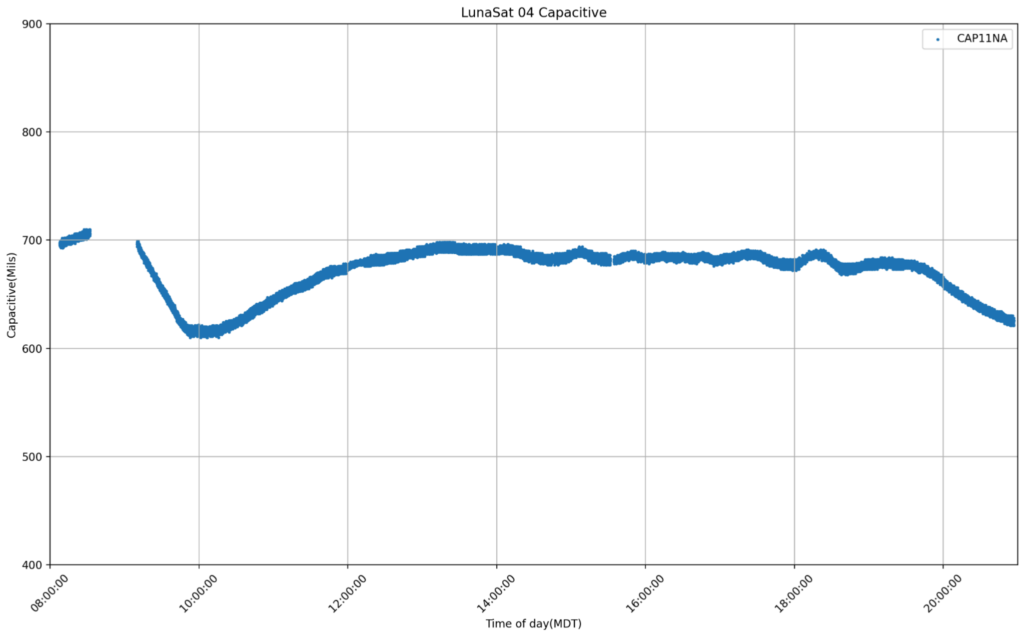
20:00:00
Time of day(MDT)


LunaSat 04 Capacitive
CAP11NA
900
800
700
600
500
400
Capacitive(Mils)
08:00:00
10:00:00
12:00:00
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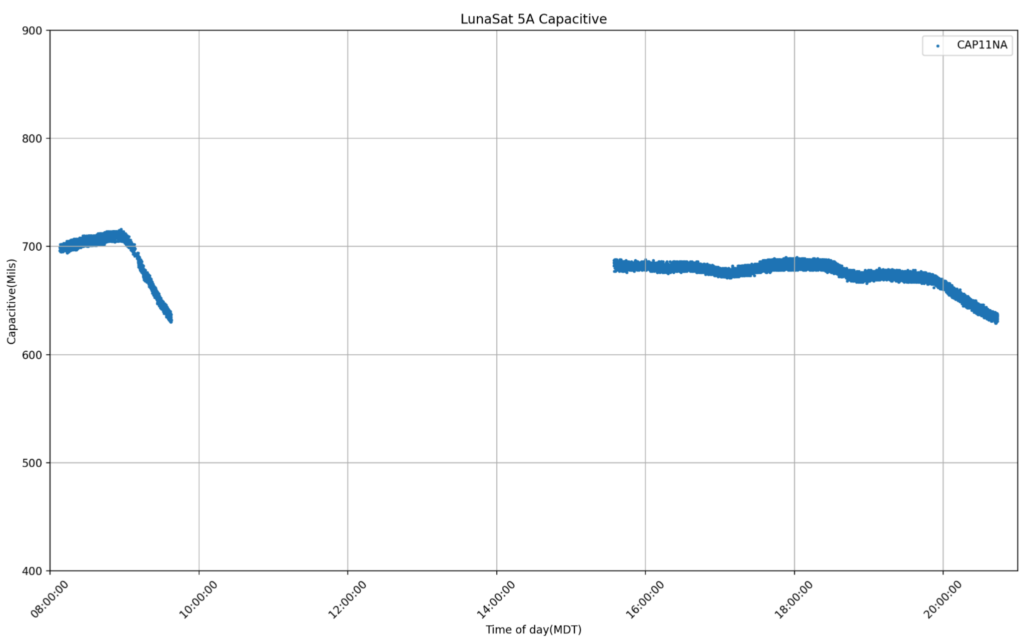
20:00:00
Time of day(MDT)


