Project TELL

Team 100 Project Technical Report to the 2018 Spaceport America Cup

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The Swiss association ARIS - Akademische Raumfahrt Initiative Schweiz – presents its inaugural hands-on project: the rocket TELL. The project was carried out by students of ETH Zurich and HSLU with the support of industry experts and academia. Within project TELL, a sounding rocket was designed and built during two semesters for the Spaceport America Cup 2018 held in New Mexico, USA. TELL targets an apogee of 10'000 feet above ground level with a commercial off-the-shelf Aerotech M2400 solid motor. For recovery, a drogue parachute will be released by ejecting the nose cone at apogee followed by the main parachute out of the same compartment at 1500 feet above ground level. As payload, the rocket carries a camera filming biological cells under the extreme launch conditions in a 1.5 CubeSat Unit. Furthermore, the rocket has an altitude control system consisting of three air brakes which will be deployed after the motor has burnt out. Its controller is located on a sensor board with two redundant barometers in the lower body avionics. A WiFi connection links the lower body avionics with the ground communication and the GPS module in the glass fibre nose cone.

Abbreviations

ARGOS	=	*Advanced Rocketry Group Of Switzerland*
ARIS	=	Akademische Raumfahrt Initiative Schweiz
AGL	=	Above ground level
C_p	=	pressure coefficient
CAD	=	Computer Aided Design
CFRP	=	carbon fibre reinforced plastic
CoM	=	Center of Mass
CONOPS	=	Concept of Operations
CoP	=	Center of Pressure
COTS	=	Commercial Off-The-Shelf
ETH Zürich	=	Federal Institute of Technology Zürich
FEM	=	Finite Element Method
FSM	=	Finite State Machine
FWD	=	Forward
GFRP	=	glass-fibre reinforced plastic
GPS	=	Global Positioning System
HSLU	=	Hochschule Luzern
IREC	=	Intercollegiate Rocket Engineering Competition
NC	=	Nosecone
PCB	=	Printed Circuit Board
RTOS	=	Real Time Operating System
SRAD	=	Student Researched and Developed
US	=	United States

I. Introduction

TELL is the first project initiated by the association ARIS - Akademische Raumfahrt Initiative Schweiz - formed by students of ETH Zurich and HSLU. ARIS aims to connect students with a fascination for aerospace technologies and engages them in hands-on engineering challenges. With this in mind, a Swiss-wide network with industry experts and academia needs to be established.

A. Team Structure & Management Strategies

Team TELL consists of 47 bachelor and master students matriculated at the ETH Zurich and HSLU: The project manager and founder is supervising an operational and a technical team (see Figure 1). About a fourth of team TELL are active in the operational team providing an organizational, financial and legal framework. The technical part is then divided into seven sub teams supervised by a system engineer

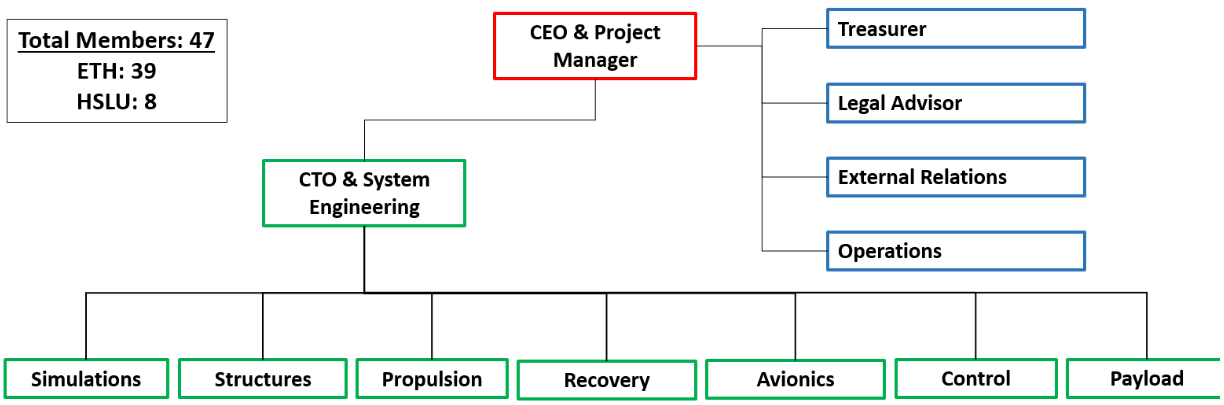

Figure 1. TELL Organization Chart

B. Academic Program

All students work on this project on a voluntary basis because they are fascinated by the field of aerospace and by the challenges of designing and building a sounding rocket. As a cooperation between the universities ETH and HSLU could be established, several students can write their semester, industrial or bachelor thesis within the project TELL. Some of them are listed in the table below:

Author	Title	University
Raphael Schnider	Multisensor acquisition system for educational and competition rockets	ETH Zurich
Laurent Jung	Numerical simulation of the combustion process of a paraffin based hybrid motor	ETH Zurich
Michael Kurmann	Sensor fusion for a sounding rocket	HSLU
Simon Herzog	Position determination via GPS for a sounding rocket	HSLU
Anna Kiener	Mechanical integration of the avionics in a sounding rocket	HSLU

C. Stakeholder Program

One of the main goals of TELL is to establish a long-term partner network across Switzerland, and eventually, across central Europe. ARIS's stakeholders are key to the success of a financially, logistically and technically challenging project such as TELL. Accordingly, the stakeholders related to TELL influence all its activities (see Figure 2).

The main technical and operational requirements of TELL are defined by IREC. Sponsors and partners from academia, industry and private persons are the foundation for financing the project and team. Intellectual guidance of the project is overseen by academics, but also private advisors. Students, infrastructure and basic support is provided by the universities and their associated laboratories. In addition, the Advanced Rocketry Group of Switzerland (ARGOS) is a project critical stakeholder for our team as it facilitates and certifies test launches in Switzerland and provides important feedback.

The detailed stakeholder analysis as well as the value flow table and the mapping is given in the appendix CC.

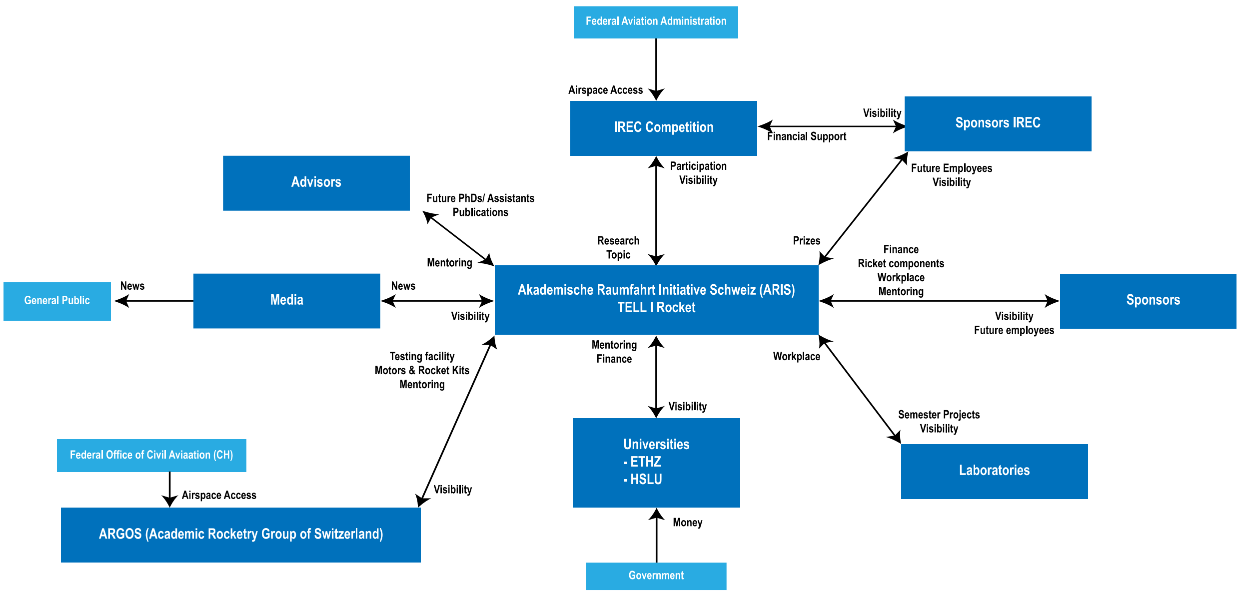

Figure 2. Hub & Spoke Network Model applied to TELL

D. Requirements List

The IREC Rules & Requirements Document and the IREC Design, Test & Evaluation Guide are the base for TELL's requirements. On top of this, the team defined its own requirements to account for its vision and the framework in which the members could work in. The full requirements list can be seen in appendix DD. The main requirements are:

- Launch TELL stable and safely
- Reach target apogee of 10.000ft. AGL as precisely as possible
- Recover without significant damages
- Recover, save and validate collected data and learnings for future projects

II. System Architecture Overview

A. Top Level Overview

Figure 3 shows an overview of TELL. The rocket is divided into three sections: 1) Lower Body, 2) Upper Body and 3) Nose Cone Section. The two red lines show where the rocket is connected with field joints, whereas the blue line indicates where the nose cone is inserted into the body tube as a coupling tube. The list below indicates the integrated subsystems, Table 1 shows TELL's main Data:

