# Post-flight review (17.12.2023)

## Launch day observations

### Recovery (Daniels)

Overall it was possible to achieve what was needed(receiving the location from one of the onboard devices and recovering it). For receiving data our setup was a modified Cansat base station with a 433 ¼ wave antenna mounted on the roof. The 2.4ghz antenna was always kept inside the car and we didn't pay much attention to trying to get a range ping signal from Payload FC.

Observations:

- I hadn't been informed that the telemetry data from the main ground station in Cēsis won't be uploaded to Sondehub.amateur (this wasted some time for us in which we could have been trying to receive data).
- Switching between receiving BFC and payload was tedious, it would have helped to have the ability to receive both.
- The moment an antenna was put on the car roof we started receiving data. Longest distance achieved (100km during ascent at a height of 10km)
- Neither the BFC nor Payload answered any commands I sent to them.
- When I received data from BFC the data was never corrupted, but the delay between received packets was very inconsistent.
- Payload FC sent telemetry data consistently but sometimes data was slightly corrupted and the checksum check algorithm wasn't implemented for this FC on the receiving station. It seemed like after receiving one packet (which was corrupted), another one came in 5 seconds later which was consistently not corrupted. (Receiving failed with status code -7)
- When the 2.4ghz antenna was pointed in the payload FC direction we received ranging pings from the FC. Estimated longest distance achieved (25-30km during descent at a height of 5km). Worth noting that the antenna placement was very suboptimal.
- Had problems with receiving data from RS41. The range was much weaker than any of our flight computers.
- The last received telemetry packet was at a height of around 100-200m (relative to ground level) from the payload FC.
- When driving to the landing location we started receiving telemetry at a distance of around 1-2km. Worth noting that the raccoon launch platform landed in a tree around 10m from the ground level.
- Next time need to watch a short tutorial on how to turn of Gopros
- The power switches in the box were a nice addition but an external power plug would be even better because opening the box in the cold is very tedious.
- Need to pay more attention to not losing micro SD cards.
- Need to remember to charge the laptop. I started with 50% battery, luckily this was enough

- To keep the command up to date during recovery we flagged ourselves as a chase car in Sondehub and streamed screen share in discord. But a much better alternative to streaming would have been uploading data directly to Sondehub.amateur

## Launch (Gundars)

Overall, the launch happened without too much hassle. The BFC and the PFC were turned on successfully with minimal issues. The rotator functioned as expected, the azimuth tracking was spot on, but as expected the elevation tracking issue below 1.5 km was present, but after the distance increased, the elevation tracking functioned properly. The rotator tracked the balloon to the distance of around 27 km, after which we stopped receiving a signal. After a few minutes of trying to receive the data and sending data request commands, we decided to stop tracking and pack everything up.

Observations:

- The workplace was set up quickly, and work on performing final checks began soon after.
- First problems arose when we tried to perform a test with the detaching system. After sending a command to detach, nothing happened. We started investigating the issue, and found out that signal was not being changed on the terminals. I started looking into the software, and trying to find the culprit, and changing the code to see if the issue is software related. Using the test code, we measured the voltage on the terminals, but it showed 0 volts. In the meanwhile, Arvīds G. contacted Alens, and we tried changing the output pins and testing, finally changing the output pin to 14 fixed the issue of no signal being sent. Although, the issue was fixed theoretically, the radio command to detach still didn't function. I implemented a quick, but not a great, fix to the issue, but it was decided that we won't be testing the detach system, and the hardware for it was taken out of the platform.
- This issue with the detach system could have been the cause for the issue with the RS-41. Arvīds G. did physically do voltage measurements and checking wire connections, and, in doing so, could have detached the probe on the RS-41.
- No SD card was inserted in the PFC. This meant that we had to unscrew the PFC from the structure to insert it.
- The wire connecting the payload and PFC was plugged in the wrong way, We need to make sure a connection can't be plugged in the wrong way.
- Turning on the BFC and doing the final communication testing was really simple and happened without any issues.
- Turning on the PFC was a little more complicated, and it didn't happen as smoothly as it should have.
    a. Sending a command to PFC from the base station is not really user-friendly, with having to switch to transmit mode to send a command and with there being no indications to what commands are possible to send.
        - This resulted in me sending the data send command as a test command, but this command set the PFC in mode where it constantly sent messages, and it didn't listen to the data send stop command.
        - Because of this, we had to do a power cycle of the payload, which meant that we had to take apart the completed platform to access the power switch.

        - After the power cycle, the PFC was successfully put in the armed mode and the heating and ranging system was turned on.
    b. After turning on the heating system, the PFC was transmitting an info message about a large difference in the inner temperatures. This should not have been transmitted over the radio, but only saved to the info log file.
- Wireless communication between rotator Heltec and another Heltec connected to a PC did not work, The rotator was able to send received telemetry messages to the other Heltec, but it couldn't receive any messages. I want to mention, that, in general, working with the ESP-NOW system has been problematic:
    a. Sending messages that are longer than 30 characters, more often than every 10 seconds, means they can get lost.
    b. The simple example code might work, but trying to implement it in a larger system, can cause issues with receiving, as we experienced this time.
- Due to the connection not being two-way, I decided not to use the software made for the rotator. This meant that:
    a. Manual commands through the serial console had to be sent. Which in itself is not a problem, but it is more work, than simply pressing a button or entering some values.
    b. I had to stand in the freezing wet cold wind next to the rotator with a computer connected by a USB cable to it. Not great for me or the computer.
- The rotator only had a single antenna on it, a 433 MHz Yagi antenna, that was connected to the rotator Heltec.
- The payload base station was held in hand, and it only had a small plug type antenna connected to it. Due to this, and the fact that I had to hold a computer and write commands in the serial console, meant that the payload base station was mostly oriented horribly for receiving any signals.
- Most of the time I didn't even have the payload base station serial monitor opened. This was due to me being busy trying to see, if I received a signal from BFC, and sending data request commands to it, to try to get more frequent GPS coordinate updates.
- The BFC was set in the data send mode, which should have meant that telemetry messages should have been received every 10 seconds, In reality, we were lucky if the rotator received a message once every 30 or 40 seconds.
- I kept sending data request commands to BFC, as sending this command meant that the rotator received a message pretty much a second later. This worked as intended.
- The rotator lost signal from BFC at around 24.68 km of ground distance at an altitude of 7.6 km (25.8 km in a straight line). This is very surprising as the antenna was pointed perfectly in the direction of the balloon and the antenna was a directional Yagi. Even if the antenna wasn't pointed perfectly, we should have continued receiving a signal, as the recovery team received a signal from a distance of 100 km with a small antenna on a car roof.
- Addressing the confusion about the data upload to SondeHub:
    a. At no point, I was informed that we should try to upload data to it.
    b. As much as I know, the code is ready on GitHub, but I believe at no point it has been tested and integrated with the current system.
    c. The uploading of data to SondeHub could have been quite problematic to do under the aforementioned circumstances, and it wouldn't have been useful anyway.

Improvements I would like to see:

- No changes to the software on the launch day, it is just stupid to do that.
- Many of the launch day issues regarding communication could have been resolved with a proper and reliable base station system.
- With the rotator showing that it is almost fully functional and with the hassle of handling multiple base stations, learning intricacies and maintaining each base station's software, I would like to suggest an idea of making a fully integrated base station, that would follow the idea of the current rotator setup.
- This base station could house:
    - Multiple 433 MHz LoRa modules so we can receive from different systems simultaneously.
    - A 2.4 GHz LoRa for ranging.
    - A GPS module.
    - Screen to display actual information.
    - Buttons for manual control.
    - Logging to SD card.
    - Everything required to control the rotator itself.
    - A battery that can power everything for multiple hours.
    - A reliable way for two-way communication with a computer (No ESP-NOW)
- This would bring many improvements to the current system:
    - Improvements to the current rotator base station, as the wiring inside is a mess, that caused hours of time spent on debugging during testing this week.
    - The antennas are always pointed in the direction of the target.
    - No use of multiple base stations.
    - Simplified code, standardized receivable and sendable messages.
    - Integrated control software, possibly using Yamcs mission control and OpenMCT.
    - On the launch day, all we would have to do is connect the antennas, turn it on, and connect it with a PC.

