



Berlin Experimental Astronautics Research Student team e.V.
c/o TU Berlin - Institute for Aerospace Engineering
Marchstraße 12-14
10587 Berlin
Club-Mail: info@bears-space.de
Subgroup-Mail: rocket-systems@bears-space.de
Website: www.bears-space.de

Team 08 Technical Report to the 2025 EuRoC

The STARGAZE Rocket



Submitted by:

BEARS Rocket Systems

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We want to thank everybody who made this project possible with hard work and dedication, the people who helped and supported us and the people who laid the groundwork of our club and rockets.

You are making this dream come true!

The STARGAZE Team

Anna Voos
Aris Groh
Caspar Galen
Elias Rische (Mechanical Team Lead)
Eric Rübhausen (prev. Team Lead)
Florian Just
Igor Taukchi
Joshua Wiener
Lina Machens
Linda Fattah
Matthias Klose
Matti Keller (Airbrake and Payload Team Lead)
Max Wiencke
Miria Behrisch
Niklas Freund (Software Team Lead)
Simay Ikibiroglu
Soyo / Carl Treichel
Thalis Arampatzis (Electrical Team Lead)
Tobias Ellendt (Recovery Team Lead)
and
Benjamin Brumm (Team Lead)

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1. Introduction

Student project work, such as the development, manufacturing and operation of high-altitude research rockets, is an essential part of engineering studies and offers students the opportunity to expand their skills beyond the theory of their studies. The European Rocketry Challenge (EuRoC) is held annually since 2020 in Portugal and offers student teams to fly their rockets under strict requirements. Teams are compared by criteria such as rocket performance, degree of innovation in design and operational safety, documentation and precision of apogee to name a few. For the first time ever, a team from Berlin has been able to qualify for participation at EuRoC in October 2025.

BEARS e.V.

Berlin BEARS e.V. is a student club at TU Berlin founded in May 2022 with the goal of enabling students to work on space-related projects complementary to their studies. The club focuses on a variety of projects ranging from rovers for the European Rover Challenge (ERC) to experiments launched on the DLR REXUS rocket. It is closely linked to the Institute of Aerospace Engineering at TU Berlin as well as the Chair of Space Technology, but acts completely independently on many of their projects. Because of this, many projects are exclusively funded by generous industry partners that support us financially and/or with guidance, services and parts. Any student passionate for space engineering is welcome to participate in any of our projects or even propose their own ideas.

Rocket Systems Subgroup

The Rocket Systems subgroup deals specifically with the development, production, and operation of sounding rockets with the aim of incrementally increasing each rocket's capability. As of April 2025, the team consists of approx. 20 students from different fields of study. Three launches have already been completed: the STARMOON rocket in October 2021 (apogee ≈ 700 m), STARDUST in October 2024 (apogee ≈ 2500 m) as well as MOONDUST in August 2025 (apogee ≈ 1200 m). The major goals of these past flights were to test improved manufacturing approaches for fins and for the nose cone, as well as making our recovery system more bulletproof.



Figure 1.1: Launch of STARDUST October 2024 and BEARS group foto 2025

One of the long-term goals of the subgroup is the integration of an in-development LOX–ethanol pressure-fed engine, which is approaching testing. STARGAZE, our EuRoC 2025 competition rocket, has been designed with this future integration in mind so that both projects can be merged efficiently.

1.1 STARGAZE Rocket Project

STARGAZE was developed with the goal of improving every part of BEARS's rocket systems, from fiber reinforced polymer manufacturing, to avionics and bulletproofing our Recovery subsystem all while adding two completely new mechatronical subsystems. These subsystems, namely our Payload "DÖNER'nt" and our airbrake are also specifically tailored to EuRoC to give us an edge over our competitors.

Timeline

The first concept studies of STARGAZE started in November 2023, after the design and most of the production of the STARDUST rocket was finished. The initial plans did not foresee to have an active flight control system atop the rocket, which changed a year later as students made quick progress on the design of a new airbrake subsystem.

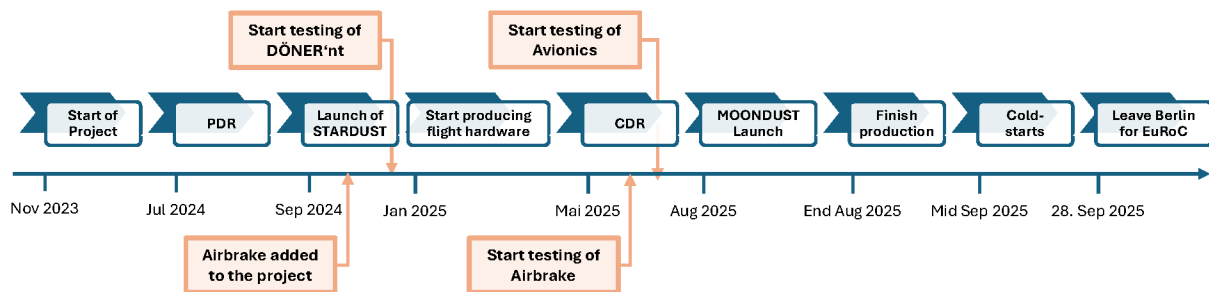


Figure 1.2: Timeline

Major Challenges

A major challenge behind STARGAZE was the decision to create a fully in-house manufactured fiber-reinforced polymer aerostructure, which also uses a new coupling design between compartments. This introduced the necessity to learn new manufacturing methods, using low-cost materials and tools as well as a DIY-approach. These manufacturing methods had to be iterated multiple times in a trial-by-error approach. Additionally, the STARGAZE team had no access to a continuous workspace in which work on composite materials could be carried out. The achievement of tight deadlines was only possible due to other student associations at TU Berlin that let us use their workshop.

When it comes to our avionics, the team underestimated the complexity of the chosen concept. The learning curve for writing the software, the cost of components and the difficulty of finding new members who are eager to work on electronics exceeded our expectations. The cost aspect was again mitigated by our sponsors, which were absolutely crucial to the project's success.

Additionally, the recovery system proved to be a challenge due to the difficulty of launching frequently in Germany, as a complete test of this subsystem is only possible with actual flight tests. The rockets that were flown since starting STARGAZE development, namely STARDUST and MOONDUST, showed improvements over old designs but did not go perfectly smoothly either.

The addition of our Payload and Airbrake subsystems proved to be challenging, as it increased the complexity of the system. The former did so especially by introducing the necessity of completely redesigning the compartment's primary structure. The latter introduced complexity due to the electrical integration with the flight computer. All of those challenges have however been overcome. The major reason for this: a team full of passionate and motivated up and coming rocket engineers aiming to push their own and their team's boundaries.



Figure 1.3: STARGAZE's sponsors for EuRoC 2025

Sponsors/Partners

The STARGAZE rocket project could not have been possible without the help of its sponsors. Due to being the most complex of BEARS's rockets to date, it was also the most costly one. To overcome these costs, our financial sponsors have been invaluable, special thanks therefore goes out to **Reflex Aerospace GmbH**, **Nicomatic GmbH** and **HalloPetra GmbH**.

Good engineering is done with proper software. For this, we must thank our sponsors **Siemens Digital Industries Software** and **Ansys, Inc.** Additionally, the STARGAZE team is indebted to all its parts sponsorships giving us discounts or free components. Without their help, this project would not have been possible. These are namely:

- **AISLER B.V.** for PCB manufacturing
- **3dk Trading GmbH** for high quality 3D-printing filament
- **Würth Elektronik eiSos GmbH & Co** for electronics components
- **igus GmbH** for parts, from stepper motors to linear rails and plain bearings
- **Therma Thermofühler GmbH** for thermocouples and accessories
- **Hans-Erich Gemmel & Co. GmbH** for discounts on various metal semi-finished products

Without the help of **CFX Berlin Software GmbH** and **Dr. Rölleke Labor GmbH** we would not be able to run our high-fidelity CFD analyses.

Gratitude must also be shown towards the **Institute of Aerospace Engineering** at **TU Berlin** and especially the **Chair of Space Technology**, which have given us unrestricted access to workspaces and storage space and most importantly allowed us to outsource the manufacturing of our aluminum milled parts to their workshop. One major partner that has been vital to especially our fiber reinforced polymer manufacturing has been the more than 100 years old **Akaflieg Berlin e.V.**, a TU Berlin founded student club, which is building gliders. They were generous enough to let us use their workshop.

2. System Architecture

This chapter details the design of the Rocket system.

2.1 Overview

STARGAZE is a rocket in the 3 km class that has been under development by BEARS e.V. since 2023. The rocket is built using a segmented design with a fiber-reinforced polymer structure and aluminum couplers. It belongs to the COTS class, which means that a commercially purchased solid rocket motor is used as the propulsion system. The rocket is divided into five segments (hereafter referred to as compartments), from bottom to top:

- Motor compartment + aerodynamic stabilizers (hereafter referred to as "**Fins**")
- Avionics, hereafter referred to as "**Electronic compartment/EC**"
- Airbrake
- Payload, hereafter referred to as "**DÖNER'nt**"
- Recovery system, hereafter referred to as "**Recovery**"

The recovery system is located both in the upper compartment and in the nose section above it (hereafter referred to as "**Nose-cone**").

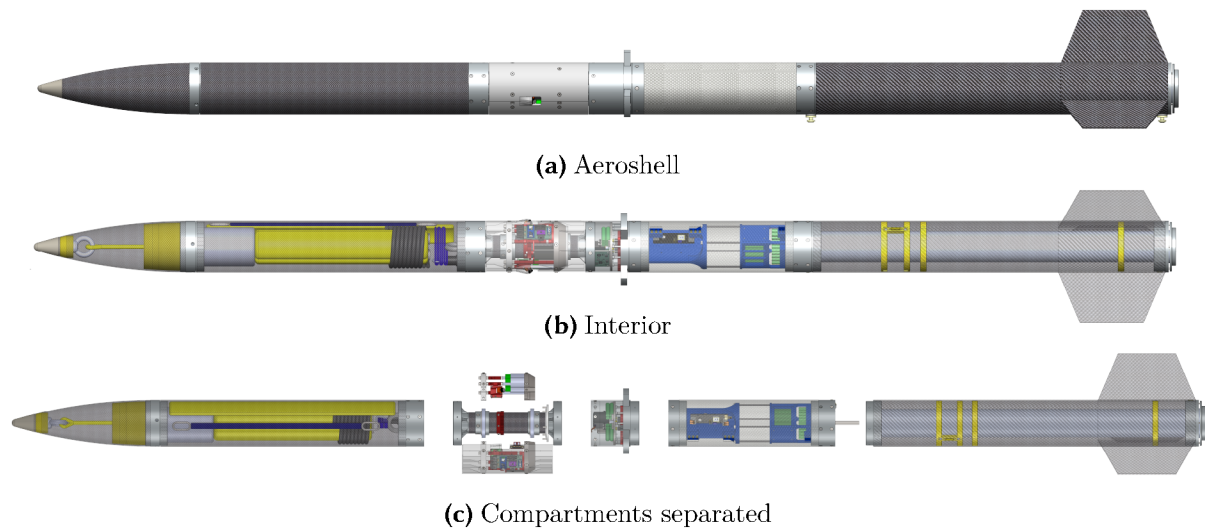


Figure 2.1: STARGAZE Rocket with all its compartments (left to right: Recovery, DÖNER'NT, Airbrake, Avionics, Motor)

Couplers between compartments are joint using radial screws, while being glued to the composite tubes themselves. The Recovery subsystem follows a standard 2-staged pyrotechnically deployed approach. The avionics use a in-house developed flight computer called "MAX-FC", that is characterized by a modular design which keeps more complicated electronics tasks, such as the integration of our future bi-liquid rocket engine, in mind. The payload as well as the airbrake are two mechatronical subsystems, each of them using a new and innovative design approach to accomplish their respective function. All umbilical connections are located opposite to the rail-buttons, which can be seen in the figure.

2.2 Propulsion subsystem

The STARGAZE rocket is powered by a COTS solid rocket motor. The motor is a Pro75 6800M3700-P from Cesaroni Technology Incorporated (CTI). It was purchased at Eurospace Technology. EuRoC officials will organize and manage the transport from Eurospace Technology to the launch site. The motor will be used in a 6 grain CTI motor case using a special CTI M3700 (0.7 grain) spacer, as this motor uses special propellant grains, which are longer than normal for CTI Pro 75 motors and equate to 5.3 "standard grains". The M3700 motor requires bonding of the grains to the liner, which will increase the time needed to prepare for integration of the motor.

The BEARS team, especially the individuals who will assemble the motor, have previous experience with CTI Pro 75 motors and their assembly, having used them on two previous flights. Thus BEARS also had some of the required hardware. Additionally motor choice was simplified by the fact, that the M3700 motor was the only motor available at Eurospace Technology, that could be used for a STARGAZE flight to 3km.

The M3700 motor has a comparatively short burn-time and high thrust.

2.2.1 Motor specifications

The following table and graph summarize motor performance data. They are provided by the manufacturer of the Motor, Cesaroni Technology Incorporated.

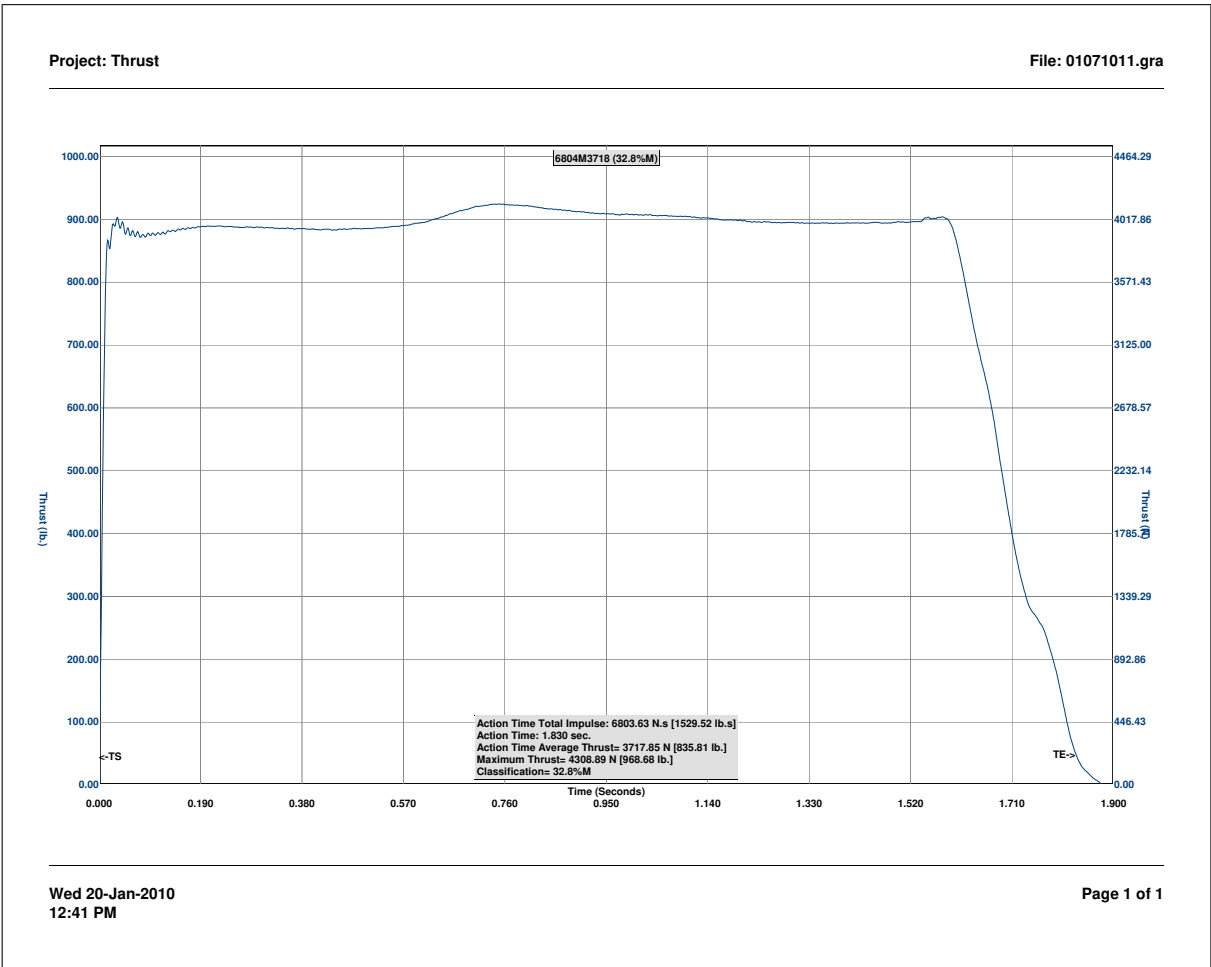


Figure 2.2: M3700 Motor Thrust Curve (from [3])

Motor Designation	6800M3700-P
Total Impulse	6800,3 Ns
Maximum Thrust	4158,1 N
Average Thrust	3710,0 N
ISP	233,73 s
Burntime	1,83 s
Propellant Weight	3019 g
Casing	CTI Pro 75
Type	reloadable

Table 2.1: M3700 Motor Data (from [3])

2.2.2 Structural interface

The force transmission from the motor to the rest of the rocket happens via two ways. First, the Bottom Ring of the motor compartment shares a contact surface with the Rear Retainer of the motor case. Additionally, a 3/8 inch threaded rod connects the Forward Closure of the Case with the plate in the electronic compartment. Two screw nuts secure the rod to the plate, which itself is connected with six M4 screws to the rest of the rocket.

Under the motor case, the Retainer is placed and screwed to the Bottom Ring of the motor compartment using four M4 screws. Therefore, the case is secured from falling out.

The inner diameter of the Bottom Ring and the Coupler of the motor compartment is 76 mm, so these two parts center the case inside the rocket. There are additional rings out of PLA glued inside the motor tube, which assist with the centering, but are mainly used for easier assembly.

