TEAM 24

CONCEPT REPORT
to the
EuRoC 2023

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1. Introduction

TU Wien Space Team is a student organization engaging in various projects in aerospace engineering. Our mission statement is to foster the Know-How and enthusiasm for aerospace technologies in our peers by providing an accessible entry into rocketry and giving members the opportunity to learn. The team is working on several different projects ranging from solid propelled two staged rockets, which can reach the edge of space to hydrogen powered autonomous airplanes and from CubeSats to rockets with liquid and hybrid propulsion systems.

Project Lamarr originates from last year's project µHoubolt, which laid the foundation for the knowledge we gathered in our organization with regards to building bi-liquid rocket engines. After the adventure of participating in the EuRoC 2022, we are now highly motivated to come back in 2023, whilst setting a new challenge with a higher target altitude and more powerful propulsion system.

Our mission objectives with our rocket named "Hedy", in memorial to the Austrian actress and inventor Hedy Lamarr, are the following:

1. Flight to an altitude of 9 km
2. Successful recovery with 2-stage parachute system
3. Gathering telemetry and performance data throughout the full duration of the flight
4. Thorough documentation to conserve knowledge in our team

2. System Concept

Hedy is a single staged liquid fuelled rocket, propelled by a mixture of ethanol and liquid oxygen. We strive for simplicity and value light weight components, therefore, we designed structural linerless CFRP tanks and in combination with an overall highly integrated system, aim to keep the rockets mass below 25 kg.

Tanking procedures happen remotely and fully automated via our ground support equipment and software stack which we developed and tested through various other projects in the last years. Processes inside the rocket are governed by an SRAD electronic stack which is in control of actuators, sensing parameters and transmitting telemetry data. The vehicle will be recovered using a two-stage parachute system triggered by COTS flight computers.

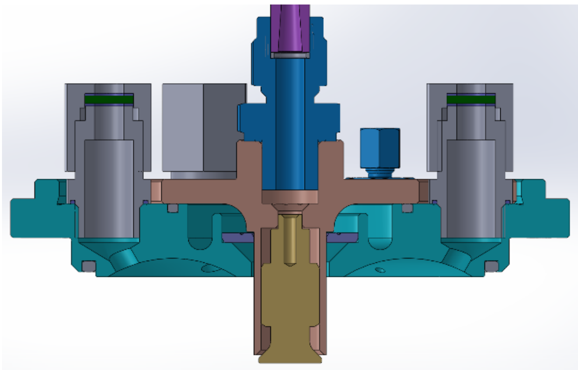
This chapter describes the subsystems of our rocket and their design concepts in further detail.

2.1 Propulsion

Thrust	2000N
Burn duration	8s
Pressurant pressure	300 bar
Chamber pressure	15 bar
O/F – Ratio	1.3
Oxidizer pressure	30 bar
Fuel pressure	30 bar

Our pressure fed 2 kN engine utilizes Liquid Oxygen-Ethanol as propellants. The Oxidizer to Fuel ratio (O/F-ratio) is 1.3. We are going with a fuel rich mixture ratio to keep the temperature in the combustion chamber relatively low while maintaining an efficient combustion. Gaseous nitrogen is used to pressurize the tanks. Our combustion chamber pressure will for now stay at 15 bar but might be increased after more testing is done to increase the efficiency.

The propellants are injected into the combustion chamber with the use of a pintle type injector with two concentric tubes. The oxidizer in the outer tube is coming out as a cylindrical stream. The fuel in the inner tube impinges a central pintle at the end of the tube, spraying out in a cone which intersect the cylindrical stream of the outer propellant. The fuel and the oxidizer will pass through a cavitating venturi before entering the injector. This way, the propellant mass flows depend only on the fluid conditions before these regulating orifices and their geometry. An improved version of our injector is currently in its final stages of design and will be manufactured in the coming weeks. The improvements are focusing on reliability, usability and weight.