## Launch (AB)

1. Building and finishing stuff while also changing the scope of the mission on the last evening, not too great. Balloon de-coupler and the separation test should have been canceled much earlier
2. Weird sound while filling hydrogen, which significantly lengthened the filling process process
3. Spent like 10 minutes holding the balloon and just waiting
4. RS41 debacle
    4.1. Temperature probe of RS41 is found to be unattached, despite being attached in the previous evening.
    4.2. Impossible to plug the probe in while it is attached to the wall, RS41 is removed out of the box
    4.3. Probe is plugged back in, as it is being pushed into position, the probe shorts out on unshielded terminals of the 2S2P battery, burning a hole in the the probe
    4.4. Despite the obvious damage to the probe, RS41 turns on fine and gets a GPS lock. No examination of the antenna cable is done.
    4.5. In flight, it is noticed that the signal strength of RS41 is much weaker than expected.
5. BFC transmissions seemed to come in only every few kilometers based on Daniels streams
6. Wireless implementation fail and button/LCD fail meant that Gundars had to stand in the freezing wet wind with a computer looking at the terminal. Due to this the rotator was stopped much earlier than it should have.
7. GoPros
    7.1. Taped and secured by string only in Cēsis
    7.2. No procedure for turning them on
    7.3. Nobody is aware of how to know whether the session is recording or not
8. Daniels kept everyone informed through Discord during launch. This allowed Alens to monitor and update the launch team on the recovery site conditions and help coordinate the recovery.
9. Heard something about corrupted payload packets being received,

## Launch (AG)

1. Fast & Operative unloading, all necessary items were there.
2. No apparent launch procedure
    2.1. Gopro startup procedure missing.
    2.2. How to tape up Gopros effectively, which resulted in time waste.
    2.3. Detach mechanism electronic circuit functional description, procedure for arming missing.
3. Not enough people knowledgeable in their respective fields, e.g. electronics systems.
4. Would be nice if needed drone/gopro/camera shots were previously defined.
5. At times I had no idea what I needed to do, so I was just sitting around doing nothing.
6. Too many large changes to the previous plan.

# Telemetry Data Analysis of High-Altitude Balloon Flight on 16.12.2023

## Introduction

This telemetry data analysis focuses on a high-altitude balloon flight which took place on the 16.12.2023. The flight aimed to test the RTU HPR Racoon launch platform, with an emphasis on the overall performance of all systems. The experiment integrated two critical onboard systems, namely the Balloon Flight Computer (BFC) and the Payload Flight Computer (PFC). This report includes analysis of the only available flight telemetry data, generated by the PFC, as the BFC did not record any telemetry data. The report also includes information about the Balloon tracking system (Rotator) performance. The analysis includes an examination of general flight information and an investigation of anomalies encountered during the mission. The report examines the root causes of these anomalies, providing an understanding of their origins and proposing solutions for possible problem rectification.

## General information

### Timing

Turned ON: 13:43:20
Turned OFF: 17:32:42
Total time ON: 13770 seconds or 3:49:30 hours
Launch time: 13:54:09 or 660 seconds after turning on
Top of ascent time: 14:48:26 or 3915 seconds after turning on
Landing time: 15:16:22 or 5591 seconds after turning on
Time of flight: 1:22:13 hours

### Time between telemetry packets

Average time between packets: 119,22 milliseconds
Median time between packets: 110 milliseconds

Max time between packets: 6105 milliseconds
Min time between packets: 66 milliseconds

Extreme values - time, which is 4 times larger than the average time
Number of extreme values: 376
Occurrences:

- 2126 ms between packets 25,34 seconds after turning on
- 3156 ms between packets 55,47 seconds after turning on
- 339 occurrences of alternating 2100 ms and 640 ms delay between packets, starting from 314 seconds after being turned on and ending around 866 seconds after being turned on
- 3279 ms between packets 3604 seconds after turning on

- 4079 ms between packets 3608 seconds after turning on
- 6105 ms between packets 3614 seconds after turning on
- Other occurrences are around 500 ms, scattered around the entire turned on timeframe

### Altitude

Max GPS altitude: 23471.88 meters or 23.47 kilometers
Max barometer altitude: 4187.81 meters or 4.19 kilometers

### Ascent/Descent speed

Average speed from GPS altitude:

- Ascent:
  - 175 meters to 5000 meters is 5.94 m/s
  - 5000 meters to 10000 meters is 7.17 m/s
  - 10000 meters to 15000 meters is 8.82 m/s
  - 15000 meters to 23472 meters is 7.22 m/s
- Descent:
  - 23472 meters to 15000 meters is -26.35 m/s
  - 15000 meters to 10000 meters is -16.59 m/s
  - 10000 meters to 5000 meters is -11.40 m/s
  - 5000 meters to 1000 meters is -8.12 m/s
  - 1000 meters to 300 meters is -7.00 m/s
  - 300 meters to 155 meters is -6.81 m/s

## Analysis

### Flight Trajectory

The maximum GPS altitude achieved was recorded at 23,47 kilometers, while the barometer altitude reached only 4,19 kilometers. The ascent phase increasing ascent speeds, with the balloon ascending at an average speed of 5,94 m/s from 175 meters to 5000 meters, up to an average speed of 7,22 m/s from 15000 meters to the maximum altitude of 23472 meters. During the descent, the balloon exhibited a rapid descent rate, descending from 23472 meters to 15000 meters at an average speed of -26.35 m/s. The balloon slowed significantly at lower altitudes, down to around -7 m/s from 1000 m to 300 m. The balloon landed at around -6.8 m/s.

The balloon's trajectory, originated from Cēsis airfield (57.321031, 25.321915) and concluded approximately 15,5 kilometers west of Preiļi (56.293298, 26.477513), 134,5 km away from the launch place. The flight ended with a landing in a tree, approximately 10 meters above the ground. See figures [1][2][3].

### Temperature

The temperature inside the enclosure housing the onboard computers exhibited a notable variation throughout the mission. Starting at approximately 3 degrees, the temperature increased to 8,5 degrees before launch. During the ascent phase, the internal temperature dropped to around -2 degrees, reaching its lowest point of -6 degrees towards the end of descent. Subsequently, as the balloon had landed, the temperature gradually increased, reaching almost 14 degrees before the system was powered down. See figures [4][5].

The payload container, equipped with a PID controlled heating element, aimed to maintain a stable temperature of 35 degrees. Upon activation, the heating element quickly elevated the temperature to 50 degrees, generating a maximum of 4 watts of heat. After cooling down to the target temperature, the system sustained a consistent temperature around 35 degrees, with minimal fluctuations of approximately 0,2 degrees higher or lower. The power to sustain the stable temperature during the flight was just under 1 watt, decrrequired easing to approximately 0,6 watts after landing. See figures [6][7][8][9].

Within the payload container, two temperature sensors were used, including a dedicated temperature probe and a temperature sensor integrated into a barometer. The latter consistently recorded lower temperatures, with an initial difference of up to 10 degrees, which later stabilized to around a 5 degree difference during the flight. See figure [4].

## Pressure

As anticipated, the external pressure dropped during ascent and increased during descent. The atmospheric pressure before launch measured at 100806 Pa, slightly below normal pressure levels. Upon landing, the external pressure stayed around 101000 Pa, and at the top of ascent, the pressure had decreased to just 2800 Pa.

The hermetically sealed payload container maintained an initial internal pressure lower than the external pressure, measured at approximately 95640 Pa. During the ascent phase, the pressure inside the container decreased at a slower rate, approximately 6 Pa per second, compared to the external pressure drop of around 50 Pa per second. However, at an altitude of approximately 19.9 km, a rapid leak in the seal occurred, leading to a substantial increase in the rate of pressure loss to 700 Pa per second. The internal pressure plummeted to 30 kPa at an altitude of 21,2 km, at which point the pressure sensor stopped providing readings due to a software related issue. See figure [10].

## Acceleration/Gyro

Throughout the ascent, the balloon exhibited slight acceleration variations, although no significant deviations were observed. The ascent phase was characterized by a rough trajectory, marked by fluctuating acceleration and rotation values across all axes.

During the descent phase, the balloon did not experience free fall, and the lowest recorded acceleration was only around 3 m/s².