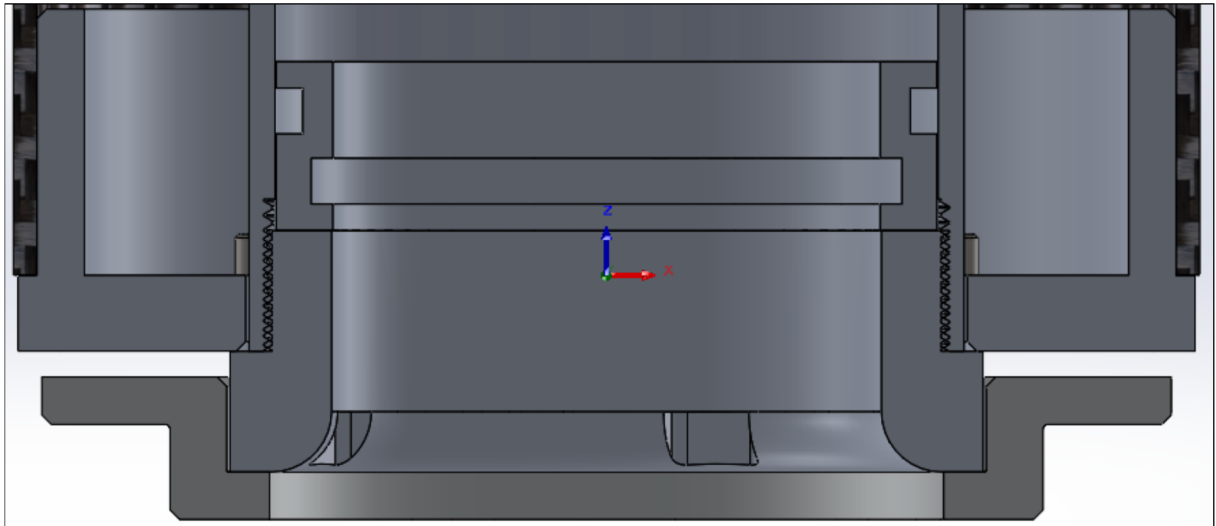


Figure 2.3: Bottom Motor Compartment

2.3 Aerostructure

STARGAZE mainly consists of three materials:

- Aluminium 6060
- Glass fiber reinforced polymers
- Carbon fiber reinforced polymers

The epoxy used for bonding our composite parts is Easycomposite's E-111L mixed with a 10:4 Resin:Hardener ratio. For each glass and carbon fiber part we utilize the same weave. For glass fiber parts we use glass fabric, and for carbon fiber parts we use a two layered bidiagonal weave with a $\pm 45^\circ$ fiber direction.

2.3.1 Body tubes

2.3.1.1 Design

The following table demonstrates all the outer parameters of our body tubes.

Compartment Name	Outer Diameter	Inner Diameter	Length
Motor Compartment	125 mm	120 mm	855 mm
Electrical Compartment	125 mm	120 mm	378 mm
Payload Compartment	55 mm	50 mm	205 mm
Recovery Compartment	125 mm	120 mm	652 mm

Table 2.2: Tube Parameters

The second table displays the specific materials that were used to build the tubes.

Compartment Name	Fiber	Epoxy	Density Per Layer	Layer-count
Motor Compartment	Carbon Fiber	HP-E111L	302 g/mm ²	Five Layers
Electrical Compartment	Glass Fiber	HP-E111L	280 g/mm ²	Eight Layers
Payload Compartment	Carbon Fiber	Procured from Carbon-Composite AG		
Recovery Compartment	Carbon Fiber	HP-E111L	302 g/mm ²	Five Layers

Table 2.3: Tube Materials

2.3.1.2 Manufacturing

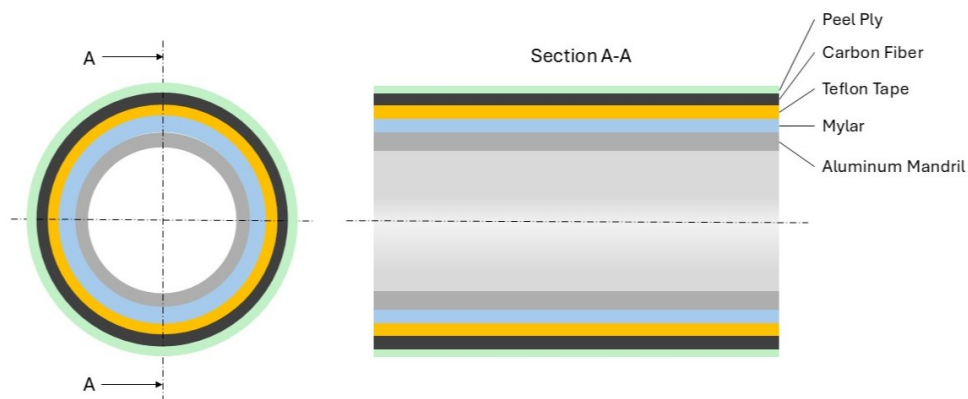


Figure 2.4: Tube Manufacturing Layers

For the manufacturing of our body tubes a mandril was used, which was then hand laminated on the outside with carbon fiber. All of our body tubes were manufactured the same way, besides the payload tube, which had to be bought. A section view of all the layers used during manufacturing of the body tubes can be seen in figure 2.4.

Main body tubes

A large aluminum tube with the outer diameter of 120 mm and a thickness of 3 mm was used as a mandril to manufacture all body tubes. Before starting manufacturing, the mandril was sanded down to ensure easier delaminating later on.

At first, the aluminum mandril was wrapped in mylar to prevent adhesion. On top of the mylar wrap, teflon tape was wrapped around the tube with overlaps at the edges to prevent adhesion of the carbon fiber laminate. After the mandril was prepped, a first layer of HP-E111L epoxy was applied on top of the teflon tape, followed by the first layer of bidiagonal ($\pm 45^\circ$) carbon fiber weave on top. Each carbon fiber layer had the circumference of the mandril to ensure easier application. The layers were placed on top of each other at a 45-degree angle relative to each other a total of five times, creating 3 layer (in the 5-layer case) with $0/90^\circ$ fiber orientation for axial stiffness. After all layers were added, another layer of peelply was tightly wrapped around the laminate to take up excess epoxy. This setup could now cure for three days before being easily removed from the mandril due to the mylar and teflon tape base, which came off as one piece and left the cured carbon fiber tube. They were then cut down to the right size and sanded down. In the case of the electrical compartment, the same order of events was used. The only difference being in number of layers and material, since basket weave glass fiber was used instead of bidiagonal carbon fiber with eight total layers instead of five. The last manufacturing step was to cut holes for a rail button, magnetic connectors, X-T 30 plugs and for venting. The holes were made with a drill and then finished with a file.

Payload tube

The payload tube has a reduced diameter of 55 mm, as is further detailed in section 2.6. The loading of this part under bending would cause higher deformation due to the reduced aerial moment of inertia, although structural analysis results have shown that these are far from critical (see Appendix). To create a precise outer diameter, a negative-mold manufacturing approach was planned for. It was decided to procure the part from Carbon-Composite AG, as the quality from this manufacturing approach considering the reduced stiffness due to its geometry was considered to be insufficient. They use HT, UHT and IM carbon fiber, those are either directly impregnated with an epoxy resin matrix or previously processed into a woven fabric and then impregnated. The resulting prepreg is wrapped around their cores and then cured in a tempering furnace. The bought tube was also sanded down by them.

2.3.2 Coupling joints

The coupler design has the main function to realize the compartment design and also maximizing stiffness of the rocket.

2.3.2.1 Design

Standard couplers

The couplers are used to connect each compartment. On each side of every body tube, a coupler is glued to the tube. The adhesive surfaces have a diameter of 120 mm and a height of 20 mm. M3 DP 490 Scotch-Weld is used as glue. The inner diameter is 110 mm. Above the adhesive surfaces, the couplers increase the outer diameter to 124 mm. Therefore, the top edge of the

body tubes has contact with the couplers and the main load transmission is through this contact. The connection to the next compartment is with a g6/H7 fit, so one of the couplers lowers its outer diameter to 118 mm g6 and the other coupler increases its inner diameter to 118 mm H7. The fit has a height of about 20 mm. The two couplers are connected with six horizontal M4 steel screws. The thread is in the smaller coupler.

The lower couplers of the recovery and electrical compartment have six additional holes above the fit. They are necessary to screw the plates into the compartments. Additionally, three couplers have a threaded hole for the railbuttons.

An exception with the fits is the connection between the recovery compartment and the nose cone. The difference between the diameters is 1 mm, so it is a loose fit.

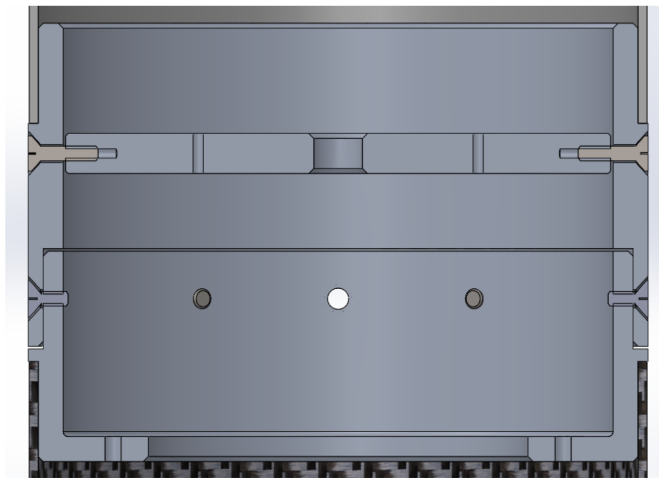


Figure 2.5: Connection between motor and electrical compartment

Payload couplers

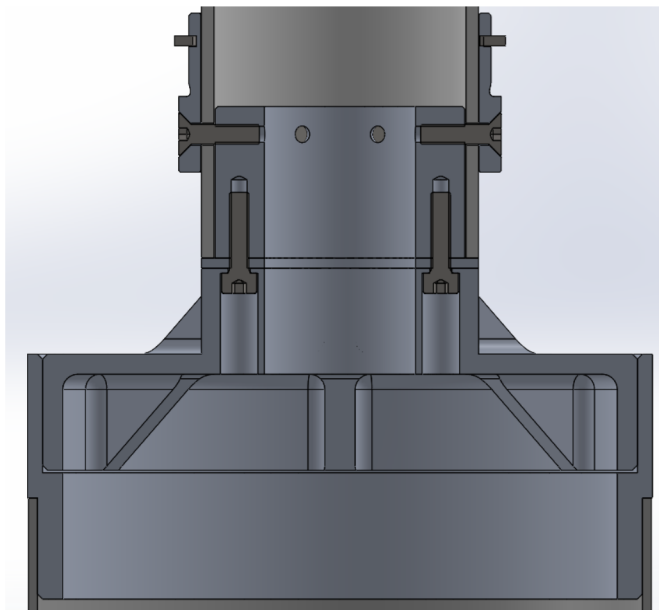


Figure 2.6: Connection between electrical and payload compartment

Due to the smaller diameter of the carbon tube in the payload compartment, a different coupler design is necessary. An insert is inserted at both ends of the payload tube and glued. The adhesive surfaces have a height of 30 mm. Above the adhesive surfaces, the couplers increase the outer diameter to 55 mm. The inserts possess threads for the coupler and ring holdings. The payload couplers are connected to the inserts with six axial-oriented M4 screws. The couplers have the same outer diameter as the inserts, but increase the diameter to 118 mm g6, so they can connect to the other couplers in the usual way. The couplers have six stiffening ribs to ensure structural integrity.

Airbrake structural interface

The metal parts of the airbrake have an inner diameter of 118 mm H7 at the connection and have six through holes for M4 screws, which contrary to the other coupling are inserted axially, not radially. Therefore, they can be connected to the standard couplers. A detailed description of the metal parts is provided in section 2.5.

2.3.2.2 Manufacturing

The metal parts are machined out of aluminum, mostly 6060 aluminum. The semi-finished products are milled with a CNC milling machine. After that, the holes are added and the surface is sanded to a surface roughness of Rz 16.

2.3.3 Nose-cone

The outer shape of our nosecone stayed similar to our previous rockets. Only the manufacturing method using a negative mold and carbon fiber as the material have changed. Also the tip is now a separate part in order to ease the assembly process of the related recovery system eyebolt.

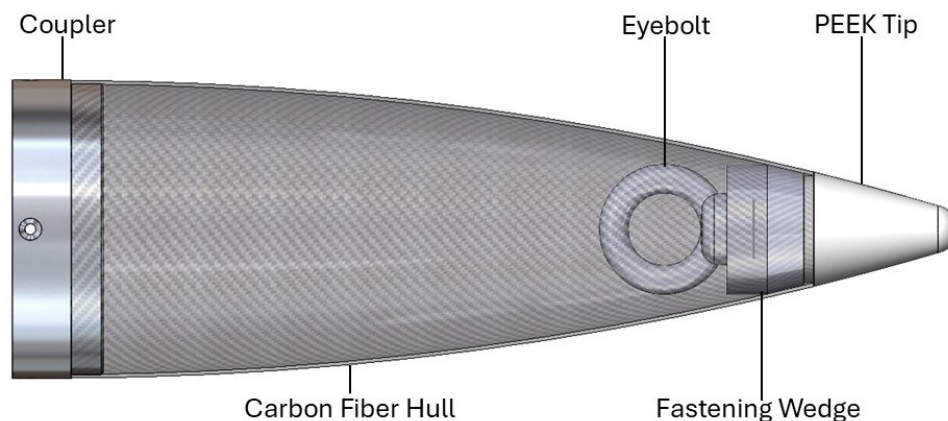


Figure 2.7: NoseCone Structure

2.3.3.1 Design

The function of the nose cone is to reduce the drag, withstand the aerodynamic forces and provide space for the parachute system. With the calculated flight profile, preliminary estimations have shown, that no critical aerodynamic heating should occur. The shape of the nosecone is tangent ogive, which was used in previous rockets as well due to the below sonic speed. An alteration was made to manufacture the nosecone out of two parts, one big structural part made out of carbon fiber and the tip out of PEEK. The material for the tip was chosen for future upscaling of the rocket to supersonic speeds and higher tip temperatures. It can be screwed from the inside with the eyebolt and a wedge which tightens. That way the eyebolt is centered and fixates the tip.



(a) Laminating nose cone halves



(b) Joining nose cone halves

Figure 2.8: Nose cone manufacturing

2.3.3.2 Manufacturing

Two 3D printed molds are used to manufacture the nose cone. These are printed out of PLA on a Voron 2.4 3D Printer with a layer height of 0.1mm. After printing the inner surface of the mold is sanded down until the individual layer lines are no longer visible. The two mold halves are then coated in a layer of PVA mold release and sealed with forming wax to prevent the unwanted outflow of epoxy later in the process. Once the PVA mold release has solidified a first layer of epoxy is applied to the mold surface after which the first of the three layers of carbon fiber weave is applied on top. The layers of carbon fiber weave are purposefully oversized for one half and undersized for the other to allow the halves to latch together easier later in the process. Once all layers are applied and appropriately infused with epoxy the two halves are combined and held in place using several clamps. The assembly is then left to cure for at least three days before the nose cone is extracted from the mold. Once the nose cone is free, remaining voids in the seam section are filled in with filler putty and sanded down to create a smooth outer surface. Both ends of the nosecone are then trimmed to size in order to fit together with the nose tip and recovery compartment coupler which are later attached using epoxy. Before this step a 3D printed spacer is also inserted into the bottom of the nosecone which forms part of the recovery system.

2.3.4 Fins

The number of three fins stayed the same like our previous rocket designs, as seen in fig 2.9. Due to the higher drag, the manufacturing method was improved to a tip-to-tip carbon fiber layup, as well as higher surface and alignment requirements during manufacturing.

2.3.4.1 Design

Due to the substantial effect of the fin shape on the overall stability of the rocket, their design was made iteratively using the flight simulation software. Three fins were chosen. Since fins have a significant influence on drag, they also affect the apogee. Modifying the fin semi-span influences the position of the center of the pressure the most. Therefore the fins are purposely manufactured bigger than they need to be to be able to cut the fins to the exactly needed semi-span to reach the targeted caliber stability of the rocket.

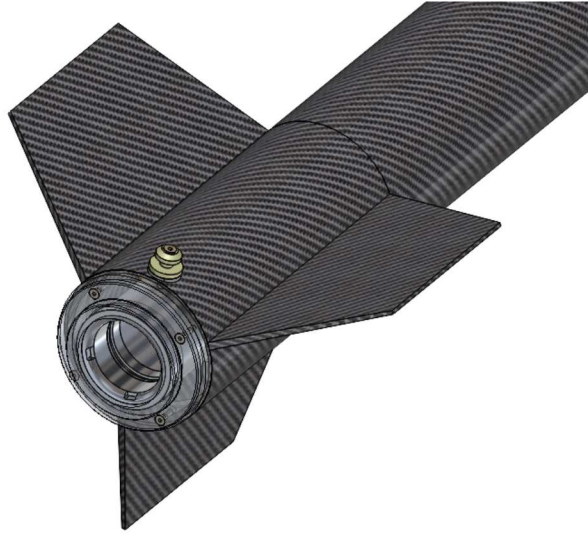


Figure 2.9: FinCan Structure

2.3.4.2 Manufacturing

The fins are cut out of a 4 mm thick sheet of glass fiber composite plate and then sanded down to remove inaccuracies in the shape caused by the cutting process. The sanding also prepares the surface of the fins to later improve epoxy bond strength. To attach the fins to the motor compartment airframe a 3D printed fin jig is used. A small root bond of epoxy is applied between the fins and airframe which is then left to harden before the fin jig is removed. A large epoxy fillet is then attached to the sides of the fin to increase bond strength, this can be seen in figure 2.10. The epoxy used in this step is mixed with micro-balloons to increase viscosity which will let the fillet hold its shape better. Once the fillets are hardened the surface of the fillet and fins is sanded again and then treated using IPA. A break-angle test can then be performed to test the surface quality. Three layers of carbon fiber weave are then applied tip to tip between each two sets of fins. Similar to the nosecone the surface is coated in a layer of epoxy before the weave is applied to prevent the formation of bubbles and delaminated areas. After hardening any excess material is sanded away to leave a smooth sharp edge behind.



Figure 2.10: Applying the epoxy fillets

2.3.5 Rail interface

STARGAZE has two railbuttons. One of them is placed at the bottom of the rocket and is screwed to the Bottom Ring, the other one is placed between the motor and electrical compartment and screwed to their couplers. A M5 screw is used to secure the railbuttons. The railbuttons are specially designed to fit the rail provided by EuRoC and are made out of iglidur® i3. Between the buttons and the rocket, a washer made out of PLA is placed.

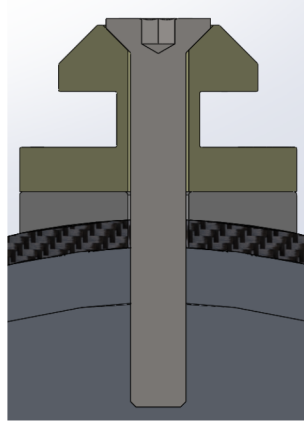


Figure 2.11: Cross Section of bottom railbutton

To ensure the vertical position of the rocket on the rail, a combination of a screw, screw nut and washers is clamped at the bottom of the rail and the rocket is placed on top of it.

2.4 Avionics

The avionics system is comprised of two flight computers and one electronic payload: the MAX-FC. Both flight computers are the Altimax G4. Additionally, the mandatory CATS-Vega computer is used as a logging device. The MAX-FC was originally intended as a fully functioning flight computer, however it is now operating as a payload providing its sensor data to the Airbrake in order to allow for accurate apogee estimation.

