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Mission description

The mission will take place in the Black Rock Desert. It consists of using a rover to transport and deliver a 5x5x5 cm, 50g supply payload within two hours of launch from a rocket. Once released at an altitude of approximately 10,000 ft, the rover must descend in a controlled manner to the ground and travel precisely to the delivery point, maintaining the integrity of the payload throughout the journey.

Objectives

General objective

Develop an autonomous rover capable of accurately transporting and delivering a payload measuring 5x5x5 cm and weighing 50 g within a maximum time of two hours after launching from a rocket, ensuring the integrity of the payload during the journey

Specific objectives

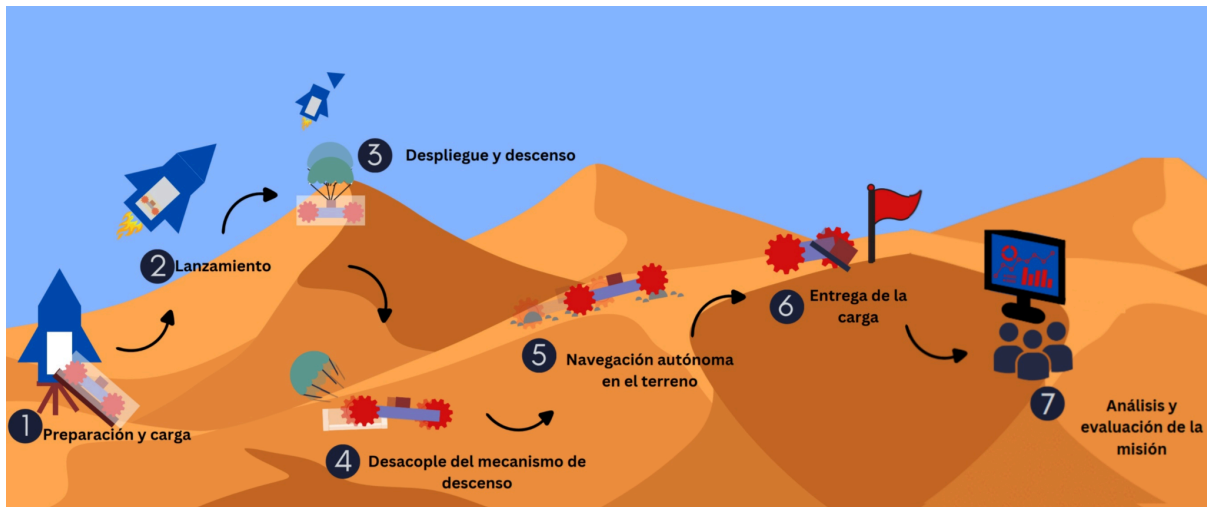
Design a rover with a rigid and lightweight structure capable of withstanding the stresses of launch aboard the rocket and enduring the impact of landing, as well as the irregular conditions of the terrain.

Develop a mechanism that enables the rover to perform a safe and controlled descent from the rocket to the ground, minimizing impact forces.

Program the rover's autonomous navigation system by integrating sensors, positioning algorithms, and control strategies that allow the rover to move accurately and efficiently toward the delivery point, ensuring stability, maneuverability, and autonomy on irregular terrain.

Implement securing and protection mechanisms that keep the payload stable and safe during transport, minimizing the risk of damage and ensuring proper deployment at the designated delivery point.

ConOps



Phase 1. Pre-launch preparation: The rover is placed inside the rocket's payload compartment, securing its position for launch.

Phase 2. Launch: Once secured on the launch platform, the rocket is launched and ascends to the designated deployment point, where the rover is released from the rocket's payload compartment.

Phase 3. Controlled descent (Landing): The descent mechanism is activated to ensure a safe landing for both the rover and the payload.

Phase 4. Separation of the descent mechanism: Once the rover has successfully landed, it detaches from the mechanism used during descent.

Phase 5. Autonomous navigation: The rover begins its traversal using navigation sensors and algorithms that detect position and adjust the trajectory direction.

Phase 6. Payload delivery: The rover reaches the designated point, reduces its speed, stops at a specific location, and delivers the payload accurately using the release mechanism.