In the upper atmosphere, severe rotation was observed, with consistent and inverting rotations of 1 rad/s on the y and z axes and a -2 rad/s rotation on the x-axis. As the balloon descended, the rotations gradually decreased in severity. See figures [11][12].

## Time between telemetry packets

The median time between packets was observed to be 110 milliseconds, indicating a generally consistent telemetry data logging rate. However, anomalies were identified in the telemetry message intervals, with both extreme values and patterns of delays.

The time between messages range from 66 milliseconds (minimum time between packets) to 6105 milliseconds (maximum time between packets). There are 376 extreme delay values, where the time between packets was at least 4 times larger than the average. Specific instances of these occurrences include delays of 2126 ms and 3156 ms shortly after turning on, as well as 339 occurrences of alternating 2100 ms and 640 ms delays between packets. This pattern persisted from 314 seconds after being turned on until approximately 866 seconds after activation. Additional occurrences of delays around 500 ms were scattered throughout the entire timeframe. See figures [13][14].

The identified extreme anomalies can be attributed to software-related issues associated with the heating system and payload container pressure readings. Initial anomalies, following power-up, are linked to commands for turning on the heating system and transitioning into ascent mode. While suboptimal, these anomalies are non-critical due to the inherent sluggishness of these processes, caused by the non-optimised nature of the used software.

The subsequent 339 occurrences of delays are attributed to a software bug in the heating system, triggered by significant differences between inner temperature sensors. This led to unintended radio transmissions, initially intended for logging only. The three large occurrences of delays towards the end of the flight resulted from a similar issue related to payload container pressure readings. The low pressure values due to the experienced pressure leak, triggered the sensor failure detection system, which resulted in the sensor being disabled, and error messages being sent over radio, which were intended for logging purposes only.

The rest of the increased delays might be explained by simultaneous sensor data processing, but the extended delays caused by software bugs highlight potential issues in the logging mechanism.

## Battery

The battery voltage started at approximately 6,46 volts, suggesting an initial state of charge (SOC) of around 30% [16]. However, given that all batteries were fully charged before launch, this deviation is likely attributable to the challenges in accurately estimating SOC at low temperatures.

During the initial heating system startup, the battery voltage experienced a slight dip below 5,8 volts due to the substantial current draw required for heating the payload container. As the heating process slowed, the voltage returned to the initial levels, but gradually decreased as the internal temperature of the system declined. The lowest recorded voltage was 5,95 volts.

After landing, the battery voltage showed a slow and steady increase, reaching a peak of around 6,18 volts. Subsequently, it began decreasing, possibly influenced by the battery voltage declining as the SOC decreased. The final voltage was approximately 6,15 volts, before the system was powered off. See figure [15].

The observed battery performance indicates that the current setup has more than sufficient battery capacity, with the potential for the entire system to operate for several additional hours. Moreover, it highlights the challenge of relying on SOC tables for accurate assessments of battery state at low temperatures, and the significant impact of sub-zero temperatures on voltage levels.

## Tracking system - Rotator

During the initial part of the ascent, the balloon was tracked by the tracking system known as the Rotator, which received radio messages from the BFC. The rotator functioned as expected, and pointed the antenna in the balloon direction up until the balloon had reached the GPS height of 7,6 km, after which signal was lost.

The rotator functioned as expected, with the elevation tracking issue being present. The azimuth tracking being correct, but the elevation tracking not being correct below distances of 1,5 km. The elevation angle below these distances is calculated to be 90 degrees. After the first telemetry packet was received by the rotator with the distance being 1,7 km, the elevation tracking started functioning properly. The rotator tracked the balloon to the distance of around 25,8 km, after which we stopped receiving a signal.

The rotator lost signal from BFC at around 24,68 km of ground distance at an altitude of 7,6 km (25,8 km in a straight line). This is very surprising as the antenna was pointed perfectly in the direction of the balloon and the antenna was a directional Yagi. Even if the antenna wasn’t pointed perfectly, the system should have continued receiving a signal, as the recovery team received a signal from a distance of 100 km with a small antenna on a car roof.

## Encountered issue analysis

Most of the issues and anomalies encountered during flight were software related.

Notably, the payload container temperature was not kept at a consistent 35 degree temperature. The initial spike to over 50 degrees is not acceptable and would have failed the payload experiment before it even began. The issue is related to the heating system PID loop, which was not extensively tested with low temperatures. The heating system also saw significant changes to the heater control system, with the used MOSFET being changed, which invalidated the previously calibrated PID values. Although, once the target temperature was reached, the temperature was kept consistent, which shows that the PID system works in certain conditions, with only the initial heating needing significant improvements.

Another significant issue encountered was the pressure sensor inside the payload container being flagged as failed, because of low pressure inside the container, caused by a leak between the container itself and the container lid. The sensor failure detection system was initially implemented to reduce the chance of full system failure, if a single sensor failed. The failure detection system looks at two parameters - how long it takes to read the data, and if the measured value is outside the expected range. In this case, the leak caused low pressures to be recorded. As the pressure fell below the set limit, the system thought that the sensor had failed, and flagged it as failed, which meant that no further data was read. This issue meant that no data further data was read, and it is impossible to know at what altitude the leak stopped. The next day, after taking the SD card out of the PFC, the system was turned back on, and telemetry readings were transmitted. This showed that the pressure inside the payload container was around 88 kPa. This means that the leak must have stopped at some point during descent.

The payload container seal failure shows that a new container has to be designed before the payload experiment is flown, as during development and this flight, issues with hermetically sealing the container have been encountered.

The last notable issue encountered is related to the inconsistencies in the delay between logged telemetry packets. This issue was mainly caused by the logging system itself and improperly configured info and error message logging, as no info or error message should have been transmitted over radio. Although, this is not the only issue, and there are most definitely other underlying issues related to the logging system, as transmitting messages is a non-blocking function, and such long delays between logged telemetry packets should not have been experienced.

The delays that were caused shortly after turning on the PFC are related to turning on the heating system and switching into ascent state. As with the precious issue, this should not have caused that much of significant delays. Although the switching between states is coded suboptimally, with delay function being used, this is only part of the problem, as radio messages were transmitted at the start, which again is the probable cause of the increased delay.

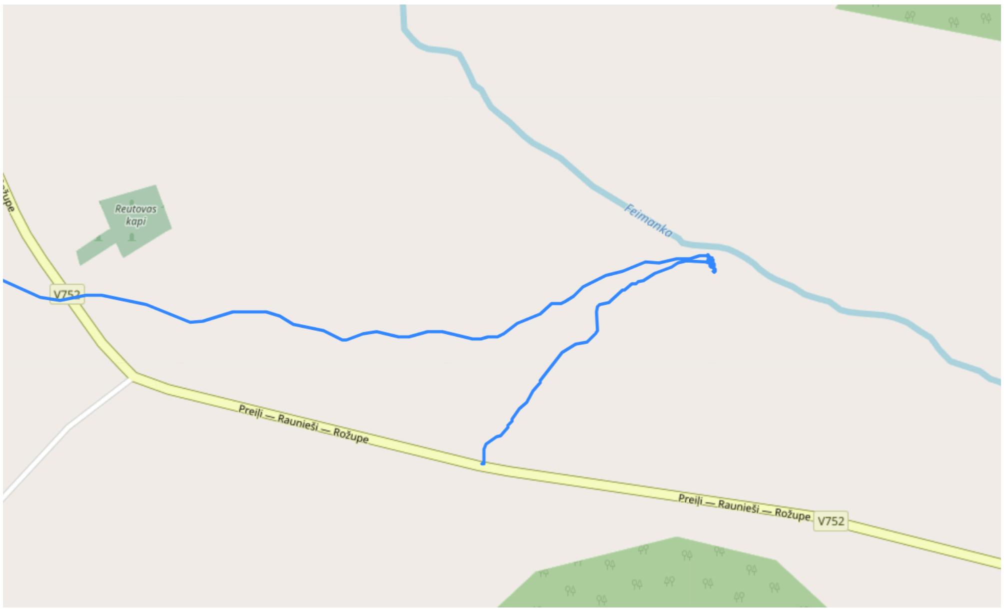
## Suggestions/Fixes

The encountered anomalies during the flight, particularly those related to software, emphasize the need for specific improvements to enhance the reliability and performance of the system.

