Lamarr Technical Report

TU Wien Space Team

September, 2024 - Vienna, Austria, Earth

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0 Abstract:

Lamarr is a bi-liquid propelled rocket project by the TU Wien Space Team. Designed and manufactured almost exclusively in-house, with the needed know-how slowly built up over precursor projects and the project's life cycle, the team has created a robust and lightweight rocket with the necessary testing and Ground Support Equipment to operate it safely. The rocket is designed to fly to an altitude of 3 km - thus being in the L3 launch category - using its engine powered by ethanol and liquefied oxygen and to then safely return to the ground thanks to a two-stage recovery system. The engine design has been iterated upon over the years, with many improvements on every part from the injector over propellant feed and pressurization system and igniters to combustion chamber concepts. Throughout the entire project special care has been put into safety, ranging from refining checklists to be as clear as possible, over a remote controlled oxidizer loading system to SRAD normally open vent valves and burst discs for passive depressurization. As liquid rockets need a lot more and more complex Ground Support Equipment than a typical solid propelled rocket, considerable amount of time has also been invested in simple and easy to use Mission Control software that can control both the rocket while on the pad and the GSE. The transported payload was built by a student team from Upper Austria. The main mission is to validate a self-made accelerometer.

1 Introduction:

TU Wien Space Team is a student organization engaging in various projects in aerospace engineering. Our mission statement is to foster the know-how and enthusiasm for aerospace technologies in our peers by providing an accessible entry into rocketry and allowing members to learn. The team is working on several projects ranging from solid propelled two-staged rockets, which can reach the edge of space, to hydrogen-powered autonomous airplanes. As well as CubeSats and rockets with liquid and hybrid propulsion systems. Project Lamarr originates from previous year's project µHoubolt, which laid the foundation for the knowledge we gathered in our organization regarding building bi-liquid rocket engines. After the adventure of participating in the EuRoC 2022, we are now highly motivated to come back in 2024, while setting a new challenge with a more powerful liquid oxygen powered propulsion system.

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

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

2 System Architecture:

2.1 Overview:

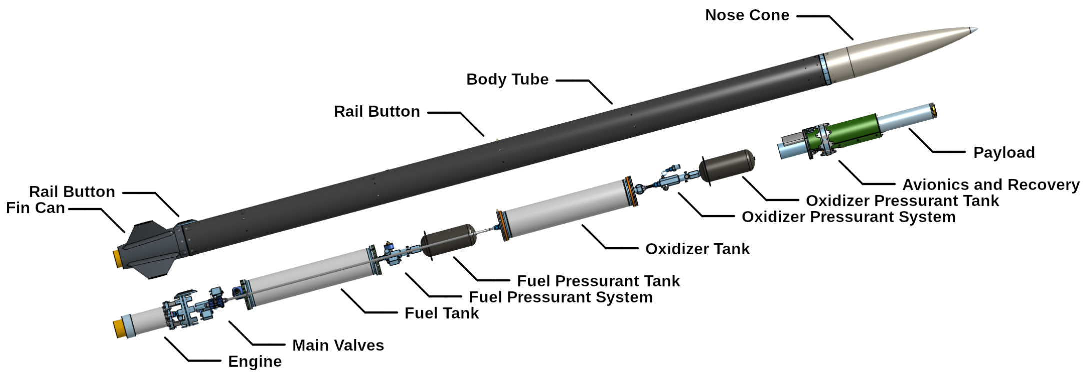


Fig. 2.1: Assembly of Hedy

2.2 Propulsion:

Thrust is provided by a SRAD pressure fed bi-propellant liquid propulsion system. It utilizes liquid oxygen and ethanol as propellants and is pressurized by two nitrogen tanks through mechanical pressure regulators. The system is optimized for simplicity, low mass and small size. All main subsystems are described in detail below: the pressurization systems, the propellant tanks with piping, valves and filling, the engine and thrust transmission. A diagram of the whole fluid system can be found in 2.9. The entire propulsion system, which is shown in figure 2.1 is assembled separately from the rest of the vehicle and can be tested standalone without it. It is installed into the airframe by sliding it into the body tube from the rear as one integrated component, only requiring the wiring harness to be plugged in and a few screws to be installed.

2.2.1 Pressurization Systems:

Two 1.2 L COPVs are holding nitrogen gas, 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 mechanical pressure reducer, originally intended for pressurizing paintball markers. These regulators have shown some issues with providing enough massflow to the propellant tanks which led to the decision to use them in a two-stage system. The first stage mechanical regulators are configured to provide 60 bar of pressure, which provides the highest massflow. The second stage utilises ball valves as pressurization valves which are actuated by servo motors. These motors open and close the valves to keep the pressures at the entries of the venturis at a specified level. A check valve is placed after the second stage on the oxygen side to prevent the propellants from entering the pressurant tanks. After the pressurization valve and the check valve on the oxygen side there are custom made normally-open solenoid valves which provide the ability to vent the propellant tanks, making it possible to vent both tanks during filling.

The regulators include two burst discs, one 'high pressure' burst disc with a 517 bar burst pressure to protect the pressurant tank and one 'mid pressure' burst disc with a 124 bar burst pressure on the output. Since this output burst disc's burst pressure is much greater than the opening pressure of the magnetic vent valves and the 'low pressure' tank burst discs, this 'mid pressure' burst disc is not expected to be needed unless COTS paintball pressure regulator fails while the pressurant ball valve is fully closed off.

The pressurant system on the oxygen side consists of two manifolds that are connected through a carbon fiber encased PTFE tube which ensures a thermal decoupling between vent valve and pressurization valve, 'low pressure' burst disc and pressure sensor. The end of the smaller manifold which is screwed into the LOX tank also functions as a diffuser. Both pressurization system assemblies are axially supported by the connection to their respective propellant tank and on the oxygen side additional through the carbon fiber encased PTFE tube. Radial support against the body tube for the pressurant tanks is provided by 3D-printed plastic spacers.

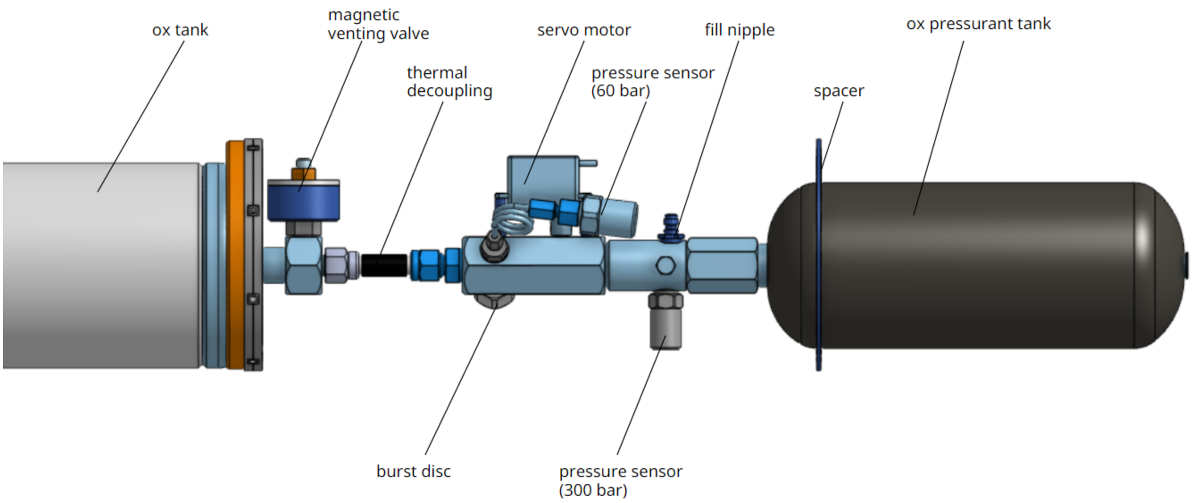


Fig. 2.2: Ox Pressurization System

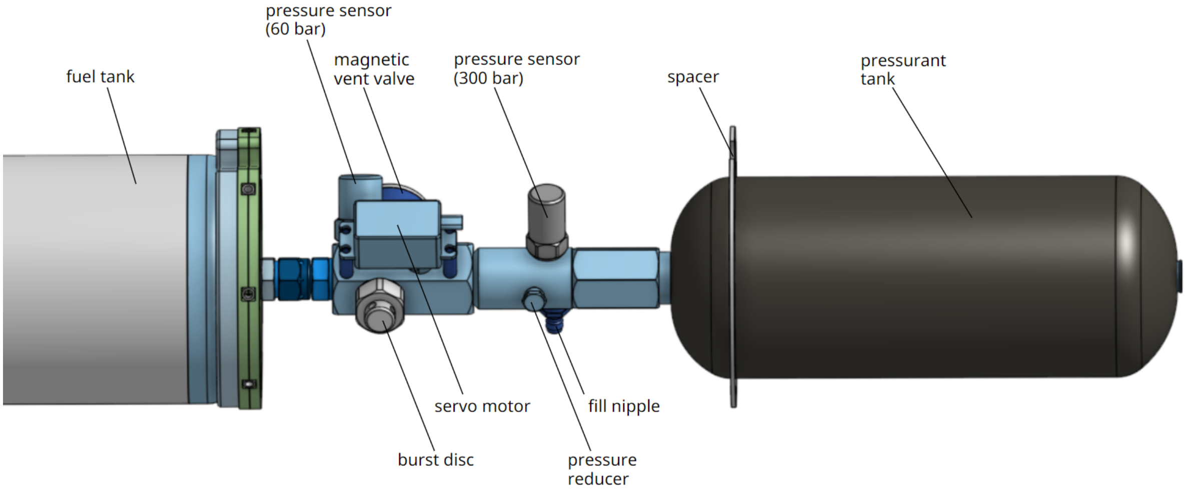


Fig. 2.3: Fuel Pressurization System

Filling:

For filling the pressurant tanks with nitrogen two COTS quick connectors, each mounted to the mechanical pressure regulator stage, are used to connect to the filling system. Connecting the fuel filling system is also done via a different 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 and piping:

The propellant tanks consist of three parts made from thermally curable EN AW 6082 aluminum which are welded together. The tank heads are standard torispherical heads, milled from solid aluminum blocks. The tank walls have a thickness of 2.5 mm and are welded to the tank heads using TIG welding. After welding the propellant tanks are heat treated to maximize the alloy´s potential toughness. The heat treatment consists of two steps:

- solution annealing at 535 °C for 20 min, quenching in water to room temperature
- artificial aging at 170 °C for 10 h, slow controlled cooling to room temperature

This is the exact alloy and heat treatment used for the propellant tanks for µHoubolt, Hedy's predecessor which launched at the EuRoC in 2022. They were designed by the team but are one of the few components manufactured externally. This allowed for a more optimized end-cap design to be manufactured and additionally the welds were done by a professional welder, assuring consistency. The tanks are designed to withstand an operating pressure of 50 bar with a safety factor of 2,1 before plastic deformation occurs. The tanks are designed for a burst pressure of 140 bar. Both tanks have the same shape and contain the same volume of propellant which is enough for a burn time of 8 s. Due to the higher density of the liquid oxygen the filling level is lower than the filling level of the ethanol. This extra space prevents excessive amounts of liquid oxygen to spill out of the vent valve due to off boiling while filling the tank. The tanks have a diameter of

115 mm and a cylindrical length of 527 mm giving them a volume of 5.2 L and a mass of 1460 g

The main propellant lines are made out of aluminium tube with 8 mm inner diameter and 10 mm outer diameter which are connected to tanks and main valves with COTS fittings. On the LOX side the FKM o-rings in the fittings are changed to PTFE o-rings to withstand the low temperatures. The main lines below the main valves contain also the critical venturis. The main lines for LOX are also sleeved with a PTFE tube as insulation.

Both propellant tanks are held in place with milled GFRP plates that are screwed to the body tube and 3D prints which distributes the forces onto the GFRP plate. On the LOX side the GFRP plate and the 3D print have a hole for the LOX main line to pass through.

2.2.3 Valves:

Main Valves:

Both main valves consist of different modified COTS ball valves, actuated by COTS servos. These modifications were necessary, particularly replacing the valve seats with materials capable of handling a cryogenic environment, to ensure a reliable and leakproof supply of liquid oxygen to the engine. The fuel main valve housing is 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 housing. The main propellant lines are made out of aluminium tube with 8 mm inner diameter and 10 mm outer diameter which are connected to tanks and main valves with COTS fittings. On the LOX side the FKM o-rings in the fittings are changed to PTFE o-rings to withstand the low temperatures. The main lines below the main valves contain also the critical venturis.

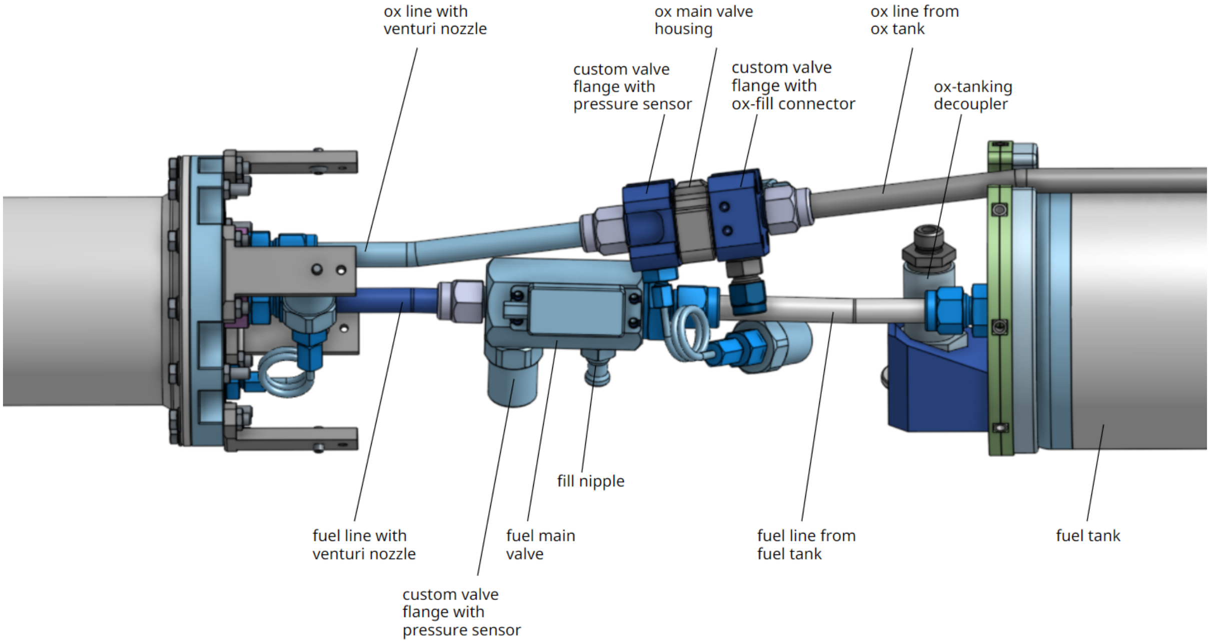


Fig. 2.4: Main Valves

Magnetic Venting Valve:

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. This allows vaporized oxygen to leave the oxidizer system to avoid pressure build-up and automatically depressurizes the system in the case of a loss of power.

It consists of an outer body with a magnet and an inner stem with a steel plate on the top that is being pulled onto the magnet upon actuation. The stem is then pressed into an o-ring in the pressurization valves, sealing off the system. Upon release or loss of power the stem is pushed outwards and fluids can flow through the stem to the outside of the rocket through a hole in the body tube.

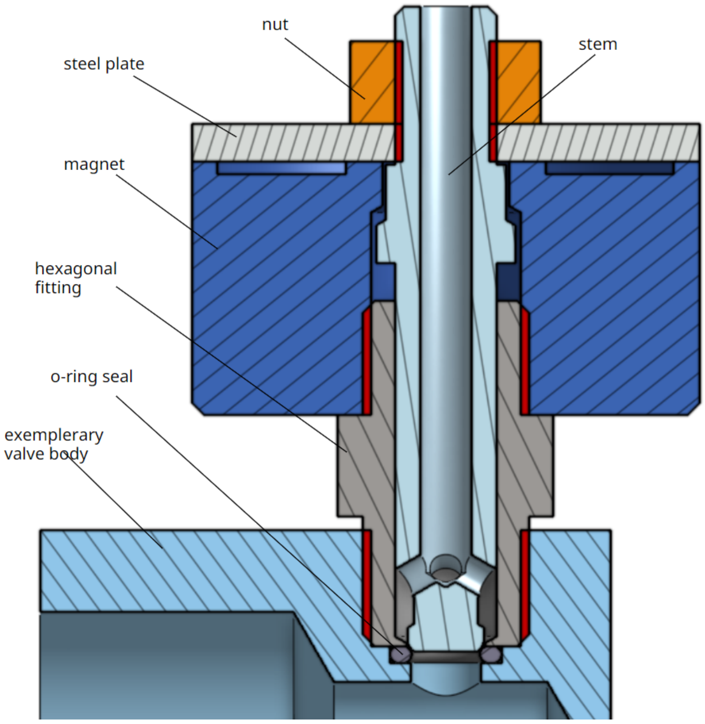


Fig. 2.5: Magnetic Venting Valve

2.2.4 Engine:

The engine uses ethanol and liquid oxygen as rocket propellants with an oxidizer/fuel ratio of 1.24. 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.

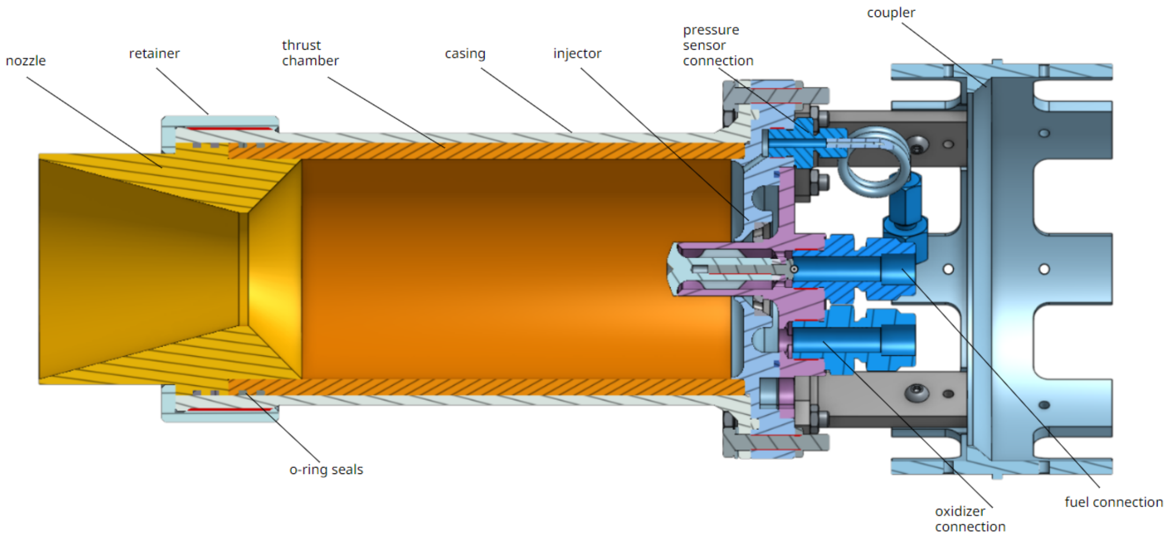


Fig. 2.6: Engine

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. Both propellants enter the injector through PTFE sealed fittings. LOX flows through a rotation inducing hole into the Oxidizer distribution channel where it overflows a lip onto the orifice plate. There the flow direction gets straightened while the LOX flows through smaller holes aiming at a tilted surface and enter the burning chamber through the injection slit. Ethanol meanwhile gets fed through the center of the injector past the pintle with its flow straightening grooves and is injected at the pintle tip. The third fitting mounted to the injector holds the thermal decoupling for the pressure sensor. The flow regulation primarily consists of two cavitating venturis and the 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. The cavitating venturis are pressed into the main propellant line and radially sealed with a PTFE o-ring. The cavitating venturi which regulates the fuel mass flow has a throat diameter D_t of 3.1 mm and the experimentally determined discharge coefficient C_d is 0.93. The mass flow through it for a given density ρ, vapor pressure p_{sat} and inlet pressure p is governed by the following equation, as long as the pressure drop is large enough to lead to cavitation at the throat:

$$\dot{m} = C_d * A_t * \sqrt{2 * \rho * (p - p_{sat})} \tag{2.1}$$

The critical venturi for the LOX side has a throat diameter D_t of 3.7 mm with a discharge coefficient C_d of 0.95. While p_{sat} at the Ethanol side is negligible it has a high impact on the mass flow at the LOX side due to the autogenous pressurization of the LOX tank. The autogenous tank pressure reaches 19 bar shortly before liftoff which has the reason to reduce condensation of the gaseous nitrogen while pressurizing the LOX tank to operating pressure.

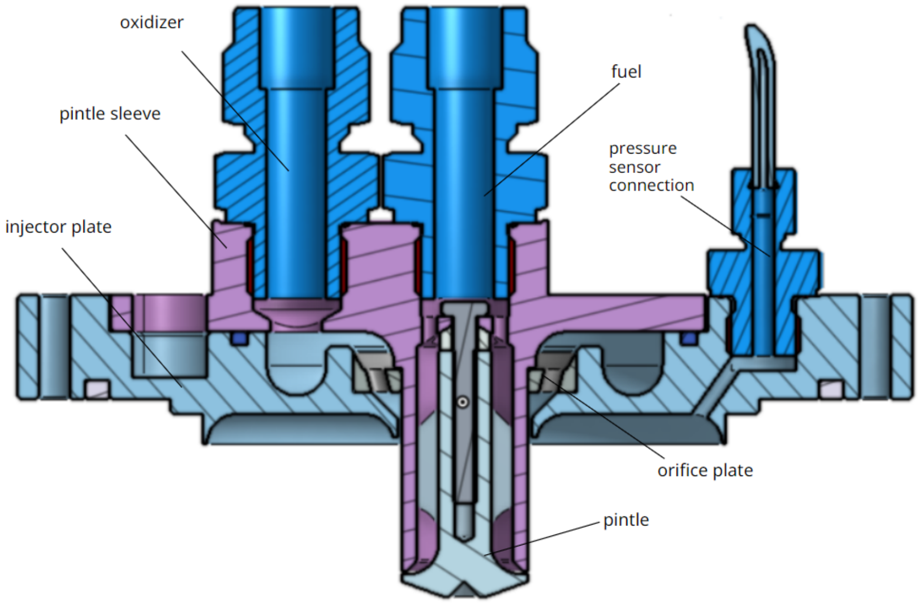


Fig. 2.7: Injector Section View

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.

The mounting of the Ignition-System is done as one of the last steps before leaving the launchpad. Arming of this system is done remotely prior to launch.

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 7 s at a chamber pressure of 15 bar. The nozzle is made out of the same material, therefore the throat will widen with the duration the engine is running and the chamber pressure will decrease.This was verified through several hot fire tests. The chamber liner and nozzle are housed within an aluminium casing, which is bolted to the injector.

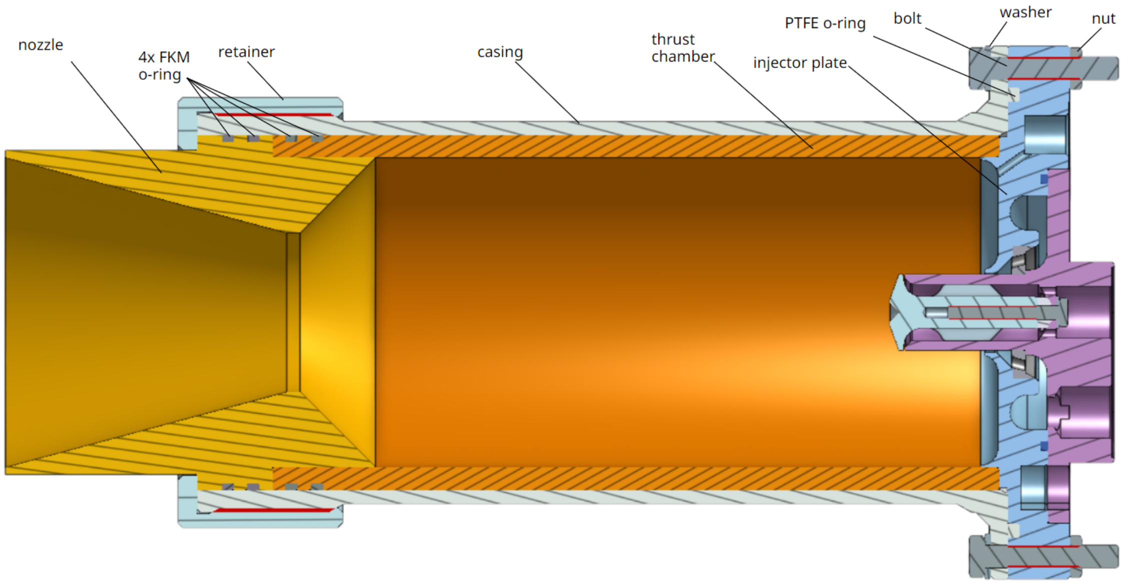


Fig. 2.8: Thrust Chamber Section View

2.2.5 Thrust Transmission:

The thrust from the engine will be transmitted axially through aluminum pillars that connect the injector to a coupler. The lower railbutton of the rocket is connected to the coupler with two pins and a M4 screw. Additionally the railbutton has a hook which rests on top of the coupler to better distribute the forces of the propulsion system during the hold down phase. The transmission structure is designed to withstand the full 2 kN produced by the engine for several seconds.

2.2.6 PnID

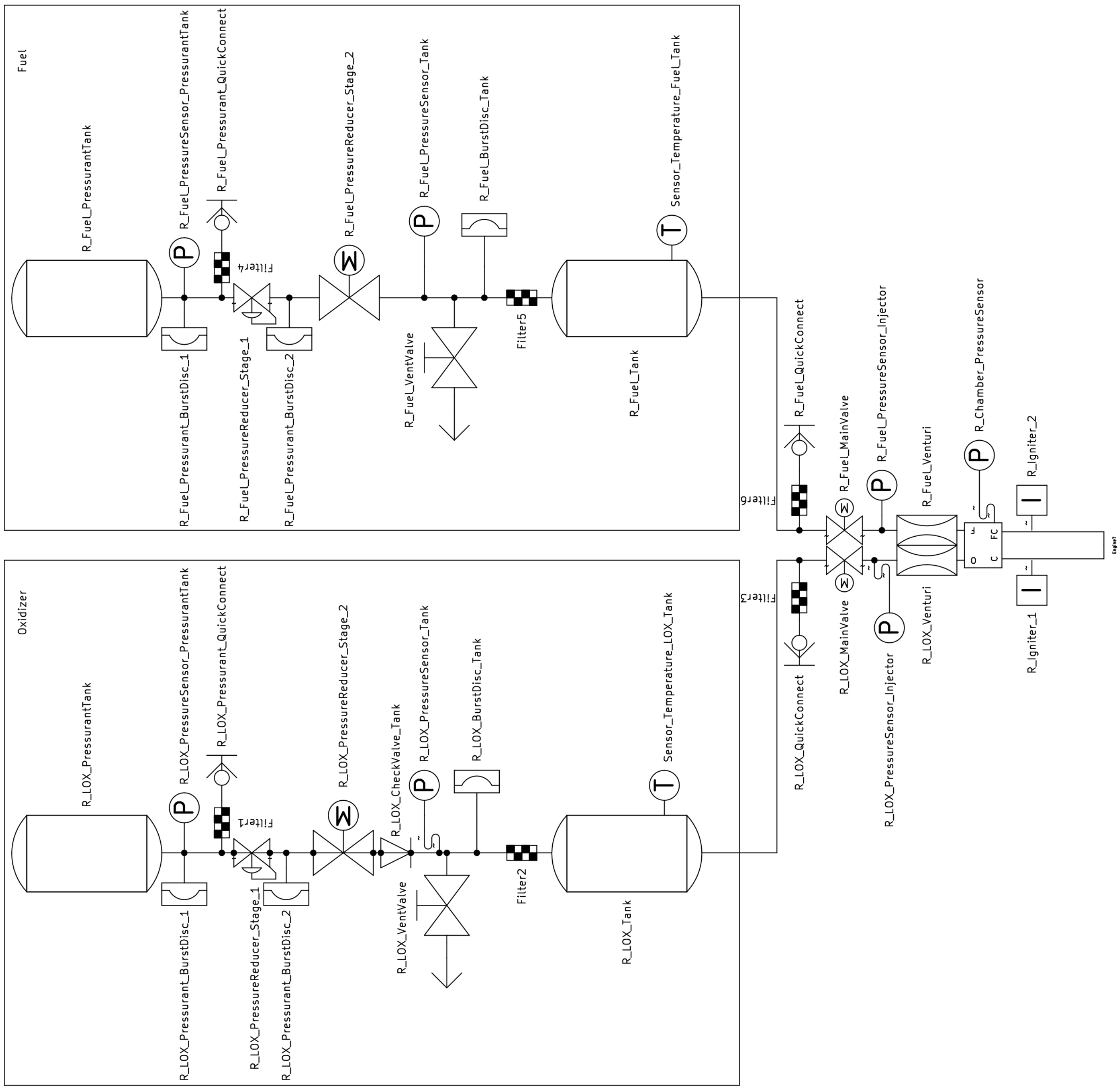


Fig. 2.9: PnID

2.3 Aerostructure:

The Aerostructure subsystem consists of nose cone, body tube, fincan, railbuttons and several interfaces between the different subsystems.

For all components, the occurring mechanical loads as well as the interaction of the various subsystems had to be taken into account. Last but not least, the aesthetics of the rocket and its recognizability should also be achieved.

2.3.1 Nose Cone:

The shape of the nose cone was decided by a parametric CFD study (Figure 2.10, for which three for our targeted velocity regime common nose cone shapes are chosen to be compared. These three 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.

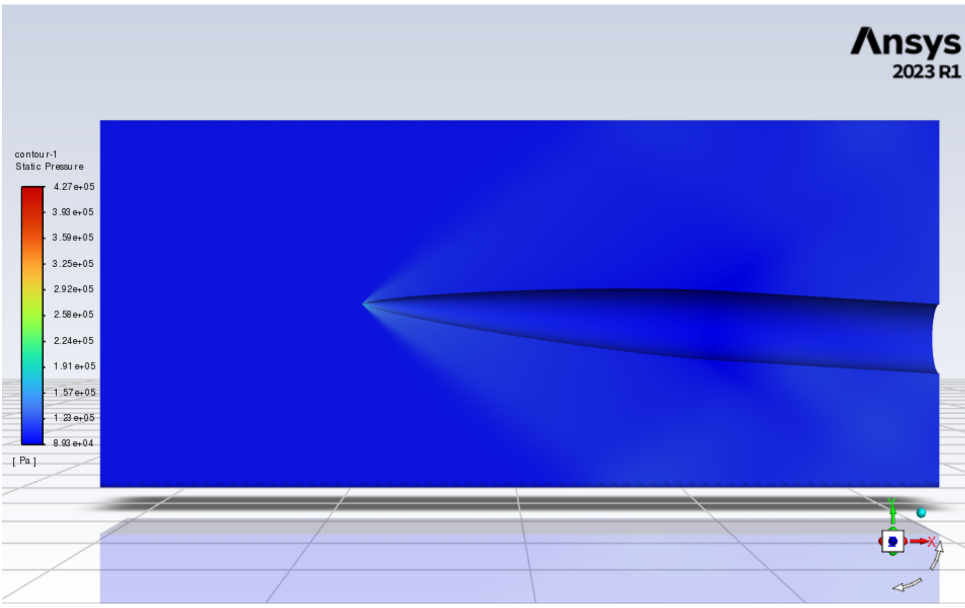


Fig. 2.10: Static pressure CFD study

The 650 mm long nose cone was manufactured from GFRP, which is transparent to electromagnetic radiation, making it the RF window of the rocket. It was laminated using a wet lay-up process in which resin is applied to dry mats. These are placed on a 3D-printed positive mold made of PLA, the surface of which was prepared for lamination with spray filler and sanding. Each sanding process of the nose cone was carried out on the lathe as seen in figure 2.11 to ensure a rotational symmetry. Curing in a vacuum bag guarantees that the individual GFRP layers are perfectly bonded together. To achieve a perfect surface, the laminated nose cone was sanded several times and any imperfections were repaired with resin. After cutting it to the correct length and drilling the holes for the coupler, the surface is finished again.

Fig. 2.11: Sanding the nose cone mold

As it proves difficult to produce a clean tip during the laminating process, a approx. 35 mm long cone will be turned from titanium and screwed to the nosecone via a GFRP ring. A rope is also attached to the ring, which ensures that the body tube and the nose cone remain together during the recovery process.

2.3.2 Body Tube:

The 2750 mm long body tube with an outer diameter of 132.8 mm is laminated using carbon fiber prepreg, because of its lightweight characteristics. As it proves difficult to laminate a tube of this length, a process was developed that ensures a high quality result. A 3000 mm long aluminum laminating core with an outer diameter of 130 mm was used for this purpose.

The core was mounted on rollers to allow for free rotation during the laminating process. An aluminium extrusion profile was attached to the cut-to-size prepreg mat over the entire length, ensuring that the prepreg is evenly tensioned. This counteracts the majority of wrinkles. A straight line is marked on the winding core with the help of a taut cord, on which the mat is placed and flattened with laminating tools to iron out the last small creases. After all layers have been applied, a thickness of 1.4 mm is achieved and the tube is wrapped in shrinkwrap and vacuum bagged. It was then cured in an autoclave, eliminating the last remaining air pockets. After curing, the pipe is coated with a layer of resin which is sanded and polished to minimize surface drag.

Fig. 2.12: Laminating the body tube

In order to guarantee that the tube can withstand the expected bending loads, the normal forces acting on the nose cone and fincan were calculated which result in the maximum bending moment. Additionally, the thrust was also taken into account and a safety factor for the composite material was calculated using the finite element analysis software Ansys 2.13. To ensure that the centering rings can withstand the acceleration forces of the full tanks, a test ring was screwed into a test tube and weighed down with the appropriate weight.

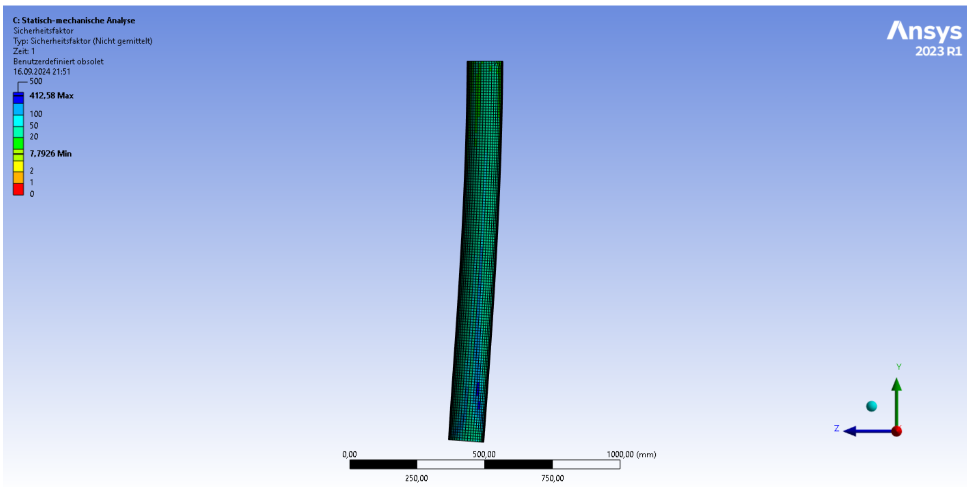


Fig. 2.13: Simulated safety factor

Coupler:

Fincan and body tube are joined using an aluminium coupler ring that provides a tight fit and is held in place via radial screws. This ring is also where the thrust from the engine is transmitted into the airframe and is explained in more detail under section 2.2.5.

The rocket's nose cone and body tube are connected through a separable coupler which is held in place by a spring steel clamp band. At apogee, once the line keeping the clamp band in tension is severed by one of the burn wires, the coupler separates and drogue parachute is deployed. A more in depth explanation is found under section 2.4.4

Umbilical Feedthroughs:

To make fueling, arming and setting up pad-communication convenient, easily accessible connectors and mechanisms are necessary while the rocket is on the launchpad. For this purpose, openings for the connections are provided on the side of the airframe.

Launch Pad Mechanical Interface:

The vehicle is connected to the launch rail using two rail buttons. The upper rail button is made of brass and is mounted with a screw that is also used to hold the oxidizer tank. The location of the upper rail button influences both the stability on the rail as well as the effective length of rail available for stabilization during launch. The bottom rail button is used to support the weight of the vehicle while on the launch pad and to hold it down until successful engine ignition is confirmed. It is screwed to the airframe fincan coupler and further explained under section 2.7.2.

2.3.3 Fincan:

To bring the center of pressure well below the center of gravity and thus ensure sufficient static stability, we opted for four fins with a semi-span of 96.4 mm and a lightweight carbon fiber construction. The stability margin over time was simulated with OpenRocket and RocketPy as seen in figure 2.14 The fillets between fins and centerpiece are designed rather extensive, so that those areas are resistant enough. The fincan ends in a boat tail in the shape of an ogive to reduce the base drag. The manufacturing process is exactly the same as for the µHoubolt project, the last liquid-propellant rocket of the TU Wien Space Team.

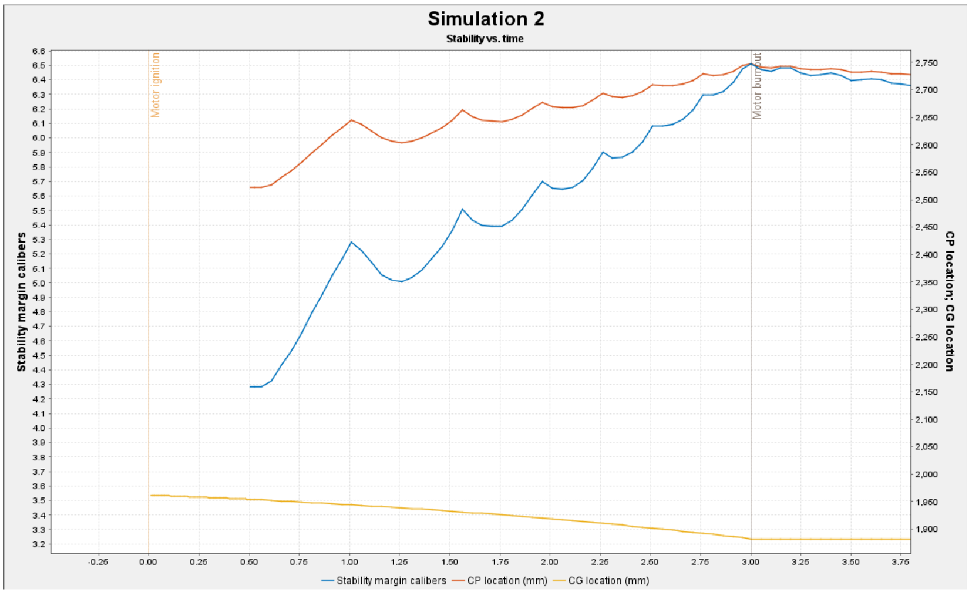


Fig. 2.14: Stability margin (cal) over time (s)

The Fin profile is based on a biconvex profile that was then adapted so that a positive mold could be 3D-printed in-house. This mold was sanded and gaps were filled with spray filler and treated with several thin layers of coat to seal pores and after that with release agent. Then a four-part negative mold consisting of high-temperature epoxy tooling gelcoat and high-temperature epoxy molding paste was taken as seen in figure 2.15. This was then used to laminate with pre-preg carbon fiber.

Fig. 2.15: Applying gel coat and molding paste

For the fin cores Rohacell, a closed-cell rigid foam, was chosen. Those inlays are both essential for the stiffness of the fins and ensure that enough pressure is exerted on the laminate during the curing process. The boards of Rohacell foam were CNC-milled to the correct form and then placed on the seven carbon fiber mats before the negative mold was assembled.

The inside of the fincan was strengthened with another two layers of carbon fiber. After being sealed in a vacuum bag and cured by being gradually heated to 135°C in the oven, the fincan was sanded, cut down to the lengh of 280 mm and prepared for painting with a sanded and polished resin layer.

2.3.4 Livery Design and Surface Finish:

As already mentioned, all rocket parts that are exposed to the airflow are coated with a resin layer and then sanded and polished to minimize the surface drag.

To accomplish a flawless look as well as create a surface that mitigates some of the solar heating experienced in the EuRoC launch environment, the nose cone is painted white, because it encases most of the electronics. The decision was made in favor of lacquer and against adhesive foil, since the latter has proven to be both unsightly and less resistant.

On the body tube the team name, the project name, the academic affiliation and the sponsor logos are arranged into a minimalistic design. The fins all feature the Team ID and the Austrian flag. Each of them additionally displays a unique but simple graphic pattern of black and white to allow ground-based observers to track and record the launch vehicle's altitude.

To achieve a satisfactory result the whole airframe was sanded and coated with transparent primer. After drying, stencil stickers with cutouts for the markings were applied. The white paint was then sprayed on and allowed to harden. The stickers were then carefully removed and the airframe covered with a clear, matte two-component coat.

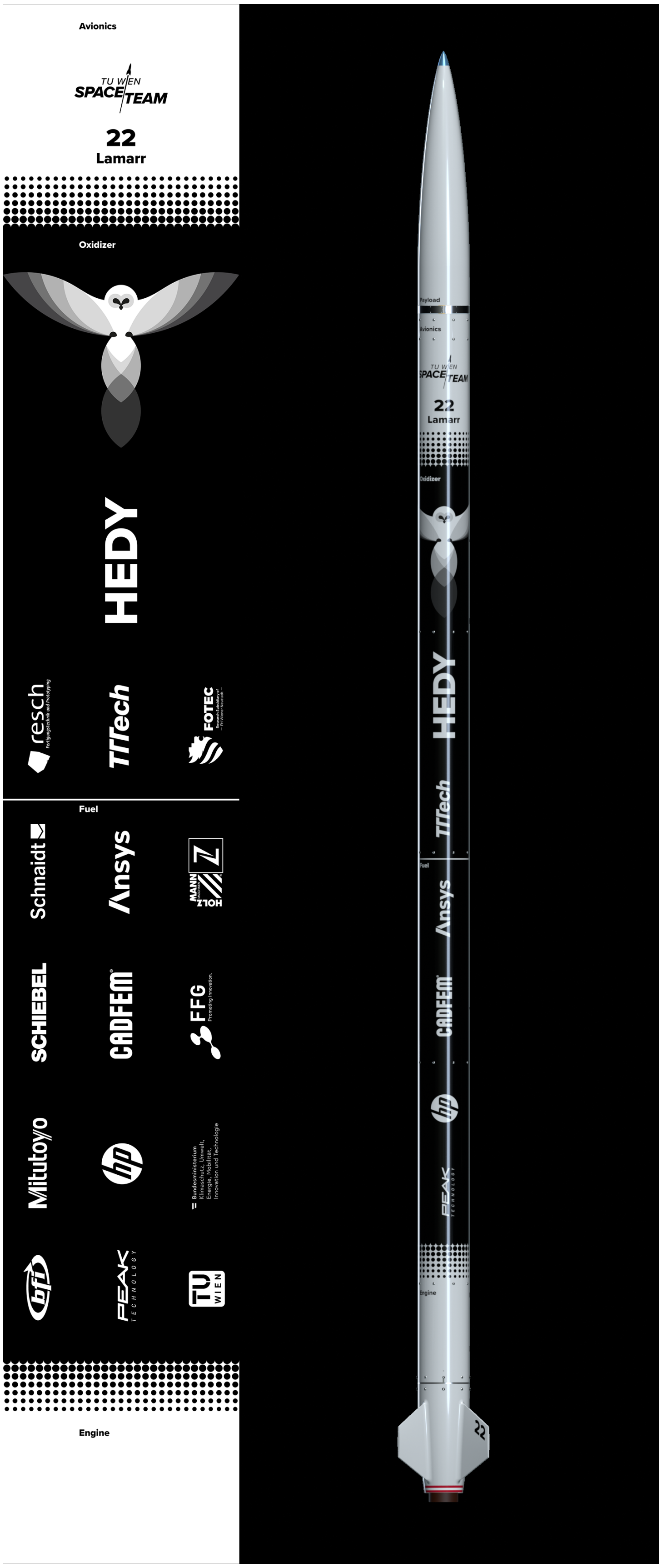


Fig. 2.16: Rocket livery design.

2.4 Recovery:

2.4.1 Recovery Overview:

Our rocket employs a fully redundant two-stage recovery system. Both the initial deployment event and the main deployment event are triggered by nichrome burn wires, which are connected to the pyro channels of the two flight computers, one Altimax G4 Altimeter acting as the main flight computer and a CATS Vega as the backup flight computer.

The rocket's nose cone and body tube are connected through a separable coupler, which is held in place by a spring steel clamp band. At apogee, once the line keeping the clamp band in tension is severed by one of the burn wires, the coupler separates and drogue parachute is deployed.

When the rocket has descended to an altitude of 450 m, the line connecting the drogue parachute to the body tube is cut and the drogue parachute pulls the main parachute out of the rocket and strips off the parachute's deployment bag.

Main and drogue parachute lines have integrated shock absorbers.

2.4.2 Parachutes:

The drogue and main parachutes are dimensioned such that the initial braking force of both parachutes are comparable. Since the main parachute and drogue parachute are tied to the same hardpoint inside the rocket, it can thus be efficiently designed to withstand both forces with adequate reserves.

Both parachutes are manufactured out of the canopies of decommissioned skydiving parachutes. The individual segments and gores were cut out of the fabric using a soldering iron to minimize fraying and stitched together with regular cotton thread using a sewing machine. The parachute shroud lines are fashioned out of 2 mm thick aramid cords with an individual breaking strength of 2500 N.

For the drogue parachute, a cross design was chosen since it can be manufactures easily and robustly. In addition, cross parachutes have the advantage of mitigating parachute opening shock loads and it can be easily visually distinguished during descent from the main parachute because of its shape. The edge length of the cross parachute is 35 cm and for the purpose of the drag force and terminal velocity calculations the drag coefficient was estimated to be 0.55, with the entire canopy area being used as reference area. To verify these assumptions, three previous rocket flights using cross parachutes were evaluated, with calculated and measured descent velocity matching well. Three shroud lines are sewn to each edge, for a total of twelve lines.

The main parachute is of the annular type, fashioned out of ten gores of alternating red and white parachute fabric for high contrast and visibility. The segments were laid out for a 2.1 m diameter toroidal parachute using the ChuteMaker parachute gore template generator. To calculate the drag force of the parachute, a drag coefficient of 1.8 was assumed for the toroidal geometry of the annular parachute. On each of the 10 seams a shroud line is attached.

Prior to deployment, the main parachute resides in a deployment bag fashioned out of the same tear-resistent fabric used for the canopies.

For each of the parachutes, an expected descent velocity was calculated using the drag equation:

$$F_D = \frac{1}{2} p v^2 C_D A \tag{2.2}$$

The term for the drag force F_D was set to be equal to the gravitational force F_G of the rocket, and the equation was solved for the velocity v. However, in addition to the drag force experienced by the parachute, the influence of the body tube on descent was also taken into account. The drag force experienced by a long cylinder parallel and perpendicular to airflow was calculated and then the air resistance of the body tube at different angles of attack between 0 and 90 degrees was roughly estimated using linear interpolation. For the body tube, a 3 m long cylinder with a diameter of 130 mm was assumed. The air resistance of the fins and nose cone were neglected for this estimation.

As can be seen in figure 2.19, the air resistance of the body has a significant influence on the expected terminal velocity of the rocket, especially when looking at the descent velocity after the initial deployment event. This finding is also in line with the measured descent velocity of past rocket flights undertaken by the TU Wien Space Team.

Using equation 2.2, we also calculated the expected maximum drag forces experienced by the rocket during parachute deployment. For this purpose, different deployment speeds were taken into consideration. For the initial deployment event, because of a large number of variables influencing the horizontal speed of the rocket at apogee, like wind speed and launch rail angle, a wide array of velocities was used as input for the calculations. These results can be seen in figure 2.21.

For the main parachute braking force estimation in figure 2.22, the results of the terminal velocity calculation from figure 2.19 were used.

In conclusion, the behaviour of the body tube and the resulting drag force has a large influence on terminal velocity of the rocket during the initial descent phase, in turn affecting the opening load on the main parachute significantly. That is why, in order to limit main parachute opening loads and provide ample safety margin in case the drogue parachute under-performs, a particularly large cross parachute design was chosen, targeting an initial descent velocity of around 23 m/s.

2.4.3 Lines, Links and Shock Absorbers:

A detailed overview of all parachute lines, links and hard points can be seen in the two line diagrams 2.17 and 2.18.

Almost all load bearing parachute lines are fashioned out of braided aramid sleeve manufactured by Siltex. Such aramid braid has been used as parachute line by the TU Wien Space Team for several rocket launches in the past with great results. The aramid braid has the advantages of regular aramid rope like high strength, flame resistance and excellent durability against abrasion while also offering further benefits in handling and processing, such as being well suited for splicing eyes into the ends as well as sewing segments together for the use as shock absorbers. Short segments of aramid braid with spliced eyes have undergone static load tests to verify that they are capable of withstanding at least 5000 N of force.

A short segment of line which connects the drogue parachute to the parachute bulkhead inside the body tube is made out of polymide rope and is cut during the main deployment event, allowing the drogue parachute to pull the main parachute out of the parachute tube. Since aramid is very resistant to high temperatures, it is unsuitable for this task. Instead, 3.8 mm thick polyamide rope with a nominal breaking strength of 2490 N is used. For this purpose, it is tied into a continues loop with a knot and run through the parachute bulkhead on one end and a soft shackle on the other such that 4 lines of rope run parallel from one point to the other. Two nichrome burn wires are placed on two of those lines and cutting the loop at any point results in the entire connection releasing immediately.

In order to determine the breaking strength of a folded polyamide rope loop and to figure out what knot would be most suitable to this purpose, static load tests were conducted and it was found that the loop would always break in one of the two attachment points, well in excess of 5000 N.

To link different elements of parachute line system, in place of the more common steel screw links, soft shackles made out of 6 mm thick aramid rope are used. Since both the CATS Vega's antenna and our own radio antenna are fixed on the parachute tube, these self-made soft shackles offer the advantage of not interfering with the outgoing radio signals from our avionics, improving our chances of maintaining an uninterrupted telemetry link with our rocket during flight.

For this very same reason we decided to forgo the use of steel swivel links in our recovery system, given that none of the hard points the parachute lines are connected to are at risk of being unscrewed by the rocket parts spinning in the air and building up torsion in the lines. The parachute bulk head in the rocket is fixed to the body tube with screws radially, and all lines are tied directly to it and not to a ring nut or eye-bolt. Similarly, the hard point in the nose cone is a GFRP disk that is glued into the forward end of the nose cone with holes in it to tie the parachute lines to the part directly.

Both parachutes are connected to the rocket components through shock absorbers made out of 18 mm diameter Siltex aramid sleeves with a wall thickness of 0.3 mm. The aramid braid is folded lengthwise and stitched along its length with high strength polyester sewing thread. Since our shock absorbers start ripping open at around 500 N and we only want them to activate during the most critical part of the parachute opening shock during the moments of highest load, two absorbers are used in parallel to bring the activation force up to around 1000 N.

2.4.4 Clamp Band Coupler:

During flight, the body tube and nose cone are held together by an aluminium coupler made of two halves which are pressed against each other by plastic clamps. The force acting on the clamps is provided by a spring steel band which is kept in tension by a short loop of fishing line with a thickness of 0.4 mm. During assembly, the line is run through a hole in a tensioning screw sitting in a locknut. Once the line has been tied into a loop with a knot, the tensioning screw is turned until the clamp band sits flush against the surface of the body tube. The lines are slightly deflected by a pair of ceramic cylinders with 0.3 mm diameter with nichrome burn wires coiled around them. This nichrome burn wire has a resistance of 2.4 Ω and when a voltage of 12 V is supplied to them, they quickly heat beyond 1000 °C cutting the fishing line retaining the clamp band in less than a second.

During testing, it was discovered that the mechanism was not completely symmetric, with one side more than twice as fast as the other. We realized that, when the fishing line is wrapped around the tensioning screw, the two halves of the loop going towards the ends of the clamp band leave the screw on the same side, with one line passing closely by the ceramic cylinder and the other line going past the second cylinder with a wide clearance. To mitigate this, a steel pivot with a diameter of 2 mm is used to deflect the fishing line and force it closer to the second ceramic cylinder. As a result, both halves of the burn wire cutting mechanism now have the same actuation speed.

In order to calculate the forces that are expected to act on the coupler during flight, the Barrowman Method was used. The normal force on the nose cone was calculated using the following formula:

$$F_N = \frac{1}{2}\rho v^2 \frac{1}{4}\pi D^2 \alpha (C_{N\alpha})_C \tag{2.3}$$

with ρ being the air density, v the rocket velocity, D the diameter of the rocket, α the effective angle of attack and $(C_{N\alpha})_C$ the slope of the normal force coefficient at $\alpha = 0$.

For our rocket, conservative estimates were made for the flight characteristics, the angle of attack for example was assumed to be 10°. The resulting normal force acting on the nose cone was found to be around 300 N. Using this estimate, static load tests were performed on the clamp band coupler and nose cone, discovering a large number of structural weak points in the assembly which were subsequently reinforced.

In the first prototype, the part holding the tensions screw was glued to the parachute tube. When the clamp band is put under tension by a force F_C, the tension screw would bear a force of $2F_C$. During our tests, we discovered the possibility of the screw failing. In addition, the force acting on the screw was also acting on the parachute tube, which broke out of its base plate because of the long lever arm magnifying the torque, resulting in the parachute tube and base plate epoxy connection failing. Because of this, the part holding the tension screw was moved from the parachute tube directly to the lower coupler, which can withstand the force of the clamp band without problem. Finally, the next weakest link was found to be the fishing line tying the ends of the clamp band together, which was upgraded from a thickness of 0.2 mm to 0.4 mm without notable decrease in actuation time.

Taking the result of the calculation for the normal force on the nose cone, the bending moment M_C acting on the coupler was estimated to be around 150 N m. Using this figure, the force acting on the crowns of the upper and lower coupler, which are used to connect them to the body tube and nose cone respectively, was calculated using the formula:

$$F_{crown} = \frac{M_C}{2D} \tag{2.4}$$

The force F_{crown} was found to be approximately 600 N for the lower coupler, and the crown were subsequently designed with a safety margin of 2, using high strength 6082 aluminium alloy. In addition, static load tests of a crown dummy were performed, and the aluminum part was recorded withstanding in excess of 1100 N of force without deforming.

2.4.5 Recovery Avionics:

Two different flight computers are used in our rocket to trigger the recovery system.

An **Altimax G4 Altimeter** is acting as the main flight computer. It is connected to the same battery packs as the remaining electronics inside the rocket. Two sets of nichrome burn wires are connected to pyro channel 1 and pyro channel 2 respectively, the first one releasing the clamp band and triggering the initial deployment event, and the second one cutting the polyamide rope and releasing the main parachute. The Altimax G4 has been flown in several rockets build by the TU Wien Space Team in the past and has worked reliably so far. It is capable of outputting up to 15 A continuously, but in order to keep the recovery mechanism symmetric between the two flight computers and make it impossible to accidentally mix up the connectors, burn wires with a resistance of 2.4 Ω are used for every one of the line cutters, limiting the current to 5 A when the battery input voltage of 12 V is applied to the pyro channel.

The Altimax is programmed to power pyro channel 1 at apogee and pyro channel 2 during descent at an altitude of 450 m. It supplies each pyro channel for a duration of 3 seconds.

The second flight computer is a **CATS Vega**. Besides recovery, it is also responsible for altitude logging and tracking. As the redundant backup flight computer, it is supplied by its own dedicated 12 V battery pack. In order to be able to supply the burn wires with the necessary current of 5 A, the PTC fuses on each of the two pyro channels are bypassed.

The CATS Vega is programmed to power pyro channel 1 at apogee for 3 seconds, and pyro channel 2 at an altitude of 450 m for a duration of 6 seconds, since the actuation time for the polyamide burn wire is significantly longer than that of the clamp band line cutter.

2.4.6 Recovery Test Flight:

In April of 2024, a rocket powered by a solid propellant motor was launched containing a prototype of the planned recovery system. The rocket has an inside diameter of 130 mm and a nose cone closely matching that of our liquid propellant rocket, allowing us to test a same-scale prototype of the recovery system in flight. The recovery system was fully redundant, with both an Altimax G4 and CATS Vega acting as flight computers on board. In addition, a prototype of the payload was also mounted inside the nose cone.

The rocket flew to an altitude of 600 m and the decoupling mechanism worked flawlessly, with the drogue parachute deploying quickly as planned. When the rocket reached an altitude of 250 m, the main release mechanism triggered, successfully severing the line connecting the drogue parachute to the body tube. However, the drogue parachute did not manage to pull the main parachute out of the parachute tube. During ground tests, we verified that the weight of the test rocket was enough to pull the main parachute out, even though there was some resistance because of the deployment bag being too large and rubbing up against the inside of the parachute tube. However, during flight, the large body tube and fins of the rocket introduced a lot of drag, slowing down the rocket body and reducing the force from the drogue parachute acting on the main parachute. Furthermore, because of the pronounced drag of the fins, the rocket body was not hanging on the drogue vertically but at an incline, further hindering the main parachute from exiting the parachute tube. Both drogue and main parachute lines were fitted out with 300 N shock absorbers. Since the rocket had a low horizontal velocity at apogee and there were no aggressive winds, the drogue parachute shock absorbers did not trigger. Those on the main parachutes line were not triggered because the main parachute did not deploy. While the function of all recovery mechanisms was confirmed, the most important learning from the test flight was to make the deployment bag of the main parachute smaller in circumference, so that, even if the main parachute tries to expand inside the bag, it does not stretch out far enough to rub up against the parachute tube and hinder the deployment of the main parachute in any way.

