

Flight Report
HARPIA

Team 01 - EuRoC 2026 Flight Report

Aerospace Team Graz (ASTG)
Graz University of Technology

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HARPIA EuRoC 2026 Flight Report

Test ID	ALL_04
Test Name	HARPIA EuRoC 2026 Flight
Date	17.10.2026
Location	Campo Militar de Santa Margarida, Portugal
Module	ALL
Authority	Lukas Kolland
Environment	27 °C, clear sky
Checklists	All checklists in CL_Checklists

Overview

This report documents the flight of HARPIA at the European Rocketry Challenge (EuRoC) 2026. The purpose of the report is to provide an overview of the launch operations, flight performance, subsystem behavior, recovery, post-flight inspection, and identified anomalies.

The report is based on flight computer data, telemetry data, propulsion measurements, recovery electronics, onboard video footage, ground station logs, and the post-flight inspection of the vehicle.

In the first launch window, the launch was scrubbed after successful operations until oxidizer top-off, where the oxidizer vent valve servo malfunctioned. After switching the servo during the first launch window, a second attempt was made for the second window.

Due to an error in communications with EuRoC, the arming of the recovery system was only done right before the launch window opened instead of right away. The arming of the student researched and developed (SRAD) system malfunctioned, and there was no time for quick fixes. It was considered to fly only with the commercial-off-the-shelf (COTS) CATS Vega system, but after discussion with EuRoC MCO this was not allowed, and the launch was pushed back into the third launch window, 16:00 to 17:00.

Following a nominal filling procedure, the rocket was ready at the start of the launch window, and after clearance for final irreversible operations, the procedure continued. The lift-off was at 16:07:50, and engine shutdown was after 8.06 s. At an official apogee of 9196.6 m, measured by the CATS Vega, the first deployment (FD) triggered and ejected the drogue parachute. With a stable descent until 450 m, where the second deployment (SD) was triggered and the main parachute was ejected, the rocket was recovered with minimal cosmetic damage.

The mission overall was a complete success, from integration and procedure to the final flight.

Table 1: Key flight results.

Apogee, official	9196.6 m
Apogee, SRAD GNSS	9417.5 m
Max. speed	600.1 m/s
Max. Mach number	1.72
Max. acceleration	88.9 m/s^2
Rail exit velocity	40 m/s
Engine burn duration	8.06 s
Time to apogee	41.6 s
Total flight time	383 s

First Launch Attempt

Propulsion

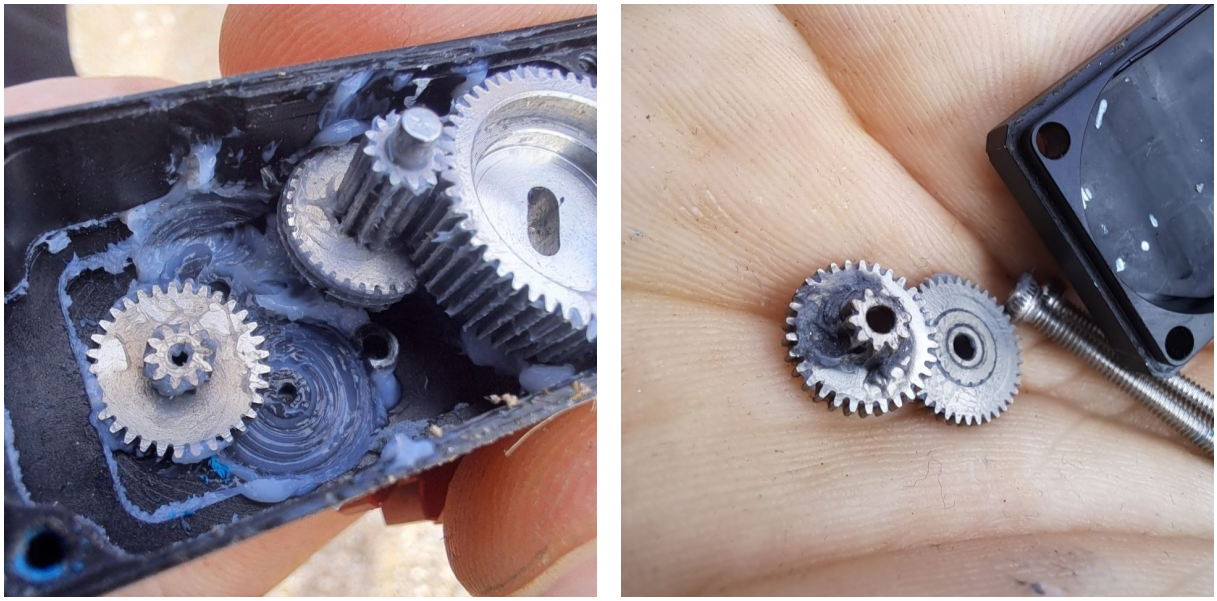
The first scrub occurred during the tanking procedure in the first launch window. Fuel as well as oxidizer were already loaded. During the loading of pressurant gas and the pressurizing of both propellant tanks, an issue occurred with closing the oxidizer vent valve.

The vent valve did not close even after reopening and attempting to re-close it. The angle sensor of the valve showed that each attempt to open and re-close it left the valve at an angle that was further open than before. This led to the decision to scrub in the first launch window.

The servo actuating the oxidizer vent valve had already failed at Hot-Fires before and was immediately suspected as the failure point. The fuel tank was depressurized, and specialized personnel were sent to the front as soon as possible to exchange the servo for a spare one.

The panels enclosing the middle fluid system where the servo is located were removed to access the servo. No freezing or overheating was observed that could have caused this issue. The servo was replaced and adjusted using the angle sensor and feedback from the launch rail personnel. The extension to plug in the servo and connect it to the CANary was essential to be able to make this switch this quickly. During previous testing, a lot had to be dismounted to access the usual plug-in spot; thus, this extension was added.

Although the servo was the failure point again, it failed in a new way. The internal gearing is suspected to have slipped, which caused the different valve positioning after the opening and closing attempts. Discoloration of the grease in the gearing further supported the theory of internal gearing issues. Additionally, the valve could be activated but did not reach the correct positions. Figure 1 shows images of the damaged servo after extraction.



(a) Internal gearings with ripped teeth of a gear. (middle gearing)

(b) Gearings of the servo with dark grease due to metal abrasion.

Figure 1: Gearings of the servo after failure to close the oxidizer vent valve.

During the servo exchange, a visible N_2 leak was confirmed due to residue from leak finder and condensation. It was visible in the data before but minimal enough to not be addressed further.

The N_2 purging of the middle fluid as well as the tailcone was tested for a longer time during this flight attempt. Initially, after it was activated, the pressure was around 2.5 bar, which was in the expected and ideal range. The flow and pressure are regulated using a manual pressure regulator. Due to the slowly decreasing bottle pressure, the pressure regulator slowly opens more, and purging pressures slowly rise to 8 bar. This emptied the 300 bar N_2 bottle within around 1 h. For future projects, a different way to regulate the flow has to be considered.

Second Launch Attempt

Avionics

During the first scrub and in order to guarantee safety while the vent valve servo was changed, all pyrotechnics were disarmed. In preparation for the second launch window, the launch rail crew waited for the go-ahead from EuRoC to continue with arming the rocket's pyrotechnics. During the final minutes at the rail and after the go-ahead was issued, the recovery system was armed again. However, only the CATS Vega system successfully armed; the SRAD system did not arm even after repeated attempts. Due to time constraints, the launch rail crew had to leave without the ability to investigate further.

A launch only with the CATS system was not allowed by EuRoC. Therefore, the launch attempt in the second launch window had to be scrubbed.

After the second launch window closed, the team approached the launch rail again and tried to fix the problem by testing whether the GSE or electrical umbilical connection was at fault. After measuring the correct arming voltage on the USB-C electrical umbilical cable, it was concluded that the issue had to be on the arming PCB in the rocket or the electrical umbilical FPC in the rocket.

In order to gain access to the avionics stack, AST removed the recovery section, with the nosecone attached via shear pins, while the rocket was vertical on the launch rail. After the avionics stack was removed, the arming paths were measured, and a short circuit to ground in the SRAD arming path was identified. After the necessary soldering was done to remove the short, the avionics stack was mounted in the AVI tube again, and the nosecone was re-attached properly.

After confirming the CAN bus connection to the nosecone was established, the tracking CATS Vega in the nosecone was activated again, and the final launch procedures could proceed for the third launch window. Both the SRAD and COTS systems were armed successfully.

Propulsion

While the avionics issues were being tackled, the pressures for both propellant tanks were kept below 33 % of the maximum expected operating pressure (MEOP). The high-pressure nitrogen tank was left pressurized as it is stored in a COTS composite overwrapped pressure vessel (COPV). The bottles used for the launch could not pressurize the COPV to exceed the pressure it was tested to.

Empty gas bottles were replaced by new ones to set up everything for the following launch attempt.

The continuous depressurization of the oxidizer and thawing in between led to a lot of condensation and ice forming at the bottom of the oxidizer tank. The oxidizer quick disconnect (QD), which was disconnected during the first launch window, was reattached with some difficulties. The ice also formed on the QD, but after warming it, re-attachment was possible.

Aerostructure

After the second launch window closed, the nosecone with the recovery section had to be removed from the avionics section to get access to the avionics stack, because the fault had been traced to there. To save time, the decision was made to keep the launch rail upright and remove only the recovery section with the nosecone from the avionics section. The recovery section could successfully be removed and safely laid to the side. Then AVI could get access to the avionics stack.

After AVI managed to fix the issue, the recovery section was very carefully placed on top of the avionics section again and screwed on tightly. This procedure could only be done because no radax screw was right where the rail profile runs and therefore all screws could be accessed.

Flight Configuration

The final flight configuration of HARPIA is summarized in Table 2.

Table 2: Flight configuration of HARPIA.

Parameter	Value	Unit
Dry launch mass	34.0	kg
Fuel mass	6.2	kg
Oxidizer mass	15.9	kg
Pressurant mass	2.5	kg
Total launch mass	58.6	kg
Fuel tank pressure	42	bar
Oxidizer tank pressure	35	bar
Pressurant tank pressure	284	bar
Launch rail angle	84	°

Environmental Conditions

The environmental conditions shortly before launch are summarized in Table 3. The weather was sunny with light cloud cover in the first two launch windows, but sunny in the last one.

Table 3: Environmental conditions at launch.

Parameter	Value	Unit
Ambient temperature	26.6	°C
Ground level wind speed	3.5	m/s
Wind direction	NW 303	°
Atmospheric pressure	995	hPa

Launch Operations

The procedure followed the checklist CL_ALL_01 without exceptions. The oxidizer tank was full at approximately 15:45, and the procedure was on hold until GO from EuRoC for the first irreversible operation, which was the oxidizer QD disconnection. After getting the final GO/NOGO call from EuRoC, the procedure was continued, and the rocket was ready for lift-off at 16:06. After that, the final authorization for launch from EuRoC's MCO was given, and the terminal countdown was initiated.

Flight Timeline

The main flight events are summarized in Table 4.

Table 4: Timeline of the HARPIA flight.

Event	Time
Ignition	T -1.70 s
Fuel Main valve opening	T +0.00 s
Ox Main valve opening	T +0.08 s
Holddown fired and Lift-off	T +0.20 s
Rail exit	T +0.76 s
Engine shutdown	T +8.24 s
Apogee and Drogue Deployment	T +41.6 s
Main deployment	T +307 s
Touchdown	T +383 s

The time until engine shutdown was programmed to be 8.24 s as this was the time which was estimated to result in the target burn duration of 8.09 s. The discrepancy stems from an additional 75 ms added, which is the delay before the oxidizer main valve is opened after the fuel main valve. Another 75 ms are added to take the holddown into account, which is estimated to open after said time. This takes into account the time the sensors wait to fulfill the criteria as well as the mechanical steps it takes to remove the pin.