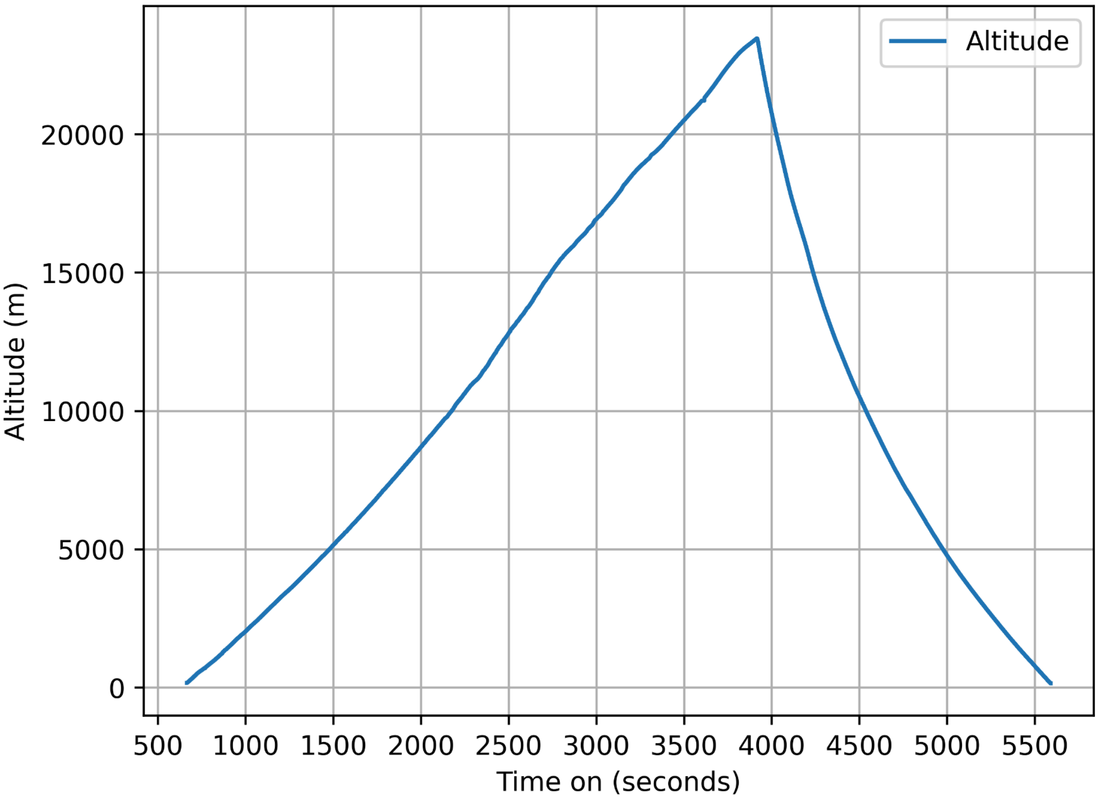
1. A full rehearsal of all actions to be performed on launch day.
2. Extensive testing of all systems.
3. Improvements and changes to the way the sensor failure detection system works.
4. Complete redesign of the payload container.
5. Improvements to coding practices with an emphasis on finding root causes of issues.

## Figures

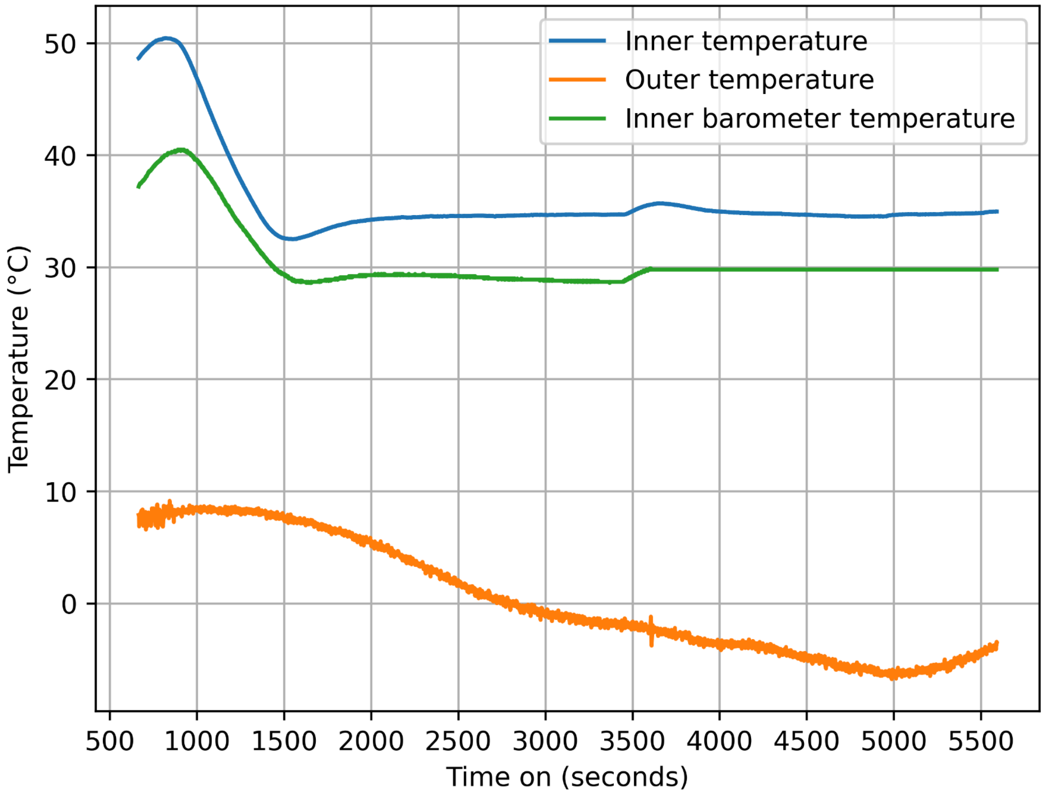
Flight trajectory [1]



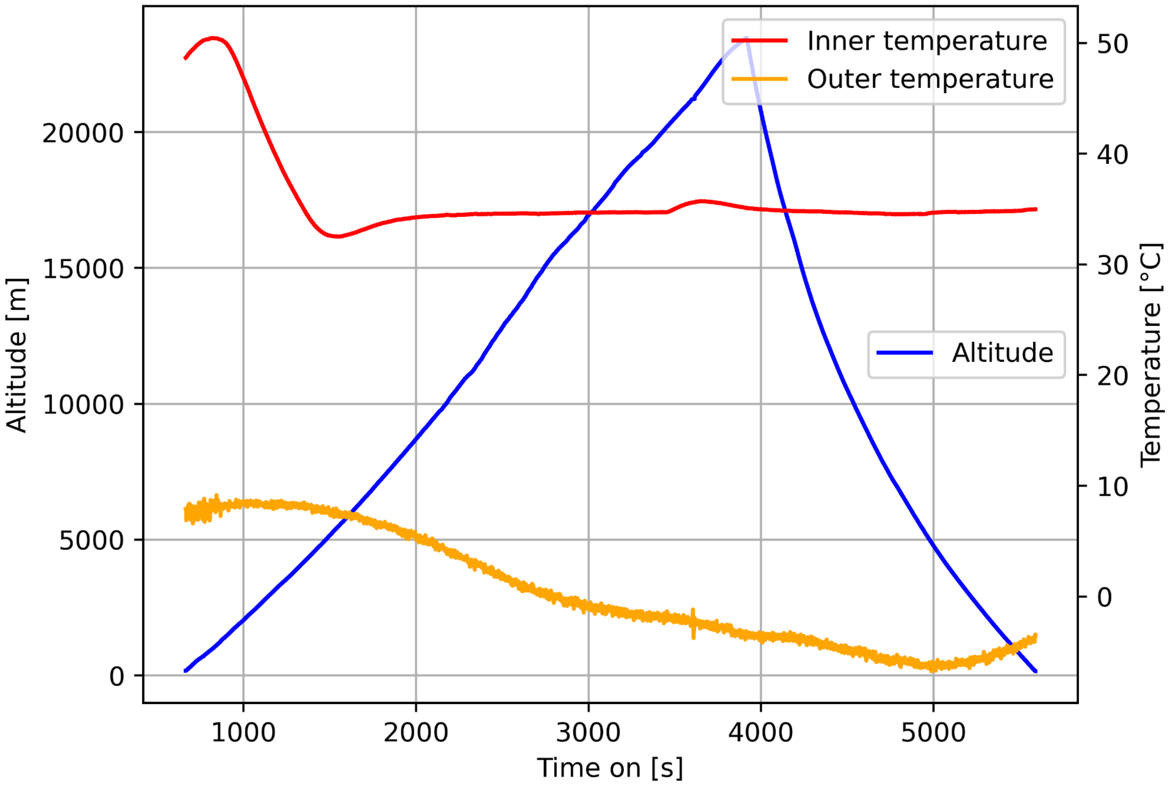
Landing location [2]