The pressurant pressure is reduced from about 270 bar in the pressurant tank to about 60 bar by a mechanical pressure reducer and afterwards to 30 bar by a motor actuated ball valve before entering the propellant tanks. A check valve is placed between each propellant tank and the corresponding electric pressure reducer to prevent contamination of the pressurant tank. Tank pressure sensors are installed in both feed systems, as are burst disks. To make sure we fill the rocket with the exact amount of liquid oxygen a dip tube connected to the manifold between the tank and pressure reducer is inserted into the tank. Venting valves are installed to aid the tanking process and bleed orifices are used as an additional safety feature if all connection to the rocket is lost while fully tanked and pressurized. As the very low temperature and reactivity of liquid oxygen can lead to serious issues, only components compatible with oxygen and cryogenic conditions or extensively tested components are used for this part of the system.

The main fuel valve is a small COTS ball valve, the main oxidizer valve consists of the body and inner components of a COTS 3-piece ball valve in combination with custom aluminium flanges. The top one includes the connection for filling the oxidizer tank, which is a COTS quick connector with integrated check valve. Both main valves are servo actuated.

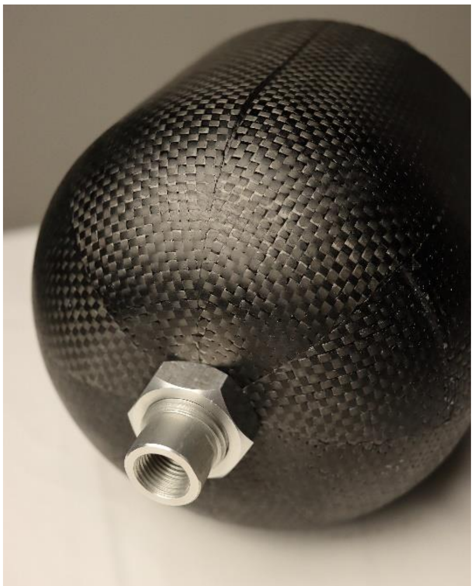
For pressurant tanks and pressure regulators, the decision again fell on equipment normally used for paintball. Those components are highly reliable and thoroughly tested as they are usually operated in environments close to humans. Therefore, we can ensure operational safety of the high-pressure part of our system whilst using cheap, light weight and readily available components.

Ignition is accomplished by four small redundant pyrotechnic igniter cartridges, containing an e-match and a mixture (<2.5g total) of Potassium nitrate, sorbitol and magnesium, commonly referred to as “rocket candy”. They are installed in the engine head and can be quickly replaced. A lot of testing has been done on the ignition system and we now have a very reliable and effective way of igniting our engine.

2.2 Aerostructure

Our rockets aerostructure consists of the nosecone, body tube and fin can. Oxidizer and fuel tank are designed to be structural, meaning their outer diameter equals the body tubes outer diameter. Therefore, the body tube in parts also serves as a tank wall.

The inner diameter of the body tube is set at 130 mm. The wall thickness at its thickest point, where the oxidizer tank is located, is 2.1 mm. To reduce weight, the wall thickness is slightly adjusted to 1.6 mm outside of the tank area.



A carbon fibre tube is wound, into which laminated CFRP heads are glued. While the tube is completely designed and manufactured by our sponsor PEAK Technology, the end caps are designed and laminated by us with support from them. This includes the design of the geometry, the laminate lay-up, selection of the right glue and a possibility to connect hoses/pipes to the pressure vessels. As of writing, the first tube is finished and a longer core for the final body tube is in progress. The first one will be used for testing purposes to verify integrity of the design under all expected circumstances. Those tests include gluing tests with subsequent inspection of the inside of the glued surfaces as well as burst tests.

The oxidizer tank presents a major challenge due to the low temperature and usually poor compatibility of adhesives with liquid oxygen. Feedback with our sponsor Loctite shows that Loctite UK 8160 might be a possible option but has not been tested with liquid oxygen yet. Due to its low shear strength a rather long adhesive surface is needed with a length of around 70mm. The burst test will give the team more information. The bonding process was practiced and improved with a mock-up tube and heads until the results were satisfactory. For each tank that is tested or flown, the bond is checked for irregularities like air entrapments with a CT scan. To avoid ice build-up on the outside and to reduce boiloff, the tank will be insulated with an external insulation which is dropped automatically shortly before take-off.