Phase 7. Mission reporting: Upon completion, the team evaluates the rover's performance and analyzes the data collected during the mission.

Mission requirements

We consider as unsuccessful any requirement that could not be completed due to failures or incomplete phases during the mission.

Table 1. Mission requirements

Id	Description	Outcome
TYO-001	The rover must move autonomously, after landing, toward the center of the target.	Unsuccessful
TYO-002	Deliver a payload with dimensions of 5×5×5cm and a weight of 50 g to the center of the target.	Unsuccessful
TYO-003	Transportar una carga con dimensiones de 5x5x5 cm y con un peso de 50 g hasta el centro de la meta	Unsuccessful
TYO-004	Ensure that the payload remains intact throughout the entire trajectory.	Partial success
TYO-005	The rover must land without sustaining damage that compromises its structural integrity or operational capabilities.	Partial success

In this case, the rover did not progress beyond Phase 4, and therefore failed to meet the requirements related to autonomous movement. However, the payload remained intact during the free fall experienced by the rover, as did the structure and its electrical components, with the exception of one wheel that became detached and prevented movement.



System requirements

We consider as unsuccessful any requirement that could not be completed due to failures or incomplete phases during the mission.

Table 2. System requirements

Id	Description	Outcome
SRT-001	The rover must be able to determine its position accurately and autonomously during the mission	Unsuccessful
SRT-002	The mission must be completed within a maximum of 2 hours after the rocket launch	Unsuccessful
SRT-003	The descent must be within a terminal velocity range of 5 m/s ² that has been predefined to ensure a safe and controlled landing	Unsuccessful
SRT-004	The rover must maintain its functionality after the parachute is deployed during its launch	Unsuccessful
SRT-005	The rover must be designed according to the established size parameter with a maximum height of 240 mm and a maximum diameter of 146 mm	Successful
SRT-006	The rover's design must ensure that the total weight of the system, including the rover and the descent	Successful

	system, does not exceed 1050 g	
SRT-007	The rover's battery must be provide enough power to supply all systems for no less than 2 hours	Partial success
SRT-008	Receive the report of the data obtained during the mission	Unsuccessful

Referring to the system requirements, the rover didn't complete phase 4. An outcome is considered unsuccessful when the rover couldn't land in a controlled manner and, therefore, could not navigate autonomously. Due to this event, we couldn't verify the lifetime of the battery during all the mission, however, it remained in perfect condition after landing, that's the main reason why we consider it as partial success. On the other hand, our rover fulfilled all the dimensions and weight established by the competition.

Rover dimensions and weight before launch

Table 3. Rover's dimensions and weight

Diameter (mm)	140
Height (mm)	220
Total mass (g)	≈ 940

Subsystem requirements

Mechanical subsystem

Wheels

Table 4. Wheels requirements

Id	Requirement	Outcome
RDS-001	The wheels must withstand impacts equivalent to a fall from 3 to 3.6 km onto sandy and clayey soil without suffering permanent deformations.	Successful
RDS-002	The wheels must feature a design that maximizes traction on sandy and clayey terrain.	Successful
RDS-003	The maximum diameter of each wheel must be 140 mm.	Successful
RDS-004	The maximum width of each wheel	Successful

	must be 25 mm.	
RDS-005	The wheel material must withstand temperatures of up to 50 °C without causing damage that affects its operation after 2 hours of exposure.	Successful
RDS-006	The wheels must be removable and replaceable within a maximum time of 2 minutes.	Successful
RDS-007	The weight of each wheel must not exceed 80 g.	Successful
RDS-008	Each wheel must include a coupling system compatible with the rover's motor and transmission system.	Partial success
RDS-009	Each wheel must withstand a maximum static torque of 0.162 Nm without deforming or losing functionality.	Successful
RDS-010	Each wheel must withstand a maximum dynamic torque of 0.361 Nm without deforming or losing functionality.	Successful