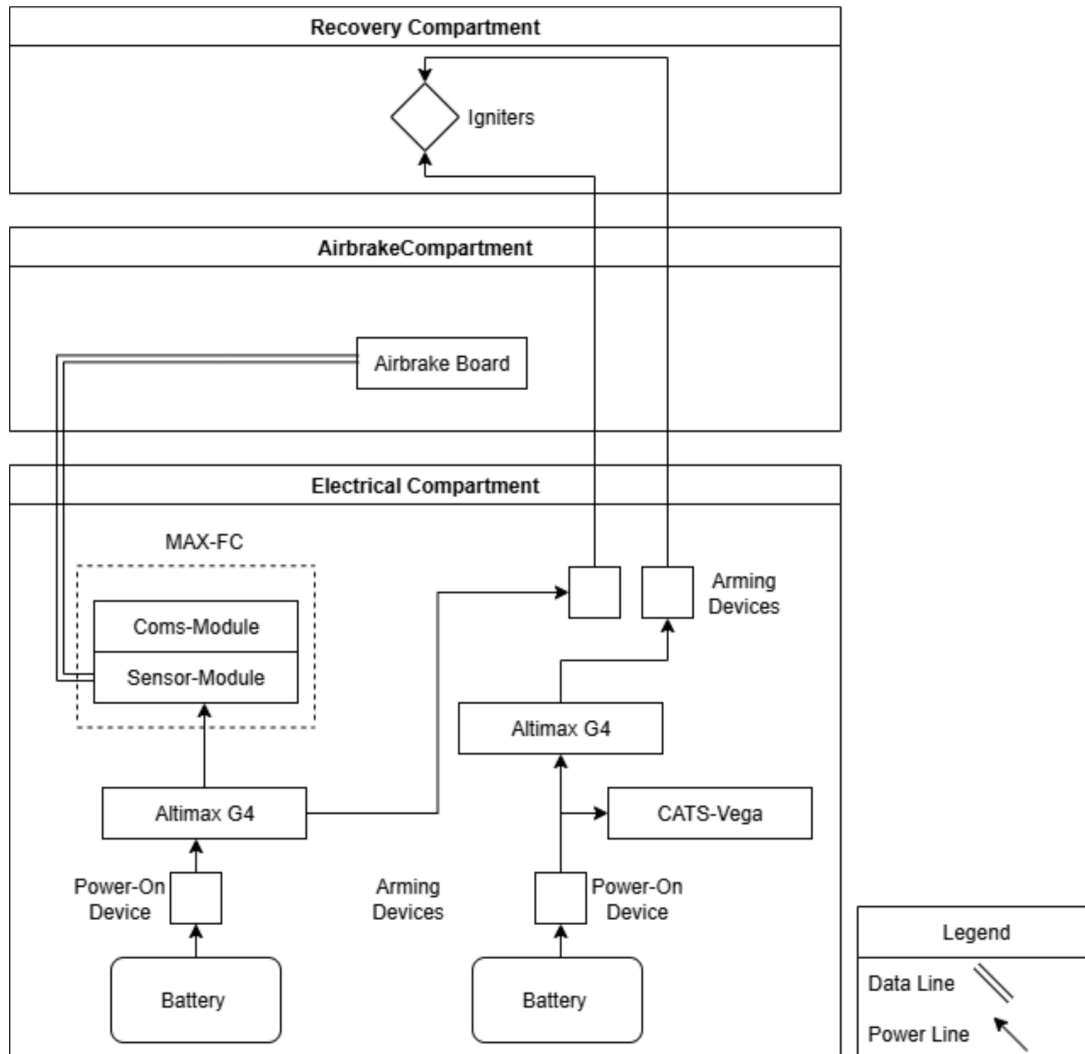


Figure 2.12: Avionics Blockdiagram

2.4.1 Power Supply

Each flight computer is powered by its own dedicated NiMH battery, consistent with the rest of the batteries used throughout the rocket. Both flight computers are powered by packs of 8 batteries. The CATS Vega and the MAX-FC are connected to the power supply of one Altimax G4. To make sure the battery will last the maximum of 6 hours on the pad, the batteries will be constantly charged from an external 7 Ah lead battery. The lead battery is connected to three power converters providing power for the battery stacks. The power converters are connected with 3 magnetic connectors to the rocket. The umbilical cable between the connectors and the power converter is 5 m long. For the Electronics Compartment and the payload, the "868 Mating Target Pad Connector" with 6 pins is chosen. These connectors will fall off during the start with

little resistance. Since multiple battery stacks are the same, these will be charged in parallel until the launch. Since the parallel circuit is located outside the rocket, the electronics are separated during the flight.

2.4.2 MAX-FC

The MODULAR ADVANCED EXPERIMENTAL FLIGHT COMPUTER (MAX-FC) consists of two different PCBs. These boards are the sensor board and the communications board. The exact function of these boards is described below. Both boards are connected to the same power line, but do not communicate with each other. Additionally, the Airbrake PCB is connected to the sensor board via an I²C bus. The PCBs have the same dimensions of 45mm x 55mm and each has its own power converter. The microcontrollers are flashed using the Serial Wire Debug interface.

Sensor Board

The sensor board provides the data for the Airbrake module. The following sensors are used:

- Temperature sensor
- Low G IMU
- High G IMU
- Barometer
- GPS module

All these sensors are connected to the microcontroller via the same I²C Bus. Additionally, an external flash memory module is included and can be accessed via SPI to provide the sensor board with the ability to log its own sensor data. The measured sensor data is actively pushed onto the I²C bus.

Communication

The communication module is used for RF telemetry from MAX-FC. It uses 430-440 MHz Amateur Radio frequencies, adhering to international and national regulations. It is almost completely a one-way (downlink only) system, with the only exception being a command that activates the cameras on the rocket. The module uses a commercial RF solution on a sub-board. This solution contains a serial interface, modem, transceiver, power amplifier, low noise amplifier and filters. It uses "LoRa" communication / encoding protocol technology from Semtech. This technology is regarded for a very high encoding gain and high interference resistance. The maximum transmitting power is 1 W. The theoretical maximum range is over 5 km. The range was tested to be 2 km on a previous hardware version. The hardware is designed in such a way that the same module can be used with a laptop as a receiving station or with the flight computer in the rocket as a telemetry broadcaster.

An antenna can be attached to the PCB via IPEX or SMA connectors. The antenna is then also mounted to the internal structure of the compartment. A VX-400/160 SMA antenna is used. As the entire compartment is the RF window (it is made from glass fiber reinforced composites), the antenna is placed close to the center of it. There are no significant metal structures and as few cables as possible close to the antennas.

The communications board shut down the entire data bus and due to time constraints it will not be connected to the remaining Boards. It will still be inside the rocket to keep the cable in place.

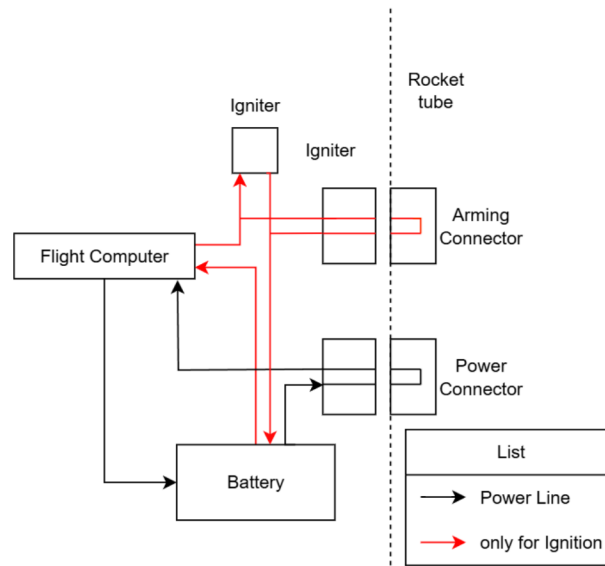


Figure 2.13: E-Activation

2.4.2.1 Interface

Given their close proximity, the PCBs are directly connected to each other via a custom connector and cables.

2.4.2.2 Activation

Power-On

The Power-On function is accomplished with the use of XT-30 Connectors. To turn the power on, the connectors need to be inserted so the current can flow from the batteries to the flight computers. The connectors close the positive power line to the flight computers. The batteries can still be charged without these connectors. These connectors stay in place for the flight and fully sink into the rocket.

Arming

The Arming and Power-On is also achieved with XT30-Connectors. They are inserted so the rocket is disarmed. As shown in figure 2.13 should a signal appear in that state, it will be pulled towards the battery. Once the connectors are removed, the signal will be transmitted through the igniter.

2.4.2.3 Bracket and Harness Design

To ease the integration of the individual compartment connectors will be placed between almost all structural joints. The charging current must be transferred from the Motor- to the Electrical-Compartment. One GX12 connector with 6 pins will be used. Within the electronics compartment the power cables are directly connected to the two batteries. The GND cable travels to the flight computers while the power cable is interrupted by the power-on connector. XT30 connectors are used to separate the flight computers and the batteries from the remaining structure since some parts are glued into it. The ignition outputs of the Altimax are directly connected to the arming connectors and to one of the GX12 connectors at the top of the electrical compartment.

After the electronics compartment, most cables need to be routed to the Recovery Compartment and the nosecone. A total of 3 GX12 Connectors with 6 pins each are located above the electrical

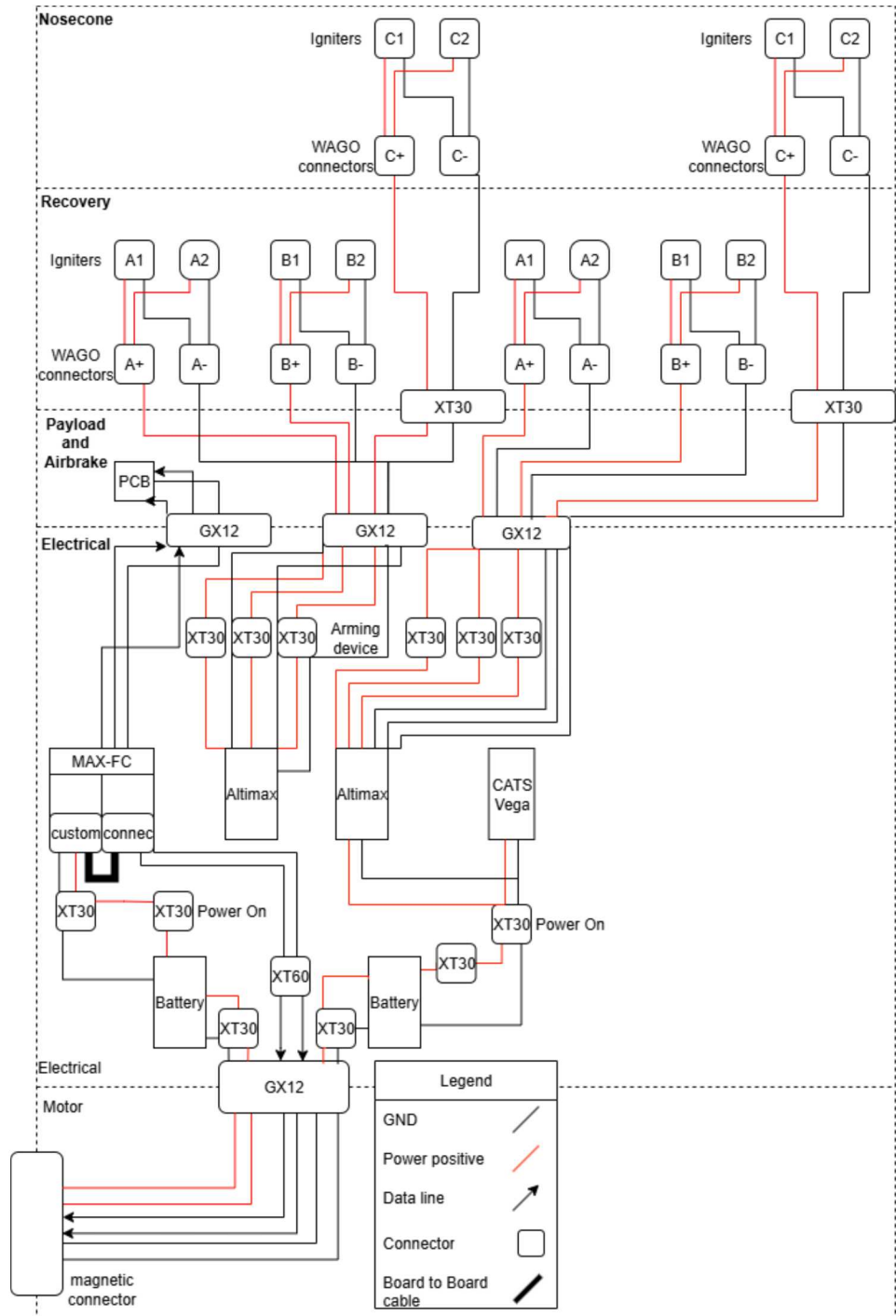


Figure 2.14: Lower Wiring Harness

compartment. From one GX12 connector, only three cables are connected for the PCB in the Airbrake system. Each of the other two connectors holds the ignition cables of one flight computer. They are transferred through the Airbrake and on top of the Payload. Here the ends of the cables are connected with WAGO connectors directly to the igniters. The four cables that transfer power to the igniters inside the nosecone need one additional XT30 between the Payload and the Recovery. At the nosecone they are again connected with WAGO connectors to the igniters.

Connectors will be labeled and cables color-coded to minimize errors during the integration. To reduce the load on each connector and minimize potential damage, cable ties are used to secure the cables at various points along the rocket.

2.4.3 Telemetry Ground Station

The ground station provides up- and downlink communications with STARGAZE during flight. It uses an identical communications board to the one used on the rocket by MAX-FC (see section 2.4.2). However, for the ground station, the communications board is connected to a laptop running Windows 11 via USB. The laptop runs a custom Python software that handles incoming telemetry messages and visualizes them for use by launch personnel during pre-flight, flight and recovery operations. Additionally, it provides the ability to remotely send digital arming commands to the rocket while it is on the launch pad. These only affect the launch detection of the MAX-FC and power up the on-board cameras. All other avionics are unaffected.

2.5 Airbrake

The Airbrake subsystem is a compartment located between the Avionics and Payload compartment. Structurally it is an exception to the other compartments, as the short length of the compartment means a fiber-reinforced body tube would add unnecessary complexity without reducing mass, which is why it is entirely made out of milled aluminum parts.

Functional description

The Airbrake subsystem's function is to manipulate the vehicle's drag to make the altitude of the apogee controllable. During the boost phase and during Airbrake dormancy afterwards, the Airbrake control surfaces, herein called "Flaps", are retracted to minimize the drag of the rocket. At a certain point they become deployable and are controlled using a closed-loop control algorithm that estimates the vehicle's attitude and position and propagates its expected apogee using inertial and barometric sensor-data. The goal is to precisely achieve the targeted 3 km of altitude above ground.

2.5.1 Structural design

The upper coupler forms the connection between the Airbrake and payload compartments. At the same time, the coupler is used as a cover for the Airbrake's electronics compartment. The compartment is connected to the payload coupler using six M4x8 screws. There are several through holes in the base of the coupler. The four in the middle are for the plain bearings of the shaft-mounted gears and the motor. The three large through holes at the edge are for various cables that extend to the rocket's recovery compartment. The other six holes at the edge of the struts are for screws that connect the lower coupler to the upper one. Two of the three struts have additional holes into which the electronics suspension is screwed. The upper coupler has been optimized for mass reduction in terms of manufacturing, which is why only a central web remains as a load-bearing element. To further reduce manufacturing costs, an additional stage has been integrated so that tolerance machining of g6/H7 is only carried out in the area where the payload coupler is screwed in.

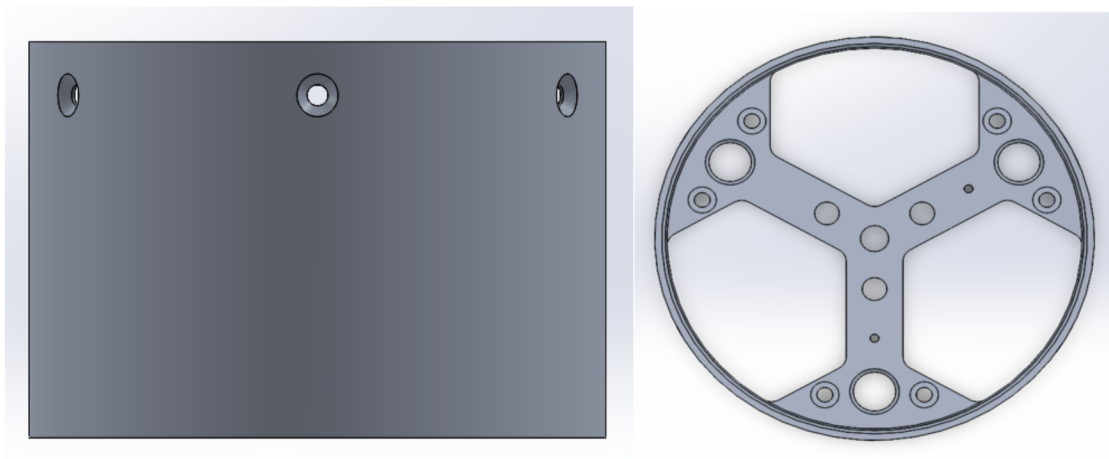


Figure 2.15: Side and top down view of the upper coupler

The lower coupler connects the rocket's electronics compartment to the airbrake and is also bolted in place. The structure is partially interrupted here to make room for the flaps. Furthermore, the

slides of the rails are attached to the lower coupler, via which the flaps are pushed outwards. As with the upper coupler, there are additional holes in the middle to hold the plain bearings of the shafts. Here, too, the focus was on reducing mass as much as possible, but this was not achieved because the rest of the rocket's structure runs over the couplers of the airbrake compartment, requiring a larger contact surface between the couplers of the airbrake compartment. To further ensure structural stability, especially in the area of the holes, the geometry was reinforced with ribs. The original rib design proved to be too complex to manufacture and was therefore simplified. To shorten the manufacturing time, additional fillets on both the ribs and the flaps were removed.

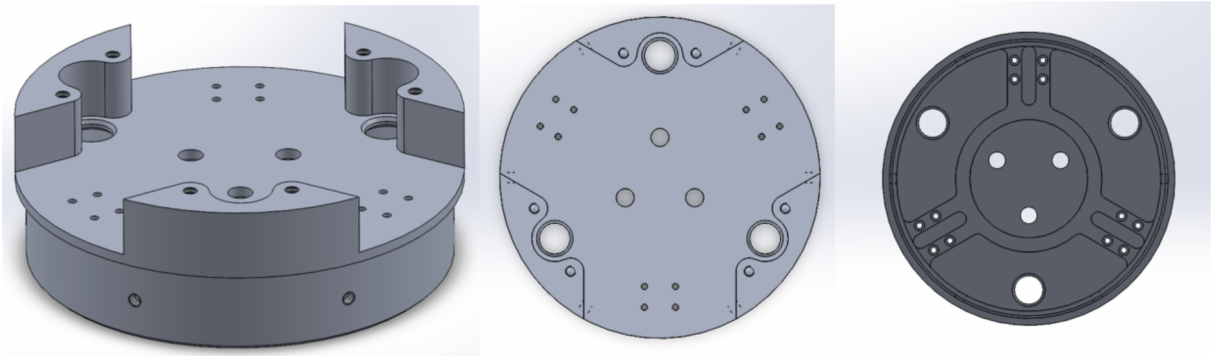


Figure 2.16: Side, top and bottom down view of the lower coupler

The following pictures show a cross-sectional view of the entire compartment, alongside the entire compartment integrated into the STARGAZE rocket. The electronics compartment with the motor, batteries, and circuit board can be seen in the upper center. The circuit board and motor are screwed onto their mountings, shown here in blue. A shaft runs from the motor through a plain bearing, shown in yellow, down to the central gear wheel. This gear wheel is connected to three other gear wheels, which are connected to the flaps' racks. Below these, the slides attached to the lower coupler can be seen. The two couplers are fastened together with M4 countersunk screws.

