Project Freyja

Team 05 Technical Report for EuRoC 2025

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Stockholm, Sweden
November 27, 2025

Abstract

The Freyja project is the second rocket that the Association of Engineering Students in Rocketry brings to the European Rocketry Challenge, and the third hybrid rocket devised by the association. Competing in the Hybrid 3 km (H3) category, the Student Researched and Developed (SRAD) hybrid engine is paired with an active altitude control system in the form of radially-deployed air brakes to enable the rocket to come within 50 m of the target 3000 m apogee.

The recovery system uses a combination of pressurized CO_2 as well as pyrotechnic charges to ensure a safe and stable descent. Similarly to the Signý rocket recovery system, which competed in EuRoC 2023, the parachute will feature a reefing mechanism to save mass and minimize volume.

Keywords

ÆSIR	the Association of Engineering Students in Rocketry
EuRoC	the European Rocketry Challenge
H3	Hybrid 3 km competition class
SRAD	Student Researched And Designed
CanSat	Category of rocket payload, designed to fit in a typical soda can
ABS	Acrylonitrile Butadiene Styrene
PID	Proportional-Integral-Derivative
RocketPy	Rocket trajectory simulation software
PCB	Printed Circuit Board
CAN	Controller Area Network
COTS	Commercial Off-The-Shelf
RTD	Resistance Temperature Detector
ADC	Analog-to-Digital Converter
SPI	Serial Peripheral Interface
GPIO	General Purpose Input/Output
PWM	Pulse-Width Modulation
GCS	Ground Control Station

Contents

1 Introduction

1.1 Team Introduction and Structure

The Association of Engineering Students in Rocketry (ÆSIR) was founded in 2016 and is the largest student rocketry association in Sweden. Bearing more than 40 members and several active projects in rocket research and development, ÆSIR aims to continue development and improvement of its designs while learning and teaching about rocketry not only to its members, but to the aspiring young rocketry enthusiasts all across Sweden.

The Freyja rocket team is comprised of 20 KTH students from several distinct technical backgrounds; covering the spectrum of engineering disciplines available at the university. This disciplinary diversity not only strengthens the team's capabilities, but also shows that rocketry exists as an interest completely independent of exactly where one's academic ambitions lie — and it is ÆSIR's mission to provide the opportunity to pursue it.

The association has seen three launches since its foundation, including the debut at the 2023 edition of the European Rocketry Challenge. One of the primary goals of the association since then has been to participate each year, improving on existing designs while working on other projects simultaneously.

The project team is composed of a team lead, wherein the tasks are divided between subteams with a subteam lead, which include:

- **Structure**
  The structure team is responsible for the structural parts of the rocket, for example the composite fuselage and joints between rocket sections.
- **Propulsion**
  The propulsion sub-team is the group responsible for engine simulations and design of the hybrid motor.
- **Avionics**
  Avionics include all the electronics in the project, ranging from the rockets recovery system and sensor reading to remote control of the ground support equipment.
- **Recovery**
  The recovery team is responsible for making sure the recovery chute is ejected properly and safely to ensure a stable descent whilst minimizing horizontal drift after separation.
- **Ground Support Equipment**
  As the name suggests, the ground support equipment subteam is responsible for all equipment on the ground during launch, for instance the filling system and the launch tower. This group is also expected to provide the team with test stands for static testing.

1.2 Project Goals and Objectives

Project Freyja aims to test and build new technologies and expertise within ÆSIR, such as air brakes and 3D-printed fuel grains, and enhance already existing systems in avionics and ground support equipment.

On an organizational level, our goal is to broaden our network within the industry and to establish relationships with other student rocketry teams. Participating in EuRoC gives us a great opportunity to reach these goals.

2 Launch Vehicle System Architecture

2.1 Overview

Freyja consists of six sections. The nosecone & payload bay, where the CanSat payload is located. The recovery bay, which contains the parachute and the separation mechanism. The avionics bay, which houses the flight computers, batteries and ancillary electronics and radio modules. The air brakes section. The oxidizer tank section, which contains the N_2 and N_2O tanks and associated plumbing components, enclosed in a carbon fiber shell. And finally, the fin-can section, which accommodates the valves and plumbing for the oxidizer and the combustion chamber.

2.2 Propulsion Subsystem

The Freyja engine is a hybrid rocket engine powered by N_2O and two 3D-printed ABS fuel grains stacked on top of each other.

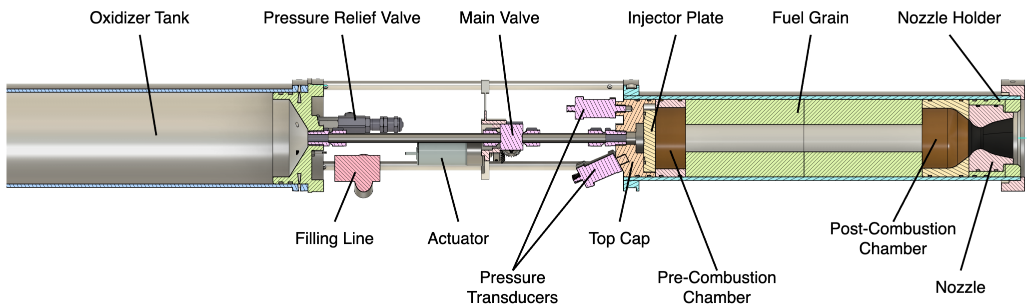


Figure 1: *Freyja propulsion system.*

The system uses a simple showerhead injector, and a manual valve actuated by a motor. It features a pre-combustion chamber and a post-combustion chamber to help increase the turbulence and enhance the mixing between the fuel and the oxidizer, the rocket's performance, a technique that has been tested previously on ÆSIR's Mjollnir rocket with great success.

The nozzle is made of graphite, and the whole assembly is held together by the nozzle holder ring.

Two pressure transducers measure the pressure before and after the injector.

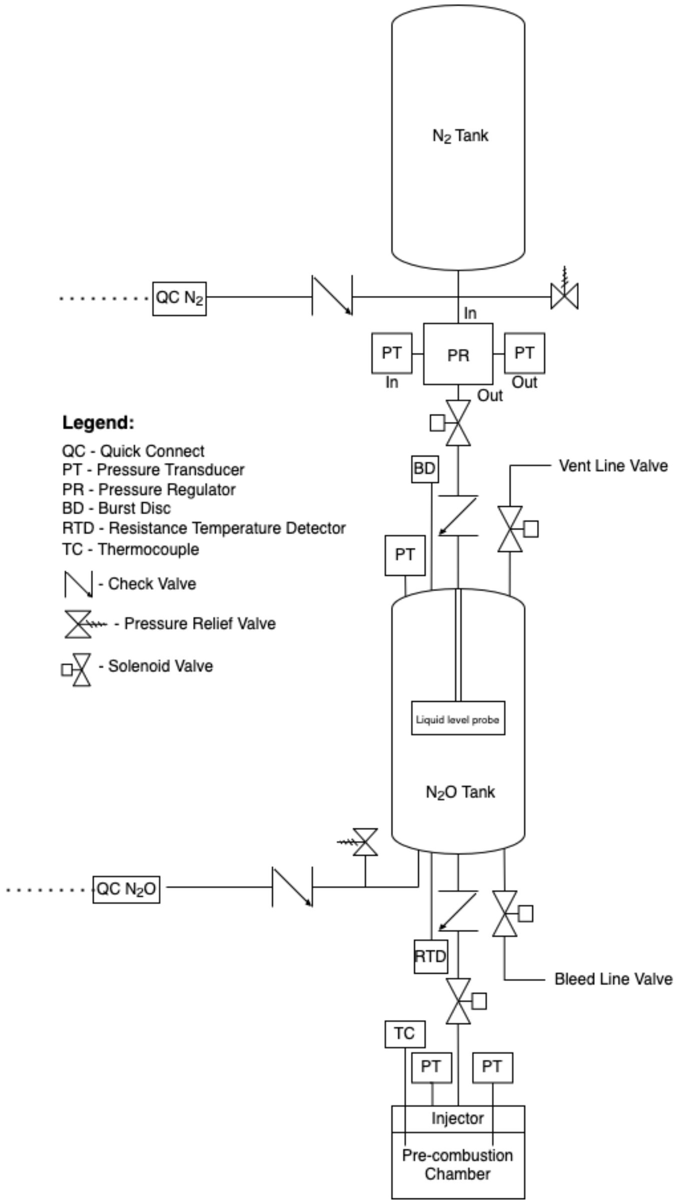


Figure 2: *Freyja plumbing system.*

The above shows the plumbing layout of the entire vehicle. The N2 tank is pressurized to 200 bar, and it's output fed through a pressure regulator to regulate it down to 55 bar. Once a solenoid opens, the tank pressurizes the N2O in the main tank. When the main valve opens, the liquid flows into the injector and into the combustion chamber.

2.3 Aerostructure Subsystem

The recovery bay, oxidizer tank and fin-can sections of the aerostructure are made of carbon fiber. The nosecone & payload bay, and the avionics bay are made of fiberglass for the purpose of radio transparency, all made in-house with a wet layup process.

The fins were made using an aluminium mold and pre-preg carbon fiber material, then cured in an oven. They were attached to the body tube using epoxy and carbon fiber reinforcement.

2.4 Recovery Subsystem

2.4.1 Recovery Subsystem Overview

The recovery subsystem consists of two main systems. One system responsible for "reefing" and "unreefing" of the parachute. The other system is responsible for separation of the payload-recovery bay bulkhead from the recovery bay. The recovery subsystem before deployment is housed within the recovery bay and to a certain degree within the avionics bay. The system is set up in such a way that the separation system is mounted through the "avionics-recovery bay" bulkhead. The same bulkhead also has a u-bolt attached through it and a hole for required wiring. Attached to the u-bolt is a shock cord. The shock cord is subsequently connected to the parachute and another u-bolt that is attached to the payload-recovery bay bulkhead. The "payload-recovery bay" bulkhead is attached to the recovery bay with nylon screws.

2.4.2 Reefed Parachute System

The reefed parachute system consists of a modified conical red and white 120" parachute with a 20" spill hole. The parachute is modified in such a way that a "reefing line" can be attached around the edge of the parachute. This has been done to decrease the effective diameter of the parachute and therefore have an increased descent speed. The increased descent speed will be achieved after the initial deployment of the parachute and the parachute will be considered to be "reefed". At 250 m altitude a commercially available pyrotechnic line cutter will sever the reefing line allowing the parachute to fully deploy and stop being reefed. When the parachute has been fully deployed it will achieve its touch down speed and land soon thereafter.

2.4.3 CO_2 Separation System

The system to initiate separation of the nose cone and main rocket body will be done through a CO2 ejection system. The CO2 ejection system is a commercially available system known as "The Eagle" from "Tinder Rocketry". The system engages the separation by increasing the internal pressure inside the recovery bay so that the nylon screws that hold the bulkhead break due to the shear forces from the increased internal pressure of the recovery bay. Within the recovery bay the parachute will be stored within a protective bag with accompanying shock cord will be stored there as well.

2.5 Air Brake Subsystem

The Air brake subsystem is a mechanically actuated assembly that deploys control surfaces to generate drag. It employs a crank-slider mechanism, where a central rotating crank is connected to each flap via a link arm, converting rotational motion into radial displacement. The crank turns, and each arm pushes a flap outward, each arm pushes its respective flap outward to increase drag and decelerate the vehicle. The system is shown in both its retracted and deployed configurations in Figure 3. The flaps are mounted on linear guide rails, for low-friction motion and sufficient load-bearing capacity to withstand aerodynamic forces when deployed.