Chassis

Table 5. Chassis requirements

Id	Requirement	Outcome
CHS-001	The chassis must withstand impacts equivalent to a fall from 3 to 3.6 km onto sandy and clay soil without sustaining permanent deformations	Successful
CHS-002	The dimensions of the chassis must not exceed 140 mm in width and 90 mm in height	Successful
CHS-003	The chassis should be able to be disassembled in less than 5 minutes	Successful
CHS-004	The total weight of the chassis must not exceed 160 g	Successful

Wrapper

Table 6. Wrapper requirements

Id	Requirement	Outcome
ENV-001	The weight of the packaging must not exceed 80 g	Successful
ENV-002	The wrapping must withstand a force of 500 N without opening	Unsuccessful
ENV-003	The packaging must withstand an impact equivalent to a fall from 3 to 3.6 km onto sandy and clay soil without opening	Unsuccessful

Payload deployment system

Table 7. Payload deployment system requirements

Id	Requirement	Outcome
SLB-001	The system must not exceed 20 g, including the activation mechanism	Successful
SLB-002	The system must keep the load fixed during navigation under vibrations up to 10 Hz	Unsuccessful
SLB-003	The system must release the load in less than 3 minutes	Unsuccessful

Recovery system (parachute)

Table 8. Recovery system requirements

Id	Requirement	Outcome
PRC-001	The parachute weight must be within a range of 55 to 60 g.	Successful
PRC-002	The parachute must be made of a compact and lightweight material, capable of withstanding a maximum force of 245 N.	Successful
PRC-003	The parachute must be designed to achieve a descent velocity of less than 6 m/s.	Partial success
PRC-004	Parachute deployment must be completed in less than 120 seconds, avoiding excessive oscillations that could affect landing accuracy.	Unsuccessful
PRC-005	The release system must allow the parachute to be detached in less than	Unsuccessful

	2 minutes so that it does not interfere with the rover's movement.	
PRC-006	The parachute volume must not exceed 12 in ³ .	Successful

Electrical subsystem

Sensors

Table 9. Sensors requirements

Id	Requirement	Outcome
EDS-001	The system must measure atmospheric pressure throughout all mission phases, with an operating range from 300 hPa to 1100 hPa.	Partial success
EDS-002	The system must measure acceleration along the X, Y, and Z axes during all mission stages, with a minimum range of ± 16 g.	Partial success
EDS-003	The system must determine the rover's position using GPS, with a minimum accuracy of 2.5 m.	Successful
EDS-004	The system must include a Time-of-Flight (ToF) sensor for obstacle detection with a minimum range of 2 m.	Successful
EDS-005	The system must measure ambient light intensity in the visible spectrum, with a minimum resolution of 1 lux and a measurement range from 0 to 100,000 lux.	Successful
EDS-006	Sensor data acquisition must be performed at a minimum frequency of 50 Hz to ensure real-time system response.	Successful
EDS-007	The microcontroller must belong to the ESP32 S3 series, with at least 8 MB of Flash memory and 2 MB of PSRAM.	Successful
EDS-008	Angular velocity must be measured along the X, Y, and Z axes using a gyroscope with a minimum range of $\pm 2000^\circ/s$ and a resolution of 16 bits.	Successful

EDS-009	All system sensors must have libraries compatible with Arduino firmware.	Successful
EDS-010	The system must include a magnetometer measuring along the X, Y, and Z axes, with a minimum operating range of ± 8 gauss.	Successful
EDS-011	The system must include a camera capable of processing images and detecting objects.	Successful

Actuators

Id	Requirement	Outcome
EDA-001	The system must include two geared DC motors, one for each wheel, capable of generating sufficient torque to move on sandy terrain.	Successful
EDA-002	The system must use two motor drivers with a minimum operating voltage of 12 V, capable of handling up to 2 A per channel and supporting PWM input.	Successful
EDA-003	The system must allow the parachute to be released in less than 10 seconds after landing.	Unsuccessful
EDA-004	The system must be electronically controlled using a MOSFET.	Successful
EDA-005	The system must release the $5 \times 5 \times 5$ cm, 50 g payload in less than 10 seconds after reaching the target.	Partial successful
EDA-006	The system must implement the payload release mechanism using a MOSFET.	Successful
EDA-007	The system must verify the status of each sensor before launch and throughout the mission.	Successful
EDA-008	The system must process ToF camera data to adjust the rover's trajectory in real time during the final-mile stage.	Partial successful
EDA-009	The system must transmit data via radio frequency or LoRa with a	Successful

	minimum range of 7 km.	
EDA-010	The system must send data to the ground at least every 10 seconds during the mission.	Successful
EDA-011	The system must include a 16 MB microSD memory for data logging.	Successful
EDA-012	The system must include a USB-C port.	Successful