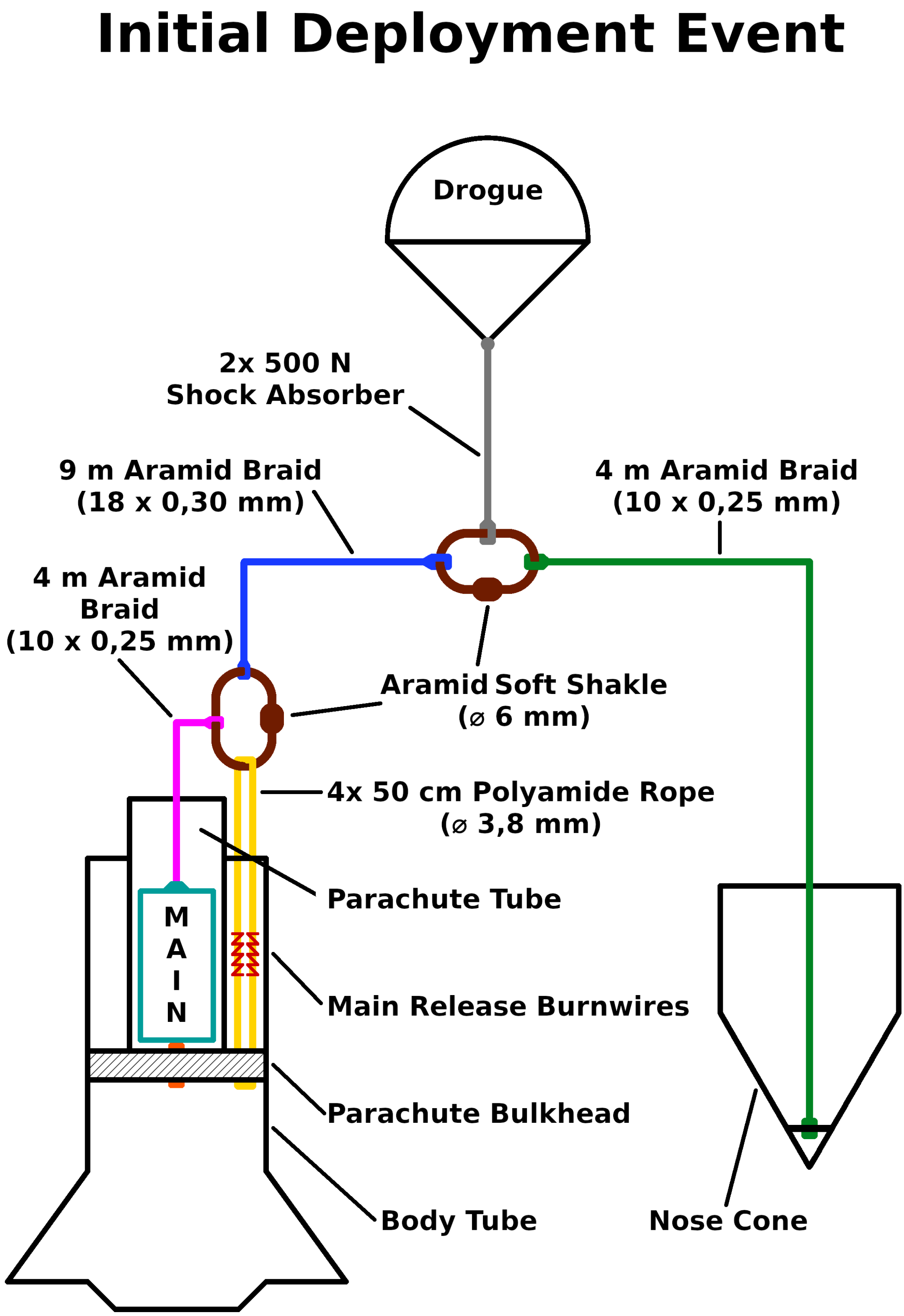


Fig. 2.17: Line diagram after the initial deployment event at apogee

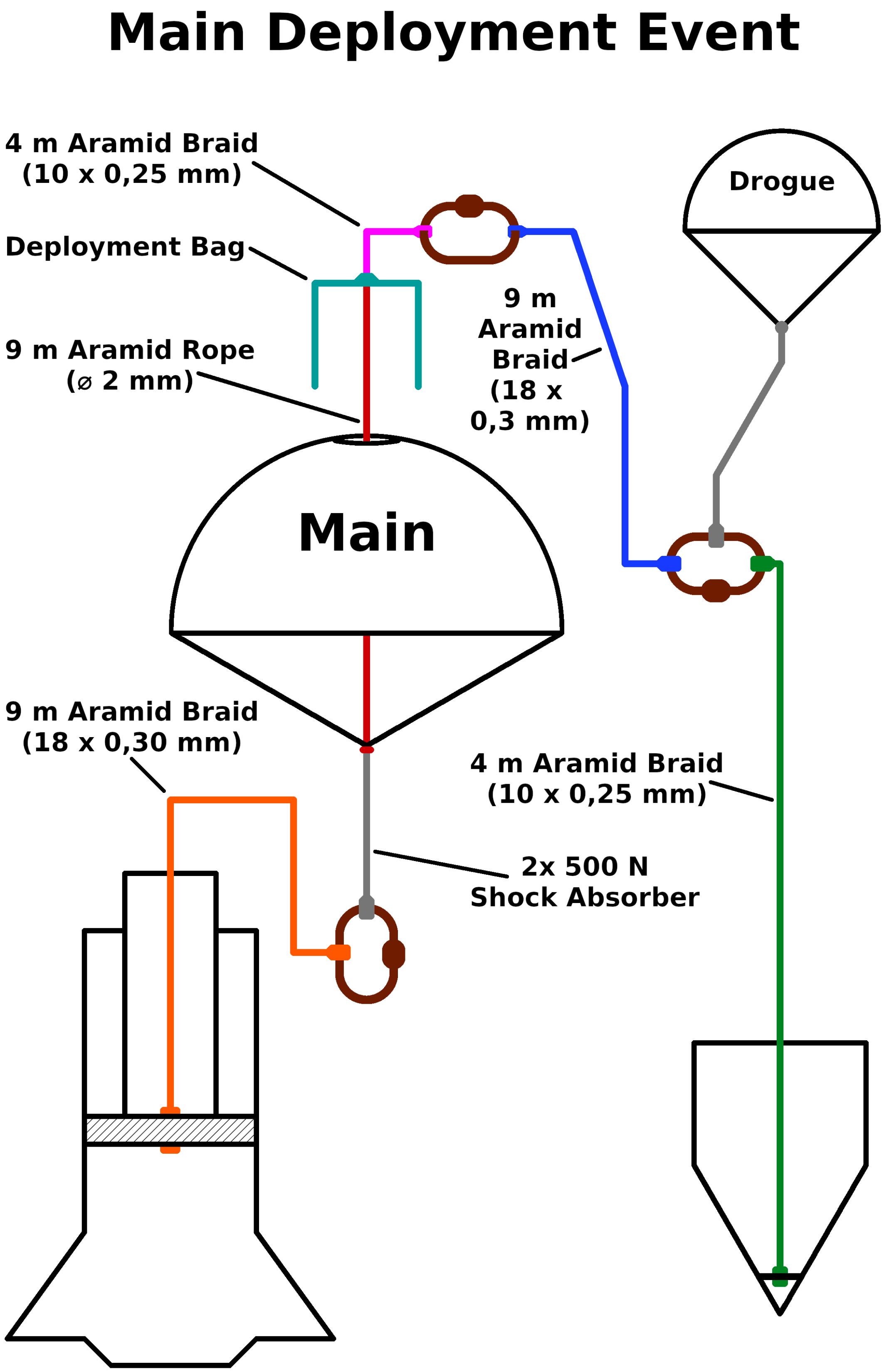


Fig. 2.18: Line diagram after the main deployment event at 450 m altitude

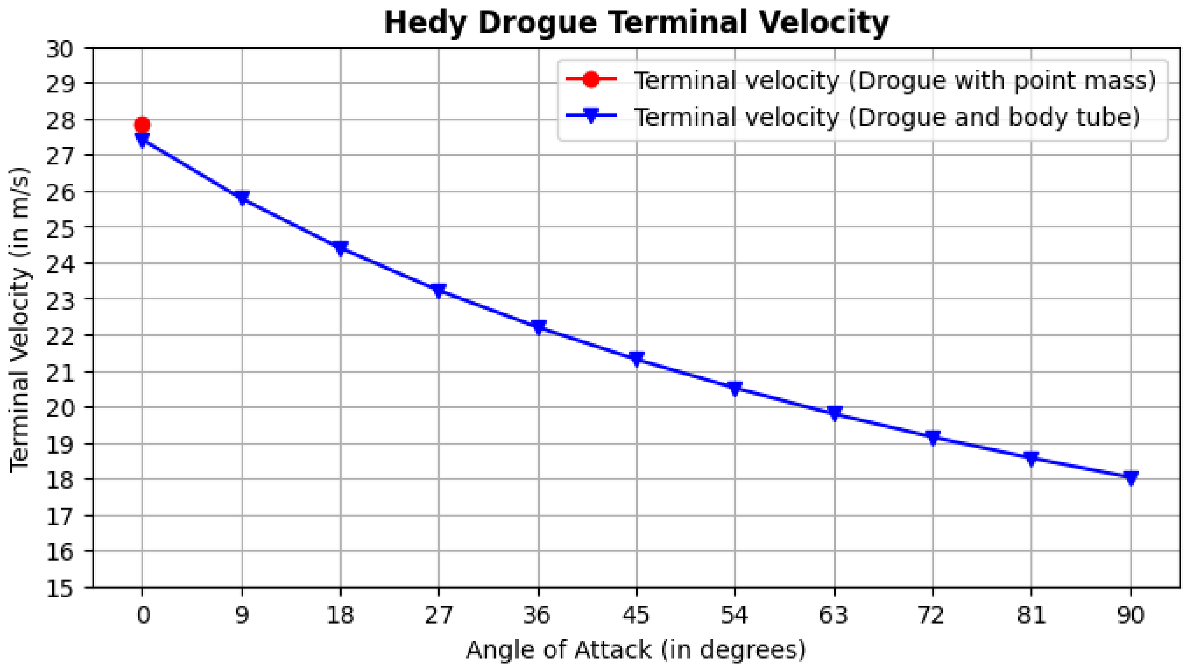


Fig. 2.19: Terminal velocity of the rocket after deploying the drogue parachute, factoring in the air resistance on the body tube at different angles of attack

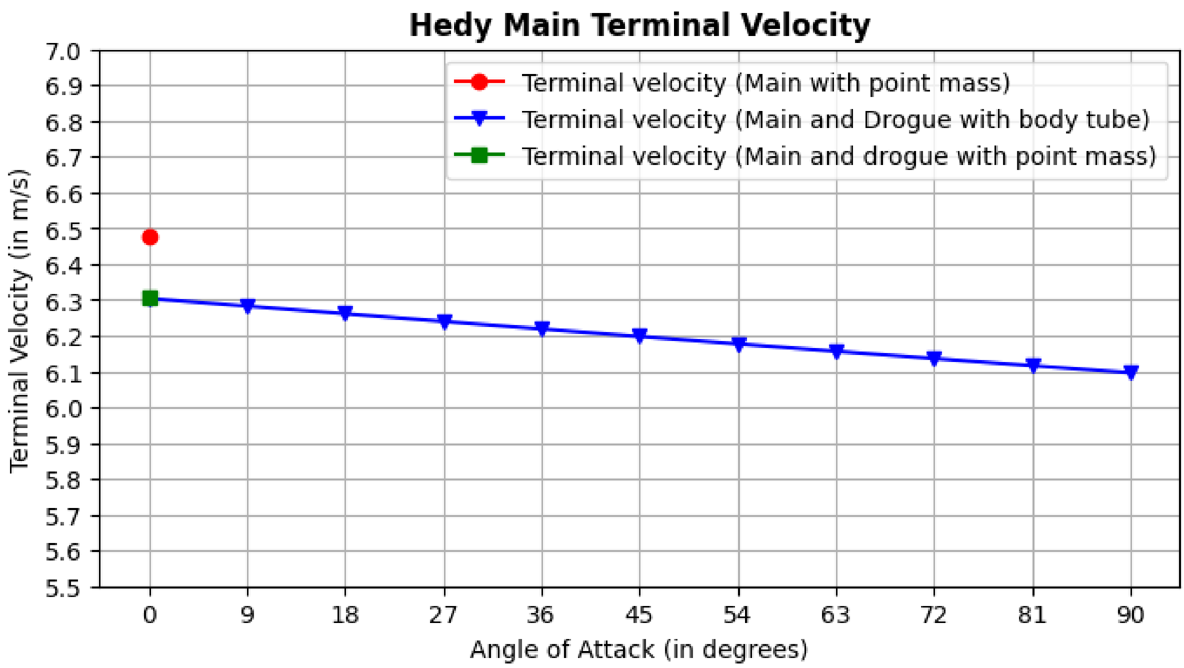


Fig. 2.20: Terminal velocity of the rocket after deploying the main parachute, factoring in the air resistance on the body tube at different angles of attack

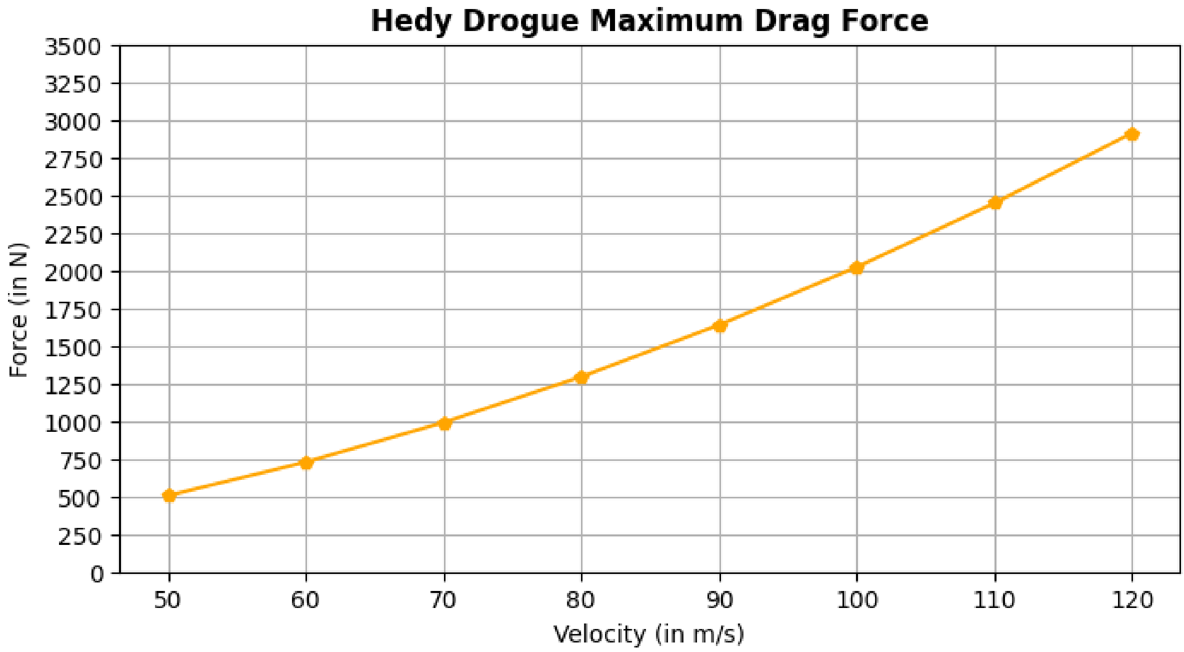


Fig. 2.21: Maximum drag force generated by the drogue parachute at different deployment velocities

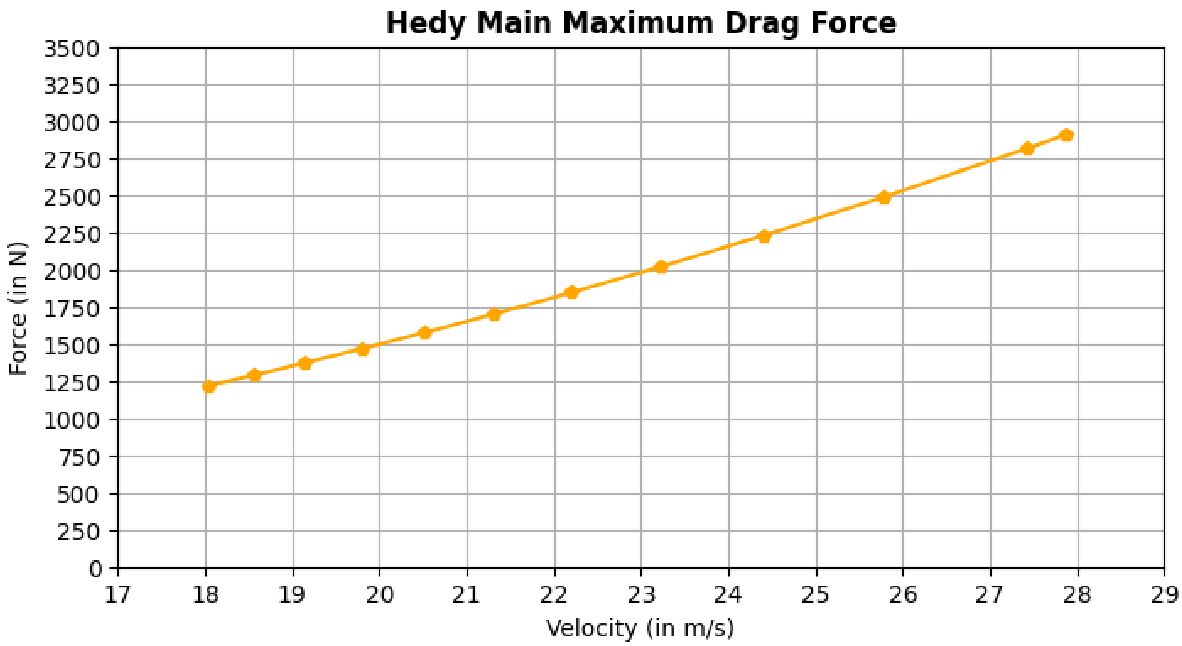


Fig. 2.22: Maximum drag force generated by the main parachute at different drogue terminal velocities

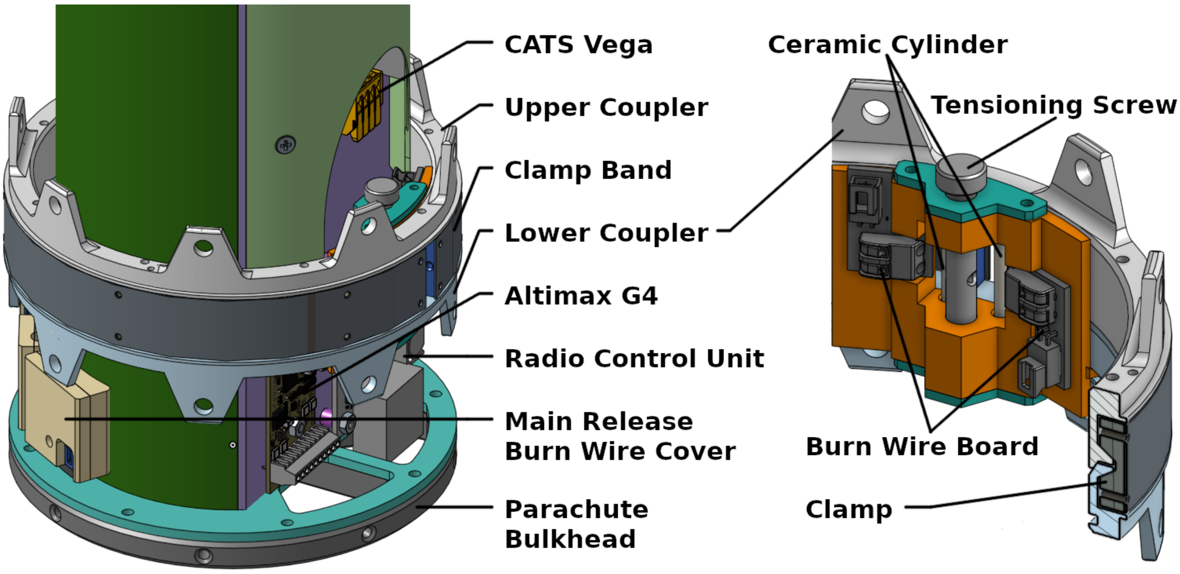


Fig. 2.23: Clamp band coupler and adjacent recovery components

2.5 Payload:

2.5.1 Abstract:

Fascinated by the piezoelectric effect, which generates a voltage in response to applied pressure, the student team WerndlExplorer from Upper Austria embarked on a mission to explore its practical applications. Their "EVA" payload comprises two stacked CanSats meticulously engineered to capture and analyze critical flight data. The primary mission involves measuring temperature and pressure to determine altitude and rocket velocity during ascent and descent, complemented by an Inertial Measurement Unit (IMU) for comprehensive flight tracking. Additionally, the team has crafted a novel accelerometer leveraging the piezoelectric effect: as the rocket accelerates, a seismic mass presses against a piezo crystal, generating a voltage that translates into acceleration data, validated against the COTS IMU outputs.

Enhancing the mission's scope, the TU Wien Space Team has incorporated a RunCam to provide a unique perspective on the rocket's parachute chamber and capture acoustic data for subsequent analysis. A lithium-ion battery powers the onboard electronics managed through a step-down converter and a UPS-HAT(C), with a Raspberry Pi Zero 2W at the helm. A remote-controlled RBF system allows the rocket to activate the electronics on command. This multifaceted approach aims to comprehensively evaluate the rocket's performance and the feasibility of using piezoelectric materials in advanced sensor technologies.

2.5.2 Mission Diagram:

Figure 2.24 illustrates the chronological sequence of the mission.

2.5.3 System Architecture:

Payload EVA:

Onboard electronics: The onboard computer system is based on a Raspberry PI Zero 2 W. A lithium-ion battery is used for energy storage (single 18650 cell / 3Ah). A COTS battery management system *UPS HAT (C)* is used which supports cell protection, is a charging controller and a voltage booster to generate +5V for powering the Raspberry PI. Battery voltage and current are monitored. Pre-launch charging of the battery is supported. A second battery CR2025 powers the real-time clock when the payload is switched off.

Power switch: The payload features an integrated microswitch (pressed by the *red remove before flight stick*, see figure 2.25) and supports an external switch connected to the rocket's main switch. When both switches are *open*, the payload is armed. If either switch is closed, the payload is turned off.

A switch-off delay is implemented via a microcontroller so that the main computer can be shut down cleanly.

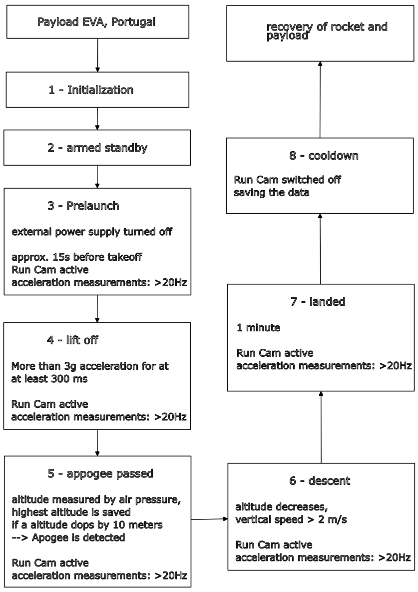


Fig. 2.24: Chronological sequence of the mission

Fig. 2.25: Rendering of Payload EVA - outside

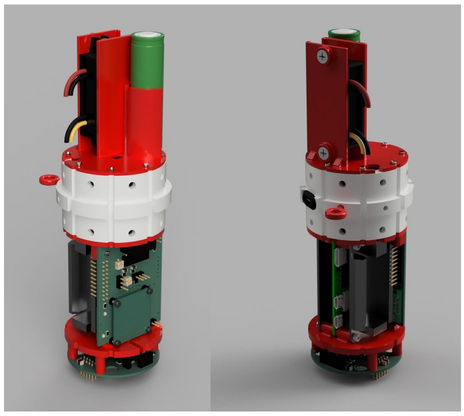


Fig. 2.26: Rendering of Payload EVA - inside

Self-developed acceleration sensor: An acceleration sensor was developed using a piezo crystal and an M10 nut. The nut's inertia applies a force to the crystal, generating an electrical voltage.

The piezo circuit board provides two measurement methods. The first employs impedance transformers to isolate the input and output of the operational amplifier, minimizing errors from the piezoelectric plate's high internal resistance and adjusting the voltage for the Raspberry Pi. However, this method led to imprecise data integration.

To reduce measurement errors, the second method uses a charge amplifier with high- and low-pass filters. This approach minimizes noise and improves data quality, with values integrated directly due to the wiring. Selecting optimal components for filtering was challenging, so soldering bridges and interchangeable components were added for quick adjustments.

Self-developed electronics:

Piezo-PCB: This PCB contains the analogue circuits for piezo signal conditioning, a BME280 Sensor (ambient pressure, temperature and humidity, breakout board), a IMU MPU-6050 (6 axis acceleration and gyro sensor, breakout board), a RTC DS3231 clock chip and a Power MOSFET and DC/DC step up 5V to 8V for powering RunCam and LED spotlight.

LED-PCB: This PCB contains LEDs for RunCam spotlight, Interface to Hedy (rocket), Power Switch circuitry and generates status signals for Raspberry PI: external 12V connected, RBF status (for shutting down cleanly).

RunCam Video/Audio capture device: A RunCam Split, integrated on the bottom of the payload, captures video and audio of the parachute compartment. An LED spotlight ensures visibility even in darkness during launch. Controlled by the Flight Controller, the RunCam activates when the external power supply is disconnected (approximately T = -15s) and continues recording for 30 seconds after landing.

Validation of measured data:

Figure 2.27 compares vertical acceleration data from the IMU with integrated values from the piezoelectric sensor. While both show similar peaks and correlate with acceleration, the piezoelectric sensor's acceleration appears to increase steadily, likely due to noise and integration errors. To address this, additional high- and low-pass filters will be added, and the wiring will be upgraded from impedance transformers to a charge amplifier.

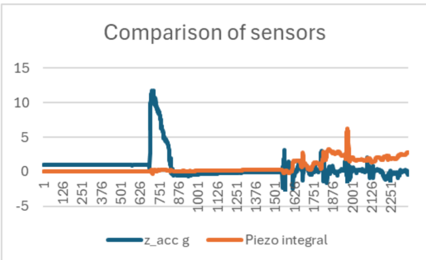


Fig. 2.27: Comparison of sensors

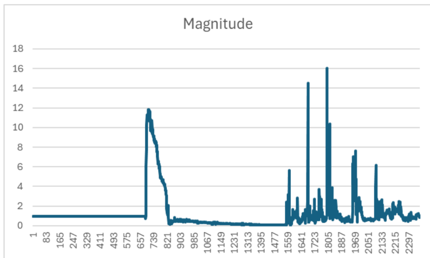


Fig. 2.28: Magnitute

Diagram 2.28 shows the magnitude of the acceleration vector calculated with the data collected by the IMU during a rocket launch in Straubing, Germany. The acceleration during lift-off was about 12g.

Technical specifications:

Item	Quantity
Weight	700g
Size	double CanSat form factor: 66mm diameter, 230mm height
Main Battery type	Protected Li-Ion 18650 3,7V 3Ah (11,1Wh) by Samsung
Battery current consumption	approx. 400mA (prelaunch)
	approx. 1.2A during flight when camera is active
Battery runtime	approx. 3.5 hours
Clock battery	CR2025

Tab. 2.1: Technical specifications

2.6 Avionics:

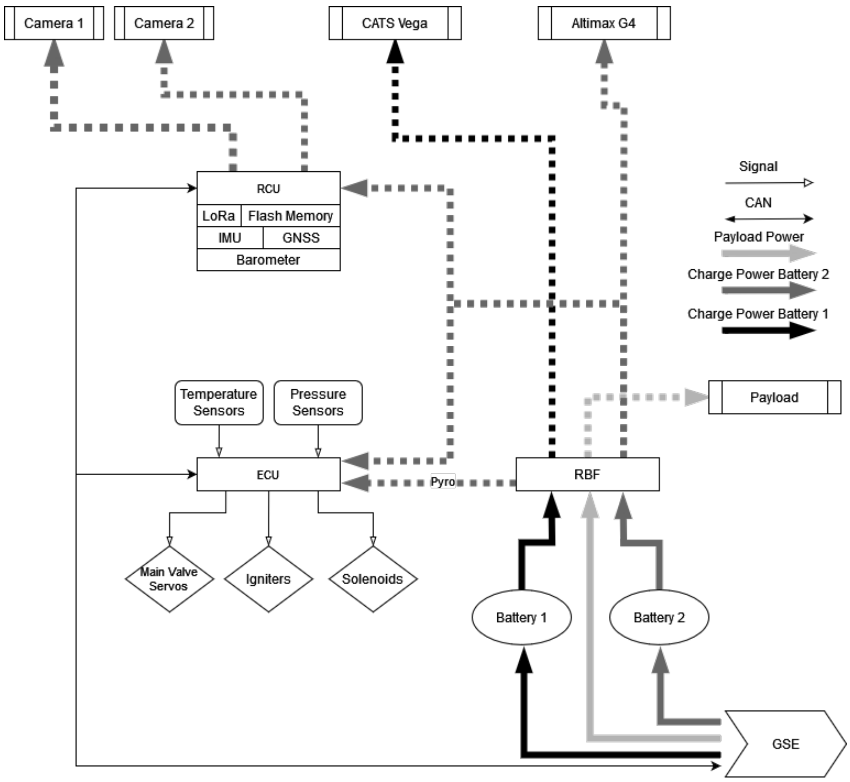


Fig. 2.29: Subsystem Block Diagram

2.6.1 Physical Architecture:

The following section describes our two custom units, both equipped with an ARM processor and a CAN-FD interface: ECU and RCU.

The ECU (Engine Control Unit) 2.30 is a critical component within the avionics system, designed to manage all electronics essential for the liquid propulsion system. It controls the main valve servos, the vent solenoids, and the igniters, providing reliable actuation for these key propulsion elements. Additionally, it includes inputs for chamber, tank and venturi pressure sensors, as well as tank temperature sensors. Voltage monitoring of all power rails ensures the system remains within operational parameters.

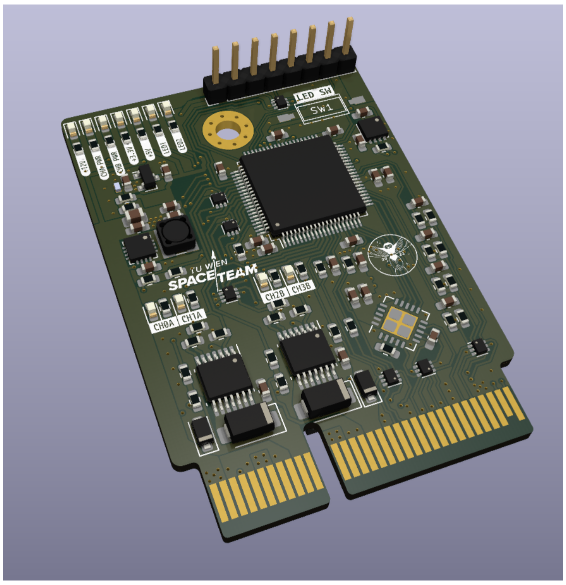


Fig. 2.30: ECU

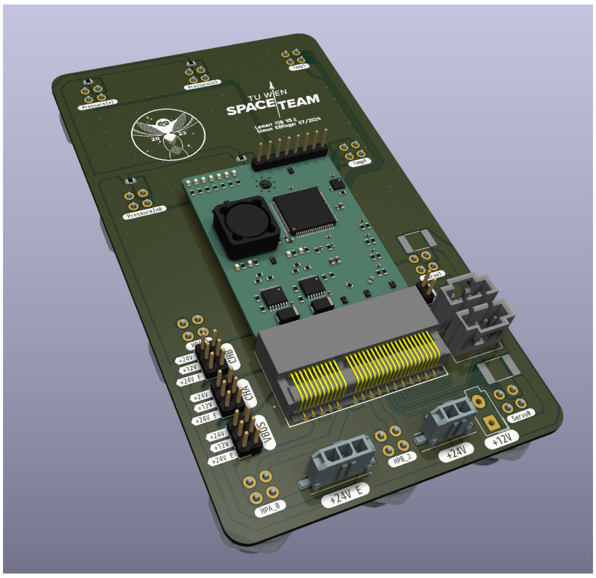


Fig. 2.31: IOB

The ECU is built around an STM32 microcontroller and features four high-power channels utilizing high-side IC switches with current limiting and sensing functionality. These channels can also be configured in hardware to operate as pyro channels with continuity-checking capabilities. For precise measurements, the ECU includes four 4-20mA pressure inputs and two PT100 inputs, ensuring accurate pressure and temperature monitoring.

A 32 Mbit external NOR-flash chip is integrated into the ECU for logging all data packets sent to mission control at full sampling speed. This functionality is particularly valuable during flight, where data transmission is limited by LoRa communication. The ECU communicates via a CAN bus interface, facilitating robust and reliable data transmission between various avionics modules.

The ECU's compact card edge form factor allows it to be used in conjunction with a breakout board, optimizing space and facilitating integration within the overall avionics architecture. Additionally, the ECU is utilized in the test stand, where it connects to a larger breakout board, called IOB (Input Output Board) 2.31, featuring M12 connectors for each sensor and actuator, providing a robust and scalable testing environment. This allows a seamless transition from operation on the test stand to operation in the rocket.

The RCU (radio communication unit) 2.32 consists of communication and sensing hardware. A GNSS module, an IMU and a barometric pressure sensor collect important data for recovery and post-processing. Again, all data is logged to external flash memory. A 868 MHz LoRa module sends data to the ground station.

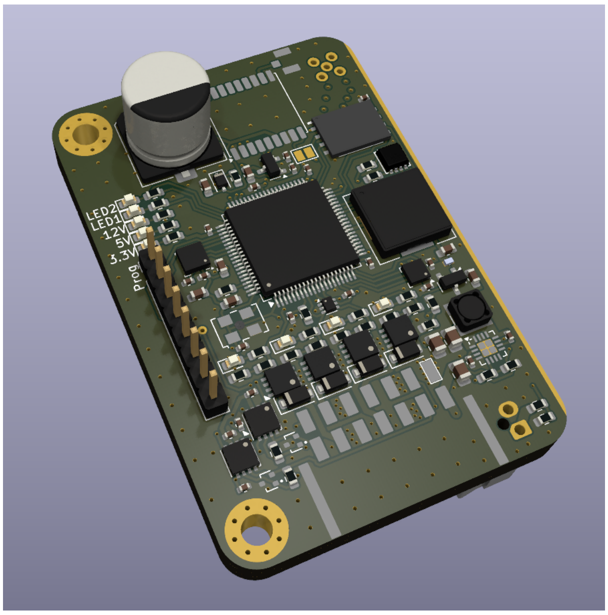


Fig. 2.32: RCU

2.6.2 Operational modes:

Safe: Once the rocket is mounted the RBF pin is pulled halfway, which powers on all avionics onboard. At this point data is redundantly sent via 868 MHz LoRa and the rocket can be fully controlled by our Mission Control software via a 2.4 GHz directed radio link, the only exception being the ignition, which is still physically disconnected from power by the RBF pin. Thus, the final pad preparations including fueling and preparing oxidizer filling are done in this mode.
Armed: Once the on-pad preparations are done and the pad area is vacated, the RBF pin is pulled out completely, which exposes the ignition circuitry to power. The whole system is now operational. When the pad is cleared, oxidizer filling begins, marking the last event before launch.
Internal Control: After oxidizer loading is completed the rocket is put into internal control, where the ECU begins its internal sequence.
Holddown: If neither hold nor abort is commanded by the operator or the ECU, the ignition sequence is automatically started. After ignition the holddown clamps are still engaged holding the rocket firmly on the launchpad. The rocket stays in holddown mode until sufficient engine performance is detected by measuring combustion chamber pressure.
Lift-off: If suitable chamber pressure is detected by the ECU, it commands the launch pad to release the holddown clamp. The rocket leaves the launchpad, disconnecting the electrical umbilical cord, and, thus, the power and CAN connection to the launch pad. This leaves us with only the unidirectional LoRa communication. The rocket is now fully controlled by the ECU.
Powered Ascent: During the powered ascent phase, data is being sent to Mission Control at all times. At the end of the planned burn time, the ECU closes the main valves to shut down the engine, also known as Main Engine Cutoff (MECO).
Unpowered Ascent: With the ECU having finished its internal sequence, the SRAD avionics only remain active to transmit data, shifting focus towards the COTS altimeters

detecting apogee.
Recovery: Once apogee is detected, the two-phase recovery begins with the ejection of the nose cone and drogue chute. This marks the last operation mode of the rocket.

Pre-Launch Sequence:

The Pre-Launch Sequence is conducted on our self-developed Web-Client. It contains a dynamic and interactive Piping and Instrumentation Diagram (P&ID/PnID) for monitoring and controlling all components, the tanking system as well as avionics inside the rocket. A checklist is carefully processed that states each step needed for preparing and tanking the rocket for launch. Each step is announced by the Launch Commander and is re-validated and executed manually by Mission Control. At T-10 seconds internal control is activated and the rocket self-checks for any malfunctions during engine startup and launch.

Abort Sequence:

In case of any malfunctions during engine startup either the internal control system can abort or Mission Control can send an abort to the rocket manually. In either case, the main valves are instantly closed to prevent any thrust generation. After that, a separate checklist is conducted manually to revert the system back to a safe state.

CAN protocol:

To establish steady communication with ground systems as well as the rocket, the CAN-FD protocol is used. The whole setup is split into three buses that are all connected to an Ubuntu server. Since the CAN bus is disconnected from the rocket at lift-off, a separate internal CAN bus is used to maintain communication between ECU RCU. The umbilical PCB is able to bridge CAN messages between the internal and external CAN busses. A self-developed protocol is used on top of the CAN-FD protocol to establish the controllability and flexibility needed for Mission Control.

2.7 Ground support equipment:

While solid rocket motors can be handled in a safe manner relatively easily, bi-liquid rockets propose an additional challenge before launch. Since the fuel and oxidizer are in a much more volatile state, they are loaded immediately prior to launch. Because the startup of an SRAD bi-liquid engine is slower and less reliable than a solid motor, a hold-down system should be used to maximize launch velocity and prevent an incomplete startup or hard-start from throwing the rocket into the air.

Due to these reasons, we decided to use and modify our own launchpad, rather than adapting one of the launch rails provided by the event organizers.

2.7.1 Launch Rail:

Our launch rail structure consists of sections of Globaltruss FD33-200 triangular aluminium trusses, commonly used in stage construction and rigging. Mounted to it with pipe clamps are sections of 30x30L aluminium extrusion, sourced from DOLD Mechatronik, acting as the launch rail. It extends an additional 1 m from the trusses. This structure is mounted on top of a trailer for ease of transportation. Guy wires connected to ground anchors further stabilize the structure, especially against wind forces.

This basic structure has been used as the main launch platform for TU Wien Space Team for a number of years, being used for small rockets built by new team members, recovery test vehicles and our dedicated CanSat rocket. It was also used to launch our previous bi-liquid rocket µHoubolt at EuRoC 2022.

For Hedy, the launch rail has been extended by 4 m to 11 m in order to ensure a sufficient rail exit velocity.

2.7.2 Hold-down System:

The purpose of the Hold-down System is to hold the rocket in place, until nominal engine startup and sufficient thrust for a safe liftoff is confirmed. It connects to the rocket via the bottom railbutton, which is reinforced and directly connected to the thrust structure inside the rocket. The Hold-down System includes a load cell, which measures the force acting on it. This is used during the tanking phase, for feedback on the LOX fill level, and during engine startup to measure the thrust directly.

Once nominal engine startup is confirmed by both the chamber pressure sensor and the load cell connected to the hold-down system, the rocket is released by a pneumatic cylinder actuating a lever.

2.7.3 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 liquid oxygen (LOX) and high pressure nitrogen gas (HPN2) into our rocket without human presence necessary.

The dewar, valves and both cabinets are mounted to a tanking structure made out of aluminium extrusions, which sits beside the launch rail on the trailer.

Ethanol Tanking:

Since our fuel (ethanol) is relatively safe and easy to handle, it is loaded manually as one of the final tasks before we leave the launch area. A hose connected to a reservoir is attached via a quick-connector to a fill port located upstream of the fuel main valve inside the rocket. A measured amount of ethanol is then poured into the reservoir, which is lifted above the height of the fuel tank of the rocket. Gravity then feeds the fuel into the rocket.

This principle is used by the team for tanking the engine test stand. In our testing, fuel pumps have proven to be unreliable, while adding complexity due to additional power

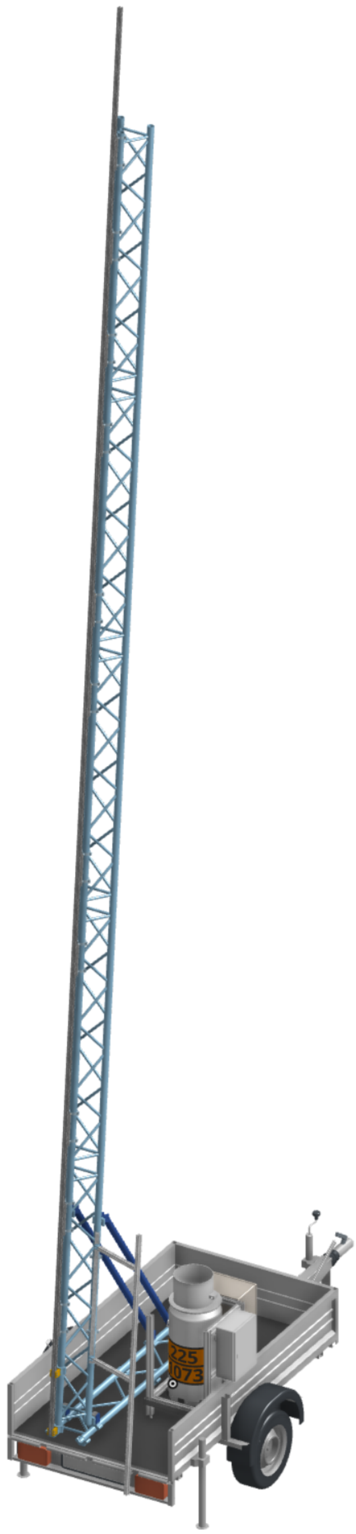


Fig. 2.33: Launch rail

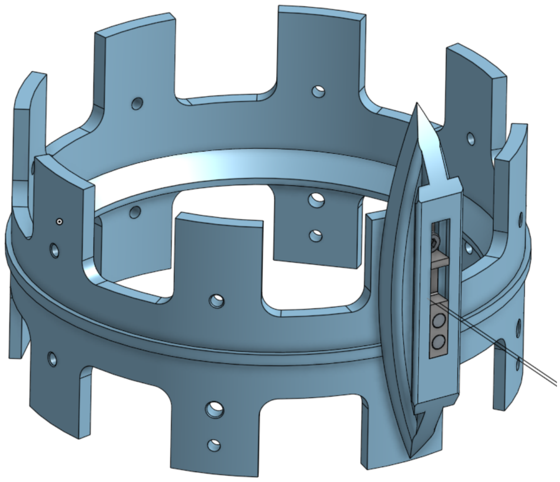


Fig. 2.34: Bottom railbutton mounted to the inner structure of the rocket

and control electronics being required. The gravity fed approach, while slower, is much more reliable.

Liquid oxygen Tanking System:

The LOX Tanking System consists of our own dewar for LOX storage, a pressurization system and a flexible hose connected to the rocket. By pressurizing the dewar with nitrogen gas at 1.5 bar, liquid oxygen is forced up a riser tube, through a tanking valve and into the rocket via a flexible hose.

Pressurization is achieved by a mono-stable 3/2 solenoid valve, connected to its own pressure regulator inside the pneumatics cabinet. There the tanking pressure, and by extension the tanking speed, can be adjusted. Due to the nature of the mono-stable valve, the dewar always defaults to being vented to atmosphere.

The LOX tanking valve is a stainless steel Swagelok ball valve, modified with LOX compatible seals and bushings. The exact valve has been used in our engine test stand and has performed reliably. A PTFE hose is used to connect to our SRAD LOX-connector inside the rocket. The LOX piping is insulated with Armacell ArmaFlex insulation material.

The dewar is positioned on top of a load cell to monitor its mass during tanking. It also has a pressure relief valve as standard.

This method of LOX tanking is the same as the one used during every hotfire test the team has conducted and has proven to be very reliable and controllable.

High pressure nitrogen Tanking System:

For pressurization our rocket requires nitrogen gas, stored as a gas at 300 bar. In order to fill our nitrogen tanks inside the vehicle, a 300 bar nitrogen bottle is connected to them without a pressure regulator. This increases the danger considerably, any rupture or other failure could be catastrophic. Thus, our system is designed in a way that minimizes pressurized components when people need to be present, with the tanking procedure being remotely controlled.

The nitrogen bottle is connected via a flexible hose to the valve section mounted to the tanking structure. A pressure gauge at the bottle connector allows for a quick check,

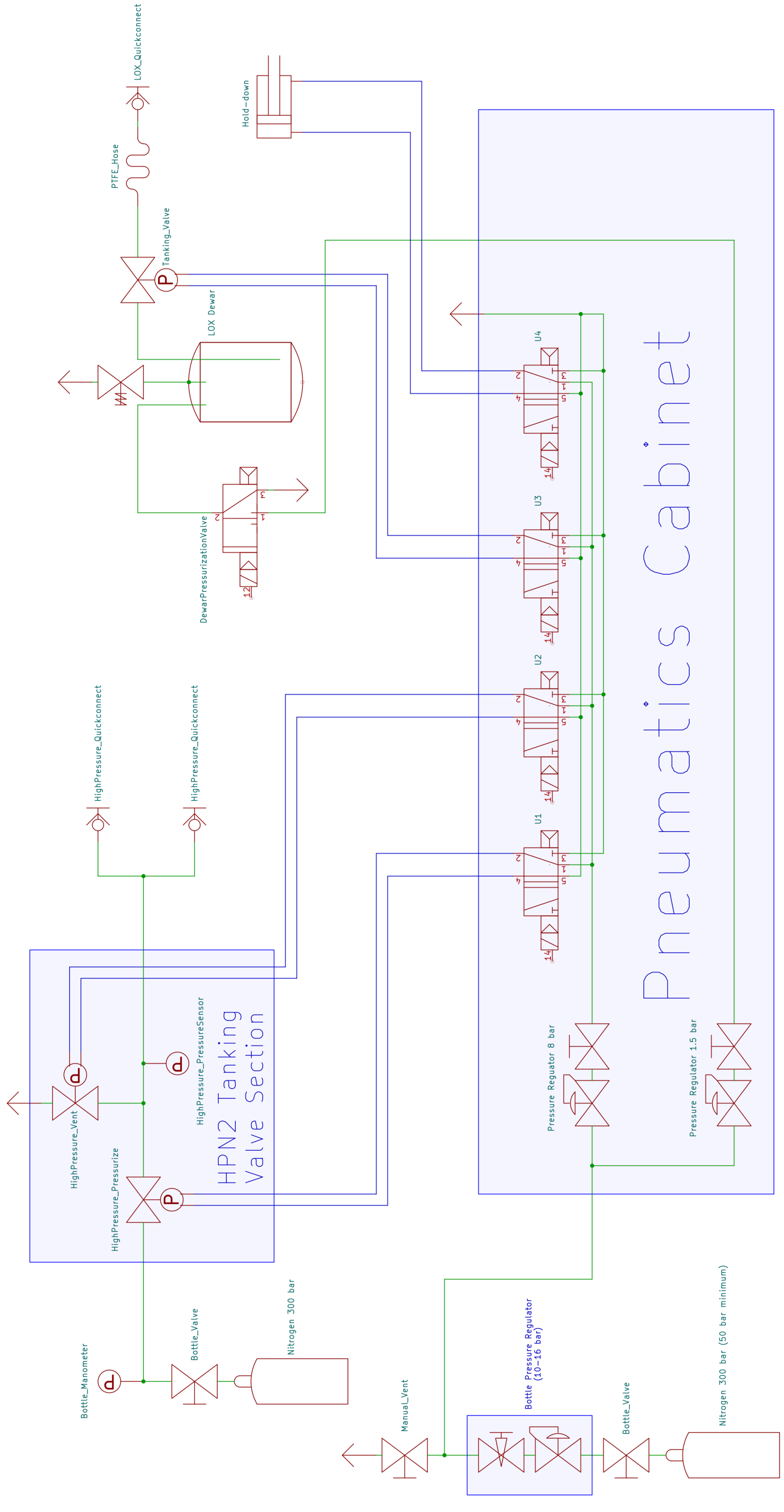


Fig. 2.35: GSE PnID, pneumatic connections in blue

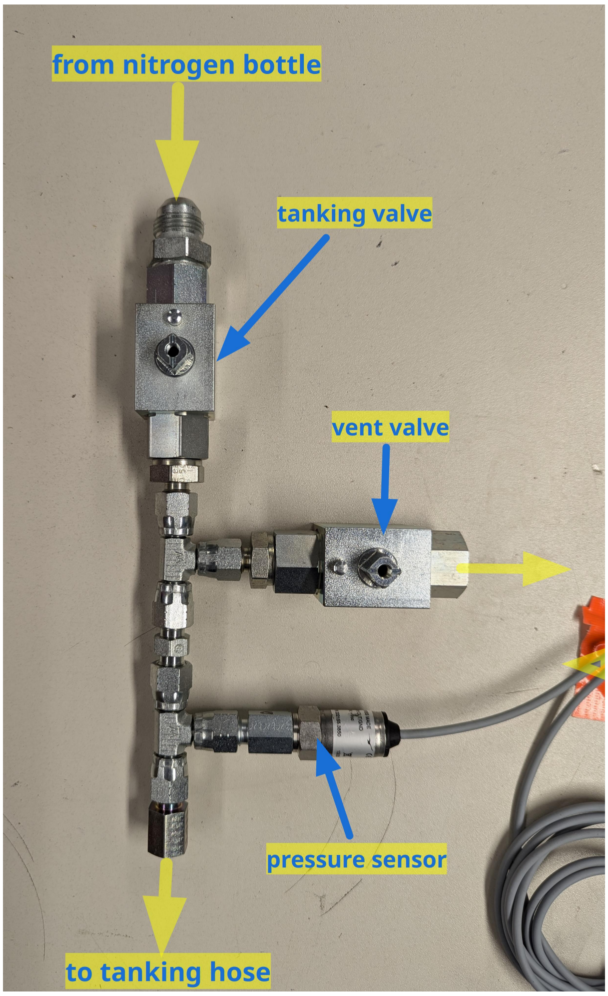


Fig. 2.36: HPN2 tanking valve section

if the bottle has sufficient pressure.

The nitrogen gas enters the valve section through the pressurization valve. At two T-fittings, a vent valve, a pressure sensor and a quick disconnect are connected. The vent valve leads to atmosphere and is used to vent the hose connected to the rocket before disconnection. The pressure sensor is used to monitor tanking progress. The connections are made with JIC hydraulic connectors rated to 310 bar

Attached to the valve section at the quick disconnect is a flexible hose leading to the retraction arm. A T-fitting splits the flow to two quick disconnects, which are connected to the fill ports of the pressure regulators inside the rocket.

Pneumatic System:

The actuation of valves has been a challenge for us for a long time. Cryogenic and high pressure ball valves require too much torque for a normal RC-servo to handle. Our self-developed BLDC-motor powered "Turboservos" worked, but proved to be temperamental and required constant adjustment. At the advice of our friends from GATE Space, we invested in pneumatic actuators (NieRuf AN02 GD-063) which have performed perfectly.

For mounting the actuators to the valves, we designed a universal mounting interface for all our ball valves. The parts are 3D-printed in ASA. Additionally we developed an

Fig. 2.37: Pneumatic actuator with feedback system, mounted to a valve on our test stand

electrical position feedback system with a visual indicator of the valve state.

The actuators are controlled by mono-stable 5/2 solenoid valves. They are configured in a fail-safe manner: if electrical power is lost, the actuators default into their safe position (closed for tanking valves, open for vent valves). In our engine test stand this allows for an electronics-independent emergency stop.

Our pneumatic system is fed by a nitrogen bottle. A bottle pressure regulator reduces the pressure to around 14 bar (but no more than 16 bar). This is led into the pneumatics cabinet, where a second pressure regulator further reduces the pressure to 8 bar for the pneumatic components, while a different pressure regulator produces the 1.5 bar needed for LOX tanking. The pneumatic valves are mounted on top of a distribution manifold and their output lines connected to pass-through fittings in the base of the cabinet.

Disconnection and Umbilical Retraction:

For the HPN2 quick-disconnects we use COTS components used for filling paintball pressurant tanks. They are pulled back with a spring-loaded part acting against the outside of the rocket, which is triggered by the retraction arm moving back.

Since we could not source a COTS quick-connect which satisfied our requirements of LOX-compatibility, low mass and bidirectional flow when connected, we opted for a SRAD approach. Our LOX quick-disconnect consists of a check valve inside the rocket and a counterpart with an electromagnet. The counterpart has a protrusion which holds open the check valve when the two parts are connected. This allows for bidirectional flow which is important in case of an abort after LOX-tanking.

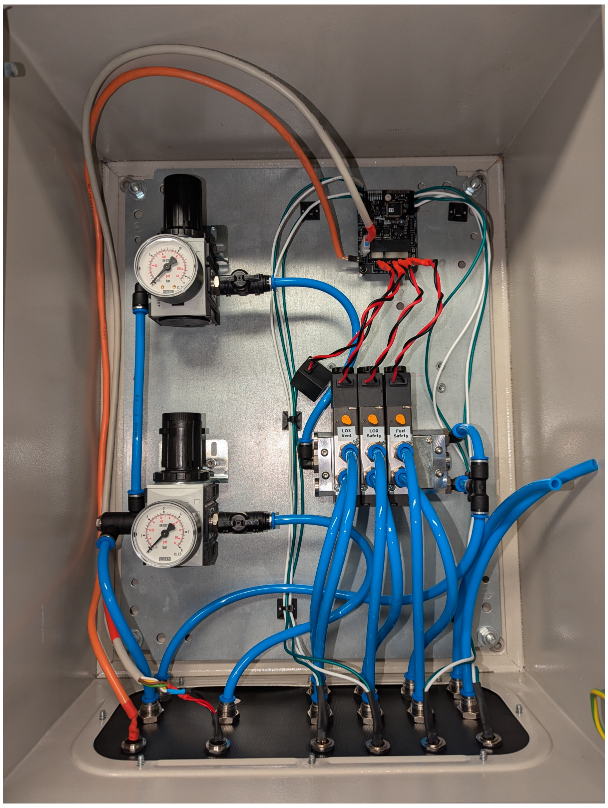


Fig. 2.38: Inside of the pneumatics cabinet (configured for test stand use)

The hoses are connected to a retraction arm, made from aluminium extrusions, which is mounted with hinges to the lowest launch rail truss. After tanking is completed, the connectors are disconnected and the retraction arm is retracted with a winch powered by a DC motor. This minimizes the risk of damage to the rocket during liftoff. The connection between the hoses and the arm is flexible, as to not interfere with the rocket mass measurement from the hold-down system.

For electrical and CAN-Bus connection an electrical umbilical is connected to the rocket with pogo-pins and magnets. It is not retracted together with the filling hoses, but is ripped off by the rocket during ascend.

2.7.4 Mission Control and Communication:

The GSE and rocket are controlled with a CAN-Bus on the ground by a server, located within an enclosure to the side of the launch rail. The server is controlled by mission control via a web interface on a Laptop, which is connected to the server with a pair of parabolic antennas used for WiFi extension. Multiple IP-camera feeds are also transmitted through this link.

Electrical power at the launch site is provided by EuRoC and is backed up with a UPS, located in the same enclosure as the server.

3 Mission concept of operation:

3.1 Rocket lifecycle during EuRoC:

1. Rocket gets presented at the exhibition.
2. On the day before the launch, the rocket gets assembled, the recovery section is prepared, and the electronics are checked.
3. On the launch day we bring the rocket to the launch site and start going through the launch day checklists.
4. After landing, we recover the rocket and return it to the launch site.
5. After inspection of the rocket, we bring it back to the exhibition area.

3.2 Launch Procedure:

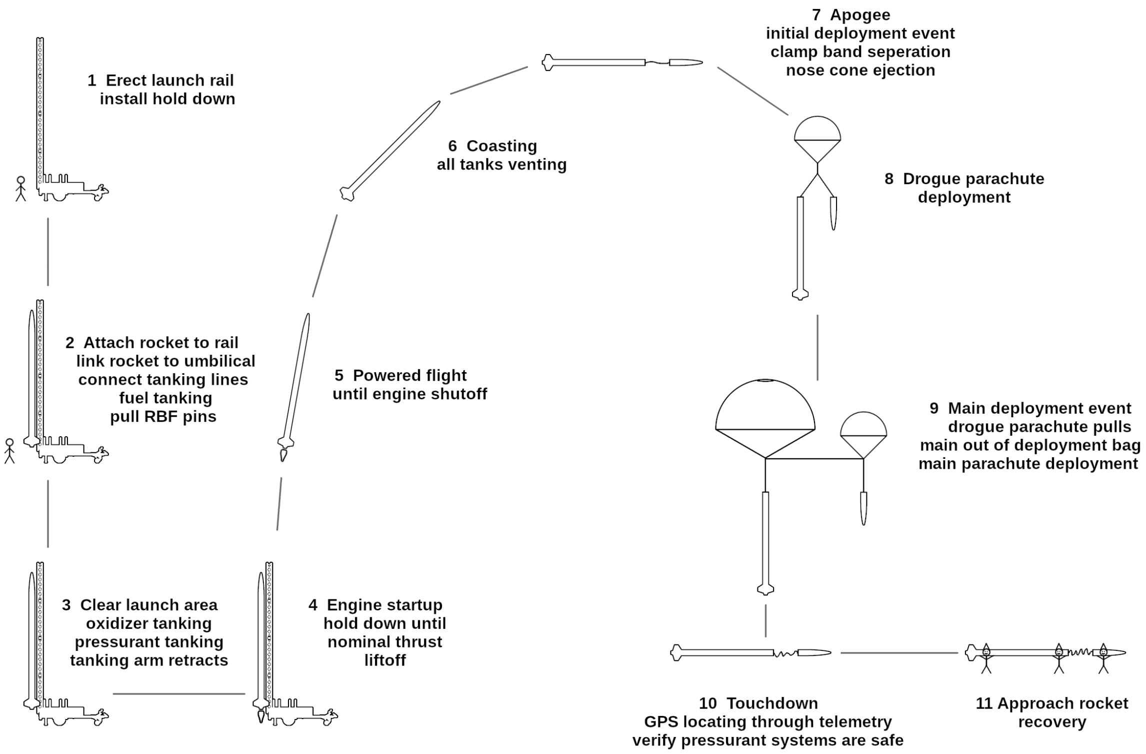


Fig. 3.1: Concept of Operation

3.2.1 Mission Control Setup:

1. Connecting directed radio link and Raspberry Pi with LoRa shield to server.
2. Powering on server, Mission Control PC and monitors.
3. Connecting Mission Control PC to server via LAN.
4. Opening Mission Control Web-Application on Web-Browser.

3.2.2 Launch Pad Setup:

1. Assembling tanking system.
2. Installing nitrogen bottles.
3. Testing pneumatic system.
4. Connecting GSE to directed radio link.
5. Sliding rocket onto launch rail with hold-down system.
6. Testing umbilical disconnection and retraction.
7. Connecting oxidizer, pressurant and electrical umbilicals.
8. Pulling RBF pin halfway to power on avionics.
9. Checking sensors and actuators, verifying movement and calibration, via Mission Control.

3.2.3 Fuel Loading:

1. Closing fuel main valve.
2. Attaching the quick-connector to the fuel fill port.
3. Filling the tanking vessel with predefined amount of ethanol.
4. Raising the tanking vessel to above the height of the fuel tank.
5. Waiting for all ethanol to drain into the rocket.
6. Covering the rocket's fuel inlet section.

3.2.4 Final Pad preps:

1. Opening pressurant bottle and checking for leaks.
2. Connecting igniters after checking for zero potential at electrical connections.
3. Staring pad cameras.
4. Pulling RBF pin.

From this point onwards the rest of the preparations until launch can be done completely remotely.

3.2.5 Oxidizer Loading:

Pressure and temperature data is closely monitored throughout the whole process.

1. Closing oxidizer main valve.
2. Opening LOX vent valve.
3. Taring LOX dewar scale and hold-down load cell.
4. Opening LOX fill valve.
5. Pressurizing dewar to start tanking.
6. Closely monitoring dewar and rocket weight.
7. As soon as target LOX amount is tanked into rocket, close LOX tanking valve.
8. Depressurize dewar.

3.2.6 Pressurant Loading:

1. Closing pressurant venting valve.
2. Opening pressurant tanking valve.
3. Waiting for stable pressurization.
4. Closing pressurant tanking valve.
5. Opening pressurant vent valve.

3.2.7 Disconnection and Retraction:

1. Disconnecting LOX disconnect.
2. Activating umbilical retract of pressurant and oxidizer tanking lines and verifying clean separation.

3.2.8 Internal Countdown and Launch:

1. The propellant tanks are pre pressurized to the operating pressure via an external sequence.
2. All system parameters are manually checked to be within range.
3. After Go/NoGo, the rockets internal control is activated via Mission Control .
4. The rocket start internal countdown, activates the igniters, and actuates all necessary valves.
5. The rocket checks for proper engine performance after ignition. This is evaluated by chamber pressure and thrust force on hold-down
6. If proper engine performance is detected by the rocket, it sends a signal to the Launch Pad to release the holddown.
7. Lift-Off is achieved once the electrical umbilical that is magnetically held in place gets disconnected by the rocket moving out of reach.

Until lift-off there is still a possibility for manual abort from Mission Control. Beginning with lift-off and the electrical umbilical disconnecting the rocket is monitoring itself and no manual abort is possible. The rocket is now in powered ascent phase.

The entire engine burn duration is about 5.7 s long, 3.7 s after hold down is released. After this time the main valves are closed and we have achieved MECO (Main Engine Cut Off).

From then on, the rocket is in unpowered ascent until apogee is detected and recovery is triggered.

3.2.9 Recovery:

1. Opening fuel main valve for remaining fuel unloading.
2. Separation of the nose cone from the body tube at apogee.
3. Drogue chute release at apogee.
4. Main chute release 450 m altitude. Backup Altimax triggers at 450 m.
5. Recovering the rocket after landing.

3.2.10 GSE Security:

1. Stopping all cameras.
2. Closing the nitrogen bottles.
3. Vent pressurant tanking system by opening the pressurant tanking valve.
4. Vent pneumatics system by opening the manual venting valve.

3.3 Simulation:

3.3.1 Landing Estimate by MonteCarlo Simulation

The estimate was obtained using the "MonteCarlo"tool in the simulation software "RocketPy."The wind velocity x- and y-factor were varied with a mean value of 0 and a standard deviation of 10. Since this tool does not support liquid motors, we approximated our liquid motor with a solid motor that has the same propellant-weight and thrust profile. To account for the change in the center of gravity (CG) due to the varying liquid mass during flight, we simplified this by positioning the motor at the rocket's CG.

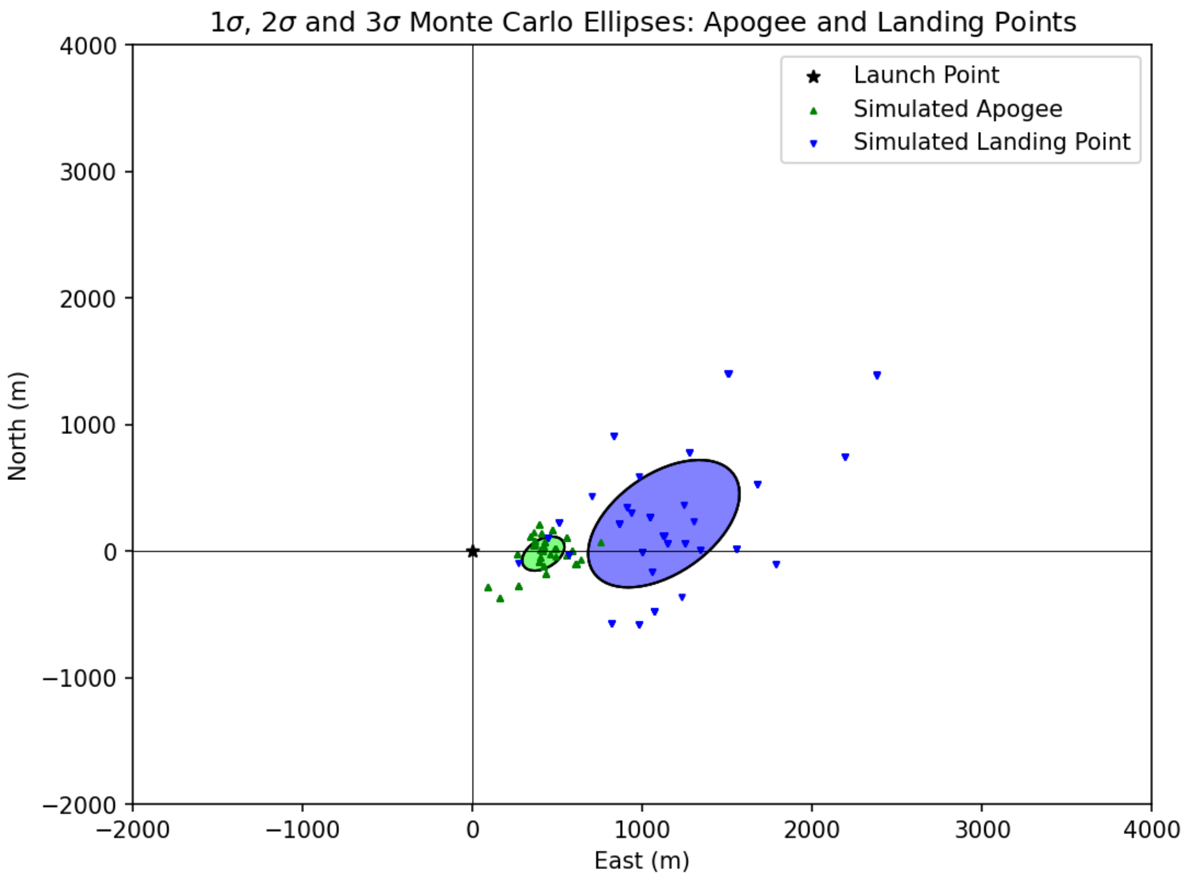


Fig. 3.2: Output of the MonteCarlo Simulation

3.3.2 3D-figure of the flight trajectory:

The 3D-trajectories were obtained by running a RocketPy simulation with the data of our rocket.