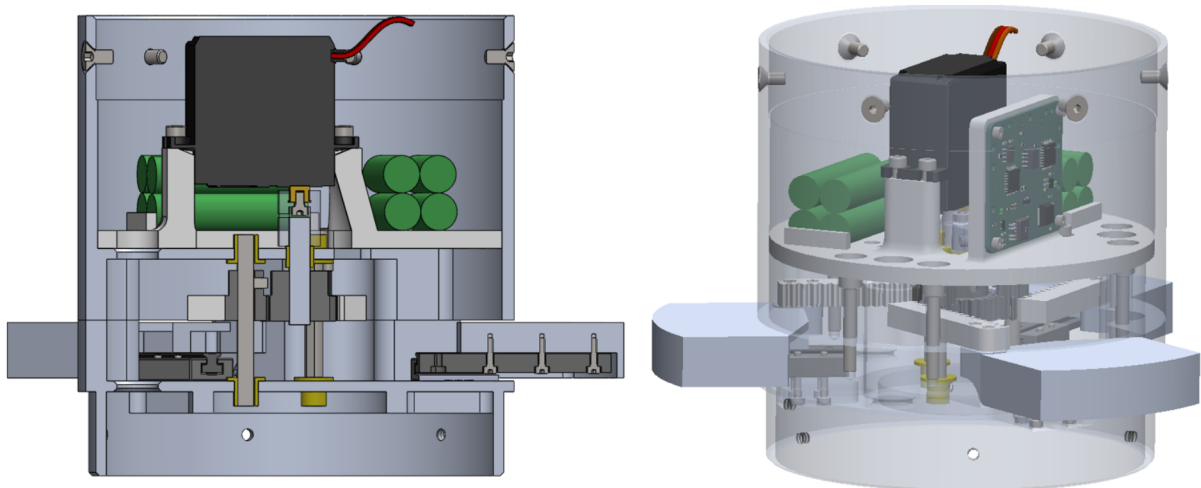


Figure 2.17: Cutaway views of the airbrake compartment and integrated into STARGAZE

Electronics bracket

The bracket must secure the motor, batteries, and circuit board while allowing the cables of the rest of the rocket to pass through it. The entire structure is printed from Engineering PLA, a high-quality and more elastic alternative to conventional PLA. The holes in the other structures are continued for the cable runs. The two battery packs for the two circuits and the motor have 4 800 mAh NiMH 1.2V cells respectively. These are attached horizontally to the electronics board with cable ties. The circuit board is screwed flat to a wall using M2.5 thread inserts inserted into the wall. The motor is placed centrally so that the motor shaft passes through the center of the plane. To align the shaft correctly, the motor is placed slightly higher in the structure. The design can be seen in figure 2.17.

Orientation and location on the rocket

Two configurations are possible in relation to the rocket, as three aft stabilizers and three flaps are used (as seen in figure 2.18): Flaps in-line with the fins and in-between the fins. The integration with the rest of the rocket allows for last-minute changes to this configuration. Aerodynamic preliminary considerations assumed that the out-of line configuration reduces the effect of the stall region behind the airbrakes on the stabilizing moment of the fins. If the stall region hit the airbrakes at lower speed, the pressure increase on the windward side at angles of attack different to 0 would be reduced. CFD simulations have however shown, that the difference for the momentum coefficient is negligible. One problem that could occur is that a faulty deployment of the airbrakes would push against the launch rail. This will be prevented through software, but if EuRoC officials see an issue with this, a last-minute change by rotating the compartment 60° is possible.

The placement of the compartment between the avionics bay and the payload compartment is a result of reduced design complexity for this configuration. Additionally, this puts the airbrake close to the center of mass, which would reduce the overall impact of the airbrake on the rocket's flight mechanics, other than increasing its drag.

2.5.2 Mechanism design

The selected mechanism is our own design, while being inspired by other rocketry team's airbrakes. The key design aspects of the mechanism shown in figure 2.18 and their respective reasoning are as follow:

- **Radial pushing of the flaps, instead of rotary movement** was used to reduce the compartment's length. A rotary mechanism also comes with added complexity by either introducing struts/linear pistons or requiring a high-torque motor for deployment.
- **Gears** are used to create precision movement in a low-tolerance design, that maximizes the stiffness of the system.
- **Two gear-stages** are used purely to increase stroke-length, which maximizes our drag area.
- **Three flaps** are used to create a symmetric rocket design (considering three aft stabilizers), which minimizes simulation effort and simplifies the rocket's aerodynamics.

The rack and pinions use module 1 teeth. The two gear-stages use 11 and 20 teeth at 11 mm and 20 mm pitch diameter respectively. A miniature linear rail system from the company igus is used, that uses self-lubricating materials. Miniature rails with recirculating balls could potentially be damaged by strong vibrations, which is why these sliding rails have been chosen. The drylin T miniature guide rail TS-04 and the matching carriage: drylin T miniature guide carriage TW-04 has been selected, which is the smallest rail available.

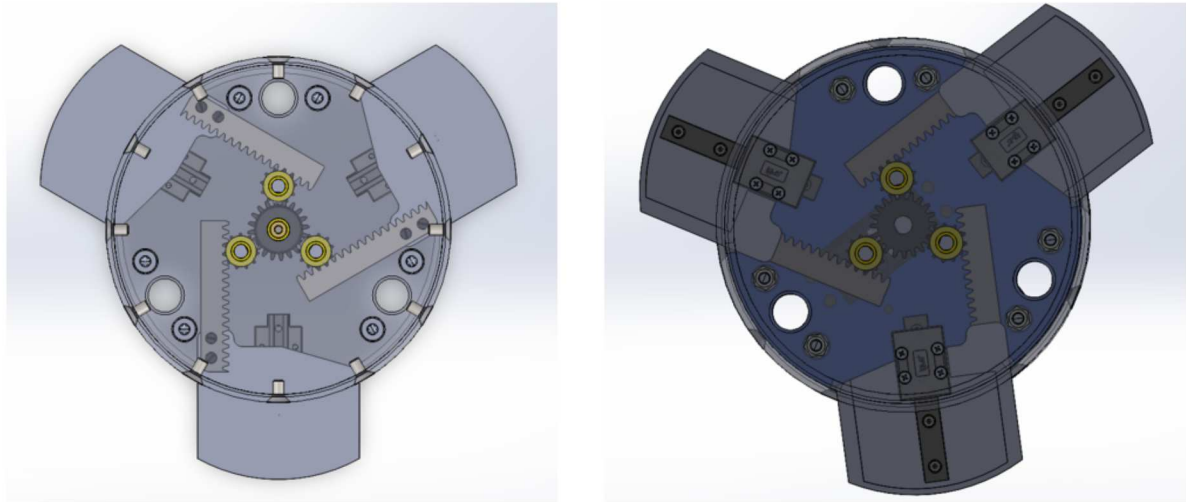


Figure 2.18: Mechanism of the Airbrake subsystem

The outer gears are connected to a 5 mm D-shaft via pins, which exert pressure on the axis through a thread and prevent slipping. As can be seen in Figure 2.19, plain bearings are used for the small gears at both the top and bottom, which rest on the upper and lower couplers in a clearance fit. These are adhesively bonded to the D-shaft and are also available from the manufacturer igus.

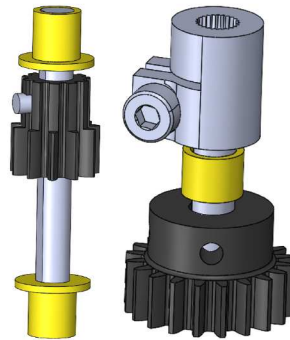


Figure 2.19: Assembly of shafts, plain bearings and gears

The large gear wheel is connected to the servo via a servo adapter from ServoCity. Power is also transmitted between the gear and the shaft via a pin. The 6 mm D-shaft is clamped into the adapter by pressure, and the adapter fits securely onto the servo's splined shaft. The adapter is attached to this splined shaft using a servo screw. A plain bearing is also used here, which ensures precise guidance in the upper coupler. Both the axles and the shaft are thus double-mounted. The gears and shafts are made of steel due to availability. Due to the limited installation space, it was decided to print the racks from Engineering PLA, as suppliers usually manufacture significantly thicker racks than necessary and the necessary post-processing would exceed the time frame.

Actuator motor

For the control algorithm it is vitally important to use a motor that knows its precise position, which the flap stroke can be derived from. For this, a closed loop motor has to be selected. Due

to the low complexity in operation, a digital brushed DC servo-motor has been chosen. The chosen motor can exert around 1.8 Nm of torque, which is more than enough to overcome the friction of the mechanism under load.

Flap design

When retracted, the flaps form part of the aerodynamic shell and are also milled from aluminum. The outer diameter is the same as that of the coupler. Here, too, the focus was on weight reduction. For this reason, the flaps are hollow except for the ribs, which are designed to stabilize the screw holes.

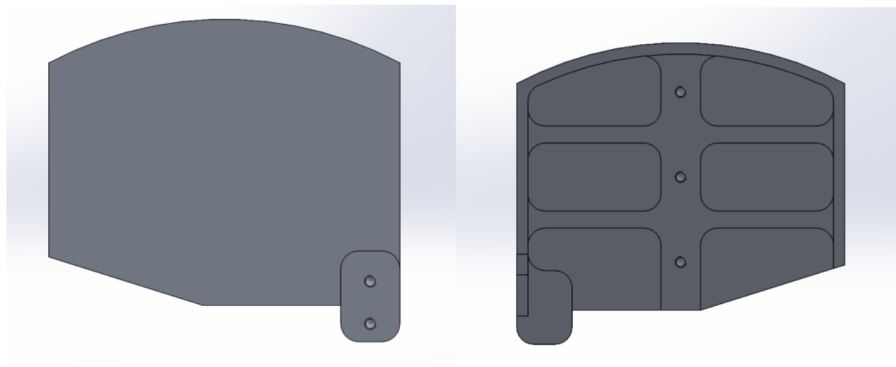


Figure 2.20: Design of the rib-reinforced flaps

Failure scenarios

EuRoC-LV-RQT-0670 specifies, that active flight control systems have to be designed to fail in a safe way. The system can fail in two major ways:

Faulty deployment due to failure of the electronics and/or software. This failure scenario does not pose any risk to people and/or the environment as the Airbrake purely manipulates drag and minimizes the impact on the overall flight mechanics. The rocket will continue to fly in a stable manner and no pitching moments will be introduced.

Structural failure of the mechanism. This could occur, if teeth of gears break or if the airbrake is broken off the rails completely. The main hazard here is the asymmetric deployment of the airbrakes, as this could induce pitching moments. These pitching moments would be very small, as the airbrake is positioned closely to the CoG during ballistic flight. Breaking of teeth and thereby destroying the mechanism has been tested, by "holding" the mechanism while the servo motor pushes against it. It was clearly observed, that the torque of the motor is not sufficient cause this failure mode. The rails and sleds are qualified for a 200 N loading. By integrating the pressure over the flaps during V_{max} the CFD-analyses have shown, that this loading is not exceeded. Even if deployment would accidentally occur during or directly after phase FA2 (thrust phase).

FEM Analysis of Airbrake-flaps

An additional failure mode, likely not causing any hazard, is the jamming of the mechanism due to high deformations under aerodynamic load. For this an FEM analysis was conducted.

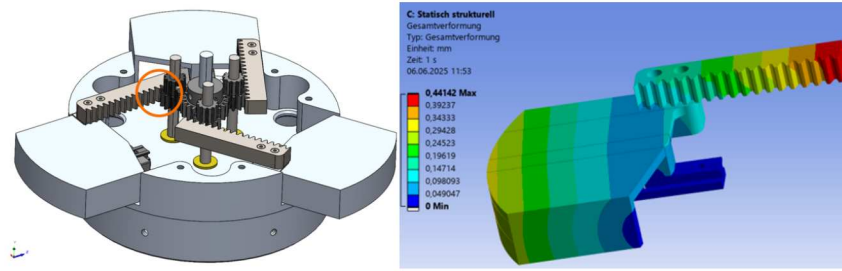


Figure 2.21: Left: Location where jamming could occur. Right: Deformation in mm under bending due to aerodynamic loads

The FEM analysis was conducted using preliminary formulae for estimating aerodynamic loading in supersonic speeds at a local Ma of 1.6 by assuming a bow shock before the flaps. This approach is extremely conservative and showed no critically high deformations due to the high stiffness of the system. The airbrakes on STARGAZE will at most experience Mach number around 1 (if faulty deployment occurs). The loads calculated from the latter described CFD analysis showed much lower loads that also stay below the 200 N rating of the rails and sleds used.

2.5.3 Airbrake electronics physical architecture

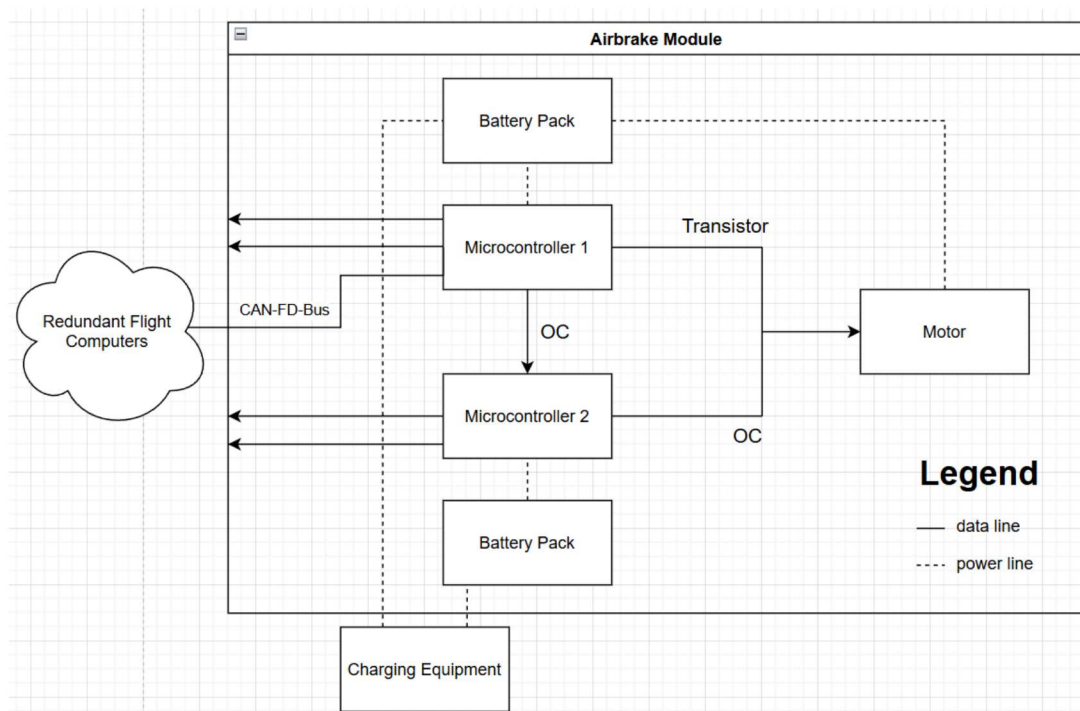


Figure 2.22: Electrical Layout

The Servo is controlled by a custom PCB. To ensure redundancy, two microcontrollers need to be used. Each of them is powered by their own battery which in turn are charged by a battery outside the rocket. The redundancy is achieved by having one primary microchip controlling the motor. Should that chip be damaged, the secondary controller will take over. The secondary chip fully extends the Airbrake instead of conducting further calculations. The main chip is constantly sending a heartbeat signal to the secondary chip via an optocoupler. Should the secondary chip cease to read a heartbeat, it will start sending its signal to the motor. Both

microchips are placed on the same board although they are electrically separated. The Board is connected to the I²C bus of the MAX-FC to receive its data. The calculations are conducted on the Airbrake board.

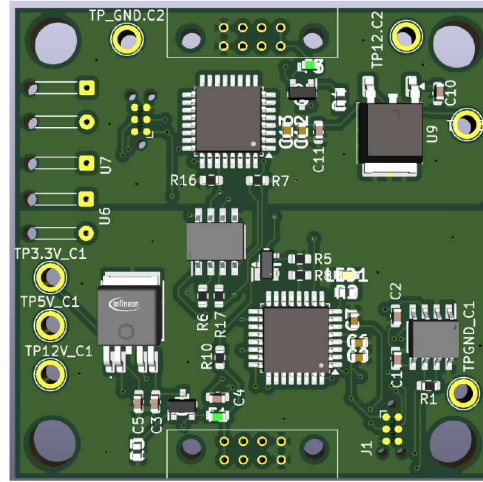


Figure 2.23: Airbrake PCB

Power Supply

Both microcontrollers have their own power supply and run on a nominal voltage NiMH 4S battery pack at 800 mAh respectively. The batteries are charged by the external battery via the same magnetic connectors as used for the avionics batteries.

Ground-based operations

Requirement EuRoC-LV-RQT-0310 stipulates that all on-board batteries must be charged on the launch pad if they are not easily removable and replaceable. In addition, the Airbrake passivation altitude (boost dormancy) must be changeable via software when fully integrated. The batteries are charged on the rocket as standard via oval magnetic connectors, which simply fall off during lift-off. It would have been cumbersome to mill an oval hole in the metal outer wall for the Airbrake compartment, which is why a round magnetic connector was chosen as an alternative, requiring only an M12 through hole to be drilled. The magnetic connectors can be seen in Figure 2.24. Last-minute changes to the boost dormancy height can be achieved via separating the airbrake compartment from the Payload compartment and flashing the chip of the primary flight controller circuit.



Figure 2.24: Magnetic connector for charging of batteries

2.5.4 Motor control

The deployment state of the airbrakes, and thus the target angle of the servo, is defined by the microcontroller via a PWM signal. The control signal from the feedback loop influences the angle so that the controlled variable is adjusted to the target angle. The controlled variable is not measured directly but estimated through apogee propagation and compared with the setpoint in order to calculate the control deviation. The principles of the control loop and apogee propagation are depicted in Figure 2.25. Before the flight, servo calibration is necessary, during which the full range of motion of the airbrakes is determined to ensure reliable conversion from target deployment state to servo angle.