Energy management

Table 10. Energy management requirements

Id	Requirement	Outcome
EDP-001	The system must include a battery with a minimum capacity of 2200 mAh.	Partial successful
EDP-002	The system must not exceed 13 W to ensure an autonomy of 2 hours.	Successful
EDP-003	The system must include a voltage regulator with a minimum operating input of 12 V in order to supply the sensors and microcontroller at 3.3 V.	Successful
EDP-004	The maximum supply voltage for the digital electronics must be 3.3 V \pm a 10% tolerance.	Successful
EDP-005	The minimum supply voltage for the power electronics must be 12 V.	Successful

Coding subsystem

Data processing

Table 11. Data processing requirements

Id	Requirement	Outcome
PDD-001	The microcontroller must be able to process the data from each sensor and transmit the corresponding information to the output system	Successful
PDD-002	A communication interface must be implemented for the exchange of data	Successful

	between the microcontroller and the external control system	
PDD-003	The system must verify the operation of each sensor before launch, ensuring that the variables are being measured correctly and the protocols are executed properly	Successful
PDD-004	An algorithm should be included to create and manage a data backup, for recovering it in case of transmission failure	Successful
PDD-005	GPS data must be processed and converted to coordinates relative to the rover's reference system	Partial successful
PDD-006	The magnetometer data must be processed and converted to coordinates relative to the rover's reference system	Successful
PDD-007	There must be a function capable of calculating the rover's heading, using the data obtained from the magnetometer	Successful
PDD-008	There should be a function that calculates statistical parameters of data sets, such as the mean and variance	Successful
PDD-009	The system must send the collected data to the external control system every 30 seconds during the mission	Successful

Recognition and control

Table 12. Recognition and control requirements

Id	Requirement	Outcome
CDC-001	Data transmission must incorporate error-checking mechanisms to ensure the integrity of information during sending and receiving	Successful
CDC-002	The motors must be controlled through drivers with a PWM signal, adjusting the speed according to the navigation requirements	Partial success
CDC-003	The system must allow the activation	Partial success

	of the discharge system with a safety mechanism to prevent accidental activations	
CDC-004	Algorithms must be developed to detect, in real time, conditions of partial or total loss of mobility of the rover	Partial success
CDC-005	An algorithm capable of measuring the angle between objects captured in recognition images, relative to the longitudinal axis of the rover, must be implemented	Unsuccessful
CDC-006	A color-based segmentation function should be implemented in order to isolate red components to identify the target.	Unsuccessful
CDC-007	An algorithm must be implemented that computes an approximation of the convex hull of a data set	Unsuccessful
CDC-008	A function must be implemented to calculate the centroid of the target points captured in the recognition images	Unsuccessful

Locomotion

Table 13. Locomotion requirements

Id	Requirements	Outcome
LDR-001	There must be a locomotion routine that allows moving forward in a straight line for a distance not exceeding 1m, with a tolerance of 0.10m.	Successful
LDR-002	A movement routine must be implemented that performs rotations around the Rover's vertical axis, according to a specified angle and a tolerance of 10°.	Successful
LDR-003	There must be an algorithm responsible for regulating the turning angle of the wheels while the Rover moves, to ensure a straight path toward the target coordinates.	Partial success
LDR-004	Upon detecting a blockage or jam, the system must execute an	Partial success

	automatic strategy that progressively increases the torque of the motors up to a maximum of 80% of their capacity to free the Rover.	
LDR-005	The position and speed of the wheels must be measured using encoders, ensuring accuracy in locomotion.	Partial success
LDR-006	An algorithm must be developed to follow an escape route in the event of immobilization caused by an object.	Partial success

Mission success criteria

Table 14. Mission outcome

Success	We consider our mission as a success if our rover could land in a controlled manner and navigate autonomously
Partial Success	If our rover could achieve phase 3.
Unsuccessful	Our rover failed before launch or didn't deploy the parachute

Referring to our mission, we consider it as partial success. Our rover and all the systems ran according to what we established in phase 1 and 2. At phase 3, the rover released successfully from the rocket and the recovery system activated correctly. After that, the shock the wrapper received when the parachute deployed, broke it and the rover fell in free fall. Even though it fell in free fall, none of the structural or electrical components were damaged, only one of the wheels came off the assembly.

