Lamarr Concept Report

Team 26 Concept Report to the 2025 EuRoC

April, 2025 - Vienna, Austria, Earth

Contents

1 Introduction:

1.1 The TU Wien Space Team

The TU Wien Space Team is a student-led association engaged in a wide range of projects within the fields of aeronautics and aerospace engineering. Current developments include an autonomous, hydrogen-powered drone, a custom-built CubeSat scheduled for launch later this year, and several solid-propellant rocket projects. We also have a proud tradition of working on liquid-propellant rocket engines. In 2022, we participated in EuRoC with µHoubolt, a rocket powered by an ethanol–nitrous oxide engine. Building on the knowledge gained from this project, our successor project Lamarr is now focused on developing a liquid-propellant rocket using ethanol and LOX, with the goal of returning to EuRoC. Although we were unable to launch at EuRoC 2024 due to insufficient preparation and testing time, we are confident that we will be ready to fly in October 2025.

1.2 Project Goals

Through the Lamarr project, we aim to advance the development of high-performance liquid-propellant rockets while ensuring that the experience and technical expertise gained are passed on to future student engineers. By fostering continuous learning and iteration, we strive to inspire even more ambitious student-led aerospace initiatives and set new milestones in amateur rocketry.

1.3 Mission Objectives

- Reach a target altitude of 9 km
- Achieve successful two-stage recovery of the rocket
- Secondary objectives:
    - Gather in-flight performance data and verify telemetry functionality
    - Provide a launch opportunity for a 1 kg payload