Apogee Estimation and Control Loop

To estimate the apogee during flight with high precision and low computational effort, a simple ballistic forward propagation of the rocket's current state is performed after burnout. In this process, the current altitude and vertical velocity are forward integrated under consideration of aerodynamic drag and gravity until the vertical velocity changes sign. The altitude reached at this point corresponds to the apogee. During propagation, the expected future deployment state of the airbrakes must be taken into account, which is simplified by assuming it remains constant. The calculated apogee is compared with the mission target altitude of 2750 m AGL in order to estimate the deviation. Currently, if the target altitude is exceeded under the assumption of a constant deployment state, the deployment state is set to 100%. Conversely, if the target altitude is undershot, the deployment state is set to 0%. The control loop, including apogee prediction, is repeated in a cycle until the apogee is reached. At that point, the airbrakes are to be fully retracted, and thus a deployment state of 0% is commanded.

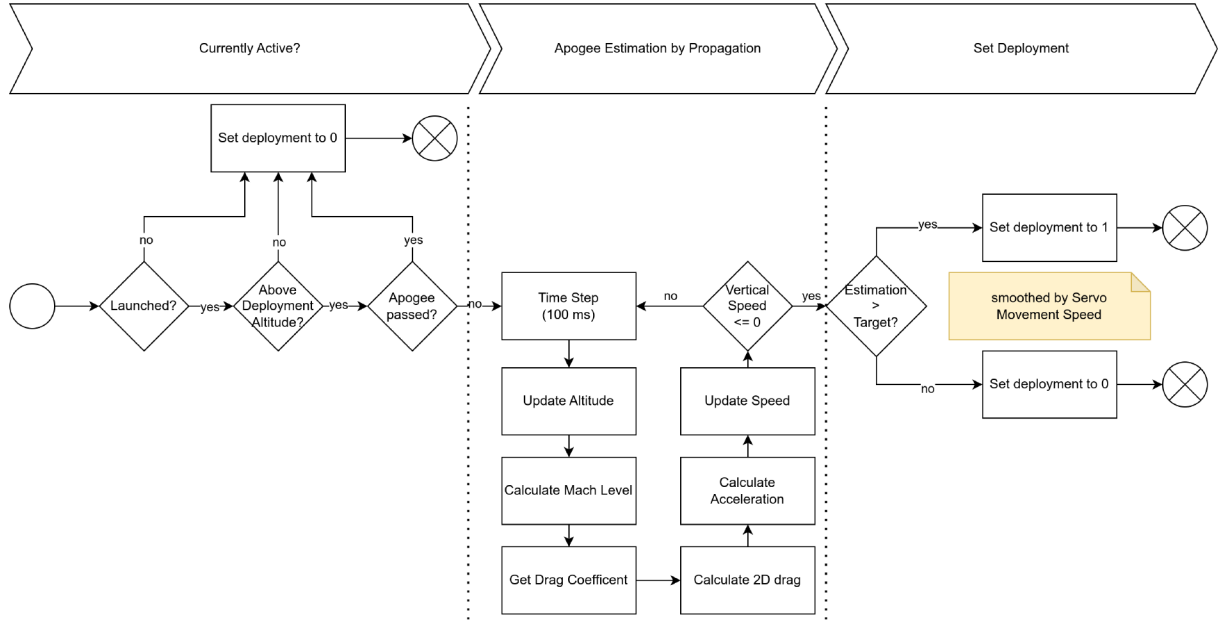


Figure 2.25: Flowchart of one iteration of the control loop including trajectory propagation

State Estimation

For accurate apogee propagation, precise knowledge of the current state is essential. The barometer integrated into the sensor module enables reliable and precise altitude measurements. However, the rocket's velocity can only be determined indirectly during flight by integrating acceleration measurements. Even small measurement errors or inaccurate initial conditions lead to a continuously growing integration error, which can result in significant uncertainties in the velocity estimation. By fusing both measurement sources in a *Kalman Filter*, the rocket's state can be estimated much more precisely and robustly. The filter combines the short-term stability of the inertial acceleration measurements with the long-term drift-free altitude information from the barometer. The computation is performed on the microcontroller in the airbrake module. The estimated state vector is given by

$$\mathbf{x} = \begin{bmatrix} z & v_x & v_y & v_z & b_{ax} & b_{ay} & b_{az} & b_p \end{bmatrix}^T,$$

where z denotes the altitude, v_x, v_y, v_z the velocities, and b_{ax}, b_{ay}, b_{az} the bias terms of the acceleration measurements, while b_p represents the bias of the barometer measurement. Since

both the accelerometer and the barometer exhibit slowly drifting biases, these are also estimated as part of the state vector. Without explicit bias modeling, a linear drift in the velocity would occur, which would distort the correction from the altitude measurement. By explicitly estimating the bias, the barometer bias b_p can be adjusted such that the acceleration measurements remain consistent and the altitude correction is not permanently shifted in the wrong direction. The apogee estimation is carried out in the inertial coordinate system. Since the sensor module is attached to the rocket, the acceleration measurements are initially given in the rocket's body-fixed frame. Therefore, the raw accelerometer data must be transformed from the body frame into the inertial frame. The required attitude information is obtained by means of a *Mahony filter*, which fuses the IMU measurements.

Data Acquisition

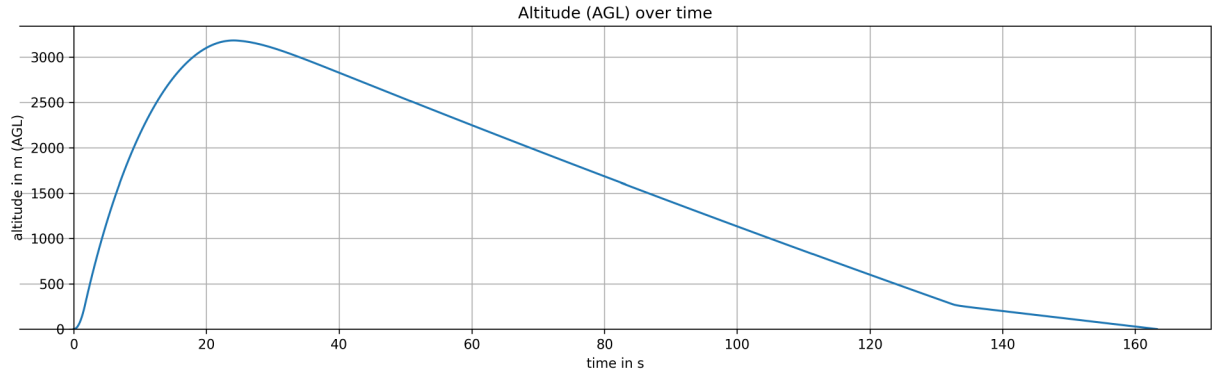
The microcontroller of the airbrake module is connected to a I²C bus. On this bus, the flight computer and the sensor module of the electrical compartment provide current sensor data at variable time intervals.

For communication on the I²C bus, the flight computer team of STARGAZE has defined a communication protocol, which specifies the structure and content of all messages on the I²C bus. These messages must be decoded by the microcontroller and filtered for those originating from the sensor module.

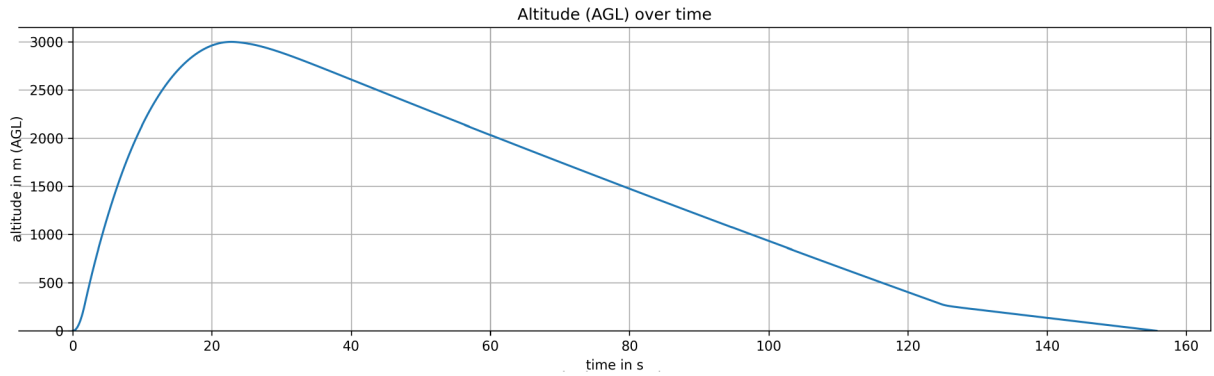
The message packets provided by the sensor module contain acceleration data along six axes as well as the current air pressure. In addition, temperature data, and a timestamp are included; however, these are not used by the airbrake module.

2.5.5 Airbrake performance prediction

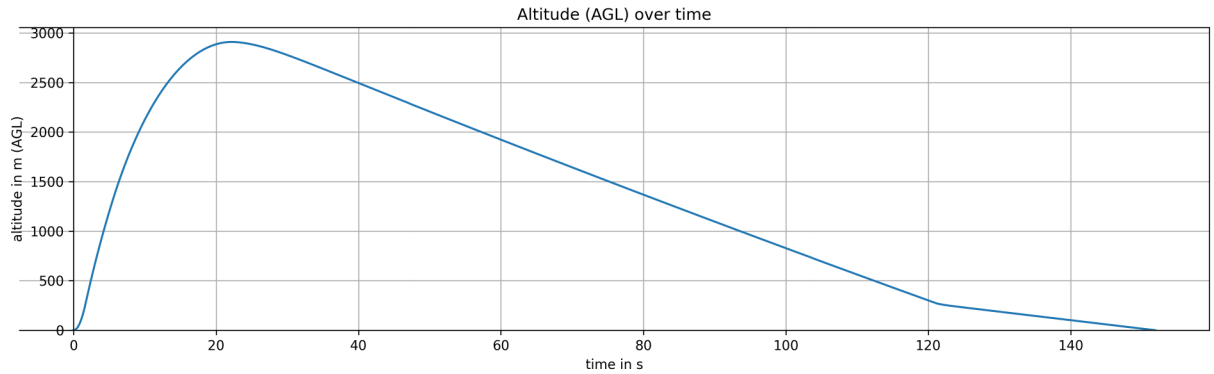
The Airbrake is modeled in the RocketPy flight simulation. The drag coefficients calculated in the CFD analysis (see section 2.5.6) are used. Furthermore, the control loop (see section 2.5.4) is re-implemented in Python for use within the flight simulation. The Airbrake is activated at a configurable altitude and is deactivated at apogee. The maximum movement speed of the servo controlling the braking surfaces is simulated in the implemented control loop. Three scenarios are tested. The first scenario assumes the Airbrake is never activated to provide a reference for evaluating the Airbrake's performance. The second scenario activates the Airbrake at 1500 m as planned for the real flight. In the third scenario, the Airbrake is assumed to be continuously fully extended between 1500 m and apogee to estimate the maximum amount of braking possible during activation time. For all three scenarios, standard atmosphere without wind is used.



(a) Scenario: Airbrake is never deployed (apogee: 3220.354 m AGL)



(b) Scenario: Airbrake control loop is activated at 1500 m AGL (apogee: 3000 m AGL $\pm$ 2 m)



(c) Scenario: Airbrake is fully deployed between 1500 m AGL and apogee (apogee: 2909.358 m AGL)

Figure 2.26: Comparison of altitude over time between different Airbrake activation scenarios

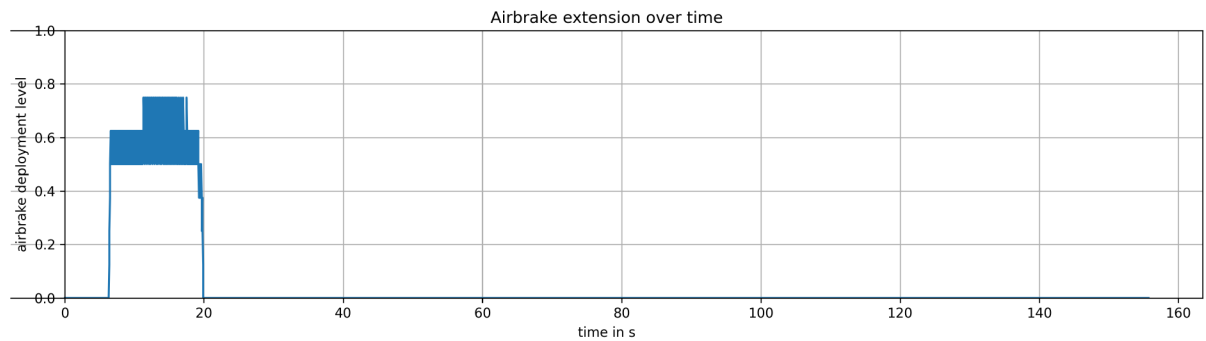


Figure 2.27: Airbrake deployment over time in the scenario where Airbrake control loop is active between 1500 m and apogee

In the reference scenario without Airbrake deployment, the rocket reaches a ballistic apogee of 3220.354 m m AGL (see figure 2.26a). With an activation height of 1500 m and the control loop active, the rocket reaches the target altitude of 3000 m AGL with a deviation of less than 2 m (see figure 2.26b). In the scenario where the Airbrake is continuously fully deployed during the active phase, the apogee is reduced to 2909.358 m (see figure 2.26c). Compared to the reference scenario without Airbrake deployment, this yields a maximum total apogee reduction of around 311 m.

2.5.6 Aerodynamics

CFD simulations are carried out to investigate the aerodynamic effects of the Airbrake on the flight performance of the rocket. This includes aerodynamic stability under the effect of crosswinds and different Airbrake positioning in the rocket, as well as the increase in drag coefficient induced by the deployment of the Airbrake. The simulations are carried out using Ansys Fluent using the BEARS HPC cluster.

The set-up for the aerodynamics simulations including mesh sensitivity studies, models and boundary conditions are documented in the appendix in section ??.

2.5.6.1 Results

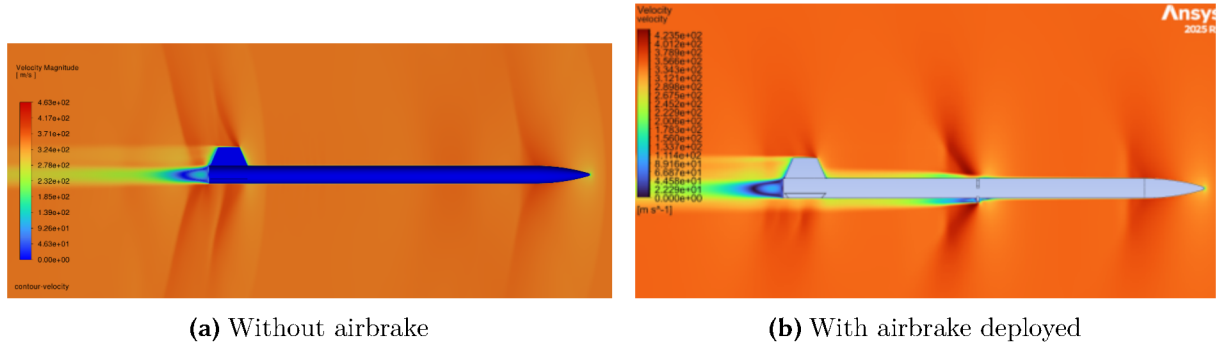
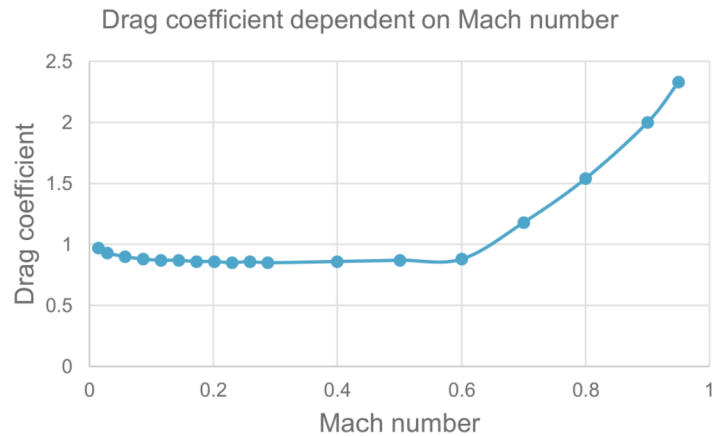
The results of the lower speed simulations under the effect of crosswinds can be seen in table 2.4. A flow speed of 60 m/s was used to validate the results with another case found in literature. The reference values of this case can be found in table 2.5. It can be seen that the Airbrake provides a sufficiently high increase in drag coefficient in order to achieve the desired braking. The results also provide an insight into the effect of the Airbrake on the aerodynamic stability of the rocket. The deployment of the Airbrake causes only a small increase in moment coefficient in a crosswind of ± 10 m/s. It can also be seen that the position of the Airbrake does not significantly alter the aerodynamic stability of the rocket, and the position of the Airbrake on the rocket can be chosen freely. For the transonic simulations, no equivalent studies could be found in literature for validation, but the flow behaviour appears to be qualitatively as expected. Bow shock waves and oblique shocks can be seen in figure 2.28b. The drag coefficient sharply increases in the transonic area which is due to these pressure phenomena. This can be seen in figure 2.29. These drag coefficient values are used in the flight simulation in section 2.5.5. The maximum drag force exerted on the individual flaps in the simulation is 136 N, which was considered when determining the design safety margins for the system.

Table 2.4: Results of the 60 m/s simulation

Configuration/Coefficient	C_m	C_d
Comparison calculation	0	0.483
Comparison calculation with +10 m/s crosswind	2.02 - 2.03	xxxx
Comparison calculation with -10 m/s crosswind	-2.03 - -2.04	xxxx
over motor & without crosswind	0	0.83 - 0.85
over motor & +10 m/s crosswind	2.11 - 2.13	1.28 - 1.29
over motor & -10 m/s crosswind	-2.06 - -2.09	1.33 - 1.35
over electrical & without crosswind	0	0.84
over electrical & +10 m/s crosswind	2.01	1.26
over electrical & -10 m/s crosswind	-2.08	1.28

Table 2.5: Reference values for the 60 m/s case

Parameter	Reference value
Speed [m/s]	60
Atmospheric pressure [Pa]	101325
Reference area [m^2]	0.006122
Reference length [m]	2.282

**Figure 2.28:** Flow field of the STARGAZE rocket at transonic/supersonic speeds**Figure 2.29:** Increase in drag coefficient at transonic speeds

2.5.6.2 Validation

As mentioned, data found in literature is used to validate the results of the low-speed simulations. Ansys Fluent is often used in industry for drag simulations, such as by Devanuri in [2] where it was used to investigate the effect of airbrakes on ground vehicles. Comparable literature cases to STARGAZE from other student rocketry teams are used for case-specific validation at a flow speed of 60 m/s [1]. The drag coefficient in literature without deployment of the Airbrake is approx. 0.46, which is comparable to the drag coefficient of 0.483 determined in the simulation. With the Airbrake deployed, the literature value of the drag coefficient is slightly lower than the simulation value, however this can be attributed to smaller flap size and differing frontal area. These similarities show that the simulated flow behaviour results are suitable to be used during the design process of the Airbrake. For higher speed simulation, no such comparable case study could be found in literature. The high speed simulation results will be validated from data from the rocket flight itself.