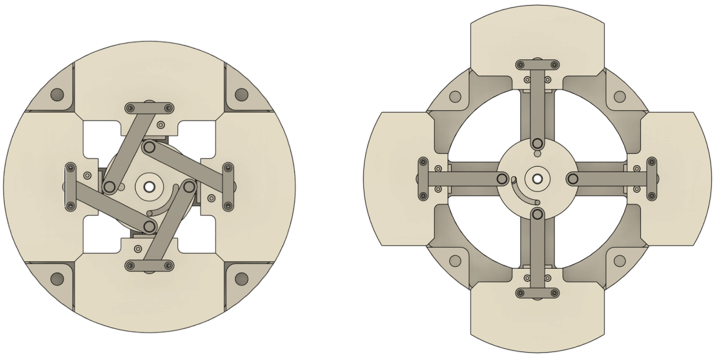


Figure 3: *Air brake in retracted and deployed states.*

To meet EuRoC safety regulations, the air brake subsystem incorporates a safety locking mechanism that ensures the flaps remain secure in the retracted position until deployment is explicitly commanded. This is done by using a **normally extended solenoid**, which acts as a locking pin on the crank. When not powered, the solenoid's plunger remains extended, mechanically preventing any motion. This design ensures passive safety by default, preventing accidental or premature extension for any reason. The cross-sectional view of the air brake subsystem, shown in Figure 4, shows the placement of the solenoid in its extended (unpowered) state locking the crank.

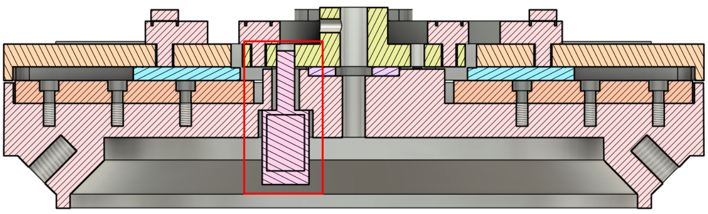


Figure 4: *Air brake cross section, highlighting the solenoid in its unpowered extended state locking the crank (yellow cross-section).*

The air brakes will only be deployed after the powered ascent phase and above an altitude of 1500 meters as per EuRoC rules for untested active control systems.

2.5.1 Air Brake regulator

The goal of the controller for the air brakes system is to provide automatic deployment of the air brakes in order to increase and decrease the drag and by extension increase or decrease the apogee by comparing it to the estimated apogee. The setpoint is the desired apogee of 3000 meters, and the measured process variable is the estimated apogee, and the error is defined as the difference between these 2 values.

Since the flight computer operates on discrete time steps, a discrete form of the PID algorithm must be used. The discrete formula implemented in the system is as follows:

$$u[k] = K_p e[k] + K_i \sum_{i=0}^{k} (e[i] \cdot \Delta t) + K_d \frac{e[k] - e[k-1]}{\Delta t} \tag{1}$$

PID tuning
To be able to choose the best values for the PID gains,a simulation-based approach was used in RocketPy. After running the simulation for different weather conditions and initial conditions, the gains that would be closest to the 3000m apogee target were chosen.

Control activation
There are two conditions that must be satisfied before the PID controller gives an output to deploy the air brakes. The first condition is that the rocket should be in coasting phase, i.e. when the motor burnout already has occurred. The second condition is the activation of the air brakes above 1500 meters above ground level, as previously mentioned.

Clamping of the PID output
The output of the PID is a single value between 0.0 and 1.0, which represents the fraction of the air brakes maximum deployment length that should be deployed. This is an artifact from the RocketPy simulation where the extension of the air brakes was defined in this way.

Anti windup
The integral term in the PID controller functions as a memory, it keeps track of the past errors and adds them up over time. It eliminates any persistent steady-state errors and help converge the system to its target, but an integral windup can occur. For instance, in a scenario where the rocket is far from its target apogee, the integral term will accumulate to a large positive error. This huge stored value keeps the controller's output stuck at maximum (full brakes) for far too long, causing the rocket to brake too hard and fall significantly short of its target. The controller becomes sluggish and unresponsive. To prevent this, a simple and effective strategy called integral clamping was implemented, which is a form of anti-windup. Instead of letting the integral accumulator grow indefinitely, a "cap" is put on its value, which is set to a constant in the C-code.

From PID value to angle
As mentioned previously, the raw output of the PID calculation is a normalized value between 0.0 (no deployment) and 1.0 (full deployment). This must be converted into a physical motor turning angle in degrees. This is achieved by a kinematics calculation for the air brake linkage. The first step towards this is to scale the output of the PID to the physical linear extension in millimeters by multiplying the output with 26.0 mm, which is the maximum extension of the brakes. The core of the conversion uses the geometric properties of the crank-and-link mechanism of the airbrakes. The goal is to find the crank angle (theta) that produces the desired deployment. The geometry can be modeled as a triangle formed by the crank arm and the connecting link. Defining x_{ext} as the desired linear deployment of the airbrakes, The final conversion formula for the angle output is

$$theta = \arcsin \frac{A^2 - (Link_L^2 - crank_R^2)}{2 * A * crank_R} \tag{2}$$

where $Link_L$ is the linkage arm length, $crank_R$ is the crank radius, and A is defined as

$$A = x_{ext} + \sqrt{Link_L^2 - crank_R^2}. \tag{3}$$

Controller accuracy
To assess the effectiveness of the controller, simulations were conducted using SRAD software. The results showed that the controller has an error of around 1.5%, which translates to ≈50 meters considering the 3000 meter apogee.

2.5.2 Air Brake Controller Unit [Loki]

Purpose The air brake controller is the PCB which controls the air brake. In detail, the purpose of the air brakes controller is to tune the aerodynamics using the air brakes extension to maintain the target apogee. This helps to create room for the design of the propulsion systems. The air brakes can deploy only when the rocket is in the coasting state and above the height of 1500m. This is with respect to the stability and safety of the fight.

Hardware

The air-brakes system is organized into three functional elements: a flight computer (referred to here as “Fjalar”), an air-brakes controller(referred to here as “Loki”) that actuates the mechanism via a stepper motor, and a dedicated solenoid controller board (“Freyr”). The air-brakes controller drives the actuator using a DRV8711-based stepper motor module provided on a Pololu carrier. In low-power states, mechanical motion is positively restrained by a solenoid latch. The solenoid can be commanded by either the flight computer or the air-brakes controller, providing two independent control paths for engagement and release of the restraint.

Command and supervision between the flight computer and the air-brakes controller are conducted over a Controller Area Network (CAN) bus. The system uses separate batteries for the flight computer and the air-brakes electronics; the solenoid controller employs solid-state relays to switch the coil while maintaining optical isolation of grounds, thereby mitigating ground loops and fault propagation across domains. In addition, the CAN connection used by the air-brakes controller is galvanically isolated from the flight computer’s CAN segment through isolated CAN circuitry located on the solenoid controller board. The solenoid control board and the air brake controller share the same battery and hence the same ground.

Software

The code is written in the C programming language and uses FreeRTOS as the operating system. There are primarily 9 threads that take care of different jobs such as CAN communication, stepper motor control, and error recovery, the state machine of the air brakes. These threads communicate using message queues, where the latest data is always overwritten.

The controller usually keeps the air brakes in the disabled mode (power save mode) and only enables it when the rocket is in the coasting phase and is armed via the flight controller. The flight controller also feeds the target angle to the flight controller to the air brakes system. In ideal conditions, the flight controller is supposed to also control the solenoid to enable air brake extension.

The stepper motor while rotating doesn't service a new request until the previous target angle is reached. This creates some response time till the next angle is taken and reduce the input noise from the algorithm

The air brakes controller has no other way to know about the rocket state than the flight controller. The flight controller therefore updates a flag called "prev armed" to decide the safe angle under circumstances such as flight computer malfunction or invalid angle. If the rocket is armed before, then the air brakes will be fully extended and if the air brakes have not been armed before, the air brakes will be fully retracted.

If the flight controller malfunctions and the air brakes need to be fully extended, then the solenoid control will be done using the air brakes. In this case, the rocket recovery will be done by the CATS Vega module. The current angle and the tracking of the rotation of the air brakes state is possible using CAN as the angle is always updated in real time. Once armed, the motor will retain its state so that the restraint is solely not dependent on the solenoid (even when the air brakes are fully retracted). Upon detection of a permanent fault, the motor tries to recover the error by resetting the driver until it recovers. The net total number of attempts is 5 after which the system goes to a permanent fault state after which it cannot operate.

2.6 Avionics Subsystem

2.6.1 Avionics assembly

The avionics assembly inside of the launch vehicle consists of the hardware below. The full assembly can be seen in Figure 5.

- SRAD flight computer (Fjalar) ×1
- COTS flight computer (CATs Vega) ×1
- SRAD telemetry modem (Brage) ×1
- SRAD air brake controller (Loki) ×1
- SRAD solenoid controller (Freyr) ×1
- SRAD propulsion motor controller (Sigurd) ×1
- SRAD propulsion sensor unit (Fáfnir) ×1
- SRAD CAN splitter (Yggdrasil) ×1
- COTS $LiFePO_4$ batteries ×3
- COTS Arming mechanism ×3

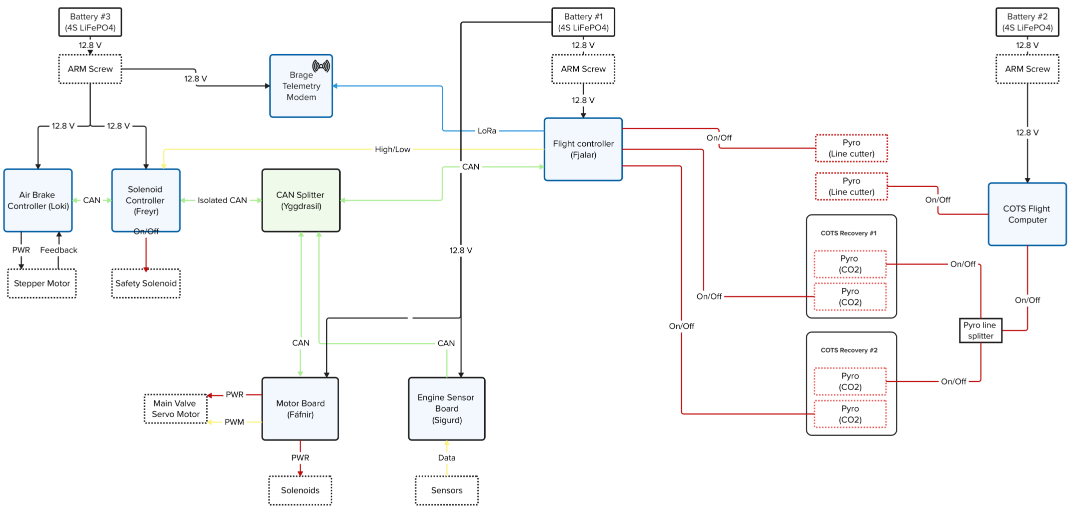


Figure 5: Block diagram of the avionics system.

Communication system

There are two types of communication between the different avionics components, the first is CAN and it is responsible for communicating information that is needed for the functionality of the system, the second is LoRa and it is needed to send information down to ground for observation. The CAN communication interface can send information at a rate up to 500kb/s while LoRa can send much less. The CAN bus connects together those components who needs to take part of information sent from Fjalar (2.6.2) using the the CAN splitter (2.6.6). A total of three components are connected to the CAN splitter (excl. the flight computer), they are Fáfnir (2.6.5), Sigurd (2.6.4), and Loki (2.5.2), these components only communicate with Fjalar, not between themselves.

The LoRa system is only used between three components, that is Fjalar, Brage (2.6.3), and the Ground Control Station (3.2), the information transmitted are samples of raw sensor data, the flight state, pose, and other important information for the ground control crew. Both systems are visualized in Figure 5.

Power system

The avionics system runs on four cell LiFePO4 batteries, the nominal voltage of these batteries are 12.8 V. There are a total of three batteries, one for each flight computer and one for the air brake system, not to interfere with the redundancy of the recovery system. The task of the three batteries can be seen in Table 1.