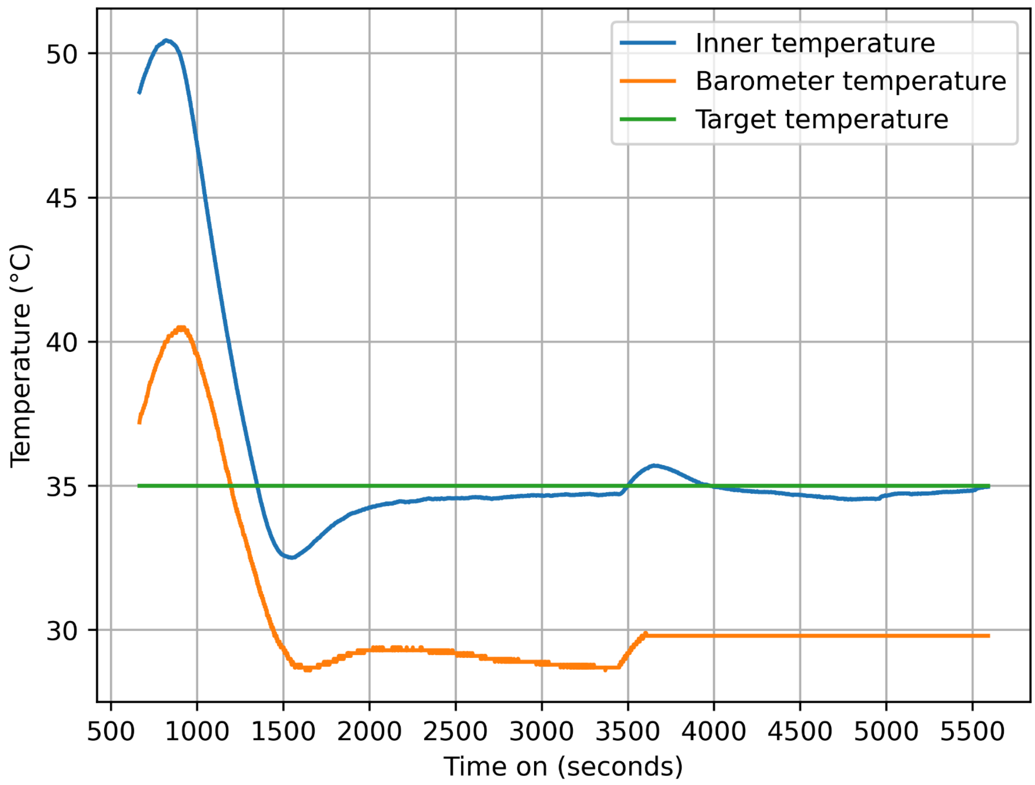
GPS altitude during flight [3]



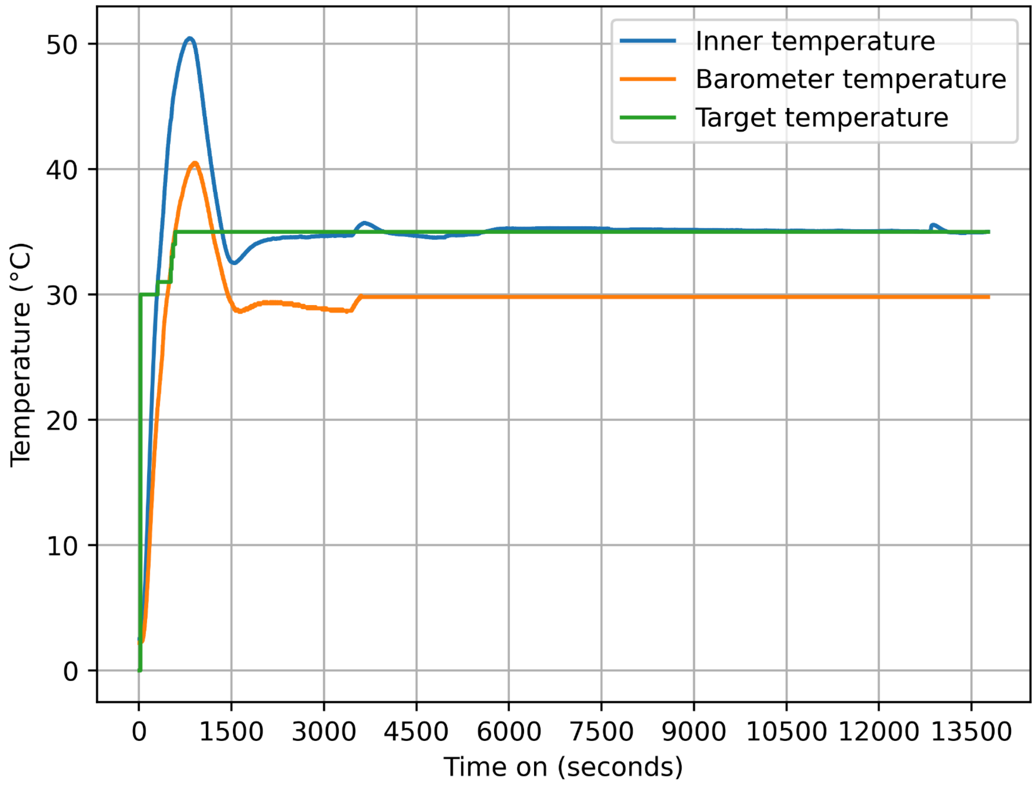
Inner and outer temperature readings during flight [4]



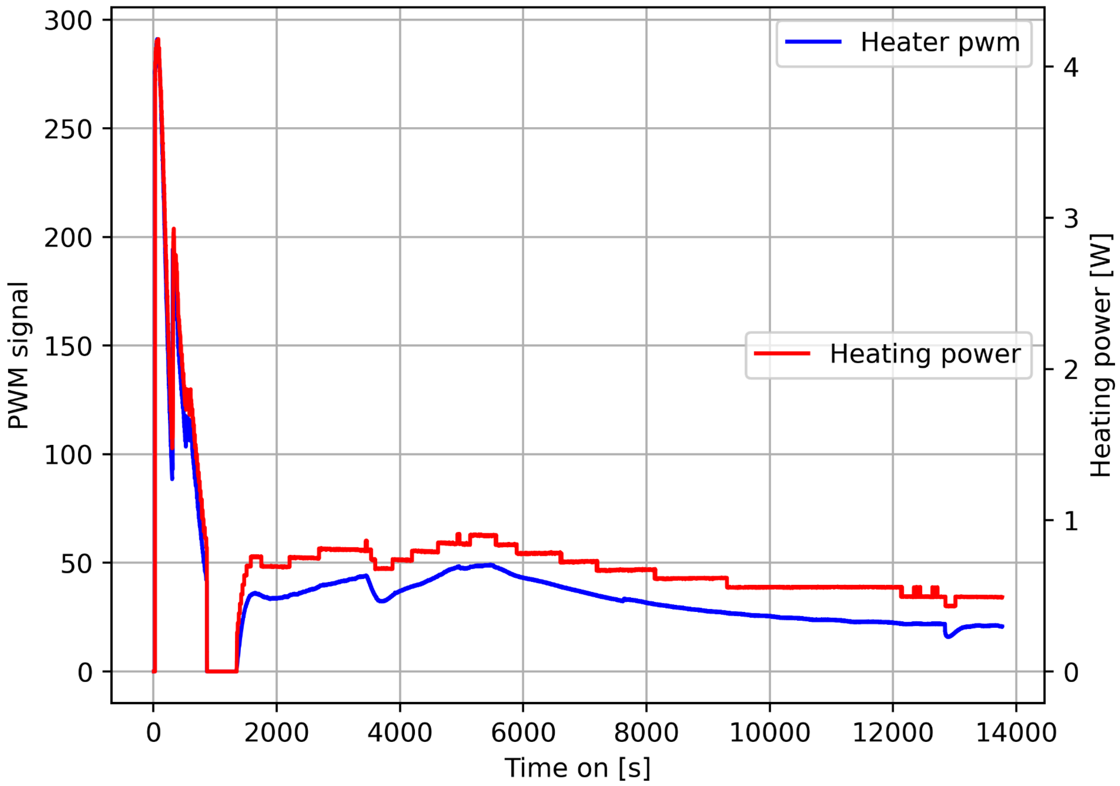
Inner and outer temperature vs the GPS altitude [5]