1) Motor
2) Control System (Air Brakes)
3) Lower Avionics
4) Payload
5) Recovery Electronics Bay
6) Recovery Parachute Compartment
7) Nose Cone Avionics

Table 1. TELL Main Data

Description	Value
Outer Diameter	150mm
Length	2419mm
Dry Mass	18.65kg
Target Apogee	10.000ft. AGL
Apogee Control	Air Brakes (3x3200mm^2)
Motor	COTS Aerotech M2400

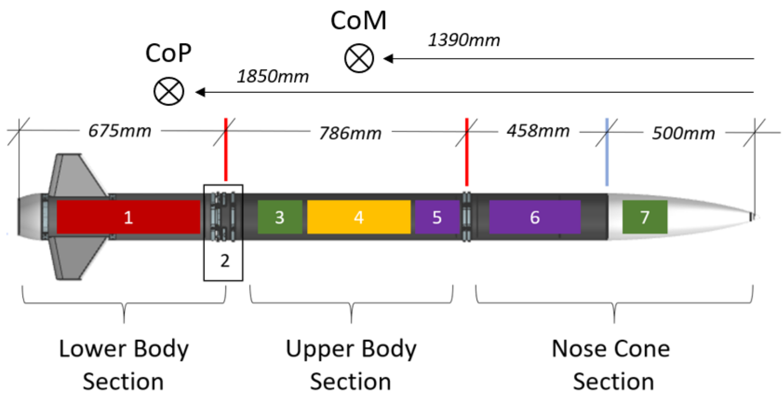

Figure 3. TELL Overview

B. Subsystem Interfaces

Figure 4 shows the whole TELL system as a block diagram and indicates with arrows the interfaces and connections. Dotted arrows indicate electrical (power and data) connections and full arrows indicate mechanical connections. Note that the recovery system is entirely electrically independent.

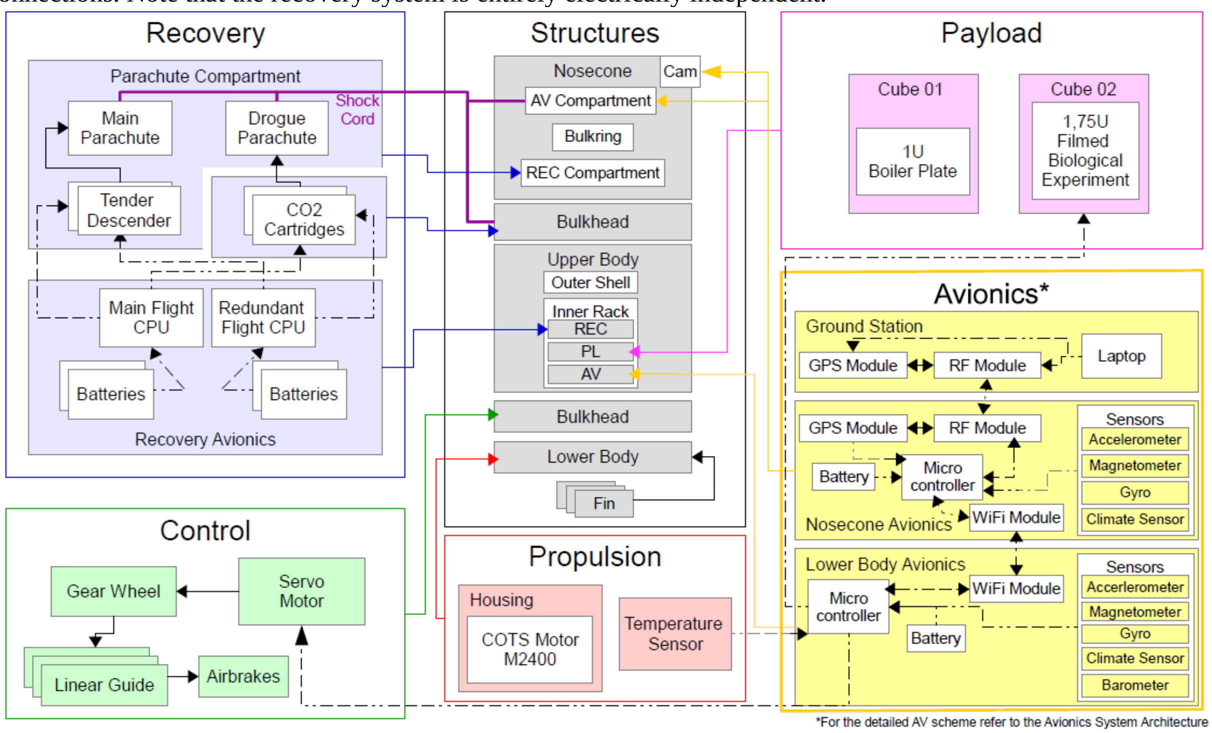

Figure 4. TELL System Architecture Interface Scheme

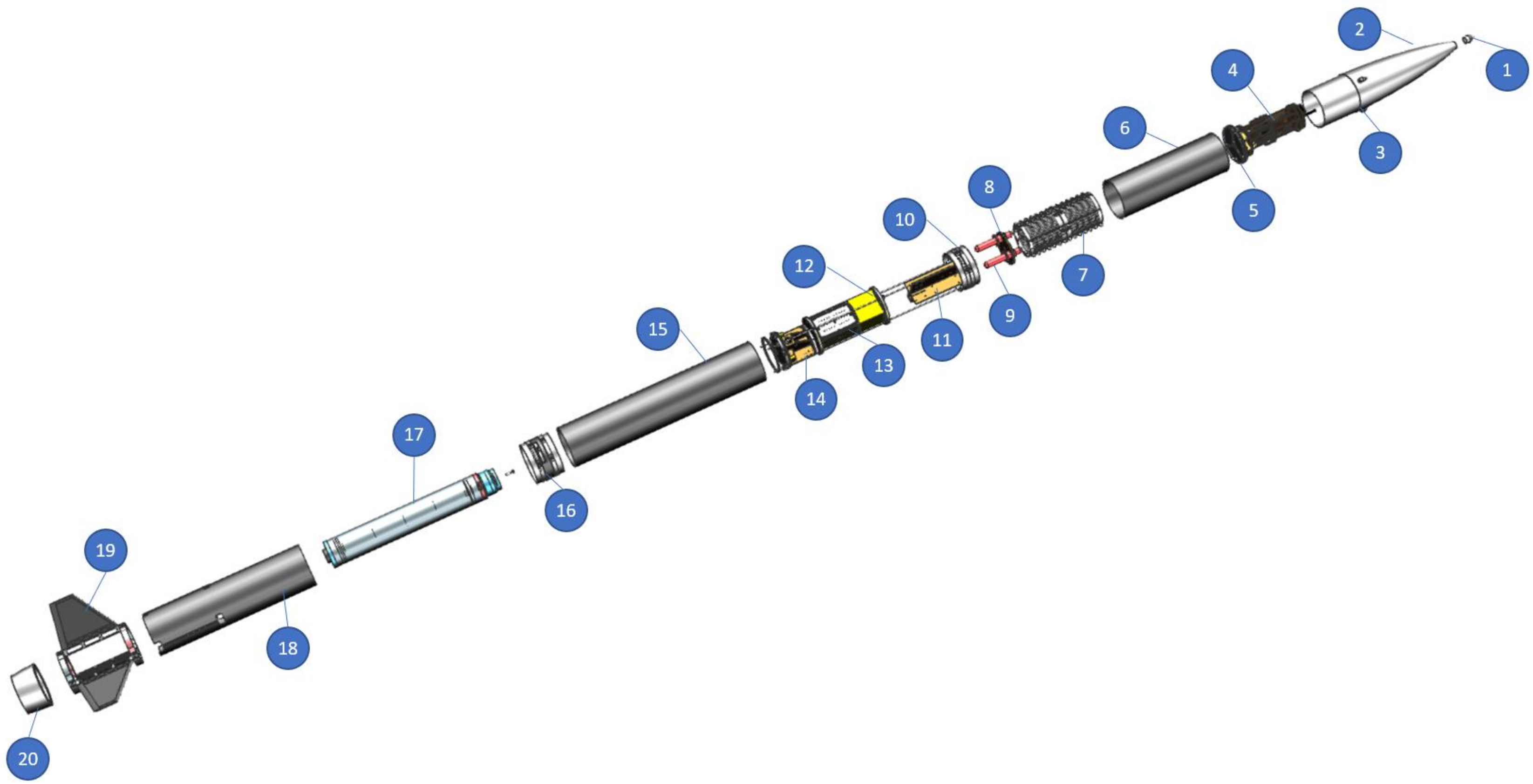

Figure 5. TELL main components

1) Nose Cone Tip	6) Nose Cone Tube	11) Recovery Electronic Bay	16) Control / Air Brakes Section
2) Nose Cone Shell	7) Recovery Parachute Tube	12) Boiler Plate Payload	17) Motor – COTS M2400
3) Bulges	8) Reoccvery Ground Plate	13) Scientific HSLU Payload	18) Lower Fairing
4) Nose Cone Avionics	9) Raptor – CO2 Cartriddges	14) Lower Avionics	19) Fin Assembly
5) Nose Cone Bulkhead	10) Rec. Bulkhead / Field Joints	15) Upper Fairing	20) Boat Tail

C. Propulsion Subsystem

At first, the use of a student researched and developed (SRAD) solid propellant motor was planned. Since it was logistically unfeasible to transport a SRAD propellant to the USA, the first iteration lead to a SRAD housing and commercial off the shelf (COTS) propellant system. As test launches in Switzerland follow Tripoli rules and the included insurance does not cover modified motors, this design was rejected. Unable to perform a full scale test in Switzerland, the decision was made to switch to a full COTS motor. The calculation of the required thrust can be found in the appendix 0.