Flight Trajectory

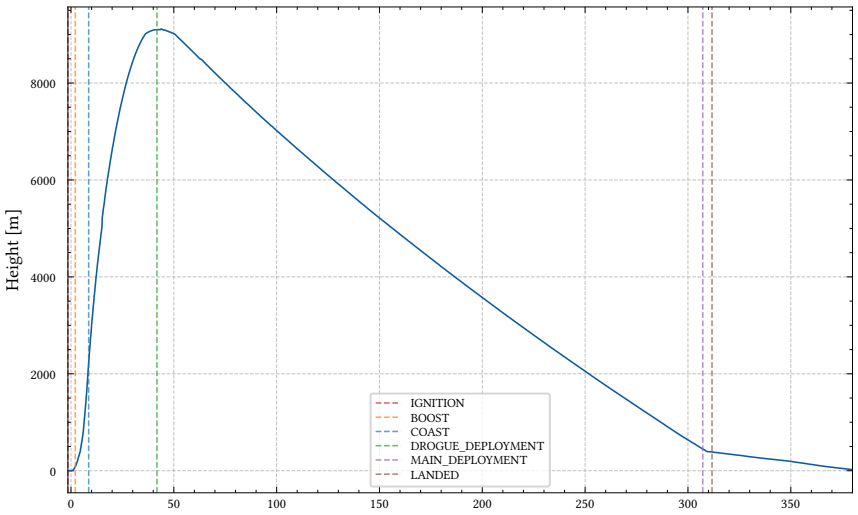


Figure 2: Flight curve calculated by the onboard extended Kalman filter with the start of the different flight states.

Altitude

Table 5 shows the received altitudes from all systems one sample before lift-off and at apogee. CATS 2 data only has AGL altitude available, as it was mounted inside the carbon fiber avionics tube and had no global navigation satellite system (GNSS) lock, which is used for ASL calculation.

Table 5: Altitudes as reported by the onboard flight computers

Source	Before lift-off (ASL)	Apogee (ASL)	Apogee (AGL)
CATS 1 (official tracking)	126.8 m	9323.4 m	9196.6 m
CATS 2 (avionics stack)	–	–	9243.8 m
SRAD flight computer	147.5 m	9259.2 m	9111.8 m
SRAD GNSS 1	170.6 m	9589.1 m	9418.5 m
SRAD GNSS 2	172.2 m	9589.2 m	9416.9 m

Table 6: Corrected apogee altitudes

Source	Apogee (AGL)
SRAD TE barometer 1	(9431.5 ± 22.5) m
SRAD TE barometer 2	(9434.3 ± 22.5) m
CATS 1 (official tracking)	(9444.4 ± 22.5) m
CATS 2 (avionics stack)	(9435.4 ± 22.5) m
Barometric, combined	(9433.9 ± 22.5) m
GNSS, mean of both receivers	(9417.5 ± 1.8) m

Altitude correction

The onboard systems convert pressure to altitude using the International Standard Atmosphere (ISA). For the corrected values, the offset of each barometer was first removed using the absolute pad pressure of 994.7 hPa, derived from nearby weather stations. The altitude was then calculated with the actual temperature and humidity profile of the day, taken from the Lisbon radiosondes and four weather models. CATS 1 is not used in the combined value because its pressure port was disturbed by the airflow in flight.

Error estimation

The barometric uncertainty comes mainly from the weather data: an error of only 0.5 K in the mean air temperature already shifts the apogee by about 18 m. The GNSS error was measured from about 3 h of data recorded with the rocket standing on the pad. The GNSS apogee altitude is the difference between two readings taken 42 s apart, at lift-off and at apogee. Its error is therefore not the absolute GNSS error but how much that error drifts within 42 s. This drift was measured from about 3 h of data recorded while the rocket stood on the pad: since the true height was constant, any change in the reported height is pure error. Across all 42 s intervals in this data, the reported height changed by 1.5 m (1σ), and this drift is assumed to be the same in flight. All uncertainties are 1σ.

Difference between received and corrected altitudes

The received barometric altitudes are about 200 m too low because ISA assumes a colder atmosphere than on the flight day, when the air was on average about 8 K warmer. Warmer air is less dense, so the same pressure drop corresponds to a greater height. The spread between the onboard systems comes from the different offsets of their barometers. GNSS does not depend on the atmosphere, so its received and corrected values agree, and the corrected barometric result agrees with it within its uncertainty.

GNSS Tracking

Figure 3 shows the closely overlapping SRAD GNSS tracks (blue) and the CATS ground track (orange). Only SRAD positions with `FIX_OK` were included. Lighter sections connect gaps without a valid fix; CATS gaps longer than 2 s were treated as signal loss.



(a) Ground tracks.



(b) 3D SRAD trajectories with ground projections.

Figure 3: SRAD (blue) and CATS (orange) GNSS tracks. Lighter sections indicate interpolation across gaps.

The launch and touchdown coordinates were taken from the first and last valid positions recorded by each SRAD receiver.

Table 7: Launch and last position coordinates.

Location	Module	Latitude	Longitude
Lift-off	GNSS 1	39.390 416°	−8.288 663°
	GNSS 2	39.390 428°	−8.288 668°
Landing	GNSS 1	39.355 806°	−8.265 190°
	GNSS 2	39.355 806°	−8.265 187°

Table 8 gives the horizontal distances from each receiver's first position to its highest and last valid recorded positions.

Table 8: Horizontal distances from the first recorded position.

Module	Apogee	Last position
SRAD GNSS 1	2308 m	4342 m
SRAD GNSS 2	2312 m	4344 m
CATS	—	4224 m

Propulsion

Observations

Due to the scrub in the first launch window, oxidizer was left in the tank for the whole day and depressurized via the vent valve if needed. This caused the humidity in the air to freeze at the bottom of the tank after the nitrogen purging bottle ran out of purging gas. After some more time, condensation on the angle sensors of the main valves caused them to show wrong values.

This could not be prevented and has been seen before on Hot-Fire days. The angle sensors are used for the feed forward (FF) control of the E-Reg and are especially important for the start-up. The angle sensors were out of the nominal range of −5° to 95°, which led the E-Reg to use its fallbacks.

The fueling and tanking procedure occurred without anomalies and was carried out according to the checklists. The minor leak of the nitrogen was visible in the data again, but due to difficulties reaching the upper fluid system, the leak was accepted. The pressure loss was within an acceptable range, and fixing it would have meant derailing the rocket. The stack was pressure tested in the days before the launch, so the reason for this leak to occur is unknown.

The launch looked nominal in terms of the flame as well as the burn duration. There were no visible combustion instabilities or plume of smoke at the engine.

Performance and Evaluation

The pyrotechnic ignitor was ignited right before the launch at T-1.7 s. The ignitor successfully ignited the engine even though it burned slower than in all previous Hot-Fire tests. The ignitor was ejected and extinguished on startup as usual and found near the launch rail. Only small areas of the ignitor were burning, most likely caused by the pyrotechnic mass being

very cold at the time of ignition due to the extended time the rocket was kept loaded and cooled.

After the first scrub, the ignitor was briefly removed from the engine in order to observe if condensation had formed on the ignitor, causing it to absorb moisture, because this was a known problem causing ignition problems in moist weather. No moisture was observed, but the ignitor's temperature was observed to be far below ambient temperature, presumably around 0 °C.

In hindsight, the ignition delay should have been chosen to be 1 to 2 seconds longer for the ignitor to be at full burn at ignition, but reprogramming of the ignition delay was not possible at this point, and the extended stand-down time was not anticipated. On further thought, the limited burning of the ignitor shows the engine igniting with lower ignition energy, providing further evidence that the torch ignitor will be sufficient to ignite it in upcoming tests.



Figure 4: Pyrotechnic ignitor used for the flight with all e-matches fired, but only small amounts of the pyrotechnic mass burned.

Figure 5 and Figure 6 show images of the engine during lift-off and flight. The flame looks fuel-rich for the whole burn duration but is consistent with the tests. The oxidizer-to-fuel ratio (O/F) was chosen so conservatively to make sure there would be no damage to the flight engine. Due to huge manufacturing delays of the chamber, the time-intensive film cooling holes were not added, which reduced safety in terms of temperature. This, as well as an overall well-performing engine, led to the decision to leave the O/F at a conservative value of 2.7.



Figure 5: Collage of images showing the engine on the rail and just after leaving it via 360° camera on top of the launch rail.



Figure 6: Collage of three rail camera images to show the launch.

During startup of the engine, one of the 3 thrust load cells started showing a constant reading of −1000 N while the other two showed average thrusts of 2727 N and 3047 N. The one showing −1000 N already went into saturation before the procedure started and was known to be non-functional. The measurements of the other two load cells seem too high, especially when interpolating the thrusts of the two ”good” load cells for the third one. Because of this, the thrust was also calculated from the chamber pressure in the following way: Using the data collected from Hot-Fire 6.2, the integrated thrust was divided by the integrated chamber pressure. The resulting coefficient was then multiplied by the chamber pressure from the flight to get an approximate thrust curve.

Because the two chamber pressure sensors varied quite a bit, a simulation with the thrust calculated from chamber pressure sensor 1, 'Calc 1', a simulation with the thrust calculated from chamber pressure sensor 2, 'Calc 2', as well as one with the average between the two pressure sensors, 'Calc Avg', are evaluated. As the thrust is only approximated in this way, the best way to verify which thrust is the most realistic was to make a RocketPy simulation using each of the three curves and compare the simulated apogees and rail-exit velocities with the measured flight values. From this comparison, it was very clear that the calculated thrust from the average of the two pressure sensors matched reality the best and will be assumed to be the right thrust curve.

For transparency, all chamber pressure readings, including the averaged one, and the resulting thrust curves are plotted in Figure 7. Table 9 shows an overview of expected as well as observed propulsion characteristics. It has to be noted here that the chamber pressures deviate enough from each other that the average pressure of both combustion chamber sensors is mentioned. Table 10 also gives an overview of how much the thrust calculated from the pressure readings varies.

Table 9: Measured propulsion performance during flight.

Parameter	Predicted	Measured	Unit
Burn time	8.09	8.06	s
Combustion pressure	26	26.9/22.5	bar
Fuel tank pressure	42	42.2	bar
Oxidizer tank pressure	35	34.3	bar

Table 10: Measured thrust during flight.

Parameter	Predicted	Calc 1	Calc 2	Calc Avg	Unit
Average thrust	4867	4305	5150	4728	N
Total impulse	38920	35305	42236	38770	Ns

Figure 7 shows the propulsion data collected during the flight.

Overall, the data shown in Figure 7 does not deviate too much from those of the previous Hot-Fires with this chamber. The Hot-Fire 6.2, which was used in the flight simulation, can be seen in Figure 8 as a reference and comparison.

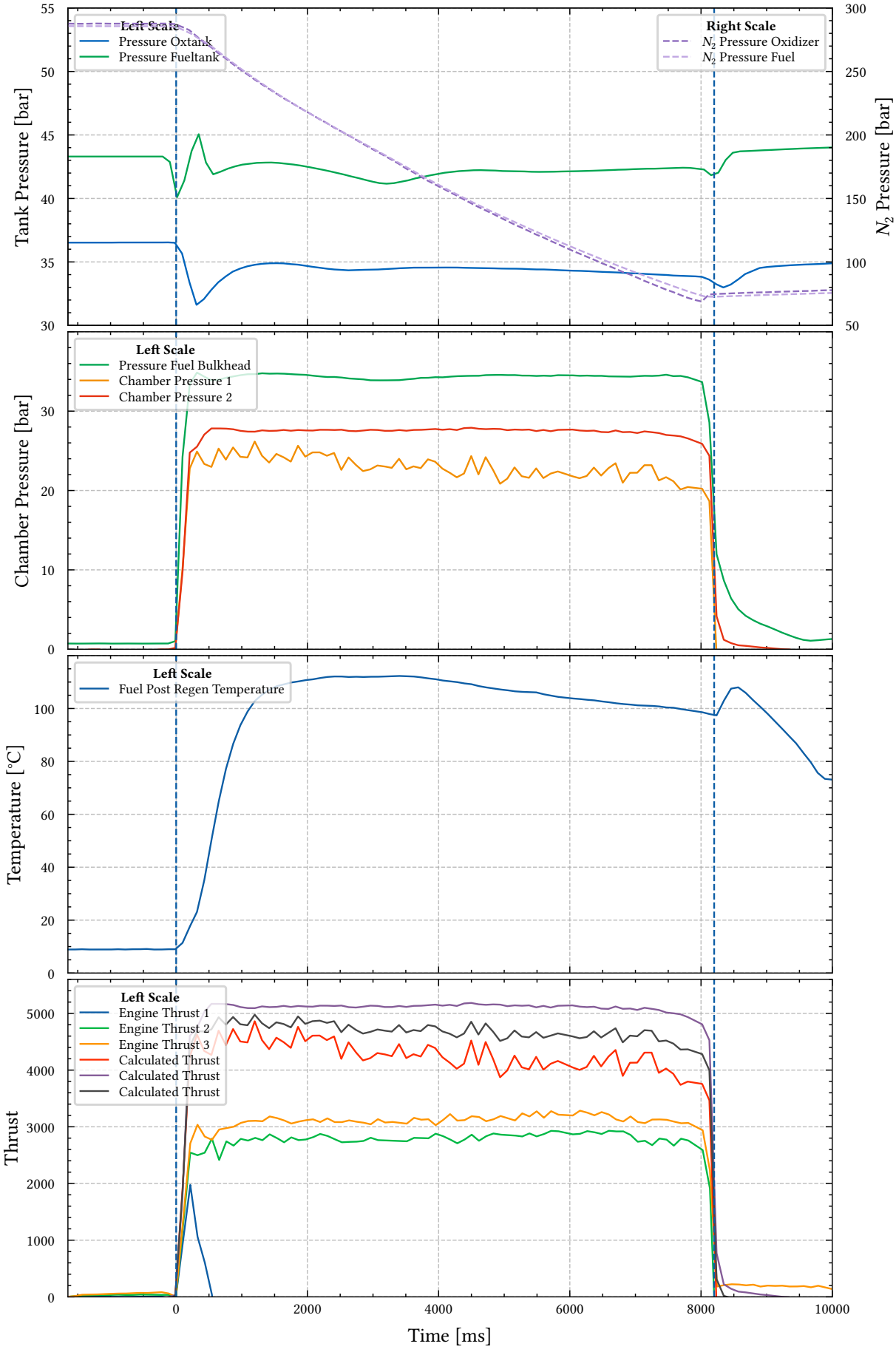


Figure 7: Propulsion data during the boost phase of the flight.