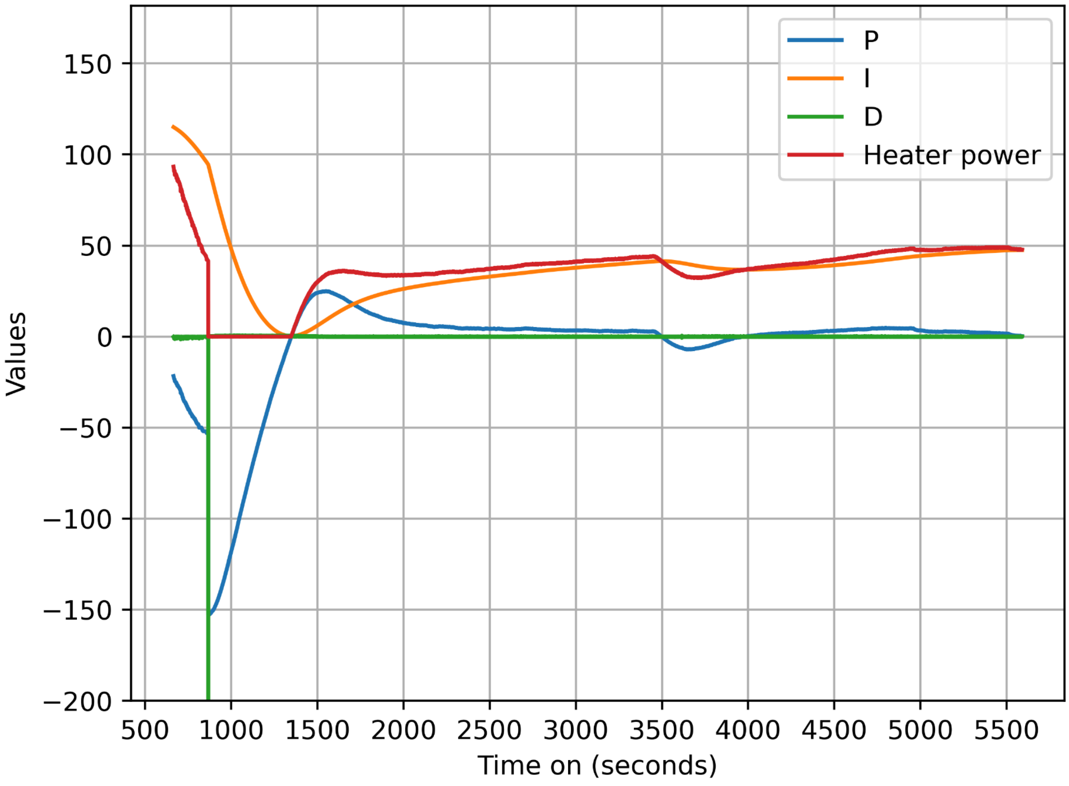
Inner temperature probe and inner barometer temperature vs the target temperature during flight [6]



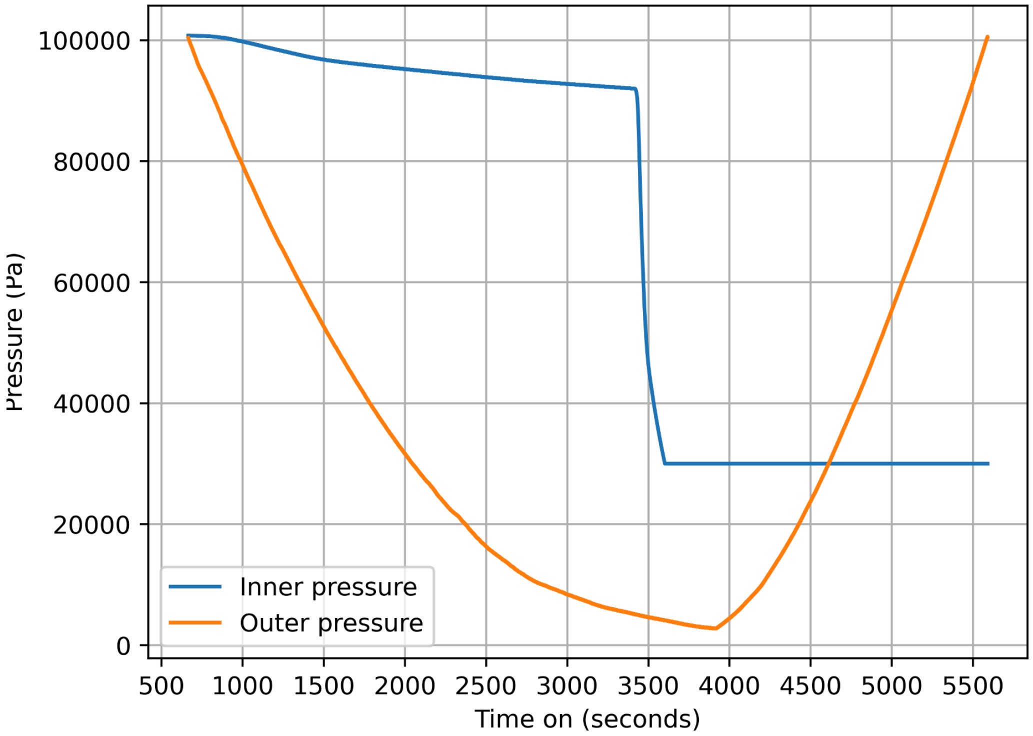
Inner temperature probe and inner barometer temperature vs the target temperature for the whole turned on timeframe [7]



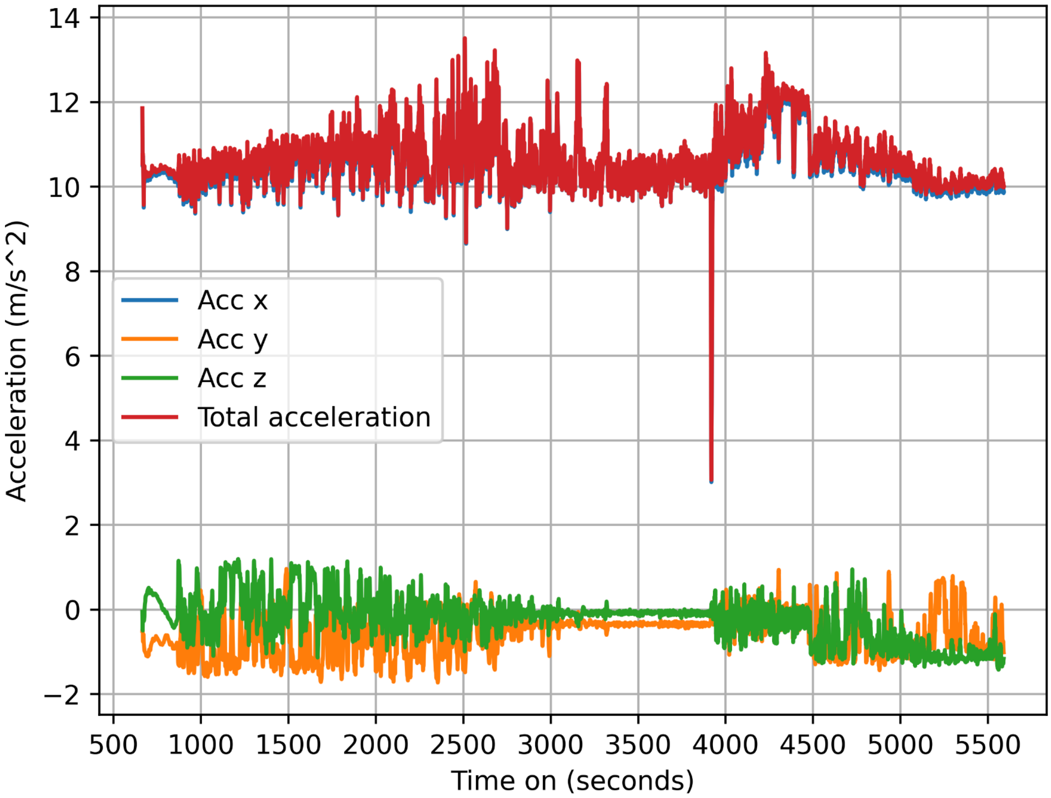
Heating system PWM value and heating element emitted power [8]