The most relevant requirements for the motor are:

1) The motor should be capable to deliver at least 7700 Ns of total impulse
2) The motor should deliver a minimum average thrust of 2300 N
3) The motor should be operable between 0-60 °C after thermal equilibration
4) The length of the motor should not exceed 751mm

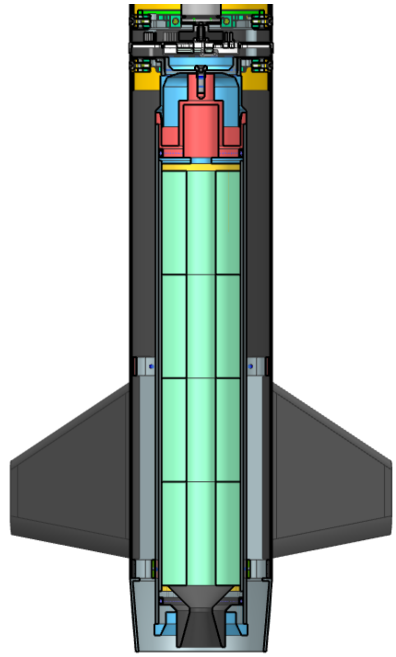

Figure 6. Structural Integration of the M2400

The motor type M2400 from AeroTech was chosen. Table 2 lists the motor's main data. The thrust curve can be seen in the appendix **FF**.

Table 2. AeroTech M2400 Main Data

Diameter	98 mm	Burn time	3.2 s
Length	597 mm	Hardware mass	3693 g
Total Impulse	7716.5 Ns	Total mass	6451 g
Average Thrust	2400 N		

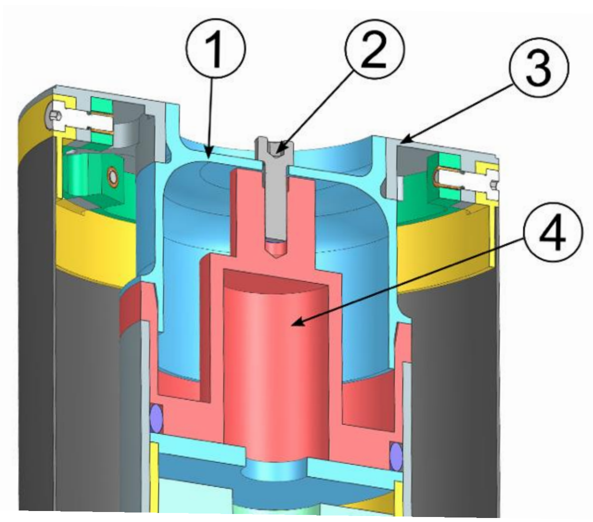

Figure 7. Motor adapter detail

The structural integration of the motor can be seen in Figure 6 and Figure 7.

The motor adapter (1) ensures the fixation to the load carrying structure and is directly threaded to the motor bulkhead (3). The centering is achieved by a cylindrical sleeve, tightly fitting to the inside of the forward (FWD) motor closure (4). While the force is entirely transmitted through the outer cylinder of the motor adapter, which directly rests on the FWD closure, motor drop out is prevented by using the 3/8 thread in the plugged closure (2). During launch, the FWD closure presses directly on the adapter shell, therefore the screw is entirely loaded on tension during flight.

The lower end of the motor is centered by an aluminium centering ring which is part of the fin clamping structure. Heat transmission is limited by heat resistant Kevlar tape between the housing and lower centering ring.

The surface temperature of the housing is monitored using a fast response Pt-100 class B (acc. To DIN EN 60751) surface temperature microsensor manufactured by 'MDW Temperatursensorik GmbH'.

D. Aero-Structures Subsystem: SRAD Nose Cone

The nose cone design and the manufacturing is entirely SRAD. It is von Karman shaped which is one of the superior shapes for transonic airspeeds, see Figure 8.

As the communication avionics are integrated in the nosecone, its material has to be permeable for the GPS and ground communication signals. To comply with these requirements the nosecone is manufactured using glass-fibre reinforced polymer prepreg (8-H satin weave). A layup of three layers of precisely cut prepreg sheets was draped with an overlap into each half-shell mold (Figure **9**). These half shells were subsequently closed, vacuum-packed and autoclaved (Figure 12). By using this method, further bonding of two single half shells was avoided.

After curing in the autoclave, the nosecone was post processed to accommodate all avionics interfaces (see Figure 13). These include the bulges, where an arming switch, a debugging interface and a camera recording the flight are situated (see Figure 13).

The nose cone tip consists of two turned aluminium parts. The ring is bonded to the nose cone shell whereas the tip can be exchanged (Figure 11).

The coupling section to the following body tube exceeds one caliber to comply with competition regulations.

Figure 14 and Figure 15 show a comparison of the CAD and the manufactured nose cone.

Figure 10. David, our Nose Cone Man

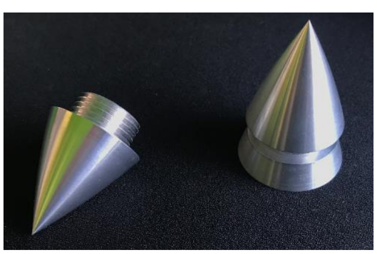

Figure 11. Nose Cone Tip

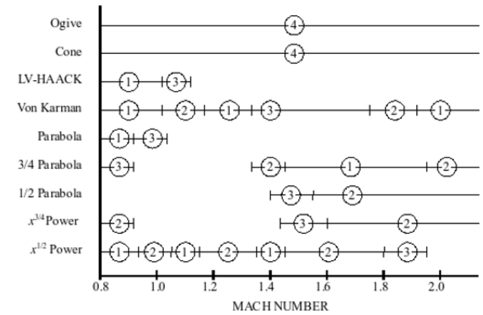

Figure 8. Comparison of drag characteristics of various nose cone shapes in the transonic to low-mach regions. Rankings are: superior (1), good (2), fair (3), inferior (4)[1]

Figure 9. GFRP prepreg sheets draped in half shell molds

Figure 12. Vacuum bagged mold is moved in the autoclave

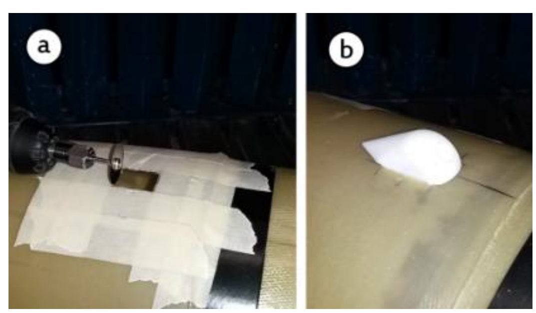

Figure 13. a) post processing; b) test fitting of arming switch bulge

[1] Source: https://upload.wikimedia.org/wikipedia/commons/a/a1/Nose_cone_drag_comparison.png

Figure 14. CAD drawing of the Nose Cone

Figure 15. Nose Cone before adding bulges

E. Aero-Structures Subsystem: SRAD Rocket Tube

The body tube is made out of carbon fiber reinforced polymer (CFRP), which gives the desired stiffness while keeping the weight low. The CFRP tubes are manufactured using a 5 end satin weave prepreg with 6 layers (0-45-0-0-45-0 degree layup). This is done using an aluminium tube as mold and curing the prepreg in the autoclave (Figure 16). The tubes are then cut with a water jet cutting machine and post-processed, adding venting holes where necessary and adding the cuts for the airbrakes (Figure 17) and the fins (Figure 18).

Figure 16. CFRP tube manufacturing

Figure 17. Air brake fairing

Figure 18. Lower Fairing with cuts for the fins

F. Aero-Structures Subsystem: Field Joints

The Field Joints are the connection between the CFRP tubes and the bulkheads where the internal parts of the rocket are fixed. They are manufactured with 7075 Aluminum.

An example of the field joint can be seen in Figure 19, Figure 20 and Figure 21: the field joint (1) is connected to the the recovery bulkhead (3) through the use of fit bolts (4), which transmit the load between the two parts. The fit bolts are kept in place by the use of a 3D printed insert ring (3) with threaded inserts. These insert rings are not subject to any vertical force.