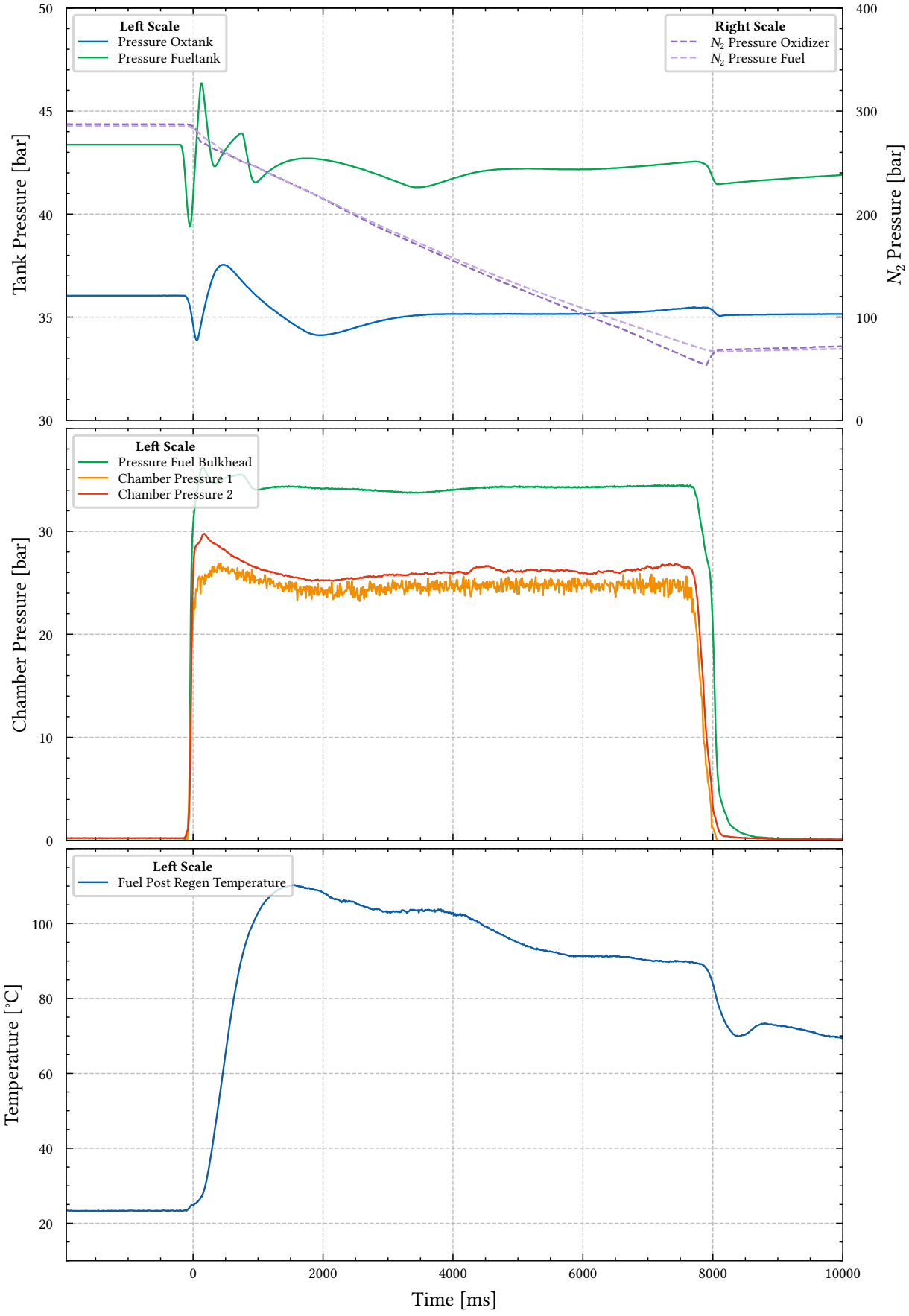


Figure 8: Propulsion data from the Hot-Fire 6.2 as comparison.

The E-Reg controller was able to keep tank pressures more or less stable during the flight. In the first second of the burn, the E-Reg has an initial dip and, for the fuel E-Reg, an overshoot, but afterwards it settles around the ideal pressures within a range of ± 3 bar. This implies that the FF control, which is important mainly at the beginning of the burn, has to be improved.

The oxidizer E-Reg was only able to regulate to an average pressure of 34.3 bar over the whole burn. This was also the case during the Hot-Fire. The reason for this may be that the N_2 downcomer has to go through the whole fuel tank to be able to pressurize the oxidizer tank. The lower pressure of the N_2 above the oxidizer tank further strengthens this theory.

The temperatures of the fuel in the cooling channels rose to 110 °C and stayed there for the rest of the burn. This compared well with previous Hot-Fires. The chamber pressures were a bit above average for one pressure sensor and a bit below average for the other.

Overall, the fluid system performed nominally except for one initial servo failure. The procedures at the launch rail in terms of fuel filling and ground support equipment were fully nominal for propulsion. The loading of oxidizer and nitrogen, as well as the pressurization and launch, occurred without anomalies as well. Overall, the engine performed as expected. The thrust was stable throughout the burn and was able to boost the rocket to an apogee of 9417.5 m, which was measured with the SRAD GNSS.

The depressurization procedure after burnout was able to fully depressurize the rocket. After a 5 s hold, the oxidizer was depressurized through the main valve. Apogee occurred, and the fuel dumping through the main valve was shifted back to after apogee instead of before. Thereafter, all four vent valves opened and fully depressurized all systems. The fuel tank was last to depressurize as the solenoid for fuel venting has the smallest orifice diameter. When the pressures of the high-pressure system and the tanks equalized, the E-Reg ran into an abort. As the goal was to depressurize, this was of no consequence; it should just be noted for future reference.

The after-flight inspection of the propulsion stack showed that there was no damage to the propulsion stack. At most, there may have been residual dust or slight damage to smaller stickers on the tanks showing the sponsor logos. Figure 9 shows the lowest part of the propulsion stack which touched down first.

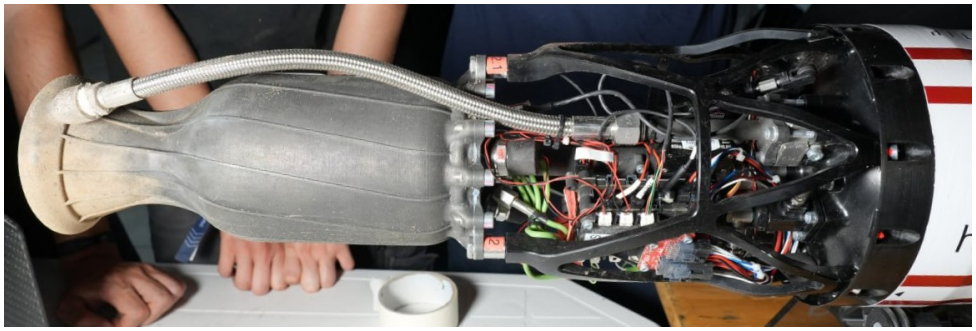


Figure 9: Lower fluid system and engine after the flight.

Aerostructure

Flight simulations

The original flight simulation as submitted to the RocketPy team the day before launch contained inaccuracies regarding the fin sizing of the rocket, resulting in an alarmingly high

static margin (3.5 to 5.2 calibers) being reported. The error originated from a misinterpretation of the CAD expressions for fin sizing (root chord, tip chord, sweep length, span), which did not represent the actual measurements of the fins. The issue was noticed and promptly fixed after a EuRoC official in contact with ASTG vaguely expressed growing concerns regarding overstability.

The flight simulation, as discussed in the morning briefing with the RocketPy team, was simulated using the thrust curve from Hot-Fire 6.2 and GFS weather forecast data from the first planned launch window at 10:00 and predicted an apogee of 9515.8 m after 41.5 s and a top speed of 615.6 m/s. Thus, the simulated apogee and top speed are within ≈1% and ≈8% of the measured data of the SRAD systems, respectively.

Reanalysis with the GNSS tracking data, updated weather conditions for the proper launch time, and in-flight thrust data results in a predicted apogee of 9339 m.

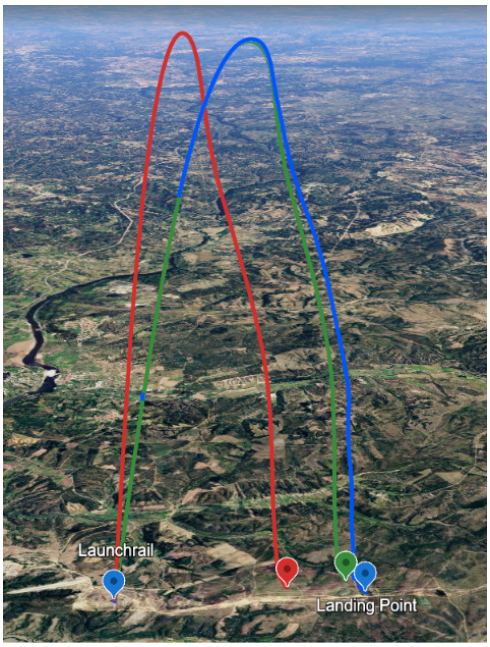


Figure 10: GNSS tracking Data (blue) and simulated flight path for 84° (red) and 81° (green) rail inclination.

The reanalysis also suggests that the rail inclination deviated from the simulated 84° target. A simulated rail inclination of 81° closely recreates both the angle of the ascent phase and the amount of downrange distance covered both before and after apogee (see Figure 10). This could suggest that the real rail inclination was lower than planned, with the main suspect being the aluminum truss profiles flexing downward after the inclination angle is set.

Integration

The rocket was integrated in two steps. The pre-integration took place in the evening before the launch day, when the nosecone and recovery section were assembled, as well as the whole propulsion stack, including the avionics section with the avionics stack and the tailcone at the bottom of the propulsion stack. The pre-integration went smoothly and according to the checklists. All system checks could be done without any time pressure on the launch day.

For the launch day itself, only connecting the REC radax to the upper AVI radax needed to be done after the igniters were inserted into the recovery section and the last system checks by avionics were finished. When checking the ox vent valve in the Valvebay section by activating it, a click sound was heard when the valve closed again. Since the three radial cameras are located on the hull panels, all having a cable wired to the CANary, they were checked. Therefore, the corresponding panel was removed, and the cables and the plug of the camera were inspected. A small indent on the plug was found, and to prevent that from happening again, the cables were taped to the Valvebay structure. After closing the panel again, the ox vent valve was actuated to check if the solution was working, which it did. Other than that, no complications occurred during integration on the launch day, and the rocket was fully integrated and ready to be brought to the MCO as soon as the morning briefing was finished.