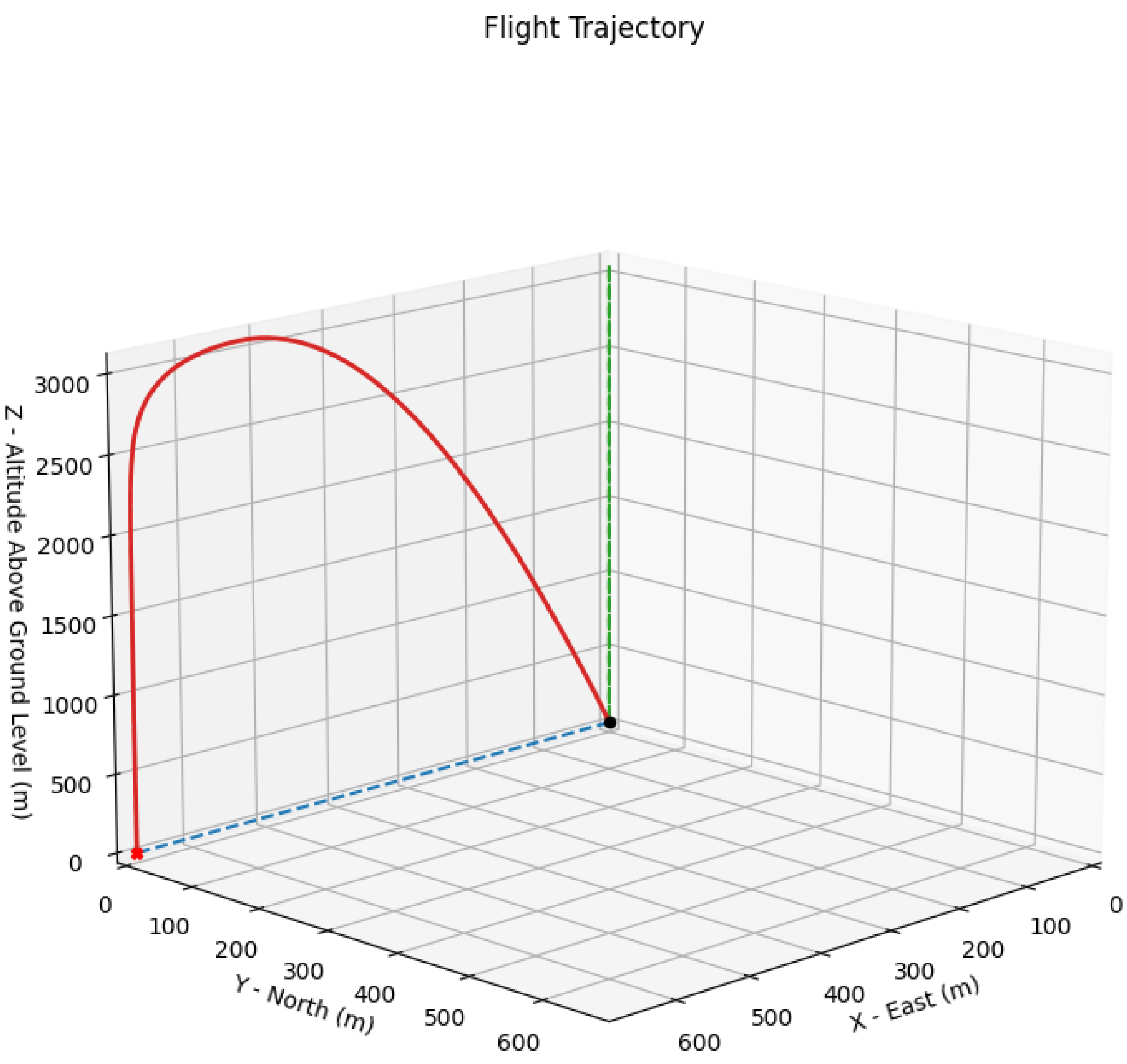


Fig. 3.3: 3D-trajectory without wind

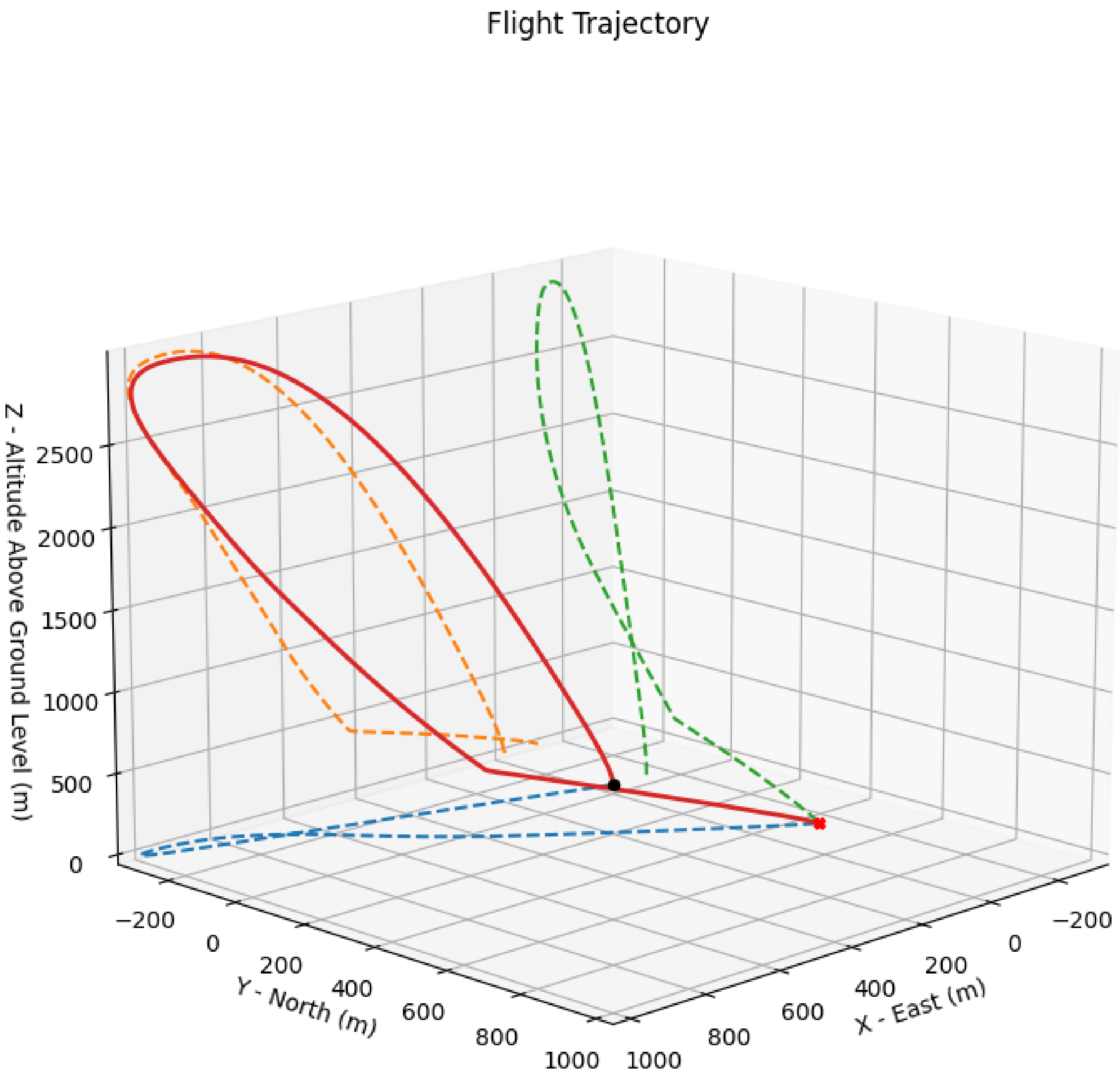


Fig. 3.4: 3D-trajectory with predicted winds

4 Conclusion and Outlook:

Project Lamarr and its Rocket Hedy embody the TU Wien Space Team's 5 year tradition of developing liquid-propelled rockets. Leveraging years of expertise from previous projects, Lamarr represents a leap forward, incorporating numerous advancements over its predecessors.

One of the project's key achievements lies in its ambitious scope. It was a challenge to determine which of the many innovative ideas to prioritize in order to meet deadlines, and which to defer for future exploration. A notable change was the transition from nitrous oxide to liquid oxygen as the oxidizer, requiring not only new infrastructure but also a steep learning curve for the team.

Ongoing challenges include managing time to complete and thoroughly test all systems, as well as ensuring proper documentation to pass on vital knowledge to future team members. As is common in volunteer-based teams, we face limitations in manpower, particularly during university exam periods. Addressing this issue may involve rethinking the recruitment process for upcoming projects.

The students now leading Project Lamarr began with little knowledge, but through dedication and experience, have grown into experts who will pass their insights to the next generation. This continuous transfer of knowledge will enable future Space Team members to further refine and expand the team's capabilities. In addition to technical knowledge, the experience to work on hands-on practical project of the caliber of a space project is invaluable for life as well as for their careers.

Several areas for improvement have already been identified for future projects. For instance, we began exploring the use of structural tanks to reduce the rocket's weight but ultimately switched to aluminum tanks due to time constraints. This decision also affected the decision to lowering the flight goal from 9 kilometers to 3 kilometers, as it allowed us more flexibility with the rocket's total mass. Achieving a 9-kilometer altitude would be an exciting challenge for future endeavors, in addition to minor and major updates.

A Appendix

A.1 System Data:

Mass (Dry)	15 000 g
Fuel Mass	2060 g
Oxidizer Mass	2497 g
Pressurant Mass	126 g
Mass (Wet)	19 683 g
Tank Volume (Fuel)	2700 mL
Tank Volume (Ox)	1750 mL
Length	3702.5 mm
Diameter (Body)	132.8 mm
Diameter (Nozzle)	75 mm
Pressurant Pressure	300 bar
Oxidizer Pressure	30 bar
Fuel Pressure	30 bar
Pressurant Pressure	300 bar
Nominal Thrust	2000 N
Combustion Chamber Pressure	15 bar
Burn Duration	5.2 s (Including 2s Holddown)
Total Impulse	6.200 N s
Max Speed	294 $m\,s^{-1}$ (Mach 0.85)
Apogee	3 km
Descent Rate (Drogue)	29 $m\,s^{-1}$
Descent Rate (Main)	6 $m\,s^{-1}$
Altitude Main Chute Deployment	Altimax G4: 450 m, Backup CATS Vega: 450 m
RF (LoRa) Frequency	868 MHz

Tab. A.1: General System Data

A.2 Detailed test reports:

Test Report

Test Type	Hotfire Test
Date / Time	04.09.2024
Participants	Liquids team
Module	Propulsion
Component	Engine

Testing purpose:

- Evaluate the performance of both the fuel and oxidizer systems, focusing on mass flow measurements.
- Validate the automatic fuel pre-pressurization system, which is analogous to the final setup in the rocket.

Preparation:

- Followed standard checklists.
- Installed a weighting system for the fuel side for more accurate measurement of fuel mass flow.

Results:

- **Ethanol Mass Flow:** The ethanol flow rate, though not ideal due to pre-pressurization, was deemed nearly sufficient for the duration of the test. However, the issue with the pre-pressurization system affected the accuracy of the flow regulation.
- **System Stability:** The ethanol pressurization system failed, potentially due to the power supply being insufficient when multiple solenoid valves were engaged simultaneously during the test. Previous cold flow tests had shown nominal performance with this system, but the increased demand during the hotfire test may have overloaded the power supply.
- **Thrust:** Even though the fuel system did not behave as planned, the engine still delivered around 160 kg of thrust which would be deemed sufficient for a flight.

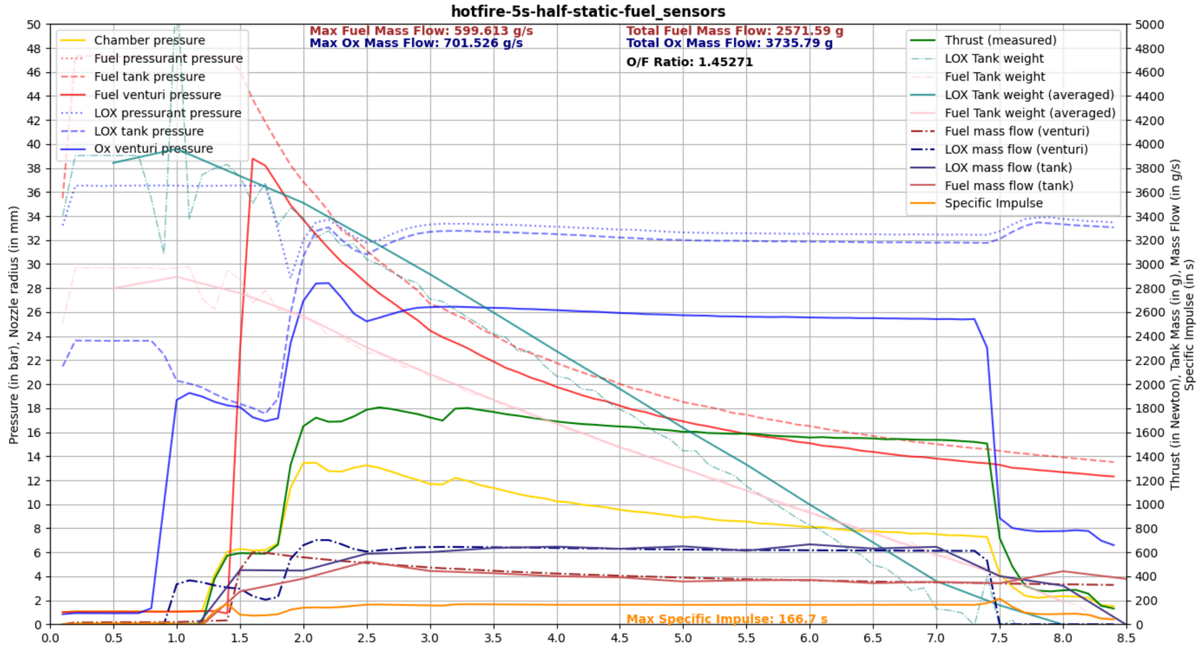
Discussion:

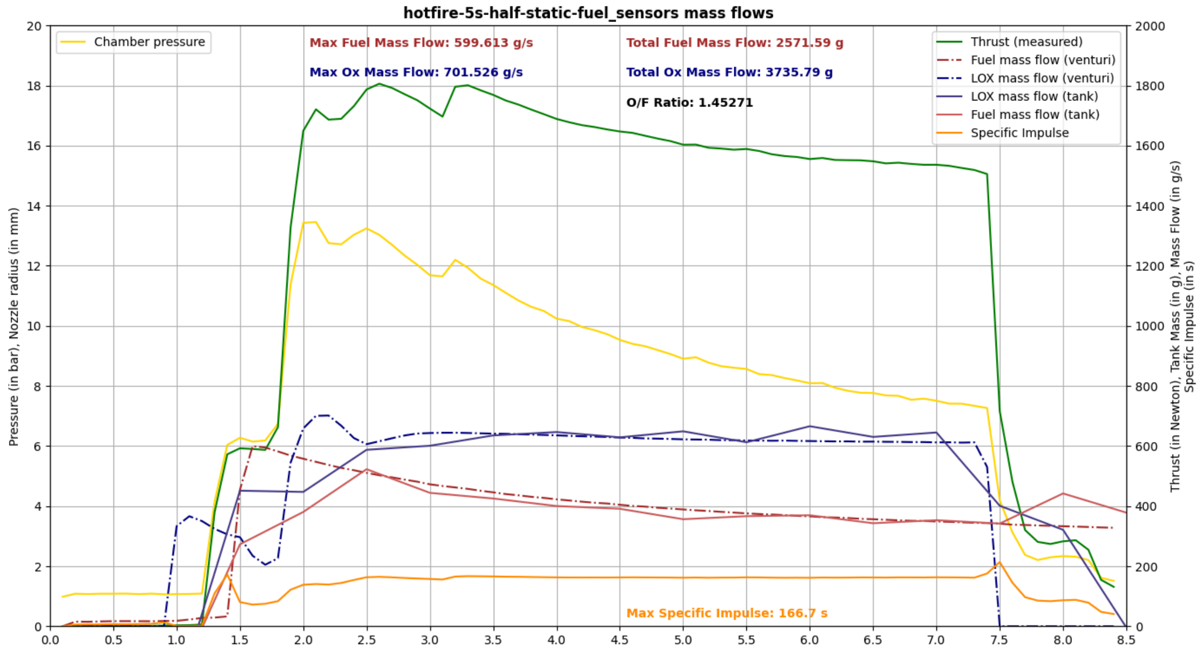
- The automatic pressure regulation system for the ethanol tank failed, leading to manual pre-pressurization.
- Initial tank pressures were not nominal, particularly for ethanol, which reached almost 50 bar instead of the intended 30 bar.
- Ethanol was fed through the pre-pressurized gas volume due to the failure of the solenoid valve responsible for pressurization.
- Both the LOX and ethanol tanks were equipped with weight sensors, allowing precise mass flow calculations during the test.

Learnings:

- The pressure regulation issue in the ethanol tank is suspected to have been caused by an inadequate power supply to the solenoid valve during hotfire. This was not an issue in previous cold flows.
- Manual pre-pressurization affected test accuracy but provided useful insights into the system’s behavior under non-ideal conditions.
- The load cell data from the ethanol tank was highly reliable, allowing for confident mass flow estimates.

Attachments:





Test Report

Test Type	Hotfire Test
Date / Time	05.08.2024
Participants	Liquids team
Module	Propulsion
Component	Engine

Testing purpose:

- Measure and analyze mass flow rates of ethanol and liquid oxygen (LOX) during engine operation.
- Evaluate engine thrust and stability of the LOX system.
- Compare different methods of calculating mass flow rates.

Preparation:

- Followed standard checklists.
- Set up for both the Tank Weight Method and Venturi Method for mass flow calculations.

Results:

- **Ethanol Mass Flow:** Calculated mass flow rate was 600 g/s, significantly higher than the design value of 465 g/s, indicating a possible discrepancy in the discharge coefficient for ethanol.
- **LOX System Stability:** Oscillations in the LOX pressure were largely eliminated, and the system response was stable.
- **Mass Flow Agreement:** The mass flow rates calculated using the Venturi Method and Tank Weight Method were in good agreement during steady-state conditions at full thrust.
- **Thrust vs. Chamber Pressure:** The thrust decrease was less than expected based on the chamber pressure drop, likely due to nozzle ablation increasing the throat diameter, leading to higher thrust at a given chamber pressure.

Discussion:

- The initial dip in oxidizer pressures at the start of the test might indicate the LOX system nearly began oscillating again, potentially due to line warming post-prechill.
- Venturi method calculations were under review for potential errors related to different partial pressures not being accounted for.
- The ethanol mass flow discrepancy suggests a need to revisit the discharge coefficient's dependency on fluid type.

Conclusion and Future Work:

- **Specific Impulse:** Calculated specific impulse based on mass flow rates, with further analysis planned.
- **Further Analysis:** The team will back-calculate ethanol and LOX mass flow rates from previous tests to ensure consistency and refine specific impulse data.
- **Planned Improvements:** Upcoming tests will focus on optimizing the pressurization system, with continued refinement of engine performance as a secondary goal.

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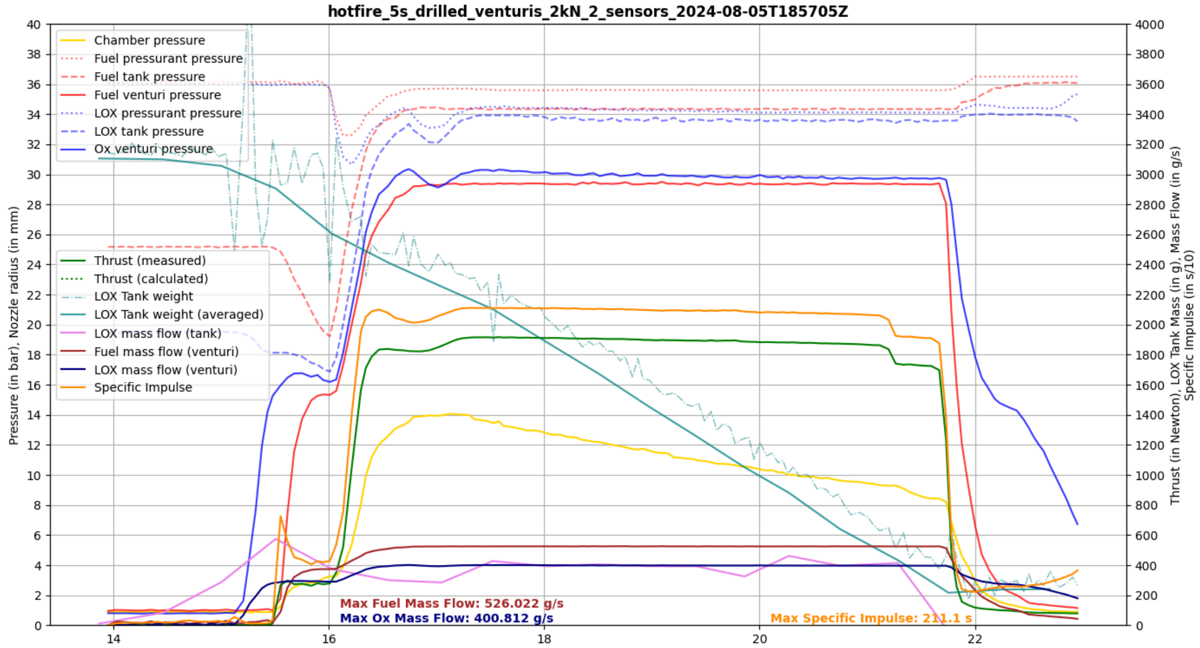


Test Report

Test Type	Hotfire Test Series (3 Tests)
Date / Time	13.07.2024
Participants	Liquids team
Module	Propulsion
Component	Engine

Testing purpose:

- Evaluate the LOX mass flow and its impact on engine performance.
- Analyze impact of LOX preheating and autogenous pressurization
- Assess the relationship between nozzle ablation, chamber pressure, and thrust.

Preparation:

- Followed standard checklists.

Results:

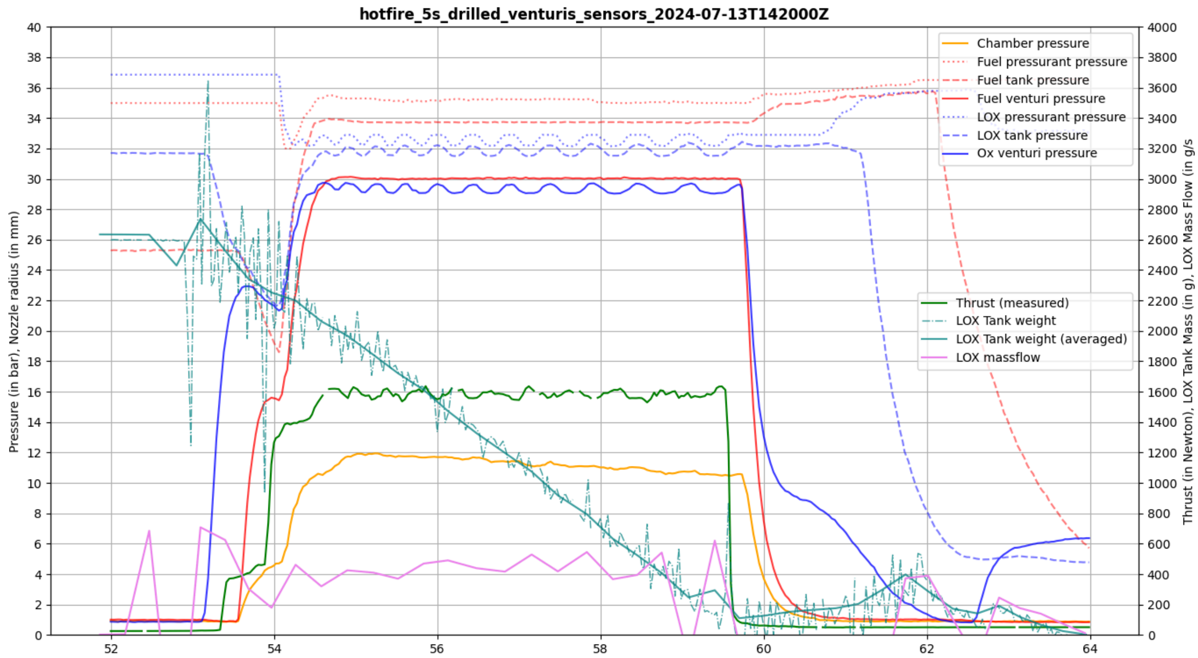
- LOX mass flow was below the required 600 g/s.
- Significant pressure oscillations in LOX tank and Venturi, leading to combustion instability.
- LOX Venturi pressure start-up behavior improved in tests 1 and 2, with immediate regulation to 30 bar.
- Notable nozzle ablation observed, particularly in tests 2 and 3 (throat diameter measurements: 39.86 mm, 46 mm, 46.07 mm).
- Discrepancy of more than 10% between calculated and measured thrust in tests 2 and 3.
- Increased time delay between chamber pressure and thrust measurement compared to the previous test on 03.06.2024 (approx. 0.1 seconds).

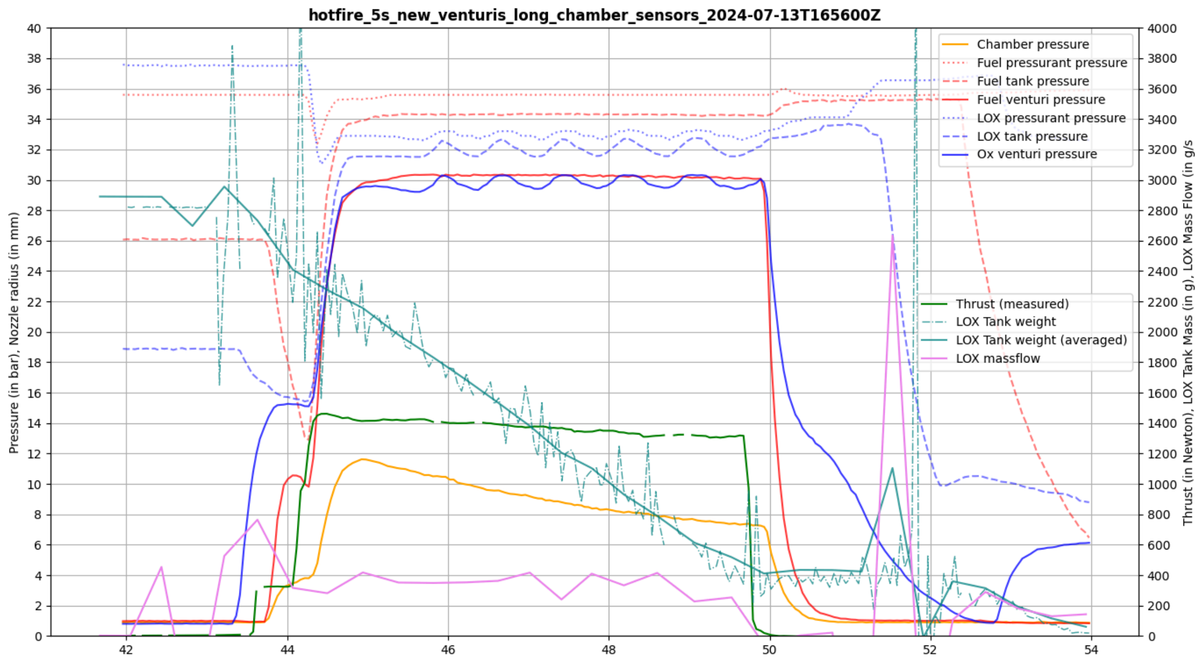
Learnings:

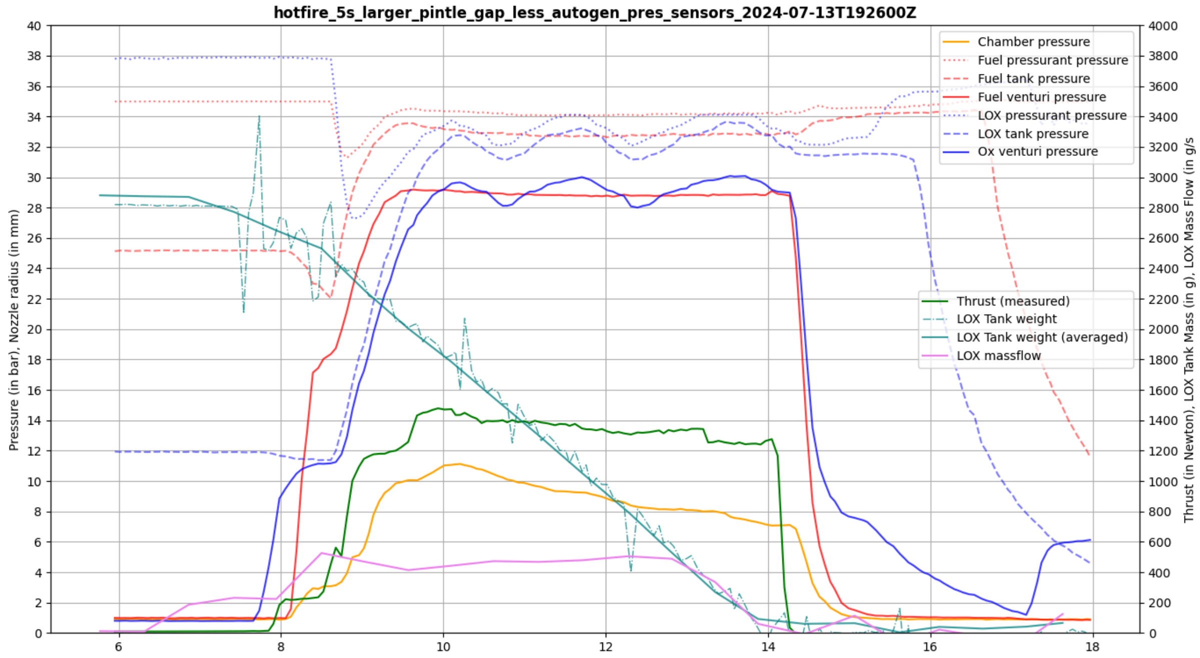
- LOX mass flow rate needs improvement to meet the required specifications.

- Pressure oscillations may be linked to insufficient pre-chilling and issues with the LOX safety valve or diffuser.
- Nozzle ablation requires further investigation, with a focus on the correlation between ablation, chamber pressure, and thrust.
- The start-up sequence for LOX pressure control has been successfully optimized.

Attachments:






hotfire_5s_larger_pintle_gap_less_autogen_pres_sensors_2024-07-13T192600Z
Pressure (in bar), Nozzle radius (in mm)
Thrust (in Newton), LOX Tank Mass (in g), LOX Mass Flow (in g/s
Chamber pressure
Fuel pressurant pressure
Fuel tank pressure
Fuel venturi pressure
LOX pressurant pressure
LOX tank pressure
Ox venturi pressure
Thrust (measured)
LOX Tank weight
LOX Tank weight (averaged)
LOX massflow

Test Report

Test Type	Hotfire Test
Date / Time	01.06.2024
Participants	Liquids team
Module	Propulsion
Component	Engine

Testing purpose:

- Verifying the engine's functionality.
- Comparing the engine's actual performance to theoretical models.
- Verifying the functionality of custom-designed propulsion components.
- Gaining information about the thrust chamber's ablation.

Preparation:

- Followed standard checklists.

Test execution:

Test Sequence:

- t=-2: Initiate igniter.
- t=0: LOX main valve 100% open.
- t=0.5: Fuel main valve 100% open.
- t=6: Close main valves.

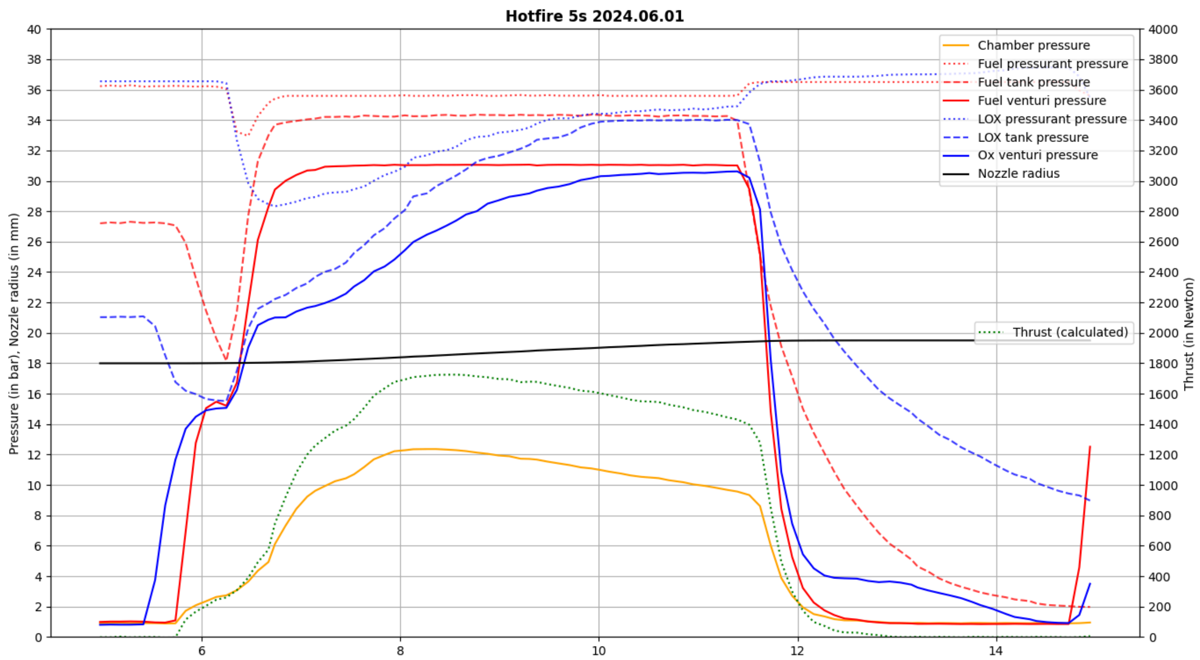
Results:

- Achieved 12.5 bar peak chamber pressure.
- Thrust sensor failed during the test.
- Pintle injector performed successfully.
- Lower-than-expected thrust chamber ablation; phenolic liner used with 8mm wall thickness, approximately 1mm ablated.
- Engine weight reduced from 3566g to 3440g post-test.

Learnings:

- Thrust chamber ablation is less severe than anticipated; phenolic liner might be optimized for future tests.
- The importance of activating the sound suppression system during testing, with potential integration into the test sequence.
- Identified a leak in the oxidizer tanking valve, which will be addressed before the next test.
- Mitigation of trapped LOX between the main and safety valve via a burst disk, pending venting adjustments.
- Thrust back-calculation based on chamber pressure, estimated at 1.86 kN (expected).
- Venturi modifications planned for the next hotfire test.
- Validation of the pintle injector for flight use.

Attachments:



Test Report

Date / Time	14.08.2024 / 12:00
Participants	Simon Waldl
Module	Propulsion
Component	Adapter Pressuranttank
Version	1
Test No.	2
Test Type	Hydrostatic
Doc. Ref.	Propulsion-Adapter Pressuranttank-T2

Testing purpose:

Evaluating the structural strength up to a pressure of 45 MPa for 30 minutes, to see if the designed geometry is safe and functional.

Preparations:

The whole assembly was cleaned with distilled water and Isopropanol-Alcohol to get rid of remnants from manufacturing and oils. To ensure proper disassembly all threads have been lubricated with a drop of oil. The pressureregulator's side was closed off with a plug, which has the same UNF-5/8-18 thread and O-Ring geometry as the regulator. This side (5/8-18-side) was tightend until the O-Ring (NBR90, 14.5x2mm) was fully compressed and the mating surfaces touched and was then tightened to ensure enough contact force for the triangle groove. The tank side is exchanged with a massively oversized dummy tank with the exact geometry of the later used flight-tanks. The adapter was connected to the dummy tank until the mating surfaces touched and was then only slightly tightened, as this is a radial o-ring seal (NBR90, 17.5x2mm) and no extra preload is mandatory. The dummy-tank is connected to a ¼" -fitting for connecting to the test pump hose, and was sealed with a USIT-Ring (NBR80, BS821 for 1/4").

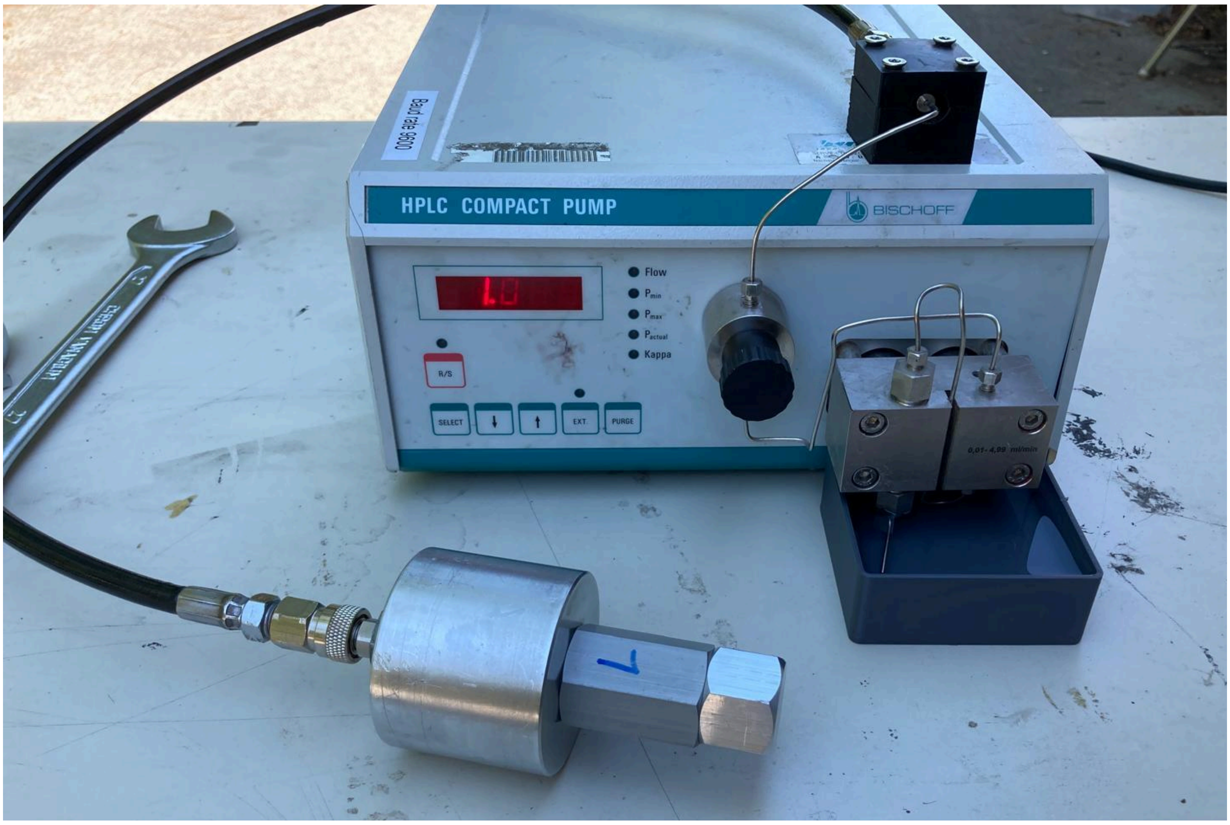


figure 1 - overview testsetup

figure 2 - overview testparts with O-rings

Test execution:

<u>Adapter 1:</u>

The Testassembly and the pump hose have been filled with distilled water until full and then connected.

The Pump settings where set to:
Flow=2 ml/min
Pmax=50 MPa
Kappa = 5

Pump was activated.
At a pressure of 25MPa(250bar) the USIT ring between hose-fitting and dummy tank started dripping.

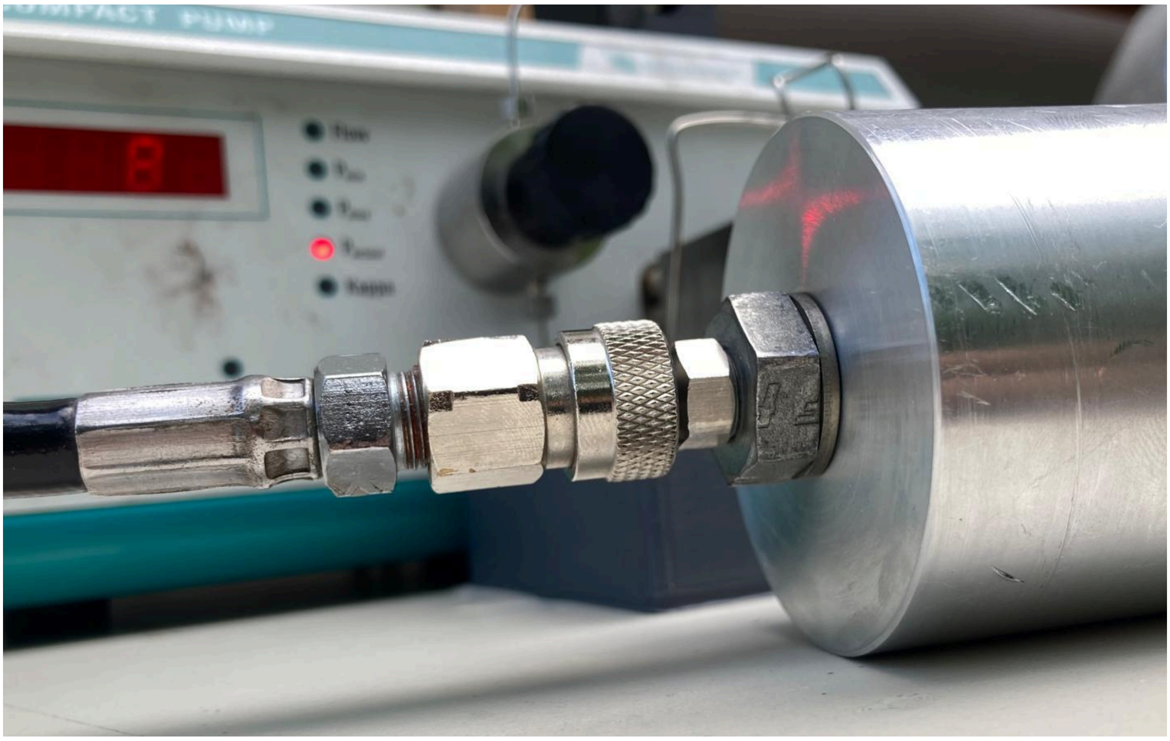


figure 3 - connection between dummy tank and hose fitting with USIT ring

The pressure was vented and fitting disconnected. The fitting was cleaned, the sealing surface has been recut and polished and again assembled and connected as described in the preparation section.

Pump was activated again.
After 5 min a pressure of 45MPa (450bar) was reached and the pump deactivated.
No deformation of any kind was detectable, also no water droplets have formed on all 3 sealing points.
After over 30 min wait time the pressure fell to about 44.2 MPa (442 bar), still no leaking was noticeable.

figure 4 - adapter 1: no leakage after 30+ min wait time

Test setup was vented and adapter 1 was removed for the test of adapter 2
No deformation was visible after a detailed search of the critical locations by eye.

<u>Adapter 2:</u>

The second adapter was filled with water and installed with new o-rings the same way as mentioned above.

Pump settings are(same as test for adapter 1):
Flow=2 ml/min
Pmax=50 MPa
Kappa = 5

Pump was started and kept running until a pressure of 45.3MPa (453bar) was reached.
No leakage or droplets evolved at any sealing point.<

After turning off the pump pressure started to drop at a rate of about 1MPa/min but still no water drops could be found.

The purge vent of the pump was tightened and the test table was moved so the (black) pump hose was in the shade as in the test for adapter 1. Temperatures have been around (30°C to 35 °C) ove the test period.

The pressure was again pumped up to 45.1MPa (451bar).
After a waiting period of 30 min, pressure dropped to 43.8MPa (438bar).
Still no visible leakage or water drops at any of the sealing points.

figure 5 - adapter 2: no leakage after 30+ min wait time

Preassure was purged and Testsetup disassembled. No visible Deformation on Adapter 2 after a detailed search on expected failure locations.

Results:

Both adapters show no signs of failure up to a pressure of over 45MPa (450bar) and 30 min wait time.
None of both adapter’s sealing points showed any leakage at any time of the test.

There have been slow pressure drops over the extended wait time of 30 min (<0.05 MPa/min) . These can be connected to Temperature changes and the black elastic hose for connecting the test pump and high surrounding ambient Temperature of over 30°C .

Attachments:

Test video adapter 1:
hydrostatic preassure test adapter 1 up to 450 bar.mp4

Test Report

Date / Time	4.3.2024 / 18:00
Participants	Simon Waldl
Module	Propulsion
Component	Adapter Pressuranttank
Version	1
Test No.	1
Test Type	Hydrostatic
Doc. Ref.	Propulsion-Adapter Pressuranttank-T1

Testing purpose:

Evaluating the prototype's seal tightness to a pressure of 45 MPa for 10 minutes, to see if the designed geometry is functional. For the final parts a pressure of 1.5 times the design pressure and 2 times the actual expected duration is mandatory.

Preparations:

The whole assembly was cleaned with distilled water and Isopropanol-Alcohol to get rid of remnants from manufacturing and oils. It was assembled with two NBR O-Rings in place and slightly compressed. The pressureregulator-side was closed with a plug. The tank side is exchanged with a massively oversized dummy tank with the exact geometry of the later used flight-tanks. The dummy-tank is connected to a ¼" fitting.

plug coldwelded into thread—> test was a failure

possible solutions:

other material for adapter

eloxatinng aluminium body

use LOX compatible grease

Test execution:

-

Results:

-

Learnings:

-

Attachments:

-

Test Report

Date / Time	2.7.2024 / 11:00
Participants	Simon Waldl
Module	Propulsion
Component	Decoupler
Version	1
Test No.	3
Test Type	Hydrostatic
Doc. Ref.	Propulsion-Decoupler hydrostatic 3

Testing purpose:
Evaluating the prototype's seal tightness to a pressure of 4.5 MPa (nominal 3MPa) for 10 minutes, to see if the designed geometry is functional. WhichFor the final parts a pressure of 1.5 times the design pressure and 2 times the actual expected duration is mandatory.

<u>first step:</u>
At what pressure is the magnetic holddown-force overpowered and the Decoupler openes?

<u>second step:</u>
Is the checkvalve closed? Is the pressure dropping?

<u>third step:</u>
Is the checkvalve free of leaks up to a Preassure of 4.5 MPa and a duration of 10 min?

Preparations:

The whole assembly was cleaned with distilled water and Isopropanol-Alcohol to get rid of remnants from manufacturing and oils. All Parts have been Installed according to the CAD assembly:

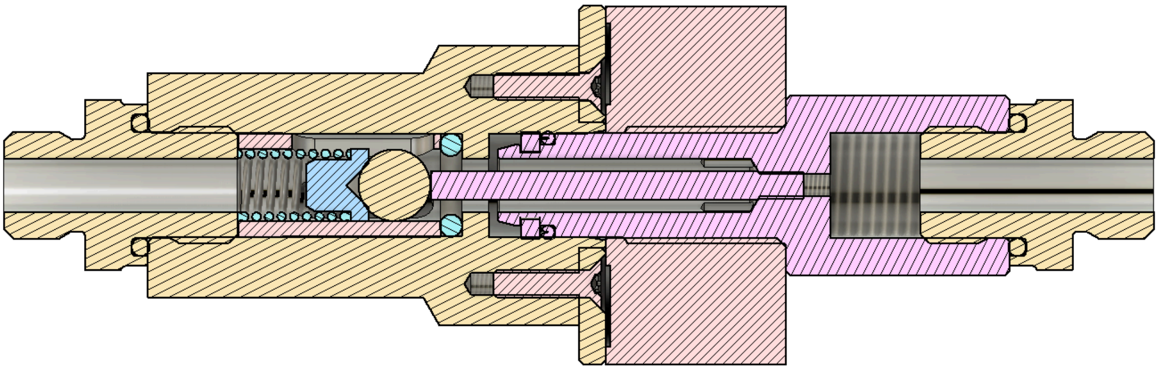


Figure 1-Decoupler Assembly section-view in CAD

The constructional changes since last test (Propulsion_Testreport-Decoupler_20240702_hydrostatic 2) are only on the checkvalve side. The valve-ball was changed to 304 stainless steel because the original balls startet rusting after last tests:

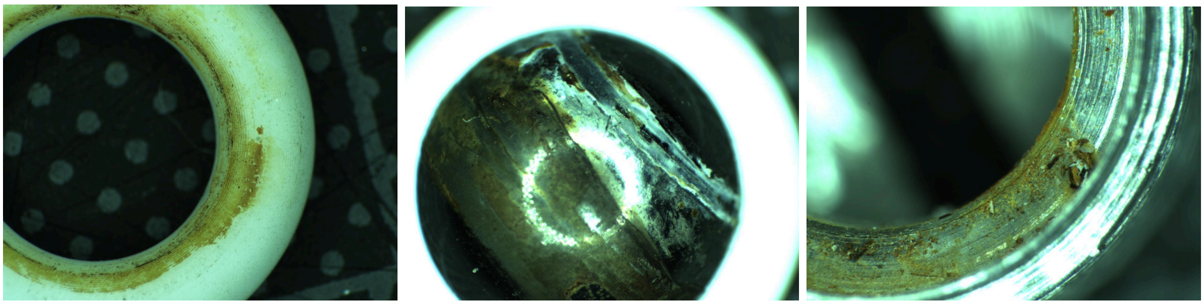


Figure 2-rust on checkvalve parts (O-ring, valvebody, sleeve)

For preventing any damage to the valve-body, a protective PTFE plunger was added. Also the sleeve geometry was simplified and is no longer a screw-in part. Finally the new stainless steel spring (D8,d1,n9) was installed.
This new Decoupler-assembly was connected to a ¼” fitting sealed by a Usit ring on the checkvalve’s side and closed off with a NBR-Ring sealed endcap on the fillnipple’s side.

Figure 3-Checkvalve parts

With the Decoupler assembled and the Magnet hooked up to a 12v powersupply, the pressure testing pump was filled with distilled water, hose and Decoupler-body.

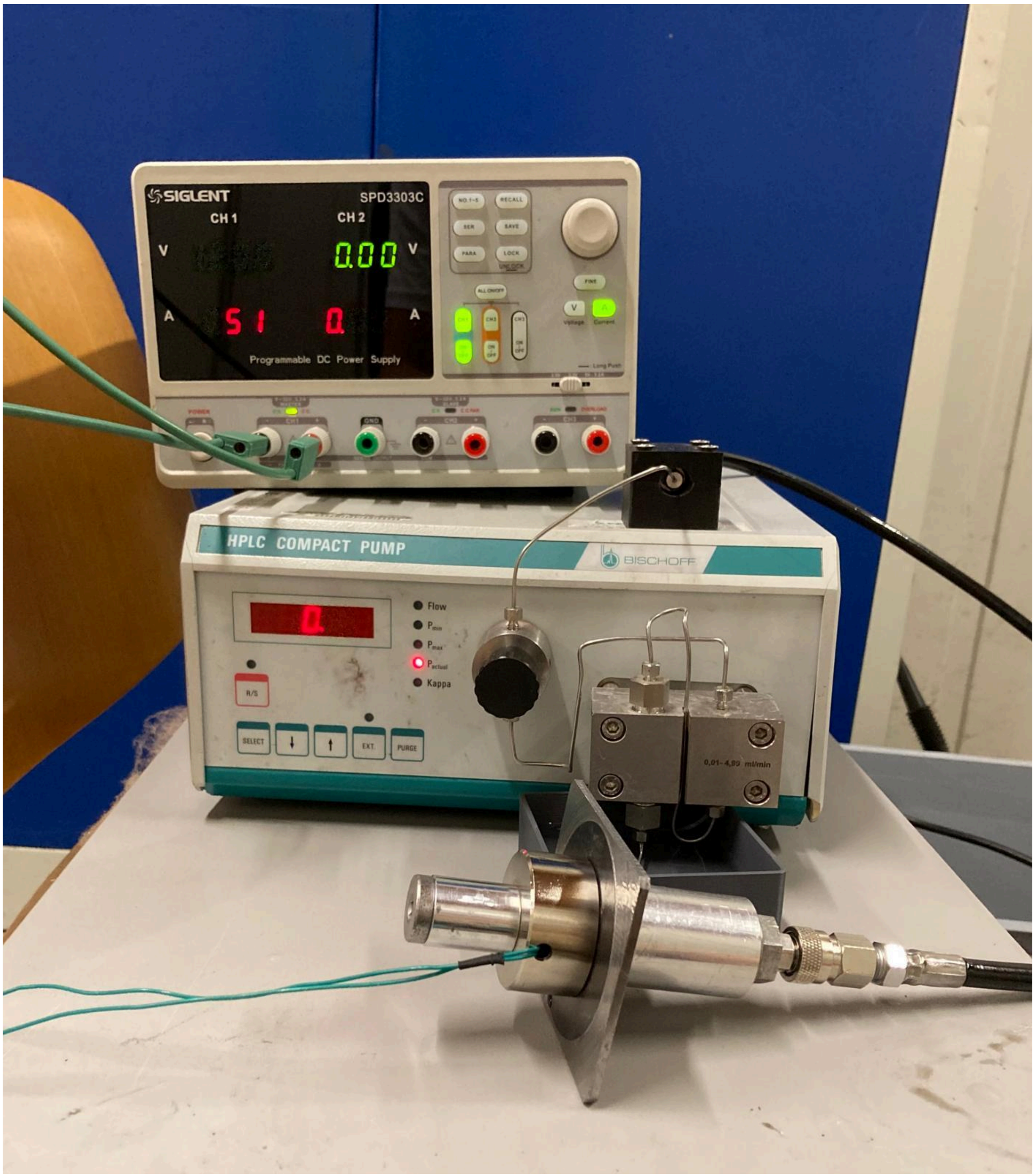


Figure 4-Testsetup

Test execution:

<u>Setup check:</u>

The setup was fully dried and slowly pressurized to about 0.5 MPa and the two sealing points (endcap and hose-connector) have been checked for leakage. No leakage was observed.

<u>pump-settings for all tests:</u>

Flow 0.1 ml/min

Pmin	0 MPa
Pmax	50 MPa
Kappa	50

<u>1.Holdownforce:</u>
Measured pressure shows signs of fluctuation, probably because it is a piston pump and cannot create a continuous flow. This problem was migrated by lowering the flow to 0.10 ml/min. The measured pressure slowly climbed up to 1.8 MPa (=18bar) without the Decoupler decoupling. Only in the exact second a pressure of **1.9 MPa** (19bar) was measured by the pump. The holddown-force was overpowered and the **Decoupler opened up** and the Decoupler-Nipple **fully ejected**.

<u>2.Correct closing of checkvalve:</u>
After ejecting the Decoupler-Nipple the pressure dropped to about 1 MPa and the pump was stopped. After a waiting time of at least 1 min still no further decrease of pressure was measured. Only a small droplet of water dripped out, This can be matched to the small amount of water captured between Decoupler Nipple and the actual sealing surfaces. This decoupling process was tested 3 times at pressures between 1 and 1.5 MPa and showed the exact same outcome.

<u>3.45bar and 10 min:</u>
For the final teststep the pressure was increased up to 6.5MPa and no leakage was noticeable even after a wait time of at least 15 min.

Results:

Decoupling under pressure works very well. Maybe even better at higher pressures (10+ bar) than lower ones (around 3 bar), which was not tested.

The checkvalve reliably closes after decoupling. After an initial pressure drop due to the decoupling process the pressure is held and shows no further decrease.

The checkvalve withstands a pressure to at least 65 bar and is able to hold the pressure and therefore shows minimal to no leakage over a periode of 15 min.

Learnings:

The checkvalve geometry is working as intended and the force generated by the spring is high enough to ensure proper decoupling and sealing, but not overpower the electromagnet. The Piston for protecting the valve-body fro the spring is also doing it’s job and not jamming the system.

As mentioned in the report of the second hydrostatic test, the seal between Nippel and Muffe ist still holding up perfectly without special treatment except keeping it clean.

Attachments:

-

Test Report

Date / Time	2.7.2024 / 11:00
Participants	Simon Waldl
Module	Propulsion
Component	Checkvalve
Version	1
Test No.	2
Test Type	Hydrostatic
Doc. Ref.	Propulsion-Decoupler Checkvalve

Testing purpose:

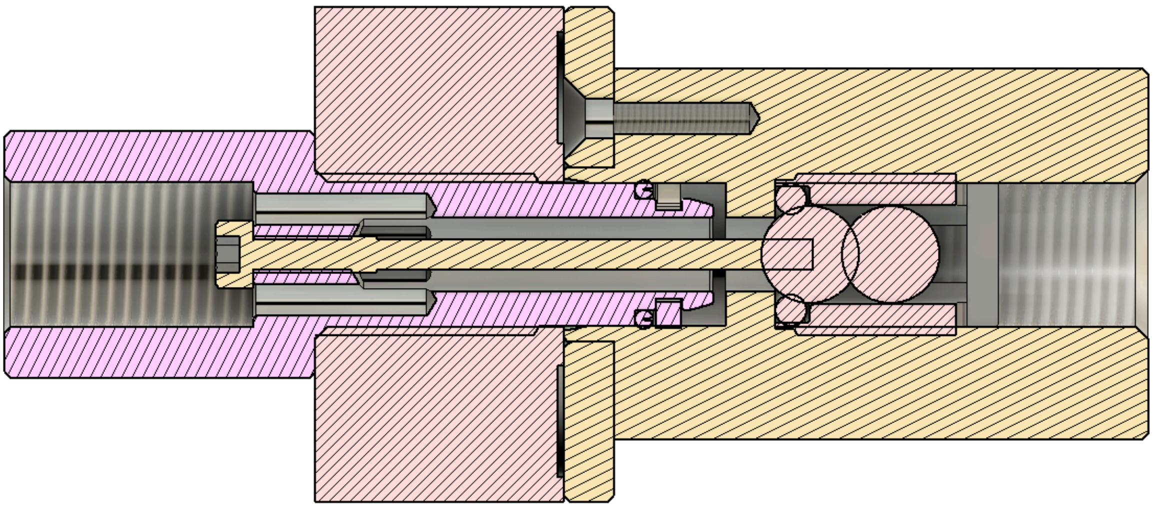
Evaluating the prototype's seal tightness to a pressure of 4.5 MPa for 10 minutes, to see if the designed geometry is functional. For the final parts a pressure of 1.5 times the design pressure and 2 times the actual expected duration is mandatory.

Preparations:

The whole assembly was cleaned with distilled water and Isopropanol-Alcohol to get rid of remnants from manufacturing and oils. The PTFE o-ring was preset by connecting a water hose. For the actual pressure test, the Decoupler-body was connected to a ¼" fitting sealed by a Usit ring. Distilled water was filled into the test-pump, hose and Decoupler-body.

Part overview:

CAD assembly:



Test execution:

First run:
Everything was connected, and the decoupler assembly was dried.
Pump was started and immediately the check valve started to drip. When waiting for some time air-bubbles could be seen in the valve outlet. Possibly

because of the remaining air in the system. al other connectors and fittings stayed dry.

Second run:

Disassembled everything and checked for possible causes. There was no visible Damage or deformation on the O-ring or sealing-surfaces. The spring used in the first run was exchanged for a much stiffer one and was assembled again. When assembling, the much higher force created by the spring was extremely noticeable.

After assembly and drying the pump was started. Pressure was raised up to 8,5 MPa (=85bar), and no leakage was noticeable even after 5 min passed. Everything was disassembled and checked for damage again. Slight deformation on the O-Ring on flat sealing surface, between the Decoupler's body (Muffe) and the diameter of the O-Ring changed from 11,5 to 11,8 mm, which is the inner diameter of the UNF ⅜-19 thread.