2.6 DÖNER'nt (Payload)

This section describes the only payload on-top of the STARGAZE rocket.

Function description

Fin-stabilized rockets tend to spin due to small manufacturing errors in the alignment of the fins, which results in unwanted non-zero cant angles. Due to our planned manufacturing method of integrating the fins with the motor-compartment via tip-to-tip lamination, these small manufacturing errors will likely be unavoidable. The resulting spin of the rocket will decrease the quality of the on-board camera footage of the rocket. The payload subsystem aims to mitigate that effect. The name "DÖNER'nt" stems from the fact that the payload does not spin. The payload has therefore been realized as a mechatronical system that decouples on-board video cameras from the rocket's roll-rate, the freedom of rotation relative to the rocket is allowed by being mounted on top of the rocket's primary structure via two bearings. The roll-rate of this decoupled compartment is held at $0^\circ/\text{s}$ by using a closed-loop controlled stepper motor and gear-coupling. The active video footage stabilization will be in effect throughout the upwards trajectory up until apogee. During drogue deployment, the system will passivate. The payload will turn on again during main parachute descent. The flight phases are determined via the Payload's own IMU, which also serves as sensor data for the control loop.

2.6.1 Structural design

The payload compartment's structural design is detailed in section 2.3. The full assembly can be seen in figure 2.30, which also shows the bearing shoulders, bolted into the insert that is adhesively bonded to the carbon tube, as well as the bearings themselves and the inner gear, which is 3D-printed and bolted into an inner ring inside of the carbon tube.

Due to this design, the outer aeroshell is not load-bearing. Because of this, the two parts of the aeroshell, shown in figure 2.32, were manufactured by 3D-printing PETG for improved resistance to sunlight. This allowed to create more complex geometries, which was helpful in e.g. designing a protective cap for the cameras, that allows the camera lense to be moved further outward and therefore capture the fins and airbrakes. Additionally, incorporating various holes and cutouts for umbilicals and screws became easier. The design also uses stiffeners to account for the lower strength of the material, making sure that any aerodynamic excitation does not cause dynamic loading of the part thereby destroying it.

2.6.2 Mechanism Design

A simple geared mechanism is used which is powered by a NEMA11 stepper motor. The selection of the motor is the primary driver of the dimension of the inner structural tube. Testing has shown, that a NEMA8 motor supplies enough torque with only a very small margin, which is why a NEMA11 motor is chosen. A stepper motor is used as it permits precise speed control at very low speeds, with the main drawback being a maximum speed of around 2000 RPM, with a steep drop-off in torque above 1000 RPM. This upper limit has been deemed to be sufficient, although accurately estimating the rocket's spin rate is not possible, as it is only a result of small errors in fin alignment.

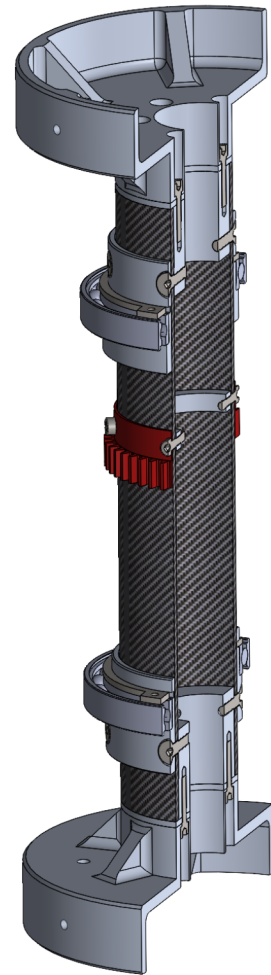


Figure 2.30: Primary structure of the payload subsystem

Mechanical platform for electronics and drive train

The payload itself is mounted onto the structural tube in a double-bearing configuration, with one bearing permitting axial movement. Both bearings were chosen to be ball bearings for decreased cost. The inertial loads during maximum rocket acceleration do not exceed the maximum axial load of the ball bearings. These bearings sit on aluminum shoulders, which are screwed to the structural tube and are secured via circlips, the design is based on applicable engineering standards. Placed atop of these bearings is a 3D-printed platform with an additional ring for axial alignment at the top bearing. The platform and the ring are connected via six M5 threaded rods, as shown in figure 2.31. These threaded rods allow for easy integration of all electronics equipment, such as batteries, microcontrollers, motors and cameras via self-securing nuts.

Removability for weigh-in

EuRoC-LV-RQT-0890 specifies the necessity for the payload to be removable. Because of this, the platform shown in figure 2.31 is split in half and connected via screws. Because the lower base plate serves as a fixed bearing, an additional "bearing-lid" is used, which requires loosening of six additional screws for the payload to be removable. This is shown as best as possible in figure 2.32. The bearings, the bearing shoulders, the circlips as well as the inner gear are therefore only retrievable by disconnecting them from the primary structure and then removing the payload couplers from the carbon fiber tube. Because of this, it is proposed, that these parts do not count as part of the actual payload that is being weighed, but are part of the rocket itself. Additionally, the airframe can be separated from the payload via loosening of twelve countersunk screws. We propose to include the two airframe halves for the weigh-in, but can also take it off beforehand. The proposed parts for weigh-in would total around 1500 g.

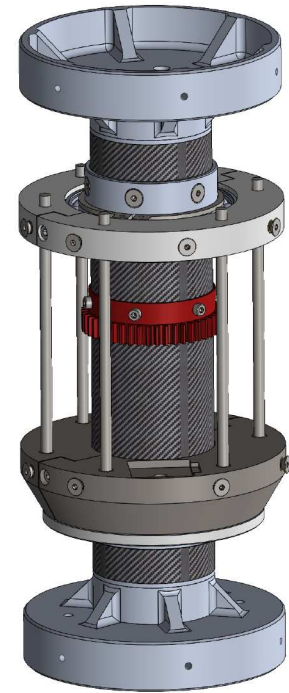


Figure 2.31: Platform for electronics and drive train

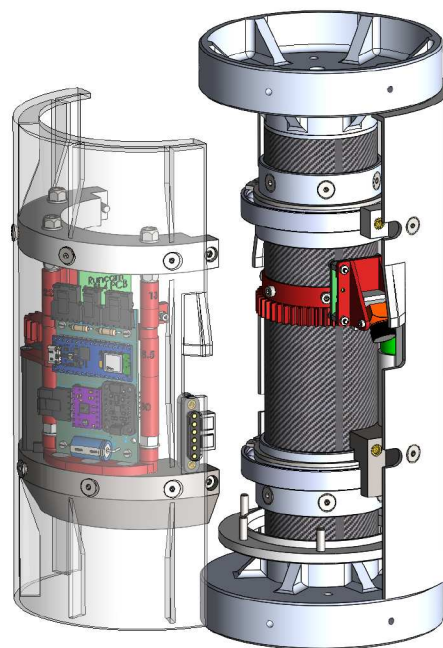


Figure 2.32: Removable payload with internal structure

2.6.3 Electronics and Software

Electronics for this subsystem are non-redundant in hardware and software as the subsystem in terms of failure is no hazard to a nominal flight.

Electronics

The electronics can be separated into 4 groups:

1. Power supply: 11 x 1,2 V NiMh cells at 2100 mAh in parallel for a maximum voltage of around 14,5 V
2. Cameras: 2 x RunCam split v4
3. Motor: NEMA11 open loop stepper motor
4. Custom PCB

The battery pack voltage is a requirement of the procured motor and the capacity is the result of the total current budget, which would exceed 800 mAh NiMH cell discharge rates. The cameras are chosen due to their high quality at a very small form factor. The stepper motor is open-loop, as precise knowledge of the motor's speed and/or position is not useful for the control loop. The custom PCB combines three separate COTS boards: an ESP32 Arduino Nano as the microcontroller, a DRV8825 motor controller and a ICM-20948 9-axis IMU. The microcontroller controls the motor, reads the IMU sensor data via I2C, implements the control-loop, turns the cameras on via UART and handles different flight phases. Additionally, the microcontroller is connected to the main avionics bay via an umbilical cable and a magnetic connector that separates during lift-off. This umbilical cable gives information prior to lift-off via an opto-coupler, which allows the ESP32 to only activate the motor and cameras a few seconds prior to lift-off, which mainly prevents over-heating of the compartment.

Appendix H in the appendix shows the circuit diagram of the custom PCB, which can also be seen in the CAD assembly in figure 2.32.

Software and control loop

The software is C++ using the Arduino library as well as some modified libraries for the motor driver and IMU to reduce software overhead and increase speed. Aside from handling different flight phases (using accelerometer sensor readings and the information from the umbilical cable) and turning cameras and motor on and off, the software implements the control loop. This control loop is a SISO (single input single output) closed loop that reads the roll-rate from the gyroscope. As the target roll-rate of the payload itself is 0 rad/s, the gyro-reading is equal to the error-value. PID control is implemented. The system is not fully simulated beforehand, as almost all system parameters, such as skin friction of the airframe, the actual rocket's spin rate as well as the motor torque can only be poorly estimated. A hardware approach is therefore chosen, the determination of the PID-values happens via a test-campaign, that uses a prototype of the subsystem.

Ground-based operations

The payload subsystem uses Mill-Max oval 6-pin connectors for communication with the main avionics bay (two pins) and an additional two pins for battery charging. This connector uses two magnets and some 3D-printed parts for alignment.

2.7 Recovery

This chapter describes the recovery system of the rocket in assembly as well as in functionality.

2.7.1 Subsystem Physical Architecture

The rocket employs a dual deployment recovery system located in the nose cone and the upper section of the airframe directly beneath it. The nose cone houses the hardware necessary for the drogue parachute deployment at apogee, including Polyester ropes, pyrotechnic charges, the drogue parachute, three metal plates and a 3D printed inner and outer shell. The section of the airframe beneath contains the hardware needed for the main parachute deployment, consisting of polyester ropes, a wire rope, tether and release device (Tender Descender - TD2) (seen in figure 2.35), the main parachute with deployment bag and pyrotechnic charges as well.

The system uses polyester ropes with a Polypropyl core, a diameter of 7 mm and a breaking load of 9.7 kN, with an exception of the rope from the nose cone tip eyebolt to the forward attachment, which has a thickness of 5 mm, selected due to space limitations. These ropes serve as the primary load carriers during and after the two parachute deployment events. Each rope connection - defined as the entire rope path from a parachute to the bottom of the recovery compartment - is sized to be four times the diameter of the attached parachute. Double figure-eight knots are used to attach ropes to other components via swivel links, complying with EuRoC-LV-RQT-0400. In addition to the Polyester ropes, the system includes a loop of 3 mm thick aluminum wire rope, secured with two press sleeves in a series, also made of aluminum. According to the datasheets, the aluminium wire rope and the press sleeves have breaking loads of 5.42 kN and 4.2 kN, respectively. Our MATLAB simulation predicts a drogue opening shock force of 1.6 kN, which is well below the capacities of both components. The eyebolts are made of stainless steel, with an M12 in the Nose Cone and an M16 at the bottom of the recovery compartment. The nose cone connects to the airframe through a metal coupler, which is secured by four M4 shear pins. The diagram below illustrates the rope plan used by the former flown rocket Moondust and will be used for Stargaze as well as it is designed for the loads of Stargaze.

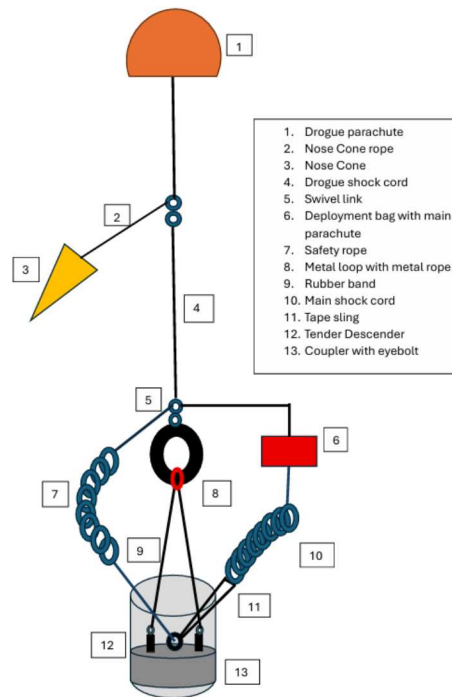


Figure 2.33: Rope plan with open drogue parachute

Initial deployment

The ejection of both parachutes starts at different times. Therefore two ejection events are needed. It's beginning with the ejection of the nose cone for the drogue parachute deployment. First, a total of 4 g of pyrocharge - distributed across two jars - is activated by two igniters each. The explosion leads to high pressure, which will push the parachute plate, which will push the inner shell containing the ropes and the drogue parachute. This will also break the plastic screws by the push plate. Results in the deployment of the drogue parachute. The design of the outer shell, which is glued to the carbon fiber nose cone, ensures the direction of the pressure, due to the raised edge that the metal plate presses against.

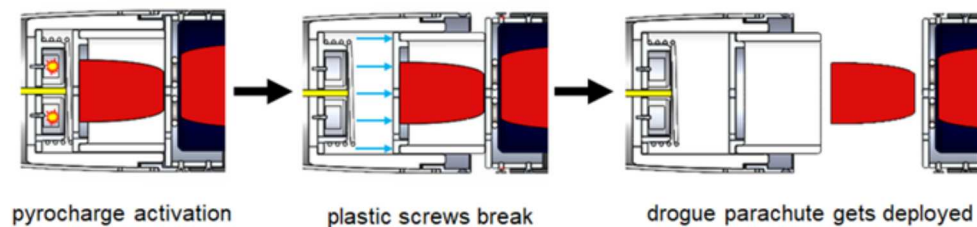


Figure 2.34: Nose Cone ejection

Main deployment

The drogue parachute pulls on the main swivel link (five in the rope plan above) until the ignition of the Tender Descenders at 400 m. The main parachute is then ejected by the ignition of one of the two igniters inside a TD. For redundancy, two TDs are used, each equipped with two electric

matches, which are fired by separate flight computers. The safety rope and main shock cord are taped to reduce the shock force. The meaning of the safety rope is to connect the drogue parachute with the airframe, after the ejection of the main parachute. Immediately after the ignition of the TDs, 4 g of pyrocharge located near the TDs ignites to push the components above it out of the airframe, in case friction between the ropes themselves or the ropes and the airframe is too high. The rope plan has been designed to account for two scenarios:

1. **Both TDs release:** In this case, the eyebolts of the TDs remain connected to the wire rope loop with a rubber band to prevent losing the eyebolts after flight.
2. **Only one TD releases:** In this case, the released TD passes through the wire rope loop and breaks the rubber band, allowing a normal deployment of the main parachute.

2.7.2 Parachutes

For the initial deployment, a 30" (76.2 cm) diameter parachute with a CD of 1.5-1.6 is selected and for the main deployment an 84" (213.36 cm) parachute with a CD of 2.2. Both parachutes are made of rip stop nylon, made by Fruity Chutes and comply with the EuRoC coloration requirements. The main parachute is black and yellow and the drogue red and white. The parachute size is determined through MATLAB simulations to achieve the required descent rates for each flight phase, predicting descent velocities of 23.48 m/s after initial deployment and 6.83 m/s after main deployment. The parachutes have been tested for filling time and stability with a drop test from a tall building.

2.7.3 Recovery test-flight (MOONDUST)

On August 29, 2025, our team launched MOONDUST, a smaller version of our previous rocket. The purpose of this flight was to validate the recovery system that will later be implemented in our EuRoC rocket, STARGAZE. In particular, we aimed to confirm reliable parachute deployment after the previous rocket had experienced rope entanglement during flight because of too high friction inside the recovery airframe.

MOONDUST has approx. half the mass of STARGAZE (12 kg), inner and outer diameters of 120 and 125 mm, respectively, and reached an apogee of about 1200 meters. Apart from the reduced size, the rocket used the same rope plan and recovery components as STARGAZE. For the test flight, a 15-inch drogue parachute and a 48-inch main parachute were deployed, both made of Nylon. The drogue parachute deployed successfully as planned. The main parachute, however, deployed a few seconds after the drogue deployment instead of at the intended altitude of 300 meters. This occurred because the deployment bag was placed at the very top of the recovery compartment and was exposed to airflow, causing it to flap and eventually release the parachute too early. Premature deployment has been identified as the main issue of the test. The other components have all worked as expected. The mentioned problem can be solved with a small modification of the recovery system, one option being to secure the deployment with a weak retention method, such as masking tape, which will release easily as soon as the bag is pulled by the drogue parachute to the desired altitude. Another option is to place the deployment bag below the main shock cord instead of the test configuration, where the order was reversed. Overall, the test achieved its primary goal and provided important insights into what needs to be modified so that the system is ready for implementation in STARGAZE.

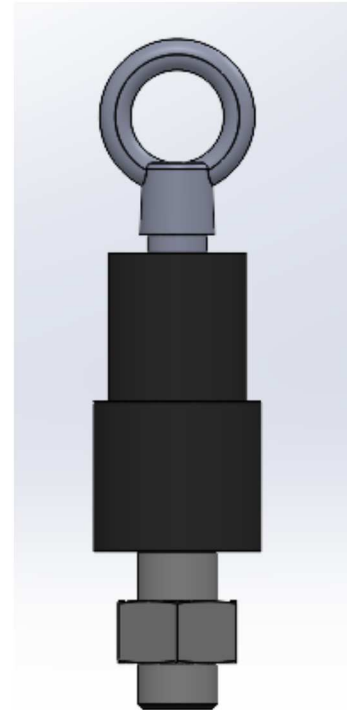


Figure 2.35: CAD from Tender Descender

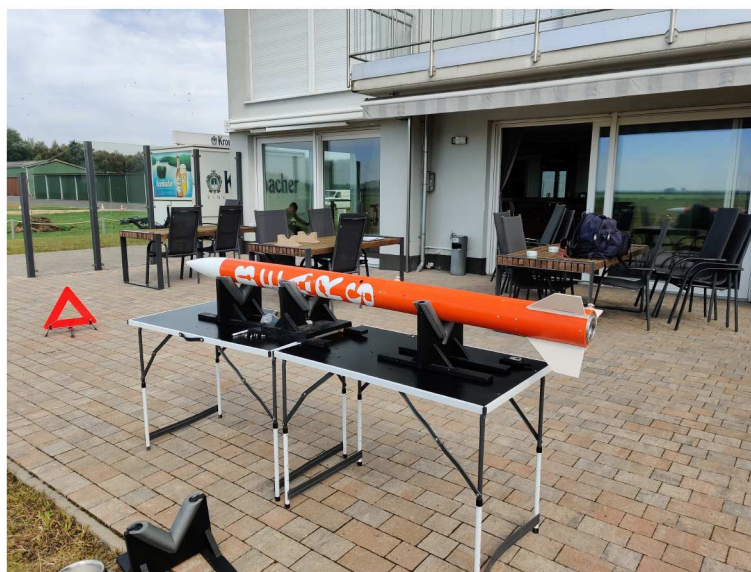


Figure 2.36: MOONDUST ready to launch

3. Mission concept of operations

3.1 Mission phases and launch procedures

Procedures at EuRoC 2025 will begin with the team preparing the rocket for the Flight Readiness Review (FRR). The rocket will be disassembled at the joints and the avionics will be outside of the aerostructure. The payload will be removed from the compartment for weigh-in. If no criteria is marked red, the team can prepare to resolve any provisionally accepted criteria (marked as yellow). The next day will see the rocket fully assembled at the launch range early in the morning for the Launch Readiness Review (LRR). If passed, the team can proceed to launch. The steps taken as well as the life phases beyond that are shown in table 3.1.