2 System Architecture:

2.1 Overview:

2.1.1 Concept of Operation:

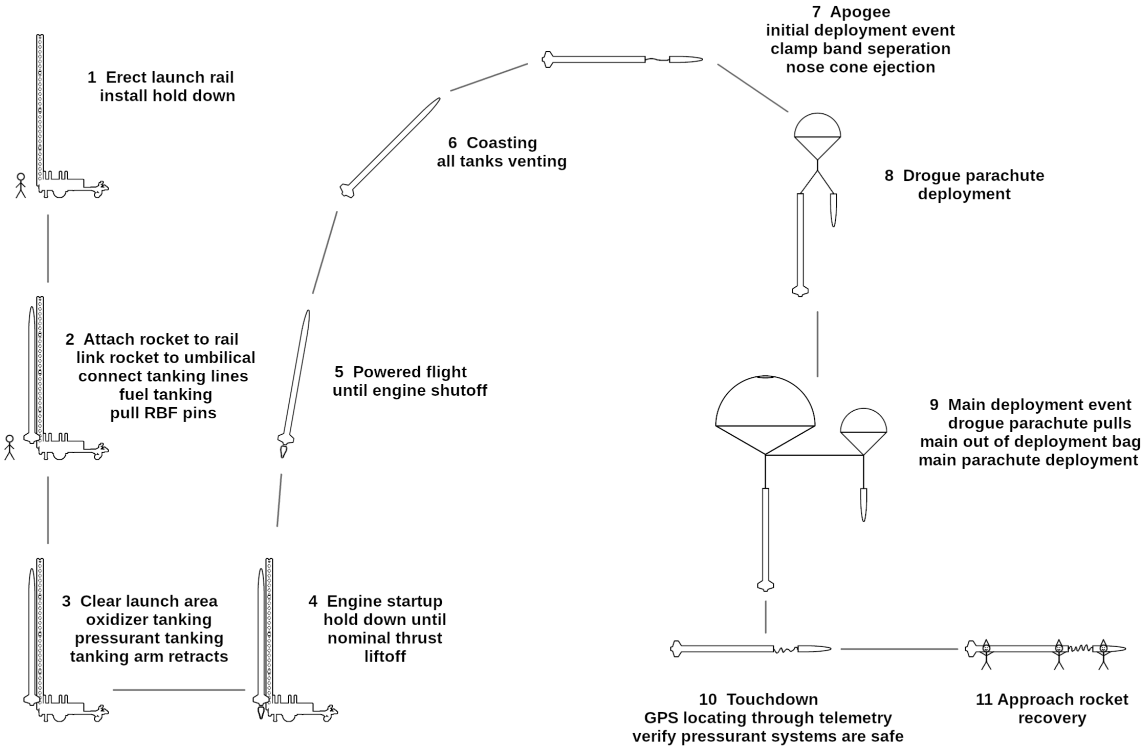

Fig. 2.1: Concept of Operation

After the GSE is set up and checked, the rocket is attached to the launch rail with the hold-down system. The tanking connections for liquid oxygen and pressurization as well as the electrical umbilical are attached to the rocket. The avionics are powered and the state of the rocket systems are checked. Ethanol is tanked, the igniter is installed, and RBF pins are pulled, fully arming the rocket. After vacating the launch pad, liquid oxygen is remotely tanked and topped off as needed during hold time. Shortly before launch the pressurizer is tanked, the umbilical connections are remotely disconnected and retracted. After a 10 second countdown engine startup commences. If sufficient thrust for stable flight is measured, the hold-down system releases the rocket. After the powered flight phase, ending in controlled engine shutoff, the tanks are vented during the coasting phase. At apogee, the initial deployment event separates the nose cone and deploys the drogue chute. After descent under drogue the main deployment event deploys the main chute. Recovery of the rocket is aided by telemetry data confirming the touchdown location and a safe vehicle state. After locating and recovering, the rocket is brought back to the launch site for further investigation.

2.1.2 Physical Architecture:

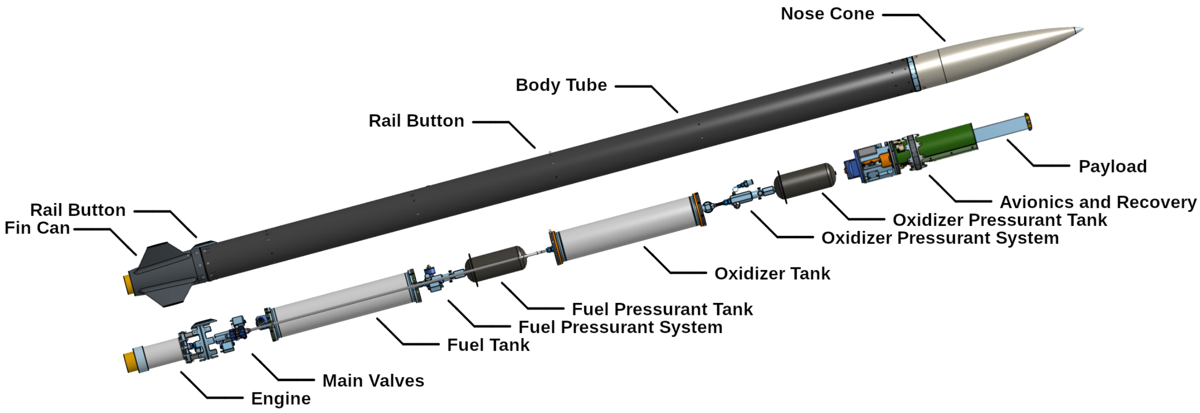

Fig. 2.2: General assembly of rocket

The rocket can be broadly divided into four main subsections arranged from aft to fore. The **engine bay** houses the thrust chamber, servo-actuated main valves for both oxidizer and fuel, sensors, and two propellant fill ports. A dedicated Engine Control Unit (ECU) manages valve actuation and data acquisition in this section. The **fuel and oxidizer systems** each consist of a propellant tank and a pressurization assembly, including a pressurant tank, pressure reducer, servo valve and ECU. While both systems are similar in structure, all oxidizer-side components are fully LOX-compatible to handle cryogenic conditions.

At the front, the **electronics and recovery bay** integrates the recovery flight computers, our in-house developed Radio Communication Unit, power supply systems, as well as the parachutes and payload bay.

2.1.3 Rocket Dimensions, Mass Estimates and Performance Figures:

Mass (Dry)	16 200 g
Mass (Lift Off)	24 800 g
Length	3745 mm
Diameter (Body)	132.8 mm
Initial Pressurant Pressure	300 bar
Propellant Pressure	38 bar
Thrust	2000 N
Combustion Chamber Pressure	15 bar
Burn Duration	8.1 s
Total Impulse	16.200 N s
Maximum Speed	$548\,\mathrm{m\,s^{-1}}$ (Mach 1.6)
Target Apogee	9 km
Descent Rate (Drogue)	$26\,\mathrm{m\,s^{-1}}$
Descent Rate (Main)	$6\,\mathrm{m\,s^{-1}}$
Altitude Main Chute Deployment	Altimax G4: 450 m, Backup CATS Vega: 450 m
RF (LoRa) Frequency	868 MHz

Tab. 2.1: General System Data

2.2 Propulsion:

Propelling the rocket is a pressure-fed engine that uses ethanol and liquid oxygen as rocket propellants and nitrogen as pressurant. The propulsion system consists of two pressurization systems, two propellant tanks, two main valves and the engine.