Holddown System

The holddown system worked as intended. The ejection was triggered by the chamber pressure being 20 bar for 50 ms after the ignition. The chamber pressure was at 25 bar with the load cells measuring below the threshold of 3200 N. Figure 11 shows data of the holddown actuation by the chamber pressure. The pin got caught by the 3D-printed pin catchers, and the housing didn't take any damage.

In the following pictures, the holddown after the flight is shown. Everything got very sandy due to the lift-off. In Figure 12, one can see the bent lower plate of the housing, which got unhooked from the back plate since it was only slid on. Figure 13 shows all the dirt that was collected inside the housing. The system used two charge cups with two igniters each for redundancy. All four igniters fired, as can be seen in Figure 14, and the pin was ejected. The pin took no damage, only a lot of dust; see Figure 15.

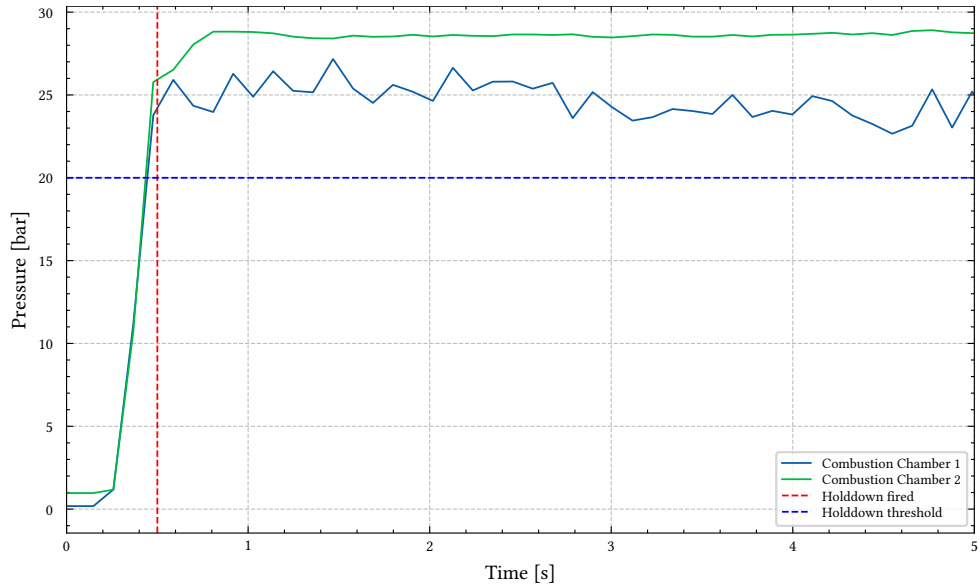


Figure 11: Actuation of the holddown system triggered by the chamber pressure.

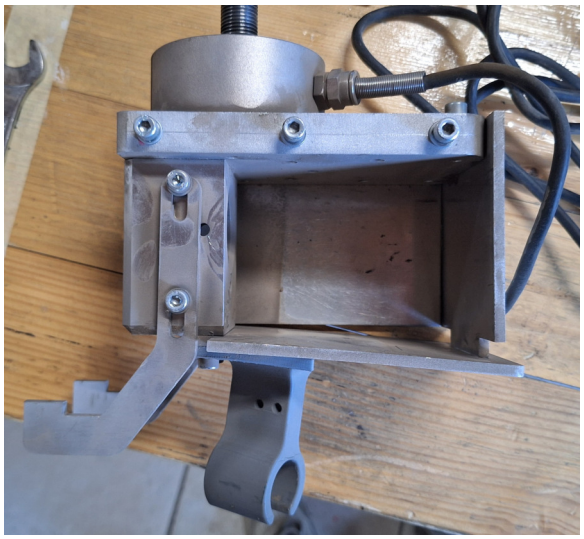


Figure 12: Housing with the bottom plate a bit bent.



Figure 13: Housing on the inside with a lot of dirt.



Figure 14: All four fired igniters in the two charge cups.



Figure 15: Holddown pin after the flight.

Pitot-Static-Probe

The pitot-static probe (PSP) was inserted into the cradle and the tip protection installed. Said protection was removed prior to erecting the launch rail.

The PSP functioned as expected, probing both dynamic and static pressure and transporting said pressures through the tubes, connectors, and cradle to the pressure sensors. Examination of the pressure data showed no signs of leakage.

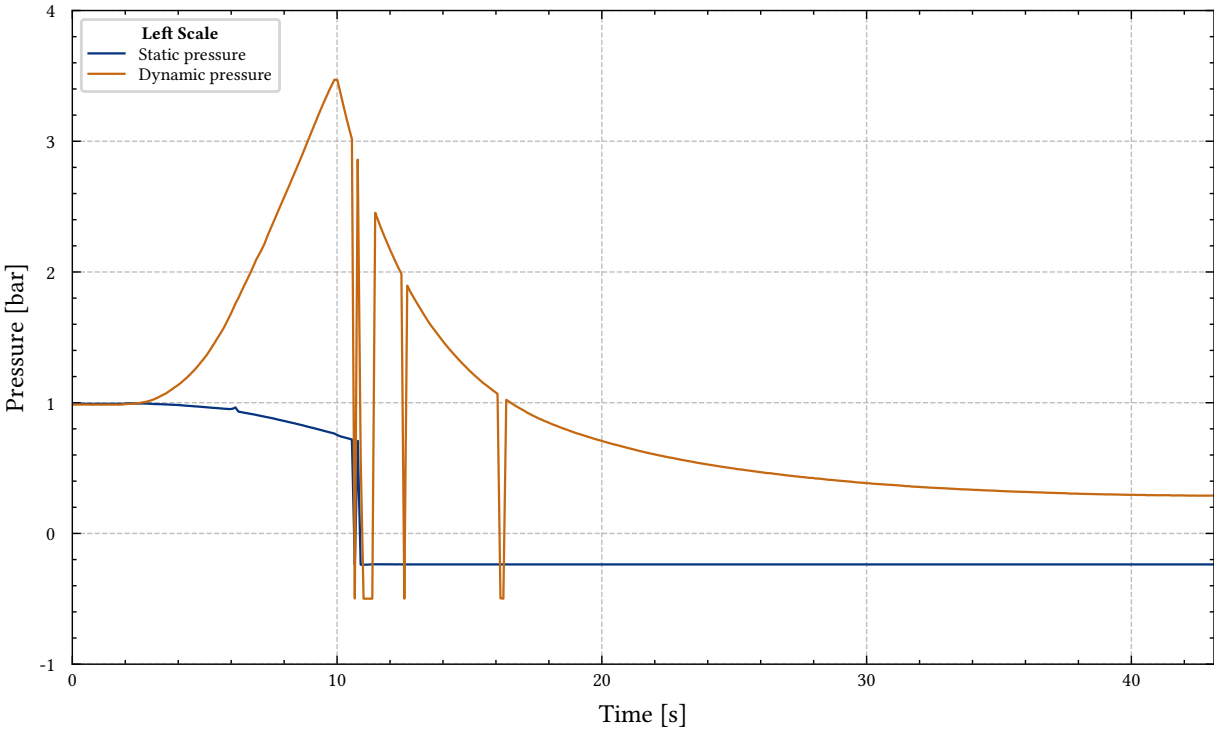


Figure 16: Plot of both pressure sensor readings.

Due to an issue in the sensor electronics, the static pressure sensor data went missing after engine shutoff. The dynamic pressure sensor data also cut off several times during the coast phase, but recorded readings until apogee, when the nosecone separated, cutting power from the electronics.

The calculated maximum speed was determined to be approximately 1.72 Mach. This is only a rough calculation but matches both the flight simulation and the Kalman filter speed data.

Post-Flight Inspection

The rocket was fully recovered and, according to the post-flight review, had minimal damage. As the pictures in Figure 17 show, the major damage was the paint job that chipped off. In the recovery section, both camera covers were dismounted due to the flight forces in ascent and took away some paint and stickers beneath them. In the avionics section, the stickers around the sun sensor cutouts were already a bit lifted off from the shell due to further adjustments to the cutout after the stickers were placed. This is most likely the reason that these big paint parts chipped off in the avionics section. The same explanation is presumed for the chipped paint on the tailcone around the QD cutout.

During flight, the touchdown protection was dismounted. The dual lock strips that were used to connect the touchdown protection to the tailcone disconnected. This is suspected to be due to the airflow produced by the NACA ducts, which dismounted the touchdown protection through pressure buildup inside the tailcone. Another possibility would be that the U-shaped cover of the touchdown protection, which was designed to prevent the touchdown protection from sliding off the tailcone during touchdown, produced too much drag during the rocket's ascent. Even though the rocket landed without a touchdown protection, the tailcone did experience minimal damage in this circumstance.



Figure 17: Condition of the vehicle after recovery.

Avionics

All states besides the landed state were triggered correctly during flight by the automatic state detection, as seen in Figure 2. This is due to a short spike in velocity above 0 during main descent, as seen in Figure 19. It can be avoided by increasing the landed state detection duration threshold.

For the flight, all ”hard” aborts were deactivated. Previous tests showed that if the engine is used as tested, a sensor reading that would trigger an abort indicates a damaged sensor and not an event requiring an abort. Soft aborts, on the other hand, are still left in as these are used to tell the system how to react to certain non-nominal situations. This was supported by a highly configurable abort configuration file which helped to easily communicate what aborts are implemented.

Overall, the highly configurable CANaries were extremely helpful during testing and also helped by easily showing the ground truth on what sensor was connected to what input of the printed circuit board (PCB).

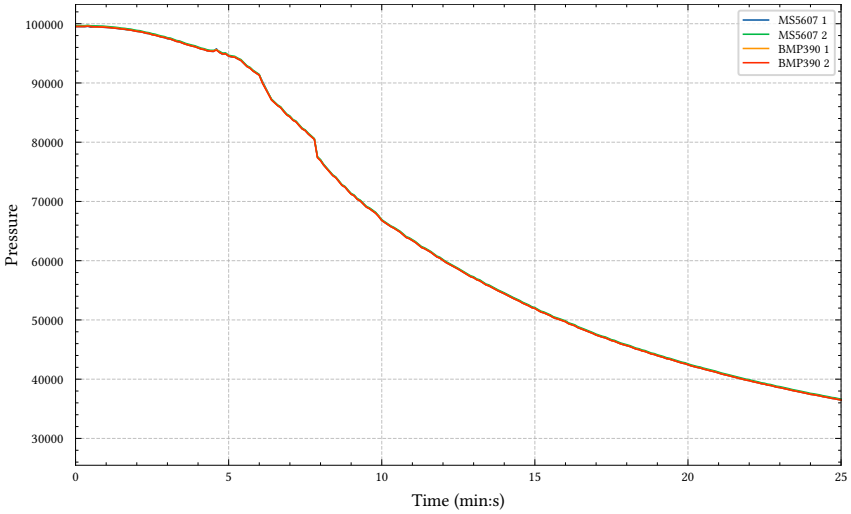


Figure 18: The barometric data at the start of the flight with a noticeable anomaly.

During flight, all altitude estimation sensors worked as intended, but the barometer did not, as seen in Figure 18. It was expected that there would be an anomaly in the barometric data around Mach 1. Nevertheless, the anomaly seen in the plot is in a different direction than previously investigated flight data.

The extended Kalman filter was prepared to filter an anomaly that results in higher altitudes. This happened shortly, as seen in Figure 19, but then quickly changed again when decelerating. The Kalman filter was not designed for anomalies that reduce the altitude. Furthermore, the BMP390 sensors went into saturation, and this was also handled by the filter.