Battery number	Components to power
1	Fjalar, Fáfnir, and Sigurd.
2	CATs Vega.
3	Brage, Loki, Freyr.

Table 1: *Avionic batteries and their tasks.*

Recovery electronics

The main purpose of the recovery electronics is to activate the main and drogue parachute while also being redundant as per EuRoC requirements. Each of the three systems, detailed in Section 2.4.3 are redundant by being connected to both the SRAD Fjalar flight computer and the COTS CATs Vega flight computer, see Figure 5.

Avionics bay

All avionics components are located inside of the avionics bay, with cables extending to the recovery bay, air brakes and to the engine section. The avionics bay was designed to enable a rack like mounting of all PCBss, given that an adapter was made for them. The rack is a sliding rack where a PCB adapter can be slid in and fastened.

2.6.2 Flight Controller [Fjalar]

Purpose

The flight computer of Freyja, called Fjalar, plays a critical role in the system. The purpose of Fjalar is to handle all the heavy logic in the avionics system, it is responsible of, but not limited to, controlling actuators in the propulsion system, activating the recovery system, reading from various sensors, actuating the air brakes and transmitting telemetry to the telemetry modem. The CATs Vega COTS flight computer is also used, but only for the recovery system in order to keep up with EuRoC regulations.

Hardware

Fjalar comes equipped with a range of different components that lets the flight computer function as it does in Freyja, the most notable of these are: 3 pyrotechnic channels with continuity detection, high acceleration accelerometer, barometric sensor, gyroscope, GNSS, Flash memory, LoRa, CAN, I2C, USB-C, and UART ports.

Software

Fjalar is written in C, and runs on Zephyr RTOS (real time operating system) whos POSIX API makes up the framework of the software An RTOS was chosen because of the time critical nature of rocketry. The code base of Fjalar is split up into multiple components who together handle all of the flight computers responsibilities, there are twelve main threads which handle initialization, state machine, state estimation, communication, actuation, control, and aerodynamic analysis, see Figure 6. A further description of Fjalars state estimation, control algorithms, and communication intefaces, see Appendix ??.

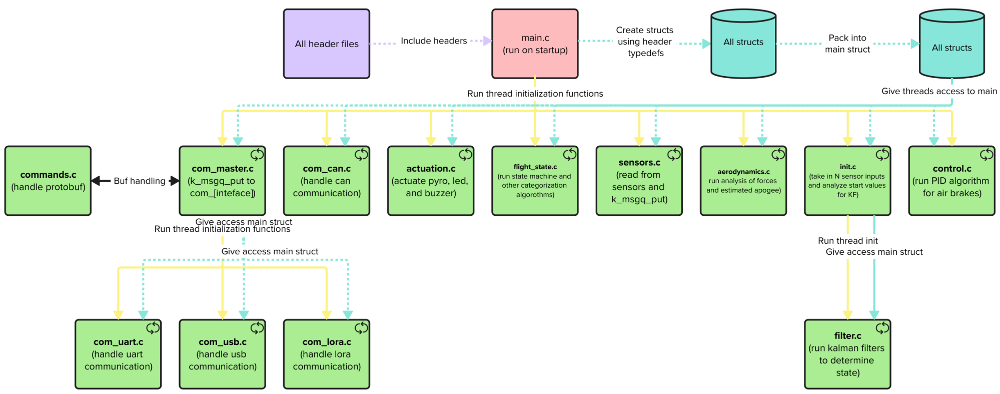


Figure 6: *Software framework of the Fjalar flight computer.*

Fjalar uses a state machines to make various decisions throughout her flight, the different states, their transition requirements and their consequences can be seen i Table 2.

State	Entry requirement	Consequence
IDLE	Default upon startup	None
AWAITING INIT	Ground control station sends a message telling Fjalar that it should enter this state	Unblocks init script
INITIATED	Init script has run successfully	None
AWAITING LAUNCH	Ground control station sends a message telling Fjalar that it should enter this state	Fjalar can now send CAN messages activating the motor
BOOST	Acceleration above $15\,\text{m/s}^2$, or speed over $15\,\text{m/s}$ while being at an altitude over $10\,\text{m}$	Certain Kalman Filters disabled
COAST	Absence of thrust in aerodynamic calculations	Certain Kalman Filters enabled
DROGUE DESCENT	Velocity in z turns to the negative	Drogue deployed
MAIN DESCENT	Altitude below $200\,\text{m}$	Main deployed
LANDED	Acceleration close to 0	None

Table 2: *The different states of the state machine, and the most necessary information about them.*

2.6.3 Telemetry Modem [Brage]

Purpose

Brage is the main wireless telemetry modem. It serves as a link between the launchpad, Freyja and the base station. It is designed for ranges above 10km using 2.4GHz LoRa at 1W of transmission power. An amateur radio license is required to transmit at such high powers and to comply with this the telemetry responsible holds a Swedish HAREC license.

Hardware

The design is based on a LoRa transceiver from Semtech, the SX1280, which is then followed by an analog chain with filtering and amplification. The raw output power of the transceiver is 13dBm(20mW) which is then filtered from harmonics and amplified to 30dBm(1W). On the RX chain there is a low-noise amplifier and a band-pass filter. The board has an integrated inverted-F antenna to save space and ease integration when a long range is not required, such as between the launchpad and the base station.

A 2.4GHz quarter wave monopole is used on the Rocket and base station while the integrated antenna is used on the launchpad. The exact LoRa parameters can be seen in table 3.

Software

The firmware is developed in Rust using the Embassy framework for the STM32U5 series. The intent is to bridge the CAN-busses as transparently as possible between all units. Since the 2.4GHz-band can be crowded a "listen before talk" (LBT) scheme is employed. This means that the firmware reads the signal strength to tell if another device is currently

Table 3: Modem Configuration

Parameter	Value
Modulation	LoRa
Spreading Factor	12
Bandwidth	1600 kHz
Coding Rate	4/8
Bitrate	2.4Kbit/s
Link Budget	124dBm
Range	16Km
Frequency	2.4GHz

using the band before transmitting.

2.6.4 Propulsion Sensor Unit [Sigurd]

Purpose
The Propulsion Sensor Unit, known as Sigurd, is responsible for recording data from a variety of sensors within the propulsion system in order to further transmit the data via CAN to Fjalar, the flight computer. These sensors include various thermocouples, resistance temperature detectors (RTDs), and pressure transducers.

Hardware
Sigurd interfaces with four Type K thermocouples, four pressure transducers, and two resistance temperature detectors (RTDs). In addition to sensor inputs, the board incorporates a control channel for the dip tube, allowing it to be switched on or off during operation. For communication, Sigurd connects to the CAN bus, with an extension connector to link further downstream boards.

Software
The software for Sigurd uses is written in C and runs under FreeRTOS. The analog data is recorded through an ADC that communicates to the STM32 microcontroller over SPI. Sensor readings are recorded as raw current and voltage values from the sensors. These values are transmitted via CAN to Fjalar for processing and storage. The software is organized into functional states, with dedicated handling for each type of sensor.

In addition to data acquisition, the software also controls the dip tube actuator through a GPIO output pin.

2.6.5 Main Valve Actuator Unit [Fáfnir]

Purpose
Fáfnir, the main valve controller, is responsible for operating the actuators of the propulsion system. Its main functions include driving the motor that opens the main valve and switching solenoid valves.

Hardware
Fáfnir is built around an STM32 microcontroller that manages the actuation of the propul-

sion system. Its primary task is to control the 12 V servo motor that drives the main valve, operated through a PWM signal. To accommodate motors that require higher voltages, the board provides a screw terminal to support external step-up converters.

In addition to the main valve, Fáfnir incorporates three ports for solenoid actuation equipped with continuity checking. The board also includes support for motors with up to 3 Hall-effect sensors. However, the main valve servo motor itself does not rely on Hall sensors for feedback.

Software
Fáfnir will use FreeRTOS in combination with C, running on an STM32 microcontroller. The control logic is structured into separate tasks, such as communication, servo motor rotation, and solenoid actuation. One state manages CAN bus communication. Another controls the servo motor for the main valve by varying the PWM duty cycle. The motor is first zeroed to set a reference position prior to operation.

The three solenoid ports are also managed individually, with on/off control. Each port includes continuity monitoring, implemented through STM32 GPIO pins.

2.6.6 CAN and Power distribution unit [Yggdrasil]

Purpose
Yggdrasil, the CAN splitter, functions both as a CAN bus extender and as a power distribution hub. All modules connect to it for CAN communication, while it simultaneously provides power to those that require it. By centralizing these functions, Yggdrasil simplifies system integration and reduces wiring complexity.

Hardware
The splitter includes a single connector for the battery input, which serves as the main supply to the system. From this input, it distributes both power and CAN signals through four combined connectors, each connecting both the CAN bus and power. In addition, the board provides two connectors dedicated solely to power distribution and one connector dedicated solely to the CAN bus.

3 Ground Support Equipment System Architecture

3.1 Filling Station

The filling station is constructed with aluminium profiles, the frame is mounted on 4 wheels (2 of them lockable) for easy mobility. The plumbing, valves and sensors are affixed onto a steel plate.

The filling station can securely hold up to 4 gas bottles up-side-down for propellant filling operations.

All the valves can be remotely controlled by the Ground Control Station, the data collected by sensors are stored locally and sent to the Ground Control Station for real-time monitoring.

There are 2 live CCTV cameras mounted on the filling station, the footage is transmitted back to Mission Control through point-to-point wifi antennas.

3.2 Ground Control Station

Purpose
The Ground Control Station (GCS) serves three purposes:

1. Fueling and unfueling by controlling valves.
2. Arming and igniting rocket.
3. Displaying and logging the following data:
    - altitude
    - speed
    - acceleration
    - thrust
    - airbrake percantage
    - temperature sensors
    - recovery status

To accomplish this the GCS communicates through LORA with the launchpad and with the rocket itself.

Hardware
The GCS hardware is comprised of three main systems:

1. The Brage modem to communicate with the rocket and the launchpad.
2. A STM32 based circuit board containing toggles and buttons relevant for control as well as indicator lights. This PCB talks over CAN to Brage and over USB to a Raspberry Pi.

3. A Raspberry Pi Linux computer. This is used for logging and displaying the telemetry on a LCD screen.

All of this is contained inside a rugged and waterproof plastic briefcase, commonly known as a "Pelican case".

Software
Much of the software stack is the same as Fjaelar to allow code reuse. Thus, the code on the STM32 is also running in Zephyr.

On the Raspberry Pi, Python is used in conjunction with the graphical library DearPyGui. DearPyGui was chosen since it is fast at plotting real time data.

Security considerations
To ensure safe operation, both the software and the hardware are designed to minimize the risk of accidental valve activation or ignition. In addition to the power switch needing to be turned on there are two lockout keyrings that need to be inserted for full functionality. The first one arms the valve position send button. And the second arms the ignition button. After the hardware keyrings are in place the software may choose to block the arming if all checks are not met. But thus far, the software has no such criteria implemented but the option exists to add in the future. To indicate successful arming each keyring has a unique LED indicator light.

For reliability, it is important to reduce the number of critical systems. That is why the Raspberry Pi has no ability to send commands, it only receives. So, if it fails, the GCS will still be able to operate the launchpad and the rocket.

The briefcase also includes battery backups. If the external power source should fail, it will seamlessly switch over to the internal batteries.

4 Conclusion and Outlook

The main goal of the Freyja project was to build ÆSIR's first EuRoC competition ready hybrid rocket. At the time of writing this report, the project is unfortunately unlikely to meet all EuRoC deadlines in time for the 2025 competition. The team will continue to work towards a successful full duration static fire of the rocket and completion of all other critical testing and look for other potential launch opportunities in Europe to validate the design and construction of the rocket. The hope is that Freyja can still serve as a foundation for future improved versions of hybrid rockets from ÆSIR.