Third run:

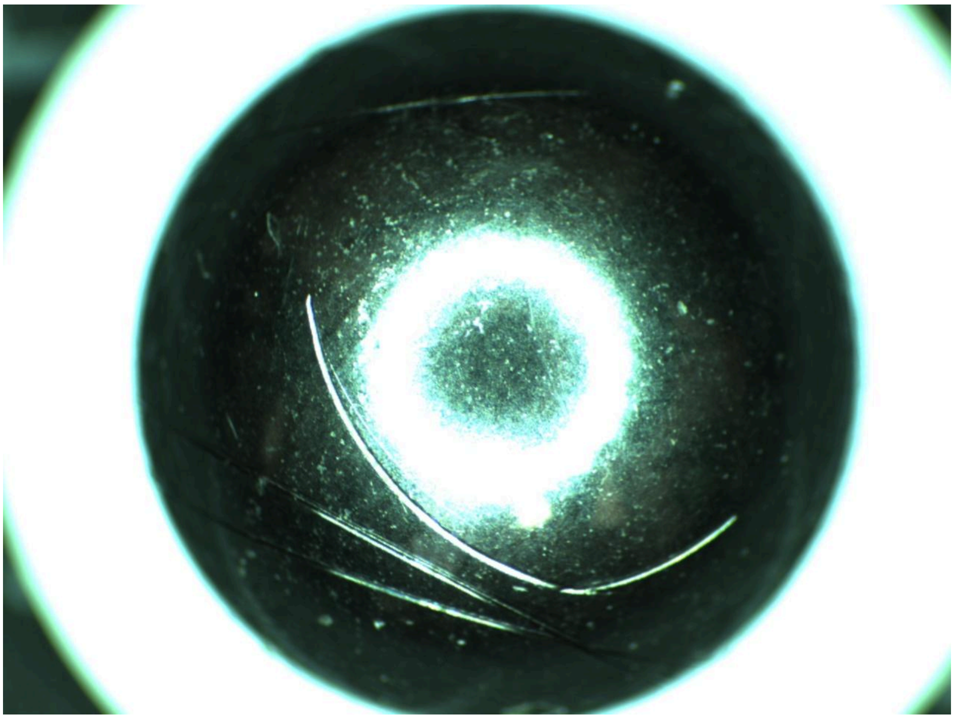
For a third run the spring was changed back to the first much weaker spring, to check if there is some kind of "grind in"-behavior. The valve was again instantly leaking from the start.

Disconnecting behavior:

After these initial tests there were some tests for the disconnecting behavior with the strong spring in place. With a pushback rod inside the Filling-Nipple in place, the Magnet was able to maintain a connection up to a pressure of 0.4 MPa (=4bar). When powering the magnet of, the filling nipple was ejected completely by the power of the spring and hydrostatic pressure. After that the check-valve closed completely. When pressure was raised afterwards, there was still no leakage even at pressures higher than 8MPa (=80bar)

Damage to valve ball:

The valve ball was badly damaged by the strong spring.



Results:

After the testing the power of the used spring was roughly measured, to estimate and compare the spring-forces inside the checkvalve.

Data weak spring:

-force constant	0.5 N/mm
-wire thickness	0.5 mm
-force closed	4 N
-force opened	6,5 N

Data strong spring:

-force constant	10 N/mm
-wire thickness	1.25 mm
-force closed	100 N
-force opened	150 N

Learnings:

For a checkvalve with PTFE O rings the initial closing force must be high enough to deform the O ring to create a proper seal. A higher Spring power is also beneficial for ejecting the fill nipple. This needs to be balanced with the available length inside the rocket and the holding power of the electromagnet. Also the valve-body needs to be protected from scratching by the spring. Sharp edges could possibly damage the O-ring and render the Valve useless. During this test the Seal between Nipple and Muffe was often opened and closed, and still had no notable leakage. Until then it was opened and closed at least 100 times, without any special treatment, except keeping it relatively clean.

Attachments:

-

Hydrostatic Test Decoupler

Date / Time	4.3.2024
Participants	Simon Waldl
Testing purpose	Hydrostatic test of the decoupler. Does the design of the nipple seal withstand a pressure of at least 6 bar and up to 10 bar? Is the strength of the magnet in combination with the structural steel core sufficient?
Changes	Version 1
Doc. Ref.	

Preparations:

Components and sealing surfaces were cleaned with isopropanol. A PTFE O-ring (9x1.5mm) was inserted and axially fixed with a PTFE retaining washer. A G1/4" adapter for the pressure test was screwed in and sealed with PTFE tape. Power supply and pump were set up. The hose was connected to the decoupler. The hose was filled until water flowed through the decoupler. The decoupler was closed, and the magnet energized (12V 0.57A).

Test execution:

1st Pressure Test:
The pump runs, and the pressure gauge shows increasing pressure with a resolution of 0.1 MPa. At 1.3 MPa, the connection comes loose. Before this, no leaks were visible.

2nd Pressure Test:
The procedure was exactly the same as the first test. At 1.1-1.3 MPa, the plug connection comes loose. It is noticeable on the pressure gauge that, after the connection opens, a further increase to 1.5 MPa is shown.

3rd Pressure Test:
Again, the exact same procedure as in the first and second tests. The

connection comes loose at a reading between 1.1 MPa and 1.3 MPa. After that, the displayed pressure again rises to 1.5 MPa, although the connection is already open.

4th Pressure Test:
Pressure was applied in intervals. Pump on for approx. 2 seconds → off for 5 seconds → on for 2 seconds → off for 5 seconds… and so on. This resulted in a pressure of 21 MPa before the connection came loose. A slight oscillation in the measurement was observed. The pump stops → pressure continues to rise (fluctuation < 1 MPa) → pressure drops slightly (by approx. 0.1 MPa).

5th Pressure Test:
Based on observations in the 4th pressure test, the pressure application speed was approximately halved (Kappa value?). Pressure was applied to over 1 MPa and below 2 MPa, and this pressure range was maintained for over 5 minutes. The aim was to investigate whether drops form anywhere or if the pressure drops. For this purpose, all sealing points were previously dried with a paper towel. Even after the holding time, no visible water accumulation or drops were formed anywhere. After the 5-minute holding time, the pressure was gradually increased in steps (short waiting times to allow the system to stabilize). A pressure of 2.4 MPa was reached and maintained. Upon reactivating the pump, the connection came loose.

Results:

A pressure of over 10 bar was reached in every pressure test. In the first 3 tests, an even higher pressure is suspected, but it could not be measured due to the setup. The peak values are significantly above 20 bar. The required value is 10 bar, which was also reached after the fifth reconnection, and no deterioration in sealing performance was observed.

Learnings:

The holding force of the magnet is sufficient. The seal also withstands the pressure. PTFE O-rings are suitable for pressures of several hundred bars, so it would be unusual if this were the bottleneck. It is pleasing that the sealing performance did not deteriorate with repeated connection and disconnection, at least in this pressure range → Not a single-use O-ring.

Attachments:

Main Release Test

Date / Time	2024-07-28
Participants	Lutfi Celik, Joscha Henkenjohann
Testing purpose	To evaluate the performance of the new Burnwire PCB and the Main Release housing, including the effectiveness of the heating wire installation and the overall assembly of the housing.
Changes	Version 1
Doc. Ref.	

Preparations:

The new Burnwire PCB and Main Release housing were assembled.

The heating wire was installed in the clamp, and the housing was constructed without additional insulation.

Tests were conducted to assess the performance of the heating wire and the housing's ability to withstand heat.

Test Execution:

The heating wire was attached to the PCB and tested under operational conditions.

Observations included the performance of the heating wire and the integrity of the housing during operation.

The clamp and housing were subjected to repeated testing to evaluate their durability.

Results:

The heating wire was securely mounted in the clamp, and contact was satisfactory.

The Main Release housing assembled easily; however, during tests, the outputs of the clamps showed signs of scorching.

The plastic of the housing began to melt slightly, and the wire embedded into the plastic, which complicated repeated testing.

Videos of tests with 0.3 mm Nichrome wire and 3.8 mm Paracord were reviewed. The cutting speed of the wire appeared adequate.

The heating wire pieces were cut to a 2.5 Ohm resistance, and the performance was generally acceptable.

Learnings:

The absence of additional insulation in the housing led to melting of the plastic and impaired the heating wire's performance.

There was insufficient space in the housing for Basalt band or PTFE insulation. A plan to use a layer of aluminum tape followed by Kapton tape for insulation was proposed.

Further testing with improved insulation materials is necessary to prevent plastic melting and ensure consistent performance.

Attachments:

Main Release Test

Date / Time	2024-04-16
Participants	Lutfi Celik, Alexander Berger, Stefan Kuttenreich
Testing purpose	To evaluate the performance of the main parachute trigger mechanism under varying tensile forces and to determine if knots in the nylon loop affect its maximum load-bearing capacity.
Changes	Version 1
Doc. Ref.	

Preparations:

Nylon loops with various knots were prepared.

Each loop was equipped with a 2.4 Ω Nichrome heating wire encased in a suitable housing.

The setup included a new lever system designed to safely apply larger tensile forces than achievable with weights alone.

A laboratory power supply was used to provide consistent voltage to the heating wires.

The test involved applying 2500 N tensile force to the nylon loops before activating the heating wire.

Test Execution:

Each nylon loop was subjected to a 2500 N tensile force for several seconds.

The tensile force was then reduced to approximately 240 N (equivalent to the rocket's weight).

The heating wire was energized to cut the nylon loop.

Tests were performed with Nichrome wires of 0.2 mm and 0.3 mm diameters to assess performance differences.

Results:

In the initial tests using the 0.2 mm diameter heating wire, the trigger mechanism failed. The wire burned out before cutting through the nylon loop, despite a short period of current flow.

Subsequent tests with a 0.3 mm diameter heating wire, which has over twice the tensile strength and less than half the specific resistance of the 0.2 mm wire, were successful. In these tests, the wire effectively cut through the nylon loop within approximately 2 seconds after the 2500 N pre-load.

The nylon loops withstood a maximum tensile force of approximately 6000 N. This indicates a safety factor of more than 2 for the 3.8 mm thick nylon ropes against the expected braking force of 2500 N.

Observations revealed that failures occurred where the ropes contacted the screw links, not at the knots, indicating that the knots did not weaken the loop significantly.

Learnings:

The 0.3 mm diameter Nichrome wire is effective for cutting the nylon loop after high tensile loading, suggesting it should be used for reliable operation.

The knots in the nylon loops did not represent a significant failure point; rather, the loops failed at contact points with the screw links.

The current design and concept are robust, and the safety factor for the nylon loops is satisfactory for the application.

Attachments:

Main Release Test

Date / Time	2023-12-29
Participants	Lutfi Celik, Victor Prack
Testing purpose	Evaluate an alternative main parachute release mechanism using nylon loops and heating wires for severing, focusing on actuation time and strength under parachute shock conditions.
Changes	Version 1
Doc. Ref.	

Preparations:

Nylon loops sewn and prepared for load testing.

Heating wires installed to cut the nylon loops and simulate parachute deployment. Multiple heating wire configurations were tested (wrapped through and around the loops).

Tested under controlled loads, aiming for consistent actuation times under various load conditions (240 N and simulated parachute shock with 1800 N).

Test Execution:

1. **Baseline Test:**
   - Under 240 N, nylon loop severed successfully in ~1 second using 0.2 mm heating wire.
   - No damage to supporting structures, with proper load handling.
2. **Simulated Parachute Shock:**
   - Initial attempts to simulate parachute shock using a drop test were unsuccessful due to inconsistent results from suspension dynamics.
   - Nylon loops pre-loaded with 1800 N (180 kg weight) to simulate shock conditions.

    - First test saw both 0.2 mm heating wires fail due to stress transfer from the elastic nylon loop, causing breakage at the insertion points.
3. **Revised Approach:**
    - Heating wire was wrapped around the loop instead of inserted through it, with no structural failures under 1800 N.
    - Further tests with 0.5 mm heating wire showed robustness but had slow release times (>10 seconds) due to lower heat output (10 W).
4. **Final Test:**
    - Reverted to 0.2 mm heating wire with a wrapped configuration, achieving a ~2 second release time at 40 W.

Results:

Nylon loop release under 240 N was reliable with actuation times around 1 second.

The wrapped configuration of the heating wire under 1800 N load was successful without structural damage.

Increasing wire thickness (0.5 mm) decreased performance due to lower heating power.

The 0.2 mm wire delivered acceptable results with ~2 second actuation time when optimized for robustness.

Learnings:

Wire insertion through the nylon loop introduces stress points and leads to wire failure under high loads. Wrapping around the loop solves this issue.

For future tests, 0.3 mm heating wire could provide a balance between robustness and heating power, potentially improving performance under high loads.

Precise measurement of parachute shock forces is necessary for further validation.

Main Release Static Load Test

Date / Time	2024-03-04
Participants	Lutfi Celik, Dominic Wipplinger, Alexander Berger
Testing purpose	To evaluate the performance of the new lever system for tensile load tests of recovery components and to assess the effectiveness of different knots and materials in terms of tensile strength.lore ipsum
Changes	Version 1
Doc. Ref.	

Preparations:

- The lever system was completed, constructed from a 170 cm long steel profile with an approximate 1:8 leverage ratio.
- The pivot point was a solid aluminum half-cylinder, and the base fixing point was a 5 mm thick L-steel profile mounted under the leg of the welding table.
- M6 ring nuts were used as anchor points for the ropes.
- Initial tests used 3.8 mm Paracord nylon ropes to check the setup's functionality and performance.

Test execution:

- The lever system was loaded with a theoretical tensile force of up to 2500 N, equivalent to the nominal braking force of parachutes.
- Breaking tests were conducted with 3.8 mm Paracord to determine the tensile strength and the effect of various knots.
- Observations included the behavior of the nylon cord under load and the stability of knots used in the tests.

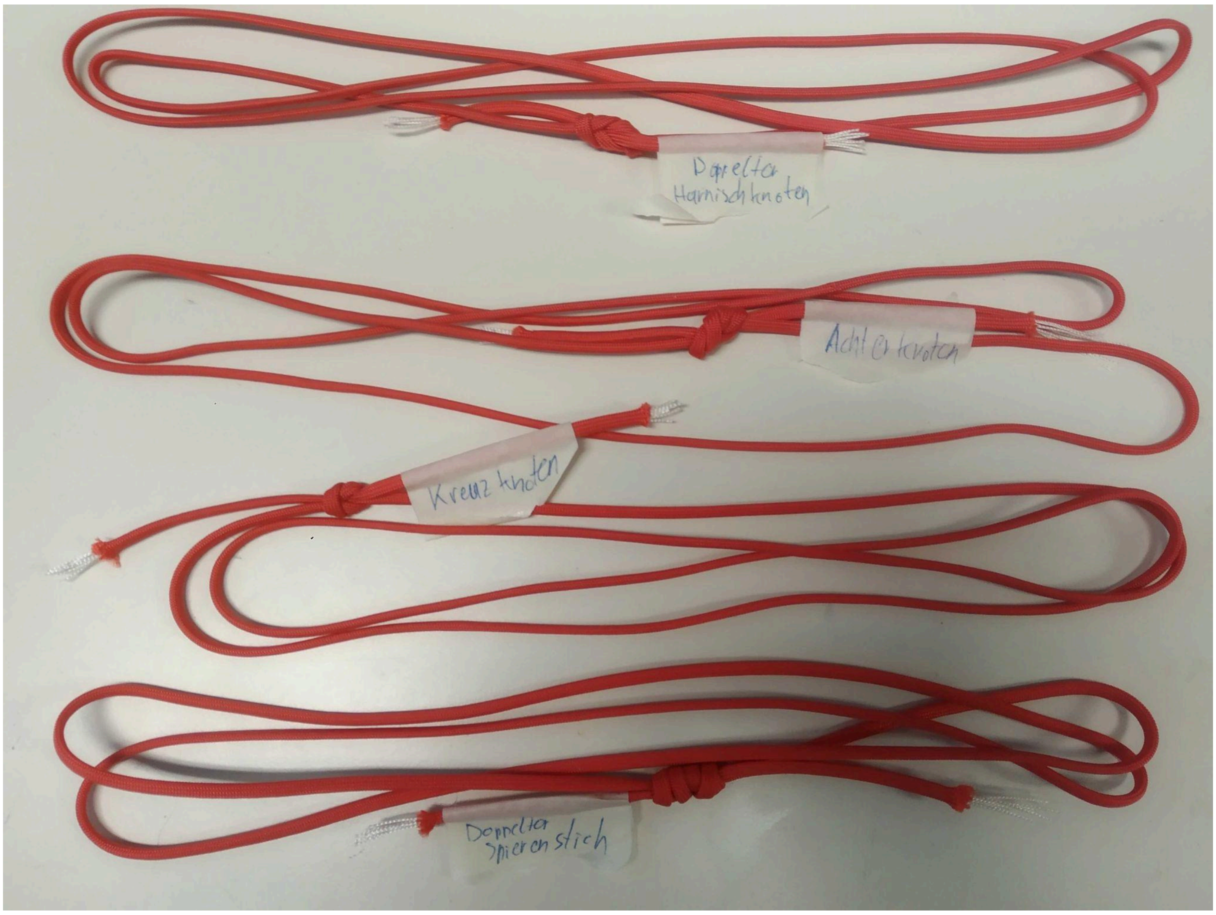
Results:

- The nylon Paracord exhibited significant elongation under load, which caused it to reach the end of the usable range of the lever.
- Knots used to secure the nylon rope to the screw links frequently shifted, impacting test consistency.
- The Paracord broke at a tensile force of 1320 N, which is below the nominal breaking strength of 2490 N.
- Observations indicated that the breakage occurred at the knot site, suggesting that knot placement and design may have affected the results.
- Subsequent tests using Aramid cord showed improved performance, with reduced elongation and more stable knot behavior compared to nylon.

Learnings:

- The significant elongation of nylon Paracord under load was a critical issue, suggesting that alternative materials such as Aramid may offer better performance for tensile tests.
- The shift and failure of knots were problematic; however, the knot type and the condition of the cord were both factors in the observed failures.
- The Aramid cord demonstrated better performance with less elongation and improved knot stability, indicating it as a preferable choice for future tests.

Attachments:


Doppelter Harnischknoten
Achterknoten
Kreuzknoten
Doppelter Spierenstich

Clamp Band Test

Date / Time	2024-02-18
Participants	Lutfi Celik, Niklas Stephan, Ying Mei
Testing purpose	Evaluate the impact of using different core materials and wrapping patterns on the clampband release mechanism's actuation time and structural integrity.
Changes	Version 1
Doc. Ref.	

Preparations:

- Two prototypes using magnesia rods were tested, focusing on thermal resistance and mechanical durability.
- The new clampband design and modifications to the coupler were prepared to eliminate unnecessary flat areas from the previous screw connection.
- Two different wrapping patterns were prepared for testing aerodynamic performance and actuation time.

Test execution:

- Magnesia rods repeatedly broke during transport, assembly, and clampband tensioning. Subsequently, aluminum oxide rods were ordered for future tests.
- The new continuous spring steel clampband functioned well during tensioning and release.
- The first wrapping pattern allowed an actuation time of <1 second, with the right side consistently below 0.5 seconds. However, the clampband didn't lie flush with the coupler.
- The second wrapping pattern improved the aerodynamic alignment but led to slower actuation times (>1 second) on both sides due to increased distance between the nylon thread and heating coil.

Results:

- Magnesia rods are not durable enough for this application; aluminum oxide rods will be tested next.
- The new spring steel clampband and clamp designs performed well under tension.
- The second wrapping pattern resulted in unacceptable delays in actuation time due to the larger distance between the nylon thread and heating coils.

Learnings:

- Using aluminum oxide rods may solve the fragility issue observed with magnesia.
- Aerodynamic improvements must be balanced with maintaining a fast actuation time, as excessive spacing reduces performance.
- Further development of the heating wire holder is needed to reduce thread spacing while preserving durability.

Attachments:

Clamp Band Test

Date / Time	2024-01-23
Participants	Lutfi Celik, Niklas Stephan, Ying Mei
Testing purpose	Evaluate the actuation time and structural improvements of the clampband release mechanism with integrated pulley pin.
Changes	Version 1
Doc. Ref.	

Preparations:

- Two new prototypes of the heating wire holder were designed and printed, both with integrated pulley pins.
- Differences in spacing between screw, heating wire coil, and pulley pin were tested to improve thread insertion.

Test Execution:

- Conducted tests on both versions:
  - The first version had increased spacing (~1mm) to ease nylon thread threading.
  - The second version had tighter spacing to maintain optimal actuation time.
- Additional tests were performed with a 0.1 mm diameter heating wire found by Florian, but it broke multiple times during setup and burned out immediately upon activation.
- An alternative wrapping method was tested to improve aerodynamic properties of the tensioned clampband.

Results:

- The first version, with increased spacing, caused a significant delay in actuation time.
- The second version, with tighter spacing, maintained an actuation time of <0.5 seconds on the side without the pin, while the side with the pin remained slower.
- The 0.1 mm heating wire proved too fragile and unsuitable for this application.
- The aerodynamic test did not yield conclusive results on actuation time.

Learnings:

- The distance between the pulley pin and the heating coil needs further reduction to improve the actuation time on the pinned side.
- The 0.1 mm wire is not durable enough for use in this mechanism.
- Aerodynamic modifications require further investigation to determine their effects on performance.
-

Attachments:

Clamp Band Test

Date / Time	2024-01-07
Participants	Lutfi Celik, Niklas Stephan, Ying Mei
Testing purpose	Test steel pin version of the clamp band Endurance test to check if clamp band is influenced by remaining armed for a long time
Changes	Version 1
Doc. Ref.	

Preparations:

- Setup of the clampband release mechanism with a steel pin used as a pulley to adjust the path of the nylon thread.
- The clampband was tensioned, and all components were checked to ensure proper configuration for testing.

Test Execution:

- Conducted two tests with the steel pin pulley in place to measure actuation time on both sides of the mechanism.
- The system was subjected to repeated tensioning to observe the effects on the steel pin.
- A long-term durability test was performed by leaving the clampband tensioned overnight before triggering the release mechanism the following day.

Results:

Both sides of the mechanism achieved a consistent actuation time of approximately 0.3 seconds, successfully meeting the goal of a sub-0.5 second release.

- The steel pin was torn out of the plastic after repeated tensioning, indicating a new weak point in the design.
- In the durability test, the clampband maintained tension overnight and still triggered successfully with <0.5 seconds actuation time.

Learnings:

- The steel pin design requires further reinforcement to avoid failures after repeated tensioning.
- Improvements are needed to enhance both the robustness and ergonomic usability of the heating wire holder to simplify nylon threading.

Attachments:

Clamp Band Test

Date / Time	2024-01-01
Participants	Lutfi Celik
Testing purpose	To address the asymmetrical release times observed during previous tests, where the release on one side was faster than the other. To explore design modifications, such as different screw sizes and support structures, to improve balance in release performance.
Changes	Version 1
Doc. Ref.	

Preparations:

1. **Asymmetrical Release Observation:**
    - During testing on 2024-01-01, it was observed that the release times between the left and right sides were not identical. Specifically, the right side of the system released under 0.5 seconds, while the left side took approximately twice as long.
    - Upon further inspection, the nylon thread was found to be winding asymmetrically through the screw during tensioning, meaning the sections of the thread to be severed by the heating coils were closer to one side than the other. This discrepancy directly contributed to the difference in release times.
2. **Potential Solution:**
    - It was hypothesized that switching to a smaller M3 screw instead of the current M4 screw might help correct this asymmetry. However, the benefit would only marginally shift the thread by approximately 0.5 mm, not enough to fully resolve the problem. Furthermore, the smaller screw would require finer threading (around 1 mm diameter), which could make the threading process more difficult and potentially weaken the screw.

3D Printing of Heating Wire Holders:

1. **Different Printing Orientations:**
   - Various orientations were tested for 3D printing the heating wire holders. Printing the holder flat required extra support material, which had to be removed and sanded down after the print was complete. However, this approach resulted in more structurally sound overhangs that securely anchored the GFK cores in place.
   - A downside to this method was that it placed the weakest axis of the 3D print in the direction of the greatest tensile force during testing, making the holder vulnerable to breakage under load.

Execution:

---

1. **Steel Pin as a Guide:**
   - a new test was conducted where a steel pin was embedded into the plastic as a makeshift pulley to guide the nylon thread closer to the left side. This modification aimed to balance the distance between the heating coils and the nylon thread on both sides, thus improving release symmetry.
   - Concerns were raised about the potential for the pin to be pulled out of the plastic under tension, but the initial setup held during the test.
   - Threading the nylon through the pin proved to be more cumbersome, but it was concluded that slight changes in the part's geometry could alleviate this issue.
2. **Proof of Concept:**
   - The release time with the steel pin was still not ideal, but the test served as a proof of concept, indicating that further refinement in the design could potentially solve the asymmetry problem.

Results:

The use of a steel pin successfully brought the nylon thread closer to the left side, improving the balance between the release times. Although the pin held during this test, the threading process was more difficult, suggesting a need for geometric adjustments to the part design.

Learnings

- Conduct further tests with an improved steel pin guide design to determine the impact on release times and ease of assembly.
- Revisit the design of the 3D-printed heating wire holder to optimize print orientation and material strength.
- Explore alternative methods of adjusting the nylon thread path to achieve symmetric release times.

Attachments:

Clamp Band Test

Date / Time	2023-12-29
Participants	Lutfi Celik
Testing purpose	To test the latest iteration of the clampband release mechanism. To assess improvements in ease of assembly, durability, and heating performance. To continue optimizing the release time to below 0.5 seconds.
Changes	Version 1
Doc. Ref.	

Test execution:

1. New Tension Screw Fabrication:
    - A new tension screw had to be fabricated since the previous M4 screw was too short for the new holder.
    - The process involved carefully grinding down the screw head with a Dremel, centering the drill points, and chamfering the holes to prevent thread damage during tensioning.
    - The threading was filed down around the holes to avoid damage to the nylon thread, and the holes were brought closer together to reflect the positioning in the tensioning blocks, allowing the nylon threads to be more easily severed.
2. GFK Core Fabrication for Heating Coil:
    - GFK (fiberglass) cores for the heating coil were cut and shaped using a bandsaw and sander.
    - These cores were fragile and became brittle after just a few tests due to heat exposure. As a result, a larger batch of small GFK rods was planned for production using a CNC machine.

    - For shaping, an electric screwdriver was used to hold the rods, allowing sanding to create near-cylindrical cores. Although the process was unconventional, it worked well with Matthias Rier’s advice to use a stationary drill for more precision.
3. Heater Wire Mount Redesign:
    - The new holder for the heating wire offered several advantages, including moving the heater cables away from the aluminum coupler to avoid short circuits and making the wire length adjustable to optimize heating performance.
    - This design reduced the chance of short circuits and ensured safer operation by eliminating the risk of the wire contacting the coupler. Additionally, insulating tape was added for extra safety.
    - The adjustable wire length allows for tuning the resistance to match the flight computer’s power output, maximizing heating efficiency.
4. Threading Configuration:
    - The threads no longer cross over the heating element, reducing the risk of the nylon thread pulling or damaging the heating wire mid-flight.
    - This design also permits more holes in the tensioning blocks and screw, which may become necessary if higher axial forces are encountered during flight. Statically loading tests will confirm if additional connections are required.

Results:

- Assembly Improvements:
  The new tension screw and modifications to the nylon threading significantly improved ease of assembly and durability. The thread was less prone to accidental cuts or damage during tensioning.
- Heating Coil Durability:
  While the current GFK cores showed some fragility after repeated use, the prototype demonstrated that the design could support high-power heating elements. Further tests with GFK rods and potential exploration of carbon fiber (CFK) cores are planned to enhance durability.

- Release Time:
  The new setup reduced the release time to under 0.5 seconds at 45 Watts, a significant improvement over previous iterations. There remains a slight gap between the heating coil and the nylon threads, which could further be minimized to achieve even faster release times.

Learnings:

1. **GFK Core Durability:**
   Current GFK cores are not as heat-resistant as anticipated. Potential solutions include switching to CFK rods or modifying the core fabrication process to improve thermal tolerance.
2. **Holder Redesign:**
   The current gap between the heating coil and the nylon threads should be reduced to increase the efficiency of the cutting process. This could further shorten the release time.
3. **Material Consideration:**
   The team will explore using CFK rods to improve manufacturing uniformity and reduce fabrication time. However, further investigation is needed into the potential risk of short circuits due to CFK's conductivity.

Clamp Band Test

Date / Time	2023-12-18
Participants	Lutfi Celik
Testing purpose	To confirm whether friction between the nylon thread and the tensioning blocks/screws is the primary cause of long release times. To evaluate alternative configurations for the nylon threading and the heating element to reduce the release time to below 1 second.
Changes	Version 1
Doc. Ref.	

Test execution:

1. Simplified NiChrome Heating Wire Setup:
   - The first test aimed to verify the hypothesis that friction from the nylon thread contributes to the long release time. A NiChrome heating wire was used, with the nylon thread only fastened on the top side at the tensioning blocks and screw.
   - As expected, the release time was significantly reduced, measuring under 0.5 seconds. However, the tension force from the clampband caused the knot in the nylon thread to come undone. To counter this, the knot had to be made considerably larger in this configuration.
2. Crossed Nylon Thread Configuration (Suggested by Georg Mikula):
   - In the second test, the nylon threads were crossed (steps 4-5 and 10-11 from the diagram were reversed). This modification aimed to bring the threads closer to the heating element and improve the cutting efficiency.
   - A short piece of NiChrome heating wire with 1 Ohm resistance was used as the heating element. The setup was recorded with a

high-speed camera and a digital stopwatch to improve time measurement accuracy.
    - The crossed-thread setup worked exceptionally well. Using the slow-motion footage, it was observed that the heating wire severed the first nylon thread after 0.2 seconds and the second after 0.8 seconds. This brought the total release time to under 1 second, meeting the team's performance goal.
3. Repeat Test:
    - The test was repeated to verify the results, yielding a cutting time of 0.3 seconds for the first thread and again 0.8 seconds for the second thread.

Results:

- Simplified Setup (Thread on Top Only):
  The test confirmed that friction between the nylon thread and the tensioning blocks/screws significantly delayed the release. Reducing the friction by removing the bottom thread attachment shortened the release time to under 0.5 seconds, but larger knots were required to prevent the thread from slipping.
- Crossed-Thread Configuration:
  This configuration performed excellently, with a total release time of under 1 second, meeting the team’s objectives. High-speed footage confirmed that the heating element cut through both nylon threads in sequence.

Learnings:

1. Heating Element Holder Redesign:
   The next step is to redesign the holder for the heating wire to accommodate a heating coil. This could further reduce the release time

to below 0.5 seconds, as the coil design is more efficient for cutting both threads quickly.

2. Robustness and Reliability Enhancements:
   The current configuration should be optimized for increased durability and reliability in various flight conditions. This includes refining the thread tensioning mechanism to ensure consistent results without requiring oversized knots or extra modifications.

Next Steps:

- Redesign the heating wire holder to support a NiChrome heating coil and repeat the tests to improve the release time further.
- Continue testing to ensure the reliability of the crossed-thread configuration and fine-tune the setup for real-world application in the rocket's release mechanism.

Clamp Band Test

Date / Time	2023-12-11
Participants	Lutfi Celik
Testing purpose	To evaluate the performance of the new prototype for the clampband tensioning and release system. To test different heating elements (NiChrome wire, electrical resistors) for cutting the nylon thread that holds the clampband.
Changes	Version 1
Doc. Ref.	

Preparation:

The assembly process was significantly improved, with easier fitting of cable lugs and M2 screws into the holder. However, insulating tape was still required on the coupler to prevent electrical shorts between the screw heads and the poles of the heating wire due to the aluminum coupler.

Test execution:

1. NiChrome Heating Wire:
    - A test using NiChrome heating wire was conducted first. Unfortunately, the release time remained long at approximately 4 seconds, as the power dissipated in the short, low-resistance wire was insufficient, and the contact between the thread and the wire was poor.
2. Electrical Resistors:
    - Next, electrical resistors with a rated power of 0.5 W were tested to determine if they could effectively cut the nylon thread.

    - The system operates at a supply voltage of 12 V and a maximum current of 5 A, providing up to 60 W of power. The goal was to maximize heating power to sever the nylon thread as quickly as possible.
    - However, resistors burned out almost immediately at this power level. Through a series of tests, the team determined that the resistors could withstand a maximum power of only 10 W for the desired duration, which was far below the system's potential capacity.
    - The tests showed a significant decrease in cutting time as heating power increased.
    - Despite the power limitation, resistors operating at 10 W were able to sever a nylon thread wrapped around them in less than one second.
3. Final Test in Recovery Prototype:
    - One of these resistors was installed in the recovery prototype to determine the actual release time. Due to limited power and poor contact between the resistor and the nylon thread, the cutting time was again approximately 3 seconds, which is still too slow for practical use.

Results:

- NiChrome Wire: The NiChrome wire was ineffective due to insufficient power dissipation and poor thermal contact with the nylon thread, resulting in slow release times (~4 seconds).
- Electrical Resistors: Resistors rated for 0.5 W were capable of cutting the nylon thread when operating at up to 10 W, but they were still not optimal. The cutting time could be improved, but achieving higher power levels without burning out the resistors remains a challenge.

Learnings:

1. Increase Power:

    - Use resistors with a higher rated power, though these may be more expensive and bulky, potentially making them difficult to fit between the coupler and parachute tube.
    - Alternatively, a longer NiChrome wire could be used. However, this would require a spool with a non-conductive, heat-resistant core to prevent deformation or short circuits during flight.
    - A thinner heating wire could also be used, but the thinnest wire currently available is already fragile and prone to breaking under tension, so a thinner wire would likely exacerbate these issues.
2. Improve Thermal Contact:
    - Tests showed that 10 W of power is sufficient to cut the nylon thread quickly, provided there is good thermal contact between the heating element and the thread.
    - Using thermal paste, as suggested by Niklas Stephan, could improve the heat transfer. However, the paste may liquefy under high acceleration during flight, so further testing is needed to evaluate this risk.
3. Mechanical Enhancements:
    - Georg Mikula suggested a design improvement where the nylon thread is stretched against the resistor, improving the thermal contact and cutting speed.
    - Using multiple resistors in parallel could increase the total power delivered to the thread, reducing the cutting time further.

Next Steps:

- Test higher-rated resistors and longer NiChrome wires in a controlled environment to evaluate their performance and durability under flight-like conditions.
- Investigate the use of thermal paste or other methods to improve thermal contact without adding unnecessary complexity or failure points.

Clampband Load Test

Date / Time	2024-04-07
Participants	Lutfi Celik, Dominic Wipplinger
Testing purpose	To evaluate the load-bearing capacity of the Clampband coupler and determine the relationship between the number of loops in the Clampband and its tensile strength.
Changes	Version 1
Doc. Ref.	

Preparations:

- The Clampband was tensioned and connected to the nosecone.
- An aluminum profile was attached with brackets to the holder, positioned 30 cm from the coupler.
- Increasing weights were applied until the Clampband failed.
- Tests were conducted with varying numbers of loops through the Clampband and the tensioning screw.

Test execution:

- The Clampband was subjected to increasing loads using weights until it ripped.
- The experiment was repeated with different numbers of loops to assess their effect on the tensile strength.
- Challenges included accurately measuring the pre-tension force required for the Clampband, which affected reproducibility and assembly during flights. Digital torque sensors were used but were insufficient due to high friction forces of securing nuts.

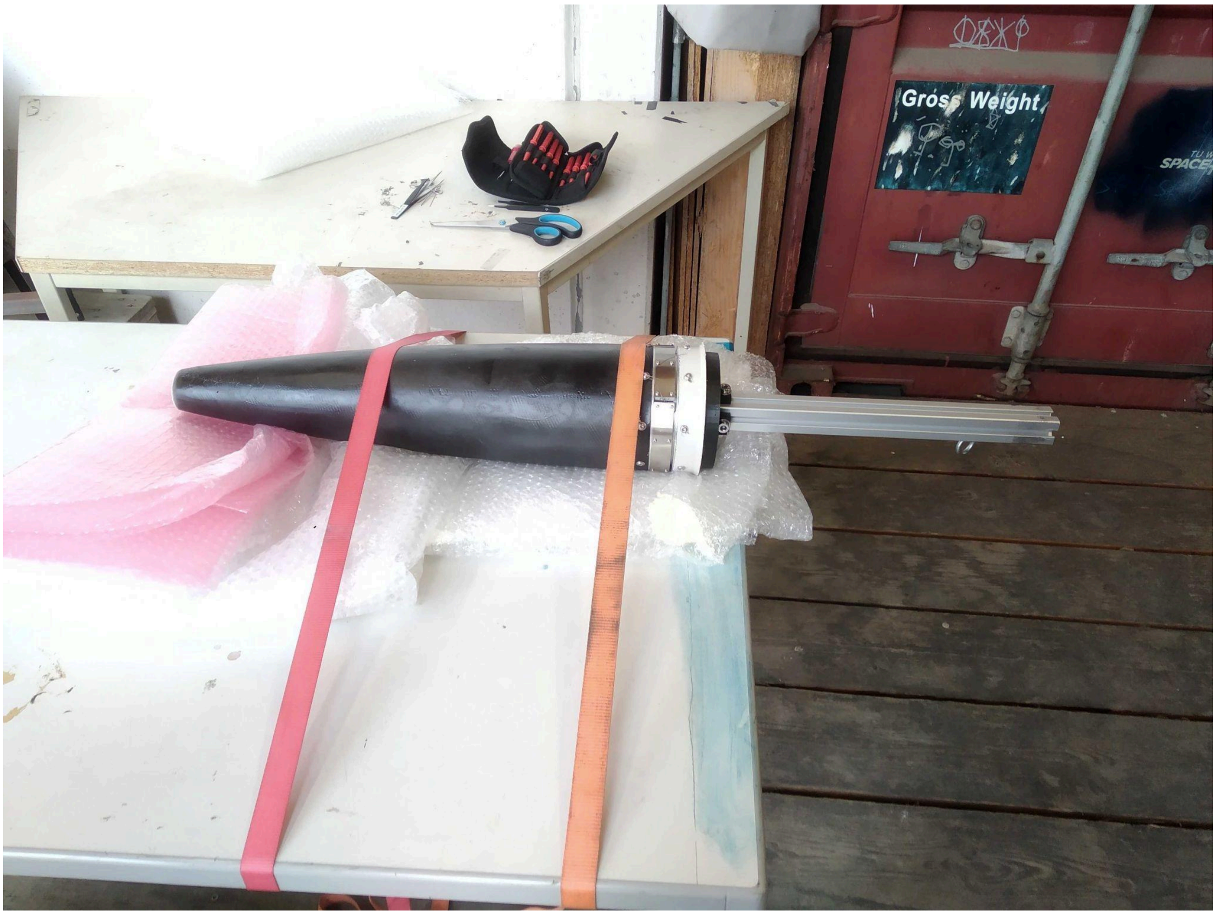
Results:

- The average breaking forces for different configurations were as follows:
  - Single thread, one loop: 105 N
  - Single thread, two loops: 140 N
  - Double thread, one loop: 165 N
- It was observed that the breaking strength did not follow a simple linear relationship with the number of loops.
- A significant issue was the difficulty in determining the pre-tension force, which impacted both the reproducibility of tests and the assembly process.
- Calculations showed that for the Starboat, with a maximum speed of 150 m/s and a nose length of 60 cm, an aerodynamic load of ~100 N is expected, which is manageable with two loops and a safety factor of ~1.5.
- For the Hedy, which requires the coupler to withstand up to 600 N of horizontal force, the system must be made significantly more robust. The current 0.2 mm fishing line is too thin, and thicker threads would be needed, though this would increase the release time.
- An important observation was that failure occurred at the knot with the double thread configuration. Attempts to use a knot with theoretically lower reduction in tensile strength did not affect the breaking strength of the Clampband.

Learnings:

- The breaking strength of the Clampband does not linearly correlate with the number of loops in the thread.
- Accurate measurement of pre-tension is challenging, affecting test consistency and assembly.
- The Clampband needs to be more robust for applications requiring higher forces, and using thicker threads could improve performance.
- Knot failure was significant, and while alternative knot designs were tested, they did not improve the tensile strength.

Attachments:


Gross Weight

Shock Absorber Test

Date / Time	2024-09-03
Participants	Lutfi Celik, Eric Drößiger, Stefan Kuttenreich, Victor Prack
Testing purpose	Determine load at which shock absorber prototype triggers
Changes	Version 1
Doc. Ref.	

Preparations:

Extra strong yarn used for both **upper thread and under thread.**

1. 20 cm absorber made out 10 mm wide aramid braid, 16 lines of parallel stitches with extra strong thread

2. 20 cm absorber made out 10 mm wide aramid braid, 16 lines of parallel stitches with extra strong thread

3. 20 cm absorber made out 10 mm wide aramid braid, 20 lines of parallel stitches with extra strong thread

4. 20 cm absorber made out 10 mm wide aramid braid, 16 lines of parallel stitches with extra strong thread

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Test execution:

1 - 4 : Weight was added to the shock absorber until it started ripping open

Results:

1. Opened at 520 N
2. Opened at 445 N
3. Opened at 550 N
4. Opened at 650 N

Learnings:

Attachments:

Shock Absorber Test

Date / Time	2024-08-28
Participants	Lutfi Celik, Eric Drößiger, Stefan Kuttenreich, Victor Prack
Testing purpose	Determine load at which shock absorber prototype triggers, determine absorbed energy
Changes	Version 1
Doc. Ref.	

Preparations:

1. 20 cm absorber made out 10 mm wide aramid braid, 16 lines of parallel stitches with extra strong thread

2. 20 cm absorber made out 10 mm wide aramid braid, 16 lines of parallel stitches with extra strong thread

3. 20 cm absorber made out 10 mm wide aramid braid, 32 lines of parallel stitches with extra strong thread

4. 20 cm absorber made out 10 mm wide aramid braid, 32 lines of parallel stitches with extra strong thread

5. 40 cm absorber made out 10 mm wide aramid braid, 18 lines of parallel stitches with extra strong thread

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Test execution:

1 - 4 : Weight was added to the shock absorber until it started ripping open

5: Drop test with 9 kg weight from a height of 20 cm to determine absorbed energy

Results:

1. Opened at 295 N

2. Opened at 300 N

3. Opened at 520 N

4. Opened at 415 N

5. 1,8 cm of absorber left

Learnings:

Attachments:

Shock Absorber Test

Date / Time	2024-08-19
Participants	Lutfi Celik, Eric Drößiger, Stefan Kuttenreich, Victor Prack
Testing purpose	Determine load at which shock absorber prototype triggers
Changes	Version 1
Doc. Ref.	

Preparations:

1. 20 cm absorber made out 10 mm wide aramid braid, 16 lines of parallel stitches with regular thread
2. 20 cm absorber made out 10 mm wide aramid braid, 16 lines of parallel stitches with regular thread
3. 20 cm absorber made out 10 mm wide aramid braid, 16 lines of parallel stitches with regular thread
4. 20 cm absorber made out 10 mm wide aramid braid, 32 lines of parallel stitches with thin thread

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Test execution:

Weight was added to the shock absorber until it started ripping open

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Results:

1. Opened at 150 N
2. Opened at 150 N
3. Opened at 135 N
4. Opened at 280 N

Learnings:

Attachments:

Recovery Test Flight

Date / Time	2024-04-21
Participants	Recovery Team
Testing purpose	Verify function of all recovery components
Changes	Version 1
Doc. Ref.	

Attachments:

component	Description	Worked well	Worked poorly	Suggestions for improvement	To do
CATS Vega	Back-up flight computer, but takes over official EuRoC altitude determination and is responsible for GNSS positioning after landing using the ground station. Has telemetry	Programmable as desired, telemetry worked, drogue and main triggers worked, flight data was recorded, state estimation was good, no problems with barometric altitude determination	No GNSS reception, flight computer crashes upon landing	Dielectric waveguide via GPS opening to improve the signal, extendable CATS Vega?	

Altimax G4	Main flight computer, no telemetry or GPS positioning, very reliable. Limited programmability	Drogue and main trigger worked, flight data was recorded, no problems with barometric altitude determination	Not programmable exactly as desired, Pyro Channels are always energized for exactly 3 seconds	Adjust the resistance of the Altimax Burnwire as it can convey more current. But then the two mechanisms are no longer symmetrical and false infection becomes possible	
RBF pin and switch	Mechanism to turn on flight computers shortly before takeoff	Plugging in and pulling out is easy, installation with pins plugged in is possible to prevent false triggering	From the outside you can't tell whether pins are pulled before you connect the screws to the heads! Position not perfect, further away from the rail would be better. Switches tripped when landing because they were sensitive to shock	It is better to use switches with a higher rating and immediately attach pin extensions when assembling so that it is clear whether the pins have been pulled or not	

Aluminum bulkhead	Transfers the entire braking force of the parachutes to the airframe. Stop point for all recovery components. CNC milled.	Radial holes and threads are excellently manufactured with a dividing head. Has endured drogue braking stress without any problems	Chamfers were only made on the top, the bottom had to be chamfered manually.		Breaking tests
Parachute tube holder	Connects the GRP parachute tube to the aluminum bulkhead. ABS 3D printing	Worked problem-free during the flight	Broken several times during stress testing. Possibly integrate with the aluminum bulkhead and make it together as a single part made of aluminum for increased strength		
Parachute tube	1.5 mm thick, 89 mm outer diameter GRP pipe. Serves as a holding point for the antennas and houses parachutes and lines inside.	Drilling of the mounting holes is possible without tearing them out, steps on the upper side to pass through lines, gluing the antenna holder and burnwire holder without any problems	The main parachute got stuck at the mouth of the tube when the rocket was in horizontal flight	If necessary, round off the parachute tube mouth, for example with a funnel/trumpet-shaped attachment to prevent it from jamming Make openings for lines in the payload holder, not in the parachute tube	

centerin g ring	Stabilizes the parachute tube against horizontal loads at the level of the lower coupler, ABS 3D printing	Installation possible without collision. Survived the flight unscathed	Questionable strength, large recesses necessary to enable installation, glue point with lower coupler torn off several times	Integrate with lower coupler and manufacture together from aluminum.	Made of GRP and screwed on
Lower coupler	Lower half of the aluminum coupler, which is held together by the clamp band.	Positive connection with the other coupler half. No concerns about strength.	Inaccurate drill holes made installation and removal difficult. Pressing in the insert nuts is complex. Holes too close to the edge.	Production of the drill holes in the future with a dividing head or with 4-axis CNC. Integrating the centering ring.	Determine crown height, measure nose cone, ask Reinhard
Top matchm aker	Upper half of the aluminum coupler, which is held together by the clamp band.	Positive connection with the other coupler half. No concerns about strength.	Inaccurate drill holes made installation and removal difficult. Pressing in the insert nuts is complex. Edges of coupler collided with antenna and blocked nose release. Holes too close to the edge. Attaching the rubber hoses	Production of the drill holes in the future with a dividing head or with 4-axis CNC. Additional chamfering on the inner edges to make it easier for the nose to become uneven	Determine crown height, measure nose cone, ask Reinhard

			is problematic.		
Payload holder	Fixes the payload (form factor 2x CanSat) on the parachute tube, connected to the upper coupler via rubber hoses, which act as the nose ejection mechanism.	Payload firmly anchored, easy access to charging socket and RBF pin.	Tightening is difficult, straps are not particularly tear-resistant and wear and tear is problematic. No way to load payload via Umblical.	Push pins to connect payload with rest of avionics to Umblical. Recesses for lines to pass through.	Pogo pins for Umblica, let WerndlExplorer know about the Umblica connection
Payload	Double Cansat from WerndlExplorer with barometer, IMU and camera. Has its own RBF pin and USB-C charging socket.	Installation problem-free, simply pull the RBF pin, measurement data recorded successfully, good camera recording thanks to LEDs.	RBF can only be pulled before installing the nose, therefore not possible on the rail.	Loading push pins required for loading via Umblical.	
Antenna holder	Fixation point for the CATS Vega dipole antenna. Protects this from the upper coupler when ejecting the nose	Successfully guides the coupler and nose over the antenna without getting stuck.	Very high. Design only possible on one side as the diameter would be too large on opposite sides.	If necessary, move it within the parachute tube	

antenna	Homemade dipole antenna for the CATS Vega, 2.4 GHz frequency	Continuous telemetry during test flight, range test up to 2 km. Similar properties to the original Moxon antenna	Too big due to SMA connector, problems ejecting the nose.	Strip coaxial cables and turn them inside out as an alternative design for a dipole antenna.	Peter ask about path antenna, or dipole antenna coaxial cable, or WLAN antenna
Main Release Burnwire	Cuts the paracord piece, allowing the main parachute to be pulled out through the braking parachute.	Easy installation, no collision with body tube. Worked on the test flight. No burning or melting of the holder.	Unfavorable design of the connection cables. Connecting brackets to parachute tubes is difficult, but necessary to prevent cable breakage	Adjust the shape of the parachute tube and glue it tightly, use JST connectors, guide the paracord better at the centering ring so that no large deflection is possible	
Main release lines	Paracord rope knotted together, which is attached to the bulkhead and the soft shackle	Withstood the load, installation was easy, triggering worked without any problems			

Clamp band	Holds the two coupler halves together during flight. Tied with a nylon thread.	Installation is reasonably possible	Nylon thread weak point of the coupler during stress tests. Clamping bends the clamp band ends outwards when opening, which rubs against the launch rail. Position of the opening at the worst point, better opposite the rail	Use thicker thread for clamp band, make clamping blocks flatter, place opening on the opposite side.	Do not tie the ends of the clamp band thread together, but loop them and connect them with the clamp band Order thicker Dyneema rope
Clampb and burnwire holder	Holds the burnwire for the clampband release mechanism and the tension screw, which is used to wind and pre-tension the clampband.	Clamping is easy, the mother retainer did its job well	Threading the thread is problematic, tensioning cannot be repeated with the same pre-tensioning force, m4 screw with radial hole is a major weak point, installing the burnwire is complex, short circuits in the first tests are a repeated problem	Glue the burnwire holder with a coupler instead of a parachute ear, install the burnwire firmly and not replace it as it is no longer necessary, use PSB as a power supply and connection point, change the geometry and make it slimmer for the centering ring, use JST connector for installation	

Camera plate	GRP plate under the bulkhead, which serves as the lid of the avionics housing and the fixation point for the black RunCam.				
Black RunCam	Camera that films vertically upwards through the bulkhead into the parachute tube. The battery pack is shared with the CATS Vega.		No recording because it was too dark and no main ejection	LEDs to illuminate the interior of the rocket	
swivel	Fixed under each of the parachutes to prevent the rocket's lines from twisting.	Tests and flight survived well#			
Soft shackle	Alternative to screw links, made from aramid rope.	Tests and flight survived well	Fastening with shrink tubing is difficult, opening requires cutting open the shrink tubing	20cm length for safety	

screw links	Connection link of various lines, 3 mm thick	Tests and flight survived well			
Drogue chute	Cross parachute, which serves as a braking parachute and pulls the main parachute out of the parachute tube.	The higher lift compared to the rocket's tail unit ensured horizontal flight of the rocket body after ejection.	Level flight detrimental to main parachute ejection	Possibly larger drug chute for a better flight attitude of the rocket, alternatively a heavier rocket with a center of gravity further back and/or a smaller tail unit.	
Main chute	Main parachute, which slows the rocket to the targeted landing speed. Stored in a deployment bag.				

Deployment bag	Self-sewn deployment bag made of parachute fabric, which houses the main parachute. With anchor points for the parachute shroud lines	Stowing the main in the deployment bag is complex, but possible, lines are securely but easily detachable with rubber bands	The deployment bag got stuck on the parachute tube mouth or the pulling force on the rope at ~45° to the mouth was not sufficient to pull it out. Tabs to cover the lines too small.	Smaller diameter relative to the parachute tube, longer shock cord	
Shock absorber	Sewn 10 mm aramid tubes, which are intended to absorb the parachute shock.	Parallel design of the shock absorbers is a good way to increase the limit of the force that triggers it		Step-shaped design, which triggers at ever higher forces.	
Aramid lines	Various lines made of aramid, and rocket parts with parachutes and to connect them together. Some with split eyes, some with knots.	Spliced eyes worked well and were easy to prepare, bowline knots on all lines that cannot be spliced are a good alternative			

A.2.1 Static Hotfire:

For this section, tests will be conducted on the 22th of September and the results shall be delivered as an attachment (number 2.3) on the 27th.

A.2.2 Liquid Propelant loading and unloading:

For this section, tests will be conducted on the 19th of September and the results shall be delivered as an attachment (number 2.4) on the 27th.

A.2.3 Combustion chamber pressure:

For this section, tests will be conducted on the 17th of September and the results shall be delivered as an attachment (number 2.5) on the 27th.

A.2.4 Proof pressure testing pressure vessels:

For this section, tests will be conducted on the 20th of September and the results shall be delivered as an attachment (number 2.6) on the 27th.

A.3 Hazard analysis report:

A.3.1 Liquid Propulsion System:

- Transport
  - **Igniter**

    Hazard: As the igniter is unsurprisingly flammable it poses a risk of starting to burn at an unwanted time.

    Mitigation: The igniter mixture is put together on premise shortly before needing it, during transport the individual components are not dangerous.
  - **Ethanol**

    Hazard: While not burning quickly, Ethanol is flammable and evaporates quickly.

    Mitigation: The ethanol gets transported and stored in their original packaging (plastic bottles).
  - **Liquid Oxygen**

    Hazard: Tipping over could break the bottle open.

    Mitigation: Only gets transported with the safety lid on.
- Usage

- **Igniter**

  Hazard: Igniter going off after being installed on the combustion chamber or while being manufactured.

  Mitigation: The ignition system is only armed once the RBF pin is removed from the PMU, which happens just before launch preparations are done and the team vacates the launch pad. Before then, the igniter voltage to start the burning is physically disconnected even on a misfire in the electronics. The person manufacturing the igniters wears eye protection and gloves. The heating plate is closely monitored to ensure proper heating temperature. All other people not involved hold their distance.

- **Ethanol**

  Hazard: Ethanol spills during handling could pose a fire risk on and around the pad.

  Mitigation: The ethanol gets filled into a large syringe away from the pad and then pushed from the syringe into the fuel tank. This removes potential spills from the pad.

- **Liquide Oxygen**

  Hazard: The nitrous oxide can explosively decompose.

  Mitigation: All parts that get in touch with the LOX get rigorously ox-cleaned. Filling the LOX tank in the rocket is one of the last steps of the launch checklist just before launch. Just one experienced member of personnel is at the launch rail. He/She opens the LOX gas cylinder. After some checks the last person leaves the launch rail. Only then the tanking of the LOX begins, controlled remotely from Mission Control.

A.3.2 Slingshot Mechanism in Recovery System:

A.3.3 Slingshot Mechanism in Recovery System:

Hazard: The slingshot mechanism of the recovery system stores considerable potential energy when loaded. During launch preparations this has to be done a while before the pad crew vacates the premises and as such the slingshot mechanism could (mis)fire when personnel is around. This could happen if the knot loosens or the recovery system fails and prematurely detects apogee on the pad.

Mitigation:

A.4 Main risks assessment:

Failure Mode	**Mission Phase**	**Failure Probability**	**Mishap Severity**	**Critical Ranking**	**Comments and Justification**
Coupler fincan/body tube screws loosen	During flight	1	2	2	Check tightness of all screws after final assembly, before launch
Body tube breaks at screw holes	During flight	1	2	2	A test section of the body tube material was tested with the expected force. A simulation of the expected forces was made
Fincan breaks at screw holes	During flight	1	2	2	A test section of the fincan material was tested with the expected force. A simulation of the expected forces was made
Nosecone breaks at screw holes	During flight	1	2	2	A test section of the tube material was tested with the expected force. A simulation of the expected forces was made

Coupler nosecone/body tube screws loosen	During flight	1	2	2	Check tightness of all screws
Coupler breaks	During flight	1	2	2	Forces on both couplers were simulated and tested with hardware
Railbutton breaks off body tube during holddown	During holddown	1	3	3	Holddown railbutton is tested during static fires
Fincan breaks at touchdown	During landing	2	1	2	Nozzle protrudes from fincan and should take landing shock. Since severity is low, no further avoidance attempts are made.
Railbutton gets stuck in launch rail	During launch	1	2	2	Check launch rail and railbutton for clearance and debris.
Clamp band separation mechanism triggers on ground, ejecting nose cone	Before launch	1	1	1	Clamp band is retained on the outside by a second line, which is removed shortly before launch

Clamp band coupler fails during ascent because of aerodynamics stress	During flight	1	3	3	Exhaustive stress testing on ground with analytically calculated maximum aerodynamic stress, safety margin
Clamp band release mechanism triggers during ascent	During flight	1	3	3	Sufficient ventilation of avionics bay to ensure reliable barometric data on altimeters
Clamp band release mechanism fails at apogee	Apogee	1	3	3	Redundancy, ground and flight tests confirm reliability of mechanism
Nose cone does not separate after release of the clamp band mechanism	Apogee	1	3	3	Slingshot mechanism to aid with separation of nose cone, thorough testing on ground
Drogue parachute or parachute line failure because of parachute opening shock	Apogee	1	3	3	Extremely short actuation time of release mechanism, use of shock absorbers, shock minimizing parachute design

Clamp band safety retainer is not removed before launch, no separation	Apogee	1	3	3	Rigorous adherence to check list routine, RBF tag on the retainer has to be physically attached to the list to proceed
Initial or main deployment event triggers at the wrong time because of faulty programming	During flight	1	3	3	Flight computer programming is verified by different people, testing mode is used to confirm behavior
Main release line fails because of stress, main parachute deploys above 450 m	During descent	1	2	2	Main release line dimensioned to withstand stress, tested until failure to verify specification
Main release mechanism fails	During descent	1	2	2	Main release mechanism uses same design as clamp band release, redundancy
Main parachute or parachute line failure because of parachute opening shock	During descent	1	2	2	Parachutes are dimensioned so both main and drogue suffer similar shocks, use of shock absorbers

Main parachute deployment bag gets stuck inside rocket or parachute fails to exit deployment bag	During descent	2	2	4	Slender design of parachute bag, practice of correct folding technique with deployment tests
Drogue or main parachute line fails because of shearing	During descent	1	3	3	Careful deburring and sanding of all edges on the coupler and parachute tube
Drogue or main parachute lines become tangled during integration or flight	During flight	1	2	2	Compact compartment for lines and parachutes, practiced folding technique for lines
Parachute attachment bulkhead failure because of parachute shock	During descent	1	3	3	Robust airframe and aerostructure design with generous safety margins, mechanical stress tests on ground
Burn wire mechanism causes fire in rocket, parachute line failure	During descent	1	3	3	Use of fire proof aramid braid for all parachute lines which are not meant to be cut by burn wire

Burn wire short circuit causes flight computer failure	During descent	1	2	2	Burn wire resistance is verified shortly before integration of recovery system, burn wire fails under extremely high current
Flight computers not turned on before launch or flight computer failure	During flight	1	3	3	Highly visible RBF pin and strict checklist adherence, confirm status of flight computers through beeping pattern and via telemetry
Flight computer battery voltage too low to trigger burn wire release mechanism	During descent	1	3	3	Batteries for avionics are continuously charged by ground support equipment until launch

Igniter losing quality due to air humidity	Before launch	1	3	3	Igniters will be made shortly before launch and stored in seal tight box with silica gel to reduce the effect of humidity; in the case of extremely high air humidty during launch procedures an excess igniter will be held in comparative conditions as the primary igniter and tested before launch
Leaks in Injector or fluid system	Before launch	1	3	3	Assembling of injector and fluidsystem according checklist
Igniter mount loses functionality or pyrotechnic material detaches before successful engine ignition	During launch	1	3	3	Tested thoroughly during engine tests and static fire tests

Leakage of hot gasses between liner and casing	During flight	2	1	2	Could slightly melt casing, but aluminium has high thermal conductivity and Liner is suitable for 5-8s of operation; already happened at tests, there was no damage to casing
Raw pyrotechnic components faulty or igniter not mixed properly	Before launch	1	1	1	Procedure is thoroughly tested before EuRoC, new sorbitol ordered, potassium nitrate dried beforehand and igniter's functionality is tested before shortly before launch
Blockage of Injection or fluid system with debris	During flight	1	2	2	Engine would lose performance ->could use filters in injector assembly or before tanking

Fincan or liner material burning due to hot gases or heat radiation	After Landing	1	1	1	Burning or hot glowing carbon/linermaterial could ignite vegetation after touch down ->extensive engine purge after burn out
Pressure relief valve not activating	Always	1	3	3	High quality COTS components are used and burst discs built into each system to avoid critical pressure
Pressurization valves leaking	Always	2	3	6	Propellant tanks would be overpressurized, danger of tank rupture ->use of 2 stage safety in form of pressure relief valve (custom-made normally opened relief valve and burst disc), extensive testing needed
Pressure relief valve activating at too low pressure	Always	1	2	2	Components are thoroughly tested beforehand to avoid malfunction

Lox fill not disconnecting after Lox tanking	Before launch	2	1	2	Would hinder liftoff, extensive testing needed. Maybe just waiting and letting components warm up would fix it
Thrust structure breaks	During flight	1	3	3	Tested thoroughly during static fire tests
Bolts and nuts are loose	During flight	1	1	1	Using washers and loctite bolt glue; have enough redundant bolts and nuts
LOX saturation pressure influencing LOX venturi flow	During flight	1	1	1	No safety risk but performance loss - venting to regulate ox tank pressure to required level before start sequence
Swapped LOX and pressurant pipes	Before launch	1	3	3	Due to the positioning of the propellant and LOX tanks, they cannot be swapped without realizing it. Furthermore, remote tanking mitigates the risk even more

Tab. A.2: Main risks assesment

A.5 Checklists:

A.5.1 Launch Checklist:

The launch checklist is a work-in-progress document pending final changes that will be introduced based on the results of static fire testing.