To gear the mass distribution towards stability, the upper tank is for LOX and the lower tank is for ethanol. Furthermore, this configuration has the advantage of using the simpler ethanol tank, which has moderate temperatures, as the one with a passage through, which is necessary to guide fluid from the upper tank down to the engine.

The shape of the nosecone was decided via a parametric CFD study, for which three for the targeted velocity regime common nosecone shapes were compared. These three shapes are the LV-Haack and Von Karman of the Haack series family as well as the power 1/2 (parabola) shape. The result of this CFD study, comparing the drag of the shapes over several velocities, is that, although all shapes are closely matched in terms of performance, the Von Karman shape stands out a little more and is therefore chosen to be used.

As with the predecessor rocket, the nosecone is the rockets RF window and thus made from fibreglass on a positive mould and subsequently sanded down. To meet the new challenges caused by higher velocities and therefore higher temperatures, the nosecone is tempered to allow the epoxy resin to resist temperatures of up to 150°C.

The nosecone is currently laminated and tempered, but not yet demoulded or sanded down to its final shape.

2.3 Recovery

The recovery system is a two-stage parachute recovery, with the drogue parachute being deployed at apogee and the main being deployed about 500m above ground. The drogue parachute will be a round cap, whilst the main parachute will be of an apex pull down form, which provides a higher drag coefficient with less material. Deployment will be triggered by a set of two redundant Altimax flight computers.

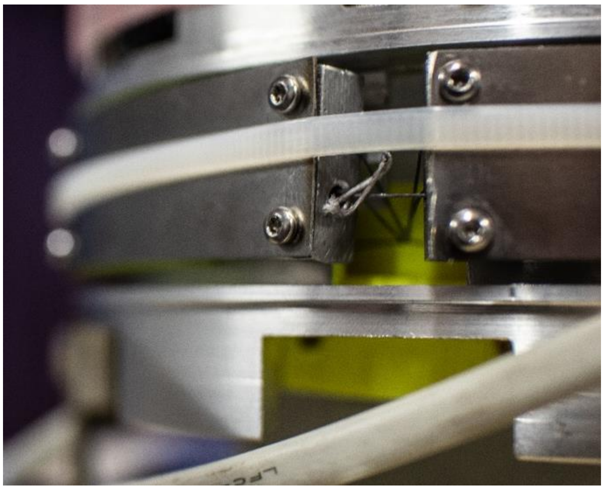
The drogue parachute will be deployed by separating the nosecone from the main body tube at apogee, ensuring a stable descent with a velocity of around 25 m/s. During ascent, the nosecone will be held on the body tube by a coupler, which is surrounded by a clamp band. The clamp band is actuated by cutting a line. This method was commonly adapted before in our team and has been proven to be a reliable method of separation.

The main pros for the clamp band mechanism are:

- Minimal overlap between nosecone and body tube, avoiding the risk of canting.
- Little space needed for the clamp band itself and the actuation mechanism.
- No moving parts or motors required for deployment.
- Minimal requirements on the complexity of electronics.

In the previous project COTS line cutters, normally used in human rated parachutes, were used to cut a line and open the clamp band. The drawback of this method was, that the price of those single-use line cutters was high (~60€ per piece), which made a bigger number of tests unaffordable. Therefore, this time we designed and implemented an SRAD burn wire to allow a higher number of repeated prefight tests with the system on the ground.

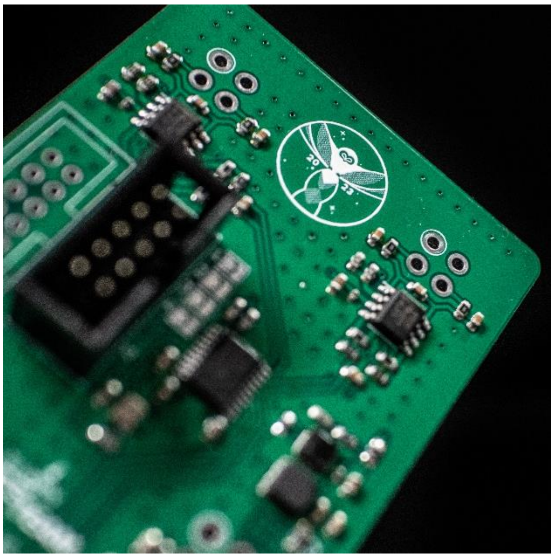
Separation of the nosecone after clamp band actuation is established using rubber bands, which act as a slingshot to reliably push away the nosecone from the rest of the rocket.