LunaSat 5A Capacitive
CAP11NA
900
800
700
600
500
400
Capacitive(Mils)
08:00:00
10:00:00
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18:00:00
20:00:00
Time of day(MDT)

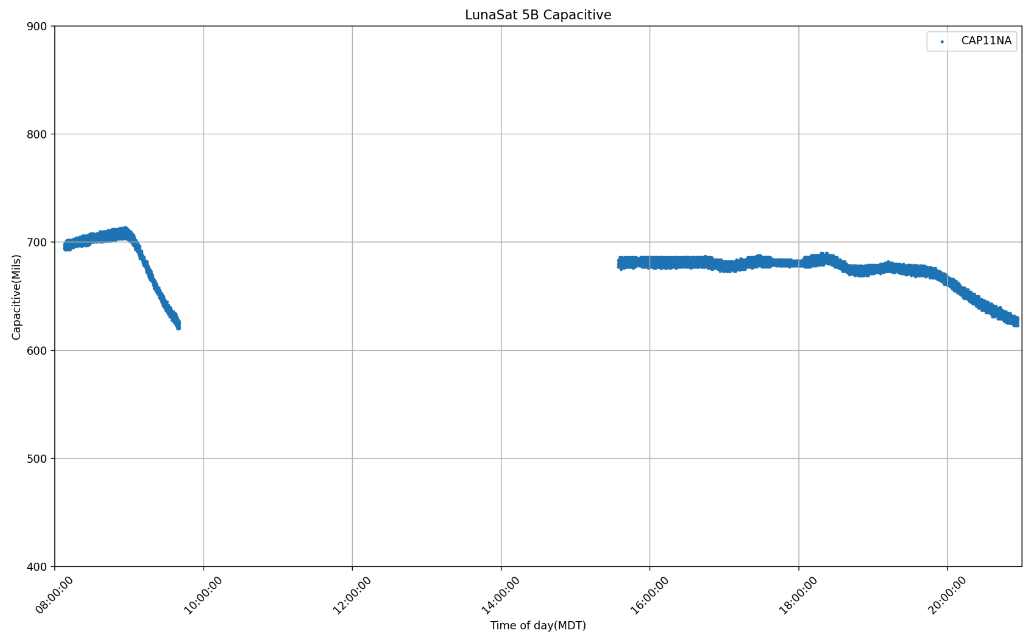

Table 2: Team Demographics

Name (i)	**Start Date**	**End Date**	**Role**	**Student Status**	**Race**(ii)	**Ethnicity**(iii)	**Gender** (i)
Veronica Corral Flores	9/9/22	Present	Faculty Advisor	Faculty	Mixed race	Hispanic	Female
Mary Hanson	9/9/22	4/7/23	Faculty Advisor	Faculty	White	Non Hispanic	Female
Elsa Carreras	9/9/22	Present	Project Manager	Undergrad	White	Hispanic	Female
Benjamin Hellem	9/9/22	Present	Systems Engineer	Undergrad	White	Non Hispanic	Male

Chloe Zentner	9/9/22	9/7/23	Structures lead	Undergrad	White	Non Hispanic	Female
Chris Brown	9/9/22	6/27/23	Avionics Member	Undergrad	White	Non Hispanic	Male
Hallie Hill	9/9/22	9/7/23	Structures Member	Undergrad	White	Non Hispanic	Female
Nicholas Mueller	9/9/22	6/18/23	Structures Member	Undergrad	White	Non Hispanic	Male
Brice Parrott	9/9/22	4/28/23	Avionics Member	Undergrad	White	Non Hispanic	Male
Zack Goldberg	9/9/22	4/28/23	Avionics Member	Undergrad	White	Non Hispanic	Male
Jack McDonald	2/8/23	6/5/23	Avionics Member	Undergrad	White	Non Hispanic	Male
Emanuele Rimini	2/8/23	6/5/23	Avionics Member	Undergrad	White	Non Hispanic	Male
Sebastian Vargas	9/9/22	12/12/22	Avionics Member	Undergrad			Male
Lauren Egaas	6/5/23	6/18/23	Avionics Member	Undergrad			Female
Peter Braza	5/31/23	8/18/23	Avionics Lead	Undergrad	White	Non Hispanic	Male
Shuyu Song	5/31/23	Present	Avionics Member	Undergrad	Asian	Non Hispanic	Male