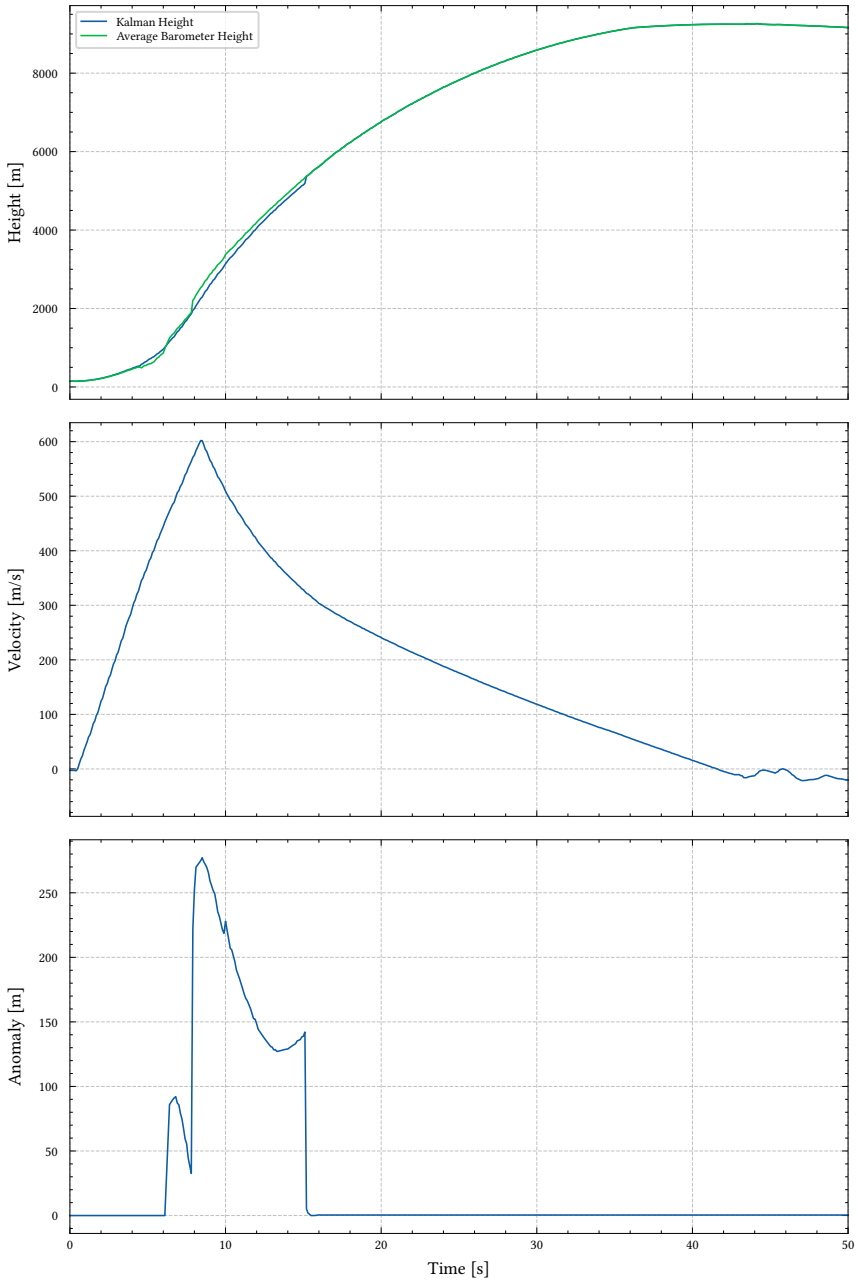


Figure 19: The result of the extended Kalman filter against the barometric data converted to meters above sea level.

Onboard Electrical Subsystems

In summary, the entire electrical system, its PCBs, as well as electrical connections, including the avionics stack, the telemetry system, and the five CANary sub-nodes, performed well during the entire launch day. Other than the hardware fault in the SRAD arming PCB, the system displayed no major mission-critical anomaly or failure.

CAN bus Communication

Both CAN bus lines worked as intended, and continuous, reliable communication between the nodes on both CAN buses was established during the flight. At apogee, the second CAN

bus, which connected the nosecone system to the flight computer, was severed as intended. Sometime during or after touchdown, the main CAN bus, which connects the propulsion system as well as the telemetry system to the flight computer, was also not working anymore due to unknown reasons. After the rocket was recovered, the system was reset from the outside and continued working again.

Backplane PCB and Power Management

The backplane and its subsystems, the battery management, the battery charging as well as reset, ignition and power distribution circuits worked as intended without any unexpected disruptions. The battery management circuit balanced and monitored each individual cell in the main battery pack as expected, and no faults were reported by the system. The battery charging behaved as expected and charged the main battery pack during the time the rocket was connected to ground power via the electrical umbilical USB-C connection.

Flight Computer PCB

The flight computer behaved as expected with no faults reported. The sensor board continuously sends barometric, speed, and gyroscopic data to the flight computer.

Black Box PCB

The black box unfortunately did not log data during flight. It had been logging data since the moment it was turned on in the integration tent, but some time after the rocket was mounted onto the launch rail, the black box started experiencing write errors every 3-20 minutes. After each error, the black box was reset from mission control. Each reset gave some extra logging time, but each time it was done, the logging time was shorter until it completely stopped logging. The system itself was healthy and transmitting on the CAN bus, but the SD card routine could no longer write to the SD card.

The only thing that changed during the transition of the rocket from the integration tent to the launch pad was the ambient temperature. The SD card on the black box is encased in a thick carbon fiber shell, which protects it from hard impacts, as well as acting as an insulator. During preflight testing, the carbon fiber-encased SD card heated up quite a lot - unfortunately, an exact temperature reading was not possible. The best guess is that the SD card stopped working due to overheating. The closest temperature reading was from the telemetry PCBs, which was around 60 degrees Celsius. The actual temperature of the SD card was most likely much higher than the reading above.

The second most probable SD card failure could be caused by a faulty flat flex cable, which is used for connecting the SD card to the black-box PCB. These cables had caused issues a few days prior to launch, so it is possible that the flight cable was not tested sufficiently to ensure proper and reliable operation over extended periods of time.

The black box was used in almost every test which was done (at least the ones where it made sense to use one), and it never had any issues. Its total runtime prior to launch was at least 80+ hours with zero outages or reported errors.

Sun Sensor PCBs

The sun sensors were able to provide a valid solar vector through the entire flight. The system reported zero errors and warnings during this time. The recorded data rate was limited to 10 Hz because the black box was not operational, so the 100 Hz CAN bus data could not be captured directly. As a result, the recorded data may not correctly or accurately represent rapid changes in the solar vector. Additionally, the built-in digital decimation filter's 15 Hz cutoff is above the 5 Hz Nyquist frequency of the 10 Hz data, which may have caused the signal content above 5 Hz to be aliased into the recorded data.

Figure 20 below shows an example of the merged solar vector path shortly after launch, with color fading over time.

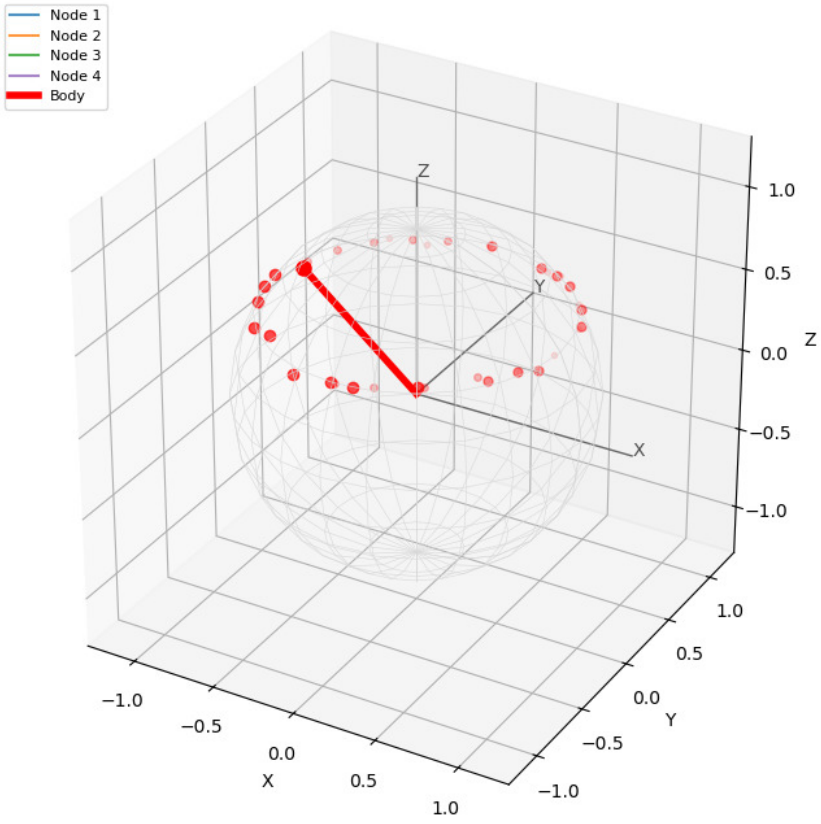


Figure 20: Merged solar vector path during boost phase

The three figures (21, 22, 23) below showcase the solar vector, including the measured normalized solar intensity of each sun sensor node during select phases of the flight.

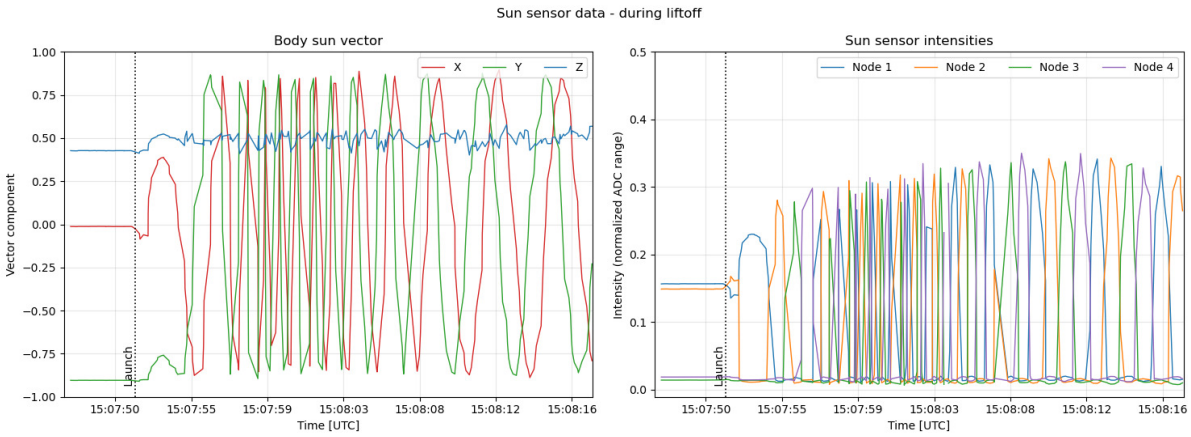


Figure 21: Merged solar vector and intensity during lift-off

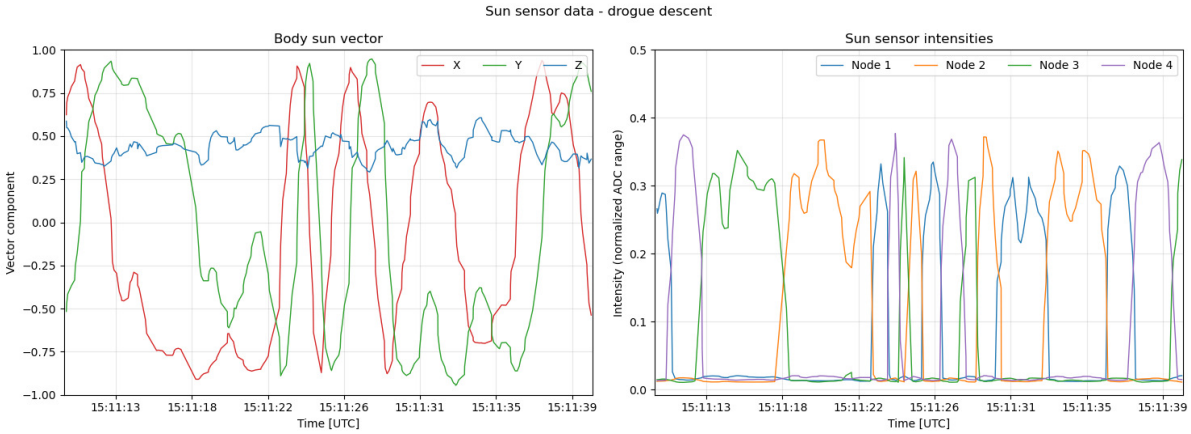


Figure 22: Merged solar vector and intensity during drogue descent

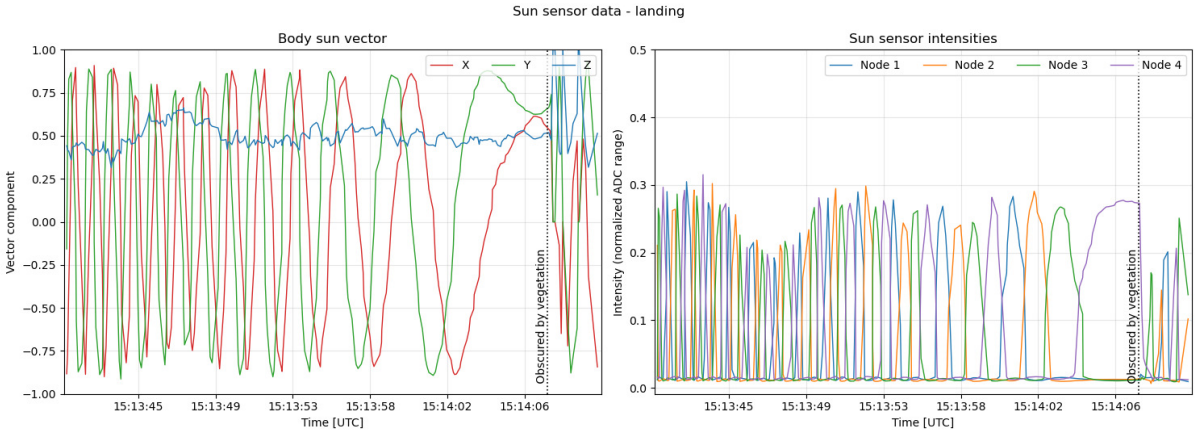


Figure 23: Merged solar vector and intensity during landing

Nosecone CANary PCB

The nosecone CANary was responsible for reading out the pitot-static-probe pressure sensors and for actuating the CATS Vega tracking system. Before and after the nosecone was removed

to fix the arming situation, the system behaved normally.