The main parachute will be deployed by releasing the drogue parachute, which is held by a spring-loaded bolt. By pulling back the bolt, the drogue line pulls out the main parachute which ensures a final decent phase with a velocity of around 6 m/s.

After many ground tests, currently, we are working on improvements with regards to the quality and reliability of the mechanism and most importantly to improve usability, as we want to ensure a minimum amount of time to get the system flight ready during launch preparations. After finishing those improvements, the system will be tested in flight using a mock up rocket flying to 700 m in August.

2.4 Avionics



The avionics for project Lamarr build heavily on the learnings from our predecessor project µHoubolt. There will be multiple modules which all communicate via a CAN bus interface. Multiple Power Management Units (PMUs) are responsible for supplying all circuits.

Furthermore, different battery systems are included, as well as charging circuitry to supply the system during launch preparations on the launch rail via an umbilical which also allows communication with the GSE via the bus.

For telemetry acquisition and data transmission the Radio Control Unit (RCU), is designed and installed. Its task is to gather data and send it to the ground station via LoRa. This data includes GNSS, barometric, IMU and all CAN messages on the bus. This way the state of the propulsion system can be evaluated before approaching the rocket for recovery.

The arguably most important unit is the custom Engine Control Unit (ECU), it controls the fuel main and reads out all the sensors. In addition, two more of those PCBs are acting as electronic pressure regulators. Opening and closing the ox main valve requires a high torque, therefore, a brushless dc motor with special FOC Controller is needed. For this purpose, a COTS STMicroelectronics DevKit is used, since it has a small footprint. Apart from those major units there will be several adapter PCBs and custom spring-loaded connectors between the nosecone and main body tube.

2.5 Ground Support Equipment

The GSE mainly is made up of four subsystems:

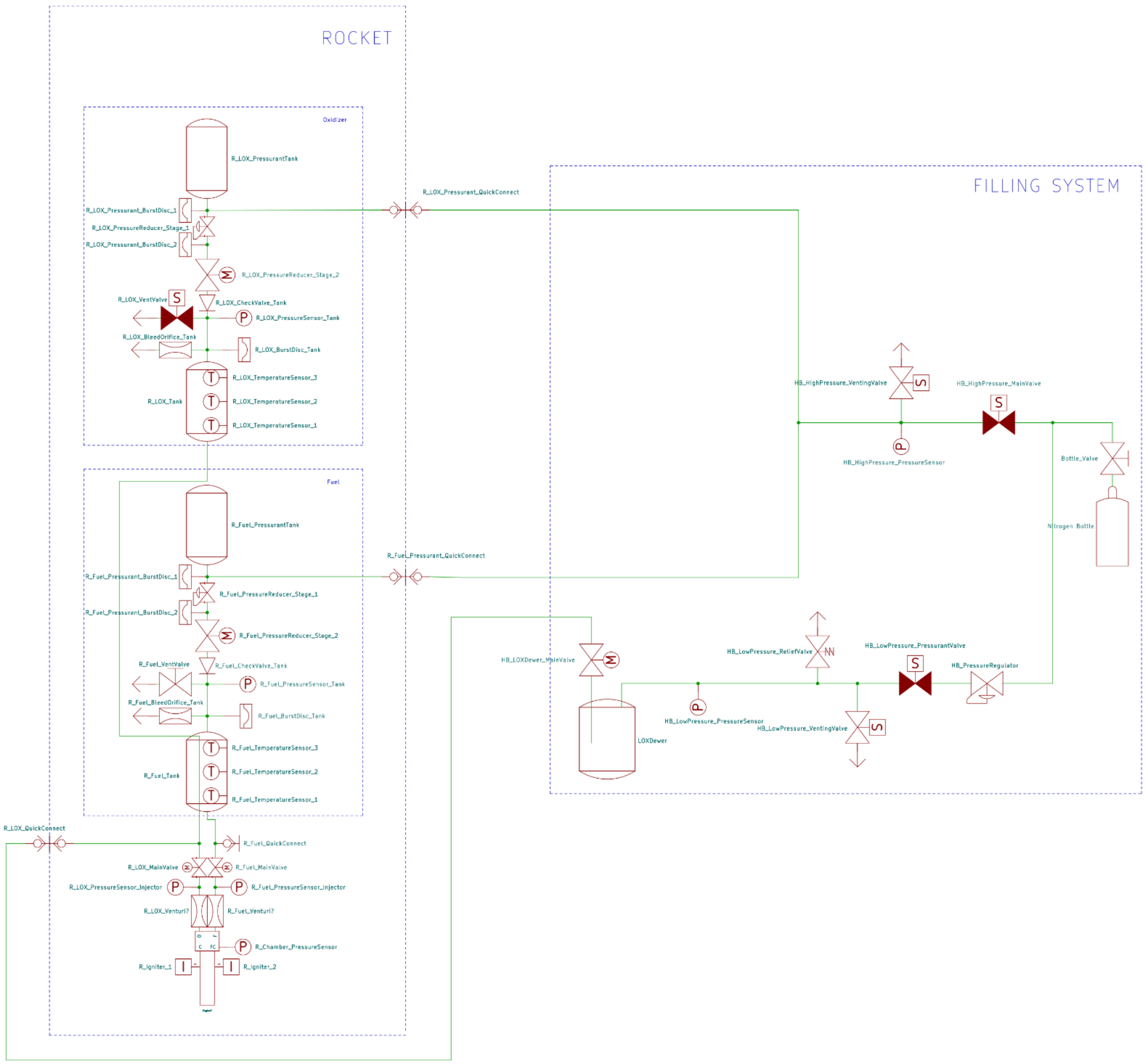
- Valve system
- LOX dewar
- Electronics compartment
- Launch rail

The tanking system can fill the vehicle with oxidizer and pressurant without manual intervention, avoiding the need for personnel next to a pressurized vehicle. Oxidizer filling is achieved by pressurizing the LOX dewar with a pressure of around 3 bar, which forces the liquid to flow into the rocket via umbilical hoses. The umbilical hoses are automatically disconnected before lift-off and connected with two-way quick disconnects, which enable flow back into the dewar in case of a launch scrub after tanking is in progress.

All systems are pressurized by a single 300 bar nitrogen bottle, from which the nitrogen is split up into multiple pathways with different pressures for pressurant tanking and dewar pressurization.

The launch rail consists of aluminium trusses onto which standard aluminium profiles are mounted. To ensure an appropriate exit velocity, the launch rail length was extended to 9m since last project.