LAMARR
Launch

Event General	
Event	Launch
Date	XX.10.2024
Planned launch/test	
Participants	
Checklist Version	2.0

Summary

Camera IPs (via VLC)	
Cam 1	http://root:DeepSpace69@192.168.0.7:5580/axis-cgi/mjpg/video.cgi
Cam 2	http://root:DeepSpace69@192.168.0.7:5581/axis-cgi/mjpg/video.cgi
Cam 3	http://root:DeepSpace69@192.168.0.7:5582/axis-cgi/mjpg/video.cgi
Mission Control	
ECUI	http://192.168.0.7

Configuration Notes	
Ox pressurant bottle pressure before test	bar
Ox pressurant bottle pressure after test	bar
Fuel pressurant bottle pressure before test	bar
Fuel pressurant bottle pressure after test	bar
Dewar pressurant bottle pressure before test	bar
Dewar pressurant bottle pressure after test	bar
Set pressure oxidizer pressurant bottle	bar
Set pressure fuel pressurant bottle	bar
Dewar mass before tanking	kg
Dewar mass after tanking	kg
Time of launch	

	Index	Checklist Item	Check	Comment

Index	Checklist Item	Check	Comment
1.	Pre-Day Preparations	☐ ☐ ☐	
1.1	Print Checklist	☐ ☐ ☐	5 times
1.2	Connect ox venturi pressure sensor	☐ ☐ ☐	
1.3	Connect fuel venturi pressure sensor	☐ ☐ ☐	
1.4	Prepare Fuel	☐ ☐ ☐	One big canister
1.5	Charge GoPros	☐ ☐ ☐	
1.6	Prepare table, bench and tent for test lead	☐ ☐ ☐	
1.7	Prepare test lead laptop	☐ ☐ ☐	
1.8	Prepare test lead power cable	☐ ☐ ☐	
1.9	Prepare test lead network cable	☐ ☐ ☐	
1.10	Prepare alufoil	☐ ☐ ☐	
1.11	Prepare breathing protection	☐ ☐ ☐	
1.12	Prepare hearing protection	☐ ☐ ☐	
1.13	Prepare eye protection	☐ ☐ ☐	
1.14	Prepare cryo gloves	☐ ☐ ☐	
1.15	Prepare UPS	☐ ☐ ☐	
1.16	Verify UPS connections		
1.16.1	Verify Server Power on UPS	☐ ☐ ☐	
1.16.2	Verify Launch Pad on UPS	☐ ☐ ☐	
1.16.3	Verify Antenna POE on UPS	☐ ☐ ☐	
1.16.4	Verify Switch on UPS	☐ ☐ ☐	
1.16.5	Verify Router on UPS	☐ ☐ ☐	
1.17	Prepare MC		
1.17.1	MC Laptop	☐ ☐ ☐	

	Index	Checklist Item	Check	Comment
	1.17.2	Two screens	☐ ☐ ☐	

Index	Checklist Item	Check	Comment
2.	Preparations	☐ ☐ ☐	
2.1	Press kill-switch	☐ ☐ ☐	
2.2	Prepare test lead tent	☐ ☐ ☐	
2.3	Prepare test lead table	☐ ☐ ☐	
2.4	Put kill switch on test lead table	☐ ☐ ☐	
2.5	Prepare power cable for test lead	☐ ☐ ☐	
2.6	Prepare network cable for test lead	☐ ☐ ☐	
2.7	Prepare test lead laptop	☐ ☐ ☐	
2.8	Prepare manual key for ox tanking valve	☐ ☐ ☐	
2.9	Power server	☐ ☐ ☐	
2.10	Power launch pad	☐ ☐ ☐	
2.11	Prepare mission control		
2.11.1	One screen ECUI	☐ ☐ ☐	
2.11.2	Other screens cameras	☐ ☐ ☐	
2.11.3	Tab open for VSCode with ssh connection on config repo	☐ ☐ ☐	
2.11.4	Tab open with grafana for venturi pressuress	☐ ☐ ☐	
2.11.5	Verify venturi pressure data in grafana	☐ ☐ ☐	select last 5 minutes
2.11.6	Open discord for communication	☐ ☐ ☐	
2.11.7	Prepare checklists, pens and paper for notes	☐ ☐ ☐	
2.12	Verify ECUI nominal		
2.12.1	Verify Kvaser CAN driver loaded	☐ ☐ ☐	`/etc/docs/linuxcan/listChannels/` should list at least 4 channels
2.12.2	Verify llserver running	☐ ☐ ☐	`docker compose ps` in `/home/config_ecui` folder

Index	Checklist Item	Check	Comment
2.12.3	Verify web-server running	☐ ☐ ☐	`docker compose ps` in `/home/config_ecui` folder
2.13	Prepare igniters		
2.13.1	Prepare mixture for at least 3 igniters	☐ ☐ ☐	
2.13.2	Mount mixture onto igniter rods	☐ ☐ ☐	
2.13.3	Test one igniter	☐ ☐ ☐	
2.14	Prepare ox pressurant line		
2.14.1	Connect regulator to bottle	☐ ☐ ☐	
2.14.2	Verify pressure adjustment closed	☐ ☐ ☐	
2.14.3	Verify 3-way valve position for venting	☐ ☐ ☐	
2.15	Prepare fuel pressurant line		
2.15.1	Verify fuel pressurant line valve open	☐ ☐ ☐	
2.15.2	Verify fuel pressurant line vent valve open	☐ ☐ ☐	
2.15.3	Connect fuel pressurant line to bottle	☐ ☐ ☐	
2.16	Prepare dewar pressurant and pneumatic line		
2.16.1	Connect bottle regulator to N_2 bottle	☐ ☐ ☐	
2.16.2	Verify pressure regulator needle valve closed	☐ ☐ ☐	
2.16.3	Verify pressure adjustment closed	☐ ☐ ☐	
2.16.4	Verify manual vent valve closed on bottle regulator	☐ ☐ ☐	
2.16.5	Connect pneumatic regulator to bottle regulator	☐ ☐ ☐	
2.16.6	Verify manual pressurize valve at pneumatic regulator closed	☐ ☐ ☐	
2.16.7	Connect dewar pressurant regulator to bottle regulator	☐ ☐ ☐	
2.16.8	Verify manual pressurize valve at dewar regulator closed	☐ ☐ ☐	
2.16.9	Connect pneumatic line to pneumatic regulator	☐ ☐ ☐	

	Index	Checklist Item	Check	Comment
	2.16.10	Open N_2 bottle	☐ ☐ ☐	
	2.16.11	Set pressure on bottle pressure regulator	☐ ☐ ☐	10 bar
	2.16.12	Open pressure regulator needle valve	☐ ☐ ☐	
	2.16.13	Verify pneumatic regulator	☐ ☐ ☐	7 bar
	2.16.14	Verify dewar pressurant regulator	☐ ☐ ☐	2-3 bar
	2.17	Install dewar		
	2.17.1	Move dewar to launch pad	☐ ☐ ☐	
	2.17.2	Verify tightness of dewar head	☐ ☐ ☐	Wrench size 8, inbus 5
	2.17.3	Connect ox tanking line	☐ ☐ ☐	
	2.18	Purge dewar pressurant line		
	2.18.1	Verify Line disconnected from dewar	☐ ☐ ☐	
	2.18.2	Open manual pressurize valve	☐ ☐ ☐	
	2.18.3	Open dewar pressurize solenoid for 3 seconds	☐ ☐ ☐	
	2.18.4	Connect line to dewar	☐ ☐ ☐	
	2.19	Mount rocket		
	2.19.1	Slide rocket into rail	☐ ☐ ☐	
	2.19.2	Secure holddown above lower rail button	☐ ☐ ☐	
	2.19.3	Ensure holddown locked	☐ ☐ ☐	
	2.19.4	Connect fuel line	☐ ☐ ☐	
	2.19.5	Connect ox line	☐ ☐ ☐	
	2.19.6	Connect Electrical umbilical	☐ ☐ ☐	
	2.19.7	Mount igniters	☐ ☐ ☐	
	2.20	Position Network Cameras	☐ ☐ ☐	
	2.21	Verify launch pad nominal		

	Index	Checklist Item	Check	Comment
	2.21.1	Verify safety light green	☐ ☐ ☐	
	2.21.2	Release kill-switch	☐ ☐ ☐	
	2.21.3	Verify safety light red	☐ ☐ ☐	
	2.21.4	Open fuel safety valve	☐ ☐ ☐	
	2.21.5	Open ox safety valve	☐ ☐ ☐	
	2.21.6	Close fuel safety valve	☐ ☐ ☐	
	2.21.7	Close ox safety valve	☐ ☐ ☐	
	2.21.8	Open fuel safety valve	☐ ☐ ☐	
	2.21.9	Open ox safety valve	☐ ☐ ☐	
	2.21.10	Press kill-switch	☐ ☐ ☐	
	2.21.11	Verify kill-switch moving safety valves to secure state and igniters off	☐ ☐ ☐	
	2.21.12	Release kill-switch	☐ ☐ ☐	
	2.21.13	Verify all pressures 0	☐ ☐ ☐	
	2.21.14	Ox depressurize solenoid	☐ ☐ ☐	
	2.21.15	Ox pressurize solenoid	☐ ☐ ☐	
	2.21.16	Ox main valve	☐ ☐ ☐	
	2.21.17	Ox tanking valve	☐ ☐ ☐	
	2.21.18	Fuel pressurize valve	☐ ☐ ☐	
	2.21.19	Fuel main valve	☐ ☐ ☐	
	2.21.20	Dewar pressurize solenoid	☐ ☐ ☐	
	2.21.21	Holddown loadcell	☐ ☐ ☐	
	2.21.22	Verify igniters not connected	☐ ☐ ☐	
	2.21.23	Pull RBF	☐ ☐ ☐	
	2.21.24	Run Sequence	☐ ☐ ☐	selected:

	Index	Checklist Item	Check	Comment
	2.21.25	Verify Sequence nominal	☐ ☐ ☐	
	2.21.26	Run same Sequence and abort right after ignition	☐ ☐ ☐	
	2.21.27	Verify abort ensures safe state	☐ ☐ ☐	
	2.21.28	Insert RBF halfway	☐ ☐ ☐	
	2.21.29	Press kill-switch	☐ ☐ ☐	
	2.22	Remove alufoil from ox vent	☐ ☐ ☐	

	Index	Checklist Item	Check	Comment
	3.	Fuel tanking	☐ ☐ ☐	
	3.1	Verify fuel main valve closed	☐ ☐ ☐	
	3.2	Verify fuel pressurant valve closed	☐ ☐ ☐	
	3.3	Release kill-switch	☐ ☐ ☐	
	3.4	Open fuel safety valve	☐ ☐ ☐	
	3.5	Remove fuel overpressure valve	☐ ☐ ☐	
	3.6	Fill fueling canister with fuel up to 7 liter marker	☐ ☐ ☐	
	3.7	Connect fueling canister filling hose to fuel line via filling nipple	☐ ☐ ☐	
	3.8	Place fueling canister on elevated surface above fuel tank	☐ ☐ ☐	
	3.9	Open fueling canister manual valve	☐ ☐ ☐	
	3.10	Fill fuel via fuel filling equipment	☐ ☐ ☐	4 kg
	3.11	Close fueling canister manual valve	☐ ☐ ☐	
	3.12	Disconnect fueling canister filing hose	☐ ☐ ☐	
	3.13	Remove fueling canister	☐ ☐ ☐	
	3.14	Connect fuel presssurant line to fuel system	☐ ☐ ☐	
	3.15	Check manual valves		
	3.15.1	Check manual ox vent valve closed	☐ ☐ ☐	
	3.15.2	Check fuel overpressure valve installed	☐ ☐ ☐	
	3.16	Save system state to version control in config ecui repo		
	3.16.1	git add ‹Sequence file›	☐ ☐ ☐	
	3.16.2	git add mappings.json	☐ ☐ ☐	
	3.16.3	git commit -m ”Pre Launch commit ‹date›”	☐ ☐ ☐	
	3.16.4	git tag launch-‹date›	☐ ☐ ☐	Date format YYYY-MM-DD

Index	Checklist Item	Check	Comment
3.17	Briefing		
3.17.1	Explain test procedure	☐ ☐ ☐	
3.17.2	Assign range safety	☐ ☐ ☐	
3.17.3	Explain safety status colors	☐ ☐ ☐	
3.17.4	Verify range safety has working access to radio communication	☐ ☐ ☐	
3.17.5	Explain GO / NO-GO poll	☐ ☐ ☐	
3.17.6	Assign Mission Control support	☐ ☐ ☐	
3.17.7	Assign Lead support	☐ ☐ ☐	
3.18	Request GoPros to be put in test tent	☐ ☐ ☐	
3.19	Position GoPros	☐ ☐ ☐	
3.20	Start recording IP Cameras	☐ ☐ ☐	
3.21	Start recording MC Screen via OBS	☐ ☐ ☐	
3.22	Callout safety status yellow	☐ ☐ ☐	
3.23	Prepare ox pressurant system		
3.23.1	Verify 3-way valve position for pressurization	☐ ☐ ☐	
3.23.2	Verify ox pressurant bottle valve open	☐ ☐ ☐	
3.23.3	Note ox pressurant bottle pressure before test	☐ ☐ ☐	Bottle-Pressure:
3.23.4	Set ox pressurant pressure	☐ ☐ ☐	10 bar
3.23.5	Verify ox pressurant pressure in ECUI	☐ ☐ ☐	
3.24	Release kill-switch	☐ ☐ ☐	
3.25	Verify ox safety valve open	☐ ☐ ☐	
3.26	Purge Ox Tank		
3.26.1	Close ox depressurize solenoid	☐ ☐ ☐	
3.26.2	Verify ox main valve closed	☐ ☐ ☐	

Index	Checklist Item	Check	Comment
3.26.3	Verify ox tanking valve closed	☐ ☐ ☐	
3.26.4	Open ox pressurize solenoid for 3 seconds	☐ ☐ ☐	
3.26.5	Check for stable ox tank pressure	☐ ☐ ☐	
3.26.6	Open ox main valve	☐ ☐ ☐	
3.26.7	Wait for ox tank and venturi pressure 0	☐ ☐ ☐	
3.26.8	Close ox main valve	☐ ☐ ☐	
3.26.9	Open ox depressurize solenoid	☐ ☐ ☐	
3.27	Press kill-switch	☐ ☐ ☐	
3.28	Vent ox pressurant line	☐ ☐ ☐	
3.29	Verify ox pressurant pressure 0	☐ ☐ ☐	
3.30	Note dewar mass before test	☐ ☐ ☐	
3.31	Mount GoPros	☐ ☐ ☐	
3.32	Connect igniters	☐ ☐ ☐	

Index	Checklist Item	Check	Comment
4.	OX Tanking	☐ ☐ ☐	
4.1	Release kill-switch	☐ ☐ ☐	
4.2	Close ox safety valve	☐ ☐ ☐	
4.3	Open ox tanking valve	☐ ☐ ☐	
4.4	Verify ox main valve closed	☐ ☐ ☐	
4.5	Verify ox tank depressurize solenoid open	☐ ☐ ☐	
4.6	Callout ox tanking start, safety status red	☐ ☐ ☐	
4.7	Verify ox tanking valve open	☐ ☐ ☐	
4.8	Get ready to close ox depress solenoid	☐ ☐ ☐	
4.9	Open dewar pressurize solenoid	☐ ☐ ☐	
4.10	Callout tanked mass every 5 seconds	☐ ☐ ☐	
4.11	Verify no leaks	☐ ☐ ☐	Steam dropping to floor should be minimal
4.11.1	If leaking halt tanking	☐ ☐ ☐	
4.12	Verify dewar overpressure valve closed, reduce dewar pressure if open	☐ ☐ ☐	
4.12.1	As soon as fluid coming from ox depress solenoid, close depressurize solenoid on call from pad crew	☐ ☐ ☐	
4.13	Pre-chill (if needed)		
4.13.1	Open ox main valve	☐ ☐ ☐	
4.13.2	Open ox safety valve	☐ ☐ ☐	
4.13.3	Prechill until liquid coming from injector	☐ ☐ ☐	
4.13.4	Close ox main valve	☐ ☐ ☐	
4.14	Close ox tanking valve	☐ ☐ ☐	
4.15	Close dewar pressurize solenoid	☐ ☐ ☐	
4.16	Note dewar mass after tanking	☐ ☐ ☐	Dewar-Mass:

	Index	Checklist Item	Check	Comment
	4.17	Callout ox tank pressure every 5 seconds	☐ ☐ ☐	
	4.17.1	If ox tank pressure exceeds 20 bar, open depressurize solenoid	☐ ☐ ☐	
	4.18	Pre-Pressurize fuel system		
	4.18.1	Verify fuel main valve fully closed	☐ ☐ ☐	
	4.18.2	Close manual fuel pressurant line vent valve	☐ ☐ ☐	
	4.18.3	Verify manual fuel pressurant filling valve closed	☐ ☐ ☐	
	4.18.4	Open fuel pressurant bottle very slowly	☐ ☐ ☐	
	4.18.5	Open manual fuel pressurant filling valve slowly	☐ ☐ ☐	
	4.18.6	Select Pre-Pressurize Sequence	☐ ☐ ☐	
	4.18.7	Callout selected Sequence	☐ ☐ ☐	
	4.18.8	Callout Pre-Pressurize Sequence start	☐ ☐ ☐	
	4.18.9	Start Pre-Pressurize Sequence	☐ ☐ ☐	
	4.18.10	Verify fuel pressurant tank pressure	☐ ☐ ☐	
	4.18.11	Note fuel pressurant tank pressure before test	☐ ☐ ☐	Pressurant-Tank-Pressure:
	4.18.12	Verify fuel tank pressure	☐ ☐ ☐	
	4.18.13	Close fuel pressurant bottle	☐ ☐ ☐	
	4.18.14	Open manual fuel pressurant line vent valve	☐ ☐ ☐	

	Index	Checklist Item	Check	Comment
	5.	Launch	☐ ☐ ☐	
	5.1	Start GoPro recording	☐ ☐ ☐	
	5.2	Pull RBF	☐ ☐ ☐	
	5.3	Clear Pad	☐ ☐ ☐	
	5.4	Go/No-Go Poll Launch		
	5.4.1	Mission Control	☐ ☐ ☐	
	5.4.2	Pad Crew	☐ ☐ ☐	
	5.4.3	Lead	☐ ☐ ☐	
	5.5	Select Sequence	☐ ☐ ☐	Selected-Sequence:
	5.6	Note launch time	☐ ☐ ☐	
	5.7	Start sequence and call out countdown	☐ ☐ ☐	
	5.8	Wait for sequence finished	☐ ☐ ☐	

Index	Checklist Item	Check	Comment
6.	Secure Pad after Abort	☐ ☐ ☐	
6.1	Depress ox pressurant system		
6.1.1	Verify ox pressurant line pressure zero	☐ ☐ ☐	
6.1.2	Open ox pressurant tank tollenoid	☐ ☐ ☐	
6.1.3	Verify ox pressurant tank pressure zero	☐ ☐ ☐	
6.2	Depress fuel pressurant system		
6.2.1	Verify fuel pressurant line pressure zero	☐ ☐ ☐	
6.2.2	Open fuel pressurant tank tollenoid	☐ ☐ ☐	
6.2.3	Verify fuel pressurant tank pressure zero	☐ ☐ ☐	
6.3	If ox umbillical not connected, proceed with ox de-tanking		
6.4	Ox de-tanking		
6.4.1	Open ox tanking valve	☐ ☐ ☐	
6.4.2	Close ox safety valve	☐ ☐ ☐	
6.4.3	Release kill-switch	☐ ☐ ☐	
6.4.4	Close ox depress	☐ ☐ ☐	
6.4.5	Verify ox tanking valve open	☐ ☐ ☐	
6.4.6	Disconnect dewar pressurant line	☐ ☐ ☐	
6.4.7	Monitor dewar weight	☐ ☐ ☐	
6.4.8	When dewar weight idle, close ox tanking valve	☐ ☐ ☐	
6.4.9	Note dewar weight	☐ ☐ ☐	Dewar-Weight:
6.5	If ox umbillical connected, proceed with ox dump		
6.6	Ox dump		
6.6.1	Open ox depress	☐ ☐ ☐	

	Index	Checklist Item	Check	Comment
	6.6.2	Close ox safety valve	☐ ☐ ☐	
	6.6.3	Release kill-switch	☐ ☐ ☐	
	6.6.4	Open ox main valve	☐ ☐ ☐	
	6.7	Fuel dump		
	6.7.1	Open fuel depress	☐ ☐ ☐	
	6.7.2	Close fuel safety valve	☐ ☐ ☐	
	6.7.3	Release kill-switch	☐ ☐ ☐	
	6.7.4	Open fuel main valve	☐ ☐ ☐	
	6.8	Depressurize ox system		
	6.8.1	Note ox pressurant bottle pressure after test	☐ ☐ ☐	Bottle-Pressure:
	6.8.2	Close ox pressurant bottle valve	☐ ☐ ☐	
	6.8.3	Vent ox pressurant line	☐ ☐ ☐	
	6.8.4	Set line pressure on ox pressurant regulator to zero (Adjustment screw out)	☐ ☐ ☐	
	6.9	Verify all pressures zero	☐ ☐ ☐	
	6.9.1	Ox pressurant pressure	☐ ☐ ☐	
	6.9.2	Fuel pressurant tank pressure	☐ ☐ ☐	
	6.10	Disconnect ECU power		
	6.11	Verify all pressures zero		
	6.11.1	Ox pressurant pressure	☐ ☐ ☐	
	6.11.2	Ox tank pressure	☐ ☐ ☐	
	6.11.3	Fuel pressurant tank pressure	☐ ☐ ☐	
	6.11.4	Fuel tank pressure	☐ ☐ ☐	
	6.12	Depressurize tanking system		
	6.12.1	Note pneumatic bottle pressure after test	☐ ☐ ☐	Bottle-Pressure:

Index	Checklist Item	Check	Comment
6.12.2	Close bottle valve	☐ ☐ ☐	
6.12.3	Vent pressure line	☐ ☐ ☐	
6.12.4	Close regulator needle valve	☐ ☐ ☐	
6.12.5	Set line pressure on regulator to zero (Adjustment screw out)	☐ ☐ ☐	
6.13	Tank depressurize valves open and sealed with alu foil	☐ ☐ ☐	
6.14	Stop recordings	☐ ☐ ☐	
6.15	Ensure safety for inspection	☐ ☐ ☐	

Index	Checklist Item	Check	Comment
7.	Secure Pad	☐ ☐ ☐	
7.0.1	Verify fuel pressurant bottle closed	☐ ☐ ☐	
7.0.2	Verify fuel pressurant line vented	☐ ☐ ☐	
7.1	Depressurize ox system		
7.1.1	Note ox pressurant bottle pressure after test	☐ ☐ ☐	Bottle-Pressure:
7.1.2	Close ox pressurant bottle valve	☐ ☐ ☐	
7.1.3	Vent ox pressurant line	☐ ☐ ☐	
7.1.4	Set line pressure on ox pressurant regulator to zero (Adjustment screw out)	☐ ☐ ☐	
7.2	Verify all pressures zero	☐ ☐ ☐	
7.2.1	Ox pressurant pressure	☐ ☐ ☐	
7.2.2	Fuel pressurant tank pressure	☐ ☐ ☐	
7.3	Disconnect ECU power		
7.4	Verify all pressures zero		
7.4.1	Ox pressurant pressure	☐ ☐ ☐	
7.4.2	Ox tank pressure	☐ ☐ ☐	
7.4.3	Fuel pressurant tank pressure	☐ ☐ ☐	
7.4.4	Fuel tank pressure	☐ ☐ ☐	
7.5	Depressurize tanking system		
7.5.1	Note pneumatic bottle pressure after test	☐ ☐ ☐	Bottle-Pressure:
7.5.2	Close bottle valve	☐ ☐ ☐	
7.5.3	Vent pressure line	☐ ☐ ☐	
7.5.4	Close regulator needle valve	☐ ☐ ☐	
7.5.5	Set line pressure on regulator to zero (Adjustment screw out)	☐ ☐ ☐	

	Index	Checklist Item	Check	Comment
	7.6	Tank depressurize valves open and sealed with alu foil	☐ ☐ ☐	
	7.7	Stop recordings	☐ ☐ ☐	
	7.8	Ensure safety for inspection	☐ ☐ ☐	
	7.9	Range safety dismissed	☐ ☐ ☐	

Index	Checklist Item	Check	Comment
8.	De - Briefing	☐ ☐ ☐	
8.1	Export data	☐ ☐ ☐	
8.1.1	cd ../simple_influx_csv_exporter	☐ ☐ ☐	
8.1.2	python3 export.py <name> gse states <startDateUTC> --end <endDateUTC>	☐ ☐ ☐	Date format YYYY-MM-DDThh:mm:ssZ
8.1.3	python3 export.py <name> gse sensors <startDateUTC> --end <endDateUTC>	☐ ☐ ☐	Date format YYYY-MM-DDThh:mm:ssZ
8.2	Share graph data in test channel	☐ ☐ ☐	with axis and timeseries names visible
8.3	Scan checklists with notes and upload to drive	☐ ☐ ☐	
8.4	Write report	☐ ☐ ☐	

A.5.2 Hotfire Checklist:

LAMARR
5 second Hotfire

Event General	
Event	5 second Hotfire
Date	04.09.2024
Planned launch/test	
Participants	
Checklist Version	1.8

Summary

Camera IPs (via VLC)	
Cam 1	http://root:DeepSpace69@192.168.0.7:5580/axis-cgi/mjpg/video.cgi
Cam 2	http://root:DeepSpace69@192.168.0.7:5581/axis-cgi/mjpg/video.cgi
Cam 3	http://root:DeepSpace69@192.168.0.7:5582/axis-cgi/mjpg/video.cgi
Mission Control	
ECUI	http://192.168.0.7

Configuration Notes	
Ox pressurant bottle pressure before test	bar
Ox pressurant bottle pressure after test	bar
Fuel pressurant bottle pressure before test	bar
Fuel pressurant bottle pressure after test	bar
Dewar pressurant bottle pressure before test	bar
Dewar pressurant bottle pressure after test	bar
Set pressure oxidizer pressurant bottle	bar
Set pressure fuel pressurant bottle	bar
Dewar mass before tanking	kg
Dewar mass after tanking	kg
Time of hotfire 1	
Time of hotfire 2	
Time of hotfire 3	

	Index	Checklist Item	Check	Comment

Index	Checklist Item	Check	Comment
1.	Pre-Day Preparations	☐ ☐ ☐	
1.1	Connect ox venturi pressure sensor	☐ ☐ ☐	
1.2	Connect fuel venturi pressure sensor	☐ ☐ ☐	
1.3	Prepare Fuel	☐ ☐ ☐	One big canister
1.4	Charge GoPros	☐ ☐ ☐	
1.5	Prepare table, bench and tent for test lead	☐ ☐ ☐	
1.6	Prepare test lead laptop	☐ ☐ ☐	
1.7	Prepare test lead power cable	☐ ☐ ☐	
1.8	Prepare test lead network cable	☐ ☐ ☐	
1.9	Prepare alufoil	☐ ☐ ☐	
1.10	Prepare breathing protection	☐ ☐ ☐	
1.11	Prepare hearing protection	☐ ☐ ☐	
1.12	Prepare eye protection	☐ ☐ ☐	
1.13	Prepare cryo gloves	☐ ☐ ☐	
1.14	Prepare UPS	☐ ☐ ☐	
1.15	Verify UPS connections		
1.15.1	Verify Server Power on UPS	☐ ☐ ☐	
1.15.2	Verify Teststand on UPS	☐ ☐ ☐	
1.15.3	Verify Antenna POE on UPS	☐ ☐ ☐	
1.15.4	Verify Switch on UPS	☐ ☐ ☐	
1.15.5	Verify Router on UPS	☐ ☐ ☐	
1.16	Prepare MC		
1.16.1	MC Laptop	☐ ☐ ☐	
1.16.2	Two screens	☐ ☐ ☐	

	Index	Checklist Item	Check	Comment
	1.17	Prepare sound suppression system		
	1.17.1	Move water tank where it will be filled	☐ ☐ ☐	
	1.17.2	Prepare system and pump	☐ ☐ ☐	
	1.17.3	Prepare power cable	☐ ☐ ☐	
	1.18	Print Checklist	☐ ☐ ☐	5 times

Index	Checklist Item	Check	Comment
2.	Preparations	☐ ☐ ☐	
2.1	Press kill-switch	☐ ☐ ☐	
2.2	Fill water tank	☐ ☐ ☐	
2.3	Prepare test lead tent	☐ ☐ ☐	
2.4	Prepare test lead table	☐ ☐ ☐	
2.5	Put kill switch on test lead table	☐ ☐ ☐	
2.6	Prepare power cable for test lead	☐ ☐ ☐	
2.7	Prepare network cable for test lead	☐ ☐ ☐	
2.8	Prepare test lead laptop	☐ ☐ ☐	
2.9	Prepare manual key for ox tanking valve	☐ ☐ ☐	
2.10	Power server	☐ ☐ ☐	
2.11	Power teststand	☐ ☐ ☐	
2.12	Prepare mission control		
2.12.1	One screen ECUI	☐ ☐ ☐	
2.12.2	Other screens cameras	☐ ☐ ☐	
2.12.3	Tab open for VSCode with ssh connection on config repo	☐ ☐ ☐	
2.12.4	Tab open with grafana for venturi pressuress	☐ ☐ ☐	
2.12.5	Verify venturi pressure data in grafana	☐ ☐ ☐	select last 5 minutes
2.12.6	Open discord for communication	☐ ☐ ☐	
2.12.7	Prepare checklists, pens and paper for notes	☐ ☐ ☐	
2.13	Verify ECUI nominal		
2.13.1	Verify Kvaser CAN driver loaded	☐ ☐ ☐	`/etc/docs/linuxcan/listChannels/` should list at least 4 channels
2.13.2	Verify llserver running	☐ ☐ ☐	`docker compose ps` in `/home/config_ecui` folder

	Index	Checklist Item	Check	Comment
	2.13.3	Verify web-server running	☐ ☐ ☐	`docker compose ps` in `/home/config_ecui` folder
	2.14	Prepare igniters		
	2.14.1	Prepare mixture for at least 3 igniters	☐ ☐ ☐	
	2.14.2	Mount mixture onto igniter rods	☐ ☐ ☐	
	2.14.3	Test one igniter	☐ ☐ ☐	
	2.15	Prepare LN_2 for ox tank cooling	☐ ☐ ☐	
	2.16	Prepare ox pressurant line		
	2.16.1	Connect regulator to bottle	☐ ☐ ☐	
	2.16.2	Verify pressure adjustment closed	☐ ☐ ☐	
	2.16.3	Verify 3-way valve position for venting	☐ ☐ ☐	
	2.17	Prepare fuel pressurant line		
	2.17.1	Verify fuel pressurant line valve open	☐ ☐ ☐	
	2.17.2	Verify fuel pressurant line vent valve open	☐ ☐ ☐	
	2.17.3	Connect fuel pressurant line to bottle	☐ ☐ ☐	
	2.18	Prepare dewar pressurant and pneumatic line		
	2.18.1	Connect bottle regulator to N_2 bottle	☐ ☐ ☐	
	2.18.2	Verify pressure regulator needle valve closed	☐ ☐ ☐	
	2.18.3	Verify pressure adjustment closed	☐ ☐ ☐	
	2.18.4	Verify manual vent valve closed on bottle regulator	☐ ☐ ☐	
	2.18.5	Connect pneumatic regulator to bottle regulator	☐ ☐ ☐	
	2.18.6	Verify manual pressurize valve at pneumatic regulator closed	☐ ☐ ☐	
	2.18.7	Connect dewar pressurant regulator to bottle regulator	☐ ☐ ☐	
	2.18.8	Verify manual pressurize valve at dewar regulator closed	☐ ☐ ☐	

Index	Checklist Item	Check	Comment
2.18.9	Connect pneumatic line to pneumatic regulator	☐ ☐ ☐	
2.18.10	Open N_2 bottle	☐ ☐ ☐	
2.18.11	Set pressure on bottle pressure regulator	☐ ☐ ☐	10 bar
2.18.12	Open pressure regulator needle valve	☐ ☐ ☐	
2.18.13	Verify pneumatic regulator	☐ ☐ ☐	7 bar
2.18.14	Verify dewar pressurant regulator	☐ ☐ ☐	2-3 bar
2.19	Install dewar		
2.19.1	Move dewar into container	☐ ☐ ☐	
2.19.2	Verify tightness of dewar head	☐ ☐ ☐	Wrench size 8, inbus 5
2.19.3	Connect ox tanking line	☐ ☐ ☐	
2.20	Purge dewar pressurant line		
2.20.1	Verify Line disconnected from dewar	☐ ☐ ☐	
2.20.2	Open manual pressurize valve	☐ ☐ ☐	
2.20.3	Open dewar pressurize solenoid for 3 seconds	☐ ☐ ☐	
2.20.4	Connect line to dewar	☐ ☐ ☐	
2.21	Mount engine		
2.21.1	Mount injector on thrust structure	☐ ☐ ☐	
2.21.2	Connect chamber pressure sensor	☐ ☐ ☐	
2.21.3	Connect fuel line	☐ ☐ ☐	
2.21.4	Connect ox line	☐ ☐ ☐	
2.21.5	Insulate ox line	☐ ☐ ☐	
2.21.6	Add fire protection to sensor and igniter cables	☐ ☐ ☐	
2.21.7	Mount hold down plate	☐ ☐ ☐	
2.21.8	Position temperature sensors	☐ ☐ ☐	

Index	Checklist Item	Check	Comment
2.21.9	Mount igniters	☐ ☐ ☐	
2.22	Install boards in front of institute container window and doors	☐ ☐ ☐	
2.23	Install sound suppression system		
2.23.1	Position sound suppression system	☐ ☐ ☐	
2.23.2	Mount sound suppression system to teststand	☐ ☐ ☐	
2.23.3	Position water tank	☐ ☐ ☐	
2.23.4	Put pump into water tank	☐ ☐ ☐	
2.23.5	Connect to power	☐ ☐ ☐	Should be extra from teststand
2.23.6	Verify pump nominal	☐ ☐ ☐	
2.24	Postition ground protection plate	☐ ☐ ☐	
2.25	Secure container doors	☐ ☐ ☐	
2.26	Connect CO2 bottle to fire extinguishing system	☐ ☐ ☐	
2.27	Turn on scale	☐ ☐ ☐	
2.28	Position Network Cameras	☐ ☐ ☐	
2.29	Verify teststand nominal		
2.29.1	Verify safety light green	☐ ☐ ☐	
2.29.2	Release kill-switch	☐ ☐ ☐	
2.29.3	Verify safety light red	☐ ☐ ☐	
2.29.4	Open fuel safety valve	☐ ☐ ☐	
2.29.5	Open ox safety valve	☐ ☐ ☐	
2.29.6	Close fuel safety valve	☐ ☐ ☐	
2.29.7	Close ox safety valve	☐ ☐ ☐	
2.29.8	Open fuel safety valve	☐ ☐ ☐	
2.29.9	Open ox safety valve	☐ ☐ ☐	

Index	Checklist Item	Check	Comment
2.29.10	Press kill-switch	☐ ☐ ☐	
2.29.11	Verify kill-switch moving safety valves to secure state and igniters off	☐ ☐ ☐	
2.29.12	Release kill-switch	☐ ☐ ☐	
2.29.13	Verify all pressures 0	☐ ☐ ☐	
2.29.14	Ox depressurize solenoid	☐ ☐ ☐	
2.29.15	Ox pressurize solenoid	☐ ☐ ☐	
2.29.16	Ox main valve	☐ ☐ ☐	
2.29.17	Ox tanking valve	☐ ☐ ☐	
2.29.18	Fuel pressurize valve	☐ ☐ ☐	
2.29.19	Fuel main valve	☐ ☐ ☐	
2.29.20	Dewar pressurize solenoid	☐ ☐ ☐	
2.29.21	Thrust loadcell	☐ ☐ ☐	
2.29.22	Ox tank loadcell	☐ ☐ ☐	
2.29.23	Fuel tank loadcell	☐ ☐ ☐	
2.29.24	Verify igniters not connected	☐ ☐ ☐	
2.29.25	Verify igniter output	☐ ☐ ☐	
2.29.26	Run Sequence	☐ ☐ ☐	selected:
2.29.27	Verify Sequence nominal	☐ ☐ ☐	
2.29.28	Run same Sequence and abort right after ignition	☐ ☐ ☐	
2.29.29	Close purge solenoid	☐ ☐ ☐	
2.29.30	Verify abort ensures safe state	☐ ☐ ☐	
2.29.31	Press kill-switch	☐ ☐ ☐	
2.30	Remove alufoil from ox vent	☐ ☐ ☐	
2.31	Verify fire extinguishers prepared	☐ ☐ ☐	$2 * CO_2$

	Index	Checklist Item	Check	Comment
	2.32	Verify at least three breathing protection masks prepared	☐ ☐ ☐	

Index	Checklist Item	Check	Comment
3.	Fuel tanking	☐ ☐ ☐	
3.1	Verify fuel main valve closed	☐ ☐ ☐	
3.2	Verify fuel pressurant valve closed	☐ ☐ ☐	
3.3	Release kill-switch	☐ ☐ ☐	
3.4	Open fuel safety valve	☐ ☐ ☐	
3.5	Tare fuel tank load cell	☐ ☐ ☐	
3.6	Remove fuel overpressure valve	☐ ☐ ☐	
3.7	Fill fueling canister with fuel up to 7 liter marker	☐ ☐ ☐	
3.8	Connect fueling canister filling hose to fuel line via filling nipple	☐ ☐ ☐	
3.9	Place fueling canister on elevated surface above fuel tank	☐ ☐ ☐	
3.10	Open fueling canister manual valve	☐ ☐ ☐	
3.11	Fill fuel via fuel filling equipment	☐ ☐ ☐	4 kg
3.12	Close fueling canister manual valve	☐ ☐ ☐	
3.13	Disconnect fueling canister filing hose	☐ ☐ ☐	
3.14	Remove fueling canister	☐ ☐ ☐	
3.15	Insert and tighten fuel overpressure valve	☐ ☐ ☐	
3.16	Connect fuel presssurant line to fuel system	☐ ☐ ☐	
3.17	Check manual valves		
3.17.1	Check manual ox vent valve closed	☐ ☐ ☐	
3.17.2	Check fuel overpressure valve installed	☐ ☐ ☐	
3.18	Save test state to version control in config ecui repo		
3.18.1	git add ‹Sequence file›	☐ ☐ ☐	
3.18.2	git add mappings.json	☐ ☐ ☐	

Index	Checklist Item	Check	Comment
3.18.3	git commit -m "Pre Hotfire commit ‹date›"	☐ ☐ ☐	
3.18.4	git tag hotfire-‹date›	☐ ☐ ☐	Date format YYYY-MM-DD
3.19	Briefing		
3.19.1	Explain test procedure	☐ ☐ ☐	
3.19.2	Assign range safety	☐ ☐ ☐	1: Assembly corner, 2: Door, 3: Institute corner
3.19.3	Explain safety status colors	☐ ☐ ☐	
3.19.4	Verify one discord user available per range safety with enough phone battery	☐ ☐ ☐	
3.19.5	Explain GO / NO-GO poll	☐ ☐ ☐	
3.19.6	Assign fire safety	☐ ☐ ☐	
3.19.7	Assign MC support	☐ ☐ ☐	
3.19.8	Assign TL support	☐ ☐ ☐	
3.20	Request GoPros to be put in test tent	☐ ☐ ☐	
3.21	Position GoPros	☐ ☐ ☐	
3.22	Start recording IP Cameras	☐ ☐ ☐	
3.23	Start recording MC Screen via OBS	☐ ☐ ☐	
3.24	Verify Range Safety staff in place	☐ ☐ ☐	
3.25	Callout safety status yellow	☐ ☐ ☐	
3.26	Prepare ox pressurant system		
3.26.1	Verify 3-way valve position for pressurization	☐ ☐ ☐	
3.26.2	Verify ox pressurant bottle valve open	☐ ☐ ☐	
3.26.3	Note ox pressurant bottle pressure before test	☐ ☐ ☐	Bottle-Pressure:
3.26.4	Set ox pressurant pressure	☐ ☐ ☐	10 bar
3.26.5	Verify ox pressurant pressure in ECUI	☐ ☐ ☐	

Index	Checklist Item	Check	Comment
3.27	Release kill-switch	☐ ☐ ☐	
3.28	Verify ox safety valve open	☐ ☐ ☐	
3.29	Purge Ox Tank		
3.29.1	Close ox depressurize solenoid	☐ ☐ ☐	
3.29.2	Verify ox main valve closed	☐ ☐ ☐	
3.29.3	Verify ox tanking valve closed	☐ ☐ ☐	
3.29.4	Open ox pressurize solenoid for 3 seconds	☐ ☐ ☐	
3.29.5	Check for stable ox tank pressure	☐ ☐ ☐	
3.29.6	Open ox main valve	☐ ☐ ☐	
3.29.7	Wait for ox tank and venturi pressure 0	☐ ☐ ☐	
3.29.8	Close ox main valve	☐ ☐ ☐	
3.29.9	Open ox depressurize solenoid	☐ ☐ ☐	
3.30	Press kill-switch	☐ ☐ ☐	
3.31	Fill LN_2 into ox tank chiller	☐ ☐ ☐	
3.32	Vent ox pressurant line	☐ ☐ ☐	
3.33	Verify ox pressurant pressure 0	☐ ☐ ☐	
3.34	Note dewar mass before test	☐ ☐ ☐	
3.35	Mount GoPros	☐ ☐ ☐	
3.36	Connect igniters	☐ ☐ ☐	

Index	Checklist Item	Check	Comment
4.	OX Tanking	☐ ☐ ☐	
4.1	Install CO_2 fire extinguishing tube above engine	☐ ☐ ☐	
4.2	Release kill-switch	☐ ☐ ☐	
4.3	Close ox safety valve	☐ ☐ ☐	
4.4	Tare ox tank load cell	☐ ☐ ☐	
4.5	Open ox tanking valve	☐ ☐ ☐	
4.6	Verify ox main valve closed	☐ ☐ ☐	
4.7	Verify ox tank depressurize solenoid open	☐ ☐ ☐	
4.8	Callout ox tanking start, safety status red	☐ ☐ ☐	
4.9	Verify ox tanking valve open	☐ ☐ ☐	
4.10	Get ready to open dewar pressurize solenoid to start tanking and close dewar pressurize solenoid to stop tanking	☐ ☐ ☐	
4.11	Open dewar pressurize solenoid	☐ ☐ ☐	
4.12	Callout tanked mass every 5 seconds	☐ ☐ ☐	
4.13	Verify no leaks	☐ ☐ ☐	Steam dropping to floor should be minimal
4.13.1	If leaking halt tanking	☐ ☐ ☐	
4.14	Verify dewar overpressure valve closed, reduce dewar pressure if open	☐ ☐ ☐	
4.14.1	As soon as fluid coming from ox depress solenoid, close depressurize solenoid on call from pad crew	☐ ☐ ☐	
4.15	Pre-chill (if needed)		
4.15.1	Open ox main valve	☐ ☐ ☐	
4.15.2	Open ox safety valve	☐ ☐ ☐	
4.15.3	Prechill until liquid coming from injector	☐ ☐ ☐	
4.15.4	Close ox main valve	☐ ☐ ☐	

Index	Checklist Item	Check	Comment
4.16	Close ox tanking valve	☐ ☐ ☐	
4.17	Close dewar pressurize solenoid	☐ ☐ ☐	
4.18	Note dewar mass after tanking	☐ ☐ ☐	Dewar-Mass:
4.19	Activate ox tank heating	☐ ☐ ☐	
4.20	Callout ox tank pressure every 5 seconds	☐ ☐ ☐	
4.20.1	When ox tank pressure reaches 7 bar, deactivate ox tank heating	☐ ☐ ☐	Set-Point: 19 bar
4.20.2	If ox tank pressure exceeds 20 bar, open depressurize solenoid	☐ ☐ ☐	
4.21	Pre-Pressurize fuel system		
4.21.1	Verify fuel main valve fully closed	☐ ☐ ☐	
4.21.2	Close manual fuel pressurant line vent valve	☐ ☐ ☐	
4.21.3	Verify manual fuel pressurant filling valve closed	☐ ☐ ☐	
4.21.4	Open fuel pressurant bottle very slowly	☐ ☐ ☐	
4.21.5	Open manual fuel pressurant filling valve slowly	☐ ☐ ☐	
4.21.6	Select Pre-Pressurize Sequence	☐ ☐ ☐	
4.21.7	Callout selected Sequence	☐ ☐ ☐	
4.21.8	Callout Pre-Pressurize Sequence start	☐ ☐ ☐	
4.21.9	Start Pre-Pressurize Sequence	☐ ☐ ☐	
4.21.10	Verify fuel pressurant tank pressure	☐ ☐ ☐	
4.21.11	Note fuel pressurant tank pressure before test	☐ ☐ ☐	Pressurant-Tank-Pressure:
4.21.12	Verify fuel tank pressure	☐ ☐ ☐	
4.21.13	Close fuel pressurant bottle	☐ ☐ ☐	
4.21.14	Open manual fuel pressurant line vent valve	☐ ☐ ☐	
4.22	Pre-Pressurize ox system		

Index	Checklist Item	Check	Comment
4.22.1	Verify 3-way valve position on ox bottle regulator for pressurization	☐ ☐ ☐	
4.22.2	Set ox pressurant pressure	☐ ☐ ☐	30 bar
4.22.3	Verify ox pressurant pressure in ECUI	☐ ☐ ☐	
4.22.4	Verify manual ox tanking valve fully closed	☐ ☐ ☐	
4.22.5	Verify ox main valve fully closed	☐ ☐ ☐	
4.22.6	Verify ox depressurize solenoid closed	☐ ☐ ☐	
4.22.7	Open ox pressurize solenoid	☐ ☐ ☐	
4.22.8	Verify ox tank pressure	☐ ☐ ☐	
4.22.9	Close ox pressurize solenoid	☐ ☐ ☐	
4.23	Callout ox tank pressure every 5 seconds		
4.23.1	If ox tank pressure exceeds 30 bar, open depressurize solenoid	☐ ☐ ☐	

Index	Checklist Item	Check	Comment
5.	Test	☐ ☐ ☐	
5.1	Range Safety 2 empty assembly	☐ ☐ ☐	
5.2	Pressurize ox system		
5.2.1	Set ox pressurant pressure	☐ ☐ ☐	35 bar
5.2.2	Verify ox pressurant pressure in ECUI	☐ ☐ ☐	
5.3	Close fire shield	☐ ☐ ☐	
5.4	Engage two fire shield pins	☐ ☐ ☐	
5.5	Go/No-Go Poll Hotfire		
5.5.1	Range Safety fence	☐ ☐ ☐	
5.5.2	Range Safety middle door	☐ ☐ ☐	
5.5.3	Range Safety bushes	☐ ☐ ☐	
5.5.4	Mission Control	☐ ☐ ☐	
5.5.5	Test Lead	☐ ☐ ☐	
5.6	Start GoPro recording	☐ ☐ ☐	
5.7	Tare load cell	☐ ☐ ☐	
5.8	Test lead request ECUI master	☐ ☐ ☐	
5.9	Select Sequence	☐ ☐ ☐	Selected-Sequence:
5.10	Note hotfire start time	☐ ☐ ☐	
5.11	Start sound suppression system	☐ ☐ ☐	
5.12	Verify sound suppression system running via cameras	☐ ☐ ☐	
5.13	Start sequence and call out countdown	☐ ☐ ☐	
5.14	Wait for sequence finished	☐ ☐ ☐	
5.15	Stop sound suppression system	☐ ☐ ☐	
5.16	Verify ox main valve open	☐ ☐ ☐	

	Index	Checklist Item	Check	Comment
	5.17	Press kill-switch	☐ ☐ ☐	

Index	Checklist Item	Check	Comment
6.	Secure Pad	☐ ☐ ☐	
6.0.1	Verify fuel pressurant bottle closed	☐ ☐ ☐	
6.0.2	Verify fuel pressurant line vented	☐ ☐ ☐	
6.1	Depressurize ox system		
6.1.1	Note ox pressurant bottle pressure after test	☐ ☐ ☐	Bottle-Pressure:
6.1.2	Close ox pressurant bottle valve	☐ ☐ ☐	
6.1.3	Vent ox pressurant line	☐ ☐ ☐	
6.1.4	Set line pressure on ox pressurant regulator to zero (Adjustment screw out)	☐ ☐ ☐	
6.2	If last hotfire: jump to ox detanking (7.)		
6.3	Verify all pressures zero	☐ ☐ ☐	
6.3.1	Ox pressurant pressure	☐ ☐ ☐	
6.3.2	Ox tank pressure	☐ ☐ ☐	
6.3.3	Fuel pressurant tank pressure	☐ ☐ ☐	
6.3.4	Fuel tank pressure	☐ ☐ ☐	
6.4	Disconnect ECU power		
6.5	Fill LN_2 into ox tank chiller and monitor	☐ ☐ ☐	
6.6	If multiple tests: callout engine switch		
6.7	Switch out engine according to propulsion checklist	☐ ☐ ☐	
6.8	Wait for engine swap confirmation	☐ ☐ ☐	
6.9	Jump to fuel tanking (3.)	☐ ☐ ☐	

Index	Checklist Item	Check	Comment
7.	Ox de-tanking	☐ ☐ ☐	
7.0.1	Open ox tanking valve	☐ ☐ ☐	
7.0.2	Close ox safety valve	☐ ☐ ☐	
7.0.3	Release kill-switch	☐ ☐ ☐	
7.0.4	Close ox depress	☐ ☐ ☐	
7.0.5	Verify ox tanking valve open	☐ ☐ ☐	
7.0.6	Disconnect dewar pressurant line	☐ ☐ ☐	
7.0.7	Monitor dewar weight	☐ ☐ ☐	
7.0.8	When dewar weight idle, close ox tanking valve	☐ ☐ ☐	
7.0.9	Note dewar weight	☐ ☐ ☐	Dewar-Weight:
7.1	Verify all pressures zero		
7.1.1	Ox pressurant pressure	☐ ☐ ☐	
7.1.2	Ox tank pressure	☐ ☐ ☐	
7.1.3	Fuel pressurant tank pressure	☐ ☐ ☐	
7.1.4	Fuel tank pressure	☐ ☐ ☐	
7.2	Depressurize tanking system		
7.2.1	Note pneumatic bottle pressure after test	☐ ☐ ☐	Bottle-Pressure:
7.2.2	Close bottle valve	☐ ☐ ☐	
7.2.3	Vent pressure line	☐ ☐ ☐	
7.2.4	Close regulator needle valve	☐ ☐ ☐	
7.2.5	Set line pressure on regulator to zero (Adjustment screw out)	☐ ☐ ☐	
7.3	Tank depressurize valves open and sealed with alu foil	☐ ☐ ☐	
7.4	Stop recordings	☐ ☐ ☐	

	Index	Checklist Item	Check	Comment
	7.5	Ensure safety for inspection	☐ ☐ ☐	
	7.6	Range safety dismissed	☐ ☐ ☐	

Index	Checklist Item	Check	Comment
8.	De - Briefing	☐ ☐ ☐	
8.1	Export data	☐ ☐ ☐	
8.1.1	`cd ../simple_influx_csv_exporter`	☐ ☐ ☐	
8.1.2	`python3 export.py <name> gse states <startDateUTC> --end <endDateUTC>`	☐ ☐ ☐	Date format YYYY-MM-DDThh:mm:ssZ
8.1.3	`python3 export.py <name> gse sensors <startDateUTC> --end <endDateUTC>`	☐ ☐ ☐	Date format YYYY-MM-DDThh:mm:ssZ
8.2	Share graph data in test channel	☐ ☐ ☐	with axis and timeseries names visible
8.3	Scan checklists with notes and upload to drive	☐ ☐ ☐	
8.4	Write report	☐ ☐ ☐	

A.5.3 Ox Cleaning Checklist:

OxClean (All Parts EXCEPT SERTO Aluminum Parts)

1. Ox Cleaning shall only be done in thoroughly cleaned room with closed doors and no open windows, make sure to wear fresh and clean gloves, do not use paper towels, clean working station in advance
2. Gather all parts in contact with oxidizer ☐
3. Disassemble all parts to base components ☐
4. Remove all visible debris (especially threads) ☐
5. Rough cleaning with water ☐
6. Cleaning with distilled water and a fresh tooth brush ☐
7. Clean with LOCTITE and seperate Toothbrush ☐
8. Soak parts for 10 minutes in LOCTITE:Water (1:4) solution ☐
9. Put in Ultra-Sonic cleaner cont. LOCTITE Solution for $5\,\mathrm{min}$ at $50\,^{\circ}\mathrm{C}$ ☐
10. Rinse off in distilled water ☐
11. Let parts dry on drying rack ☐
12. After parts are completly dry, wrap single parts in fresh aluminum foil or cover exposed areas of assembled parts with fresh aluminum foil. ☐

OxClean (Aluminum SERTO Parts)

1. Ox Cleaning shall only be done in thoroughly cleaned room with closed doors and no open windows, make sure to wear fresh and clean gloves, do not use paper towels, clean working station in advance
2. Gather all parts in contact with oxidizer ☐
3. Disassemble all parts to base components ☐
4. Remove all visible debris (especially threads) ☐
5. Rough cleaning with water ☐
6. Cleaning with distilled water and a fresh tooth brush ☐
7. Clean with IPA and seperate Toothbrush ☐
8. Soak parts for 10 minutes in IPA ☐
9. Put in Ultra-Sonic cleaner cont. IPA for $5\,\mathrm{min}$ at $50\,^{\circ}\mathrm{C}$ ☐
10. Rinse off in distilled water ☐
11. Let parts dry on drying rack ☐
12. After parts are completly dry, wrap single parts in fresh aluminum foil or cover exposed areas of assembled parts with fresh aluminum foil. ☐

OxClean (Big parts, long pipes)

1. Cleaning shall only be done in thoroughly cleaned room with closed doors and no open windows, make sure to wear fresh and clean gloves, do not use paper towels, clean working station in advance
2. Gather all parts in contact with oxidizer ☐
3. Disassemble all parts to base components ☐
4. Remove all visible debris (especially threads) ☐
5. Rough cleaning with water ☐
6. Cleaning with distilled water and a fresh tooth brush ☐
7. Clean with LOCTITE and seperate Toothbrush ☐
8. Fill parts with cleaning soultion and let it soak for 10 minutes ☐
9. Rinse thoroughly with distilled water ☐
10. Let parts dry on drying rack ☐
11. After parts are completly dry, cover openings with fresh aluminum foil or cover exposed areas of assembled parts with fresh aluminum foil. ☐

A.5.4 Propulsion assembly check:

LAMARR
Engine Assembly Checklist

Injector
Tools
14mm, 19mm Wrenches
2mm, 3mm Allen Key
Lox8

Components
Engine Head
Pintle Sleeve
Orifice Plate
Injector Shim
Pintle
PTFE O-Ring 58mm x 2mm
fillister head screw M3x10
6x countersunk head screw M5x10
2x PTFE O-Ring 11,11mm x 1,78mm
2x SERTO G1/4 fitting (without O-Ring)
SERTO G1/8 pressure line fitting (part of thermal decoupling assembly)
3mm stainless steel tube (part of thermal decoupling assembly)
SERTO G 1/8 pressure sensor fitting (part of thermal decoupling assembly)

Injector Assembly Checklist

- ☐ 1. put Orifice Plate in to Engine Head
- ☐ 2. apply Lox8 grease to PTFE O-Ring (52x2)
- ☐ 3. put PTFE O-Ring 58mm x 2mm in to Engine Head
- ☐ 4. put Shim in to Pintle Sleeve(chamfer oriented upstream)
- ☐ 5. slide Pintle in Sleeve
- ☐ 6. hold Pintle and Sleeve tight together and rotate 180°
- ☐ 7. put M3x10 screw on to allen key
- ☐ 8. screw M3x10 through Pintle Sleeve into Pintle
- ☐ 9. slide Pintle Sleeve in to Engine-Head
- ☐ 10. insert 6 countersunk head screws M5
- ☐ 11. tighten them loosely
- ☐ 12. tighten srcews in a alternating manner
- ☐ 13. apply Lox8 grease to PTFE O-Ring 11,11mm x 1,75mm
- ☐ 14. slide PTFE O-Ring 11,11mm x 1,75mm on to G 1/4 SERTO fitting (over table)
- ☐ 15. screw fitting with PTFE O-Ring in to Ox side by hand
- ☐ 16. tighten it with 19mm wrench

Injector Assembly Checklist

- [ ] 17. apply Lox8 grease to PTFE O-Ring 11,11mm x 1,75mm
- [ ] 18. slide PTFE O-Ring 11,11mm x 1,75mm on to G 1/4 SERTO fitting (over table)
- [ ] 19. screw fitting with PTFE O-Ring in to Ox side by hand
- [ ] 20. tighten it with 19mm wrench
- [ ] 21. apply Lox8 to SERTO seal faces
- [ ] 22. screw SERTO G1/8 pressure fitting by hand in to EngineHead (clean seal faces)
- [ ] 23. tighten it with 14mm wrench
- [ ] 24. apply Lox8 to SERTO seal faces of pressure fitting
- [ ] 25. put thermal decoupler on Serto pressure fitting and tighten loosely
- [ ] 26. tighten it with 8mm wrench for 1/4 turn
- [ ] 27. cover every inlet and outlet with aluminiumfoil

Thrust Chamber
Tools
2x 8mm wrench
Vaseline

Components
Injector (assembled)
Casing
Retainer
Chamber Liner
Nozzle
4x Thrust Pillars
1x PTFE O-Ring 95 x 3mm
4x FKM O-Ring 76mm x 2mm
12x hex head screws M5 x 30
12x M5 screw nut

Thrust Chamber Assembly Checklist

- [ ] 1. fix injector assembly upside down (Pintle up)
- [ ] 2. apply LOX8 to PTFE 95x3mm O-ring and burning chamber sealing groove
- [ ] 3. insert o-ring into groove
- [ ] 4. put Chamber Casing in injector
- [ ] 5. put washer (12xM5) on screws(12x M5x30) and insert them in every hole through the casing and lightly screw them in
- [ ] 6. apply vaseline to the FKM 76x2mm o-rings and their respective grooves in chamber liner and nozzle
- [ ] 7. fit the o-rings into their grooves
- [ ] 8. cover the outside of liner and nozzle in vaseline as well as the top of the liner which touches the injector
- [ ] 9. insert nozzle into liner
- [ ] 10. insert liner together with nozzle into chamber casing
- [ ] 11. push liner and nozzle in until they fit onto the injector
- [ ] 12. check if liner is tight on the injector
- [ ] 13. tighten all M5 screws by hand
- [ ] 14. tighten all M5 screws with 8mm wrench in an alternating manner until PTFE o-ring is fully compressed
- [ ] 15. screw on retainer nut on to the casing and tighten it
- [ ] 16. rotate assembly by 180°

Thrust Chamber Assembly Checklist
☐ 17. put all 4 thrust pillars on the screws in their respective positions at 45°, 135°, 225° and 315°
☐ 18. put 8x M5 washer and 8x M5 nuts on screws over thrust pillars and tighten them by hand
☐ 19. put 4x M5 washer and 4x M5 nuts on the remaining screws ant tighten them by hand
☐ 20. tighten the nuts next to the thrust pillars with an 8mm wrench

Main Lines

Tools

- 17mm wrench
- piece of clean PTFE
- Bullet
- SERTO M14x1 pilot Tool
- Chuck

Fuel Main Line

- Fuel Line
- Fuel Venturi 3,1mm
- PTFE O-Ring 6mm x 1mm
- 2x SERTO support shell 8mm
- 2x SERTO clamping ring 10mm
- 2x SERTO union nut 10mm

Ox Main Line

- OX Line
- OX Venturi 3,7mm
- PTFE O-Ring 6mm x 1mm
- 2x SERTO support shell 8mm
- 2x SERTO clamping ring 10mm
- 2x SERTO union nut 10mm

Main Line Assembly Checklist (same for both)
☐ 1. apply LOX8 on Bullet tip, on Venturi uptream end and the PTFE o-ring 6x1mm and both 8mm SERTO support shells
☐ 2. stick bullet on to venturi at the upstream end
☐ 3. slide PTFE o-ring over bullet onto the venturi, press it into the respective groove and massage it rolling between finger tips
☐ 4. stick venturi with upstream end into the downstream end of the main line)
☐ 5. use a clean PTFE piece to press the venturi in to the main line
☐ 6. press 2x 8mm SERTO support shells in to both ends of the main line
☐ 7. apply LOX8 to 2x 10mm SERTO union nuts outside and inside
☐ 8. Clamp SERTO Pilot tool in a chuck and apply LOX8
☐ 9. fit 10mm union nut and 10mm clamping ring on one end of main line and screw union nut on to the pilot tool by hand
☐ 10. tighten union nut with 17mm wrench for 1 and 3/4 turns
☐ 11. repeat the clamping of shell and union nut on other side of main line

Fuel Pressurant system
Tools
13mm, 14mm, 17mm, 19mm, 22mm, 32mm wrench

Components
Pressurant tank
Pressure adapter
Pressure reducer
Fuel pressure manifold
Serto G1/4 fitting
Pressure sensor
Magnetic vent valve
Servo
Burst disc

Injector Assembly Checklist

- [ ] 1. screw pressure adapter in to pressurant tank and tighten with wrench
- [ ] 2. screw burst disc with G1/4 USIT ring into fuel pressure manifold
- [ ] 3. screw pressure sensor in to manifold
- [ ] 4. mount magnetiv vent valve on to manifold)
- [ ] 5. mount servo onto fuel pressure manifold
- [ ] 6. screw serto G1/4 fitting into manifold
- [ ] 7. screw pressure reducer into manifold
- [ ] 8. screwpressure reducer with manifold into pressure adapter

Ox Pressurant System

Tools
13mm, 14mm, 17mm, 19mm, 22mm, 32 wrench
Lox8

Components
Pressurant tank
Pressure adapter
Pressure reducer
Upper Ox pressure manifold
Serto G1/4 fitting with PTFE o-ring
Pressure sensor
magnetic vent valve
Servo
Burst disc

Injector Assembly Checklist

- [ ] 1. put Orifice Plate in to Engine Head
- [ ] 2. apply Lox8 grease to PTFE O-Ring (52x2)
- [ ] 3. put PTFE O-Ring 52mm x 2mm in to Engine Head
- [ ] 4. put Shim in to Pintle Sleeve(chamfer oriented upstream)
- [ ] 5. slide Pintle in Sleeve
- [ ] 6. hold Pintle and Sleeve tight together and rotate 180°
- [ ] 7. put M3x10 screw on to allen key
- [ ] 8. screw M3x10 through Pintle Sleeve into Pintle
- [ ] 9. slide Pintle Sleeve in to Engine-Head
- [ ] 10. insert 6 countersunk head screws M5
- [ ] 11. tighten them loosely
- [ ] 12. tighten srcews in a alternating manner
- [ ] 13. apply Lox8 grease to PTFE O-Ring 11,11mm x 1,75mm
- [ ] 14. slide PTFE O-Ring 11,11mm x 1,75mm on to G 1/4 SERTO fitting (over table)
- [ ] 15. screw fitting with PTFE O-Ring in to Ox side by hand
- [ ] 16. tighten it with 19mm wrench

Injector Assembly Checklist	
☐	17. apply Lox8 grease to PTFE O-Ring 11,11mm x 1,75mm
☐	18. slide PTFE O-Ring 11,11mm x 1,75mm on to G 1/4 SERTO fitting (over table)
☐	19. screw fitting with PTFE O-Ring in to Ox side by hand
☐	20. tighten it with 19mm wrench
☐	21. apply Lox8 to SERTO seal faces
☐	22. screw SERTO G1/8 pressure fitting by hand in to EngineHead (clean seal faces)
☐	23. tighten it with 14mm wrench
☐	24. apply Lox8 to SERTO seal faces of pressure fitting
☐	25. put thermal decoupler on Serto pressure fitting and tighten loosely
☐	26. tighten it with 8mm wrench for 1/4 turn
☐	27. cover every inlet and outlet with aluminiumfoil

Tanks
Tools
19mm, 32mm wrench
Lox8
lower ox pressure manifold
Components
tank
1x Serto G1/4 fitting with PTFE o-ring
2x Serto G1/4 fitting with FKM o-ring
1x Serto G1/4 adjustable adapter union

Injector Assembly Checklist

☐	1. apply lox 8 on Serto G1/4 fitting with PTFE o-ring and sealing face on tank
☐	2. screw fitting into one tanks side by hand
☐	3. tighten fitting until o-ring is fully compressed
☐	4. screw lower ox pressurant manifold into the other side of the tank by hand
☐	5. tighten the manifold with a wrench until o-ring is fully compressed

A.6 Launch support Equipment:

A.6.1 Launch Support Equipment List

- Launch Rail
- Tanking structure
- LOX dewar
- Nitrogen bottle at 300 bar
- Nitrogen bottle at >50 bar
- Electronics cabinet
- Pneumatics cabinet
- Server rack with server, UPS and networking equipment
- Additional cameras
- Bottle pressure regulator
- Ethanol tanking container
- Tools:
  - Spanner set
  - Hex key set
  - Torx key set
  - Crescent wrench
  - Pipe wrench
  - Screwdriver set
  - Utility knife
  - Hose cutter
  - Multimeter
  - Scale
- PPE:
  - Gloves
  - Hearing protection
  - Face shields
  - Cryogenic gloves
- Spare parts:
  - Assorted pneumatic components
  - Pneumatic hose

- Spare LOX tanking valve
- Spare insulation material

A.6.2 Launch Support Equipment simple operational manual

Before Launch

1. Cars and trailer arrive at the launch site, rocket and materials needed for rocket preparations and mission control are loaded off at the teams preparation site.
2. Mission control is set up.
3. Trailer with launch support equipment is transported to the launch area.
4. Server rack and tanking structure is unloaded.
5. Server and networking (including IP-cameras) and additional cameras are set up, meanwhile...
6. Launch rail trusses are unloaded and arranged for assembly.
7. Trailer is aligned with launch azimuth and leveled.
8. Launch rail trusses are assembled in horizontal position, guy wires are attached to the top.
9. Launch rail is aligned and fastened.
10. Launch rail is erected to launch elevation.
11. Corner brakes are fastened in place.
12. Guy wires are fixed in place with earth anchors.
13. Tanking structure is put on the trailer, electrical and pneumatic cabinets are mounted.
14. Filled LOX dewar is transported to the launch site and lifted into place in the tanking structure.
15. Valve holder sheet is mounted in front of LOX dewar.
16. Both nitrogen bottles are transported to the launch site and fixed to the trailer with ratchet straps.
17. Electrical and pneumatic connections are made and double checked.
18. Bottle pressure regulator is connected to the pneumatics nitrogen bottle, pneumatic cabinet is connected to the pressure regulator.
19. Bottle pressure regulator is set to 14 bar.