	Phase -No.	Phase name	Marking events	
			Beginning event	Closing event
Pre-launch procedures (Pre)	Pre1	Launch check-lists	Go through launch check-list	
Launch preparations (P)	P1	Prepare for launch procedures	Place charging battery and cables close to launch rail.	
	P2	Loading solid motor	Fully integrated rocket prepared for loading	Motor loaded
	P3	Rocket onto launch rail		Rocket erected
	P4	Connect umbilicals	Connect all umbilicals, including cable EC <->Payload.	
	P5	Verify radio communication	Launch rail personnel and mission control verify radio comms, confirm to each other. Insert arming devices Insert igniter	
	P6	Arming of Recovery system electronics		
	P7	Insert igniter		
	P8	Clearing launch pad	Launch rail personnel moves to viewing area.	
Rocket ready -to-launch (LR)	LR1	Go for launch	Send rocket signal that launch is T-60s	Press launch button
	LR2	Ignition	FIRE signal sent	Combustion started
Flight Phases (F) with Ascent(A) and Descent (D)	FA1	Lift-off	Vehicle first motion	Vehicle free of launch rail
	FA2	Thrust phase	Vehicle free of launch rail	Motor burnout
	FA3	Ballistic flight	Motor burnout	1500 m AGL detected
	FA4	Airbrake controlled ballistic flight	1500 m AGL detected	Apogee
	FD1	Drogue Deployment	Firing of Pyrocharges	Drogue fully inflated
	FD2	Drogue Descent	Drogue terminal velocity reached	300 m AGL detected
	FD3	Main Deployment	Release of tender descender	Main fully inflated
	FD4	Main Descent	Main terminal velocity reach	Touchdown
Retrieval (R)	R1	Awaiting GPS data	Touchdown	GPS data received
	R2	Retrieval	Rocket located	Rocket retrieved

Table 3.1: Mission phases of the STARGAZE rocket at EuRoC 2025

After retrieval of the rocket, the Postflight Review takes place. Beyond that, the team will work hard to evaluate all gathered data.

Table 3.2 shows what each of the subsystems with active electronics do in the respective phase. The airbrake, as per requirement, will be mechanically inactive up until 1500 m AGL, while the electronics closely monitor the trajectory. During the descent, the airbrakes are going to be retracted, to prevent damaging them during landing. The payload will be active during all ascent phases. As the descent starts, the movement of the rocket will be more chaotic as opposed to a steady rotation, which is why the stepper motor will shut off. The recording continues. The Flight computer goes through all the major tasks for the operations of the recovery subsystem. Just before the launch, a signal will be send to Payload (via external umbilical) for it to turn on the camera recording.

3. Mission concept of operations

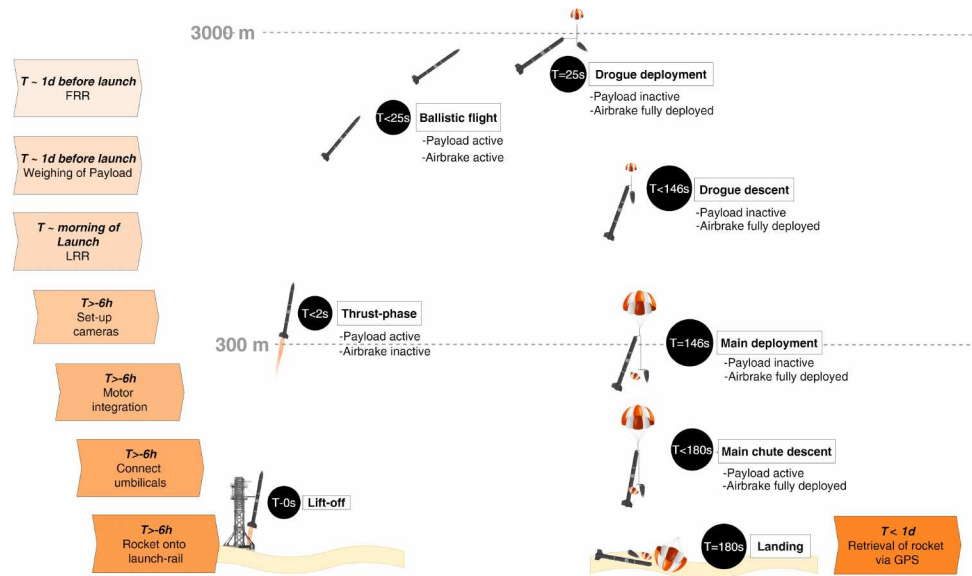


Figure 3.1: CONOPS diagram for STARGAZE 2025

	Airbrake	DÖNER'nt	MAX-FC
LR1	Inactive and retracted	Turn on camera recording and stepper motor	Idle
FA1	Calculating trajectory, mechanically inactive	Active and closed loop controlled	Provide sensor data to Airbrake
FA2	Calculating trajectory, mechanically inactive	Active and closed loop controlled	Provide sensor data to Airbrake
FA3	Calculating trajectory, mechanically inactive	Active and closed loop controlled	Provide sensor data to Airbrake
FA4	Calculating trajectory, active and closed-loop controlled	Active and closed loop controlled	Provide sensor data to Airbrake
FD1	Fully Retracted	Inactive (Stepper motor off)	Idle
FD2	Fully Retracted	Inactive (Stepper motor off)	Idle
FD3	Fully Retracted	Inactive (Stepper motor off)	Idle
FD4	Fully Retracted	Inactive (Stepper motor off)	Idle
R1	Fully Retracted	Inactive (Stepper motor off)	Idle

Table 3.2: Different activities of subsystems during each relevant mission phase

A more graphic overview of the mission profile is shown in figure 3.1.

Off-nominal operations (Airbrake/Payload)

The actions described in 3.2 are the nominal case. The payload system, if no message from the ESP-Now based relay system is received but lift-off still occurs, will "feel" this by constantly

checking the accelerometer. In this case, the cameras and stepper motor will be turned on slightly after lift-off, which will mean that the recording misses some part of the flight.

The airbrake subsystem, in the case faulty or no sensor data is supplied, will be fully deployed as per EuRoC-LV-RQT-0670.

3.2 Flight simulation

The flight simulation for STARGAZE is based on RocketPy. The rocket specifications, motor, launch location, environment and other simulation parameters are automatically configured using various custom config files and the parts list. The resulting rocket is visualized in figure 3.2.

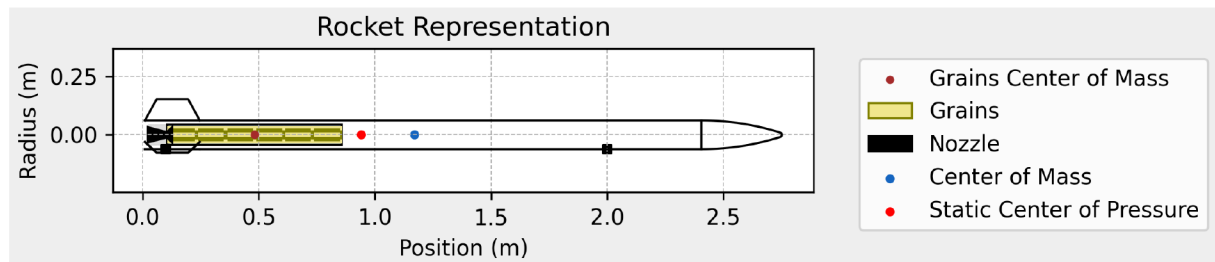


Figure 3.2: STARGAZE visualized in RocketPy

The flight simulation uses the measured total mass (without motor) and center of mass of the rocket. At the time of writing, these are 14.788 kg and 144 cm, respectively. Alternatively, the rocket's total mass and center of mass can be automatically calculated using all individual parts from the most recent version of the parts list in .csv format, which contains manually entered data determined using SolidWorks or data sheets or by weighing the parts. The rocket's inertia is determined using SolidWorks and manually entered into the config files.

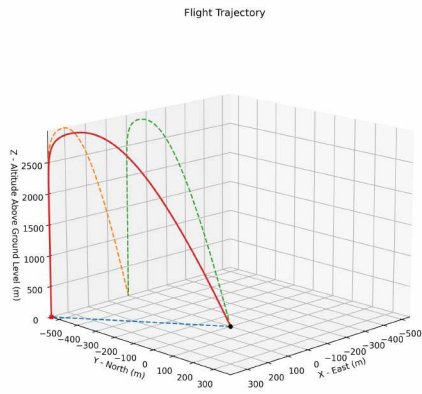
The Airbrake and its control logic are fully considered in the simulation, including drag coefficients from the CFD analysis. For more details on this, see section 2.5.5. The airbrake is configured to reduce our apogee to the target apogee of 3000 m AGL.

The simulation assumes standard atmosphere and is tested both without wind and with a constant crosswind speed of 5 m/s. The launch location is set to the coordinates of launch site A at Campo Militar de Santa Margarida.

Without wind, the deterministic simulation results indicate the target apogee of 3000 AGL m is reached after around 22.723 s, with a maximum speed of 0.959 mach at motor burnout after 1.80 s. The drogue parachute is configured to be ejected at apogee, resulting in a freestream speed of around 25.941 m/s. The main parachute is ejected at around 300 m above ground level and slows the rocket to a vertical impact velocity of around 8.512 m/s. The total flight duration is 155.409 s, following the trajectory visualized in figure 3.3. The static margin stays between 1.689 c and 2.971 c as seen in figure 3.4.

With a crosswind speed of 5 m/s, the deterministic simulation results indicate the target apogee of 3000 m AGL is reached after around 22.799 s, with a maximum speed of 0.960 mach at motor burnout after 1.81 s. The drogue parachute results in a freestream speed of around 25.941 m/s. The main parachute slows the rocket to a vertical impact velocity of around 8.512 m/s. The total flight duration is 155.733 s, following the trajectory visualized in figure 3.5. The static margin stays between 1.869 c and 2.971 c as seen in figure 3.6.

To estimate the landing ellipse, two Monte Carlo flight simulations are each run for launch sites A and B in addition to the deterministic flight simulations, where one assumes no wind and one



(a) 3D trajectory plot



(b) Google Earth visualization

Figure 3.3: Simulated 3D Trajectory in the *no-wind* scenario

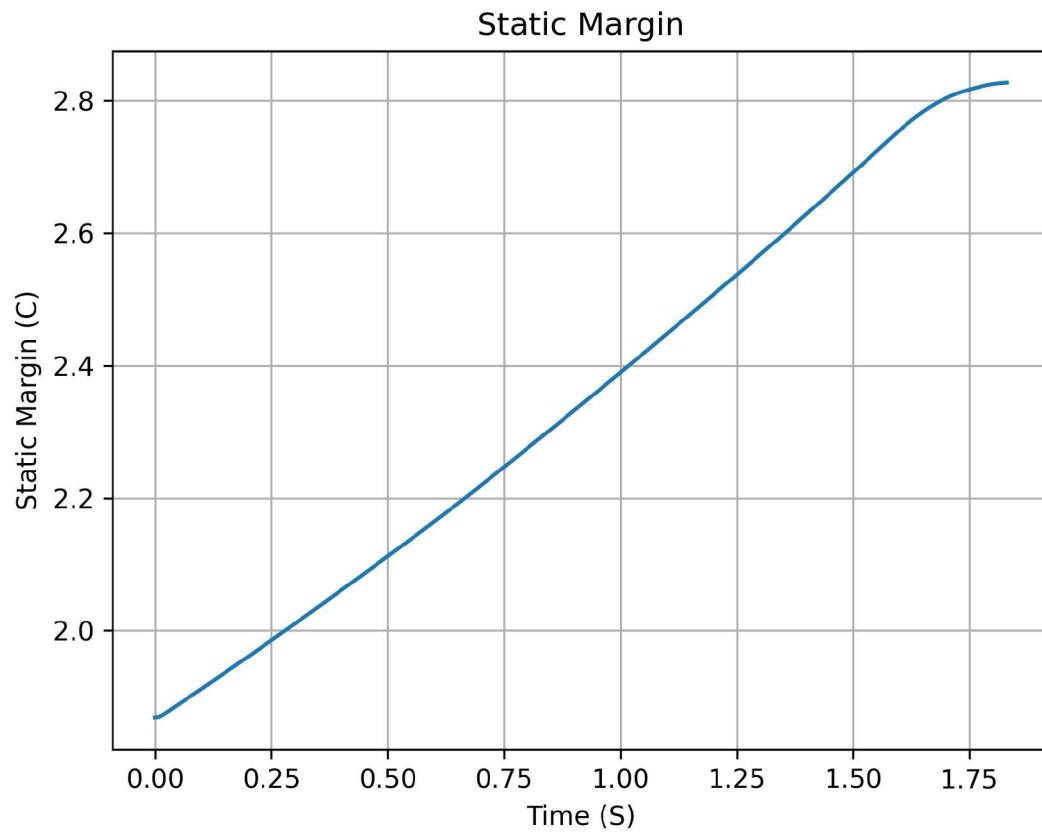
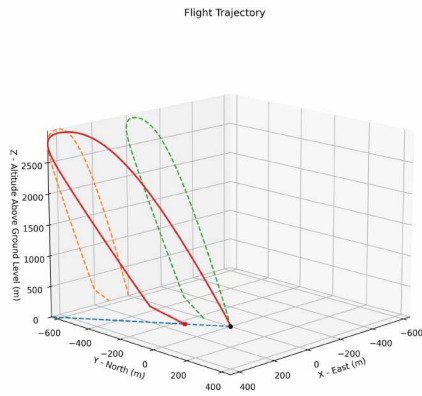
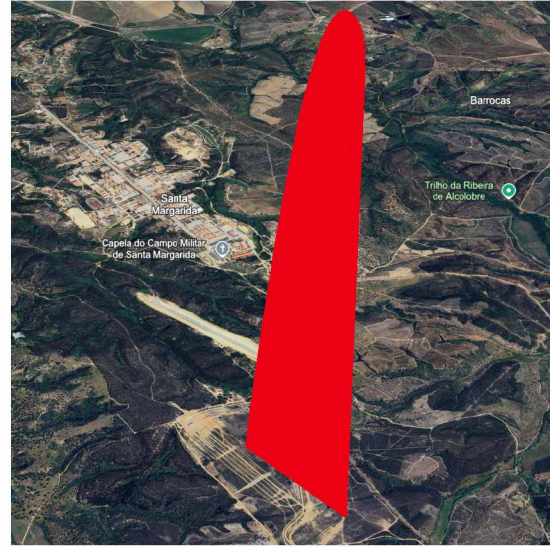


Figure 3.4: Simulated Static Margin in the *no-wind* scenario



(a) 3D trajectory plot



(b) Google Earth visualization

Figure 3.5: Simulated 3D Trajectory in the *crosswind* scenario

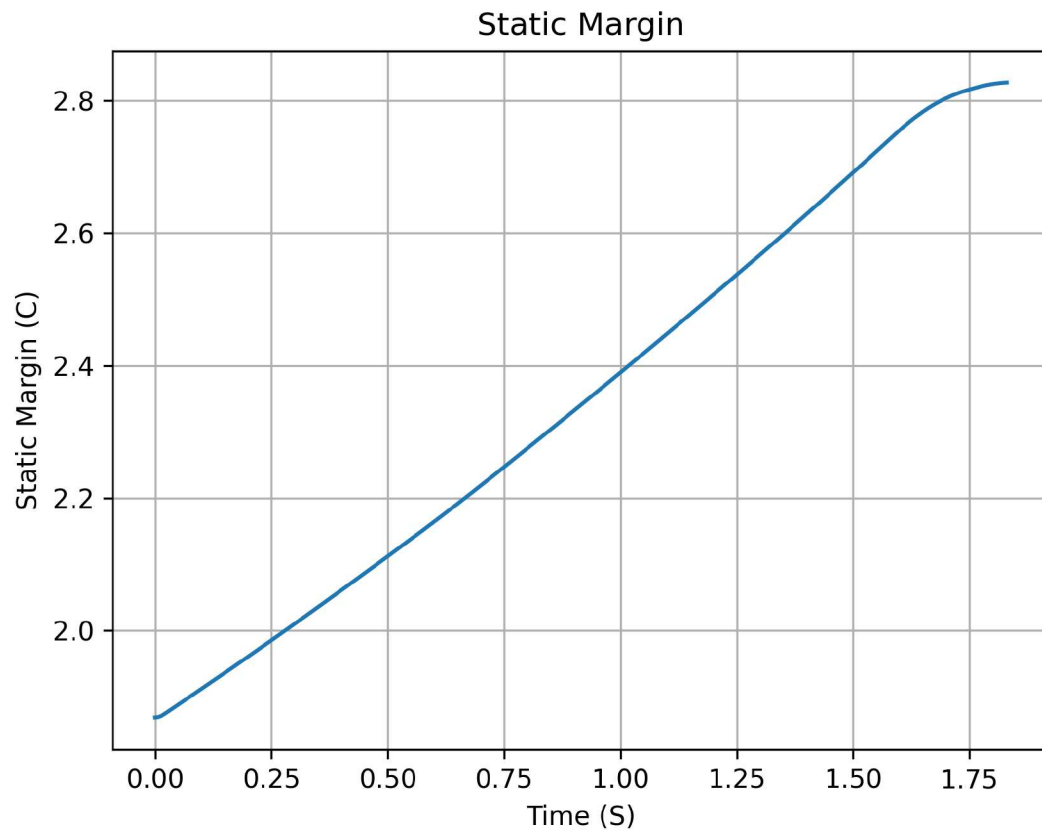


Figure 3.6: Simulated Static Margin in the *crosswind* scenario

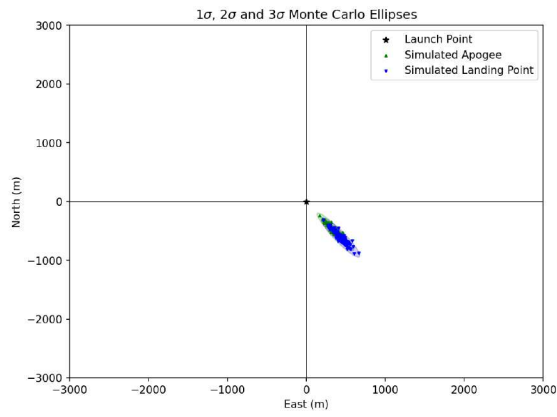
RocketPy class	Parameter	Standard Deviation	Distribution
StochasticEnvironment	wind_velocity_x_factor	$\pm 50\%$	Normal
StochasticEnvironment	wind_velocity_y_factor	$\pm 50\%$	Normal
StochasticSolidMotor	total_impulse	$\pm 10\%$	Normal
StochasticRocket	mass	$\pm 5\%$	Normal
StochasticRocket	center_of_mass_without_motor	$\pm 5\%$	Normal
StochasticRocket	inertia_11	$\pm 10\%$	Normal
StochasticRocket	inertia_22	$\pm 10\%$	Normal
StochasticRocket	inertia_33	$\pm 10\%$	Normal
StochasticRocket	power_off_drag_factor	$\pm 10\%$	Normal
StochasticRocket	power_on_drag_factor	$\pm 10\%$	Normal
StochasticParachute (Drogue)	cd_s	$\pm 10\%$	Normal
StochasticParachute (Drogue)	lag	$\pm 10\%$	Normal
StochasticParachute (Main)	cd_s	$\pm 10\%$	Normal
StochasticParachute (Main)	lag	$\pm 10\%$	Normal
StochasticAirBrakes	drag_coefficient_curve_factor	$\pm 10\%$	Normal
StochasticFlight	inclination	$\pm 1.0^\circ$	Normal
StochasticFlight	heading	$\pm 2.0^\circ$	Normal

Table 3.3: Monte Carlo flight simulation parameters and assumed standard deviation

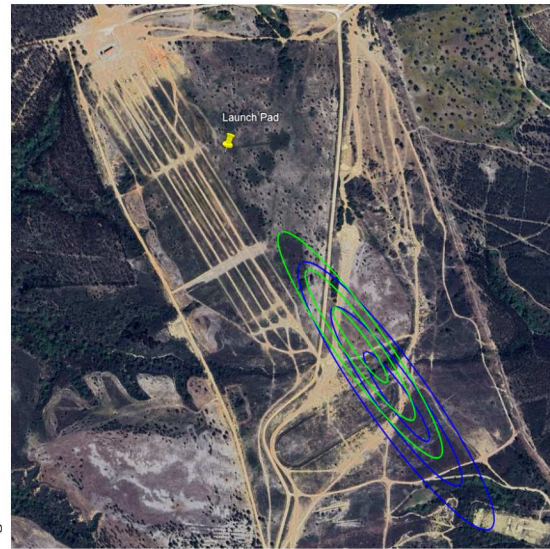
assumes 5 m/s crosswind. Table 3.3 lists the parameters for which uncertainties are expected as well as the standard deviation factors assumed in the Monte Carlo simulation. For each Monte Carlo flight simulation, 100 simulation runs are performed.