2.2.1 Pressurization System:

Two 1.2 L COPVs are holding gaseous nitrogen, pressurized to about 300 bar to pressurize each propellant tank. A two-stage pressure-regulating system is located between the pressurant tanks and the propellant tanks. The first stage is a modified COTS mechanical pressure reducer for paintball markers. The second stage uses ball valves that are actuated by servomotors. These motors open and close the valves to keep pressures at the venturis at a specified level. A check valve is placed after the second stage to prevent the propellants from entering the pressurant tanks. After the check valves, there are custom made normally open magnetic vent valves which provide the ability to vent the propellant tanks, making it possible to fill the fuel tank and vent the liquid oxygen tank during filling.

Filling:

For filling the pressurant tanks with nitrogen, two quick COTS connectors, each mounted to the mechanical pressure regulator stage, are used to connect to the filling system. The fuel filling system connection is also done using a type of COTS quick connector. Filling liquid oxygen provides several challenges, especially the very low temperatures can be problematic, which is why we developed and use our own coupling mechanism.

2.2.2 Propellant tanks:

The propellant tanks consist of two pressure vessels made of thermally curable EN AW 6082 aluminum. The tank heads are standard torispherical heads, lathed from solid aluminum stock. The tank walls have a thickness of 2.5 mm and are welded to the tank heads using TIG welding. The tanks are designed to withstand an operating pressure of 50 bar with a safety factor of 2. Before welding, the material is normalized through heat treatment, and after welding, it is heat-treated again to maximize the alloy's potential hardness. Each tank can hold enough propellant for a burn time of 8.1 s.

2.2.3 Main Valves:

Both main valves consist of modified COTS ball valves, actuated by COTS servos. Modifications were necessary, particularly replacing valve seats with materials capable of handling a cryogenic environment, to ensure a reliable and leak-proof supply of liquid oxygen to the engine. The fuel main valve is largely custom-made to also accommodate a pressure sensor, mounting points for the servo, and the filling port. For the oxidizer main valve, only the flanges are custom-made, for the same reasons as the fuel main valve.

2.2.4 Engine:

The engine uses ethanol and liquid oxygen as propellants with an oxidizer/fuel ratio of 1.3. A chamber pressure of 15 bar combined with the fuel rich O/F-ratio is chosen to keep the temperatures in the combustion chamber relatively low, while still providing the necessary performance.

Injector and Flow Regulation:

For the injector, we chose a pintle type with continuous liquid-liquid impingement. Pintle injectors generally offer good mixing behavior and consist of components that are typically easy to manufacture using conventional machines and tools.

The flow regulation primarily consists of two cavitating venturis and an orifice plate, with the orifice plate solely used to direct the fluid flow. The cavitating venturis provide a constant mass flow independent of acceleration and downstream pressure. Decoupling the mass flows from the chamber pressure simplifies the feed system design and reduces the likelihood of feed-coupled instability.

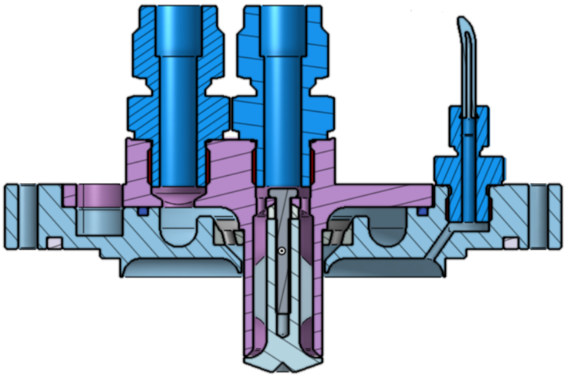

Fig. 2.3: Injector Section View

Ignition:

The ignition of the engine is achieved with an external pyrotechnic igniter that is mounted on the ground support equipment. A mixture of potassium nitrate, sorbitol and magnesium is stuck onto a threaded rod, with a 3D-printed body holding two redundant electric matches in place for the ignition of the pyrotechnic mixture. To maximize the chances of a successful engine ignition, the mixture is located in one of the thrust chambers recirculation zones.