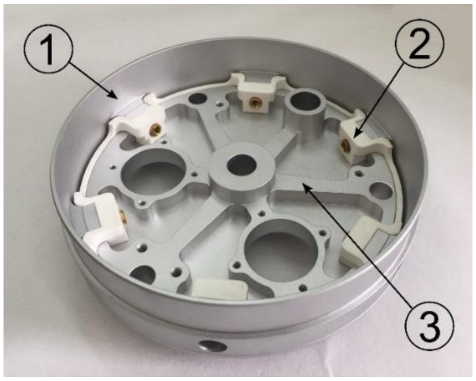

Figure 19. Field Joint attached to Recovery Bulkhead

Figure 20. Field Joint

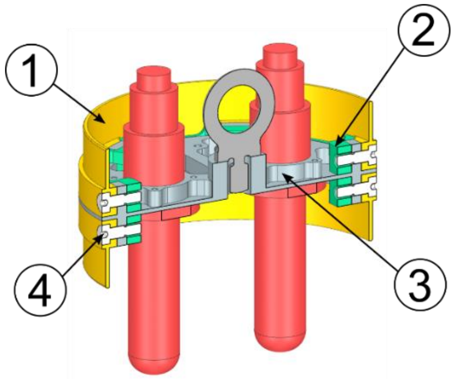

Figure 21. Clip section of connection between field joint and recovery bulkhead

The field joints are bonded to the CFRP tubes using epoxy (Araldite AV 138M-1 / Hardener HV 998-1), which has an average lap shear strength of 15 MPa for an Aluminum-CFRP bond. The bond line between the tube and the field joint is 9420 mm^2, which means the bond can sustain forces up to 140 kN, five times the maximum expected load.

Aero-Structures Subsystem: Bulkheads

The Recovery Bulkhead is the central part of the rocket. The recovery and the internal structure are directly attached to it, which means that it is the part of the rocket that is subjected to the most stress. Our lightweight design (see Figure 19 and Figure 22) will be able to withstand the load at any point of the flight.

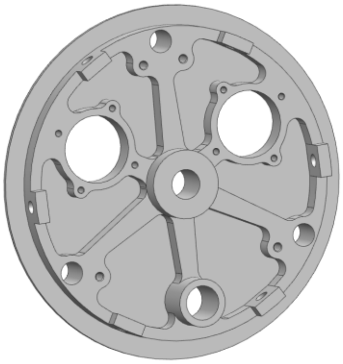

Figure 22. CAD of the Recovery Bulkhead

G. Aero-Structures Subsystem: Inner Structure

In the upper body section, an inner structure was built to hold items such as payloads. The goal of our design was to allow for the structure to be easily assembled and disassembled in the rocket and therefore provide easy access to the payload. Refer to Figure 24: The rods (1) are only attached at the top end and axially free at the lower end. Therefore the load case for launch and parachute deployment is axial tension. This is not only the favorable load for rods but ensures that the rocket hull remains as the main load carrying structure.

The decision was made to suspend the payload and the second avionics from the recovery bulkhead instead of stacking them on the air brake module to lower the load on the bonding joint. With the inner structure loads are now directly introduced to the recovery bulkhead which is directly connected to the parachute chords and can be sized adequately.

The rods are attached to the recovery bulkhead using T-shaped sleeves (2). The sleeves are bonded to the rods (for the dimensioning of the rods see appendix **GG**). These sleeves are interlocking with the bulkhead and are secured by a nut.

The payload module as well as the second avionics rest on sandwich plates (4). They are retained by clamping rings (5). The clamping rings ensure a secure axial fixation of the modules (for the dimensioning of the clamping rings see appendix HH.) This allows for a flexible module placement and therefore an adjustable CoM.

At the bottom, the rods are aligned using an additive manufactured plastic bracket which limits radial movement of the structure. As stated before, the bracket does not touch the airbrake bulkhead in the axial direction.

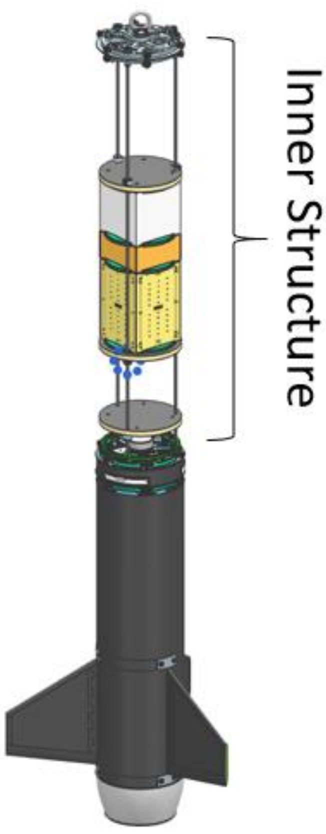

Figure 23. Inner Structure in Upper Body Section

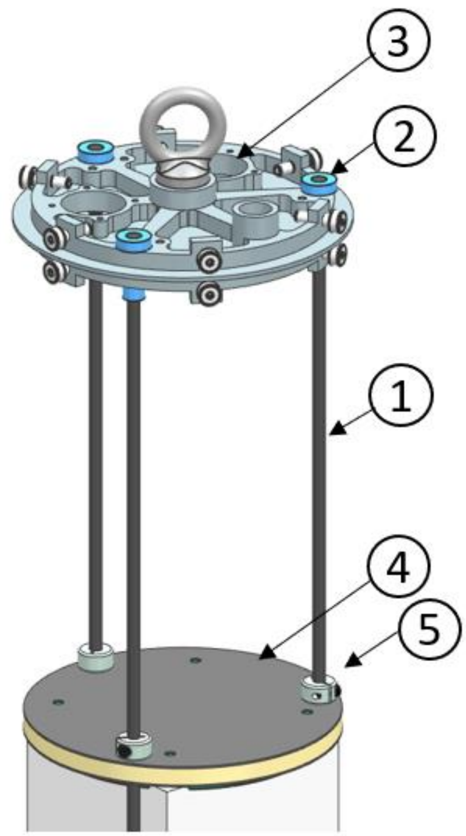

Figure 24. Components of the Inner Structure

H. Aero-Structures Subsystem: SRAD Fins

The fins are attached such that they can be exchanged. This ensures the reusability of the rocket if the aerodynamic shape has to be changed to adjust the CoP or if the fins are damaged due to touch-down. With this in mind, the team designed a clamping mechanism to expedite assembly and maintenance. The design consists of two inner rings, with the aft ring bonded to the rocket tube, and three aluminium fin-backbones (Figure 25).

Each fin consists of an aluminium backbone, an additive manufactured frame which gives the fin its aerodynamic shape and a foam core to keep the fins light weight (Figure 26). Two layers of carbon-fibre reinforced polymer prepreg (2x2 twill) are draped over the inner structure. This sandwich construction generates very stiff, yet light fins. A boat tail was added to further decrease the drag of TELL. Not only does the boat tail reduce drag but also guards the motor tube and absorbs impact engery during touch-down. In case of severe damage it can be easily exchanged.

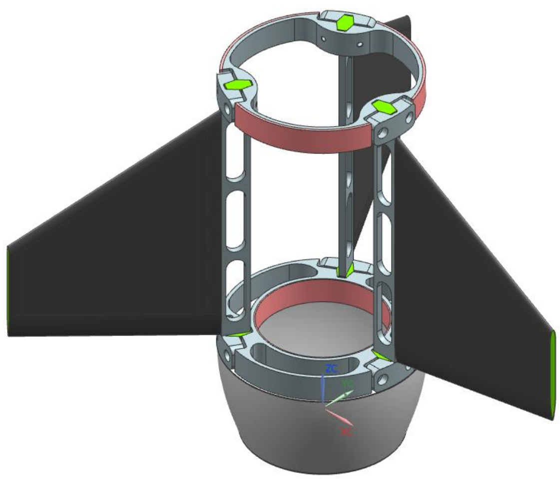

Figure 25. Fin Assembly

Figure 26. Additive manufactured frame with aluminum backbone and foam core

I. Aero-Structures Subsystem: Finite Element Method

Before the developed design was manufactured, FEM analyses were performed on all critical parts. Therefore, the critical load cases and critical parts during the flight phases were identified as:

1. Motor burn, critical parts: Upper and lower motor bulkhead with connection, buckling of the fairing
2. Main parachute deployment, critical parts: Recovery bulkhead, inner structure, field joint

The detailed analysis can be seen in appendix II.

J. Recovery Subsystem

The recovery system consists of a two event parachute ejection system:

1) As the rocket reaches the apogee, a redundant CO2 cartridge will be triggered by the redundant recovery electronics to eject the nose cone from the rocket body. Here, the drogue parachute will be released to lower the descent rate.
2) At 1500 ft AGL, a redundant release device system – the so called tender descender – will be triggered by the redundant recovery electronics to release the main parachute.

The recovery subsystem can be divided into three systems:

1) Recovery Parachute Compartment
2) Recovery Bulkhead
3) Recovery Electronics (see Figure 27).

The redundancy and connections between the electronics and the hardware can be seen in Figure 28. The system is fully redundant: each flight computer is powered by two batteries. If the main computer fails, the backup flight computer will intervene. At the apogee, the backup computer is set with a delayed timer with respect to the main computer (according to simulations), while for the second event, it is set to a lower altitude (e.g. 50 m less).