In the Monte Carlo simulation without wind, the simulation results indicate the mean apogee will be 2963.208 m AGL with a standard deviation of $\sigma = 241.471$ m, although the median is 2996.679 m AGL. The mean maximum speed is 0.946 mach with a standard deviation of $\sigma = 0.101$ mach. The landing ellipse and apogee ellipse for this scenario are visualized in figure 3.7 for launch sites A and B. The mean impact velocity will be 8.567 m/s with a standard deviation of $\sigma = 0.463$ m/s. The mean flight time will be 153.930 s with a standard deviation of $\sigma = 11.334$ s. For the histograms of these values, see figure 3.8.

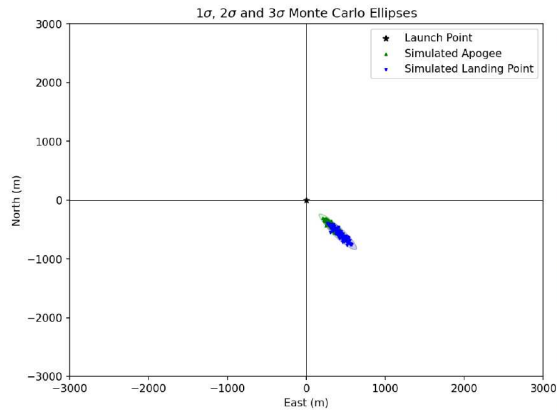
In the Monte Carlo simulation with $5 \text{ m/s} \pm 50\%$ crosswind, the simulation results indicate the mean apogee will be 2952.682 m with a standard deviation of $\sigma = 241.221$ m, although the median is 2995.965 m. The mean maximum speed is 0.938 mach with a standard deviation of $\sigma = 0.092$ mach. The landing ellipse and apogee ellipse for this scenario are visualized in figure 3.9 for launch sites A and B. The mean impact velocity will be 8.604 m/s with a standard deviation of $\sigma = 0.475$ m/s. The mean flight time will be 153.138 s with a standard deviation of $\sigma = 11.831$ s. For the histograms of these values, see figure 3.10.



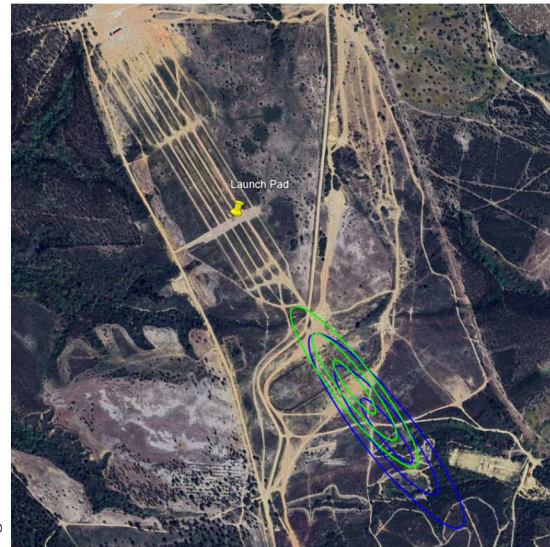
(a) Landing Ellipses



(b) Google Earth visualization



(c) Landing Ellipses (Site B)



(d) Google Earth visualization (Site B)

Figure 3.7: Monte Carlo simulation landing ellipses in the *no-wind* scenario

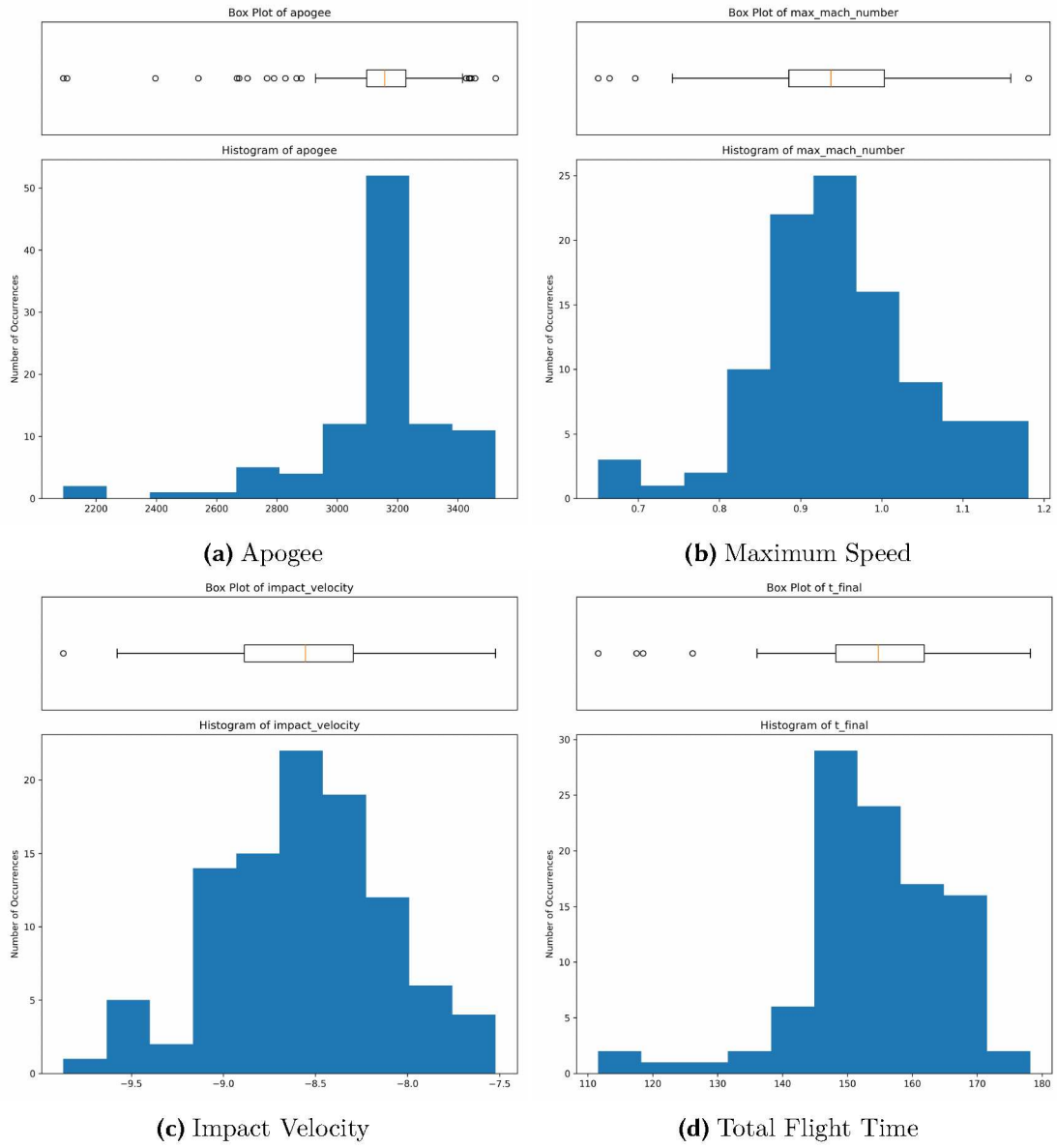
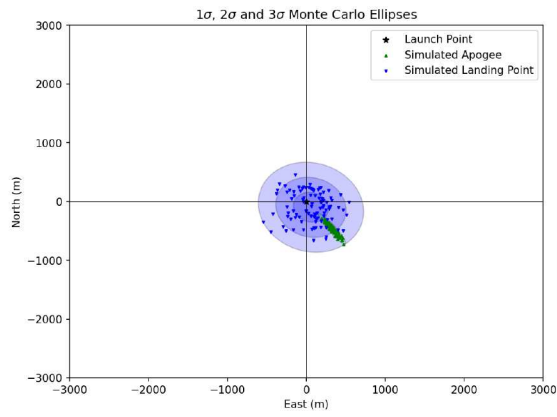
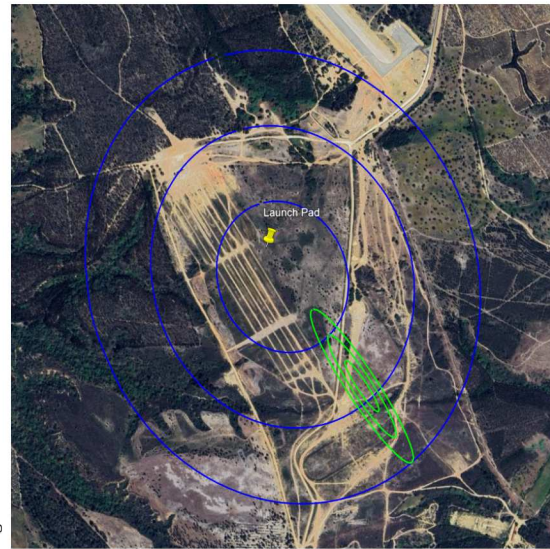


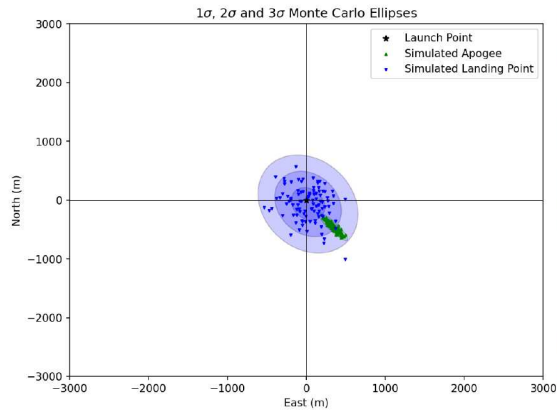
Figure 3.8: Monte Carlo simulation histograms and box plots in the *no-wind* scenario



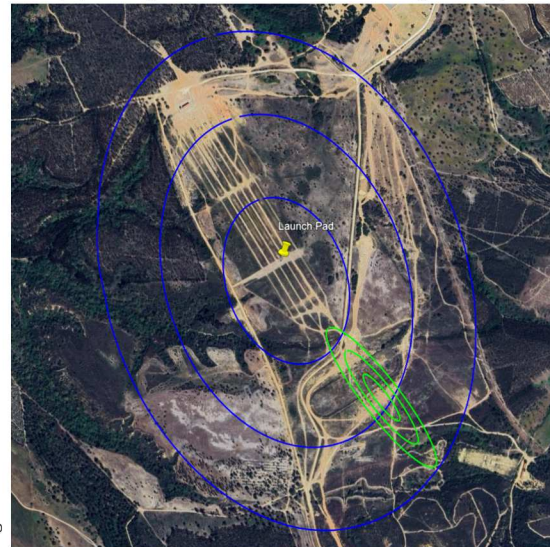
(a) Landing Ellipses (Site A)



(b) Google Earth visualization (Site A)



(c) Landing Ellipses (Site B)



(d) Google Earth visualization (Site B)

Figure 3.9: Monte Carlo simulation landing ellipses in the *crosswind* scenario

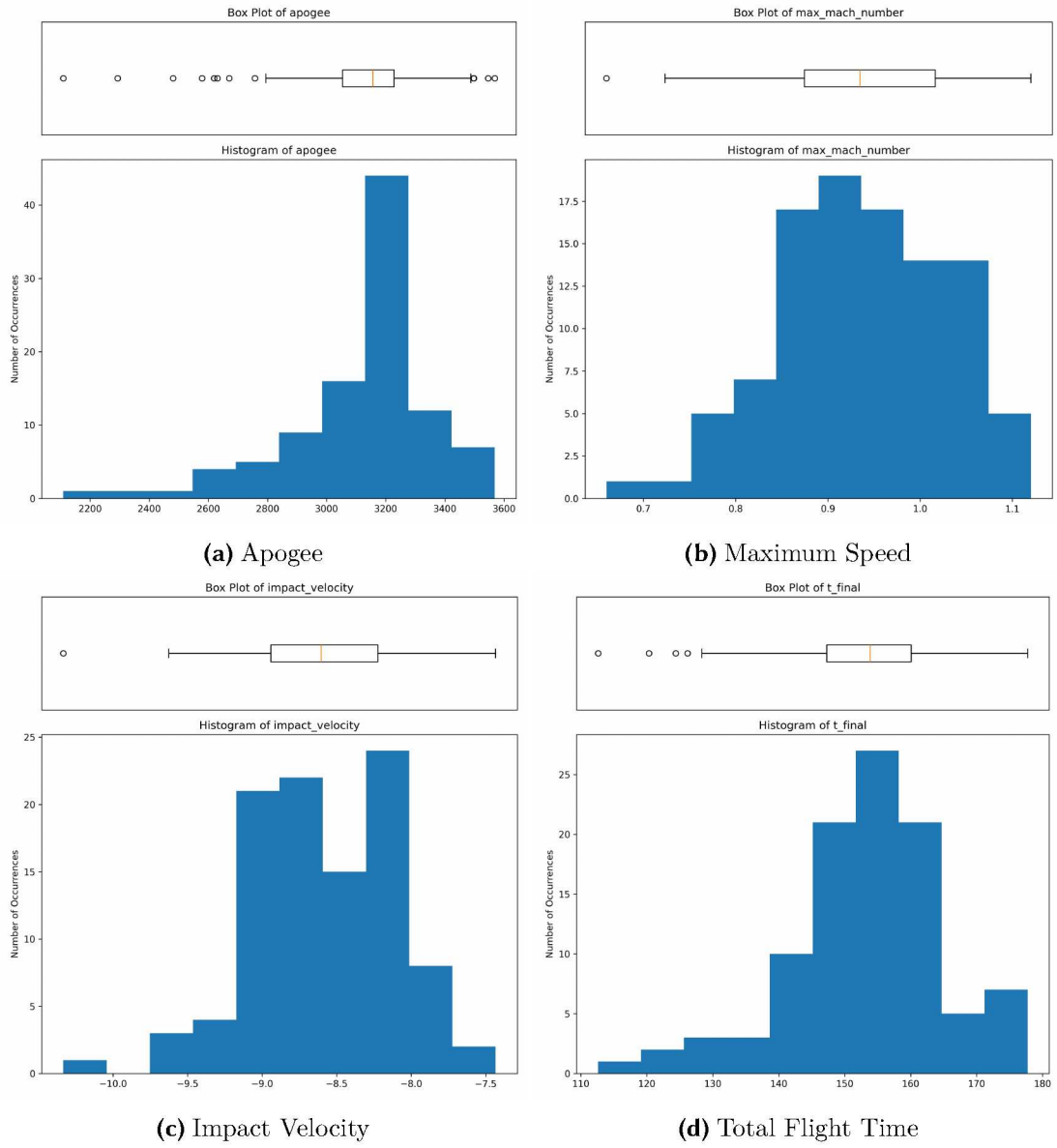


Figure 3.10: Monte Carlo simulation histograms and box plots in the *crosswind* scenario

4. Conclusions and Outlook

Achievements of the STARGAZE project

Completing the STARGAZE rocket and being able to compete at EuRoC is a great achievement, only possible through the work of the entire team and the support we recieved. The rocket is significantly more complex than all previous projects the team has completed. Thus the STARGAZE project was a full success for BEARS. Its main technical achievements for the club were the establishing and testing of techniques for manufacturing parts from carbon fibre reinforced polymers. Also the team gained significant expertise in the development of electronics, printed circuit boards and computers. As the club is very reliant on this support, a great achievement of the project is, that it has helped the club gain significant amounts of connections, especially to industry partners and sponsors. Also the club and the rocketry team has grown significantly during the STARGAZE project, and some of that can be attributed as an outcome of the project.

Lessons learned

The project was and still is a learning experience for both the entire team and the individuals who it comprises of. The team has not only learned a lot of technical skills, but also gained in management, social, financial and even artistic skills. The learning process is visible in the countless design evolutions almost all parts of the system have undergone since their first inception at BEARS.

Remaining work leading up to launch at EuRoC

In the remaining weeks to EuRoC, the STARGAZE team still has a lot of work to do. There are still some final tests and final manufacturing steps. The team is also planning to complete at least three entire "cold start" procedures (launch rehearsals) until the real launch, to verify all checklists and procedures and practice every move. The team is also planning to adjust checklists and procedures, as the EuRoC Logistics & Launch, Operations Guide is published. Decals have to be applied to the rocket and the team t-shirts have to be printed. Also a few team members have to transport the rocket and equipment by car to Portugal, which is not an insignificant endeavour.

Continuing work after EuRoC

After EuRoC, the team will thoroughly analyze the data and experience. We are planing to publish our reports, videos, photos and data in order to support other aspiring teams and future generations. In the long term, the team will then start work on new projects, and continue work on some of the systems. There are plans for a next generation MAX-FC that is more capable, for a hybrid engine rocket and for a two stage 9km rocket for a future flight at EuRoC. These options will be discussed after the event, as until then, the team is very busy.

Literature

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