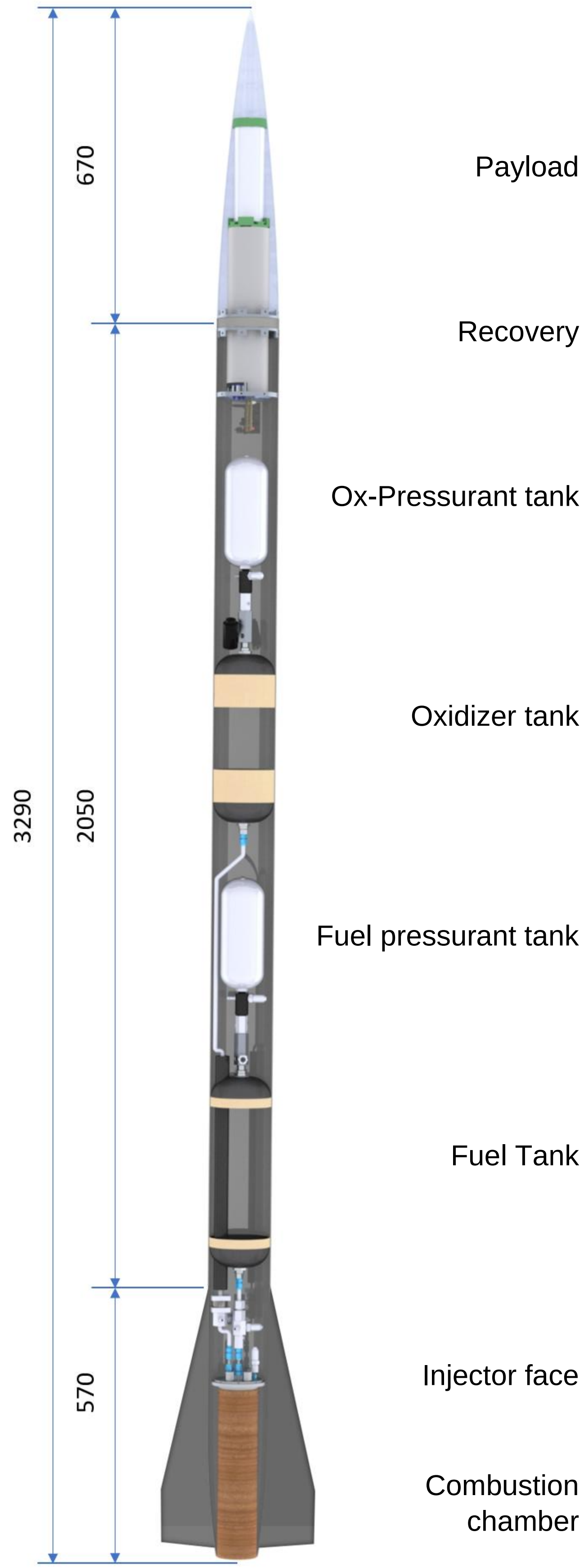
A hold down system engages with the lower rail button of the rocket, preventing premature liftoff before engine startup is completed or in case of an abort after ignition. It also acts as a scale, monitoring the mass of the rocket during tanking and measuring actual thrust produced before take-off.


ROCKET
Oxidizer
R_LOX_PressurantTank
R_LOX_Pressurant_QuickConnect
R_LOX_Pressurant_BurstDisc_1
R_LOX_PressureReducer_Stage_1
R_LOX_Pressurant_BurstDisc_2
R_LOX_PressureReducer_Stage_2
R_LOX_VentValve
R_LOX_CheckValve_Tank
R_LOX_PressureSensor_Tank
R_LOX_BleedOrifice_Tank
R_LOX_BurstDisc_Tank
R_LOX_TemperatureSensor_3
R_LOX_Tank
R_LOX_TemperatureSensor_2
R_LOX_TemperatureSensor_1
Fuel
R_Fuel_PressurantTank
R_Fuel_Pressurant_QuickConnect
R_Fuel_Pressurant_BurstDisc_1
R_Fuel_PressureReducer_Stage_1
R_Fuel_Pressurant_BurstDisc_2
R_Fuel_PressureReducer_Stage_2
R_Fuel_VentValve
R_Fuel_CheckValve_Tank
R_Fuel_PressureSensor_Tank
R_Fuel_BleedOrifice_Tank
R_Fuel_BurstDisc_Tank
R_Fuel_TemperatureSensor_3
R_Fuel_Tank
R_Fuel_TemperatureSensor_2
R_Fuel_TemperatureSensor_1
R_LOX_QuickConnect
R_Fuel_QuickConnect
R_LOX_MainValve
R_Fuel_MainValve
R_LOX_PressureSensor_Injector
R_Fuel_PressureSensor_Injector
R_LOX_Venturi?
R_Fuel_Venturi?
R_Chamber_PressureSensor
R_Igniter_1
R_Igniter_2
FILLING SYSTEM
HB_HighPressure_VentingValve
HB_HighPressure_MainValve
HB_HighPressure_PressureSensor
Bottle_Valve
Nitrogen Bottle
HB_LOXDewer_MainValve
HB_LowPressure_ReliefValve
HB_LowPressure_PressurantValve
HB_PressureRegulator
HB_LowPressure_PressureSensor
HB_LowPressure_VentingValve
LOXDewer