Combustion Chamber and Nozzle:

The combustion chamber and nozzle are made of phenolic resin and cotton. During engine operation, the liner ablates, effectively insulating the surrounding casing from heat. With a wall thickness of 5 mm, the liner provides sufficient material for a burn time of 8 s at a chamber pressure of 15 bar. This was verified through several hot fire tests. The chamber liner and nozzle are housed within an aluminum casing, which is bolted to the injector.

2.2.5 Safety:

There are several safety features, which ensure that operations are safe at any time during launch preparations, tanking and launching the rocket.

Each pressurization valve and propellant tank is connected to our self-developed magnetic vent valves. These valves are designed to open passively at a specified pressure, even without power. They are normally open and close magnetically on command just before the propellant tanks are pressurized.

2.2.6 PnID:

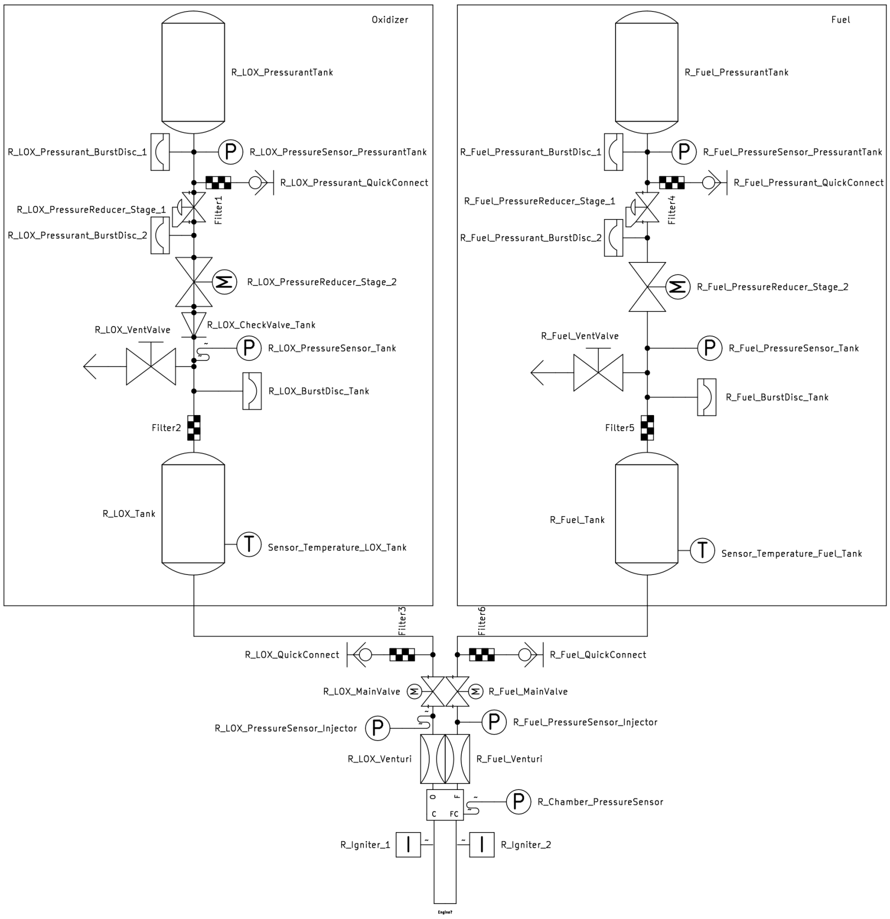

Fig. 2.4: Rocket PnID

2.3 Avionics:

The Avionics for project Lamarr builds heavily on the learnings from previous projects. There will be multiple modules, all connected via a CAN bus interface. The three different main modules are:

- **RCU** - Radio Communication Unit:
  The main goal of the RCU is a stable and reliable connection between mission control and the rocket, after the umbilical has been separated.
- **ECU** - Engine Control Unit:
  The ECU is an in-house developed I/O board capable of controlling main, pressurant and vent valves. Providing interfaces for servos, high-power channels up to 16 A constant current, thermistors, and other sensors with a 4 mA to 20 mA interface.
- **PMU** - Power Management Unit:
  The PMU can monitor the rocket's power budget and secure the onboard batteries' controlled charging and discharging process.