A Detailed Test Reports

A.1 Ground test demonstration of recovery system

A.1.1 Line cutter test

Tools:

1. The Piranha cutter box (commercially available line cutter system from Tinder Rocketry)
2. The Piranha cutter assembly guide
3. Aerotech Interlock Launch Controller
4. 12 V lead battery
5. Reefing line spool
6. PPE
7. Scissors
8. Isopropyl alcohol

Steps:

1. Assemble the Piranha cutter according to the guidelines
2. Cut an appropriate amount of reefing line from the reefing line spool
3. Insert the cut reefing line into the Piranha cutter
4. Tie the reefing line between two appropriate places so that the line is in tension.
5. Make sure Piranha cutter is on the part of the line that is in tension
6. Set cameras to record
7. Clear the area
8. Pyrotechnics responsible sets up the Aerotech Interlock Launch Controller with the 12 V Lead battery
9. Pyrotechnics responsible initiates a countdown and then detonate the blackpowder charge in the Pirahna system
10. Disassemble according to the guidelines and clean the Pirahna cutter

A.1.2 Results

There were two successful tests with two separate Pirahna Cutter systems, one being the main one and the second one for redundancy

A.2 Static hot-fire test

A.3 Combustion chamber pressure test

A.3.1 Introduction

The combustion chamber was pressure tested to ensure that it would hold during combustion.

A.3.2 Setup

The combustion chamber was sealed and plugged, and a pressure transducer was connected via a test control computer to read the pressure, to be sent to a remote computer for logging. A manual high pressure water pump meant for hydrostatic testing was connected to the system via a pressure regulator, and a manual valve was connected via a T-junction to vent the pressure to atmosphere post test. Additionally, another manual valve on the regulator itself acted as the fill valve, and allowing easier tuning of the regulator.

A.3.3 Test execution

The manual valve on the pressure regulator was set to closed, and the pump was pumped to achieve a high pressure. After achieving a back-pressure, the regulator was tuned to the correct pressure, in this case 40 bar. After which, the manual valve on the regulator was set to open, and the pump was pumped until the tank was at the right pressure, all the while double checking the readings on the pressure regulator against the digital readings from the pressure transducer. Once the correct pressure was reached, some time was allowed to pass, all the while the pressure was monitored for leaks.

A.3.4 Test evaluation and analysis

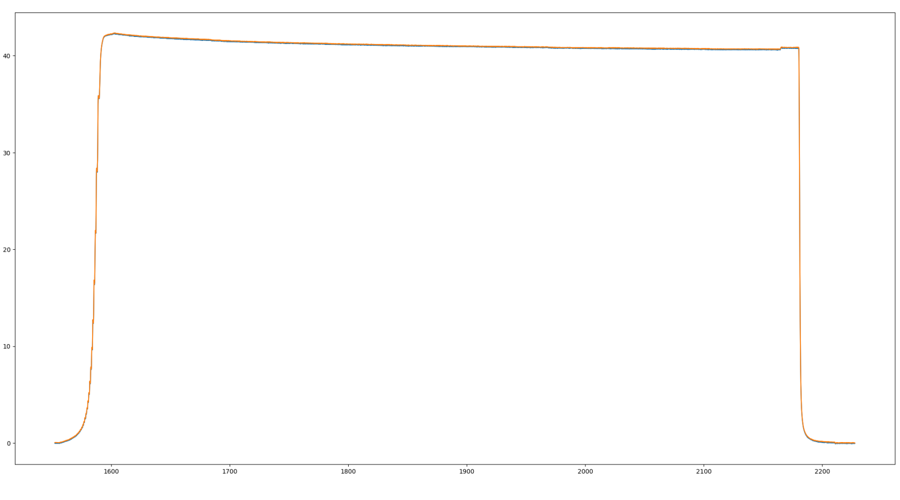


Figure 7: *Combustion chamber pressure during test, testing time in seconds on x-axis, pressure in bar on y-axis.*

As can be seen in 7, the combustion chamber performed flawlessly, holding more than 40 bar for over 30 minutes.

A.3.5 Conclusions

The combustion chamber passed the test flawlessly.

A.4 Proof testing pressure vessels

A.4.1 Introduction

The main tank was pressure tested to ensure it would hold, and to make sure it wouldn't leak during flight and subsequent tests.

A.4.2 Setup

The combustion chamber was sealed and plugged, and a pressure transducer was connected via a test control computer to read the pressure, to be sent to a remote computer for logging. A manual high pressure water pump meant for hydrostatic testing was connected to the system via a pressure regulator, and a manual valve was connected via a T-junction to vent the pressure to atmosphere post test. Additionally, another manual valve on the regulator itself acted as the fill valve, and allowing easier tuning of the regulator.

A.4.3 Test execution

The manual valve on the pressure regulator was set to closed, and the pump was pumped to achieve a high pressure. After achieving a back-pressure, the regulator was tuned to the correct pressure, in this case 90 bar. After which, the manual valve on the regulator was set to open, and the pump was pumped until the tank was at the right pressure, all the while double checking the readings on the pressure regulator against the digital readings from the pressure transducer. Once the correct pressure was reached, some time was allowed to pass, in this case 1h, all the while the pressure was monitored for leaks.

A.4.4 Test evaluation and analysis

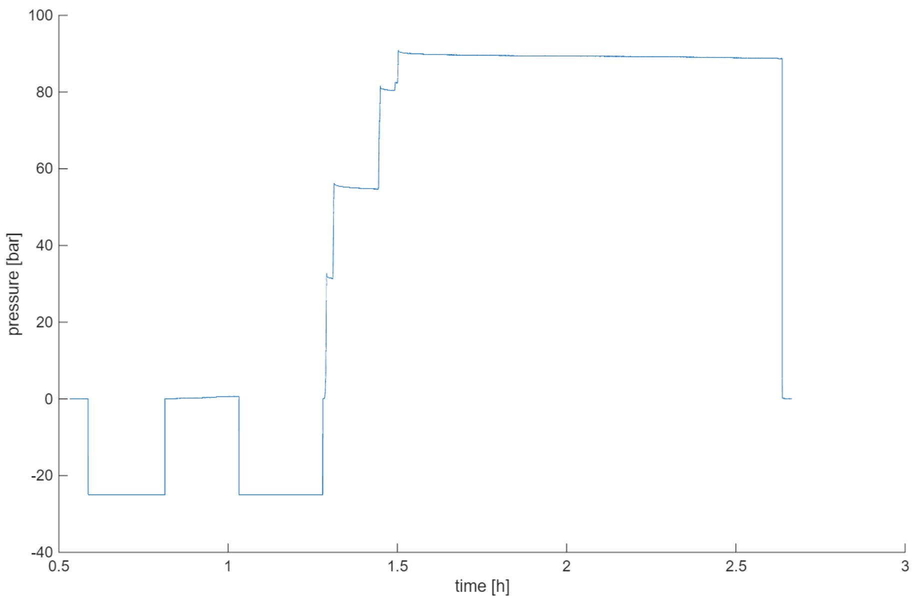


Figure 8: *Tank pressure throughout the test.*

As can be seen in 8, the combustion chamber performed flawlessly, holding more than 90 bar for over 1h.

A.4.5 Conclusions

The tank performed flawlessly. However, as observed during the flow test, the tank would later start leaking due to additional fittings and holes added after the pressure test.

A.5 Flow & Tanking test

A.5.1 Introduction

The purpose of the flow test was to show that the system could handle the temperatures and pressures reached during filling, to properly and to gain a deeper understanding of the systems behavior, and to show the system could withstand the cold tank temperatures achieved during burn.

A.5.2 Setup

The test was planned and set up according to schematic:

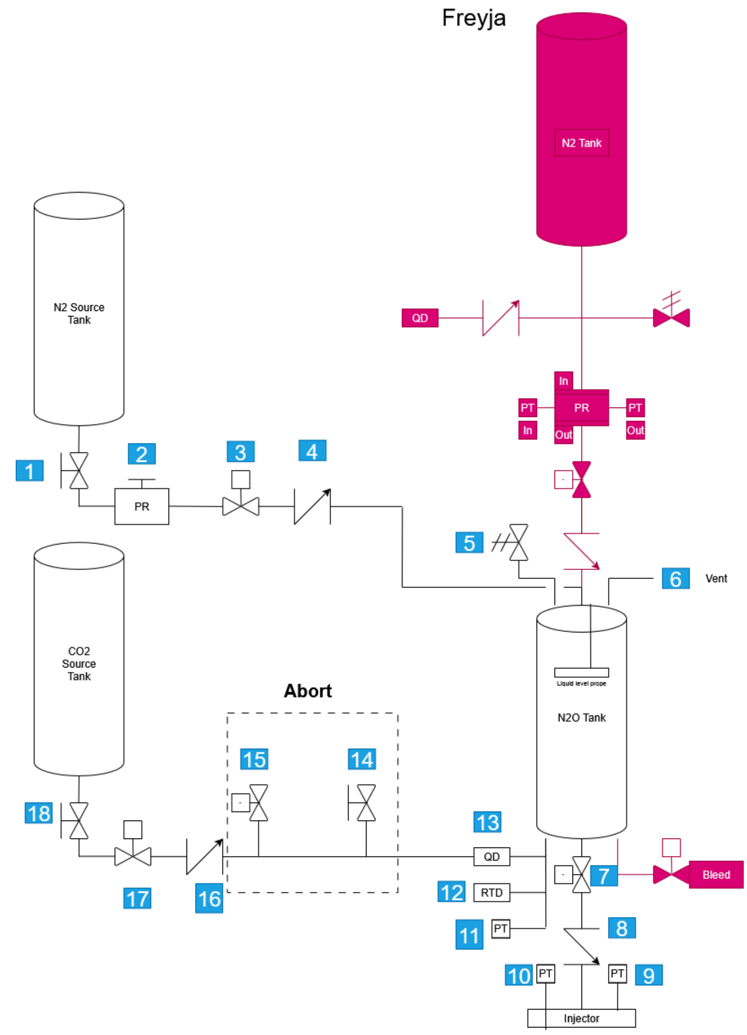


Figure 9: Flow test setup.
Pink = Used in flight configuration, but not used in this test.
Blue = Valve designator

Though some modifications/deviations were made due to last minute changes. Parts 10, 5 and 12 were not present during the test, and 13 was replaced with a straight connection.

Number	Name (shorthand abbreviation)	Valve type	Purpose
1	N2 Manual valve (N2 manual)	Manual valve	Mounted on the source tank
2	Pressure regulator (regulator)	Pressure regulator	Regulates the pressure down from 200 bar in the source tank to the 55 bar of the system
3	N2 fill solenoid (N2 fill)	Solenoid valve	Allows for remote filling / pressurization of the system with N2
4	N2 Check valve	Check valve	Makes sure no gas returns from the main tank back through the system
5	Pressure relief valve (pressure relief)	Pressure relief valve	Protects the system from overpressure. Not used in this test.
6	Always-open vent (always open)	Small orifice always open	Allows gas to escape during filling to allow for filling the tank with liquid, and acts as redundancy in case system needs to be depressurized. Means that it means that even without intervention, the system eventually reaches ambient conditions
7	Main valve	Motor-driven manual ball valve	The main valve allowing fluid to flow from the main tank to the injector
8	Main check valve	Check valve	Prevents backflow from the injector to the main tank
9	Injector pressure transducer (injector PT)	Pressure transducer	Read the injector heads pressure
10	Combustion chamber pressure transducer (Combustion chamber PT)	Pressure transducer	Read the pressure inside the combustion chamber during engine fire. Not used in this test.
11	Tank pressure transducer (tank PT / main PT)	Pressure transducer	Reads the pressure inside the tank. Main PT used to inform calls on the safety of the system, and how safe it is to approach.
12	RTD	Temperature sensor	Measures the temperature of the fluid
13	Quick disconnect	Quick connection fitting	Connects the ground system to the rocket before launch. Not present in this test
14	Manual vent valve (manual vent)	Manual ball valve	Redundant vent valve in case 15 freezes. Also acts as a backup to ensure system is in a safe state and safe to operate on so long as it's open, even if the solenoid vent valve 15 were to loose connection or freeze.
15	Solenoid vent valve (vent / solenoid vent)	Solenoid valve	Allows for remote depressurisation / venting to the atmosphere
16	CO2 check valve	Check valve	Prevents backflow into the CO2 source tank
17	CO2 fill solenoid (CO2 fill)	Solenoid valve	Allows for remote filling of the main tank with CO2
18	CO2 manual valve (CO2 manual)	Manual valve	Manual valve mounted on the source tank

Table 4: *Valve designations*

Figure 10: *Test setup.*

The test was carried out on an airfield, to which the test setup was transported along with a ground support equipment cart (GSE). The entire setup, both GSE and rocket hardware, was controlled via a single computer meant for test support, which in combination with a lack of long hoses meant the test had to be mounted in close proximity to the GSE cart. This limited the available abort options, though not enough to make for unsafe testing. It meant that the GSE system could not be approached while pressurized, and thus additional consideration had to be taken to ensure that the system was depressurized and in a safe state when manipulating the manual valves 1, 14 and 18. To mitigate this to some extent, the longest available hose was connected between the manual vent and the rest of the system, so that in the worst possible scenario, that being a blocked always-open vent, the system could conceivably be approached given enough time.