Two CO2 cartridges are built into the recovery bulkhead for redundancy, as firing only one is sufficient to separate the NC from the rocket body. If the first CO2 cartridge does not fire, the second one is triggered with 0.5 s delay. Both cartridges can be triggered by both computers.

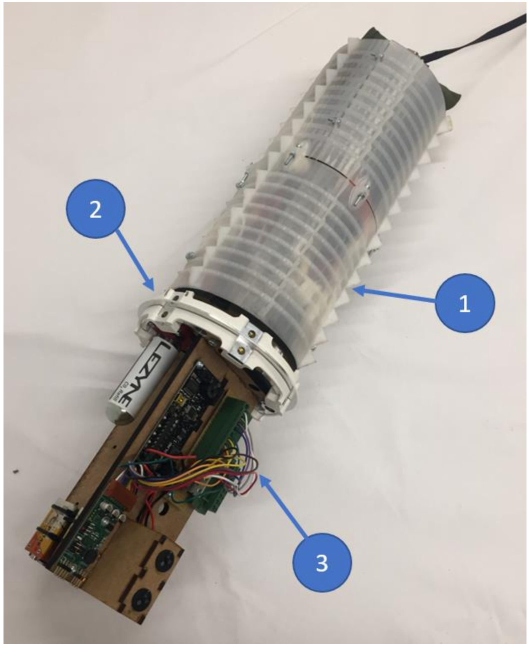

Figure 27. Recovery System

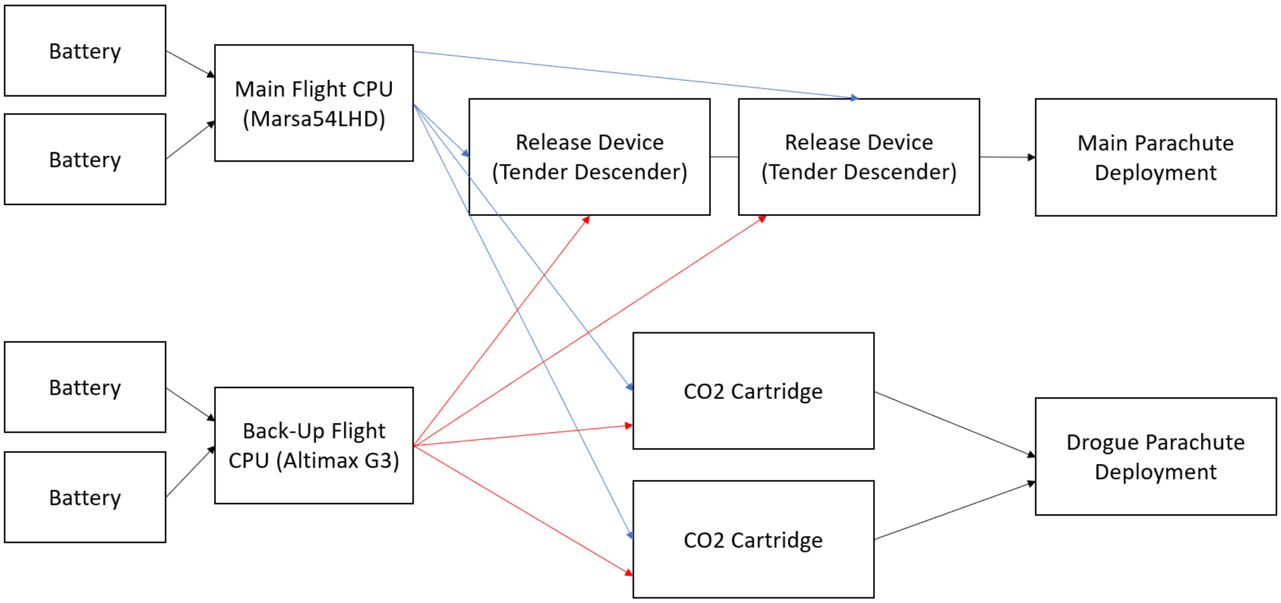

Figure 28. Connections & Back-Up of Recovery System

The connections of the links, bolts and cords in the parachute compartment can be seen in Figure 29. All parts used in the recovery system and their details are listed in Table 3.

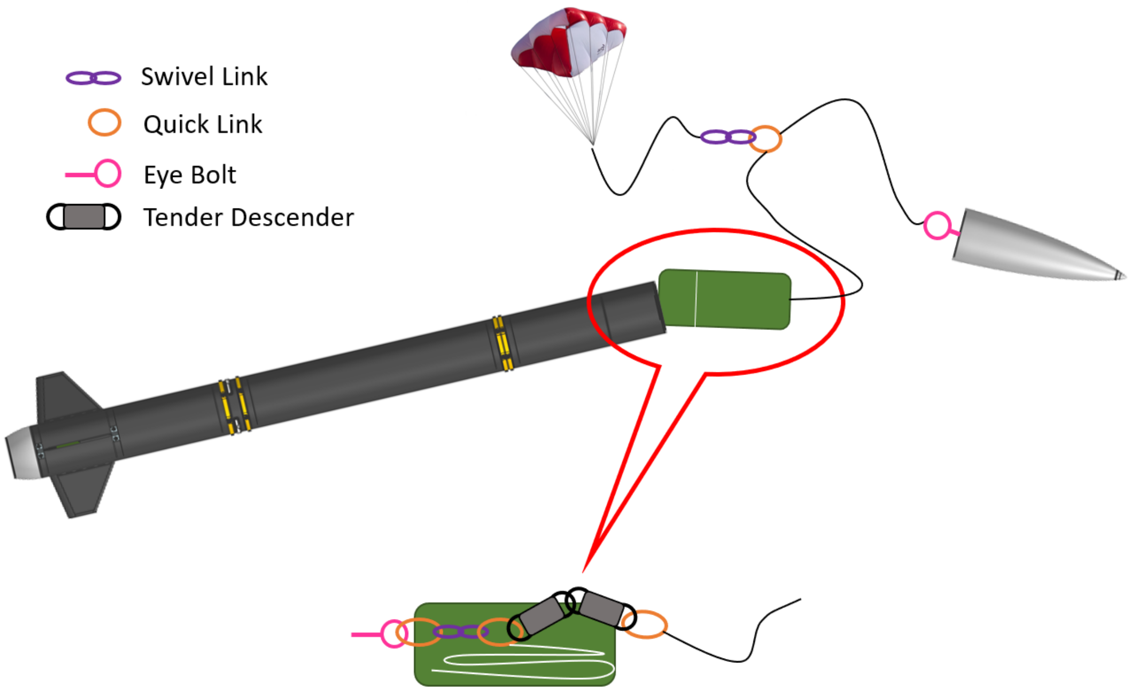

Figure 29. Cord and Link Assembly of the Parachute Compartment

Table 3. Recovery Parts List

Part	**Description**
Main parachute – IFC-96-S-OB Fruitychutes	Reduce descent rate to about 6 m/s
Drogue parachute – CFC-24 Fruitychutes	Reduce descent rate to about 30 m/s
CO2 deployment system - PCO2-RAPTOR-NC TinderRocketry	Separate nosecone for the deployment of the drogue parachute
CO2 cartridges 25g	Bottles with CO2 charge
Release device – RT-L2 Recovery Tether Fruitychutes (Tender Descender)	Holds the main parachute inside the rocket between the first event (apogee) and the second event (500 m AGL)
Main parachute deployment bag	Keeps the main parachute and its shock cord well folded
Nylon schock cord 5/8” 5 yds - SCN-625-5	Main shock cord to Kevlar harness. Tested at 8 kN
Nylon schock cord 3/8” 2 yds - SCN-375-2	Between main and pilot chute. Tested at 4.5 kN
Nylon schock cord 5/8” 5 yds - SCN-625-5	Pilot chute to nose cone. Tested at 4.5 kN
Harness 1/4" 3 ft HK-S-250	Harness between main shock cord to bulkhead. Tested at 7.6 kN
Quick links, 1/4"	Connect bulkhead to main parachute. Tested at 5.5 kN
Quick links, 1/8"	Connect deployment bag to chute, pilot chute, nosecone
Slider ring	Dampens the shock load due to the parachute opening by causing a more gradual opening
Altimax altimeter – AltimaxG3	Backup flight computer
Marsa altimeter – Marsa54LHD	Main flight computer

Detailed calculations on the dimensioning of venting holes for ensuring altimeter accuracy during flight and the dimensioning of venting holes to prevent a premature ejection of the nosecone are described in appendix **JJ**.

K. Avionics Subsytem

In addition to the recovery electronics, an avionics system is integrated into TELL with the objective to develop a reliable SRAD flight computer and telemetry module. It consists of the ground station, the lower body avionics (LB AV) and the nose cone avionics (NC AV). An overview can be seen in Figure 30.

Two GPS antenna directed into opposite directions ensure that a signal will be transmitted before and after the nose cone deployment. The ground communication ensures a connection with the ground station. Furthermore, a sensor board is integrated into the nose cone. The LB AV consists of a main PCB which includes two additional barometers. The LB AV is connected to a temperature sensor which measures the temperature of the motor, giving an on/off signal to the payload and signals to the servo motor which deploys the air brakes. Both avionics can communicate via RF using the 2.4 GHz frequency.