In addition, other PCBs, such as ground stations, adapters, and connectors, have been developed.

2.4 Aerostructure:

2.4.1 Nose Cone:

The shape of the nose cone was decided by a parametric CFD study for which three of our targeted velocity regime common nose cone shapes were chosen to be compared. The shapes are the LV-Haack and Von Kármán 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 Kármán shape stands out. As the volume of the recovery system can be used more efficiently with an LV Haack shape, it is used and the slightly poorer performance is accepted.

As with the predecessor rocket, the nose cone is the rockets RF window. Therefore, it is laminated with fibreglass-prepreg using a negative mould to achieve high surface finish. The tip of the nosecone itself is lathed out of titanium due to its lightweight characteristics.

2.4.2 Body Tube:

The body tube is laminated using carbon fiber prepreg because of its lightweight characteristics. The inner diameter is set at 130 mm and the wall thickness is 1.4 mm. This decision was made due to finite elements analysis showing that it can take the aerodynamic forces and thrust loads. To laminate the body tube a specially developed technique is used which ensures a high quality lay-up process.

2.4.3 Rail Buttons:

The upper rail button is passed through and screwed into a mounting bracket of the oxidizer tank. The head of the rail button is manufactured out of brass due to its advantageous friction properties.

The lower rail button, which is also used for the hold-down system, is designed in close consultation with the Ground Support Equipment site of the project. For further information see section GSE.

2.4.4 Fincan:

The current fincan is designed for a 3 km apogee, meaning a new fincan has to be designed and built. The fincan will be made in one piece with an in-house manufactured negative mould, carbon fiber prepreg, and Rohacell cores.

2.5 Recovery:

Our rocket features a fully redundant, two-stage recovery system optimised for realiblity and short release time. Both the initial and main deployment event are initiated by nichrome burn wire mechanisms, each triggered via pyro channels by two independent flight computers: the **Altimax G4 Altimeter** as the primary system and a **CATS Vega** as a backup.

At apogee, the first pair of burn wires severs a retention line holding a spring steel clamp band in tension. This allows the nose cone to separate from the body tube via a mechanical coupler. A set of slingshot rubber bands accelerates the nose cone away from the airframe, rapidly deploying the drogue parachute in the process, which is attached between the separated nose cone and the main rocket body.

At an altitude of 450 m, the second pair of burn wires cuts the line connecting the drogue parachute to the main body. This causes the drogue to extract the main parachute from its deployment bag. Both parachutes are manufactured in-house out of the canopies of decommission man-rated parachutes and both parachute lines feature integrated shock absorbers to reduce mechanical stress during deployment.

All critical components, including the clamp band release and the slingshot ejection mechanism, have undergone extensive ground testing and a full-scale flight test using a solid-propellant test rocket, with all release mechanisms performing nominally.