As the plumbing for the N2 pressurization system had not yet arrived, external pressurization was simulated using an external N2 50 l tank instead. To avoid some complexity, the choice was made to have only one solenoid vent and one manual vent present, mounted on the CO2 side of the system. This meant that the N2 tank, in case venting to the atmosphere was required, would be drained / vented through the main tank.

The entire test was filmed with a set of go-pro's near the tank.

The main tank was mounted to a load cell both to verify that the tank was filled properly, and to evaluate the mass flow when actuating the main valve. This load cell was hooked up to a raspberry Pi and the test data logged locally, hence the mass could not be read during the actual test.

A.5.3 Test execution

For the actual test procedures, see: E.1

The test procedure required the regulator to be tuned prior to the test. During the execution of this procedure, the regulator turned out to be improperly fastened to the N2 manual valve causing a leak, which ended up draining a large portion of the N2. This caused a rapid cool down of the N2 tank, leading to a buildup of frost.

The procedure called for a leak check after tuning the regulator, but this was deemed unnecessary, as the procedure called for the leak check to be done using N2, and leak check procedures with CO2 had not been written.

After tuning the regulator, the tank was filled with CO2 for the main test sequence. The tank did fill with CO2, though with a significantly higher gas flow rate out of the system than had been expected, leading to a lower tank pressure. The tank reached 36 bar, after which it filled with liquid CO2, indicated by the fact that the always open vent started venting mist instead of just saturated opaque gas.

Figure 11: *Mist coming out of the always open vent.*

Upon trying to actuate the solenoid valves, it was realized that they had frozen shut. The decision was made to try and do the test regardless, though upon actuating the main valve it was realized that it too did not actuate. The cause of this issue was hypothesized to be either freezing of the valve, or moisture shorting the electronics.

Due to the freezing of the solenoids, the tank could not be vented through the vent valve, and the system was too high pressure to be approached safely. The system thus had to be vented through the always open vent, which took a significant amount of time.

During disassembly, the main valve was tested when removed from the system, and it seemed to work as expected.

A.5.4 Test evaluation and analysis

The vapor temperature of CO2 at 36 bar is around 1*C, which is not low enough for ice formation and thus freezing of the solenoids. It is however possible that the liquid and vapor inside the tank were at different temperatures due to the transient filling sequence, and the boiling of the liquid causing a change in enthalpy, in which case the vapor coming out of the tank would have been 1*C, while the liquid likely was at a significantly lower temperature.

When watching back the camera footage, it can be observed that frost formation starts on the top and bottom of the tank at the same time. The bottom is likely due to the previously mentioned cooler liquid, while the top is likely caused by the cooling from the expanding gas exiting the nozzle. It is possible that the mist shown in 11 could have been partly due to gas re condensing back into liquid droplets, though plotting the tank mass over time shows that the tank did actually reach it's full capacity.

Figure 12: *Frost forming on top and bottom of the tank.*

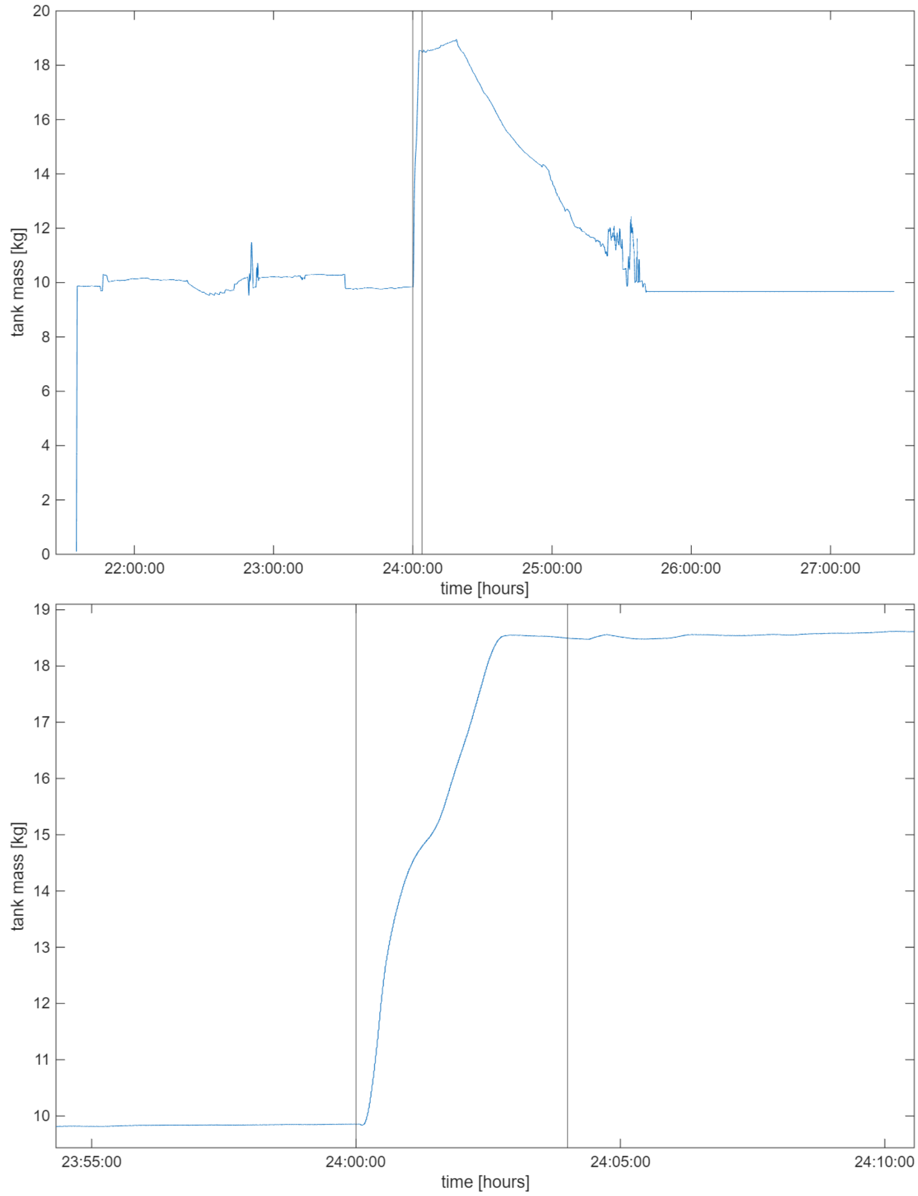


Figure 13: *Tank mass during test.*

As can be seen from the graph, tanking began at around 24:00. After starting tanking it relatively quickly reached the target mass, and after 30 minutes, the source tanks were empty, at which point the system started to loose mass slowly over the course of 2 hours.

A.5.5 Conclusions

The always open vent was hypothesized to be too large, causing too high mass flow and subsequently too low tank pressure and temperature. By decreasing the mass flow, the pressure drop over the always open vent would decrease, and hence the tank pressure would increase, and the vapor temperature would increase. The decreased flow rate would also give more time for heat to soak through the tank walls and into the liquid, increasing the liquid temperature.

It is also likely that additional leaks were present, presenting an additional orifice open to the atmosphere further decreasing the tank pressure and increasing the flow rate, as can be seen in 12. A smaller jet can be seen shooting off at an angle, perpendicular to the main jet shooting out of the always open vent.

It was also decided to perform a pressure test to validate the main valves operation under high pressure, but from the actuation test after the main flow test, it seemed that the valve worked fine and that it was something with the tank and associated systems that was the issue, likely the cold temperatures.

A.6 Hydrostatic main valve test

A.6.1 Introduction

The purpose of this test was to validate that the main valve could operate under pressure.

A.6.2 Setup

The main valve was connected to a manual high pressure water pump meant for hydrostatic testing via a pressure regulator, and a manual vent valve to depressurize the system to the atmosphere after the test. The pressure was read from an indicator on the pressure regulator.

A.6.3 Test execution

Water was pumped up to the main valve. When the signal was given, the valve would actuate and demonstrate that the valve could let fluid through.

The test was conducted twice, once to test out the current design, and once to test out a future design improvement involving changing out the DC-motor with a hall-effect encoder with a control servo.

A.6.4 Test evaluation and analysis

Both tests were successful and demonstrated both approaches to opening the main valve.

A.6.5 Conclusions

The successful demonstration of valve actuation hints that the cold temperature and frost build up was the likely culprit to the main valve malfunction during the cold test.

A.7 SRAD Flight Computer Recovery Test

B Risk Assessment

Below follows a table of identified failure modes, when they can occur, their probability of occurring, a ranking of their severity if they occur, a combined metric for their severity, and additional comments / mitigations. It should be noted that reality is often messy, and not all risks can be predicted, nor is that the purpose of this assessment. The purpose of this assessment, and thus the primary metric upon which the mishap severity is ranked, is to **make sure that the launch can be conducted safely and does not pose any danger to personnel**. Additionally, though less important, the assessment also aims to improve the probability of mission success by identifying and quantifying possible hurdles. Risks are identified by looking for sources of **stored energy** (potential, chemical, electrical, kinetic, or other), and then considering ways in which that can be released in an uncontrolled or otherwise undesirable manner.

Below follows the different metrics by which the different failure modes were rated.