Upper CANary PCB

The Upper CANary was responsible for the fuel E-Reg as well as the N2 filling. The CANary worked without problems during the launch day.

Valvebay CANary PCB

The Valvebay CANary was responsible for the Ox E-Reg and the upper Ox vent valve. During the first launch attempt, the vent valve servo connected to the CANary mechanically failed and had to be replaced. Otherwise, there were no problems with the Valvebay CANary.

Engine CANary PCB

The Engine CANary was responsible for the management of the entire engine system. Besides relevant pressure and temperature sensors, it also actuated both the fuel and Ox main valves. The CANary behaved normally during the launch day. The angle sensors connected to it started to sometimes send erroneous data as condensation started to build up on the sensor connectors. The tailcone runcams were also connected to the CANary, and both of them switched off at the same moment as the main valve sequence was actuated by the CANary during the launch. This indicated that the power draw was too high to supply both runcams reliably and sadly resulted in no tailcone camera footage.

Ignitor CANary PCB

As the torch ignitor system was not used for project HARPIA, the Ignitor CANary's only purpose was to read out the onboard thrust load cells which are mounted in the Thrust structure. Those load cells did not perform reliably, likely due to the cold temperatures leading to condensation on the sensor connectors.

Telemetry

The telemetry system was set up according to the checklist, with the LoRa frequency set to 2462 MHz. The initial mission control receiver showed a received signal strength difference of approximately 50 dB between the rocket and ground receiver. Communication was unreliable even between mission control and the integration tent. Replacing the receiver with the spare restored the connection.

The spare receiver was installed at the launch rail and connected to the network through the filling-station switch. This improved communication compared with locating the receiver at mission control, approximately 550 m away. The connection was reliable after this.

GNSS

Both SRAD GNSS receivers temporarily lost lock during early ascent, then regained it before apogee. Their measurements agree closely. GNSS 1 tracked approximately 17 satellites and GNSS 2 approximately 26, with only short variations during descent, as shown in Figure 24.

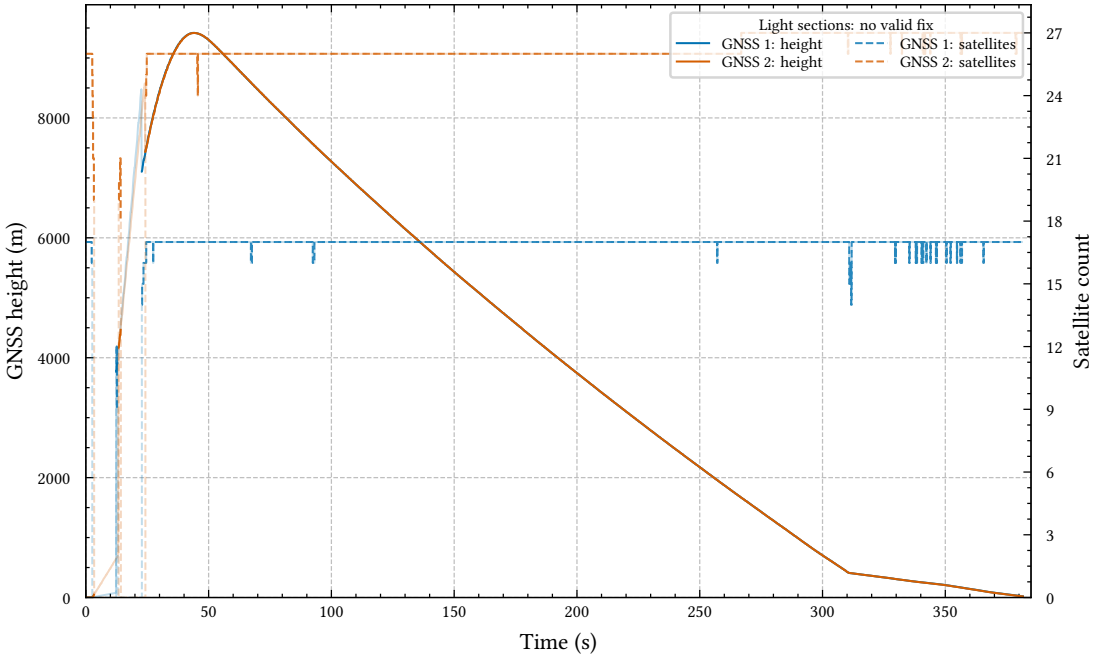


Figure 24: Altitude, satellite count, and fix status of both SRAD GNSS receivers during flight.

LoRa

The LoRa downlink transmitted approximately 80 packets per second, with approximately 60-75 packets per second received, corresponding to roughly 5-25% packet loss. Reception generally improved during descent. The mission control transmitted pings to the rocket at approximately 9 packets per second. Their reception was more varied, with short periods of complete packet loss early in flight.

The ground receiver was initially directly beside the rocket and almost directly beneath it during ascent. This may have contributed to reduced reception.

Figure 25 shows the LoRa received signal strength and transmitted and received packet rates in both directions during flight.

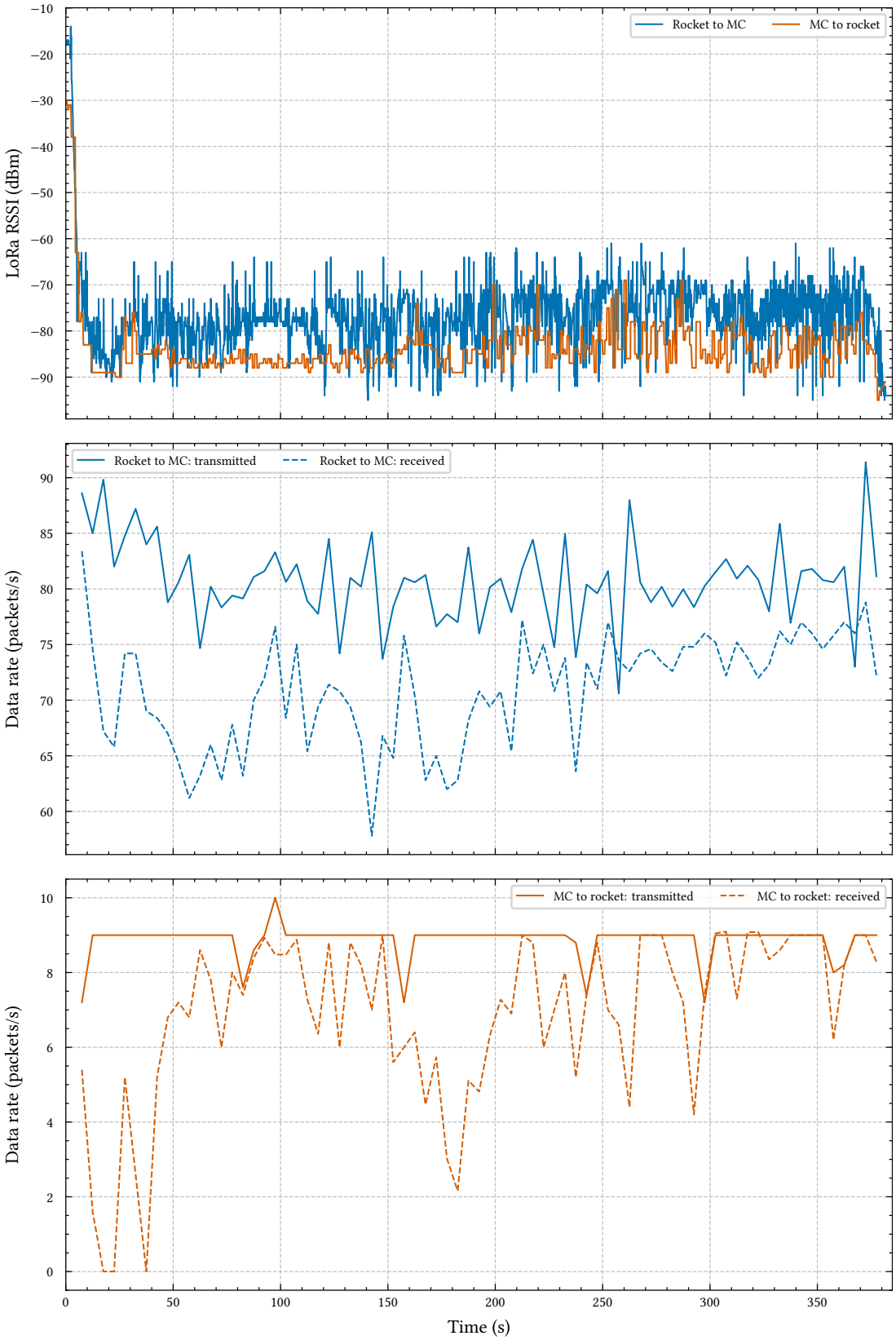


Figure 25: LoRa received signal strength and packet rates in the uplink and downlink during flight.

Recovery

Pre-assembly and Integration

The recovery section was pre-assembled before the launch day to minimize integration time on launch day. The main parachute was folded according to the checklist two days before launch, on 15.10.2026. The rest of the recovery tube, as well as the nosecone, was pre-assembled according to the relevant checklists on the evening of 16.10., the evening before launch. No particular issues during the pre-assembly can be noted.

At the launch site, the integration of the recovery section was finalized according to the checklist, with no notable issues. The resistance of all recovery igniters, as well as the status of the FD and SD, could be confirmed by the flight computer during final integration.

Before the second launch attempt, the recovery section and nosecone were disconnected from the avionics tube to give access to the avionics stack. The recovery section was not affected by this procedure.

First Deployment

At apogee, the nosecone was deployed by the FD. Once the nosecone had cleared the coupling tube, the drogue parachute had already begun to exit the nosecone coupling as seen in Figure 26. The nosecone continued to move away from the main rocket body until both the nosecone connection line and the pressureplate connection line were under tension.