20. In the pneumatics cabinet, top pressure regulator (pneumatics) is set at 8 bar, bottom pressure regulator (dewar pressurization) is set at 1.5 bar.
21. Pneumatics are pressurized, and actuator/hold-down position is checked. Actuation is checked with the manual override on the solenoid valves.
22. Connection with mission control is established.
23. Server is connected to the electronics.
24. Valve actuation by electronics is checked.
25. Dewar pressurization system is purged and connected to the LOX dewar.
26. Dewar is connected to the LOX tanking valve.
27. 300 bar nitrogen bottle is connected to the HPN2 tanking system.
28. (With hearing protection and face shields) Nitrogen bottle is slowly opened.
29. Leaks and bottle pressure >=300 bar is checked.
30. Bottle is closed and pressure vented.
31. Rocket and igniters arrive on pad.
32. Rocket is mounted on the launch rail, hold-down is actuated manually.
33. LOX and HPN2 disconnects are connected to the rocket, and disconnection and retraction is tested.
34. Non-essential personnel vacated the launch pad.
35. Ethanol is tanked into the rocket.
36. LOX and HPN2 disconnects are connected to the rocket.
37. 300 bar nitrogen bottle is opened, all pressure regulators are checked.
38. Additional cameras are started.
39. Igniter is inserted into the engine and connected to the launch structure.
40. Igniter channel is checked for zero-potential.
41. Igniter is connected to the electronics.
42. All personnel vacates the pad.

After Launch

1. Pad is approached carefully.
2. Pressurant nitrogen bottle is closed.
3. HPN2 tanking system is vented by opening the tanking valve.
4. Pneumatics nitrogen bottle is closed.
5. Pneumatics are vented by the manual venting valve.
6. Pad is disassembled in the reverse order to the pre-launch manual.

A.6.3 Launch Support Equipment details

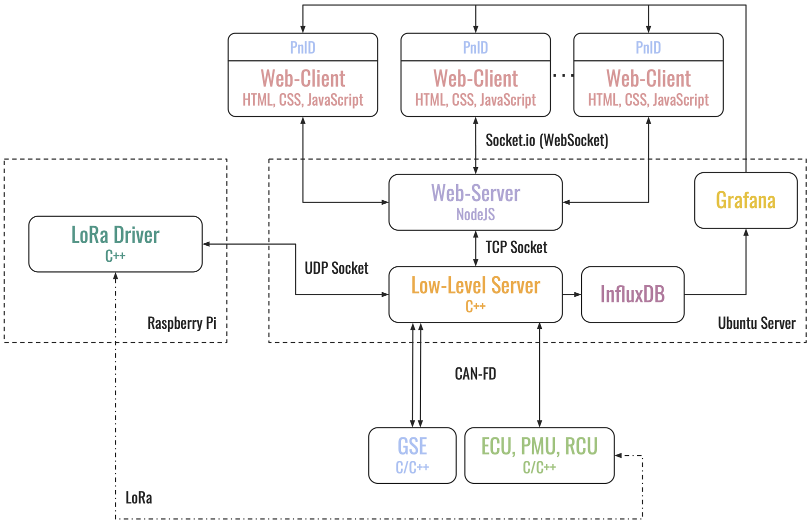


Fig. A.1: Software Architecture

Detailed Software Architecture:

Mission Control Mission Control consists of a PC or Laptop running a Web-Application (Web-Client) inside a Web-Browser. It manages the communication between the Operator and the Rocket as well as the Ground Support Equipment. The Web-Client displays all measured data and actuators in a self developed interactive Piping and Instrumentation Diagram (P&ID/PnID). Every value for each P&ID element gets validated. When out of range, it is signalled by changing colour. This way, the operator doesn't have to check each number in detail but rather only has to watch for color changes, which is much more apparent.

Ubuntu Server The Ubuntu Server uses a PCIe CAN bus extension card with four CAN bus ports. It is responsible for communication with the Hardware, i.e. GSE, ECU, RCU and PMU. Mission Control interfaces with the Hardware via a self developed software as depicted in figure A.1. The connection from the server to Mission Control can either be made by a long Ethernet cable or a directed radio link depending on the necessary safety distance of MC from the pad.

Low-Level Server Written in C++ it is responsible for managing CAN and other time critical tasks such as logging and processing sensor data.

Web-Server Uses NodeJS to host the Web-Clients and synchronize data between them.

InfluxDB and Grafana InfluxDB is a time series database for logging sensor data and user inputs. Grafana is used for real time plots and gauges on the Web-Client. It is also used for post-launch procedures.

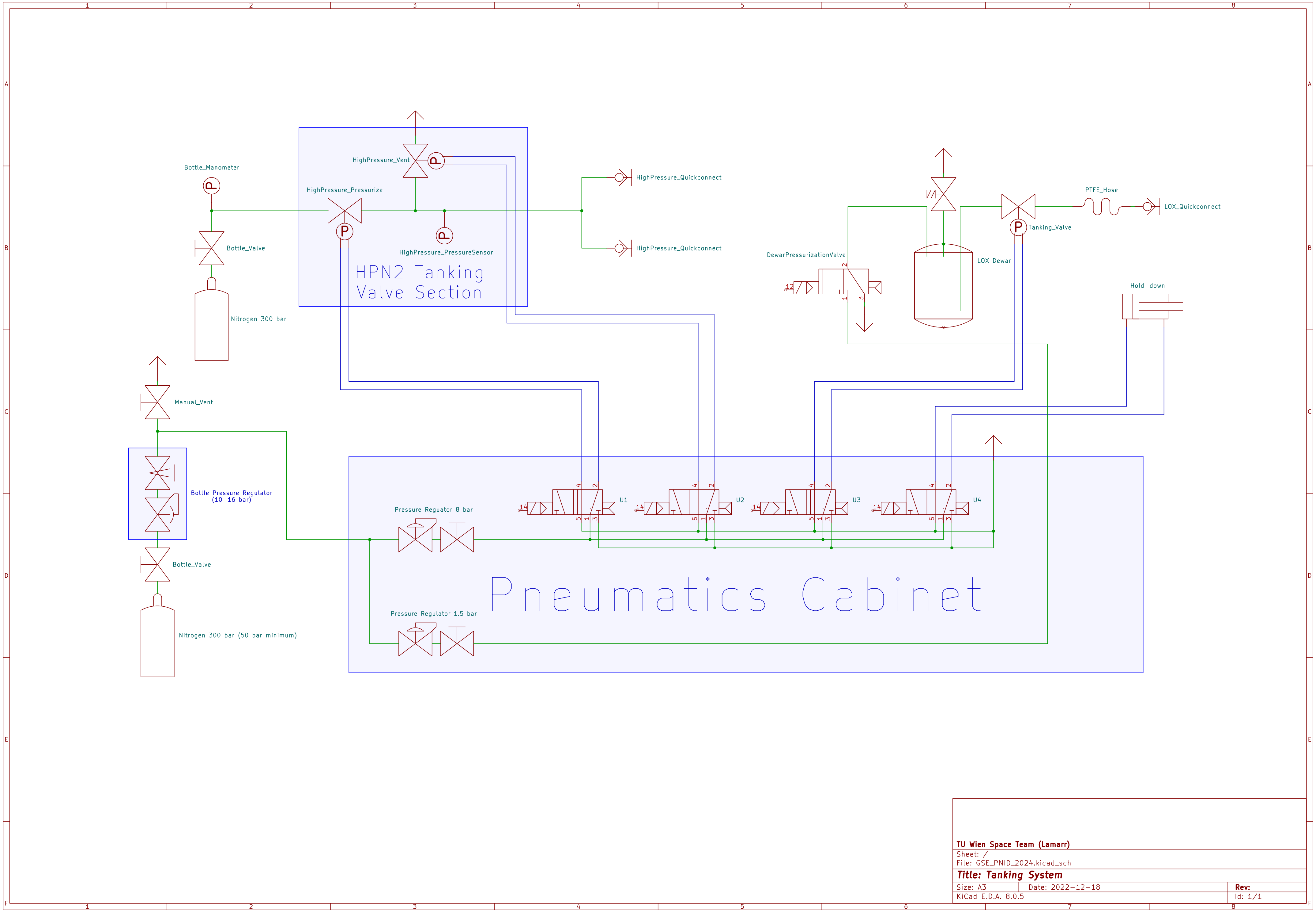
LoRa Raspberry Pi LoRa is used to communicate with the rocket during flight. A self-developed LoRa transceiver shield is connected to a Raspberry Pi, which processes and transmits the messages over UDP to the Ubuntu Server. There, they get processed like normal CAN Messages.

Detailed Electrical Architecture This section overlaps with information on the Mission Control Software, so if interactions are unclear, it is advised to read from the appendices, which cover the software architecture. Similarly to the rocket, the electronics in the launch pad are connected to the main Ubuntu Server via CAN Bus and are controlled via the same Low-Level Server and Mission Control data flow as the rocket.
The GSE electronics consists out of:

- Two ECUs (Engine Control Units) in IOBs
- One BLMB (Brushless Motor Board)

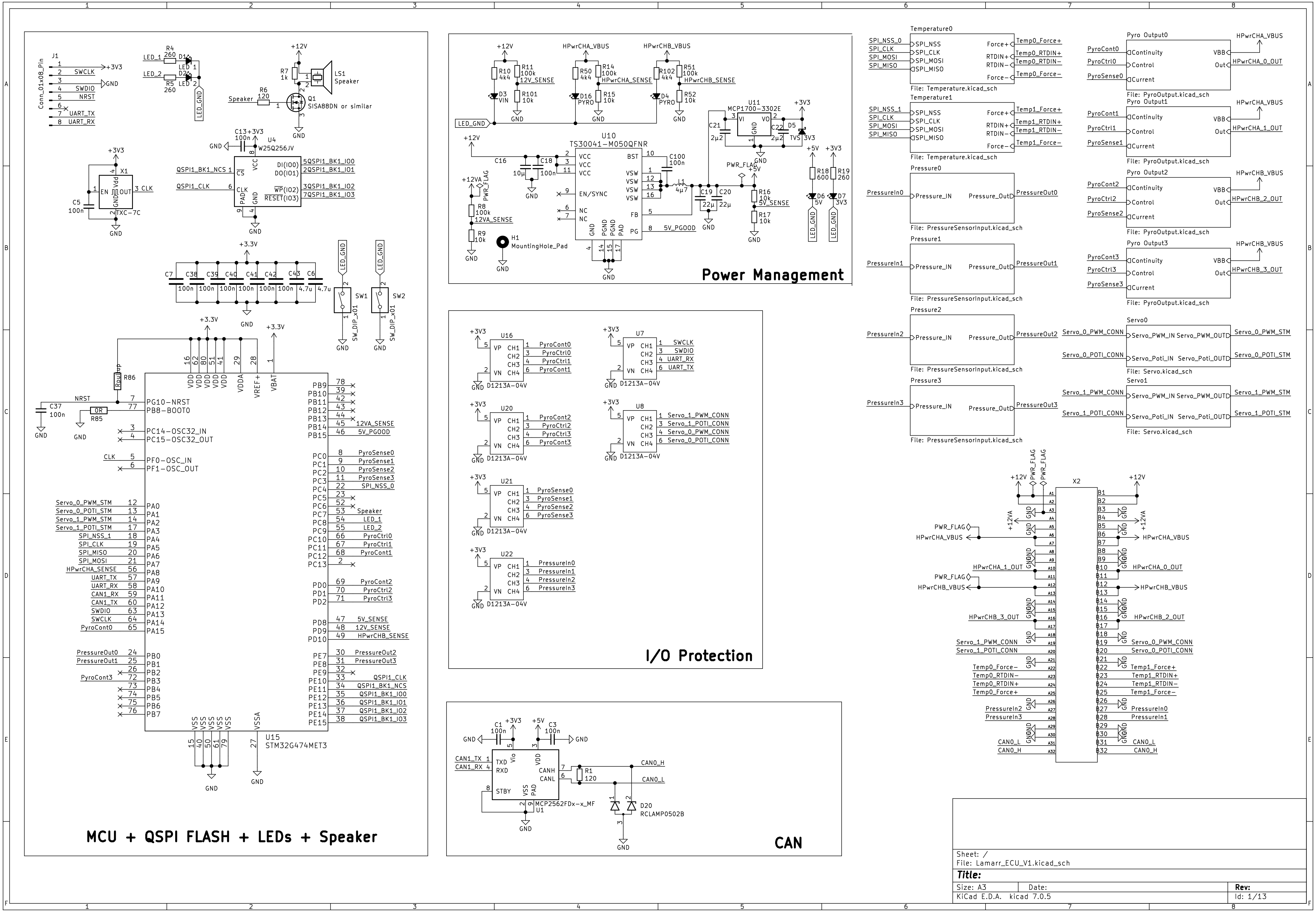
The launch pad is wired to the Ubuntu Server in a mobile rack with a CAN cable. A directed radio link connects The server rack to the Mission Control. In the server rack, connected directly to the server via LAN, a Raspberry Pi single-board computer with a LoRa shield is used for the 868 MHz radio connection to the rocket during flight. Mobile power generators power the entire GSE. During launch preparations, the electronics umbilical also provides power to the rocket, keeping the internal batteries charged until automatic disconnect at lift-off.

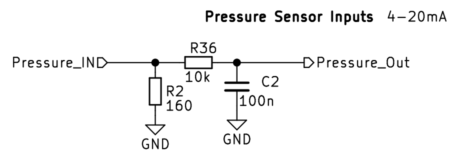
Detailed Hydraulic/Fluid Architecture


Bottle_Manometer
Bottle_Valve
Nitrogen 300 bar
HighPressure_Vent
HighPressure_Pressurize
HighPressure_PressureSensor
HPN2 Tanking
Valve Section
HighPressure_Quickconnect
HighPressure_Quickconnect
DewarPressurizationValve
LOX Dewar
Tanking_Valve
PTFE_Hose
LOX_Quickconnect
Hold-down
Manual_Vent
Bottle Pressure Regulator
(10-16 bar)
Bottle_Valve
Nitrogen 300 bar (50 bar minimum)
Pressure Regulator 8 bar
Pressure Regulator 1.5 bar
U1
U2
U3
U4
Pneumatics Cabinet
TU Wien Space Team (Lamarr)
Sheet: /
File: GSE_PNID_2024.kicad_sch
Title: Tanking System
Size: A3
Date: 2022-12-18
Rev:
KiCad E.D.A. 8.0.5
Id: 1/1

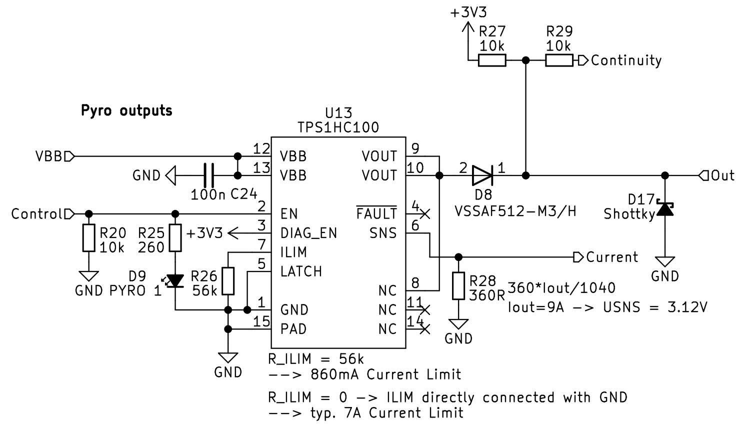
A.7 Engineering drawings:

A.7.1 Electrical drawings:


MCU + QSPI FLASH + LEDs + Speaker
Power Management
I/O Protection
CAN
U15 STM32G474MET3
U10 TS30041-M050QFNR
U11 MCP1700-3302E
U4 W25Q256JV
U1 MCP2562FDx-x_MF
D20 RCLAMP0502B
X2
Temperature0
Temperature1
Pyro Output0
Pyro Output1
Pyro Output2
Pyro Output3
Pressure0
Pressure1
Pressure2
Pressure3
Servo0
Servo1
File: Temperature.kicad_sch
File: PyroOutput.kicad_sch
File: PressureSensorInput.kicad_sch
File: Servo.kicad_sch
Sheet: /
File: Lamarr_ECU_V1.kicad_sch
Title:
Size: A3
Date:
KiCad E.D.A. kicad 7.0.5
Rev:
Id: 1/13



Sheet: /Pressure1/	
File: PressureSensorInput.kicad_sch	
Title:	
Size: A4 Date:	**Rev:**
KiCad E.D.A. kicad 7.0.5	Id: 2/13

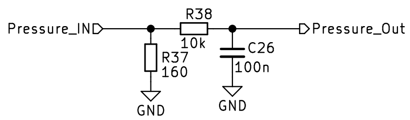


Sheet: /Pyro Output0/
File: PyroOutput.kicad_sch

Title:

Size: A4	Date:	**Rev:**
KiCad E.D.A. kicad 7.0.5		Id: 3/13

Pressure Sensor Inputs 4–20mA



Sheet: /Pressure2/
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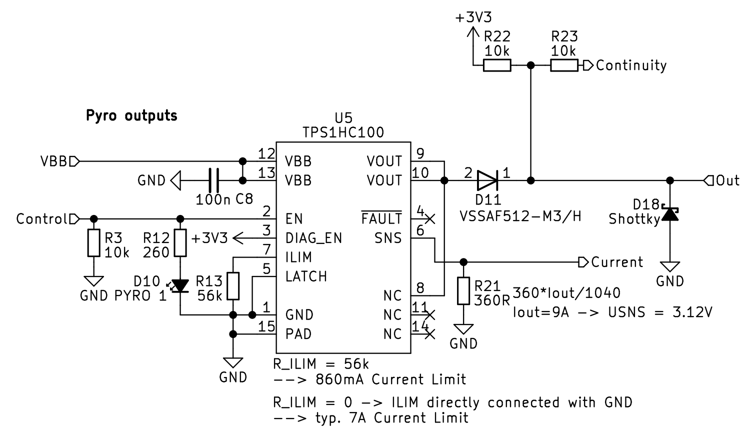
Title:

Size: A4	Date:	**Rev:**
KiCad E.D.A. kicad 7.0.5		Id: 4/13

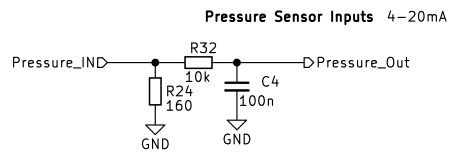


Sheet: /Pyro Output3/
File: PyroOutput.kicad_sch

Title:

Size: A4 Date:
KiCad E.D.A. kicad 7.0.5

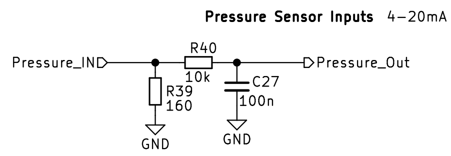
Rev:
Id: 5/13



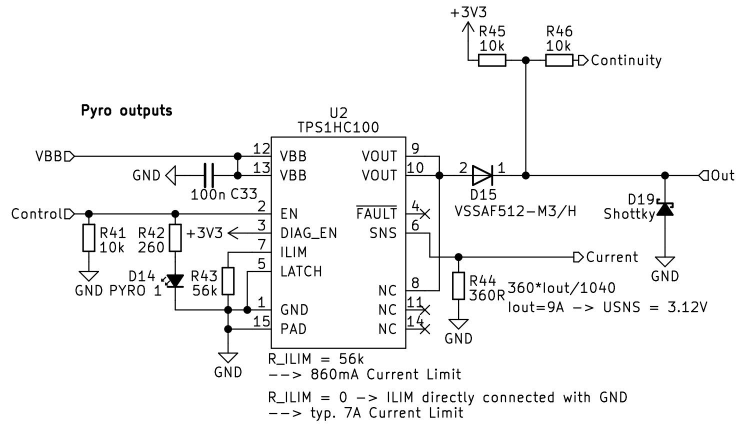
Sheet: /Pressure0/
File: PressureSensorInput.kicad_sch

Title:

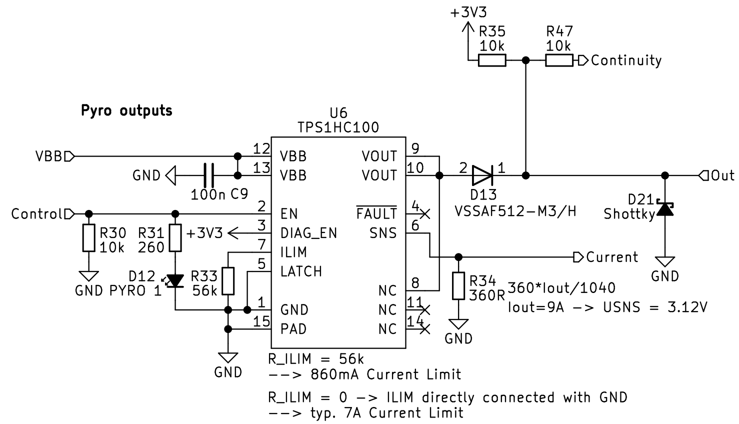
Size: A4	Date:	**Rev:**
KiCad E.D.A. kicad 7.0.5		Id: 6/13



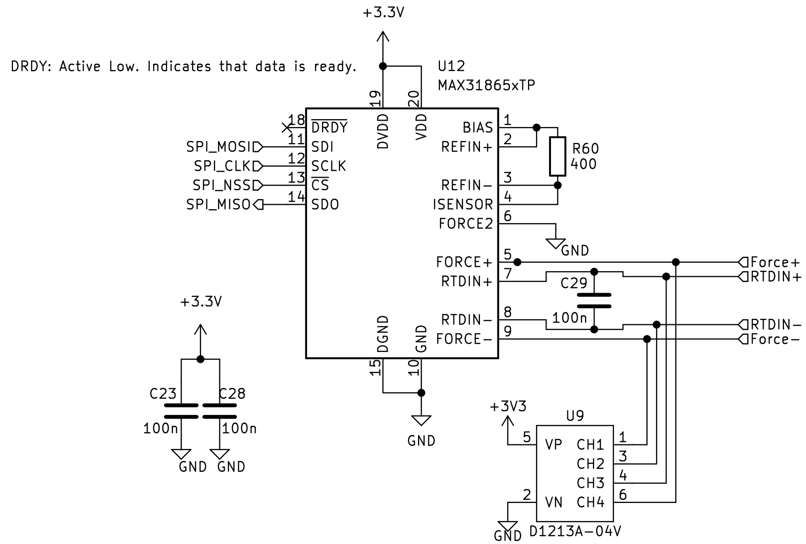
Sheet: /Pressure3/		
File: PressureSensorInput.kicad_sch		
Title:		
Size: A4	Date:	**Rev:**
KiCad E.D.A. kicad 7.0.5		Id: 7/13



Sheet: /Pyro Output1/		
File: PyroOutput.kicad_sch		
Title:		
Size: A4	Date:	**Rev:**
KiCad E.D.A. kicad 7.0.5		Id: 8/13



Sheet: /Pyro Output2/	
File: PyroOutput.kicad_sch	
Title:	
Size: A4 Date:	**Rev:**
KiCad E.D.A. kicad 7.0.5	Id: 9/13

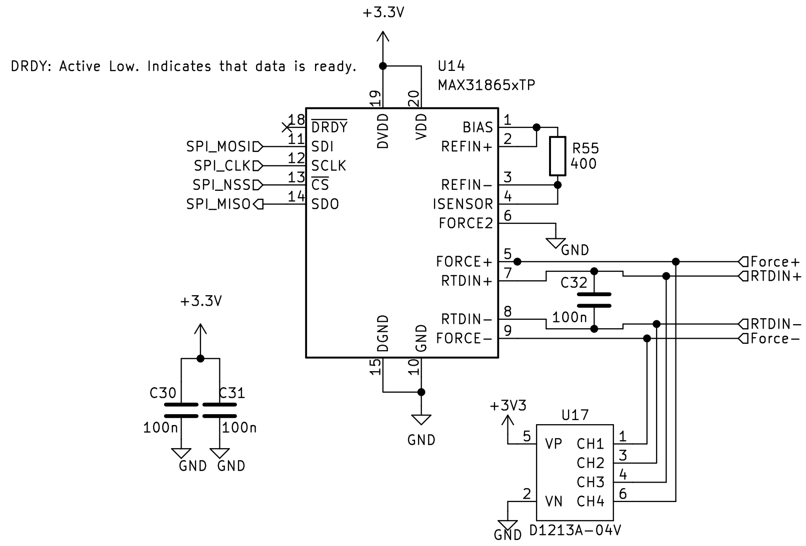


Sheet: /Temperature0/
File: Temperature.kicad_sch

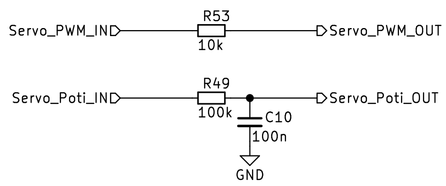
Title:

Size: A4 | Date: | Rev:

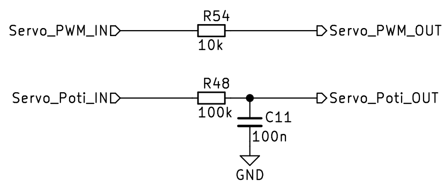
KiCad E.D.A. kicad 7.0.5 | Id: 10/13



Sheet: /Temperature1/		
File: Temperature.kicad_sch		
Title:		
Size: A4	Date:	**Rev:**
KiCad E.D.A. kicad 7.0.5		Id: 11/13



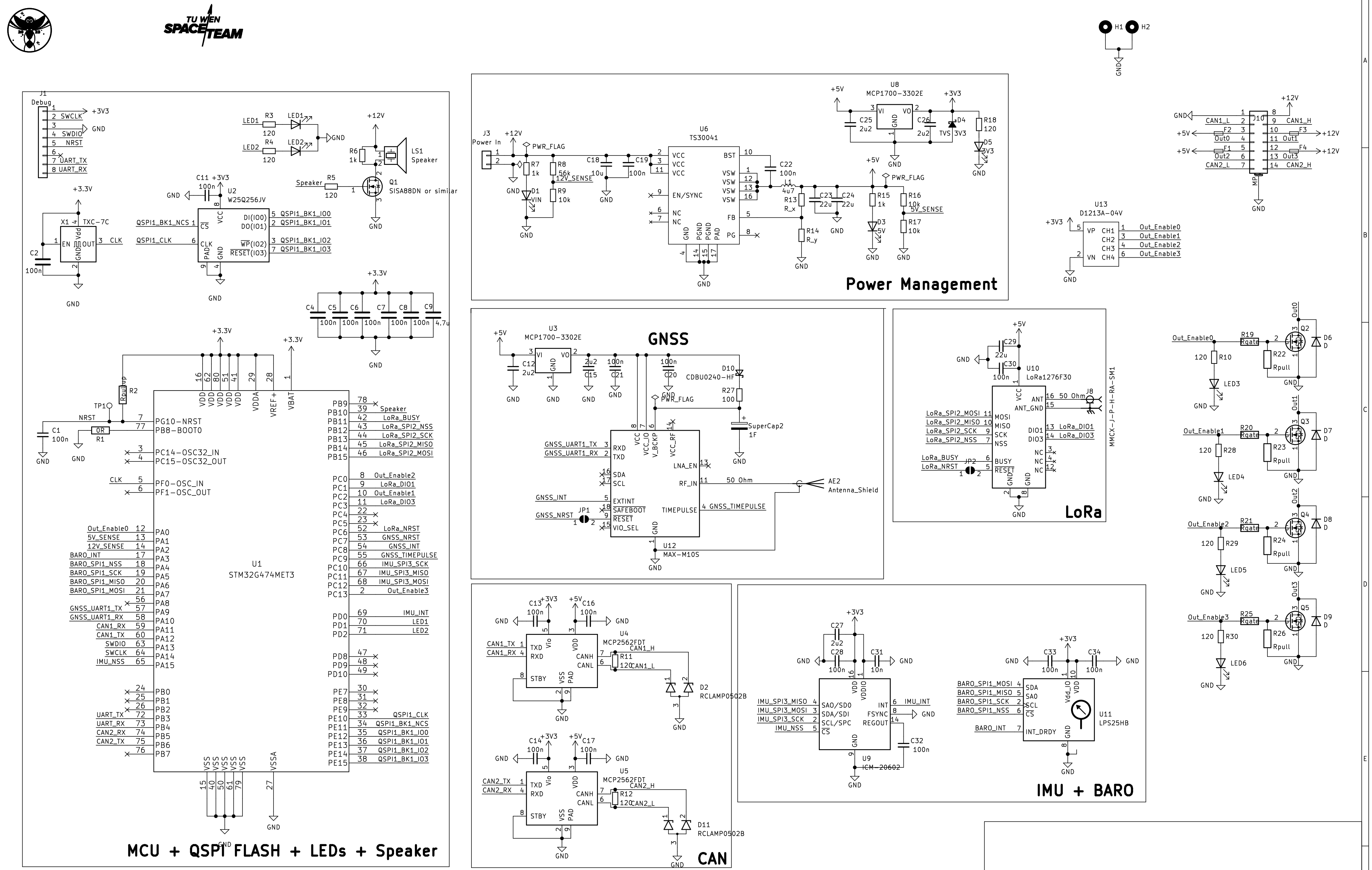
Sheet: /Servo0/		
File: Servo.kicad_sch		
Title:		
Size: A4	Date:	**Rev:**
KiCad E.D.A. kicad 7.0.5		Id: 12/13



Sheet: /Servo1/
File: Servo.kicad_sch

Title:

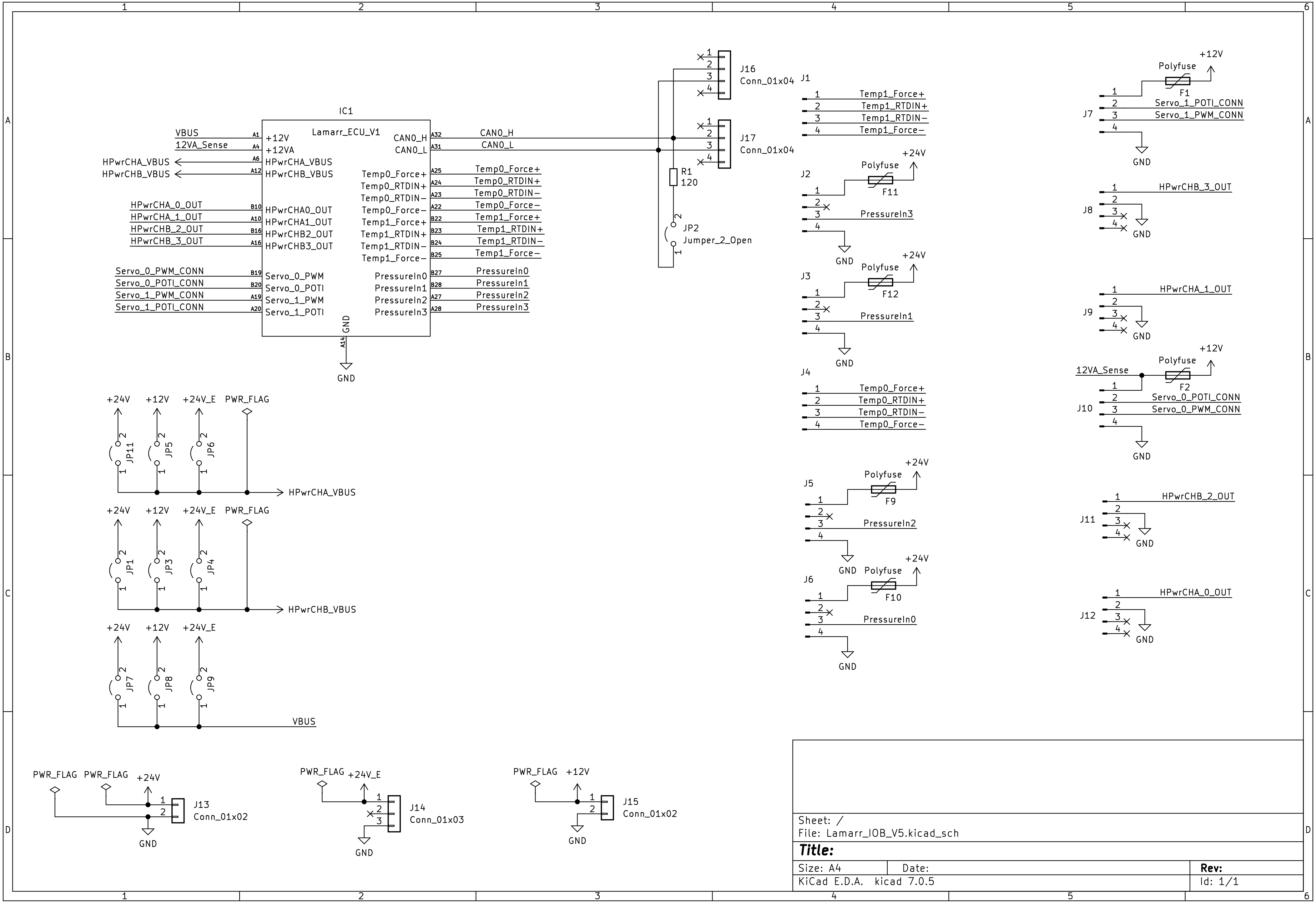
Size: A4	Date:	**Rev:**
KiCad E.D.A. kicad 7.0.5		Id: 13/13



Sheet: /
File: Lamarr_RCU_V2.kicad_sch

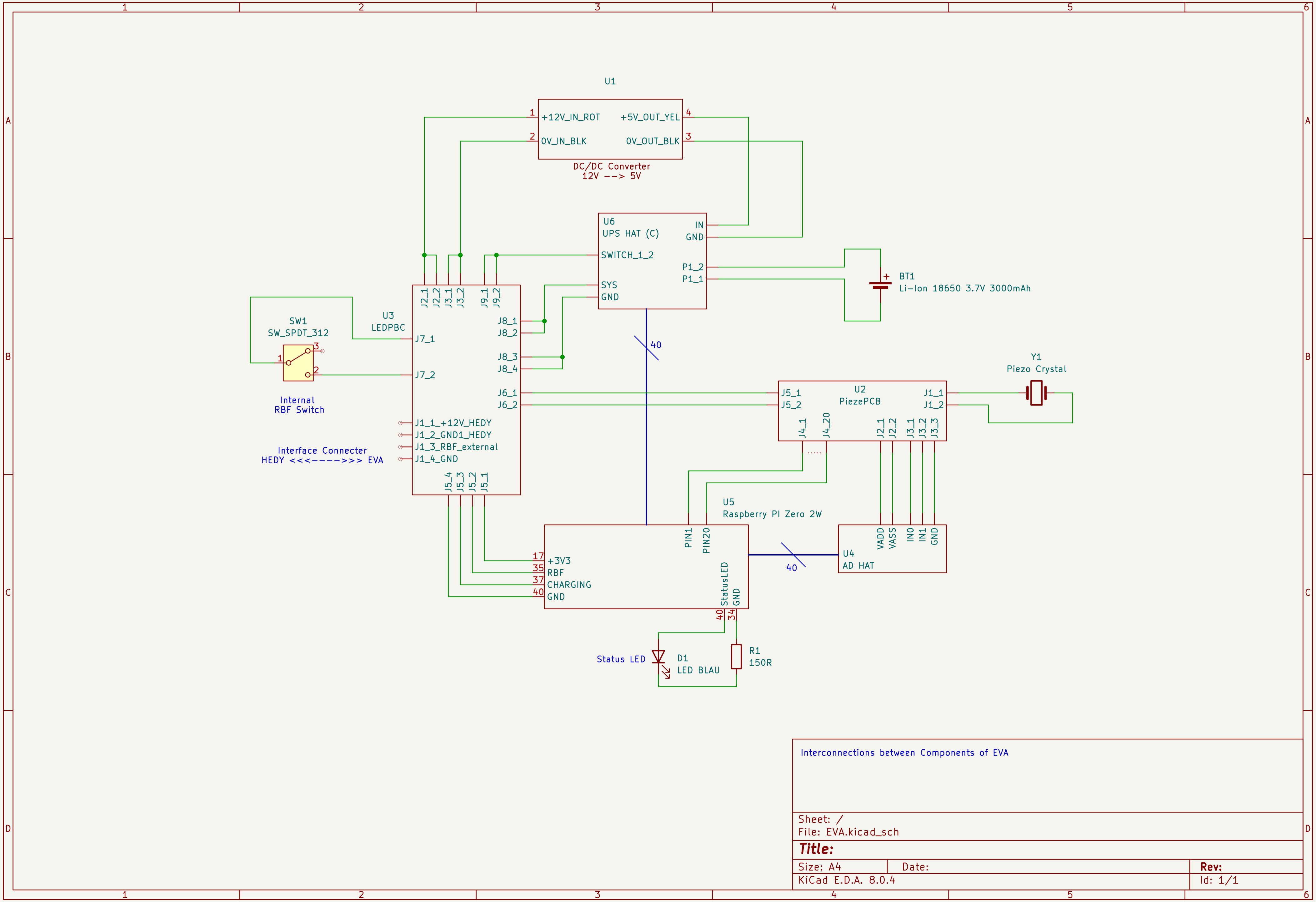
Title:

Size: A3 Date: Rev:
KiCad E.D.A. kicad 7.0.5 Id: 1/1

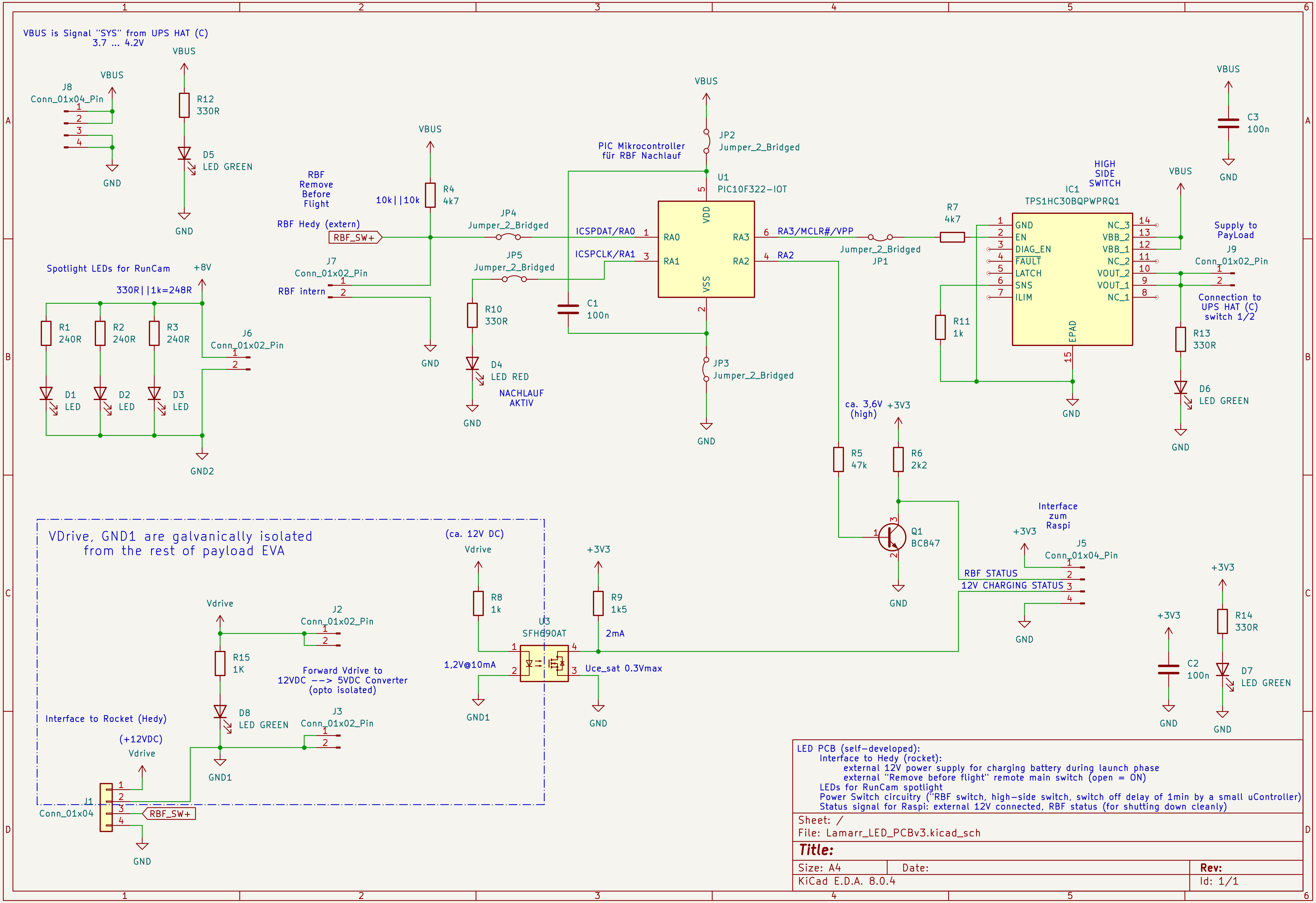


IC1
Lamarr_ECU_V1
+12V
+12VA
HPwrCHA_VBUS
HPwrCHB_VBUS
HPwrCHA0_OUT
HPwrCHA1_OUT
HPwrCHB2_OUT
HPwrCHB3_OUT
Servo_0_PWM
Servo_0_POTI
Servo_1_PWM
Servo_1_POTI
CAN0_H
CAN0_L
Temp0_Force+
Temp0_RTDIN+
Temp0_RTDIN−
Temp0_Force−
Temp1_Force+
Temp1_RTDIN+
Temp1_RTDIN−
Temp1_Force−
PressureIn0
PressureIn1
PressureIn2
PressureIn3
GND
VBUS
12VA_Sense
HPwrCHA_0_OUT
HPwrCHA_1_OUT
HPwrCHB_2_OUT
HPwrCHB_3_OUT
Servo_0_PWM_CONN
Servo_0_POTI_CONN
Servo_1_PWM_CONN
Servo_1_POTI_CONN
J16
Conn_01x04
J17
Conn_01x04
R1
120
JP2
Jumper_2_Open
J1
J2
J3
J4
J5
J6
J7
J8
J9
J10
J11
J12
Polyfuse
F1
F2
F9
F10
F11
F12
+12V
+24V
+24V_E
PWR_FLAG
JP1
JP3
JP4
JP5
JP6
JP7
JP8
JP9
JP11
J13
Conn_01x02
J14
Conn_01x03
J15
Conn_01x02
Sheet: /
File: Lamarr_IOB_V5.kicad_sch
Title:
Size: A4
Date:
Rev:
KiCad E.D.A. kicad 7.0.5
Id: 1/1

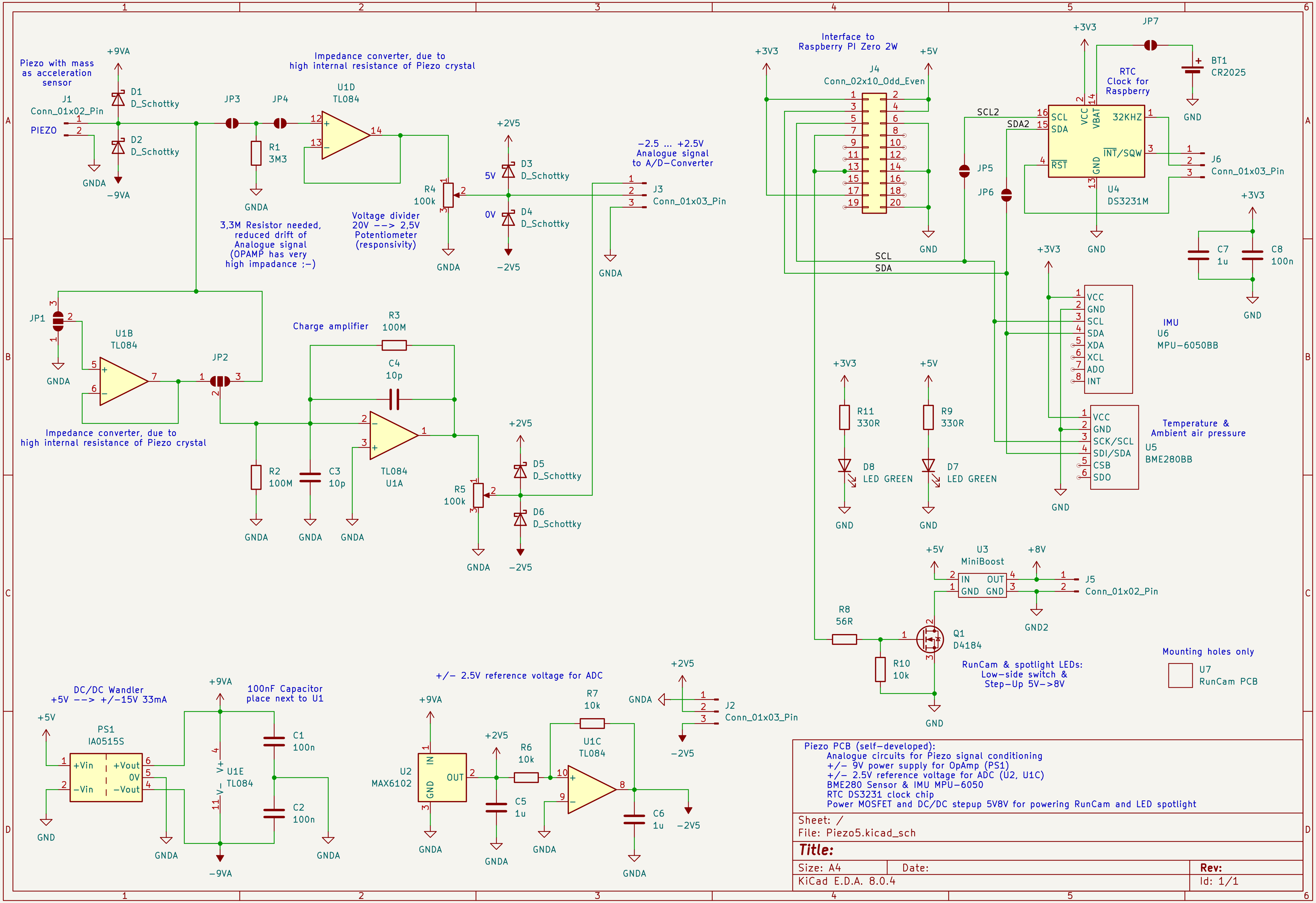
A.7.2 Payload Electrical Drawings:



U1
+12V_IN_ROT
0V_IN_BLK
+5V_OUT_YEL
0V_OUT_BLK
DC/DC Converter
12V --> 5V
U6
UPS HAT (C)
IN
GND
SWITCH_1_2
P1_2
P1_1
SYS
GND
BT1
Li-Ion 18650 3.7V 3000mAh
40
SW1
SW_SPDT_312
U3
LEDPBC
J2_1 J2_2 J3_1 J3_2 J9_1 J9_2
J7_1
J7_2
J8_1
J8_2
J8_3
J8_4
J6_1
J6_2
Internal
RBF Switch
J1_1_+12V_HEDY
J1_2_GND1_HEDY
J1_3_RBF_external
J1_4_GND
Interface Connecter
HEDY <<<------>>> EVA
J5_4 J5_3 J5_2 J5_1
Y1
Piezo Crystal
U2
PiezePCB
J5_1
J5_2
J1_1
J1_2
J4_1 J4_20
J2_1 J2_2 J3_1 J3_2 J3_3
U5
Raspberry PI Zero 2W
PIN1 PIN20
+3V3
RBF
CHARGING
GND
StatusLED
GND
U4
AD HAT
VADD VASS IN0 IN1 GND
Status LED
D1
LED BLAU
R1
150R
Interconnections between Components of EVA
Sheet: /
File: EVA.kicad_sch
Title:
Size: A4
Date:
Rev:
KiCad E.D.A. 8.0.4
Id: 1/1

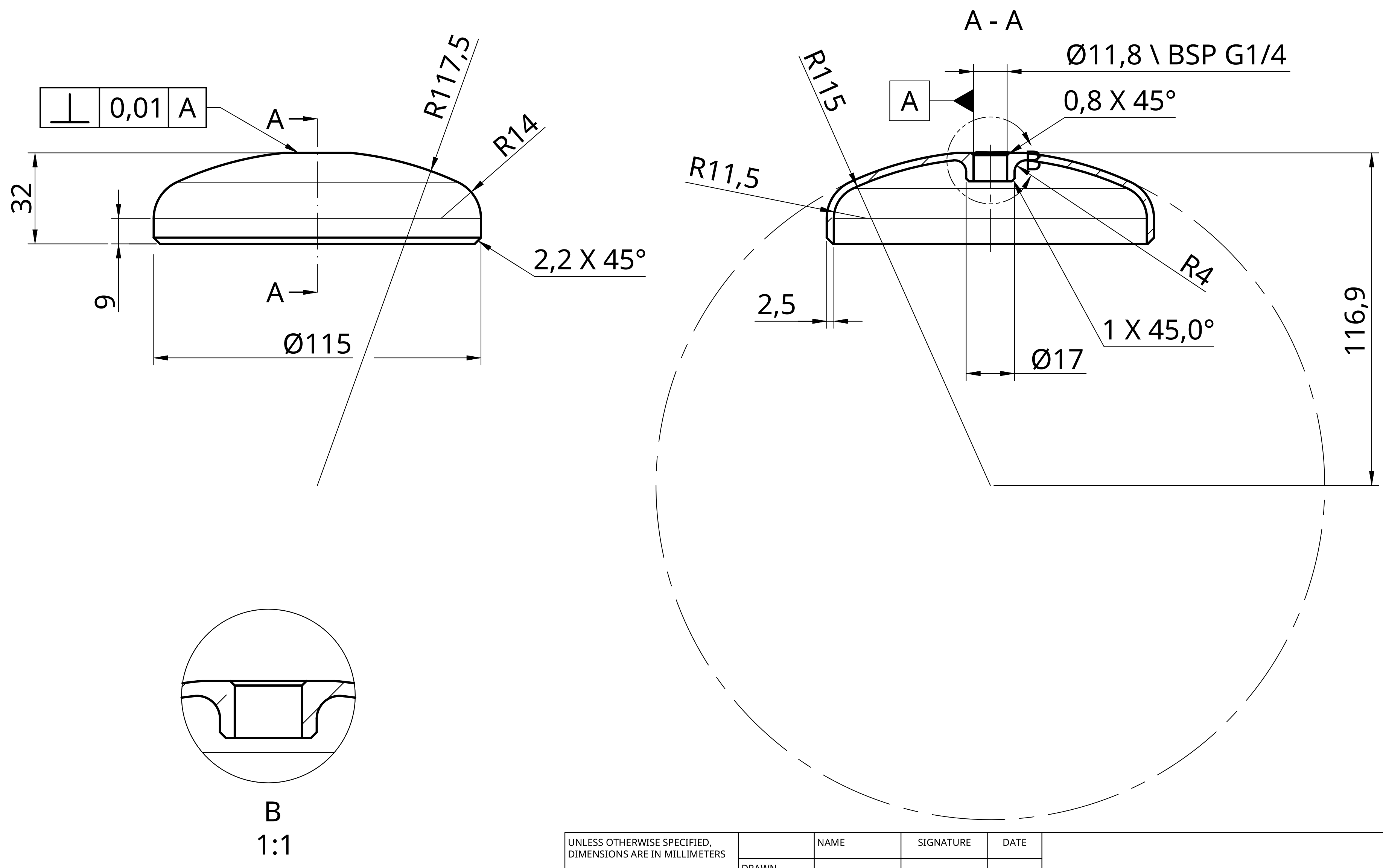


VBUS is Signal "SYS" from UPS HAT (C)
3.7 ... 4.2V
J8
Conn_01x04_Pin
VBUS
GND
R12
330R
D5
LED GREEN
Spotlight LEDs for RunCam
330R||1k=248R
+8V
R1
240R
R2
240R
R3
240R
D1
LED
D2
LED
D3
LED
J6
Conn_01x02_Pin
GND2
RBF
Remove
Before
Flight
RBF Hedy (extern)
RBF_SW+
10k||10k
R4
4k7
J7
Conn_01x02_Pin
RBF intern
JP4
Jumper_2_Bridged
JP5
Jumper_2_Bridged
R10
330R
D4
LED RED
NACHLAUF
AKTIV
C1
100n
PIC Mikrocontroller
für RBF Nachlauf
JP2
Jumper_2_Bridged
U1
PIC10F322-IOT
ICSPDAT/RA0
ICSPCLK/RA1
RA0
RA1
VDD
VSS
RA3
RA2
RA3/MCLR#/VPP
JP3
Jumper_2_Bridged
JP1
Jumper_2_Bridged
R7
4k7
HIGH
SIDE
SWITCH
IC1
TPS1HC30BQPWPRQ1
GND
EN
DIAG_EN
FAULT
LATCH
SNS
ILIM
NC_3
VBB_2
VBB_1
NC_2
VOUT_2
VOUT_1
NC_1
EPAD
R11
1k
Supply to
PayLoad
J9
Conn_01x02_Pin
Connection to
UPS HAT (C)
switch 1/2
R13
330R
D6
LED GREEN
C3
100n
ca. 3,6V
(high)
+3V3
R5
47k
R6
2k2
Q1
BC847
Interface
zum
Raspi
J5
Conn_01x04_Pin
RBF STATUS
12V CHARGING STATUS
C2
100n
R14
330R
D7
LED GREEN
VDrive, GND1 are galvanically isolated
from the rest of payload EVA
(ca. 12V DC)
Vdrive
R8
1k
U3
SFH690AT
1,2V@10mA
GND1
R9
1k5
2mA
Uce_sat 0.3Vmax
Vdrive
J2
Conn_01x02_Pin
R15
1K
Forward Vdrive to
12VDC --> 5VDC Converter
(opto isolated)
D8
LED GREEN
J3
Conn_01x02_Pin
Interface to Rocket (Hedy)
(+12VDC)
J1
Conn_01x04
LED PCB (self-developed):
Interface to Hedy (rocket):
external 12V power supply for charging battery during launch phase
external "Remove before flight" remote main switch (open = ON)
LEDs for RunCam spotlight
Power Switch circuitry ("RBF switch, high-side switch, switch off delay of 1min by a small uController)
Status signal for Raspi: external 12V connected, RBF status (for shutting down cleanly)
Sheet: /
File: Lamarr_LED_PCBv3.kicad_sch
Title:
Size: A4
Date:
Rev:
KiCad E.D.A. 8.0.4
Id: 1/1