Mishap severity	**Negligible** risk to mission / **no** risk to personnel	**Low** risk to mission / **no** risk to personnel	**Moderate** risk to mission / **no** risk to personnel	**Significant** risk to mission / **no** risk to personnel	**High** risk to mission / **negligible** risk to personnel	**Low** risk to personnel	**Moderate** risk to personnel	**Significant** risk to personnel	**High** risk to personnel
Mishap severity rating	1	2	3	4	5	6	7	8	9

Table 5: *Mishap severity assessment metric*

Failure probability	**Negligible** probability of occurring	**Low** probability of occurring	**Moderate** probability of occurring	**Significant** probability of occurring	**High** probability of occurring
Failure probability rating	1	2	3	4	5

Table 6: *Failure probability assessment metric*

Mishap severity (horizontal), failure probability (vertical)	1	2	3	4	5	6	7	8	9
1	1	2	3	4	5	6	7	8	9
2	2	4	6	8	10	12	14	16	18
3	3	6	9	12	15	18	21	24	27
4	4	8	12	16	20	24	28	32	36
5	5	10	15	20	25	30	35	40	45

Table 7: *Criticality ranking based on failure probability and mishap severity*

Criticality ranking	1	2 - 3	4 - 5	6 - 7	8 - 9	10 - 18	20 - 28	30 - 36	40<
Criticality evaluation	This failure mode is not a concern	This failure mode is of very minor concern	Justification needed. Jury may decide to review	Technical jury approval needed before launch	Technical jury approval needed before launch	Action required to reduce ranking before launch	Action required to reduce ranking before launch	Action required to reduce ranking before launch	Action required to reduce ranking before launch

Table 8: *Criticality ranking metric*

Failure mode	Mission phase	Failure probability	Mishap severity	Criticality ranking	Teams comments and justification
Tank rupture (N2O tank or N2 tank)	From tank pressurization to tank depletion	1	5	5	Pressure tests have been conducted to mitigate the risk of mission failure. Since fueling is done remotely it poses no hazard to ground crew.
O-ring failure	From tank pressurization to tank depletion	5	4	20	Pressure testing have shown this to be a common occurrence. Since fueling is done remotely, it poses no hazard to ground crew. Actions to reduce potential o-ring damage during assembly will be taken before launch.
Plumbing leaks, gas escape from fittings	From tank pressurization to tank depletion	5	2	10	Pressure testing have shown this to be a common occurrence. Since fueling is done remotely, it poses no hazard to ground crew. This can be fixed on site.
Freezing of (all 3) vent solenoid valves	From tank pressurization to tank depletion	3	5	15	This has occurred during previous flow test. In the event of this occurring a manual vent valve a safe distance away from the rocket allows for manual venting. Rapid depressurization of tank can cause dry ice to form in in the vent line, causing depress to take some time, though tank will eventually reach equilibrium as the surroundings heat the system. Additional hose after the manual vent valve gives test engineer space to actuate the valve without risking direct exposure to the gas jet, mitigating the risk of frostbite and asphyxiation. PPE provides additional protection.
Ignition failure	Ignition	3	4	12	System can be depressurized and safed remotely. No danger to personnel.
Battery over-current	Ground	1	5	5	Unlikely to happen, but dangerous if occurring while personnel is nearby. At Most likely point of occurrence (ignition) no personnel will be nearby. Regardless, integrated electronics testing to be preformed before launch
Graphite nozzle breaks during burn	Ascent	5	4	20	Likelihood unknown, static-fire test to be preformed before launch. Undesirable as could lead to falling debris.
Improper actual sealing of assembly	Ascent	4	3	12	Static-fire test to be preformed before launch
Hot gases leaking between nozzle and nozzle-holder	Ascent	4	4	16	Likelihood unknown, static-fire test to be preformed before launch
Hot gas eating up o-rings	Ascent	3	2	6	Likelihood unknown, static-fire test to be preformed before launch
Hot gas leaking between fuel-grain disks	Ascent	3	2	6	Likelihood unknown, static-fire test to be preformed before launch.
Uneven burning causing hot-spots and/or burn-through	Ascent	3	5	15	Likelihood unknown, static-fire test to be preformed before launch.
Thermal weakening of aluminium structure causing rupture	Ascent	3	5	15	Likelihood unknown, static-fire test to be preformed before launch.
Combustion instability causing transient loads	Ascent	2	2	4	More knowledge to be gained from static-fire, but affects of these in combination with aerodynamic-loads will remain unknown
Main-valve actuator malfunctioning	Launch	2	2		
PLA-printed parts failing due-to freezing	Before launch and launch	4	2	8	Likelihood unknown, static-fire test to be preformed before launch.
Vortex formation in bottom of main tank	Ascent	3	3	9	Likelihood unknown, static-fire test to be preformed before launch.
Bubble formation in main tank	Ascent	3	3	9	Likelihood unknown, static-fire test to be preformed before launch.
FOD in main tank, clogging up main valve or injector	Launch and Ascent	3	3	9	Likelihood unknown, static-fire test to be preformed before launch.
Water in Lox-tank, freezing and clogging up system	Launch and Ascent	3	3	9	Likelihood unknown, static-fire test to be preformed before launch.
Faulty pressure transducer values	?	2	9	18	Has so far never happened during testing. But if it does, we are unable to tell whether or not approaching is safe
Loss of communication with Brage before filling	Setup/ Before launch	2	2	4	No real risk involved, can try to fix or continue using Fjalar
Loss of communication with Brage after filling	Before Launch	2	8	16	May become unable to launch or vent. Could continue process using Fjalar
Fjalar failure	Before and during flight	2	5	10	
Accumulating error, ruining state estimations	Ascent	2	2		
Error in state estimation algorithms causing improper altitude estimation	Ascent	2	2	4	Risks failing the mission goal (correct height, but unlikely to cause any personnel risk)
CAN-splitter failure	Launch and ascent	2	2		
Fafnir failure	Filling, launch, and ascent	2	8	16	Depending on when in the process, it can introduce different risks
Load cell reader failure	?	1	3	3	
Engine sensor board failure	?	2	2		
Solenoid controller failure	Filling and launch	4	5	20	Somewhat likely to happen, based on previously preformed tests
Air-brake controller failure	Ascent	2	2	4	Risks failing the mission goal (correct height, but unlikely to cause any personnel risk)
Improperly tuned air-brake controllers	Ascent	3	2	6	Risks failing the mission goal (correct height, but unlikely to cause any personnel risk)
Air-brake structure failure	Ascent	2	2	4	Risks failing the mission goal (correct height, but unlikely to cause any personnel risk). Though does pose the risk of falling debris
Electronics failure due to vibrations, temperature, moisture	Before, Launch, and Ascent	3	3	9	Some additional tests to be performed, but we are unable to replicate exact conditions. Therefore some unknowns remain
Premature recovery-bay separation	Ascent	2	4	8	Unknown risk of happening, Would cause falling debris
Apogee detection failure	Apogee	2	2		
Parachute pyrotechnical deployment failure	Apogee	2	2	4	Pyrotechnics tests to be preformed before launch.
Parachute CO2 deployment failure	Apogee	2	5	10	CO2 deplyment tests to be performed before launch.
Reefing line cut above 250 m	Descent	2	1	2	Posses no real risk or danger, just longer descent time
Reefing line cutting failure	Descent	1	3	3	Line cutting test, with additional cutter for redundancy, have been preformed successfully.
Umbilical not disconnecting after tanks are filled	Before launch	2	2	4	Wait a bit and try disconnecting again. Umbilical disconnection to be attempted as part of static-fire test
Combustion chamber structural failure	Ascent	3	4	12	Likelihood unknown, static-fire test to be preformed before launch.
Main tank structural failure	Ascent	3	4	12	Likelihood unknown, static-fire test to be preformed before launch.
Improper fin alignment	Ascent	4	2	8	If occurs, unlikely to cause mayor problems
Fin structural failure	Ascent	2	2		

Table 9: Risk

C Compliance Matrix

ID	Category	Description	Compliance
0010	propulsion	Non-toxic propellants	Freyja does not contain any toxic propellant
0020	propulsion	Air-start ignition circuit electronics	Does not apply
0030	propulsion	Ground-start ignition circuit arming distance	Ignition board (Fáfnir) can be triggered remotely.
0040	propulsion	Clustered vehicle release system	Does not apply
0050	propulsion	Clustered vehicle stability proof	Does not apply
0060	propulsion	Clustered vehicle arming	Does not apply
0070	propulsion	Air-start ignition circuit arming	Does not apply
0080	propulsion	COTS solid motors	Does not apply
0090	propulsion	Ignition systems for solid motors	Does not apply
0100	propulsion	Self pressurization	Freyja makes use of a pressurization tank to self pressurize
0110	propulsion	Loading lines disconnection	Pressurization takes place after umbilical disconnect
0120	propulsion	Dissimilar connections	All lines feature dissimilar connections
0130	propulsion	Remote propulsion loading mechanism	Umbilical disconnect exists and is marked clearly
0140	propulsion	Filling/loading/unloading connections	Hatches are designed for this purpose
0150	propulsion	Filling time constraint	Filling can be done within the 90 minute constraint
0160	propulsion	Venting	Freyjas oxidizer tank has a venting system in place
0170	propulsion	Passive PRD in isolated sections of pressurized lines	Such a device exists in Freyja
0180	propulsion	PRD discharge coefficient	In theory, this should be the case
0190	propulsion	Propellant offloading after launch abort	Freyja propulsion makes use of an abort valve
0200	propulsion	Combustion chamber pressure test	Test has been completed
0210	propulsion	Combustion chamber leak proof	Freyja combustion chamber is seperated in such a way

0220	propulsion	Hybrid and liquid tanking test	Test has been completed
0230	propulsion	Static hot-fire test	Test pending
0240	recovery	Redundant recovery system electronics	All recovery electronics are redundant
0250	recovery	Redundant COTS recovery electronics	The CAT Vega flight computer is used in Freyja beside the SRAD flight computer
0260	recovery	Recovery electronics access panel	Such a panel exists in design
0270	recovery	Recovery electronics location	Electronics bay is reachable from ground
0280	recovery	Recovery electronics access	Arm screws and hatches are reachable from ground
0290	recovery	Recovery system energetic devices	Energetic devices do comply with the requirement
0300	avionics	Onboard power systems	The avionics system only uses LiFePO4 batteries
0310	avionics	Onboard power systems access	Batteries are accessible from ground since they are stored in avionics bay
0320	avionics	Launch rail standby time avionics	The avionics system has a calculated standby time of 12 hours
0330	recovery	Non-parachute/parafoil recovery systems	Does not apply
0340	recovery	Dual deployment recovery	Freyja recovery system makes use of dual deployment
0350	recovery	Initial deployment event altitude	Both COTS and SRAD flight computer trigger first parachute at apogee
0360	recovery	Initial deployment event descent velocity	Initial parachute is designed to comply with this requirement
0370	recovery	Main deployment event altitude	Flight computers trigger main deployment at 200 m AGL
0380	recovery	Main deployment event descent velocity	The main parachute was designed with this in mind
0390	recovery	Ejection gas protection	Burn protection exists in Freyja to avoid this
0400	recovery	Parachute swivel links	Freyja recovery includes swivel links at all connections
0410	recovery	Dual deployment parachute dissimilarity	The parachute has the colours white and red respectively
0420	recovery	Parachute coloration	Freyja parachute include easy to spot patterns
0430	avionics	Mandatory system	Freyja electronics include a CATs Vega flight computer