Preliminary test results

Table 15. Tests

Id	Test description	Execution
RDS-001	The objective is to simulate the drop of the wheels from a height of 20 to 25 m onto a surface and verify the presence of possible deformations.	The drop is performed from the parking tower, which has an approximate height comparable to that established in the preliminary test.
RDS-003	A vernier caliper or another instrument is intended to be used to verify that the diameter of each wheel is equal to or less than 140 mm.	A ruler was used to measure the diameter of each wheel.

RDS-004	A vernier caliper or another instrument is intended to be used to verify that the width of each wheel is equal to or less than 25 mm.	A ruler was used to measure the width of each wheel.
RDS-007	A precision balance is used to verify that the weight of each wheel is equal to or less than 80 g.	The wheel was placed on a precision balance multiple times and the obtained data were analyzed.
CHS-002	A vernier caliper or another instrument is intended to be used to verify that the chassis dimensions are equal to or less than 140 mm in width and 90 mm in height.	A measuring tape was used to measure the chassis dimensions.
CHS-004	A measuring tape was used to measure the chassis dimensions.	The chassis was placed on a precision balance multiple times and the obtained data were analyzed.

Additionally, a test was conducted to observe the behavior of the wheels when subjected to a load. For this purpose, a bottle with a mass of 600.6 g was used, since each wheel must be capable of supporting 525 g. The bottle was secured on both sides of a metal rod that passed through the wheel hub, and its behavior was analyzed. During the test, it was observed that the wheel radius decreased from 7 cm to 5.5 cm, indicating that it can support the weight of the chassis and the other components without issue. It was also verified that the wheel is still able to roll properly even under this load. The images of the tests are shown below.

Weight test

Figure 1. Weight test



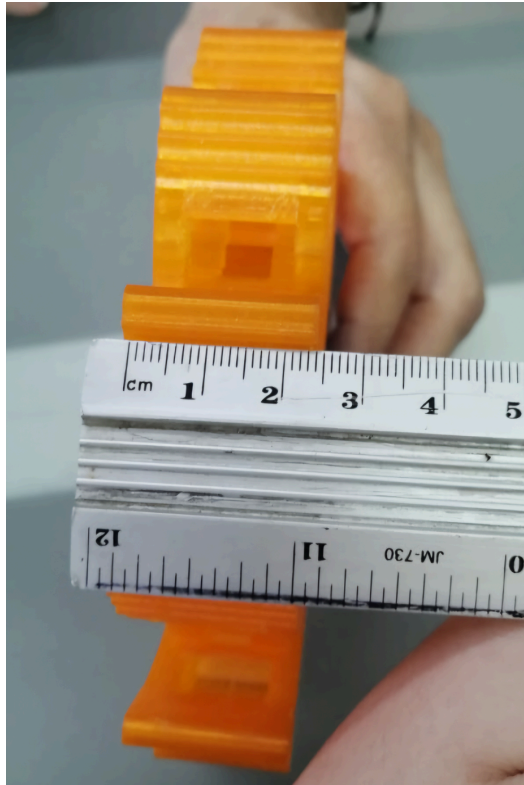
RDS-003 Requirement Test

Figure 2. Maximum diameter



RDS-004 Requirements test

Figure 3. Wheel's thickness



RDS-007 Requirements test
Figure 4. Wheel's weight



Rover assembly

The final assembly of the rover Helenor is presented below. It features two TPU wheels coupled to two PLA rims and two aluminum couplings. The chassis, responsible for supporting the rover's electronic components, was manufactured from aluminum, leaving sufficient space for the payload and the battery.