Erick Bueno	6/20/23	9/7/23	Structures Member	Undergrad	White	Hispanic	Male

9. Appendix II

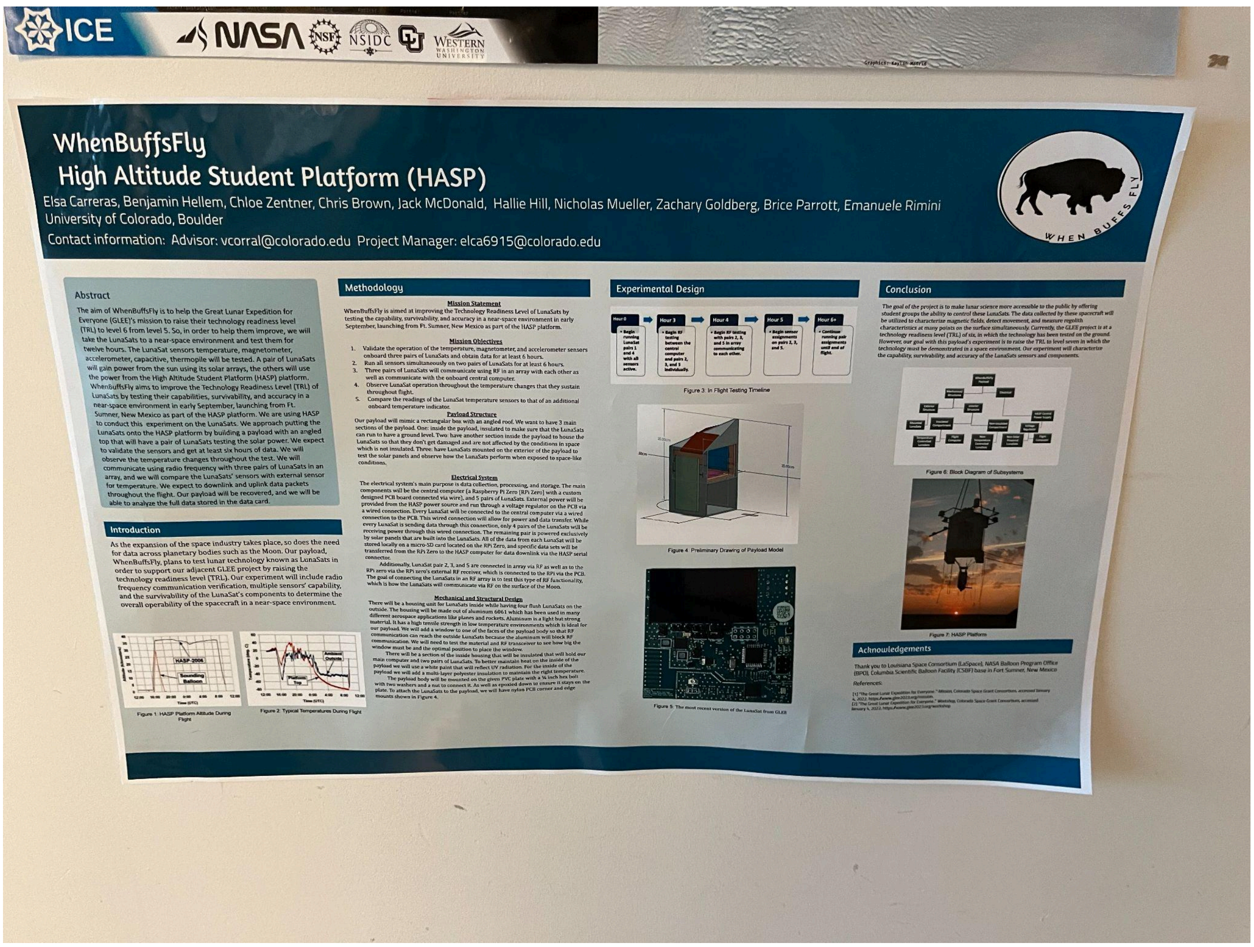

Figure 32: (Research Symposium Poster in April 18, 2023)