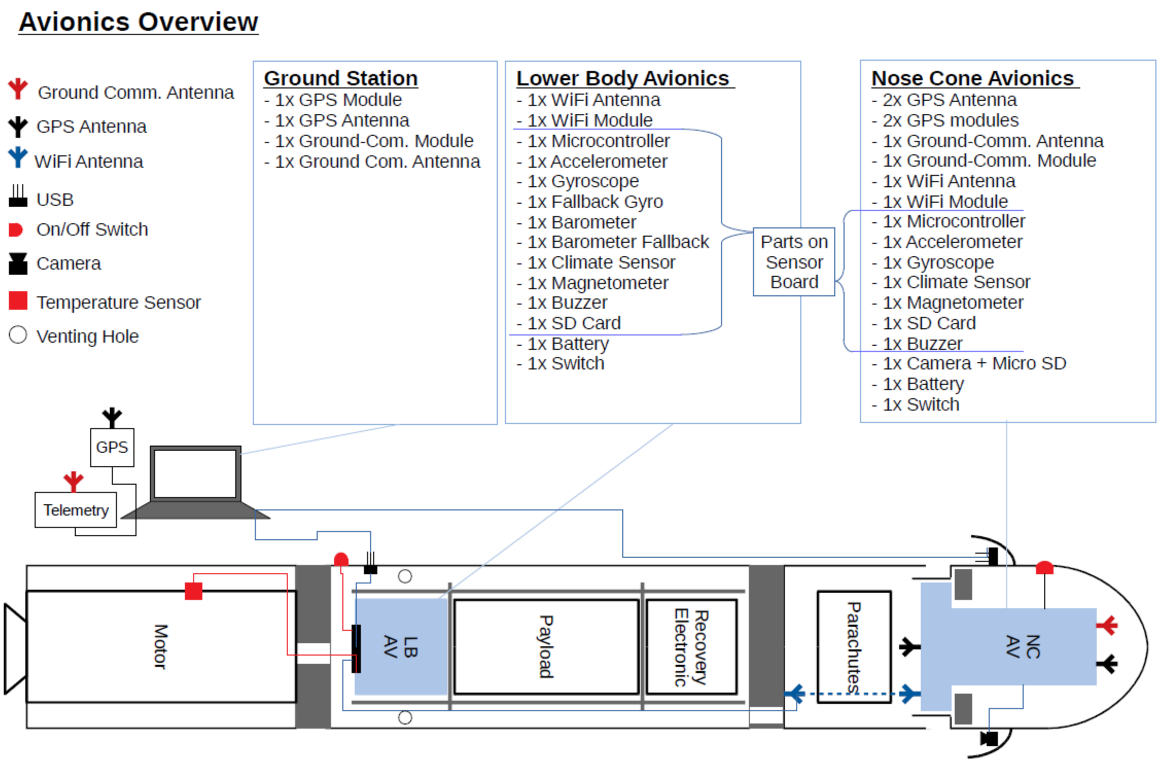

Figure 30. Avionics Overview

Telemetry Concept The telemetry frequency band is limited by regulations. Therefore, the 915 MHz (USA) and 868 MHz (Europe) band will be used. As the frequencies are different, the communication modules need to be exchanged between testing (CH) and the competition (USA). These bands provide up to 40 km transmission range in line-of-sight conditions.

Because of the complex regulations, the importance of the downlink, and the lack of a communication expert on the team, a COTS XBee module was chosen since it is compatible with both frequencies. The communication module will be placed in the NC, which is made from a non-conducting material.

GPS Concept A simple one-chip GPS module should be accurate to within 10m, which is sufficient for the final recovery. With a second GPS station on the ground, the position of the rocket can be calculated to within <1m of accuracy by differential post-processing. An online high-precision solution will be developed in the future. This modular design makes it easy to exchange the GPS module.

After apogee the NC will point towards the ground. To enable connection to the GNSS satellites, the nose cone shall be separated after apogee. A second GPS module and antenna at the bottom of the nosecone ensures that there is a GPS signal also during descent. By using two GPS modules and antennas, the possibility that both modules or antennas face the ground after landing is reduced.

A system architecture of the avoincs is given in Figure 31. A data collection overview is given in Table 4 and Table 5.

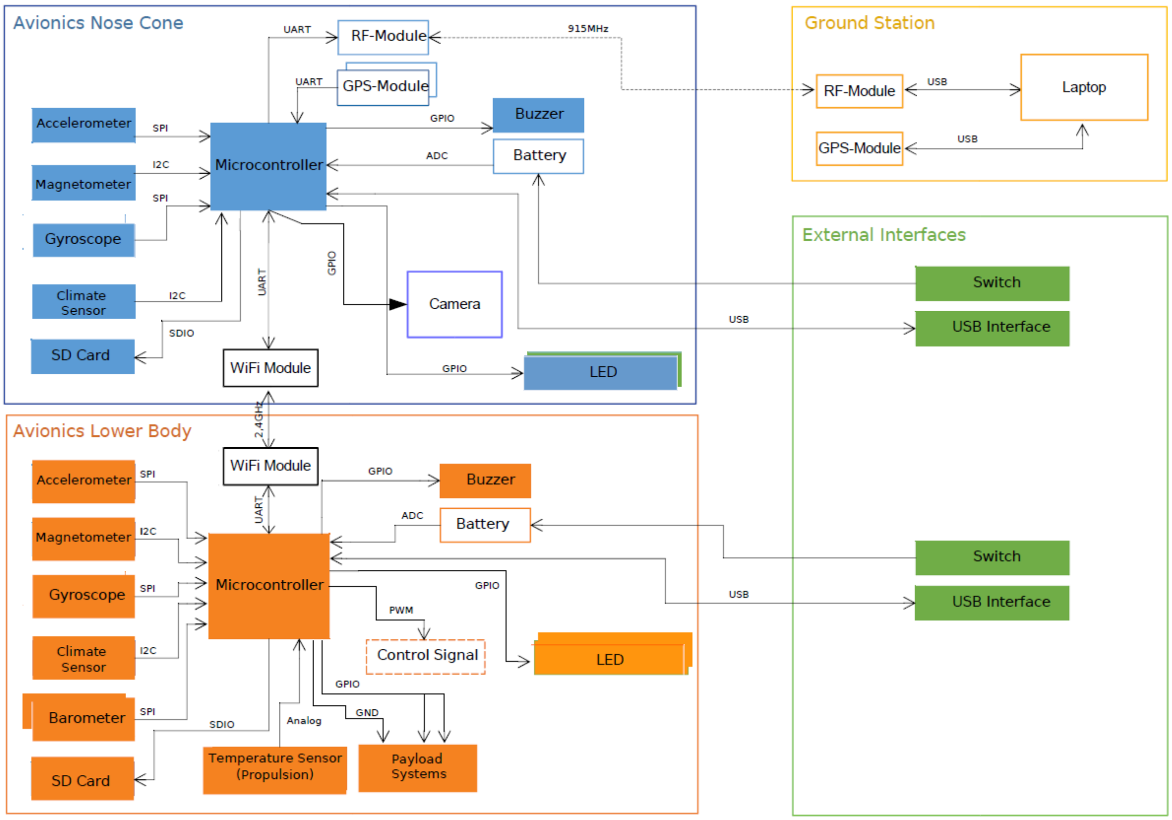

Figure 31. Avionics System Overview

Table 4. Sensors NC AV

Component	#	Data Type
GPS Module	2	Position
Magnetometer	1	Compass
Accelerometer	1	Acceleration
Gyroscope	1	Rotation
Climate Sensor	1	Temp., Humidity, Pressure

Table 5. Sensors LB AV

Component	#	Data Type
Barometer	2	Pressure
Magnetometer	1	Compass
Accelerometer	1	Acceleration
Gyroscope	1	Rotation
Climate Sensor	1	Temp., Humidity, Pressure

The Software of the Avionics shall be represented by a finite state machine (FSM). Because the software needs real time capabilities, a real time operating system (RTOS) is used. For more details on the software, refer to appendix KK.

L. Payload Subsystem: Boiler Plate Payload

The first payload consists of a 1U cubesat boiler plate payload. The payload achieves the 4kg competition requirement and can be adjusted to change the CoM. This is achieved by changing the mass of the boiler plate payload through exchangeable plates. Plates of several materials (tungsten, aluminium, plywood) are used to finely adjust the weight. The payload itself can also be shifted within the internal structure of the rocket to shift the CoM along the rocket's Z-axis.

M. Payload Subsystem: Scientific Biological Experiment

With the commercialization of space flight, flight opportunities for scientific experiments have become increasingly available and affordable. The goal of this scientific payload experiment is to build a compact, low cost microscope which allows for the filming of biological cells during a sounding rocket flight. The microscope including the optical camera, sample, controller and power supply fits into a 1.5-cubesat size unit. The microscope was built by using commercially available off-the-shelf products and rapid prototyping manufacturing techniques (3D-printing and laser cutting). This payload shows that scientific equipment can be built at low costs by using highly advanced but affordable consumer products and widely available rapid prototyping manufacturing techniques.