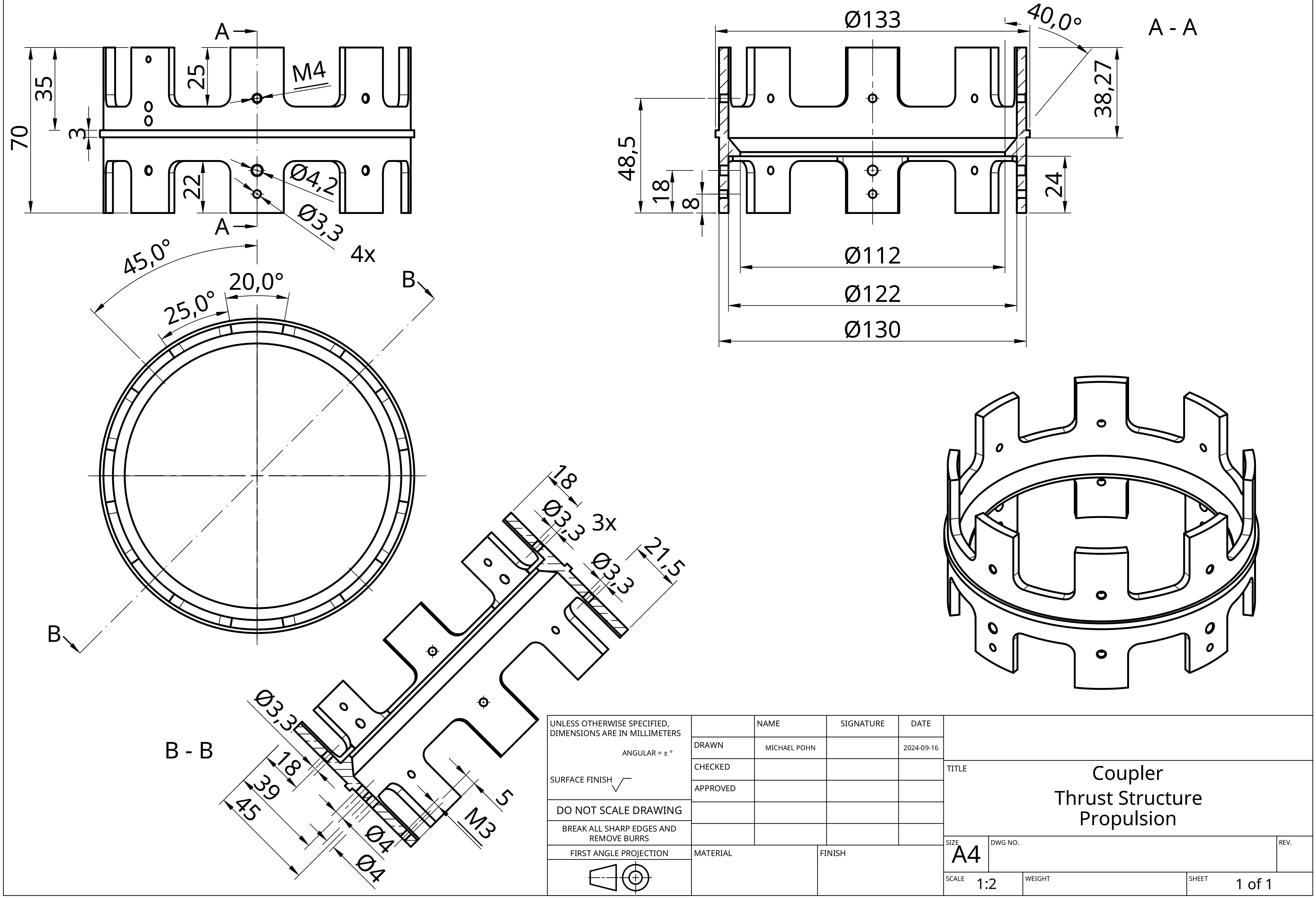


Piezo with mass
as acceleration
sensor
J1
Conn_01x02_Pin
PIEZO
D1
D_Schottky
D2
D_Schottky
+9VA
-9VA
GNDA
JP3
JP4
R1
3M3
U1D
TL084
Impedance converter, due to
high internal resistance of Piezo crystal
3,3M Resistor needed,
reduced drift of
Analogue signal
(OPAMP has very
high impadance ;-)
Voltage divider
20V --> 2,5V
Potentiometer
(responsivity)
R4
100k
D3
D_Schottky
D4
D_Schottky
5V
0V
+2V5
-2V5
-2.5 ... +2.5V
Analogue signal
to A/D-Converter
J3
Conn_01x03_Pin
JP1
U1B
TL084
JP2
Impedance converter, due to
high internal resistance of Piezo crystal
Charge amplifier
R3
100M
C4
10p
R2
100M
C3
10p
TL084
U1A
R5
100k
D5
D_Schottky
D6
D_Schottky
Interface to
Raspberry PI Zero 2W
J4
Conn_02x10_Odd_Even
+3V3
+5V
GND
SCL
SDA
SCL2
SDA2
JP5
JP6
JP7
BT1
CR2025
RTC
Clock for
Raspberry
U4
DS3231M
32KHZ
INT/SQW
RST
VCC
VBAT
J6
Conn_01x03_Pin
C7
1u
C8
100n
IMU
U6
MPU-6050BB
VCC
GND
SCL
SDA
XDA
XCL
ADO
INT
Temperature &
Ambient air pressure
U5
BME280BB
SCK/SCL
SDI/SDA
CSB
SDO
R11
330R
R9
330R
D8
LED GREEN
D7
LED GREEN
U3
MiniBoost
IN
OUT
+8V
J5
Conn_01x02_Pin
GND2
R8
56R
Q1
D4184
R10
10k
RunCam & spotlight LEDs:
Low-side switch &
Step-Up 5V->8V
Mounting holes only
U7
RunCam PCB
DC/DC Wandler
+5V --> +/-15V 33mA
PS1
IA0515S
+Vin
-Vin
+Vout
0V
-Vout
100nF Capacitor
place next to U1
U1E
TL084
C1
100n
C2
100n
+/- 2.5V reference voltage for ADC
U2
MAX6102
R6
10k
C5
1u
R7
10k
U1C
TL084
C6
1u
J2
Conn_01x03_Pin
Piezo PCB (self-developed):
Analogue circuits for Piezo signal conditioning
+/- 9V power supply for OpAmp (PS1)
+/- 2.5V reference voltage for ADC (U2, U1C)
BME280 Sensor & IMU MPU-6050
RTC DS3231 clock chip
Power MOSFET and DC/DC stepup 5V8V for powering RunCam and LED spotlight
Sheet: /
File: Piezo5.kicad_sch
Title:
Size: A4
Date:
Rev:
KiCad E.D.A. 8.0.4
Id: 1/1

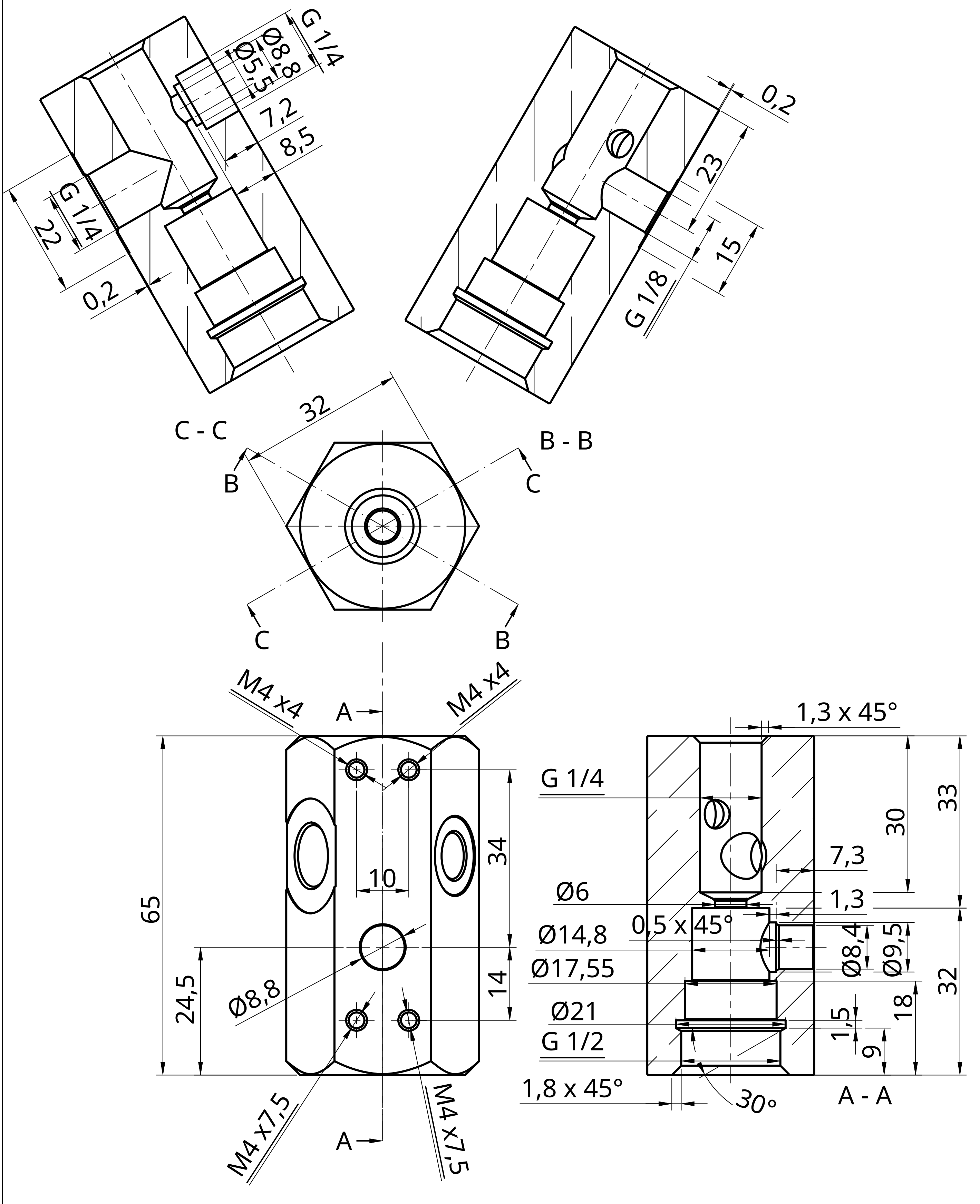
A.7.3 Propulsion Drawings:



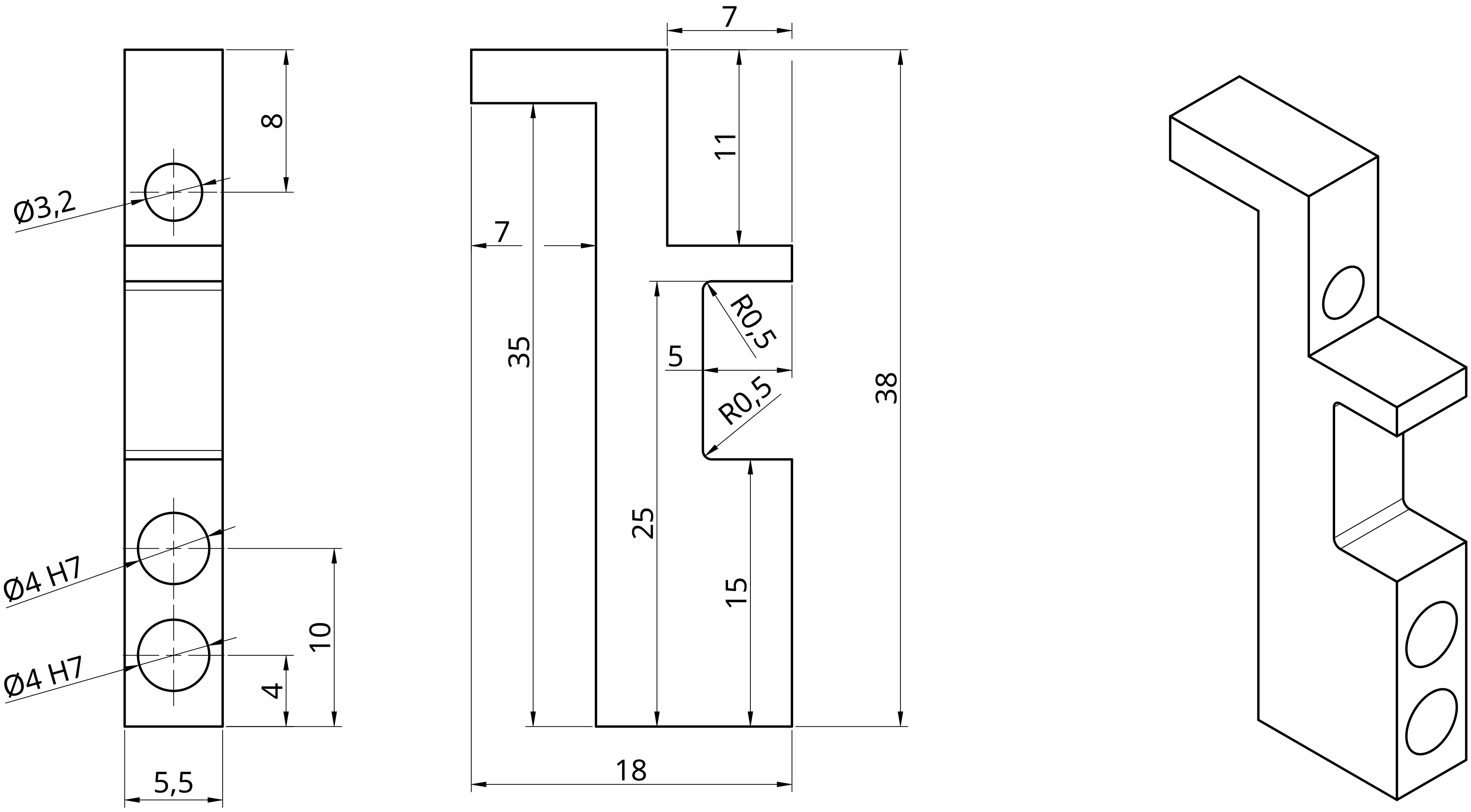
		NAME	SIGNATURE	DATE	
UNLESS OTHERWISE SPECIFIED, DIMENSIONS ARE IN MILLIMETERS ANGULAR = ± ° SURFACE FINISH	DRAWN	MATTHIAS RIER		2024-07-01	
	CHECKED				TITLE Bulk head Propellant Tank Propulsion
	APPROVED				
DO NOT SCALE DRAWING					
BREAK ALL SHARP EDGES AND REMOVE BURRS					SIZE A4 — DWG NO. — REV.
FIRST ANGLE PROJECTION	MATERIAL AW EN 6082 Lösungsgeglüht		FINISH		SCALE 1:2 — WEIGHT — SHEET 1 of 1



UNLESS OTHERWISE SPECIFIED, DIMENSIONS ARE IN MILLIMETERS ANGULAR = ± °		NAME	SIGNATURE	DATE	
	DRAWN	MICHAEL POHN		2024-09-16	
SURFACE FINISH	CHECKED				TITLE Coupler Thrust Structure Propulsion
	APPROVED				
DO NOT SCALE DRAWING					
BREAK ALL SHARP EDGES AND REMOVE BURRS					
FIRST ANGLE PROJECTION	MATERIAL	FINISH			SIZE A4 · DWG NO. · REV.
					SCALE 1:2 · WEIGHT · SHEET 1 of 1



UNLESS OTHERWISE SPECIFIED, DIMENSIONS ARE IN MILLIMETERS ANGULAR = ± ° SURFACE FINISH		NAME	SIGNATURE	DATE	
	DRAWN	MATTHIAS RIER		2024-08-10	
	CHECKED				TITLE Fuel Pressurant Manifold Fuel Pressurant System Propulsion
	APPROVED				
DO NOT SCALE DRAWING					
BREAK ALL SHARP EDGES AND REMOVE BURRS					
FIRST ANGLE PROJECTION	MATERIAL		FINISH		SIZE A4 · DWG NO. · REV.
					SCALE 1:1 · WEIGHT · SHEET 1 of 1



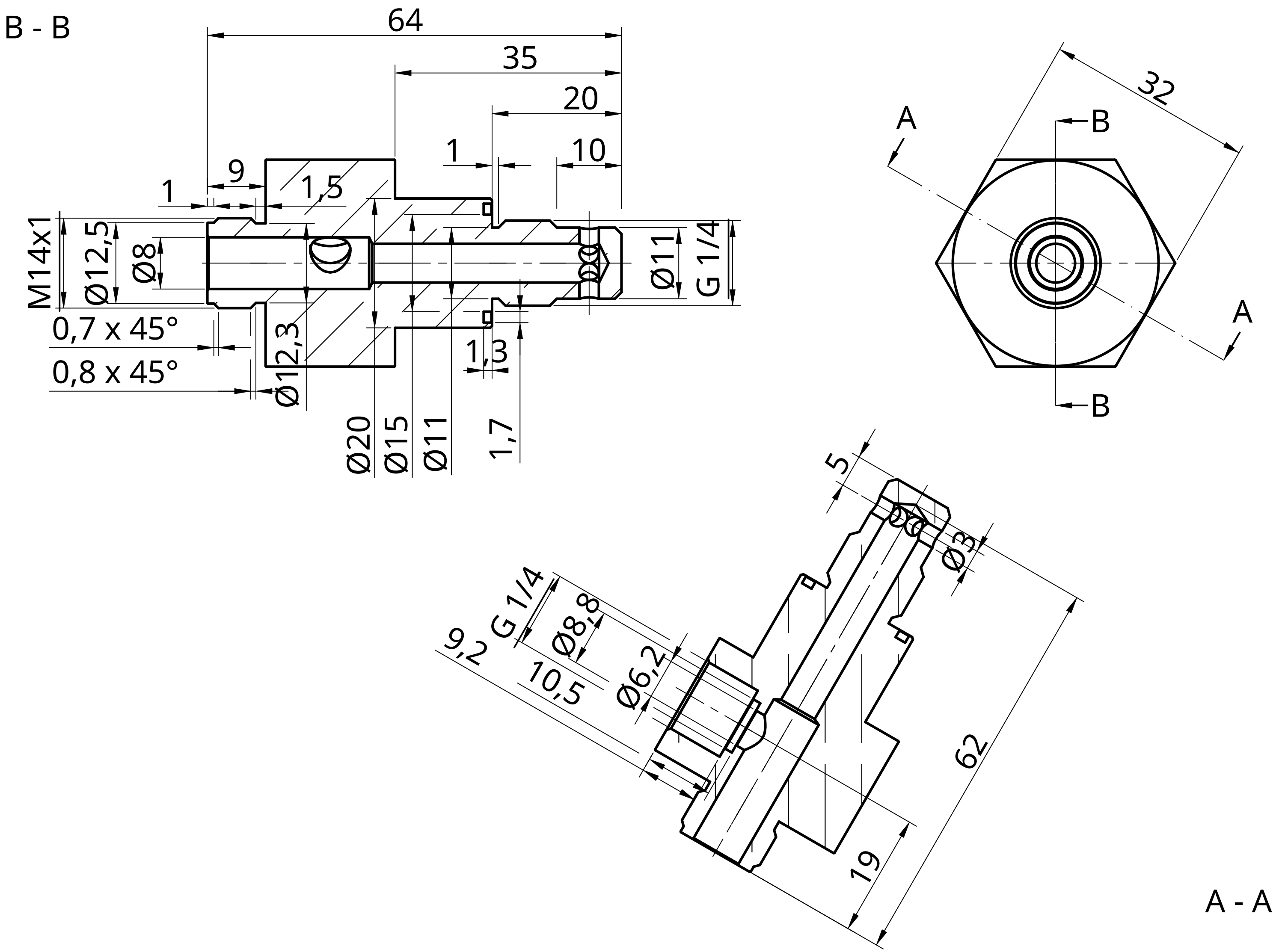
UNLESS OTHERWISE SPECIFIED, DIMENSIONS ARE IN MILLIMETERS ANGULAR = ± ° SURFACE FINISH		NAME	SIGNATURE	DATE
	DRAWN	MICHAEL POHN		2024-09-16
	CHECKED			
	APPROVED			
DO NOT SCALE DRAWING				
BREAK ALL SHARP EDGES AND REMOVE BURRS				
FIRST ANGLE PROJECTION	MATERIAL		FINISH	

TITLE

Interface
Lower Railbutton
Aerostructure

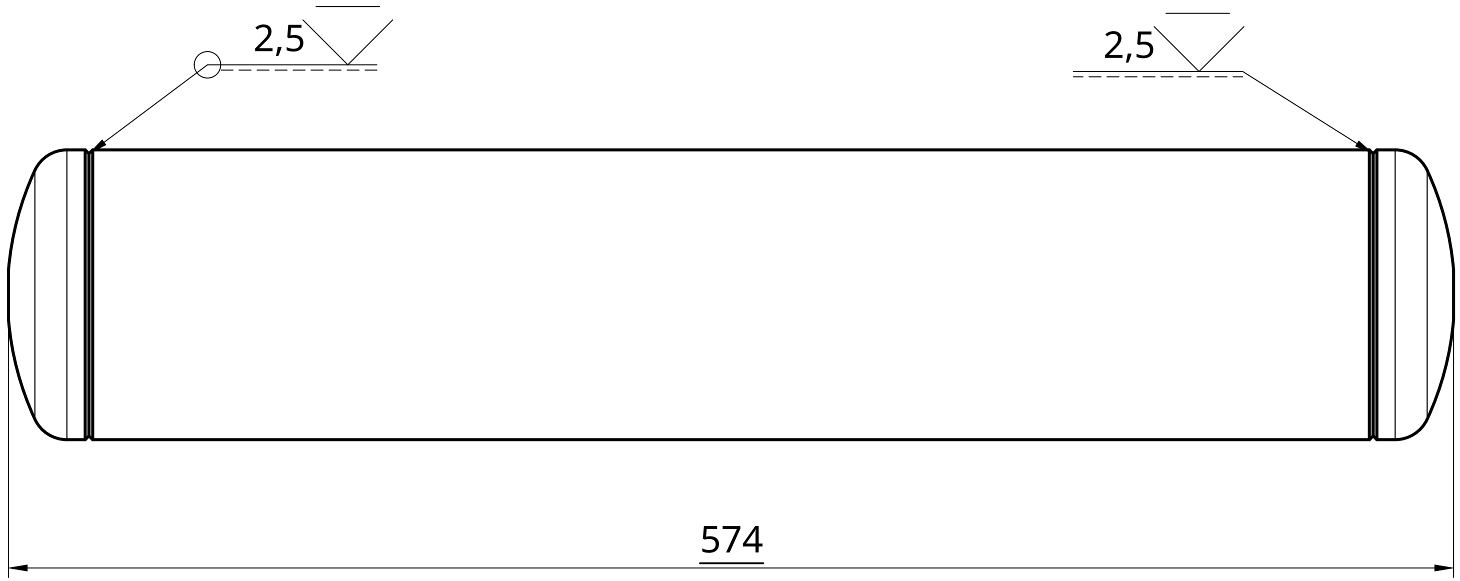
SIZE	DWG NO.	REV.
A4		

SCALE	WEIGHT	SHEET
3:1		1 of 1

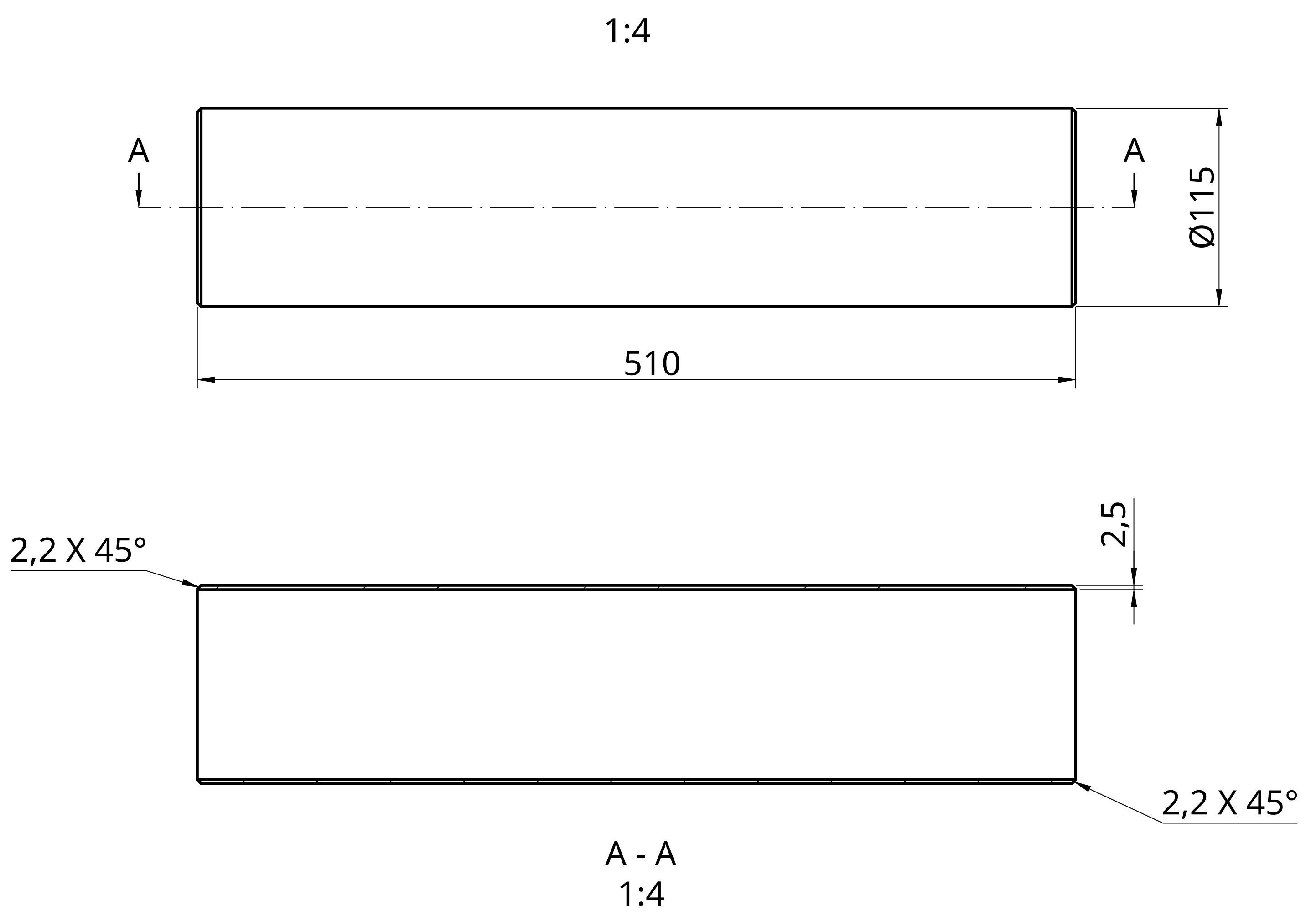


UNLESS OTHERWISE SPECIFIED, DIMENSIONS ARE IN MILLIMETERS ANGULAR = ± ° SURFACE FINISH		NAME	SIGNATURE	DATE	
	DRAWN	MATTHIAS RIER		2024-09-11	
	CHECKED				TITLE Lower Ox Pressurant Manifold Ox Pressurant System Propulsion
	APPROVED				
DO NOT SCALE DRAWING					
BREAK ALL SHARP EDGES AND REMOVE BURRS					SIZE A4 / DWG NO. / REV.
FIRST ANGLE PROJECTION	MATERIAL		FINISH		SCALE 1:1 / WEIGHT / SHEET 1 of 1

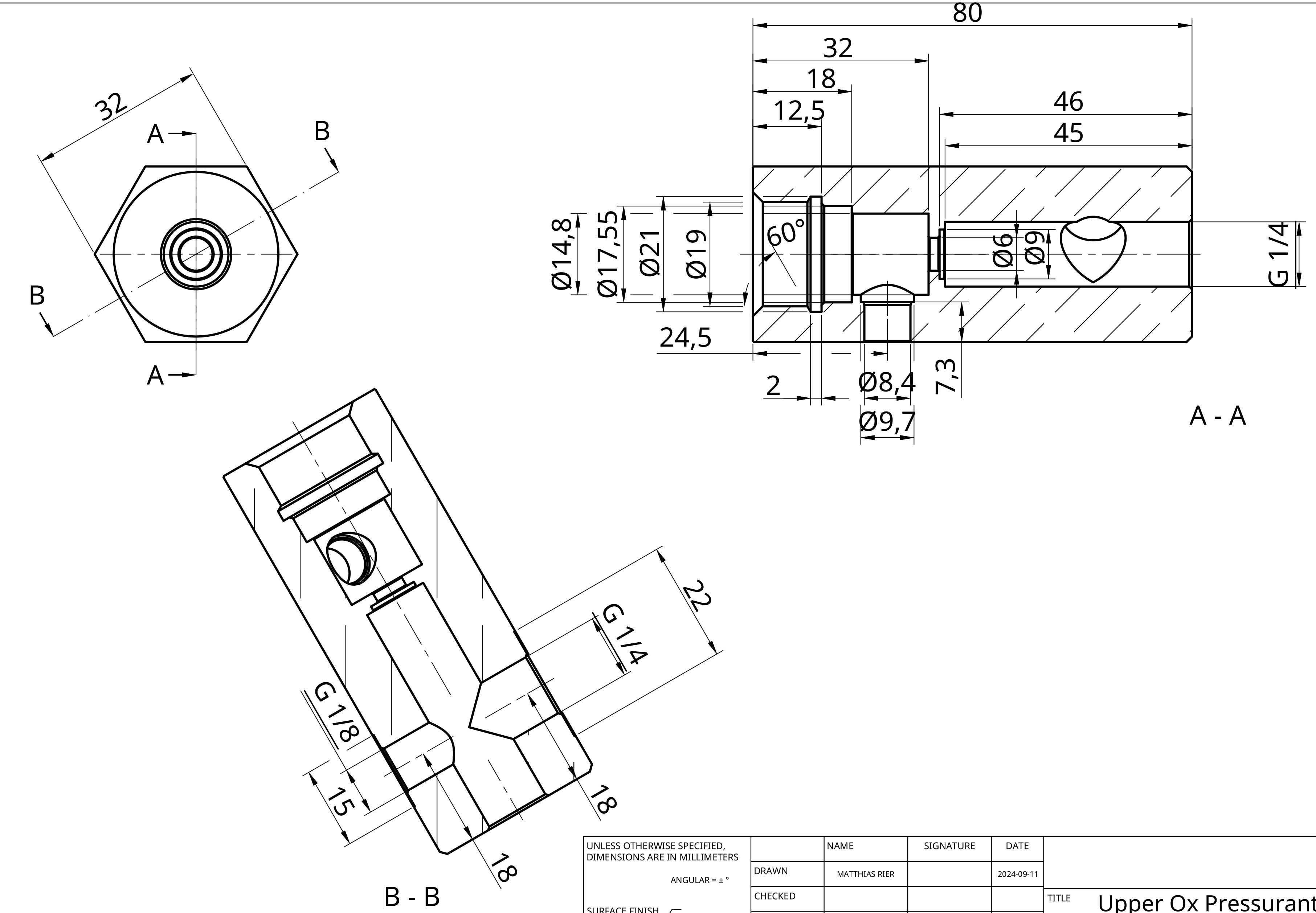
1:3



UNLESS OTHERWISE SPECIFIED, DIMENSIONS ARE IN MILLIMETERS		NAME	SIGNATURE	DATE	
ANGULAR = ± °	DRAWN	MATTHIAS RIER		2024-07-01	
SURFACE FINISH	CHECKED				TITLE Propellant Tank Propellant Tank Propulsion
	APPROVED				
DO NOT SCALE DRAWING					
BREAK ALL SHARP EDGES AND REMOVE BURRS					
FIRST ANGLE PROJECTION	MATERIAL EN AW 6082 Lösungsgeglüht	FINISH			SIZE A4 / DWG NO. / REV.
					SCALE 1:6 / WEIGHT / SHEET 1 of 1



UNLESS OTHERWISE SPECIFIED, DIMENSIONS ARE IN MILLIMETERS ANGULAR = ± ° SURFACE FINISH		NAME	SIGNATURE	DATE	
	DRAWN	MATTHIAS RIER		2024-07-01	
	CHECKED				TITLE Tank cylinder Propellant Tank Propulsion
	APPROVED				
DO NOT SCALE DRAWING					
BREAK ALL SHARP EDGES AND REMOVE BURRS					SIZE A4 · DWG NO. · REV.
FIRST ANGLE PROJECTION	MATERIAL AW EN 6082 Lösungsgeglüht	FINISH			SCALE 1:10 · WEIGHT · SHEET 1 of 1

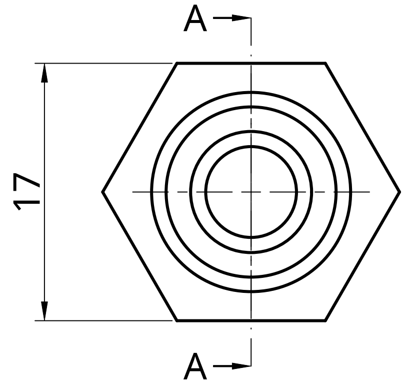


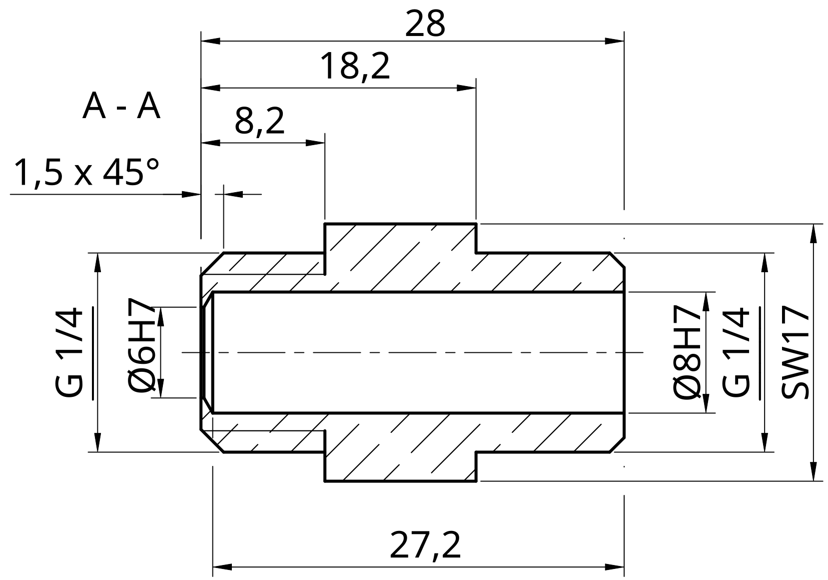
UNLESS OTHERWISE SPECIFIED, DIMENSIONS ARE IN MILLIMETERS ANGULAR = ± ° SURFACE FINISH		NAME	SIGNATURE	DATE
	DRAWN	MATTHIAS RIER		2024-09-11
	CHECKED			
	APPROVED			
DO NOT SCALE DRAWING				
BREAK ALL SHARP EDGES AND REMOVE BURRS				
FIRST ANGLE PROJECTION	MATERIAL		FINISH	

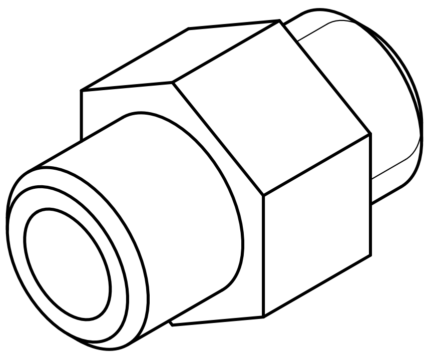
TITLE
Upper Ox Pressurant Manifold
Ox Pressurant System
Propulsion

SIZE	DWG NO.	REV.
A4		

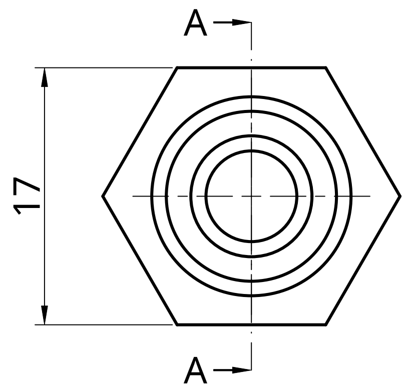
SCALE	WEIGHT	SHEET
1:1		1 of 1

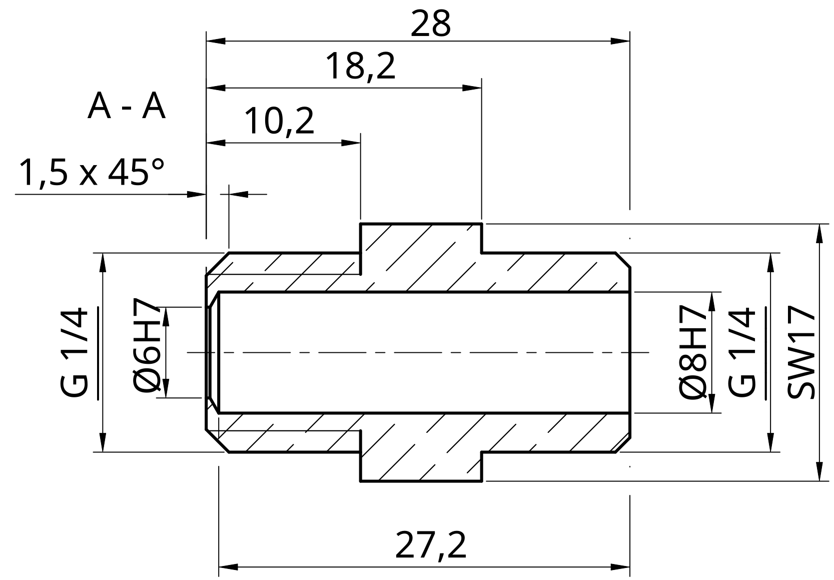


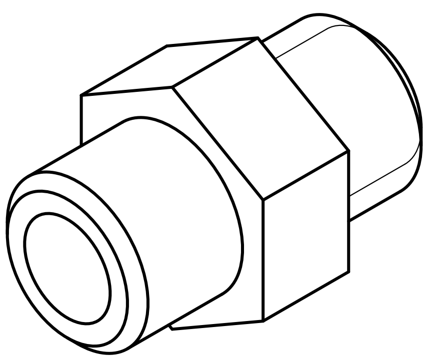




UNLESS OTHERWISE SPECIFIED, DIMENSIONS ARE IN MILLIMETERS		NAME	SIGNATURE	DATE	
ANGULAR = ± °	DRAWN	FABIO		2024-02-23	
SURFACE FINISH	CHECKED				TITLE Insert (Fuel) Magnetic Venting Valve Propulsion
	APPROVED				
DO NOT SCALE DRAWING					
BREAK ALL SHARP EDGES AND REMOVE BURRS					SIZE A4 · DWG NO. · REV.
FIRST ANGLE PROJECTION	MATERIAL 1.4404		FINISH		SCALE 2:1 · WEIGHT · SHEET 1 of 1







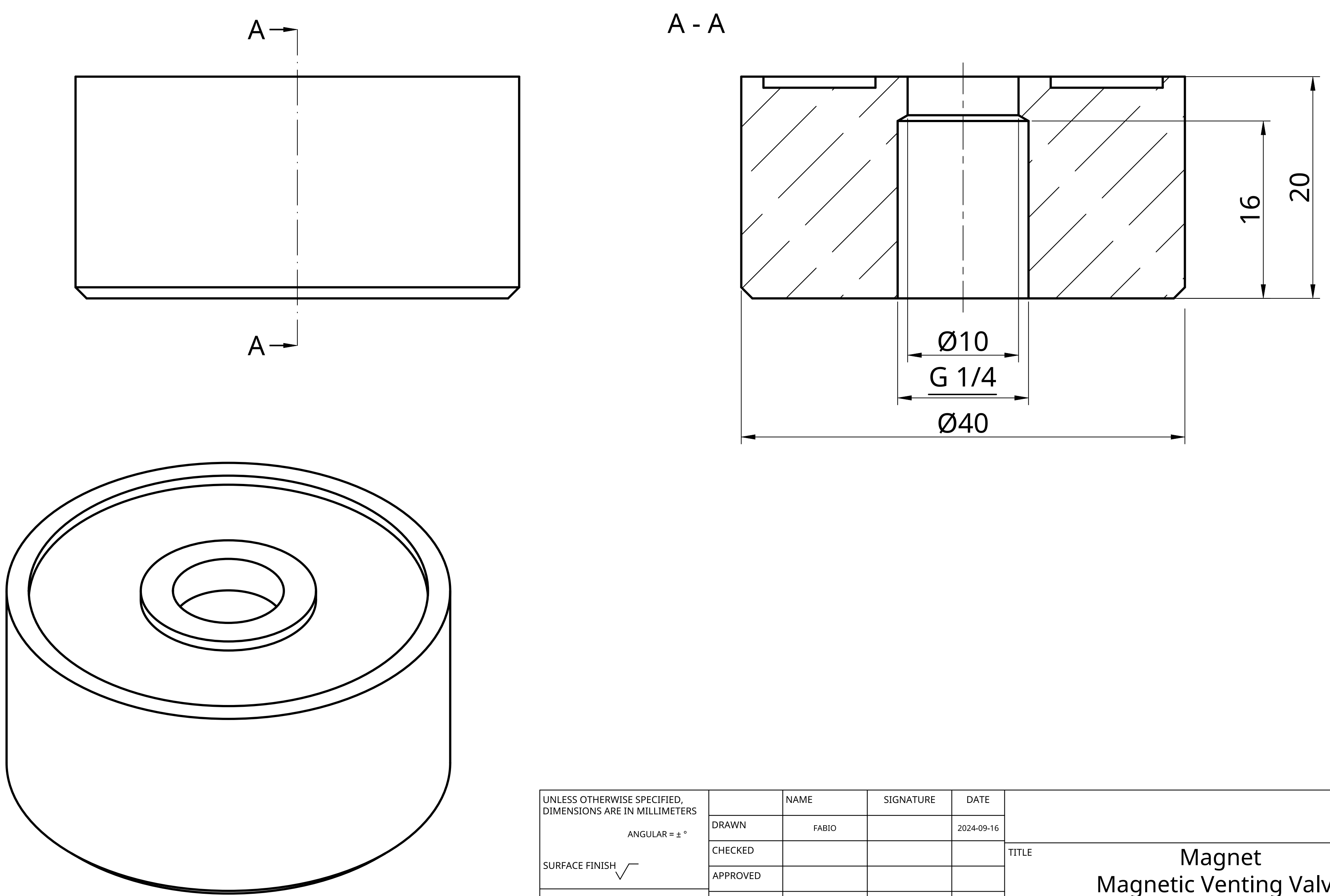
UNLESS OTHERWISE SPECIFIED, DIMENSIONS ARE IN MILLIMETERS		NAME	SIGNATURE	DATE
ANGULAR = ± °	DRAWN	FABIO		2024-02-23
SURFACE FINISH	CHECKED			
	APPROVED			
DO NOT SCALE DRAWING				
BREAK ALL SHARP EDGES AND REMOVE BURRS				
FIRST ANGLE PROJECTION	MATERIAL 1.4404	FINISH		

TITLE

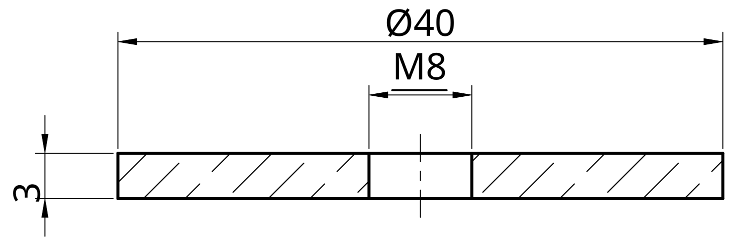
Insert (Ox)
Magnetic Venting Valve
Propulsion

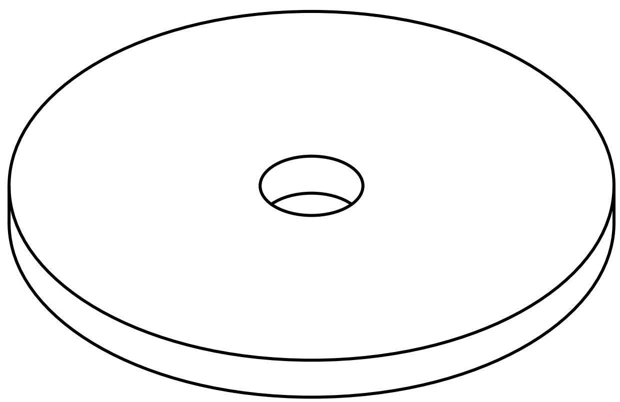
SIZE	DWG NO.	REV.
A4		

SCALE	WEIGHT	SHEET
2:1		1 of 1



UNLESS OTHERWISE SPECIFIED, DIMENSIONS ARE IN MILLIMETERS ANGULAR = ± ° SURFACE FINISH		NAME	SIGNATURE	DATE	
	DRAWN	FABIO		2024-09-16	TITLE: Magnet Magnetic Venting Valve Propulsion
	CHECKED				
	APPROVED				
DO NOT SCALE DRAWING					
BREAK ALL SHARP EDGES AND REMOVE BURRS					SIZE A4 / DWG NO. / REV.
FIRST ANGLE PROJECTION	MATERIAL: -		FINISH		SCALE 2:1 / WEIGHT / SHEET 1 of 1



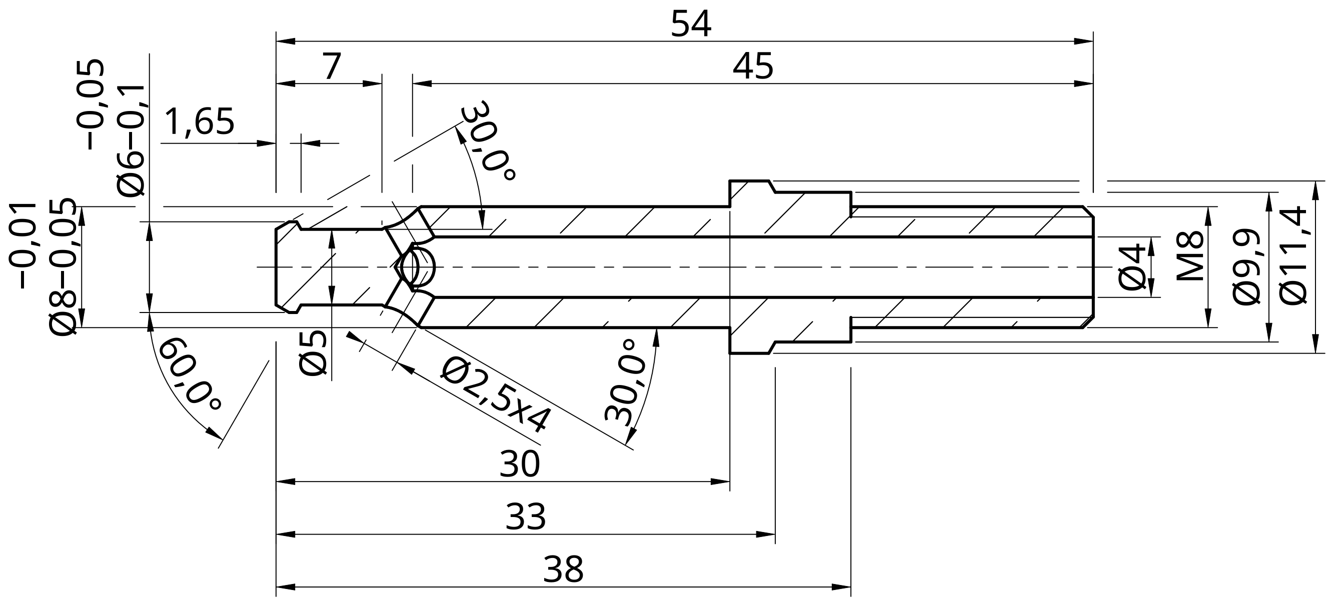


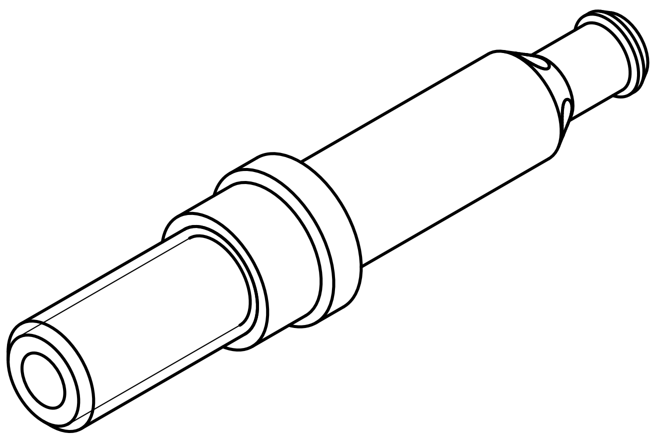
UNLESS OTHERWISE SPECIFIED, DIMENSIONS ARE IN MILLIMETERS		NAME	SIGNATURE	DATE
ANGULAR = ± °	DRAWN	FABIO		2024-09-16
SURFACE FINISH	CHECKED			
	APPROVED			
DO NOT SCALE DRAWING				
BREAK ALL SHARP EDGES AND REMOVE BURRS				
FIRST ANGLE PROJECTION	MATERIAL 1.0037		FINISH	

TITLE
Plate
Magnetic Venting Valve
Propulsion

SIZE	DWG NO.	REV.
A4		

SCALE	WEIGHT	SHEET
2:1		1 of 1



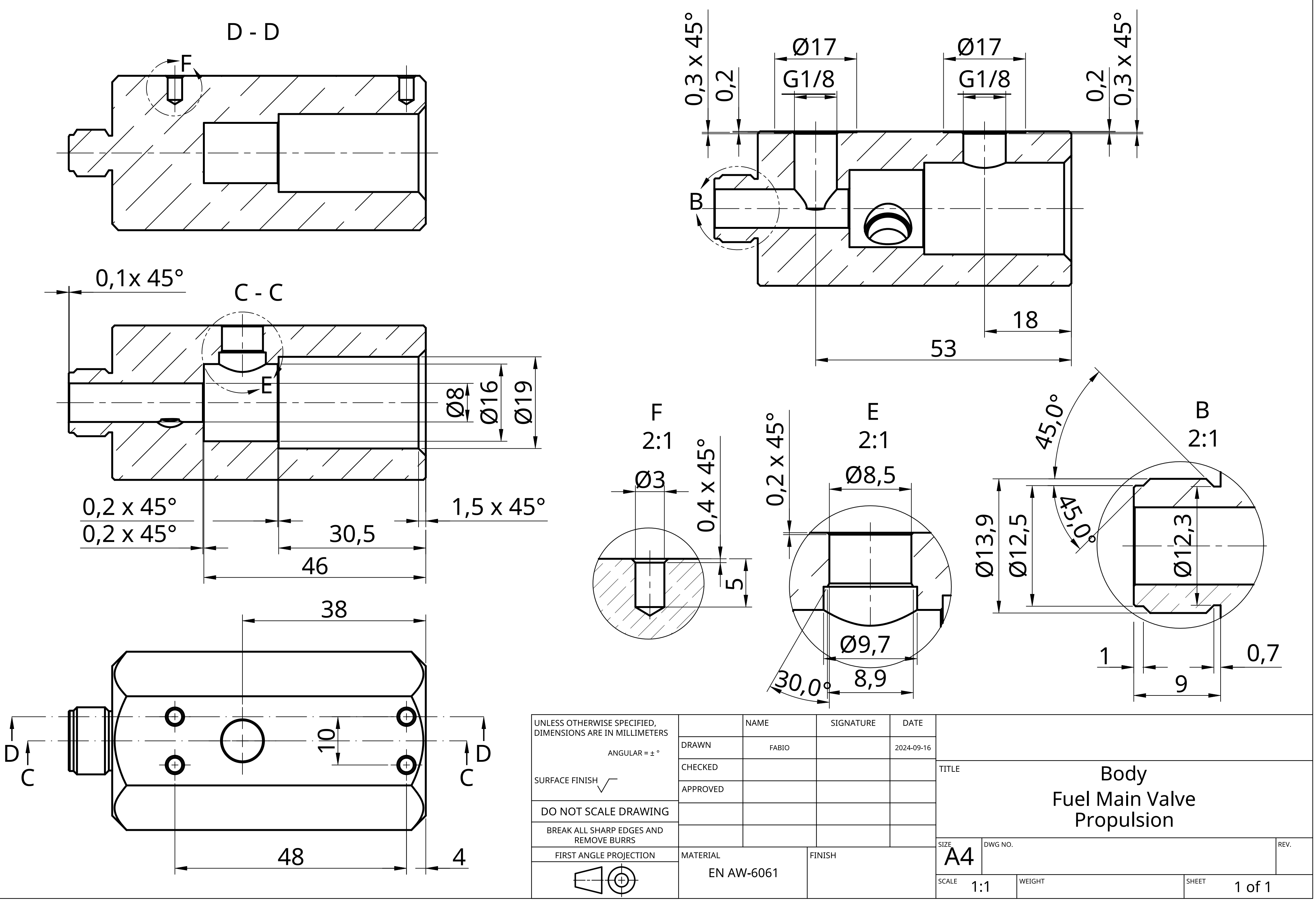


UNLESS OTHERWISE SPECIFIED, DIMENSIONS ARE IN MILLIMETERS ANGULAR = ± °		NAME	SIGNATURE	DATE
SURFACE FINISH	DRAWN	FABIO		2024-02-24
	CHECKED			
	APPROVED			
DO NOT SCALE DRAWING				
BREAK ALL SHARP EDGES AND REMOVE BURRS				
FIRST ANGLE PROJECTION	MATERIAL: 1.4404	FINISH		

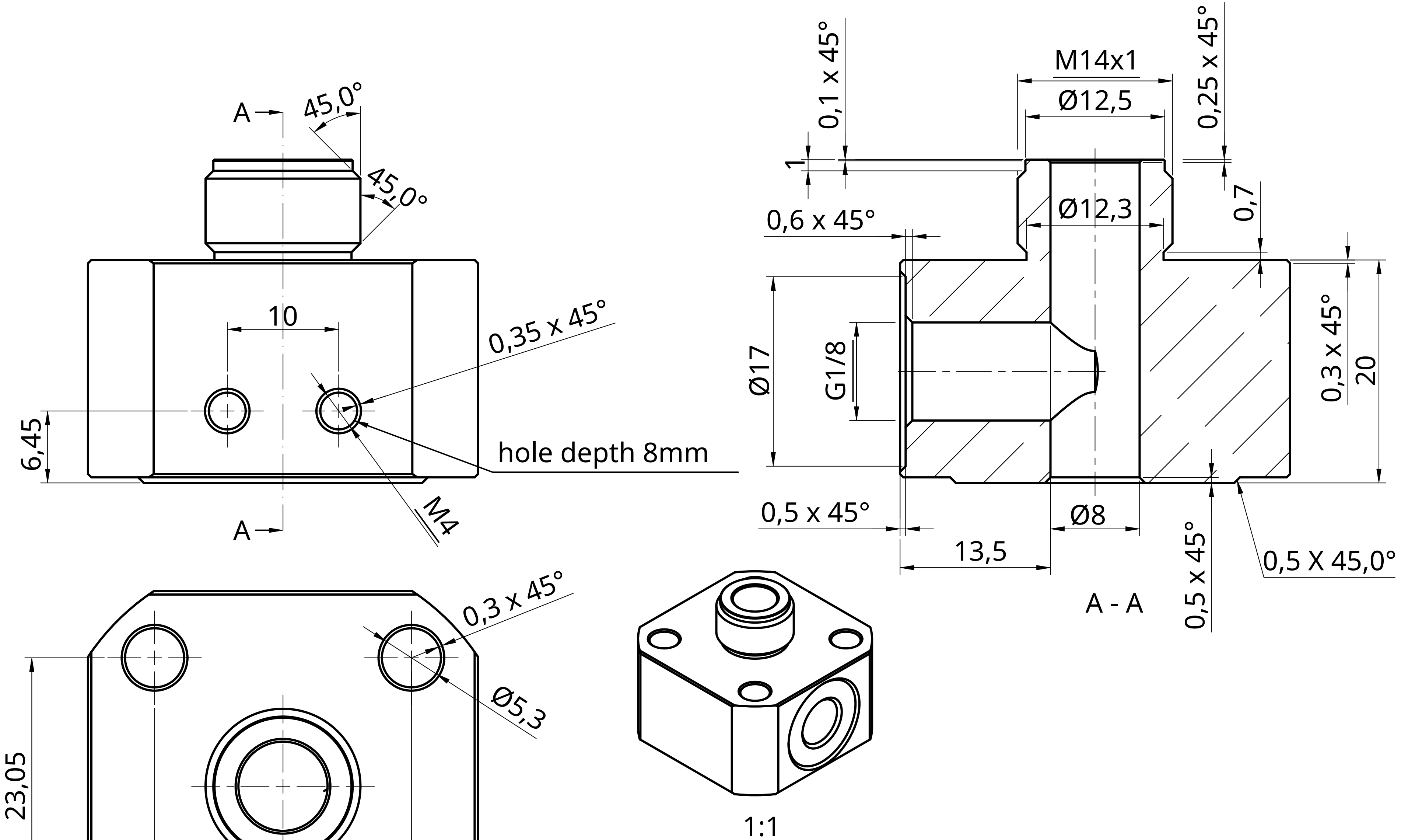
TITLE: Stem
Manual Venting Valve
Propulsion

SIZE	DWG NO.	REV.
A4		

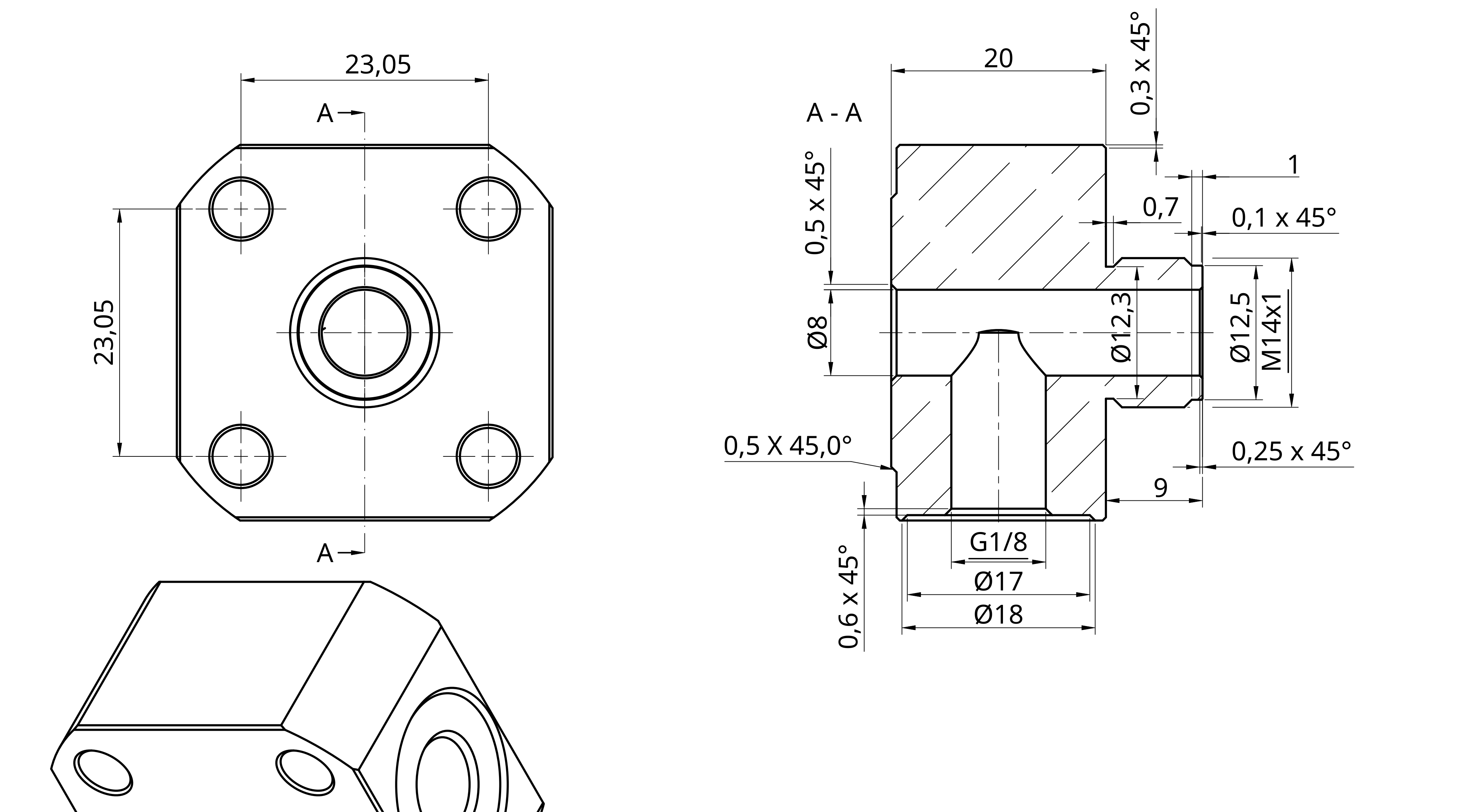
SCALE	WEIGHT	SHEET
2:1		1 of 1



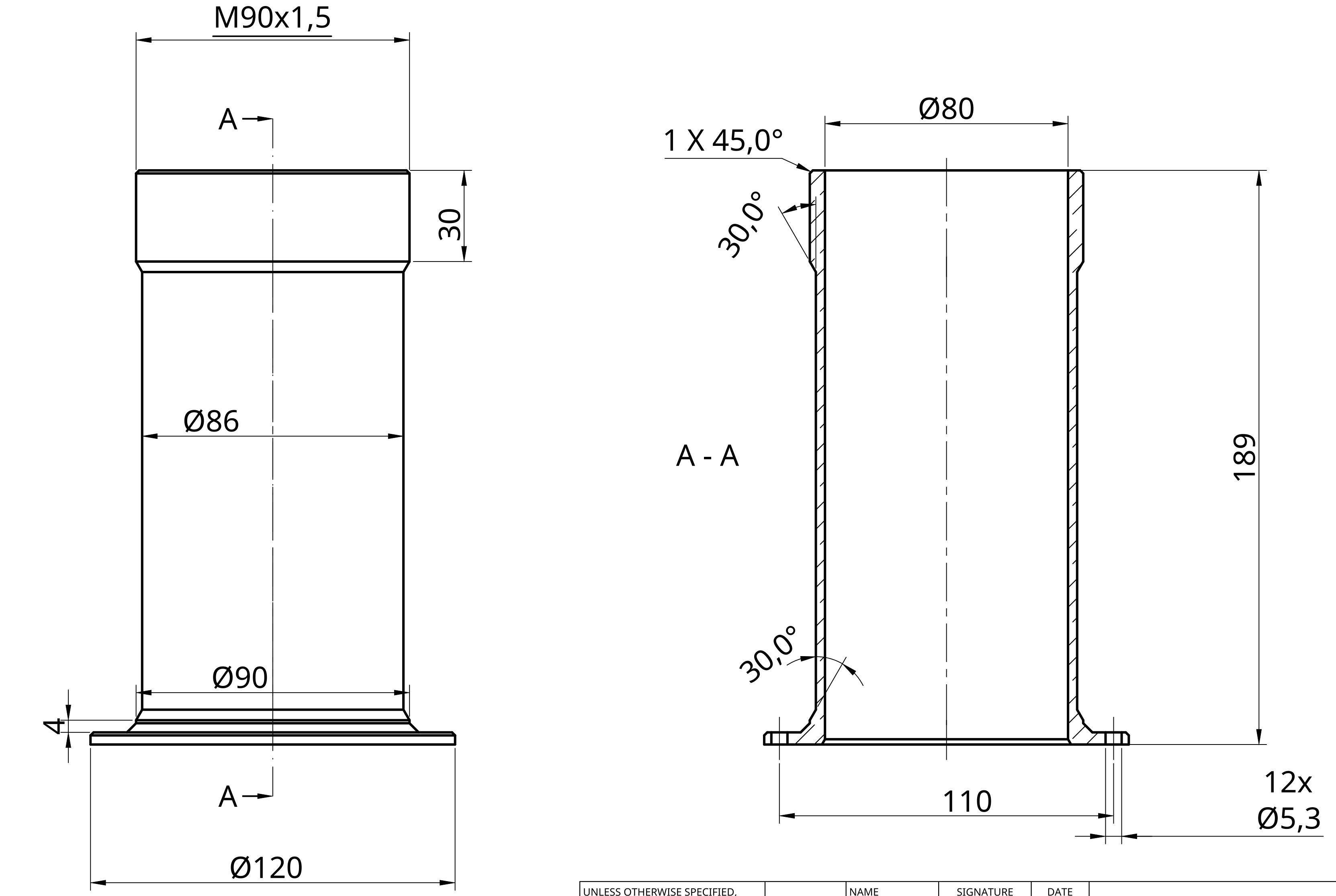
UNLESS OTHERWISE SPECIFIED, DIMENSIONS ARE IN MILLIMETERS ANGULAR = ± °		NAME	SIGNATURE	DATE	
	DRAWN	FABIO		2024-09-16	
SURFACE FINISH	CHECKED				TITLE: Body Fuel Main Valve Propulsion
	APPROVED				
DO NOT SCALE DRAWING					
BREAK ALL SHARP EDGES AND REMOVE BURRS					
FIRST ANGLE PROJECTION	MATERIAL: EN AW-6061		FINISH		SIZE: A4 / DWG NO. / REV.
					SCALE: 1:1 / WEIGHT / SHEET: 1 of 1