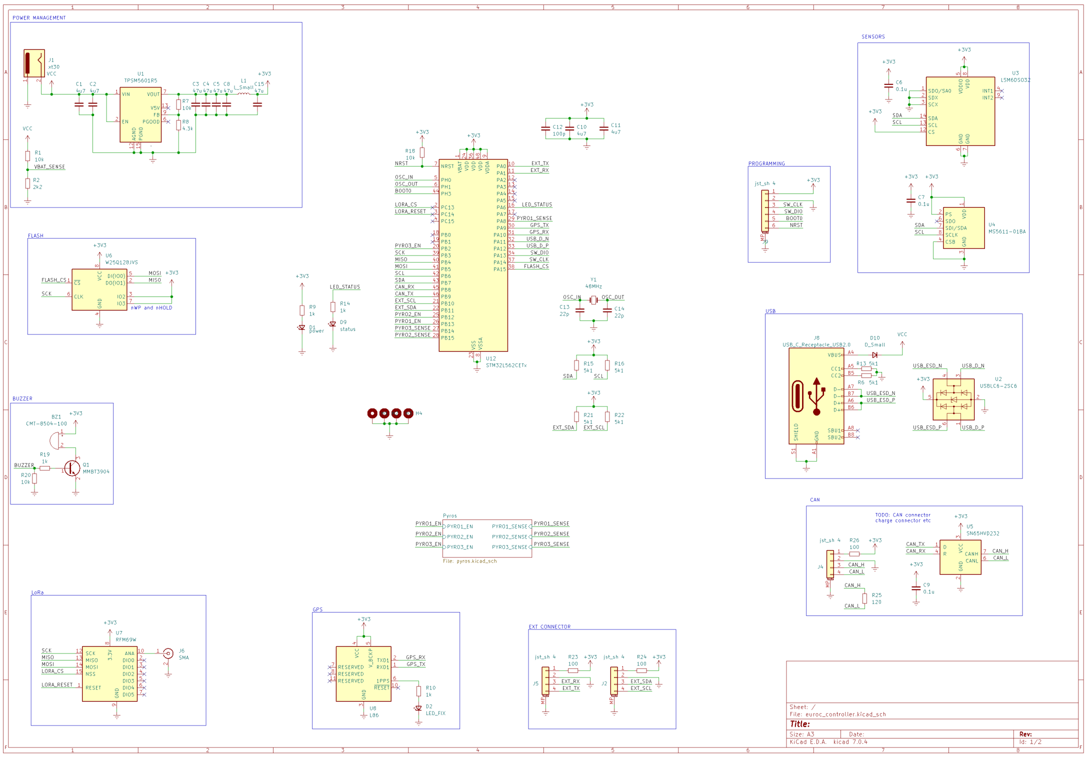
0440	avionics	CATS transmitter call-sign	CATs transmitter has been given a call sign
0450	avionics	Freyjas CATS Vega firmware	CATS Vega is updated to its latest firmware
0460	avionics	CATS receiver	CATS receiver is used
0470	avionics	CATS electronic compliance	CATS follows the required regulations
0480	avionics	Cable management	The avionics assembly makes use of cable management using various methods
0490	avionics	Secure connections	Critical cable connections are secured using external clampers or hot glue
0500	avionics	Cryo-compatible wire insulation	Does not apply
0510	recovery	Electronics thermal testing	Test is yet to be made
0520	recovery	Recovery system ground test demonstration	Test has been made
0530	manufacturing	Energetic device safing and arming	Fjalar recovery arms its flight computers, thus its recovery system using arm screws
0540	manufacturing	Arming device access	Recovery arming is accessible from ground
0550	manufacturing	Arming device location	Arming is located on the airframe
0560	manufacturing	Burst discs	COTS burst discs are used
0570	manufacturing	Burst disc pressure	COTS burst disc complies with this
0580	manufacturing	Burst disc marking	Burst discs are marked and logged
0590	manufacturing	Burst discs material	Burst discs are from the same material sheet
0600	manufacturing	Relief device	Freyja propulsion contains such device
0610	manufacturing	Designed burst pressure	Burst discs fulfill this requirement
0620	manufacturing	Designed burst pressure for composite pressure vessels	Pressure vessel is designed with this requirement in mind
0630	manufacturing	SRAD burst discs testing	Does not apply
0640	manufacturing	Proof pressure testing	Pressure tests have been made
0650	avionics	Restricted control functionality	Active control is an "air brake" system
0660	avionics	Active control stability	Freyja is stable without the active control in place
0670	avionics	Designed to fail safe Control Actuator	Fail safe is implemented

0680	avionics	Boost phase dormancy Control Actuator	Such a phase is implemented
0690	avionics	Active flight control system electronics	Active control system does not affect recovery redundancy
0700	avionics	Active flight control system energetics	Does not apply
0710	structure	Venting	All structures meet this requirement
0720	structure	Material selection PVC	No such polymers are used
0730	structure	Load bearing eyebolts type	Eyebolts are of the correct type
0740	structure	Load bearing eyebolts and U-bolts material	Correct material is used
0750	structure	Coupling tubes	Coupling tubes meet the 1D rule
0760	structure	Launch lugs mechanical attachment	Hard points are implemented
0770	structure	Aft launch lug support	Correct support is provided
0780	structure	RF transparency	Glas fiber tubes are used where RF transparency is needed
0790	structure	RF windows dimensioning	RF windows meet dimensions
0800	structure	RF windows material	Material is compliant
0810	structure	RF antennas' location	Antennas are correctly placed
0820	structure	Internal RF antennas' location	Requirement is met
0830	structure	Identifying markings	Markings are applied
0840	structure	Payloads	Payload is included
0850	structure	Payload form factor	Form factor is satisfied
0860	structure	Payload minimum mass	Minimum mass is met
0870	structure	Payload mass factor	Mass factor is correct
0880	structure	Independent payload functionality	Payload is functional
0890	structure	Payload removal for weigh-in	Payload is removable
0900	manufacturing	Payload materials	Materials are compliant
0910	manufacturing	Payload energetic devices	Does not apply
0920	recovery	Recovery system	Recovery system implemented
0930	recovery	Unique recovery system	Requirement satisfied
0940	recovery	Descent velocity	Descent rate is compliant
0950	recovery	Recovery system electronics	Electronics are compliant
0960	recovery	Payload safety critical wiring	Wiring is compliant
0970	recovery	Recovery system testing	Tests are performed
0980	recovery	Payload tracking	Tracking is implemented

0990	recovery	Payload tracking call-sign	Call-sign assigned
1000	avionics	Launch azimuth and elevation	Requirement fulfilled
1100	manufacturing	Rail take-off velocity	Velocity requirement met
1020	avionics	Hold-down system	System implemented
1030	avionics	Stability margin	Stability margin satisfied

D Checklists

E PCB schematics



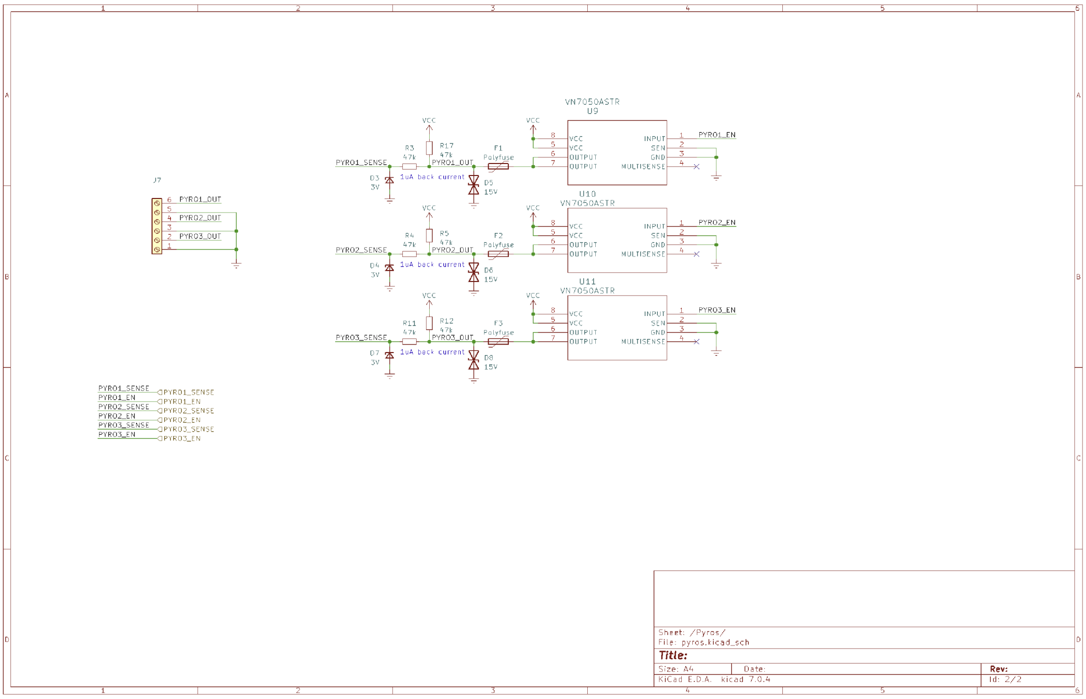


Figure 14: *Flight computer PCB schematic*

E.1 Flow test procedures

Cold test procedures [2025-08-23]

Author: Vilgot Lötberg

Approved by: Tintin Irlen

Roles:

SO [Safety Officer] : Vilgot Lötberg

TRE [Test Responsible Engineer] : Xiyao Song

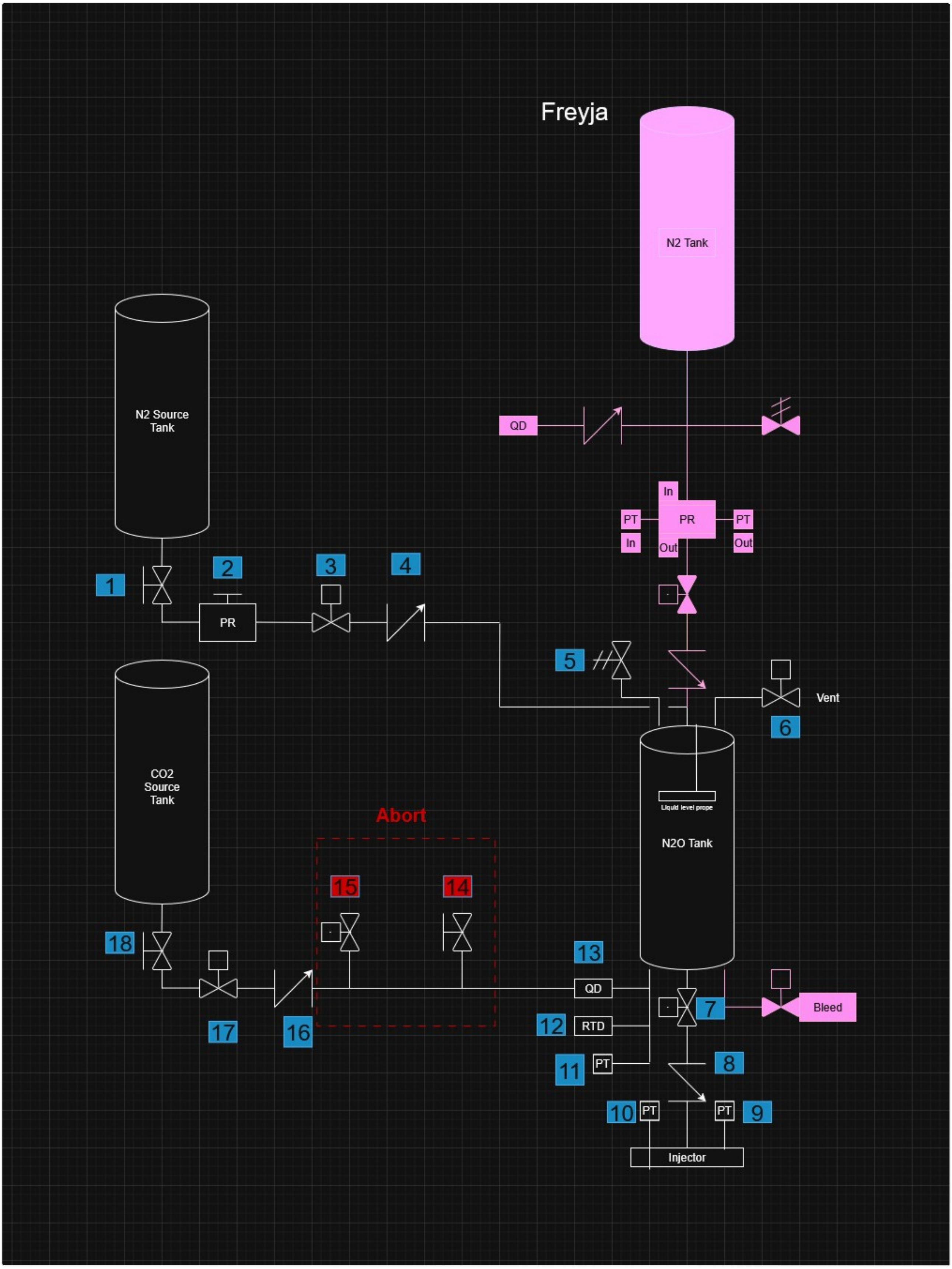
CRE [Control Responsible Engineer] : Fabian Andersson

Role descriptions:

SO: Has main responsibility over test safety, all major decisions must be approved by safety officer. Has main responsibility during the actual test sequence, coordinates the people involved, and enforces safety rules and procedures.