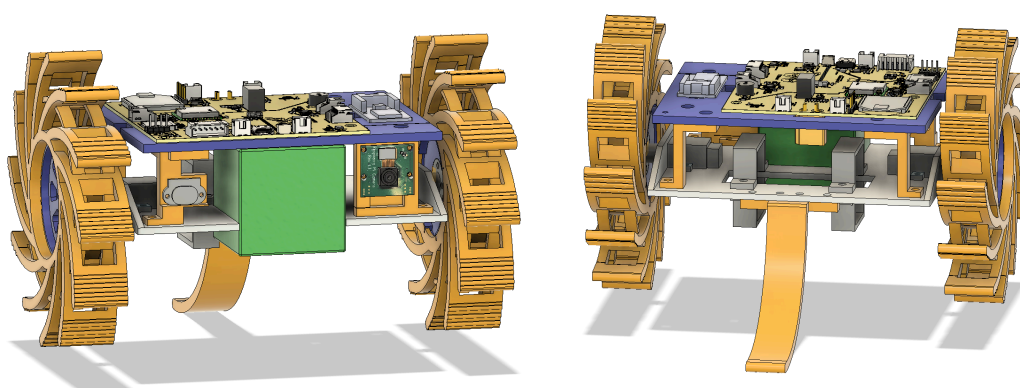
Additionally, the chassis serves as an anchoring structure for the PCB base, which was 3D-printed in PLA, along with both the front and rear legs printed in TPU. These legs provide improved impact absorption and help prevent structural failures. The front legs have a more specialized design, as they allow for the proper placement of specific electronic components required for system operation.

As part of the assembly, a net is included to secure the payload. This net is released using resistors connected to pyrotechnic channels on the PCB, enabling a controlled cutting of the net for payload delivery at the given coordinates.

Additionally, the rover includes a protective wrapper made from a PETG sheet, which was laser-cut. This wrapper is intended to protect the internal components from impacts, dust, and external agents during descent, landing, and rover operation, without compromising weight or access to internal systems.

As part of the structure, a third TPU-printed support is also included, providing additional stability to the rover Helenor. Finally, battery and motor mounts are incorporated to restrict the movement of these components and provide structural support and safety.

Figure 5. 3D Assembly



The electronic section of the Helenor rover was designed as an integrated and robust system, focused on reliability, modularity, and compatibility with aerospace applications. At the core of the system is a custom-designed PCB that centralizes power management, processing, sensing, actuation, and communication.

This PCB is mechanically anchored to the chassis through the 3D-printed PLA base, ensuring stability during descent, landing, and rover operation.

The main processing unit is an ESP32-S3-WROOM-1U-N16R8, selected for its dual-core architecture, low power consumption, integrated wireless capabilities, and full compatibility with the Arduino development environment. This microcontroller coordinates all subsystems, including sensor acquisition, motor control, pyrotechnic channels, and communication with the ground station. Programming and debugging are enabled through a USB-C interface (USB4105-GF-A), protected by USBLC6-2SC6 for ESD suppression, and complemented by dedicated BOOT, GND, and RESET circuitry to ensure reliable firmware uploading.

For payload deployment and mission-critical actions, the PCB incorporates multiple pyrotechnic channels based on AO3400A and DMN2005UFG-13 MOSFETs, protected by Schottky diodes and controlled directly by the ESP32. These channels are designed to drive resistive elements that cut restraining lines, enabling controlled release of the payload and redundancy to increase mission reliability. A GT-TC070A-H015-L1 buzzer is also included for audible status indication and debugging during ground tests.

Power is supplied by a 11.1 V (3S) 1500 mAh LiPo battery with XT60 connector, providing sufficient energy density for the mission profile. Power path management is handled by the TPS2121RUXT, allowing seamless power selection and protection, while voltage regulation is performed using a TSR 1-2433E switching regulator to efficiently step down the battery voltage to 3.3 V for the digital electronics. Additional connectors such as XT60-M, S4B-XH-A-1, S6B-XH-A-1, and BX-XH2.54-2PZZ-R ensure secure and vibration-resistant power distribution across the system.