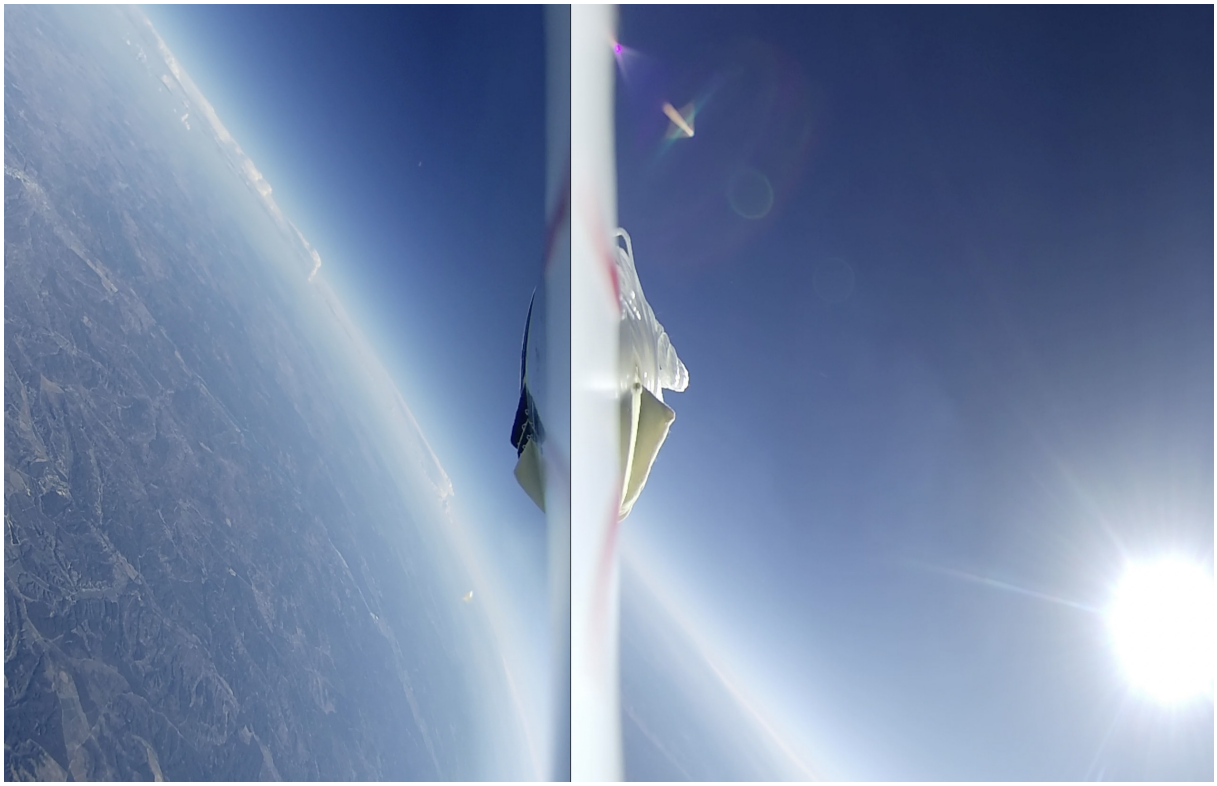


Figure 26: Drogue parachute deployment after activation of the FDs.

The onboard camera footage shows that the nosecone pulled out the pressureplate rather than the drogue parachute, as intended. Both FD units functioned correctly, and the amount

of Ar was more than sufficient to separate the nosecone. The released Ar is also visible in the onboard footage.

The onboard footage shows that the drogue parachute deployment proceeded as expected. According to the footage, the drogue parachute was fully inflated after 1.5 s, and the nominal drogue parachute descent trajectory was achieved after 4.7 s.

Further analysis of the flight footage indicates that the shockabsorber did not engage. Therefore, based on the latest shockabsorber test results, the estimated shock force acting on the system was below 300 N. Further details on the shockabsorber are provided in **??** .

Both FD activated as intended, and no signs of damage were found during post-flight disassembly. The observed contamination was consistent with expectations and previous testing. Furthermore, both igniters in each charge cup were activated. Overall, the FD system functioned nominally.

The FD was also confirmed during descent via the FD detection.



Figure 27: Drogue parachute unfolding after the nosecone got separated by both FD.

Drogue Descent

After the FD event, the drogue parachute flips the rocket body, then the rocket body oscillates for a few seconds. However, after this event, the drogue parachute descent appears to be mostly stable. The rocket also appears to start and stop rotating randomly during the whole drogue descent. During the whole descent, the nosecone appears to stay at the same level as the pressure-chamber-plate, as it was designed to not get entangled in parts of the line arrangement. The nosecone did not become entangled with either the lines or the drogue parachute.

The drogue parachute descent velocity (see Figure 28) also appears to match up with predictions. At high altitude, the descent velocity is measured by the SRAD flight computer to

be around 40 m/s, then, as the atmosphere gets denser, the velocity sinks to roughly 27 m/s, shortly before main deployment. The expected velocity of drogue descent based on previous flight testing was 30 m/s.

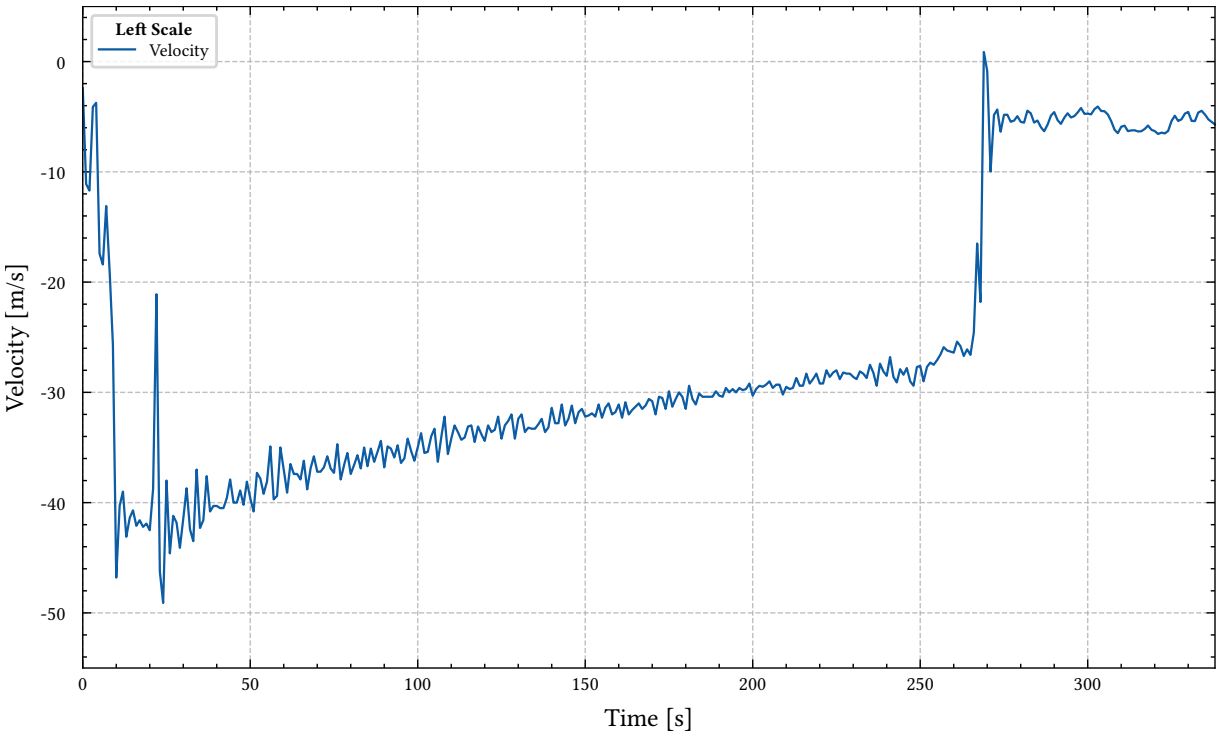


Figure 28: Descent velocities of both parachute descents. The graph starts at the moment the FD was triggered and ends at the moment telemetry was lost, shortly before touchdown. The SD event can clearly be seen in the data, as the main parachute descents much slower.

Based on the terminal velocity under the drogue parachute, the c_d value of the drogue parachute is calculated to be $c_d = 0.58$, and $c_d A = 0.72\,\text{m}^2$, with an attached mass of $m_{rocket} - m_{nosecone} = (34.0 - 2.89)\,\text{kg} = 31.11\,\text{kg}$.

Second Deployment

At an altitude of 450 m, the main parachute was released by the SD. The onboard camera footage shows the main shock cord being pulled out of the rocket together with the main parachute bag. The footage from both recovery cameras (REC Cams) shows the SD connection line being pulled out of the rocket, as seen in Figure 29, indicating that both SD systems were triggered simultaneously.

The footage also shows that the main parachute was already partially visible before the main shockcord was fully tensioned. This suggests that the aerodynamic airflow alone was sufficient to initiate the opening of the main parachute bag. The bag opened 0.54 s after the shockcord exited the REC tube. The main parachute reached full inflation a further 1.09 s later.

Observations from the Visitor Area indicated that the main parachute underwent very little rotation in the air. However, the rocket itself rotated during the descent under the main parachute, with the rotation becoming pronounced at times and reaching a frequency

of approximately 0.26 Hz. This rotation was most likely induced by aerodynamic effects. Nevertheless, the observations indicate that the rotatable eyebolt functioned as intended, allowing relative rotation between the parachute and the rocket and preventing significant rotation of the main parachute itself.

Following recovery, the main parachute bag, the SD detection line, and the bag connection line were found to be slightly entangled, as seen in Figure 30. A possible cause was the bag connection line moving too freely during deployment, combined with an excessively long Dyneema SD detection line. The Dyneema line remained intact and did not break during deployment.

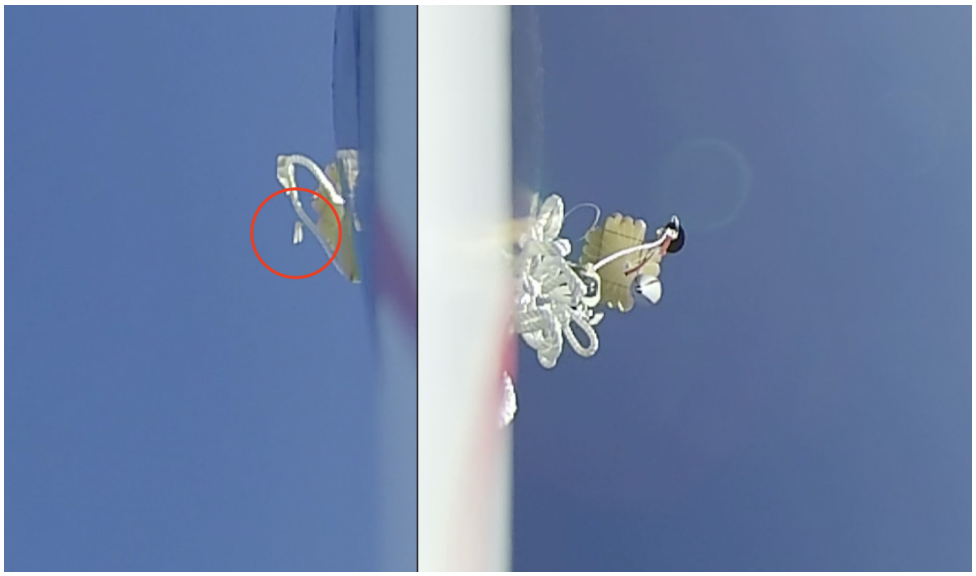


Figure 29: Shockcord and main parachute immediately after deployment, the SD connection marked in red.

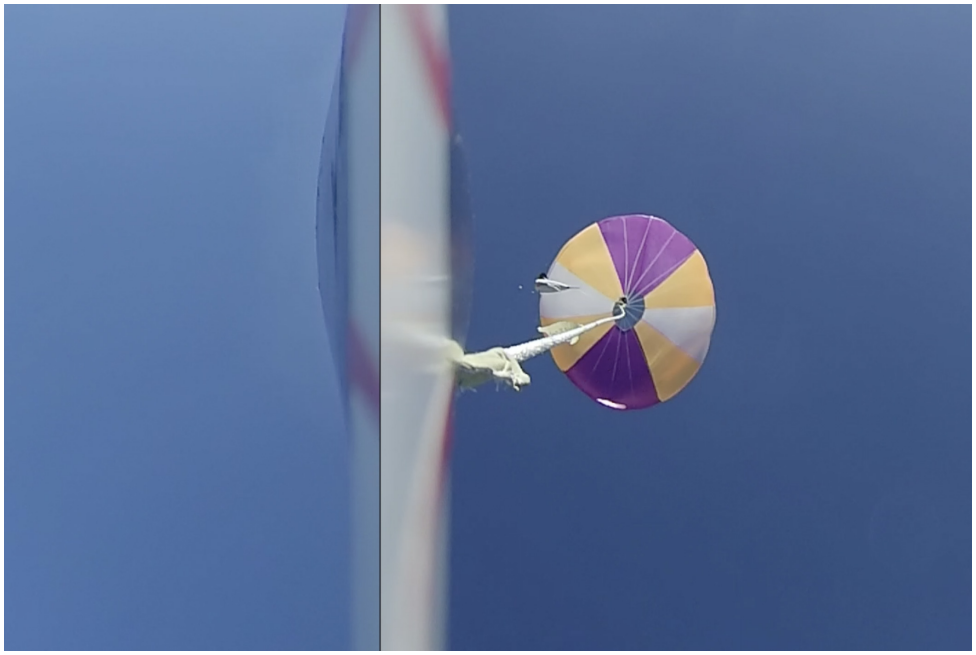


Figure 30: Fully opened main parachute.