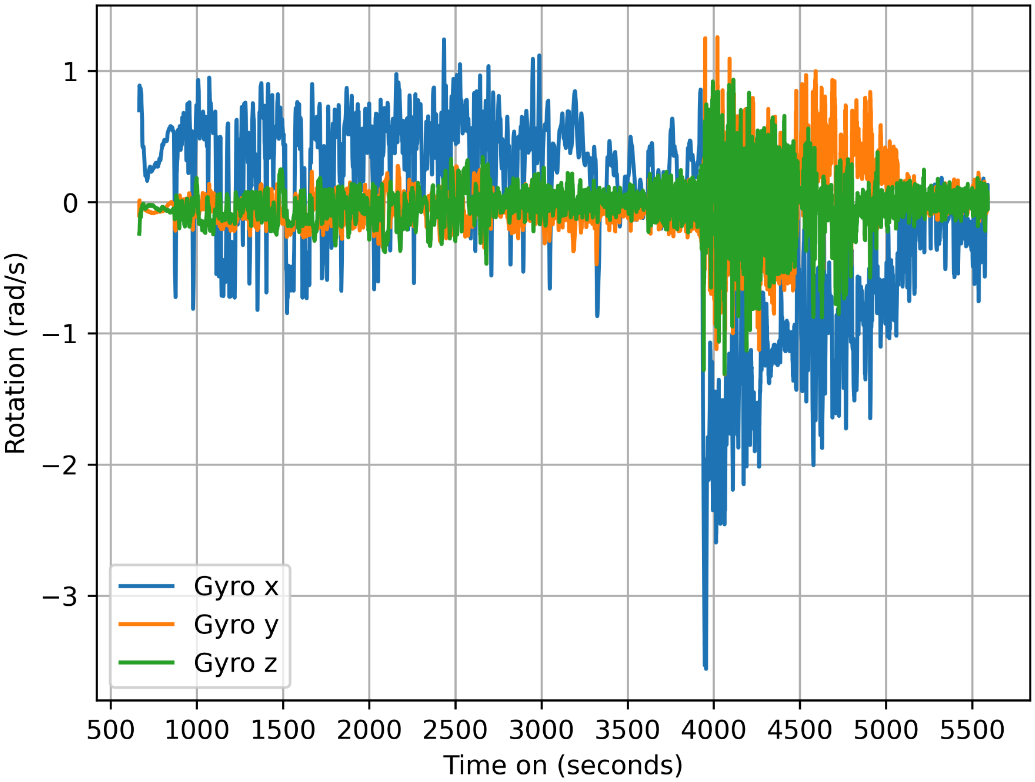
Heating system PID values [9]



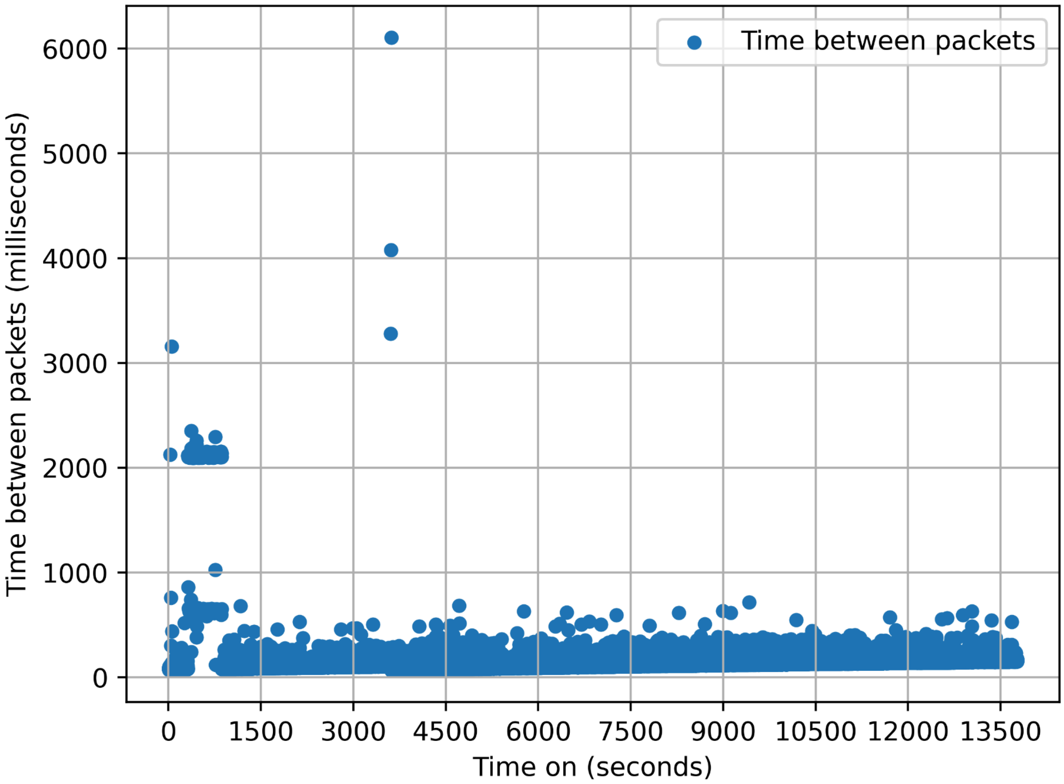
Inner and outer pressure during flight [10]



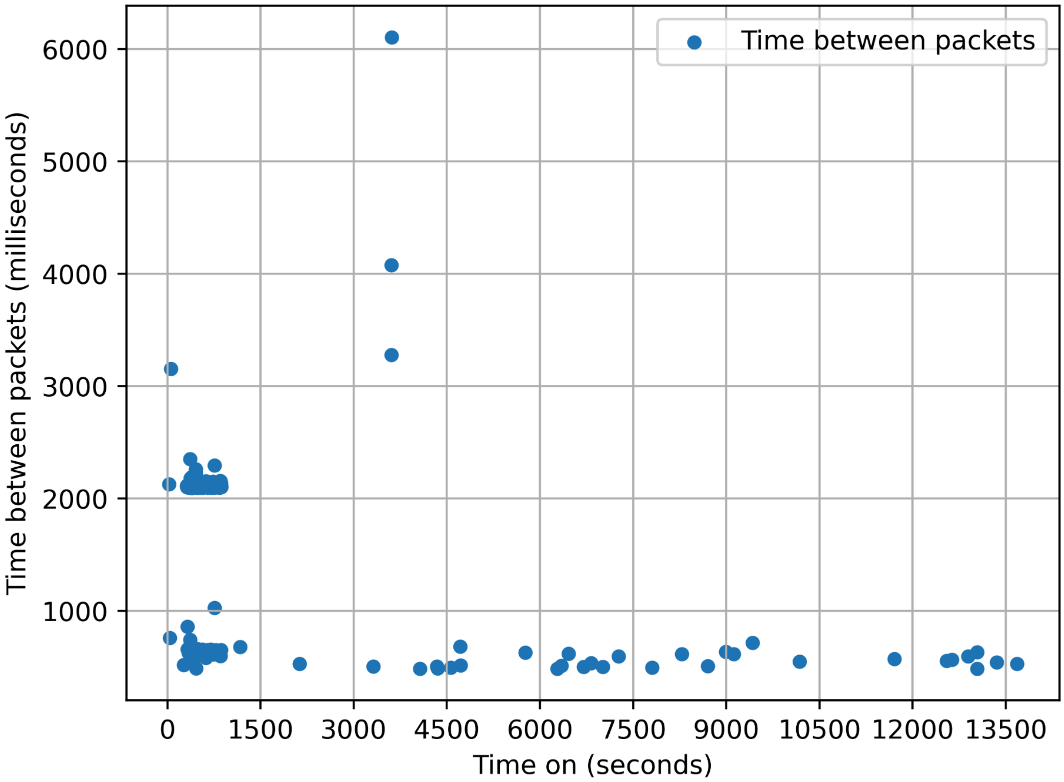
Acceleration values during flight [11]