UNLESS OTHERWISE SPECIFIED, DIMENSIONS ARE IN MILLIMETERS ANGULAR = ± ° SURFACE FINISH		NAME	SIGNATURE	DATE	
	DRAWN	FABIO		2024-09-16	
	CHECKED				TITLE Body Downstream Ox Main Valve Propulsion
	APPROVED				
DO NOT SCALE DRAWING					
BREAK ALL SHARP EDGES AND REMOVE BURRS					
FIRST ANGLE PROJECTION	MATERIAL EN AW-6061	FINISH			SIZE A4 · DWG NO. · REV.
					SCALE 2:1 · WEIGHT · SHEET 1 of 1

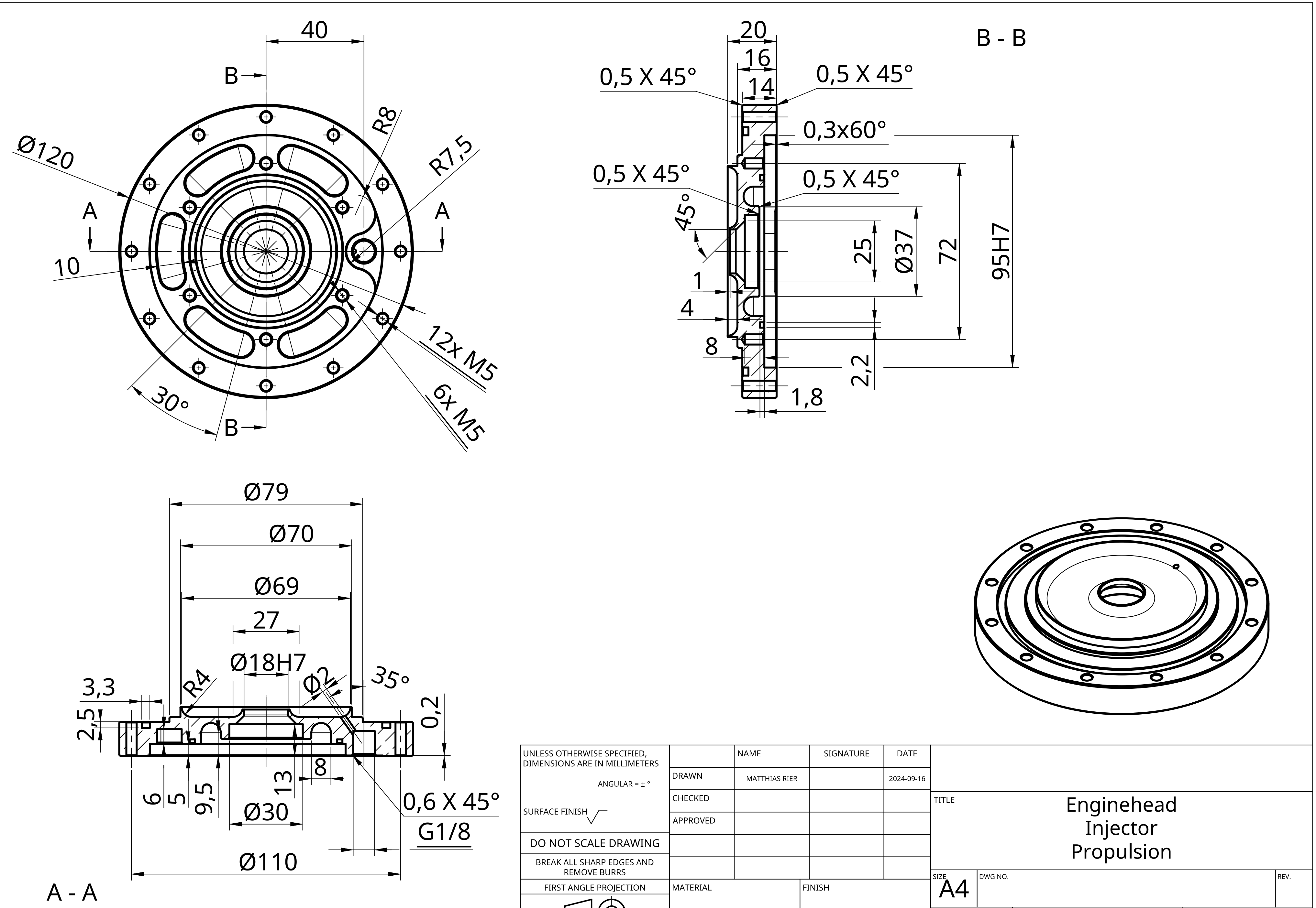


UNLESS OTHERWISE SPECIFIED, DIMENSIONS ARE IN MILLIMETERS ANGULAR = ± ° SURFACE FINISH		NAME	SIGNATURE	DATE	
	DRAWN	FABIO		2024-09-16	
	CHECKED				TITLE Body Upstream Ox Main Valve Propulsion
	APPROVED				
DO NOT SCALE DRAWING					
BREAK ALL SHARP EDGES AND REMOVE BURRS					SIZE A4
FIRST ANGLE PROJECTION	MATERIAL EN AW-6061		FINISH		DWG NO.
					REV.
					SCALE 2:1
					WEIGHT
					SHEET 1 of 1



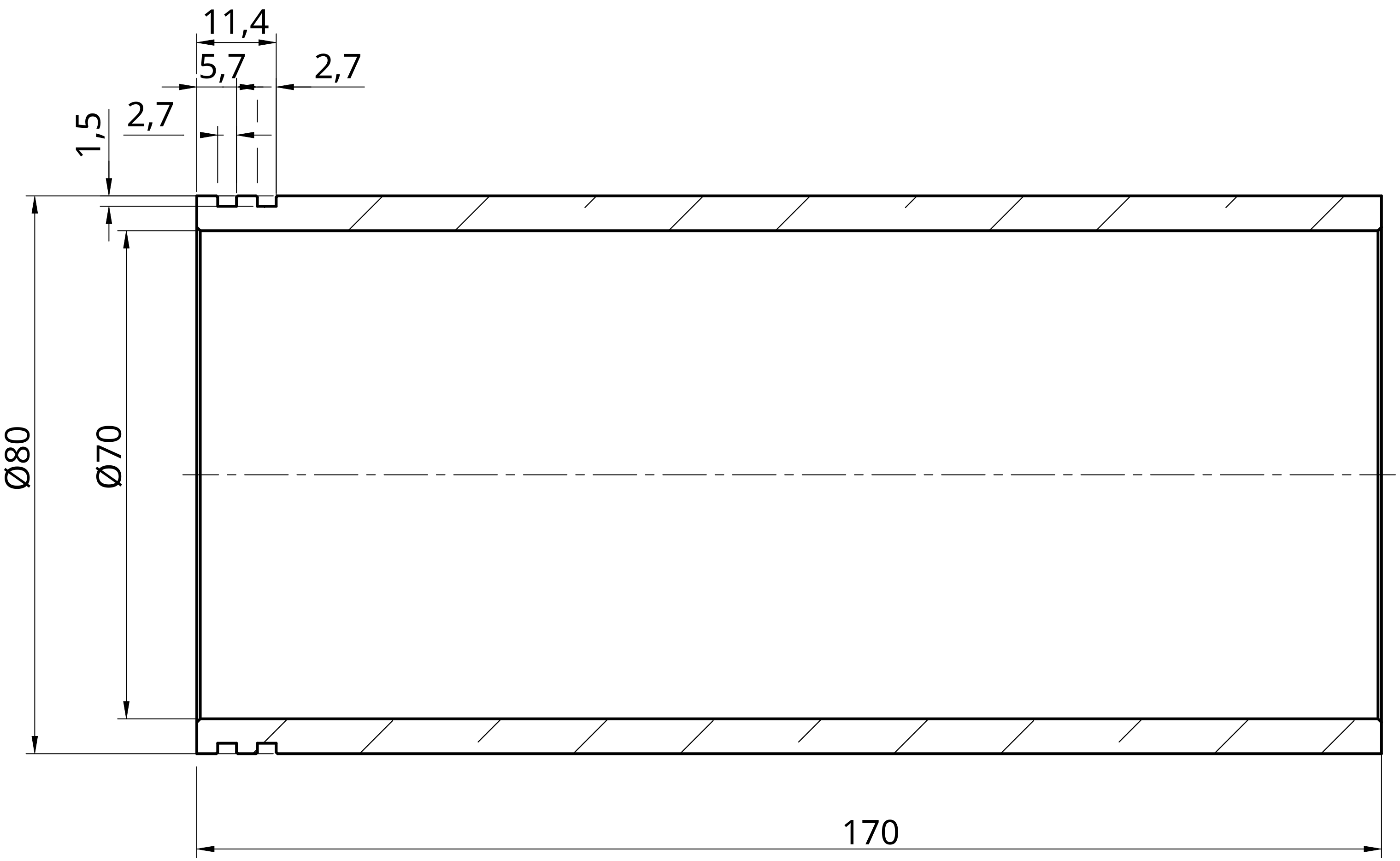
M90x1,5
Thread depth internal thread: 0,91mm

UNLESS OTHERWISE SPECIFIED, DIMENSIONS ARE IN MILLIMETERS ANGULAR = ± °		NAME	SIGNATURE	DATE	
	DRAWN	MATTHIAS RIER		2024-09-16	
SURFACE FINISH	CHECKED				TITLE Casing Thrust Chamber Propulsion
	APPROVED				
DO NOT SCALE DRAWING					
BREAK ALL SHARP EDGES AND REMOVE BURRS					
FIRST ANGLE PROJECTION	MATERIAL		FINISH		SIZE A4 · DWG NO. · REV.
					SCALE 1:2 · WEIGHT · SHEET 1 of 1

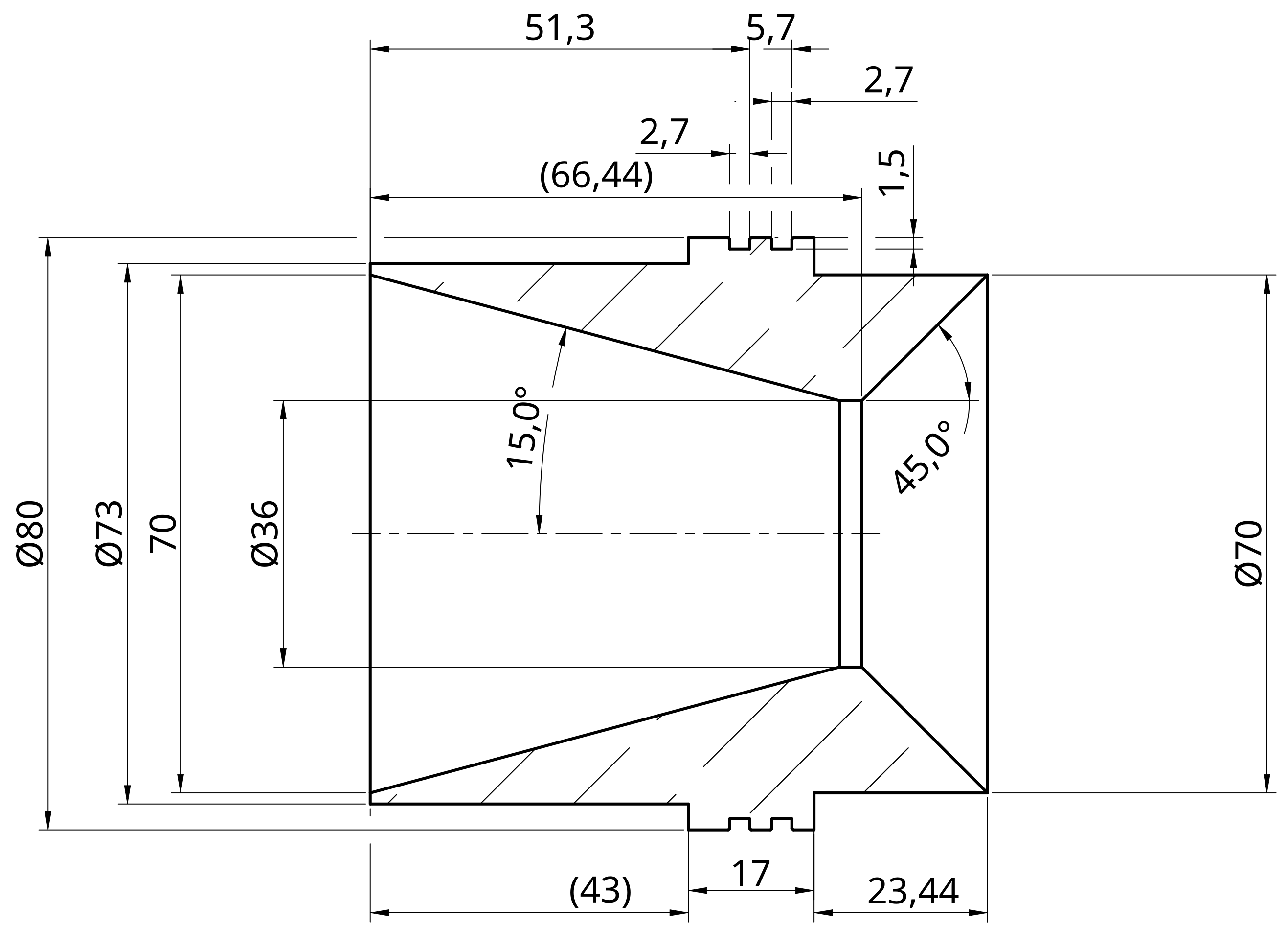


UNLESS OTHERWISE SPECIFIED, DIMENSIONS ARE IN MILLIMETERS ANGULAR = ± °		NAME	SIGNATURE	DATE
	DRAWN	MATTHIAS RIER		2024-09-16
SURFACE FINISH	CHECKED			
	APPROVED			
DO NOT SCALE DRAWING				
BREAK ALL SHARP EDGES AND REMOVE BURRS				
FIRST ANGLE PROJECTION	MATERIAL		FINISH	

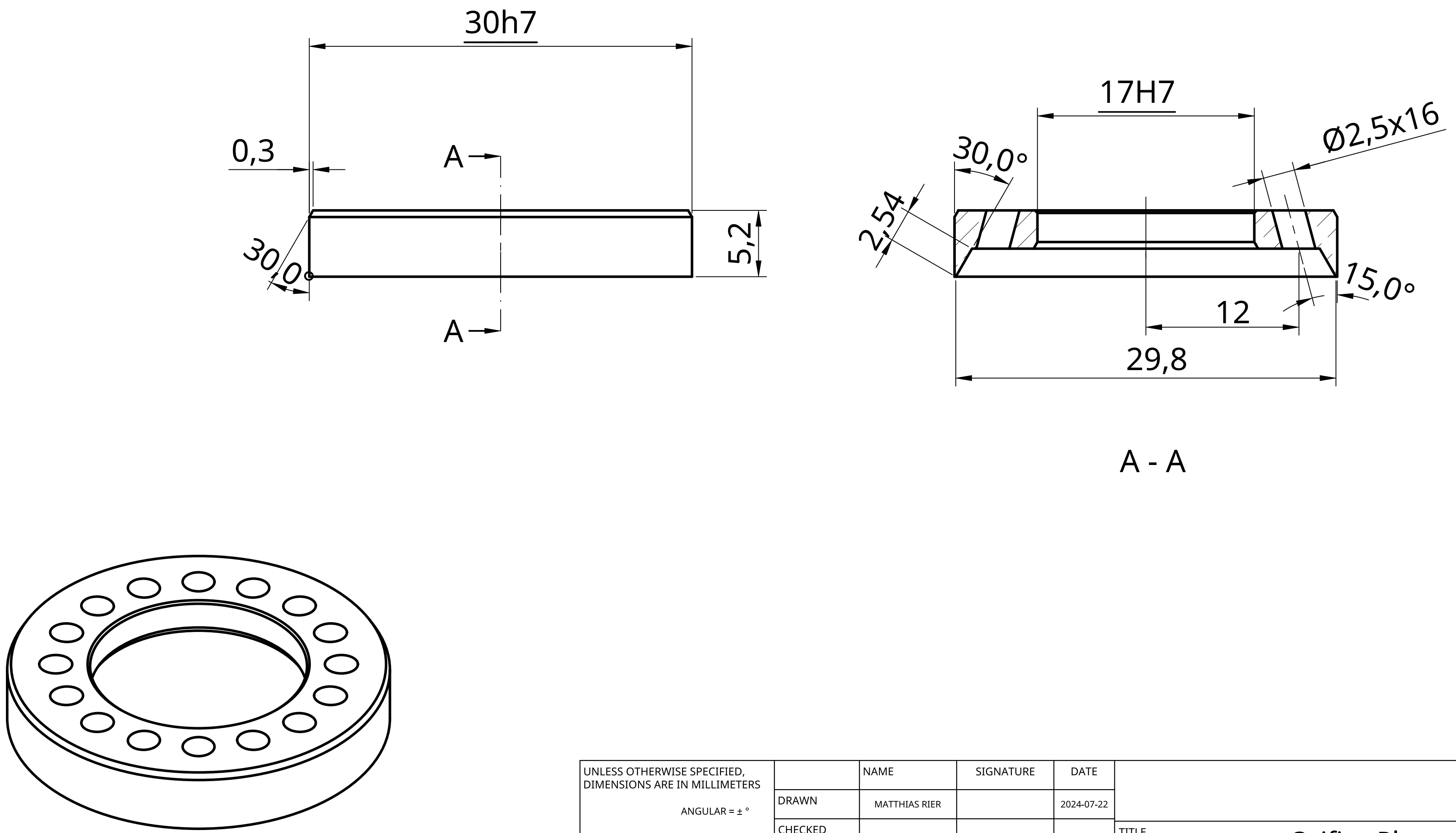
TITLE	Enginehead Injector Propulsion		
SIZE A4	DWG NO.		REV.
SCALE 1:2	WEIGHT	SHEET 1 of 1	



UNLESS OTHERWISE SPECIFIED, DIMENSIONS ARE IN MILLIMETERS		NAME	SIGNATURE	DATE	
ANGULAR = ± °	DRAWN	FABIO		2024-05-24	
SURFACE FINISH	CHECKED				TITLE: Chamber Liner Thrust Chamber Propulsion
	APPROVED				
DO NOT SCALE DRAWING					
BREAK ALL SHARP EDGES AND REMOVE BURRS					
FIRST ANGLE PROJECTION	MATERIAL: Phenolic Resin Cotton	FINISH			SIZE: A4 / DWG NO. / REV.
					SCALE: 1:1 / WEIGHT / SHEET: 1 of 1



UNLESS OTHERWISE SPECIFIED, DIMENSIONS ARE IN MILLIMETERS		NAME	SIGNATURE	DATE	
ANGULAR = ± °	DRAWN	FABIO		2024-05-24	TITLE: Nozzle Thrust Chamber Propulsion
SURFACE FINISH	CHECKED				
	APPROVED				
DO NOT SCALE DRAWING					
BREAK ALL SHARP EDGES AND REMOVE BURRS					SIZE: A4 / DWG NO. / REV.
FIRST ANGLE PROJECTION	MATERIAL: Phenolic Resin Cotton		FINISH		SCALE: 1:1 / WEIGHT / SHEET: 1 of 1



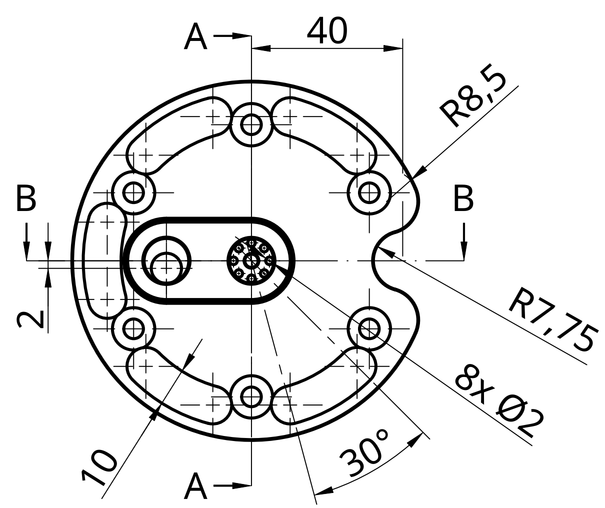
UNLESS OTHERWISE SPECIFIED, DIMENSIONS ARE IN MILLIMETERS ANGULAR = ± ° SURFACE FINISH		NAME	SIGNATURE	DATE
	DRAWN	MATTHIAS RIER		2024-07-22
	CHECKED			
	APPROVED			
DO NOT SCALE DRAWING				
BREAK ALL SHARP EDGES AND REMOVE BURRS				
FIRST ANGLE PROJECTION	MATERIAL	FINISH		

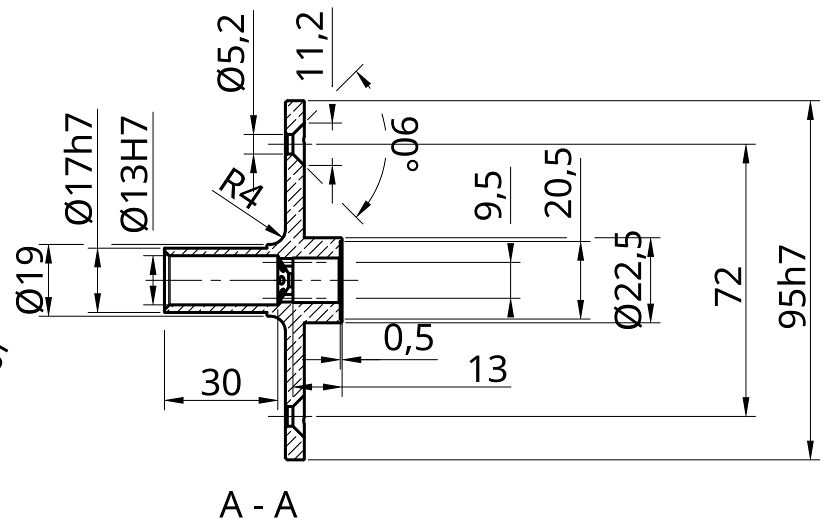
TITLE

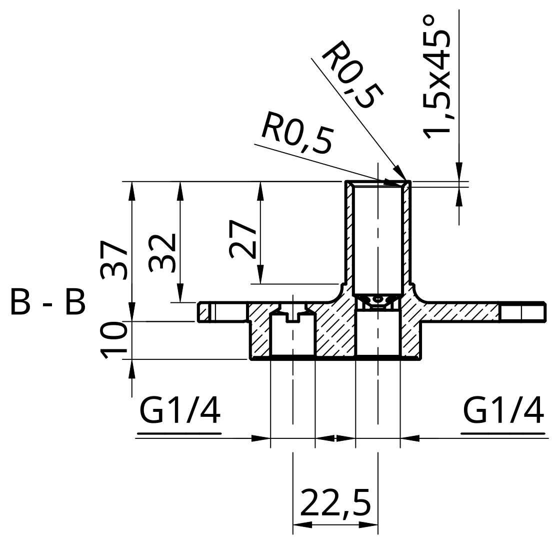
Orifice Plate Injector Propulsion

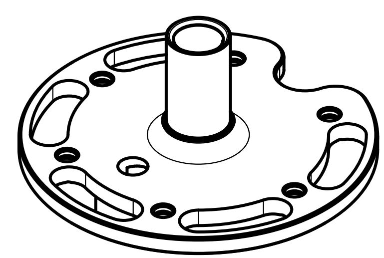
SIZE	DWG NO.	REV.
A4		

SCALE	WEIGHT	SHEET
2:1		1 of 1

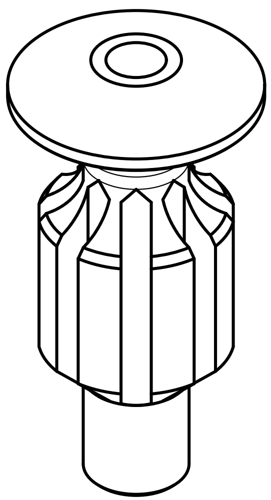


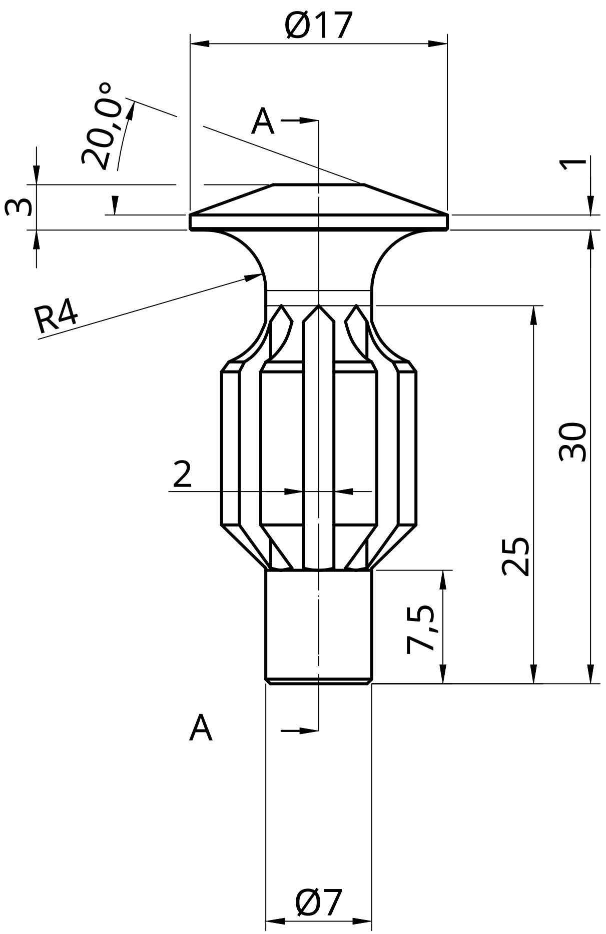


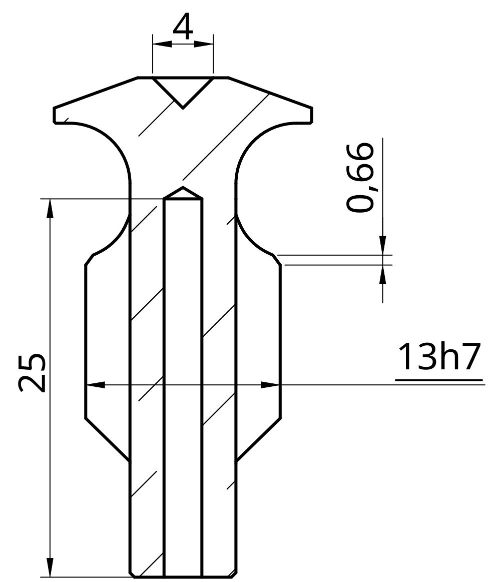




UNLESS OTHERWISE SPECIFIED, DIMENSIONS ARE IN MILLIMETERS		NAME	SIGNATURE	DATE	
ANGULAR = ± °	DRAWN	MATTHIAS RIER		2024-09-16	
SURFACE FINISH	CHECKED				TITLE: Pintle Sleeve Injector Propulsion
	APPROVED				
DO NOT SCALE DRAWING					
BREAK ALL SHARP EDGES AND REMOVE BURRS					SIZE: A4 · DWG NO. · REV.
FIRST ANGLE PROJECTION	MATERIAL		FINISH		SCALE: 1:2 · WEIGHT · SHEET: 1 of 1

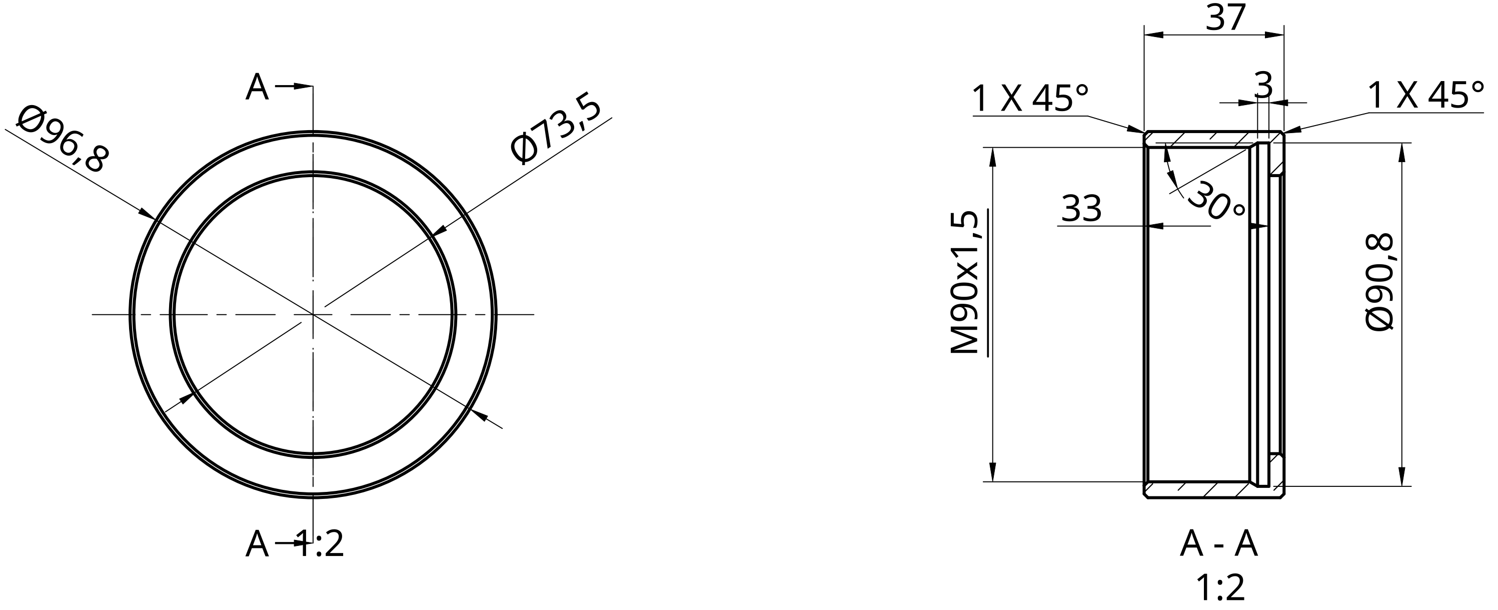






A - A

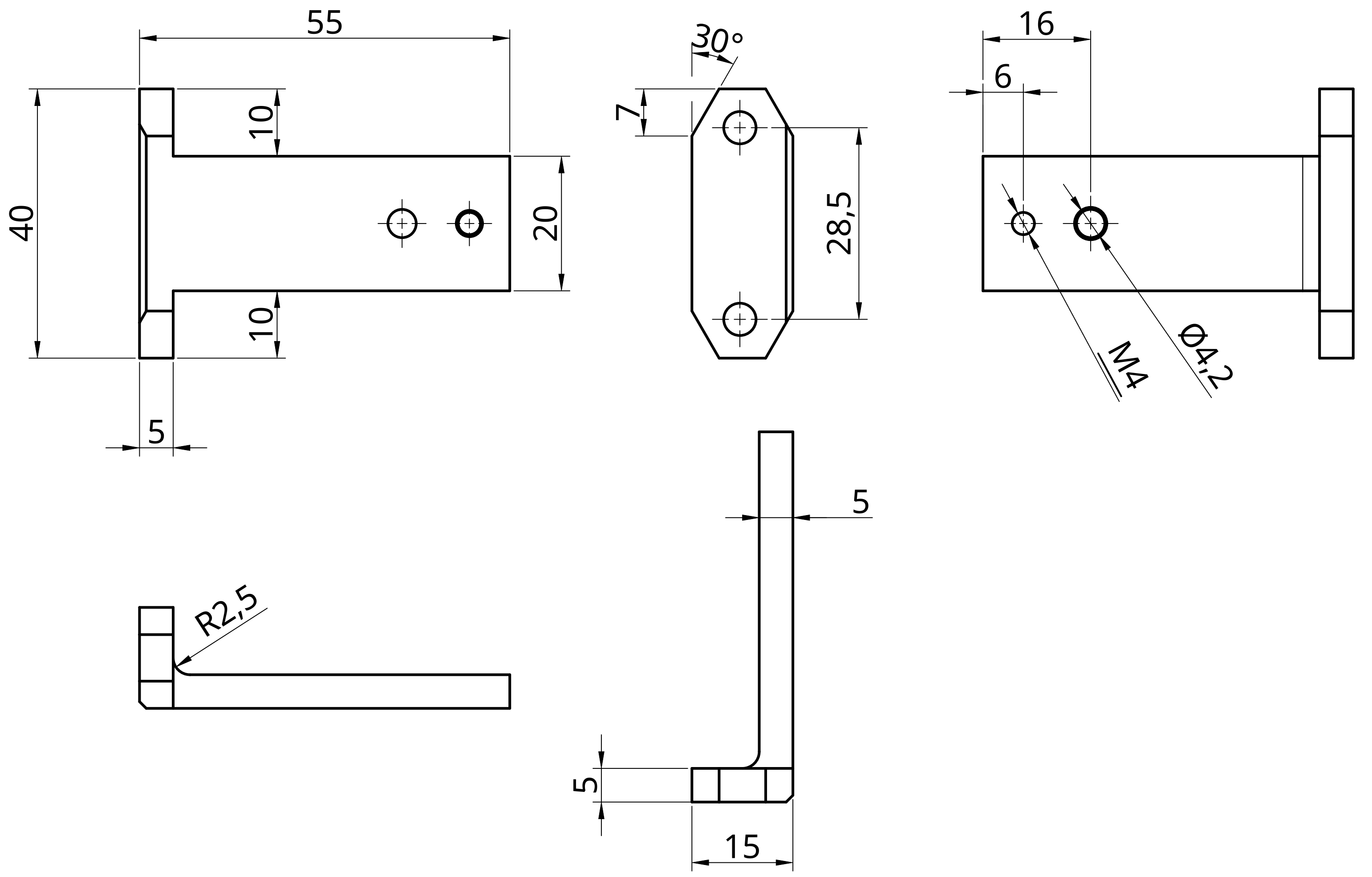
UNLESS OTHERWISE SPECIFIED, DIMENSIONS ARE IN MILLIMETERS ANGULAR = ± ° SURFACE FINISH		NAME	SIGNATURE	DATE	
	DRAWN	MATTHIAS RIER		2024-07-22	
	CHECKED				TITLE Pintle Injector Propulsion
	APPROVED				
DO NOT SCALE DRAWING					
BREAK ALL SHARP EDGES AND REMOVE BURRS					SIZE A4 · DWG NO. · REV.
FIRST ANGLE PROJECTION	MATERIAL		FINISH		SCALE 2:1 · WEIGHT · SHEET 1 of 1



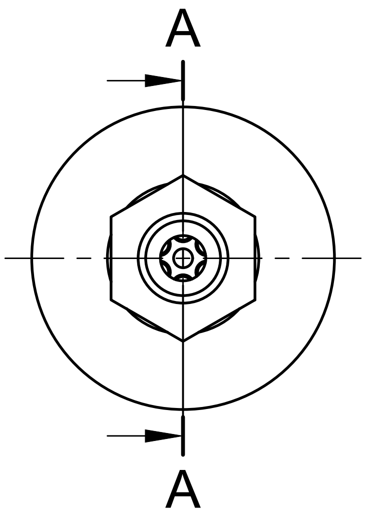
M90x1,5
Thread depth internal thread: 0,81mm

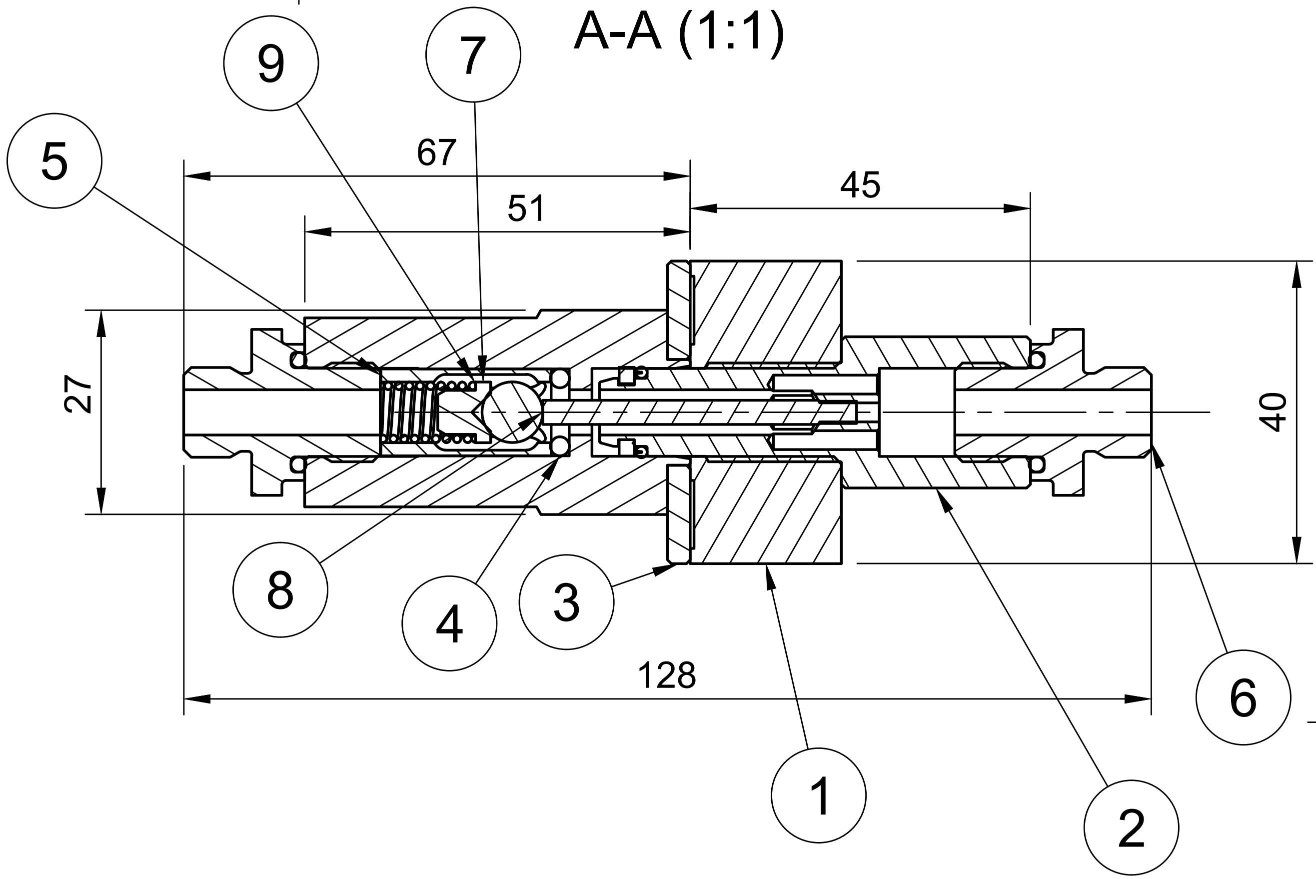
UNLESS OTHERWISE SPECIFIED, DIMENSIONS ARE IN MILLIMETERS		NAME	SIGNATURE	DATE
ANGULAR = ± °	DRAWN	MATTHIAS RIER		2024-08-18
SURFACE FINISH	CHECKED			
	APPROVED			
DO NOT SCALE DRAWING				
BREAK ALL SHARP EDGES AND REMOVE BURRS				
FIRST ANGLE PROJECTION	MATERIAL		FINISH	

TITLE	Retainer Nut Thrust Chamber Propulsion			
SIZE A4	DWG NO.			REV.
SCALE 1:4	WEIGHT		SHEET 1 of 1	



UNLESS OTHERWISE SPECIFIED, DIMENSIONS ARE IN MILLIMETERS ANGULAR = ± ° SURFACE FINISH		NAME	SIGNATURE	DATE	
	DRAWN	MICHAEL POHN		2024-08-21	
	CHECKED				TITLE Thrust Pillar Thrust Structure Propulsion
	APPROVED				
DO NOT SCALE DRAWING					
BREAK ALL SHARP EDGES AND REMOVE BURRS					SIZE A4 DWG NO. REV.
FIRST ANGLE PROJECTION	MATERIAL		FINISH		SCALE 1:1 WEIGHT SHEET 1 of 1





Item	Part Name	Mass
9	Feder D8 d1 n9 v2	1.297 g
8	Ventilkugel v2	2.104 g
7	Kugelschutz v4	0.224 g
6	Serto einschrauber v4	9.037 g
5	Hülse v6	2.165 g
4	O Ring PTFE 6.5x2.5mm v2	1.09 g
3	Muffe v8	83.367 g
2	Nippel v5	22.667 g
1	Magnet 25kg v3	177.358 g

Parts List

Dept.	Technical reference	Created by	Approved by
		Simon Waldl 03/07/2024	

Mass:
assembly - 308.346 g
flightweight - 99.285 g

Document type

Document status

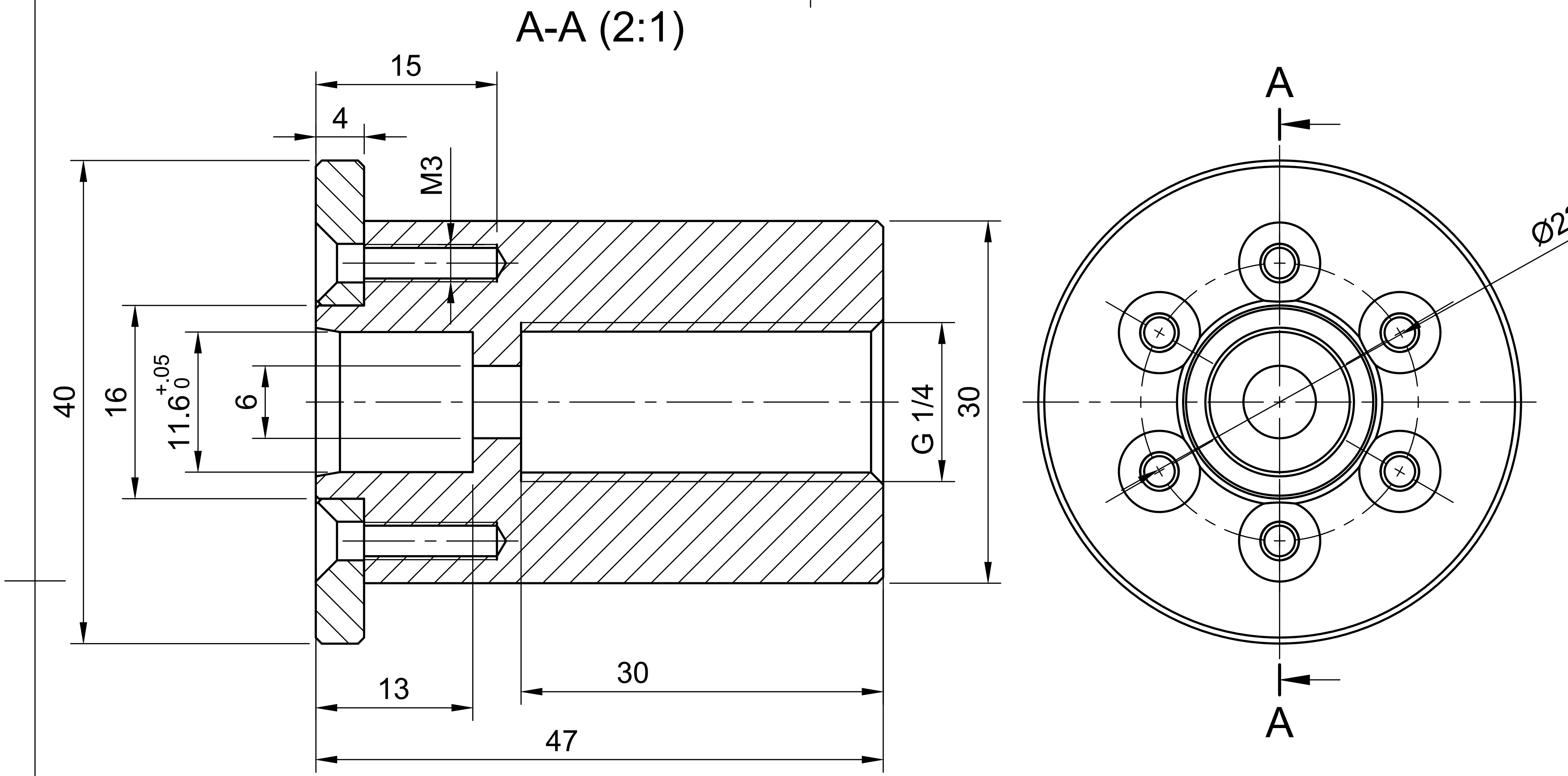
Title
Assembly Decoupler

DWG No.

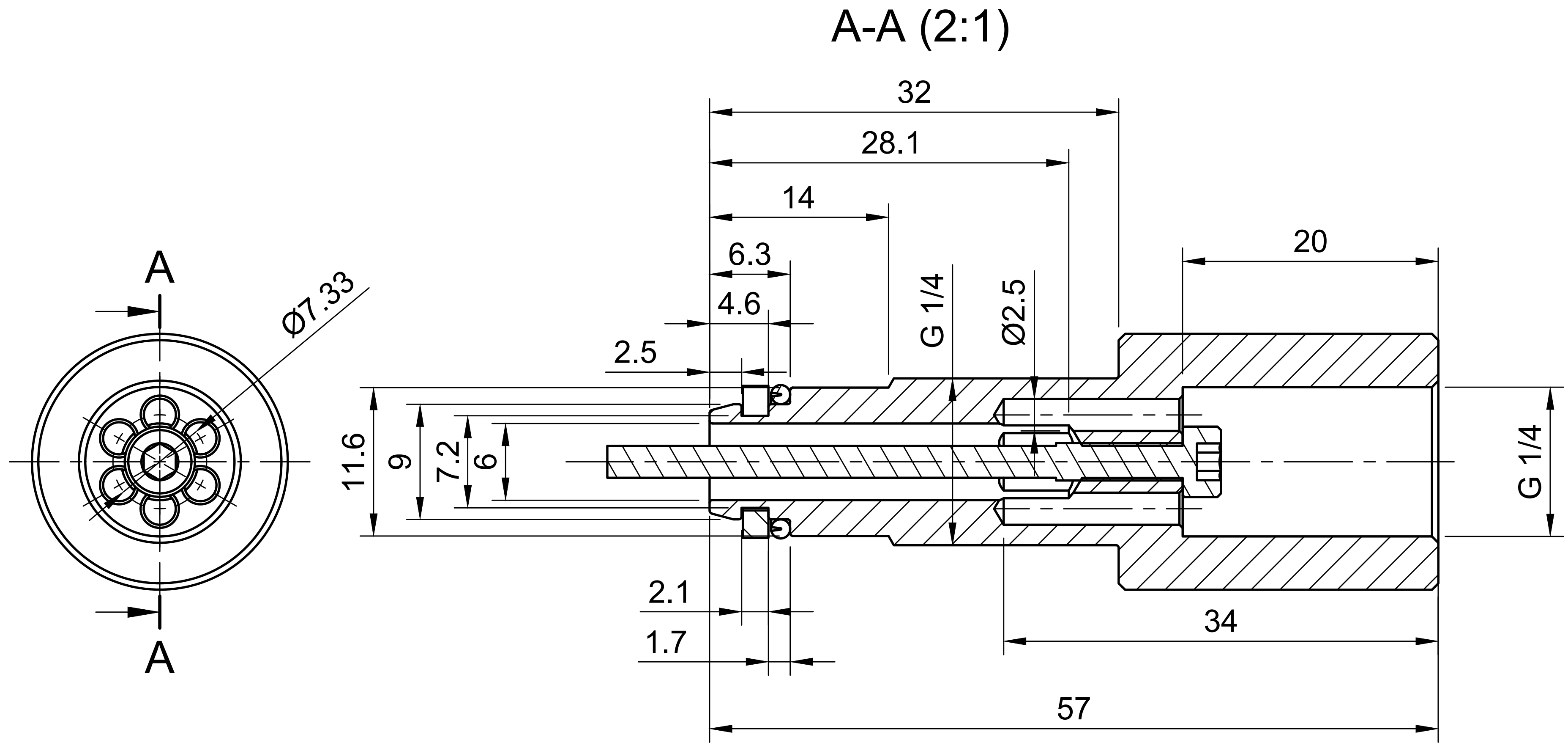
Rev.

Date of issue

Sheet
1/1

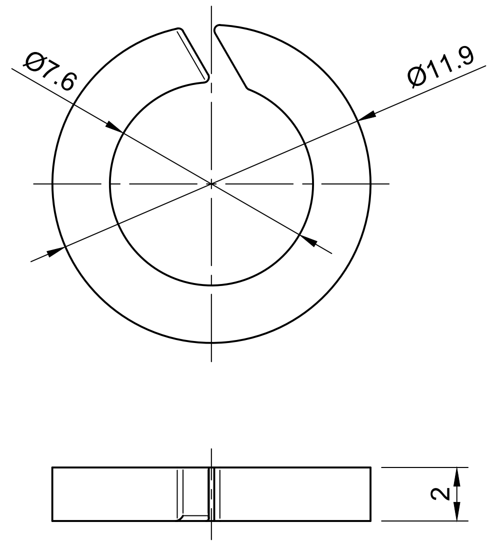


Dept.	Technical reference	Created by	Approved by		
		Simon Waldl 14/02/2024			
		Document type	Document status		
		Title: Muffe	DWG No.		
			Rev.	Date of issue	Sheet 1/1

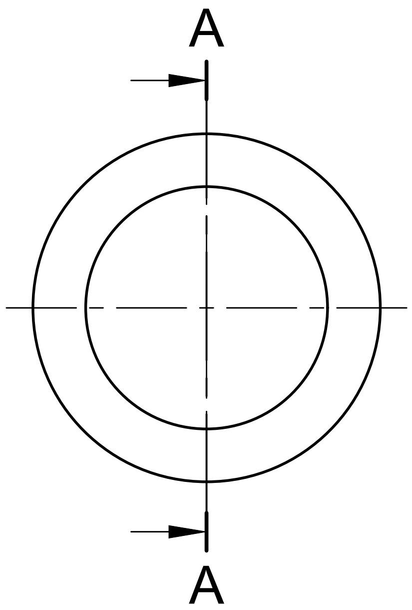


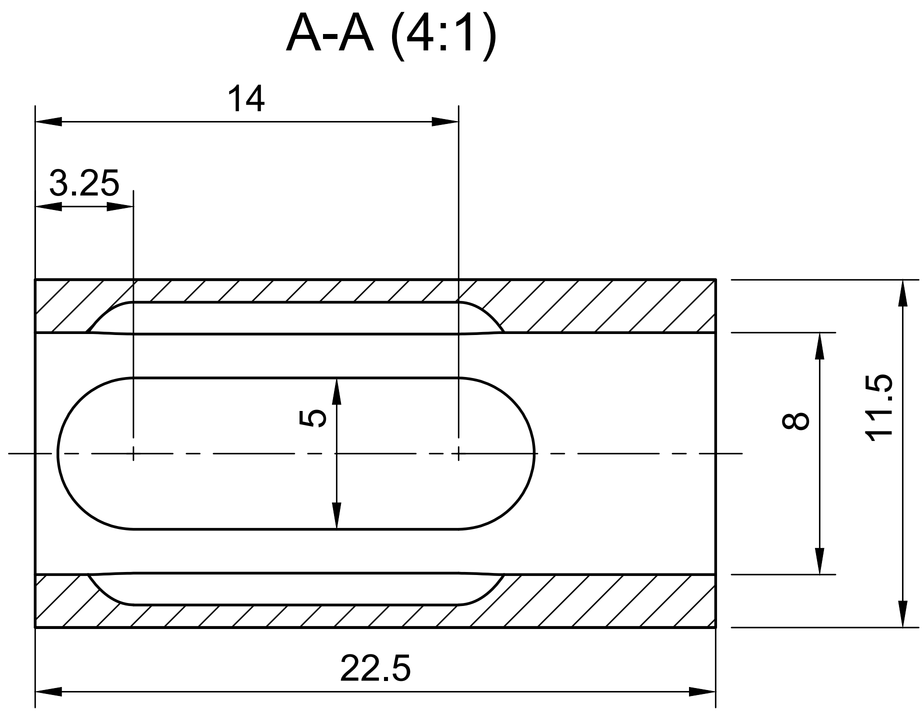
$G\,\frac{1}{4}$	11.445 mm	13.157 mm	1,337 mm
Typ	Kern Ø	Außen Ø	Steigung
Gewindetabelle			

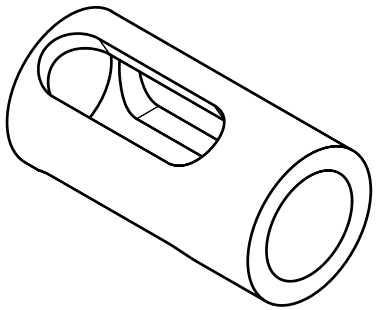
Dept.	Technical reference	Created by Simon Waldl 14/02/2024	Approved by
		Document type	Document status
		Title Nippel	DWG No.
			Rev. / Date of issue / Sheet 1/1



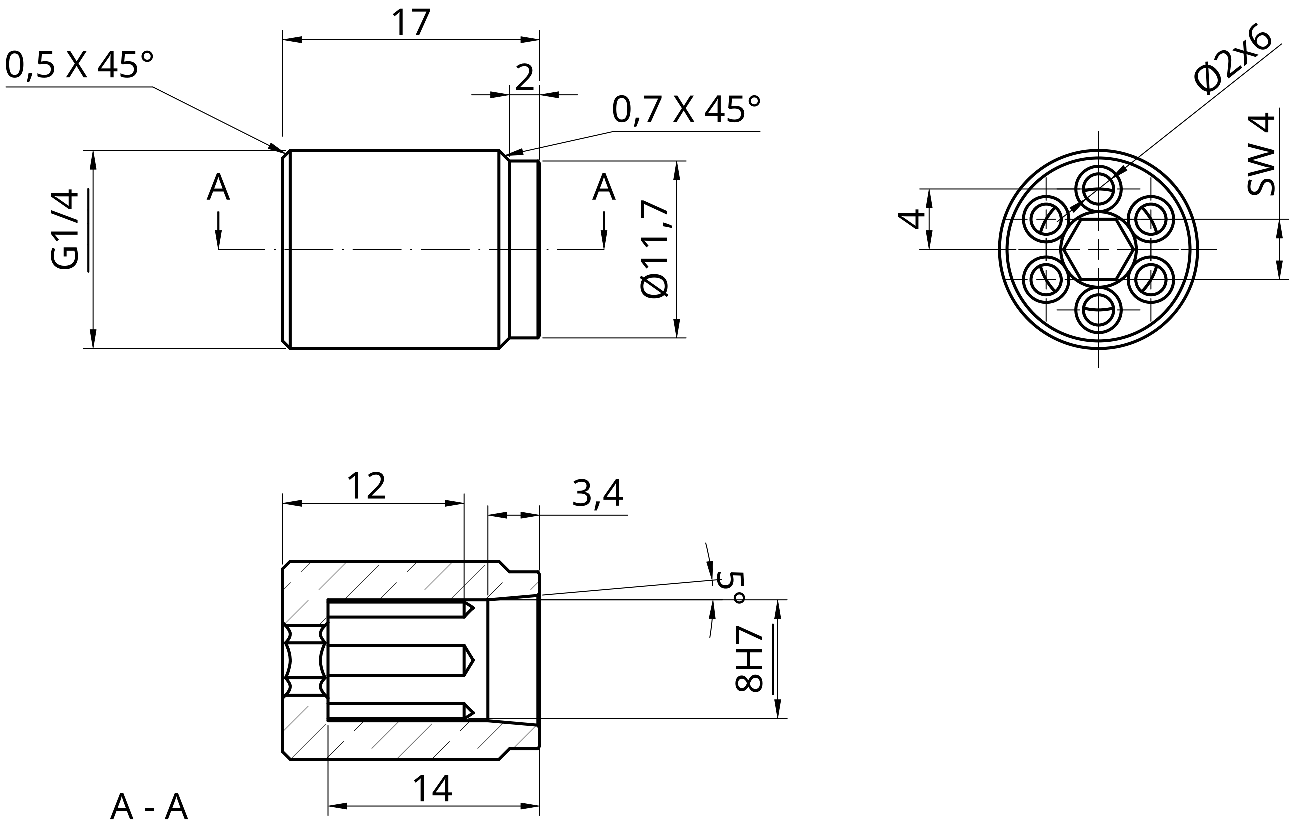
Dept.	Technical reference	Created by Simon Waldl 14/02/2024	Approved by
		Document type	Document status
		Title Nippel	DWG No.
			Rev. / Date of issue / Sheet 1/1



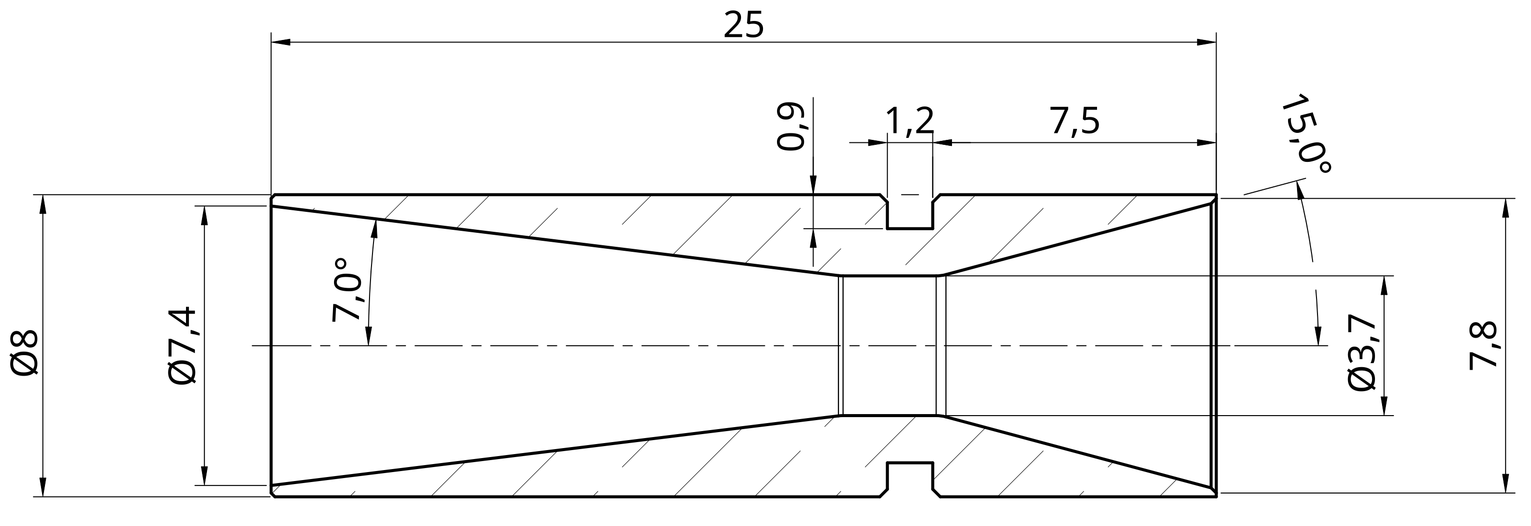




Dept.	Technical reference	Created by Simon Waldl 16/09/2024	Approved by
		Document type	Document status
		Title Hülse	DWG No.
			Rev. / Date of issue / Sheet 1/1



UNLESS OTHERWISE SPECIFIED, DIMENSIONS ARE IN MILLIMETERS ANGULAR = ± °		NAME	SIGNATURE	DATE	
	DRAWN	MATTHIAS RIER		2024-09-16	
SURFACE FINISH	CHECKED				TITLE Check Valve Ox Pressurant System Propulsion
	APPROVED				
DO NOT SCALE DRAWING					
BREAK ALL SHARP EDGES AND REMOVE BURRS					SIZE A4	DWG NO.	REV.
FIRST ANGLE PROJECTION	MATERIAL	FINISH			SCALE 2:1	WEIGHT	SHEET 1 of 1



A - A

Throatdiameter:
Fuel: 3,1mm
Ox: 3,7mm

UNLESS OTHERWISE SPECIFIED, DIMENSIONS ARE IN MILLIMETERS ANGULAR = ± °		NAME	SIGNATURE	DATE
SURFACE FINISH	DRAWN	FABIO		2024-07-09
	CHECKED			
	APPROVED			
DO NOT SCALE DRAWING				
BREAK ALL SHARP EDGES AND REMOVE BURRS				
FIRST ANGLE PROJECTION	MATERIAL		FINISH	

TITLE	Ox Venturi Injector Propulsion		
SIZE A4	DWG NO.		REV.
SCALE 5:1	WEIGHT	SHEET 1 of 1	