3. Mass Budget and Arrangement

Mass budget in kilograms:

Recovery	1.2
Avionics	1
Payload	1
Aerostructure	3.7
Propulsion	5.6
Pressurant	0.6
Oxidizer	4.8
Fuel	3.7
Total	23.6



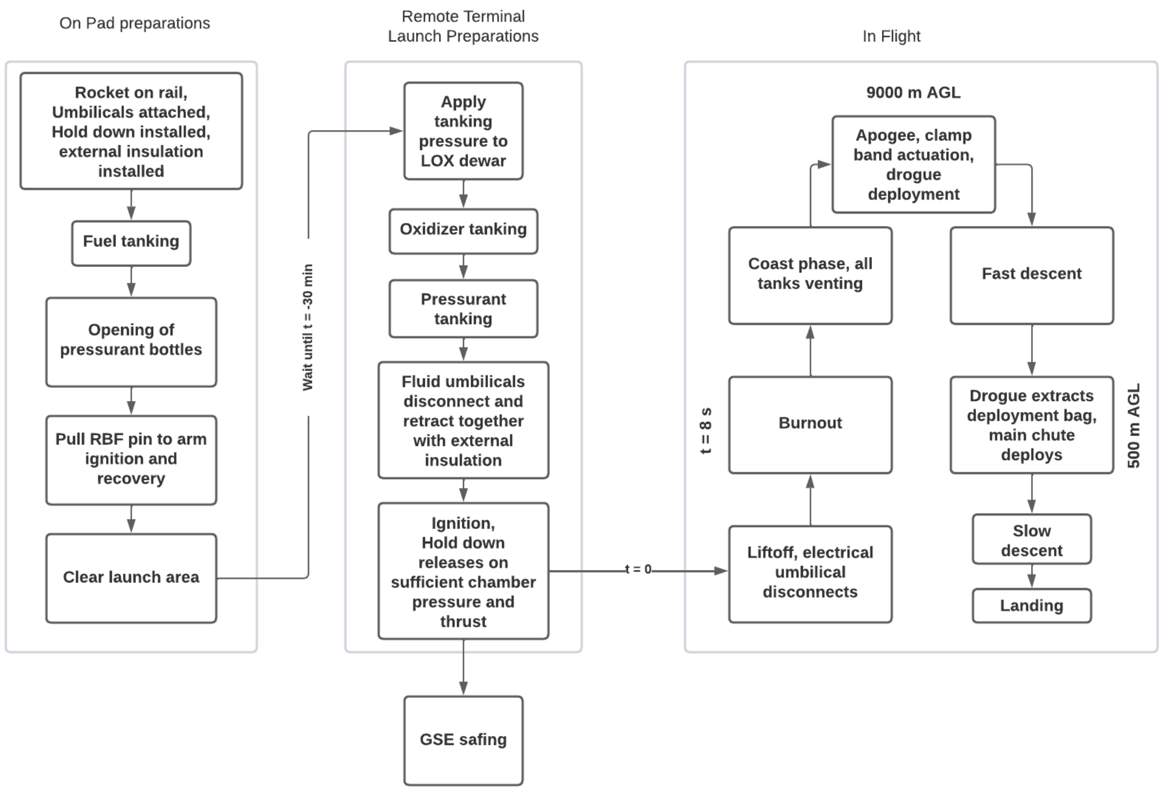
4. Concept of Operation

The following briefly describes the lifecycle of the rocket and support equipment during EuRoC and the main stages of operation.

Rocket and equipment lifecycle during EuRoC:

1. Rocket gets presented at the exhibition.
2. Final preparations on day prior to launch
    a. Final assembly
    b. Electronics checks
    c. Preparation of recovery section
3. Move GSE to launch site, erect launch rail, connect LOX dewar and pressurant bottles.
4. Final preparations according to checklists, putting rocket onto launch rail, connecting it to GSE and verifying system functionality.
5. Ensure safety on GSE after launch.
6. Recover rocket and bring it back to exhibition after inspection.