Authors: Elsa Carreras, Benjamin Hellem, Chloe Zentner, Chris Brown, Hallie Hill, Jack McDonald, Nicholas Muller, Zackary Goldberg, Brice Parrott, and Emanuele Rmini

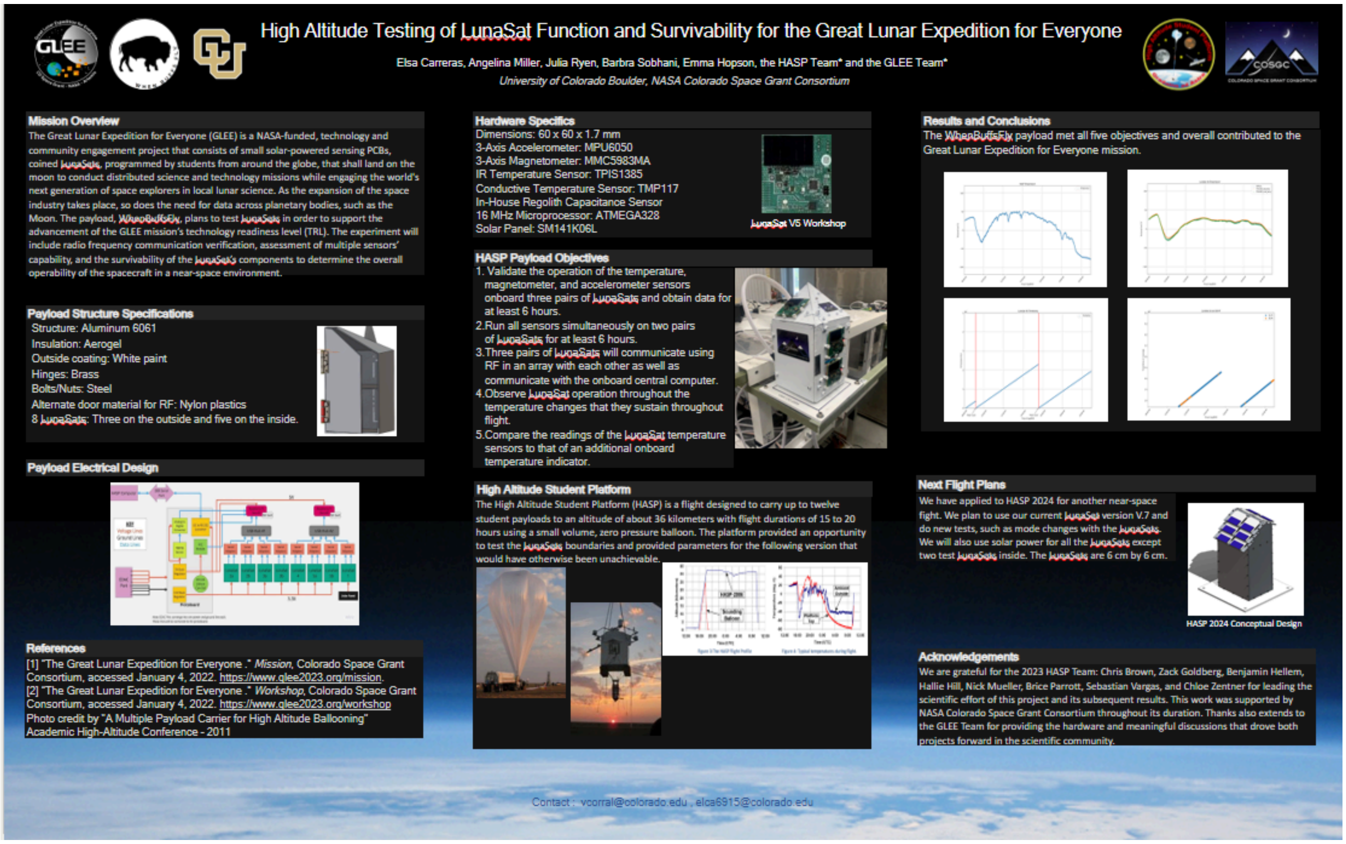

Figure 33: (HASP Poster for American Geophysical Union (AGU) December 11-15)

Authors: Elsa Carreras, Angelina Miller, Julia Ryen, Barbra Sobhani, Emma Hospson, HASP Team, and GLEE Team