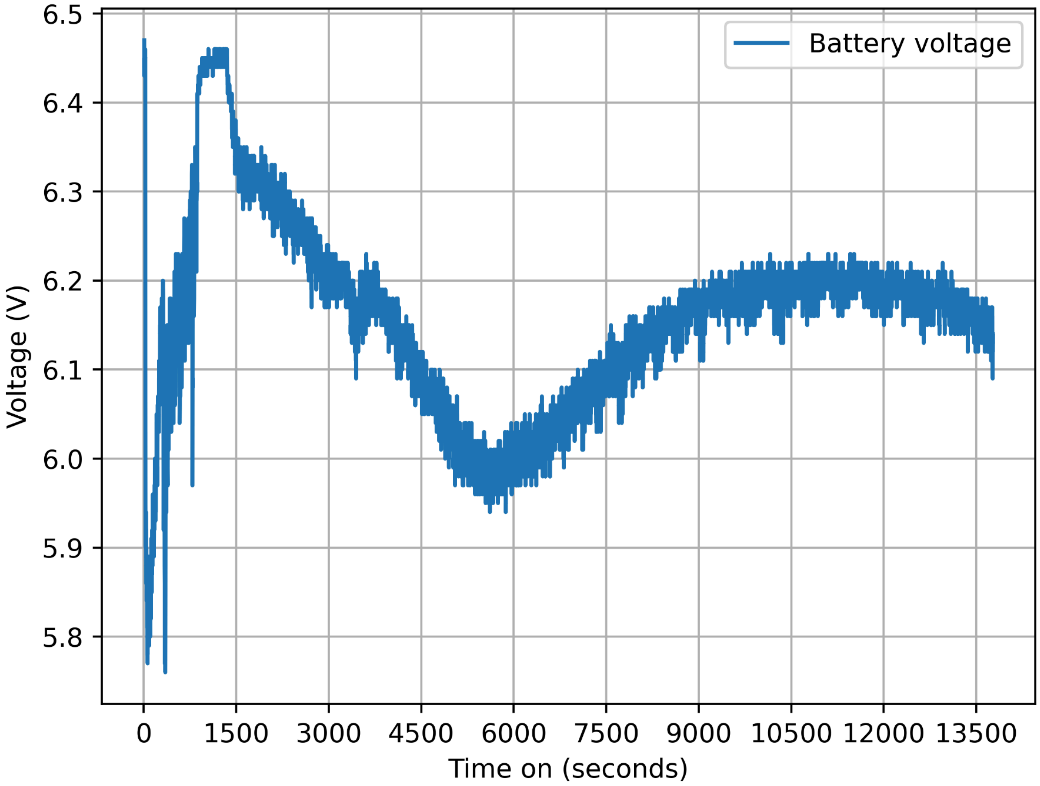
Gyro values during flight [12]



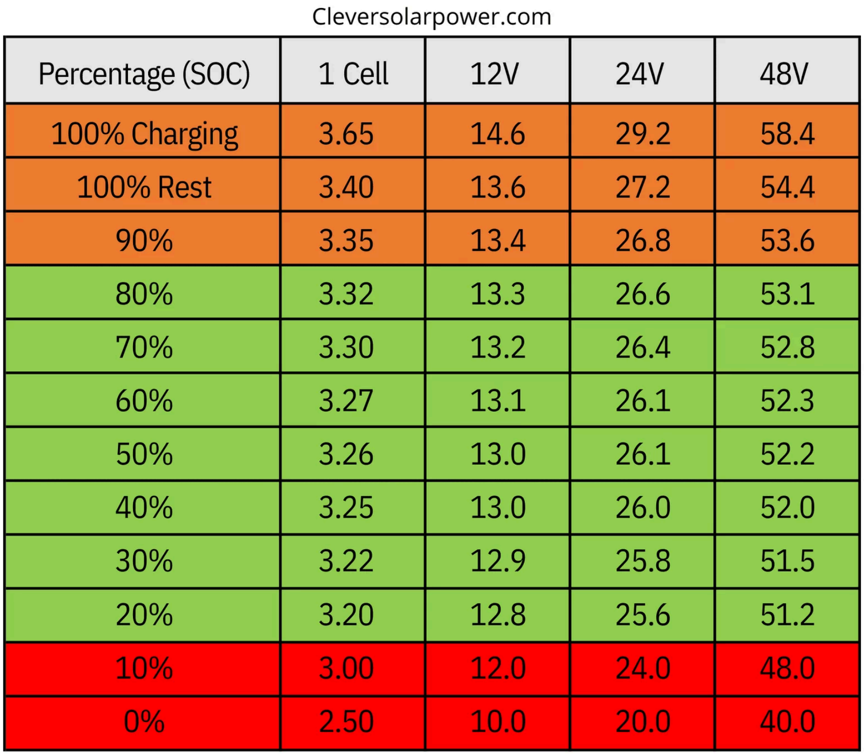
Time between logged telemetry packets [13]



Time between extreme delay between logged telemetry packets [14]



Battery voltage [15]



Cleversolarpower.com

| Percentage (SOC) | 1 Cell | 12V | 24V | 48V |
|---|---|---|---|---|
| 100% Charging | 3.65 | 14.6 | 29.2 | 58.4 |
| 100% Rest | 3.40 | 13.6 | 27.2 | 54.4 |
| 90% | 3.35 | 13.4 | 26.8 | 53.6 |
| 80% | 3.32 | 13.3 | 26.6 | 53.1 |
| 70% | 3.30 | 13.2 | 26.4 | 52.8 |
| 60% | 3.27 | 13.1 | 26.1 | 52.3 |
| 50% | 3.26 | 13.0 | 26.1 | 52.2 |
| 40% | 3.25 | 13.0 | 26.0 | 52.0 |
| 30% | 3.22 | 12.9 | 25.8 | 51.5 |
| 20% | 3.20 | 12.8 | 25.6 | 51.2 |
| 10% | 3.00 | 12.0 | 24.0 | 48.0 |
| 0% | 2.50 | 10.0 | 20.0 | 40.0 |

LiFePo4 one cell battery voltage vs state of charge[1] [16]

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[1] https://cleversolarpower.com/lifepo4-voltage-chart/

# Lidojuma izvērtējums

**Teorētiskais krišanas ātrums:**

Lidojumā tika izmantots Gredzenveida izpletnis ar šādiem parametriem:
A = 0.8656 $m^2$
Cd = 0.61 – Eksperimentāli noteikts Svīres lidojumā.
Pārējie parametri:
ρ = 1.25 $\frac{kg}{m^2}$
g = 9.81$\frac{m}{s^2}$
m = 2 kg
Tiek veikts pieņēmums, ka
$Cd_{kaste} = 1; \ A_{kaste} = 0.065\,m^2$

$$mg = F_1 + F_2$$

$$m \cdot g = \frac{Cd_{izpletnis} \cdot \rho \cdot v^2 \cdot A_{izpletnis}}{2} + \frac{Cd_{kaste} \cdot \rho \cdot v^2 \cdot A_{kaste}}{2}$$

$$v = \sqrt{\frac{m \cdot g \cdot 2}{\rho \cdot (Cd_{izpletnis} \cdot A_{izpletnis} + Cd_{kaste} \cdot A_{kaste})}} = 7.28\ \frac{m}{s^2}$$

**Reālais krišanas ātrums:**

Veicot datu apstrādi tika iegūts, ka krišanas ātrums piezemēšanās brīdī ir bijis 6.98 $\frac{m}{s^2}$.
Ņemot vērā, ka reālās dzīves apstākļi visdrīzāk atšķīrās no aprēķinos izmantotajām vērtībām, tad šāda maza kļūda ir pieņemama. Visdrīzāk Kastes radītā berze ir bijusi nedaudz lielāka, kā arī iespējams, ka gaisa blīvums bijis nedaudz lielāks.