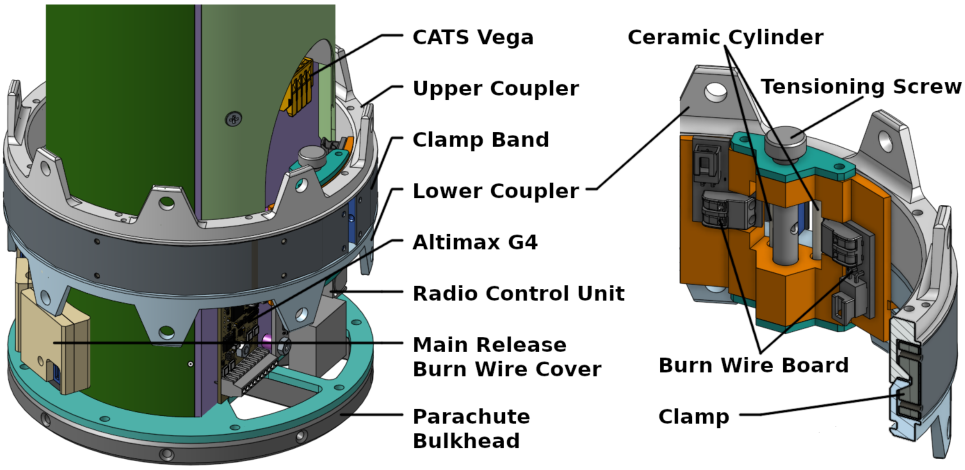

Fig. 2.5: Recovery subsystem assembly

2.6 Ground Support Equipment (GSE):

The Ground Support Equipment (GSE), consisting of the launch rail with hold-down system and the remote tanking system, enables a safe launch of the rocket by facilitating the remote tanking of liquid oxygen (LOX) and high pressure nitrogen (HPN2), and ensuring enough thrust for a rail exit velocity sufficient for stable flight.

2.6.1 Launch Rail and Hold-down System:

Our 11 m long Launch Rail consists of triangular aluminium trusses with an aluminium extrusion acting as the guiding rail. The structure, along with most of the GSE, is mounted on a trailer for ease of transportation. Guy wires connected to ground anchors further stabilize the structure, especially against wind forces.

Attached to the launch rail is out hold-down system, whose purpose is to prevent liftoff, until nominal engine startup and sufficient thrust for a stable flight is confirmed. It connects to the rocket thrust structure via the bottom rail button. The hold-down System includes a load cell, which measures the thrust force acting on it, and is actuated with a pneumatic cylinder.

2.6.2 Tanking System:

Since the tanking of hazardous substances and high pressure gas are among the most dangerous phases of launching a bi-liquid propellant rocket, we have designed a remote controlled Tanking System for loading LOX and HPN2 into our rocket without human presence necessary. Our fuel (ethanol) is loaded manually before vacating the launch pad due to its relative safety.

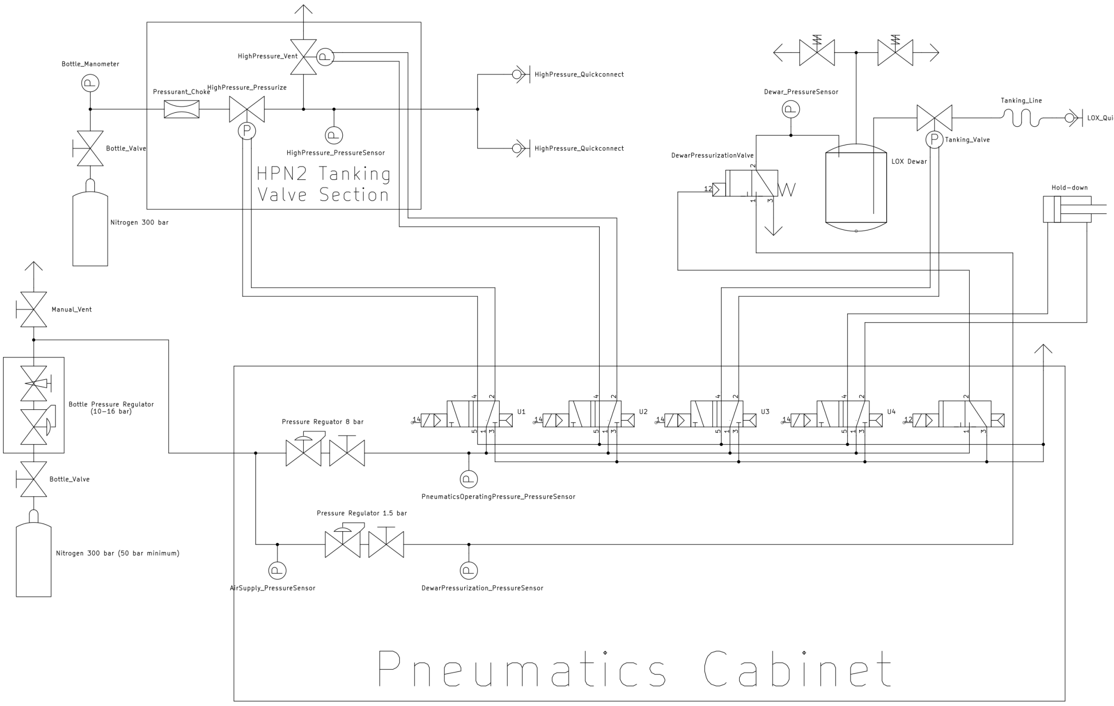

Fig. 2.6: PnID of the Tanking System

Immediately before engine startup, the LOX and HPN2 fill lines are disconnected at the rocket and retracted. For the HPN2 system, COTS quick disconnects are used. For the LOX system, we developed a custom connector with an electromagnet. A hinged metal frame supports the fill lines near the rocket and is retracted with a geared motor, which also actuates the HPN2 quick disconnects.