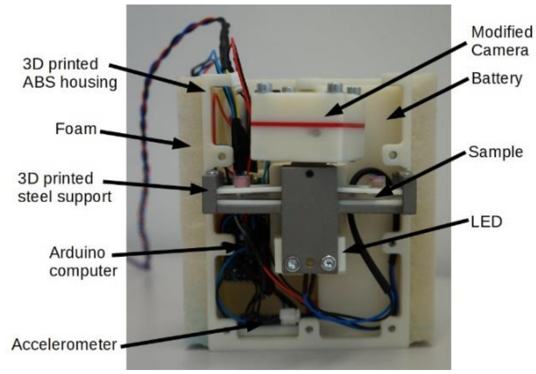

Figure 32. Opened inner housing exposing the components of the microsope

Experiment design: The microscope consists of a modified commercial camera, an LED, a support structure holding the camera, and a sample. The PCBs of the camera were enclosed in a new casing (ABS, 3D printed) and the lens was moved further away from the photo-chip in order achieve the required magnification. The support structure was 3D printed out of steel and ABS plastic.

In this experiment bovine cartilage cells (chondrocytes) were chemically fixed (denaturated) and embedded in commercial transparent slides. In order to simplify the experiment's technical and operational requirements, and to avoid legal immigration issues, non-living, fixed cells were chosen.

The camera is controlled via an Arduino computer, which also records the acceleration with two accelerometers (one on the outer and one on the inner housing). Power is provided by a Lithium-ion 5 V-battery (power-bar; consumer product).

The experiment is enclosed in a 3D printed inner housing (ABS). The housing consits of two parts which are screwed together. In addition, the inner housing is closed with a plywood lid on the top, which allows last minute access to the experiment. The experiment is finally inserted into an outer housing built from plywood, 3D printed ABS parts, screws, and epoxy glue. The outer housing follows the cubesat form factor regulations with a 100x100 mm foot print. In between the inner and outer housing, 10 mm thick polyether foam is inserted in order to dampen vibrations during launch. The technical drawing of the outer housing can be seen in appendix BB.

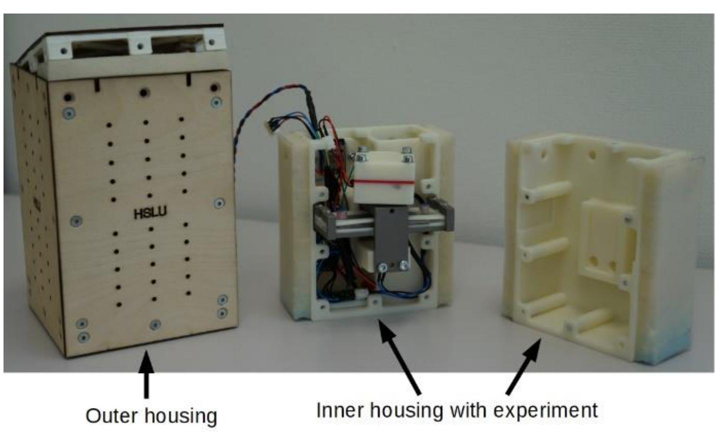

Figure 33. The two halves of the inner housing are closed and inserted into the outer housing. Foam between the inner and outer housing aims to dampen vibrations.

N. Control Subsystem

The control subsystem aims to fulfill the competition goal of accurately reaching a defined apogee altitude. This is implemented by using a slightly oversized rocket motor to implement the strategy of overshooting the target apogee and then employing air brakes to correct the trajectory.

The air brakes are a set of three control surfaces emerging from the rocket. The system is mounted above the motor into the bulkhead. The air brakes are oriented perpendicularly to the roll axis to increase drag. A servo motor receives information acquired by the sensors of the AV subsystem. The motor then moves a gear-wheel which moves three linear guides fixed to the air brake plates. More details on the air brake control system is submitted in the podium sesstion material.

Figure 34. Control System above the Motor Section

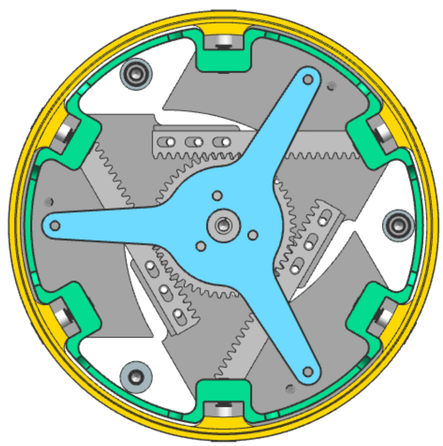

Figure 35. Air Brakes Retracted

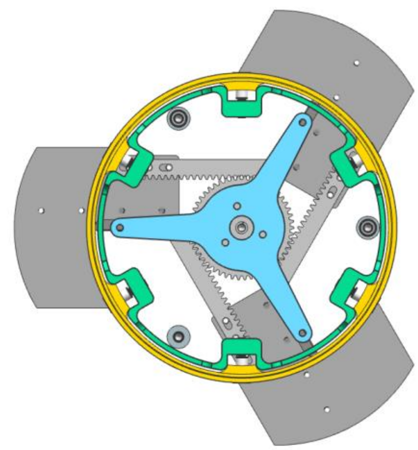

Figure 36. Air Brakes Deployed

The control software consists of four main parts:

1. **Simulation:** An optimized version of the trajectory simulator, taking into consideration launch parameters including location, weather and brake control scheme. It is used to run Monte Carlo simulations to verify the control algorithm and for the generation of the control scheme.

2. **Planning:** Using the simulation and a dynamic programming algorithm, all possible launch trajectoriesweree evaluated and a control table is generated. The control table contain optimal control values for every combination of velocity and altitude from which the target altitude can be reached. The control values are chosen such that the risk of missing the target due to deviations from the simulation is minimized. Once the risk is sufficiently minimized, the algorithm also tries to minimize brake movement during each trajectory.

3. **Online control:** This is a part of the software running on the rocket's microcontroller. The rocket's vertical position and velocity are determined independently by integrating IMU measurements as well as reading barometer values. As test flights have found a bias in the barometer readings for high velocities, the IMU will be preferred for most of the ascent phase. The control table is read out for the current position and altitude and the air brakes are extended accordingly. If the rocket falls outside the stored values, it is either too low and slow or too high and fast to reach the target altitude, and then the air brakes are either fully extended or retracted.

4. **Verification:** To assure functionality of the different software components under most circumstances, the rocket avionics are modeled within the simulator and run through different scenarios. This is done to see how the system deals with different failure cases and to verify the probability of missing the target apogee.

III. Mission Concept of Operations

O. Concept of Operations: Macro

For the days and weeks before and after the launch (t=0) a macro concept of operations was created.

Before the launch, preparations are done (write and test checklists, exercise assembly, shipping and transport to the US, final assembly and briefing).

After the launch, the focus lies on data recovery and post-processing to ensure upcoming projects have a strong base to start from.

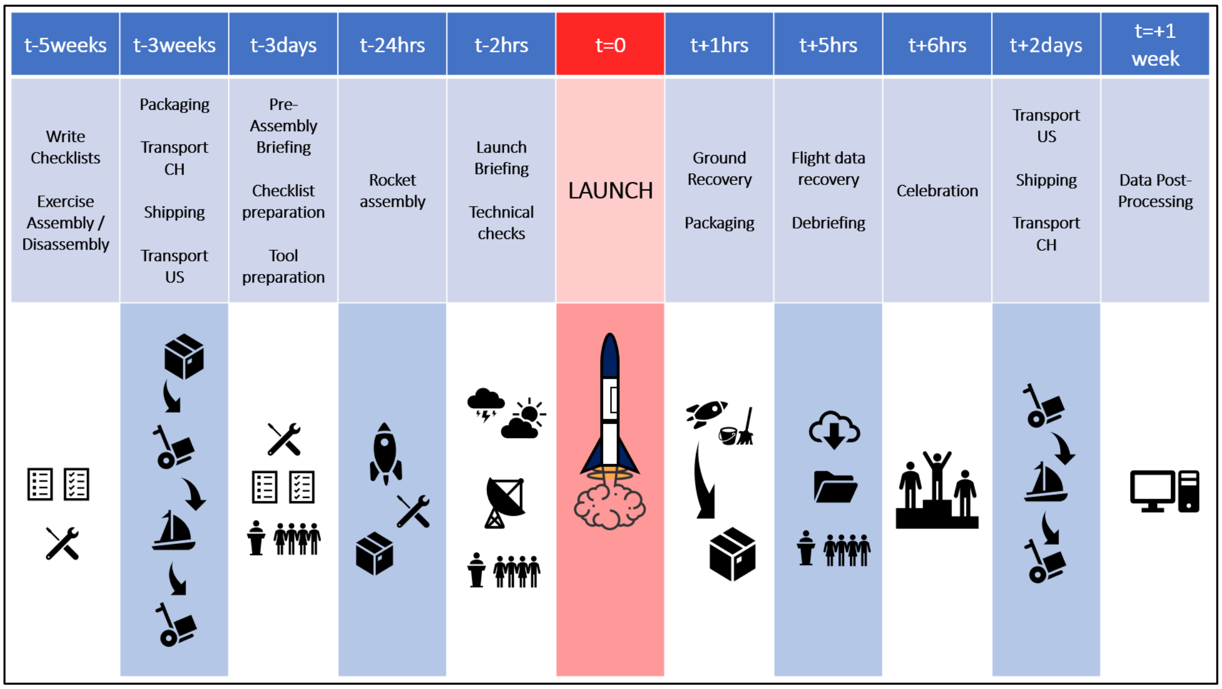

Figure 37. Macro CONOPS

P. Mission Events & Phase Transitions

The CONOPS is presented in Figure 38. The phases and their transistions are described below:

-1: ARMING PHASE Recovery Electronics is armed from the outside of the rocket with a slotted screwdriver on the launch pad. This phase ends as soon as the right sound is heard.