Figure 31: Entangled main parachute bag, SD connection and bag connection at rocket recovery.

Main Descent and Touchdown

During the flight, the rotatable eyebolt and the rotatable carabiner kept the rocket's rotation low. That allowed a smooth recording of the onboard cameras.

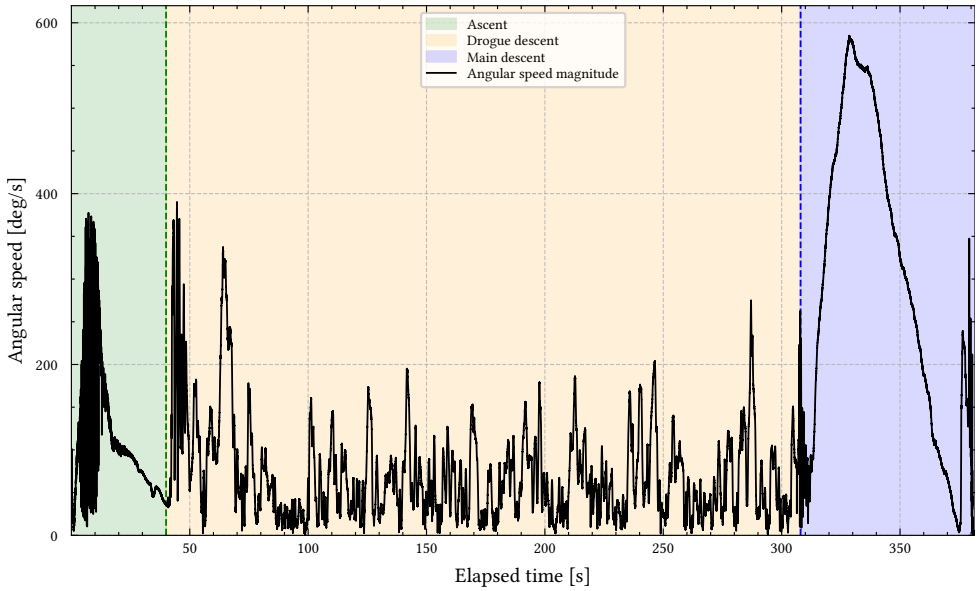


Figure 32: Rotation of the rocket body during flight in degrees per second from the data of the sun sensors

In Figure 32, one can see the different rotation speeds during the flight. During ascent, there is a bit of spinning, which slows down until the FD. After the drogue parachute comes out,

the rocket gets turned and spun by the drogue parachute, as can be seen in the data. During drogue parachute descent, the rocket stays roughly stable. The highest spinning velocity happens after main parachute deployment, although the main parachute itself stays stable.

Based on the touchdown velocity, the c_d value of the main parachute is calculated to be $c_d = 2.37$, and $c_d A = 19.03\,\text{m}^2$, with an attached mass of $m_{rocket} = 34.0\,\text{kg}$.

Table 11: Recovery performance.

Parameter	Value	Unit
Drogue deployment altitude	apogee	m
Average drogue descent rate (CATS Vega data)	32.7	m/s
Average drogue descent rate (SRAD flight computer data)	32.9	m/s
Drogue descent rate after FD (SRAD flight computer data)		m/s
Main deployment altitude above ground level (AGL)	450 m	m
Main descent rate	5.5	m/s
Touchdown velocity	5.5	m/s

Shockabsorber

During rocket recovery the shockabsorber was found to have opened roughly 11 cm, with the first 10 cm expected to tear at 300 N and the remaining 1 cm tearing at 900 N. Analysis of the flight footage appears to show, however, that the shockabsorber did not open during drogue parachute deployment, which is puzzling. After the rocket is flung around, as the drogue parachute inflates, the masking tape fixing the absorber can no longer be seen in the video. Even more puzzling is the fact that the shockabsorber cannot be seen to open at any point during the flight video. This leaves open room for interpretation:



Figure 33: Close-up picture of the shockabsorber shortly after it was found during rocket recovery, after flight.

- The shockabsorber opened during the first deployment event, as the rocket was flung around. This is supported by the fact that the masking tape disappears, as the absorber and drogue are out of view; however, the shockabsorber is not seen to be opening at the seams.
- The shockabsorber opened during main deployment. As the main was opening, the rocket dropped. As the main was beginning to take up the load, a force was exerted onto the drogue for a short time, opening the shockabsorber.

- The shockabsorber opened only during landing. However, in the flight video there appears to be very little tension on the lines connected to the drogue, making this unlikely.

Heated discussions have been going on inside the team on what caused the opening of the shockabsorber, however, a definitive conclusion could not be reached.

Payload

The gimbaled camera of the CubeSat did not record any footage. This was probably due to the very long standby time, which resulted in overheating of the system as it was enclosed in the CubeSat structure. Further investigation will be done by the high-school student, who designed and built the payload.

Conclusion and Remarks

The following points should be addressed in future projects:

General

- Keep a well-trained procedure in the following projects
- Pre-integration takes away a big portion of stress and makes the launch day way smoother and faster
- Launch dry runs before the flight trained the personnel very well, four runs were optimal because operations were trained, but no sloppiness occurred
- Be proactive with communication with EuRoC
- Keep the mindset, be on time and always prepared for all things that could happen, EuRoC is often quite chaotic

Propulsion

- Prioritize reliable servos compared to newer but smaller/lighter ones.
- Keep the level of preparedness and spares on hand to fix issues that previously occurred. Also stay flexible enough to make minor adjustments for easier handling of occurring issues.
- Improve the N_2 purging or figure out a way to keep avionics and sensors safe from condensation.
- Make sure tanking procedures stay well trained for all personnel and keep testing in flight configuration as soon as possible.
- Test subsystems whenever they are ready and fulfill required tests as soon as possible.
- Keep a fallback option for newer systems in mind should something not work out.
- Further improve E-Reg control and make it more independent of unreliable sensors.
- Improve thrust measurement and find a way to test it without a Hot-Fire.

Aerostructure

- Pre-integration significantly reduced the mental load of team members responsible for rocket integration on launch day.
- The holddown system functions as intended. It is recommended to implement two requirements, where either of them can trigger the mechanism. Additionally, a thoroughly tested system inspires confidence in the procedure.
- Make sure radax screws can be accessed while the rocket is mounted on the launch rail, where it is possible.
- Minimize cutouts overlapping with the decals in order to reduce the possibility of paint damage.
- Investigate the reason for detachment of the touchdown protection, if needed, improve its attachment method.
- PSP pressure data is accurate and can be used for speed and altitude determination.

Avionics

- Pre-integration of most avionics subsystems and pre-assembly of the avionics stack proved to be highly efficient during the final integration of the rocket.
- Conformal coating of PCBs in critical sections proved to be vital during launch preparations.
- Simplifying the electronics and the avionics stack integration proved to be vital while fixing the arming issue on the pad.
- Design change of the arming system to make it simpler and revert back to an arming pin solution.
- Design change of the black box system to make development and debugging easier and the data writing and transfer more reliable.
- Design change of the avionics stack cooling solution to ensure more efficient and more powerful cooling, especially considering that the AVI section was densely populated by PCBs in this project. A better circulation of airflow should be considered.
- Connectors in critical sections need to be protected against freezing and condensation. A new concept to prevent erroneous sensor data due to oxidation in connectors that could affect the crimps themselves or condensation in the connectors is advised.
- Design change of the runcams is highly advised in order to make testing and debugging easier. Now the entire camera mount, including the cameras themselves, needs to be disassembled completely to access the SD card.
- Implement barometers rated for higher altitudes to rely less on the Kalman filter.
- Design the Kalman filter in a way to more widely handle the Mach anomaly.
- Improve landed state detection of automatic state detection.
- Consider placing two telemetry receivers, one at the mission control and one at the launch rail, and implement switching in software. Placing the receiver at the launch rail also helps mitigate possible interference from other teams using 2.4 GHz WiFi in their mission control setups.

- Keep software highly configurable to support testing of other modules and decrease costly rewrites.
- Create more detailed and clear software requirements to reduce rewrites of software and improve work package clarity.

Recovery

- Removing nosecone and REC-section on the launch rail and re-integrating did not impair the functionality of the recovery system.
- Connecting the drogue parachute and nosecone both to the pressureplate prevented entanglement of the spinning nosecone with the drogue parachute.
- The shockabsorber opened neither at drogue parachute nor at main parachute deployment. Further improvement of KESTREL and the shockabsorber design is required.
- Design change of SD detection to prevent entanglement of SD detection line.
- Improve spark protection for the SD to the shockcords.

Mission Objectives

The achievement of the defined mission objectives is summarized in Table 12.

Table 12: Evaluation of the HARPIA mission objectives.

Mission Objective	Status	Remarks
Achieve a nominal flight cycle	SUCCESS	Nominal boost, first and second deployment
Reach an apogee of at least 9000 m	SUCCESS	Apogee: 9417.5 m (SRAD GNSS) 9196.6 m (official CATS)
Successfully recover the vehicle	SUCCESS	Rocket was recovered with minimal cosmetic damage
Operate with good and thoroughly tested procedures	SUCCESS	Operations went well and were on time

Overall Conclusions

The flight of HARPIA at EuRoC 2026 was a complete success! A beautiful ascent, target apogee reached, and both recovery deployments right on time. It could not have been a better flight.

The project overall was also a great success, with no flight-critical To-Dos still open coming to EuRoC. The team's atmosphere was also great at the competition and prior to it.

Finale Gedanken von uns:

Ich hätte mir das Jahr kein besseres Team wünschen können, jede und jeder einzelne hat einen ausgezeichneten Job gemacht. Nicht nur als Projektteam, sondern auch zwischenmenschlich. Klar ists nicht immer einfach, über die stressigen Zeiten haben wir uns sicher auch mal abgefuckt. Aber im Endeffekt wollten wir alle das beste fürs Projekt, und das haben wir auch verdammt gut hinbekommen! Einen Liquid mit anderem Raketendurchmesser auf 9 Kilometer zu befördern und auch successful zu recovern, und das in einem Jahr, bekommt man glaub ich nicht jeder hin.

Ich bin fucking stolz auf uns!

Julia und Philipp, ihr habt den Engine verdammt gut gemanagt, und das obwohl der erst Anfang Sommer da war. Es tut mir leid das ich mich manchmal zu sehr eingemischt habe, es ist leider mein Herzensmodul und das wirds auch immer bleiben.
Eva und Johannes, danke das ihr euch das Jahr vollgas reingeschmissen habt. Besonders als es darum ging die Rohre und Rakete fertig zu schleifen, schneiden, grundieren, lackieren, bekleben und wieder lackieren. Ich war sehr impressed wie schnell dann doch die Rakete fertig war und plötzlich fertig vor mir lag.
Paul und Fabian, Avionics war glaub ich bisher das beste Jahr was ich so mitbekommen habe. Ihr habt wirklich gute arbeit geleistet und seids mit keinem flight critcal To-Dos zum EuRoC gefahren!
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GaLiGrü, Lukas!

ich will einfach nochmal danke sagen. danke, dass ihr immer alles gegeben habt, auch wenns manchmal einfach nur todesanstrengend war. danke, dass wir einen monat darüber diskutiert haben, welche schriftart das schönste & hat, und dass ihr meinen perfektionismus und meine liebe zu irgendwelchen komplett unnötigen details ausgehalten habt. sorry auch, dass ich manchmal kurz vorm crashout war, damit wär ich im nachhinein gern besser umgegangen. danke, dass ihr immer daran geglaubt habt, dass wir das schaffen, auch wenns zwischendurch schwierig ausgeschaut hat. und danke, dass ihr mir oft mehr zugetraut habt, als ich mir selbst. und vor allem danke, dass wir trotz allem immer so zusammengehalten haben. ich hätt mir keine besseren leute wünschen können mit denen ich lieber an dem projekt gearbeitet hätte <3 - christiane