An electrical umbilical, providing power and a CAN-bus connection, is connected with pogo-pins and magnets. It falls off disconnected during liftoff.

LOX and Pressurant Tanking System:

During LOX tanking the dewar is pressurized with nitrogen gas, forcing liquid oxygen up a riser tube, through the tanking valve and a flexible hose into the rocket. For dewar pressurization and the pneumatics a nitrogen bottle is used. The bottle regulator first reduces the pressure to 14 bar. Smaller pressure regulators further drop the pressure to 8 bar for the pneumatics and 1.4 bar for dewar pressurization.

For tanking of the pressurant in the rocket, a 300 bar nitrogen bottle is connected to the fill port of the pressure regulators inside the rocket. Filling is controlled with pneumatically actuated ball valves, an adjustable choke regulates the filling speed.

2.6.3 Communication and Power:

For communication with the Ground Support Equipment Server and multiple IP-Cameras at the launch site, a pair of parabolic WiFi antennae is used. Ground power is provided by the organizer, with a UPS as a backup in case of a power outage.

3 Expected Difficulties and Criticalities:

3.1 Vertical Static Fire Tests

While we have already conducted a significant number of horizontal hot-fire tests of our rocket engine, performing the same in a vertical test configuration presents a non-trivial challenge. We need to redesign and adapt our mounting mechanisms, thrust measurement setup, fire suppression system, deluge infrastructure, and tanking procedures to ensure that testing is conducted safely while still yielding meaningful data and insights.

3.2 Rocket Integration

Our decision to manufacture the rocket body as a single continuous segment has introduced several integration challenges. One of the main consequences is that the entire feed system must be installed in a single operation. This makes precise alignment of vent outlets and filling ports with their corresponding cutouts in the body tube absolutely critical to guarantee the reliable operation of our self-decoupling mechanisms. To mitigate these challenges, we are developing and testing solutions to improve the internal stiffness of the propulsion system and to simplify its alignment and fixation within the airframe.

3.3 Software

In the Software department, there are still a few remaining issues that need to be addressed to ensure stable and reliable system performance. During the most recent edition of EuRoC, several challenges were identified related to both our LLserver and firmware components. These issues affected system behavior and highlighted the need for further debugging and refinement. Our current software builds on the foundation laid by our previous project, µHoublot, leveraging its core architecture while integrating several new features aimed at improving functionality and performance. As these new features are introduced, they must undergo thorough testing to ensure compatibility, stability, and efficiency within the overall system. As we progress, it will be crucial to resolve these issues and validate the new features through extensive testing procedures.

3.4 Difficulties with Cryogenic Propellants

The low temperature of LOX has posed considerable challenges in the past and continues to be a critical area of concern. While we have successfully mitigated issues such as ice build-up and condensation through insulation, and protected temperature-sensitive components, such as pressure sensors and burst disks, using thermal decoupling, components in direct contact with cryogenic oxygen still require significant attention in both design and testing. Our in-house developed valves are particularly affected and continue to be a focus of ongoing refinement.

4 List of Materials and Manufacturing Methods

ABS (Acrylonitrile-Butadiene-Styrene Copolymer)	3D-printing
Aluminium	turning, milling, thread cutting, drilling, anodizing, welding, heat-treating, bending, cutting
Brass	turning
Carbon-Fiber-Reinforced Plastics (CFRP)	prepreg-layup, cutting, grinding, drilling
Glass-Fiber Reinforced Plastic (GFRP)	milling, drilling, prepreg-layup, cutting, grinding
Polycarbonate (PC)	3D-printing
Phenolic resin cottton	turning
Polylactide (PLA)	3D-printing
Polytetrafluoroethylene (PTFE)	turning, punching
Titanium	turning, anodizing

Tab. 4.1: Materials and manufacturing methods