Main stages of operation:



5. Materials and Processes

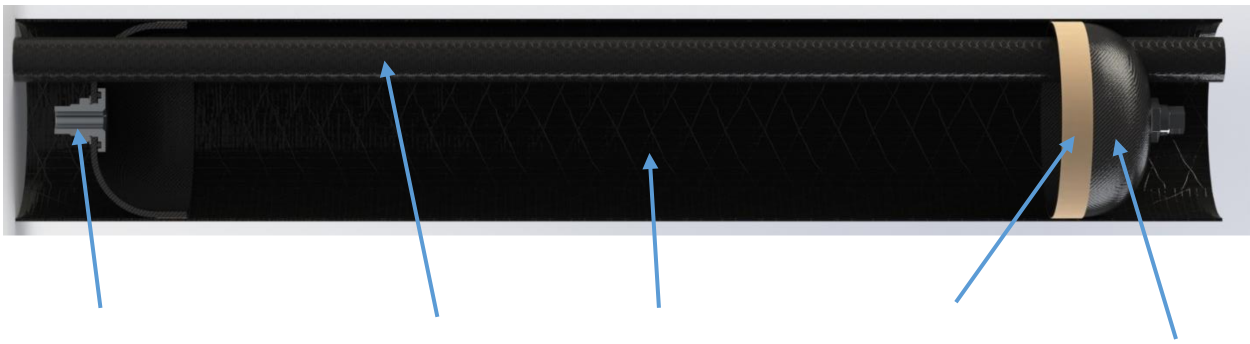
Almost all custom designed components are manufactured in house by one of our members, the only exception being the body tube and tank endcaps. This allows us to rapidly iterate with most of the components to ensure system reliability and usability.

Material	Process
ASA	3D Printing
Glass fiber composite plates	CNC milling
Glass/Carbon fiber composites	Wet and prepreg laminating, winding
Aluminium, steel, brass	Turning, milling (CNC and manual)
Aluminium, steel, brass	Drilling, filing, sawing, thread cutting, …
PTFE	Pressing
Cotton/Phenolic resin composite	Turning
Graphite	Turning, drilling
Electronic components, PCBs	Reflow soldering, hand soldering
Stainless steel pipes	Cutting, bending

6. Differentiating Characteristics

The main differentiating characteristic of our system are the structural linerless CFRP tanks with SRAD end caps, which are used for both fuel (ethanol) and oxidizer (LOX). The body tube is designed and manufactured by our sponsor PEAK Technology whereas the endcaps are designed and manufactured by us, in collaboration with PEAK. As described in previous chapters, the main challenge here is to identify compatible adhesives, as well as testing the system, which will be done by pressurization, burst tests and CT scans.

The figure shows the ethanol tank with a passage for LOX and cables. The oxidizer tank will look the same except that there is no need for the passage. Furthermore, the lower shear strength of the LOX compatible adhesive requires longer gluing surfaces.



7. Expected Difficulties, Criticalities

The designed system poses several difficulties and potential criticalities which must be addressed.

Handling LOX is difficult due to its high reactivity with other materials and its cryogenic nature. To avoid any reactions inside the tanking system and rocket, all parts are intensely cleaned with special procedures before being exposed to the oxidizer. Furthermore, adhesives used for gluing the tank endcaps into the body tube are verified for compatibility and intensively tested before usage.

Due to liquid boiling off inside the tanks, pressures can rise significantly if the system is closed and not manoeuvrable due to a potential loss of communication or power outage. Tanks and pipes are equipped with overpressure protection and manual depressurization valves to secure the system also in case of missing electronic control capabilities.

Structural linerless CFRP tanks are an ambitious method for producing pressure vessels holding liquids with cryogenic temperatures. To ensure the systems integrity, pressurization and cryogenic burst tests will be conducted. Additionally, all used tanks are analysed using a CT scan, to verify the quality of glued surfaces.