TRE: Has responsibility over the test setup, and is in charge of logistics and technical matters. Is responsible over putting the test setup and hardware together correctly, ensuring the right tools are present, etc.

CRE: Has responsibility over the test electronics, and that valves can be actuated during the test, and that data can be logged correctly. Is also the person actuating the valves during the test sequence.



Test setup. Pink = normally present in flight config, but not used in this test. Red = Abort, depressurize system. Blue = Valve labels.

Test setup.

Pink = normally present in flight config, but not used in this test.

Red = Abort, depressurize system.

Blue = Valve labels.

Some notes on danger and safety:

Danger zone open / closed vs system safe / unsafe: These are separate things. For the danger zone to be open means that people are allowed to approach the system and tamper with it, without direct supervision from Safety Officer.

The danger zone can be open if and only if the system is in a safe state. The opposite is however not true, that is, the danger zone is NOT *closed if and only if the system is unsafe.*

Whether or not the danger zone is open or closed when the system is safe is determined **ENTIRELY** by the SO. There need not be any emedietly *apparent* danger, SO is free to close the danger zone regardless. When the system is unsafe, the danger zone is **ALWAYS** closed.

Personell can approach the system when the danger zone is closed, so long as it's by the courtesy of the SO, and the system is in a safe state.

Danger zone	System	Can I approach the system?
Open	Safe	Yes
Closed	Safe / temporarily safe	Only with permission from SO
Closed	Unsafe	No
Open	Unsafe	No, run

"*Can I approach?*" - truth table.

Packing list

- [ ] Required subsystems and components
- [ ] First aid kit
- [ ] Hearing protection
- [ ] Steel toed shoes / soles

- [ ] Safety glasses
- [ ] Gloves (disposable and welding for insulation in case of venting)
- [ ] Tools
- [ ] Danger tape
- [ ] Cameras
- [ ] Thread sealant and thread tape
- [ ] Traffic-cones or something to fasten danger tape to
- [ ] Soap and water to check for leaks

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0 Main Procedure

- [ ] 0.0 Follow procedure **1 Setup**

- [ ] 0.1 Follow procedure **2 Tune regulator**

- [ ] 0.2 Follow procedure **3 Blow-down flow test**

- [ ] 0.3 Follow procedure **4 Leak check**

- [ ] 0.4 Follow procedure **5 Test Procedure**

1 Setup

- [ ] 1.0 Assemble all systems according to schematic
  Can be done in workshop / on site depending on situation
  Subsystems includes:
  - [ ] 1.0.0 Flight system
  - [ ] 1.0.1 Ground support equipment
  - [ ] 1.0.2 Control and measurment
  - [ ] 1.0.3 Assemble the subsystems together

  [NOTE] DO NOT connect the system to the source tanks

- [ ] 1.1 Solenoid check: Do the solenoids actuate correctly? Can you hear clicking?

- [ ] 1.2 Mark out danger zone with tape.

  No external people are now allowed within the danger zone.

- [ ] 1.3 Safety briefing, make sure everyone agrees on the following:
  - [ ] 1.3.0 What do we do if someone gets hurt?
  - [ ] 1.3.1 Where is first aid?
  - [ ] 1.3.2 Where is the closest hospital? How long can we expect the trip to take?
  - [ ] 1.3.3 What parts of the test are most dangerous?
  - [ ] 1.3.4 PPE !!! (Hearing protection !!, eye protection and steel toes)
  - [ ] 1.3.5 Read aloud **Some notes on danger and safety**
  - [ ] 1.3.6 Are there any people nearby that need informing that testing activity is about to be conducted?

- [ ] 1.4 Follow procedure **7 Safing** to put system into a safe state.

  Danger is not in effect yet, see 1.6.

- [ ] 1.5 Courtesy of SO, TRE approaches the system, to connect the N2 source tank and the CO2 source tank to their respective systems.

  [NOTE] Double check to make sure they're connected to the correct respective system. Failiure to do so is likely to result in explosion.

- [ ] 1.6 Danger zone is now in effect.

  Danger zone is open.

2 Tune N2 pressure regulator

- [ ] 2.0 Follow procedure **7 Safing** to put system into a safe state.

  Danger zone is open.

- [ ] 2.1 SO Ensures all personell are outside of danger zone.
  SO declares danger zone closed.

  Danger zone is closed.

- [ ] 2.2 Courtesy of SO, TRE approaches the system.

- [ ] 2.3 TRE closes manual valve ON the pressure regulator [2].

- [ ] 2.4 TRE opens the N2 source tank manual valve [1].

- [ ] 2.5 TRE tunes the regulator to 50 bar by turning the knob on the pressure regulator [2], and observing the pressure.

- [ ] 2.6 Once the correct pressure is reached, TRE closes the N2 source tank manual valve [1].

- [ ] 2.7 TRE opens the pressure regulator maunal valve [2].

- [ ] 2.8 SO can now declare danger zone open.
  Danger zone is open.

3 Blow-down flow test

- [ ] 3.0 Follow procedure **7 Safing** to put system into a safe state.

  Danger zone is open.

- [ ] 3.1 Close / ensure closed main valve [7].
  If this cannot be done automatically via ground control box, do manually.

- [ ] 3.2 SO Ensures all personell are outside of danger zone.

SO declares danger zone closed.

Danger zone is closed.

- [ ] 3.3 Courtesy of SO, TRE approaches system.

- [ ] 3.4 TRE opens N2 source tank manual valve [1], and ensures manual valve on pressure regulator [2] is open.

- [ ] 3.5 TRE opens CO2 source tank manual valve [18].

- [ ] 3.6 TRE closes manual vent valve [14].

- [ ] 3.7 TRE leaves danger zone.

- [ ] 3.8 Ensure solenoid vent valve [15] is open.

- [ ] 3.9 Open CO2 fill solenoid valve [17] to flow gas through the CO2 fill system for a short burst, then close it again.

- [ ] 3.10 Close vent solenoid valve [15].

- [ ] 3.11 Open tank vent solenoid valve [6].

- [ ] 3.12 Open CO2 fill solenoid valve [17] to flow gas through the CO2 fill system for a short burst, then close it again. Wait for tank pressure to reach ambient by reading off the tank PT [11].

- [ ] 3.13 Close the tank vent solenoid valve [6].

- [ ] 3.14 Open the vent solenoid valve [15].

- [ ] 3.15 Open N2 fill solenoid valve [3] to flow gas through the N2 fill system for a short burst, then close it again.

- [ ] 3.16 Close the vent solenoid valve [15].

- [ ] 3.17 Open the main valve [7].

- [ ] 3.18 Open N2 fill solenoid valve [3] to flow gas through the N2 fill system for a short burst, then close it again.

- [ ] 3.19 Follow procedure **7 Safing** to put system into a safe state.

  Danger zone is open.

4 Leak check

- [ ] 4.0 Follow procedure **7 Safing** to put system into a safe state.

  Danger zone is open.

- [ ] 4.1 Close main valve [7].
  If this cannot be done automatically via ground control box, do manually.

- [ ] 4.2 SO Ensures all personell are outside of danger zone.
  SO declares danger zone closed.

  Danger zone is closed.

- [ ] 4.3 Courtesy of SO, TRE approaches system.

- [ ] 4.4 TRE opens N2 source tank manual valve [1], and ensures manual valve on pressure regulator [2] is open.

- [ ] 4.5 TRE closes manual vent valve [14].

- [ ] 4.6 TRE leaves danger zone.

- [ ] 4.7 Close tank vent valve [6].

- [ ] 4.8 Close vent solenoid valve [15].
  Monitor tank pressure via PT [11].

  [WARNING] System is now closed and thereby temporarily safe. If danger occours, follow **6 Abort**

- [ ] 4.9 Open N2 fill solenoid valve [3].

  [WARNING] System is now unsafe.

- [ ] 4.10 Wait for tank pressure to reach target pressure by reading of tank PT [11].

- [ ] 4.11 When fully pressurized, close N2 fill solenoid valve [3].

- [ ] 4.12 Watch the tank pressure readings from the tank PT [11], and determine if leakage is within acceptable limits. Listen for leaks.

- [ ] 4.13 Follow procedure **7 Safing** to put system into a safe state.

  Danger zone is open.

5 Test procedure

- [ ] 5.0 Follow procedure **7 Safing** to put system into a safe state.

  Danger zone is open.

- [ ] 5.1 Close / ensure closed main valve [7].
  If this cannot be done automatically via ground control box, do manually.

- [ ] 5.2 SO Ensures all personell are outside of danger zone.
  SO declares danger zone closed.

Danger zone is closed.

- [ ] 5.3 Courtesy of SO, TRE approaches system.

- [ ] 5.4 TRE opens N2 source tank manual valve [1], and ensures manual valve on pressure regulator [2] is open.

- [ ] 5.5 TRE opens CO2 source tank manual valve [18].

- [ ] 5.6 TRE closes manual vent valve [14].

- [ ] 5.7 TRE leaves danger zone.

- [ ] 5.8 Ensure tank vent solenoid valve [6] is open.

- [ ] 5.9 Close vent solenoid valve [15].
  Monitor tank pressure via PT [11].

  [WARNING] System is now closed and thereby unsafe. If danger occours, follow **6 Abort**

- [ ] 5.10 Open CO2 fill solenoid valve [17] to start filling the tank. Watch the tank vent solenoid valve [6] for outgasing for clues on when the tank is full of liquid.

  [WARNING] System is now pressurized.

- [ ] 5.11 When signs of liquid CO2 spraying out of the tank vent solenoid valve [6], close CO2 fill solenoid valve [17]. Tank is now full.

- [ ] 5.12 Open N2 fill solenoid valve [3]. Pressure should stabilize quickly.

- [ ] 5.13 When ready, open main valve [7] to perform main test. Watch for signs of tank depletion, by which point, close N2 fill solenoid valve [3]. Watch for abnormal behaviour. If abnormal behaviour occors, open vent solenoid [15].

- [ ] 5.14 Make sure the N2 fill solenoid valve [3] is closed.

- [ ] 5.15 Follow procedure **7 Safing** to put system into a safe state.

  Danger zone is open.

6 Abort

- [ ] 6.0 Close / ensure closed: N2 fill solenoid [3] and CO2 fill solenoid [17].

  If failiure to close N2 fill solenoid or CO2 fill solenoid: Proceed to next step to empty the source tanks.

- [ ] 6.1 Open / ensure open: vent solenoid [15] and tank vent solenoid valve [6].

  If failiure to open vent solenoid [15]: Open main valve [7].

  If failiure to vent through main valve [7]: Wait for pressure to vent through tank vent solenoid valve [6] (this may take a while).

If failiure to vent through tank vent solenoid valve [6]: If tank pressure is below 2 bar (read from the tank PT [11]), approach the system with PPE and vent through the manual vent valve [14]. If above 2 bar, wait for natural leakage. DO NOT UNDER ANY CIRCUMSTANCES APPROACH THE SYSTEM!

- [ ] 6.2 System is now below 2 bar (read from the tank PT [11]).

- [ ] 6.3 Courtesy of SO, TRE approaches system and opens manual vent [14] if not already open.

- [ ] 6.4 TRE closes N2 source tank manual valve [1] and CO2 source tank manual valve [18].

- [ ] 6.4 System is now in a safe state. SO can now declare danger zone open.

  Danger zone is now open.

7 Safing

- [ ] 7.0 Close / ensure closed: N2 fill solenoid [3] and CO2 fill solenoid [17].

- [ ] 7.1 Open / ensure open: vent solenoid [15] and tank vent solenoid [6].

- [ ] 7.2 System is now open to atmosphere and temporarily safe. If danger occors, follow **6 Abort**

- [ ] 7.3 Courtesy of SO, TRE approaches system and opens manual vent [14].

- [ ] 7.4 System is now in a safe state. SO can now declare danger zone open.

  Danger zone is open.