Locomotion is achieved using DC 12 V N20 metal gear motors (200 RPM, 3 mm shaft), driven by DRV8874PWPR motor drivers. These drivers are controlled via PWM signals from the ESP32, enabling precise speed and direction control while providing built-in current regulation and protection. The motors are mechanically restrained using dedicated mounts to prevent unwanted movement and reduce stress on the PCB and wiring.

The sensing subsystem integrates multiple I²C-based sensors for environmental and inertial measurements. These include the MS561101BA03-50 barometric pressure sensor for altitude estimation, the LSM9DS1 IMU for acceleration, angular velocity, and magnetic field data, and the VEML7700 ambient light sensor. Proper pull-up resistors and decoupling capacitors were implemented to guarantee stable I²C communication and accurate measurements. A GPS HGLRC M100 module, connected via UART, provides positioning and timing data essential for navigation and payload delivery.

Communication with the ground station is handled by a radio module based on an XBee Pro, connected through UART and powered directly from the regulated supply. This radio provides a reliable long-range telemetry and command link, allowing real-time monitoring of rover status and mission execution.

Finally, the electronic design includes additional expansion and sensor connectors, such as BM04B-SRSS-TBT(LF)(SN) and PZ254V-11-04P, enabling future upgrades and modular testing. Although the TOF400C / VL53L1X time-of-flight sensor, the Grove Vision AI v2, and the OV5647 camera module were fully integrated into the PCB design, their firmware development was not completed in time, and therefore these components were not used during the final mission configuration. Despite this, their inclusion demonstrates the scalability and forward-looking design approach of the Helenor rover's electronic system.

Figure 6. PCB Design

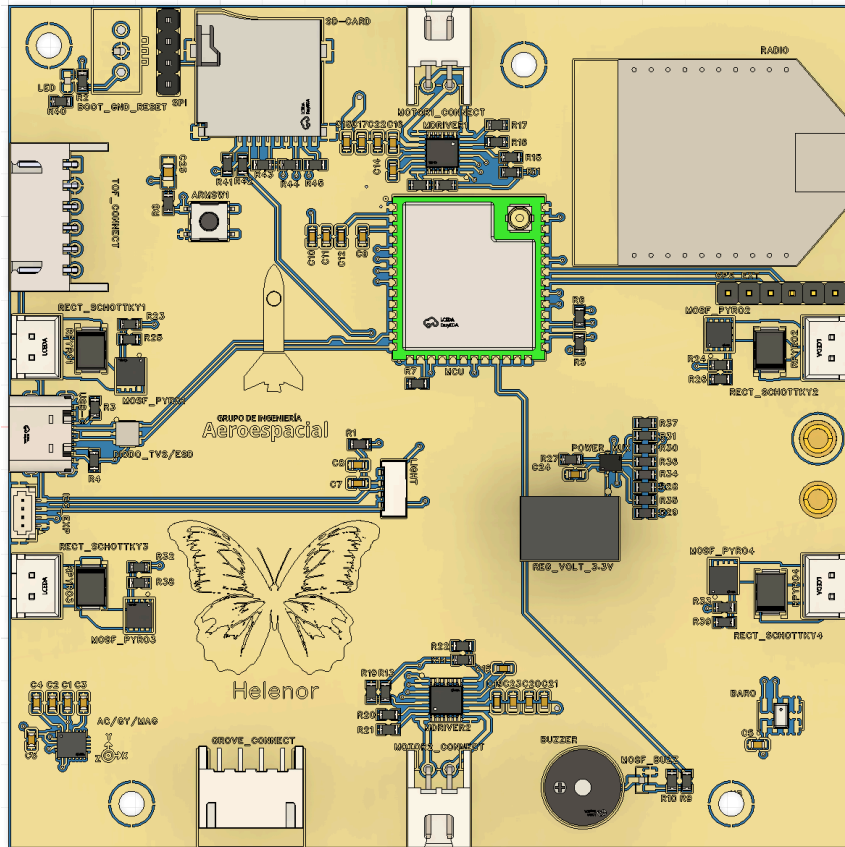


Figure 7. Final assembly