0: THRUST PHASE This phase starts with the ignition and ends with the motor burn out.

1: COAST PHASE After the burn out, the coast phase goes on until the apogee is reached. During this phase, the air brakes will be deployed and retracted to assure the targeted apogee will be reached precisely.

2: RECOVERY PHASE This phase starts as soon as the apogee is reached and ends with the touch down of the rocket and the ground recover of the system.. During this phase, the drogue parachute will be released by deploying the nose cone and will lead to a stabilized descent before the main parachute is released at 1500ft AGL.

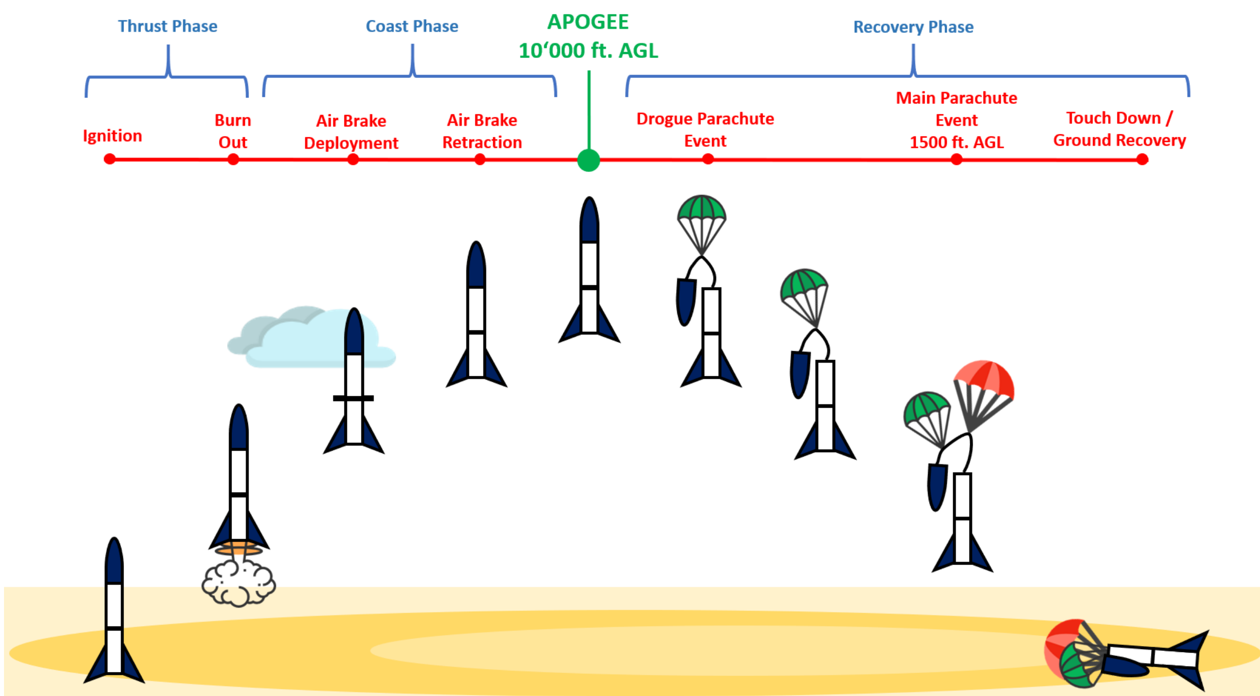

Figure 38. Launch Phases

IV. Conclusion

Project TELL is the inaugural project of the very young association ARIS founded by students of ETH Zurich and HSLU. Inspired by the story of Willhem Tell's courage in founding Switzerland, the team aims to pave the way for students to promote Swiss engineering excellence on a global stage. To do so, the 2.4 m long sounding rocket TELL 1 was built within 7 ½ months to compete at the Spaceport America Cup 2018. TELL consists of a SRAD composite and aluminium light weight structure and carries a biologic experiment to 10'000 ft with a COTS solid motor. Besides its two-stage recovery, TELL has a telemetry system in the nosecone and a control module in the lower body that are linked by WiFi. To reach the 10'000 ft as accurately as possible, actively controlled airbrakes are deployed after burnout.

Project TELL is a pioneering mission to establish ARIS as an association with a sound partner and infrastructure network as well as to create a knowledge base on rocket science. Morevoer, it was TELLs objective to include as many SRAD systems as possible in its first rocket. These ambitious goals resulted in many organizational, personnel and technical challenges and a steep learning curve. Several objectives, such as a test launch before the competition, have not yet been met. Most of all, as the project progressed, it became clear that the project cycle should start earlier to ensure design reviews also happen earlier. This would ensure enough time for long lead times of specialized parts and would enable critical tests to happen early enough. Moreover, reducing the core team to 20-30 people and enforcing physical presence are changes that need to happen to become more effective and efficient as a team. ARIS decided to devise a clear strategy to transfer this lesson learned as well as many others to the future team.

Looking back, we can see that many milestones were reached with TELL and more achievemnts will follow in the future! A rocket has been built, an organization is being established and a supportive long-term partner network enables us to announce the kick-off the follow-up project for next year. Given this, team TELL is thrilled to meet the final challenge, the Spaceport America Cup.

We are most thankful to all our partners that share with us the inspiration, passion and engagement for this interdisciplinary, intercultural initiative!

Academic Partners:

Industry Partners:

Special thanks to

Flora Keller
Werner Steiger Stiftung

Prof. Dr. Lino Guzzella,
Prof. Dr. Sarah Springman

Appendix

C. System Weights, Measures and Performance Data Appendix: Third/Final Progress Update Report

Spaceport America Cup

Intercollegiate Rocket Engineering Competition

Entry Form & Progress Update

Color Key — SRAD = Student Researched and Designed — v18.1

Must be completed accurately at all time. These fields mostly pertain to team identifying information and the highest-level technical information.

Should always be completed "to the team's best knowledge" , but is expected to vary with increasing accuracy / fidelity throughout the project.

May not be known until later in the project but should be completed ASAP, and must be completed accurately in the final progress report.

Date Submitted: 25.05.2018

Team ID: 100 — * You will receive your Team ID after you submit your 1st project entry form.

Country: Switzerland

State or Province: n/a — State or Province is for US and Canada

Team Information

Rocket/Project Name:	TELL
Student Organization Name	ARIS
College or University Name:	Eidgenössische Technische Hochschule Zürich (ETH)
Preferred Informal Name:	ETH
Organization Type:	Club/Group
Project Start Date	14.10.2017 — *Projects are not limited on how many years they take*
Category:	10k – COTS – All Propulsion Types

Member	Name	Email	Phone
Student Lead	Oliver Kirchhoff	kioliver@student.ethz.ch	41792872481
Alt. Student Lead	Anna Kiener	anna.kiener@stud.hslu.ch	41799159692
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Alt. Faculty Adviser	Prof. Dr. Székely Gerhard	gerhardstefan.szekely@hslu.ch	41413493242

For Mailing Awards:

Payable To:	ARIS Akademische Raumfahrt Initiative Schweiz
Address Line 1:	Oliver Kirchhoff
Address Line 2:	PFA K25
Address Line 3:	Technopark Strasse 1
Address Line 4:	CH-8005 Zürich
Address Line 5:	Switzerland

Demographic Data

This is all members working with your project including those not attending the event. This will help ESRA and Spaceport America promote the event and get more sponsorships and grants to help the teams and improve the event.

Number of team members

High School	0	Male	38
Undergrad	20	Female	9
Masters	27	Veterans	0
PhD	0	NAR or Tripoli	1

Just a reminder the you are not required to have a NAR, Tripoli member on your team. If your country has an equivelant organization to NAR or Tripoli, you can cant them in the NAR or Tripoli box. CAR from Canada is an example.

STEM Outreach Events

Several bachelor and semester thesis will be written in collaboration with the building of the TELL rocket. Following the title of the thesis:

"Multisensor Acquisition System for Educational and Competition Rockets"
"Numerical Simulation of the combustion process of a Paraffin based Hybrid Motor"
"Sensor Fusion for a Sounding Rocket"
"ARIS - Position Determination via GPS for a Sounding Rocket"
"Mechanical Integration of the Avionics in a Sounding Rocket"

Furthermore, a collaboration with the research competence center of bioscience and medical engineering from the university lucerne was established for the payload development.

Rocket Information

Overall rocket parameters:

	Measurement	Additional Comments (Optional)
Airframe Length (inches):	95,24	
Airframe Diameter (inches):	5,9	
Fin-span (inches):	6,3	
Vehicle weight (pounds):	32,32	
Propellent weight (pounds):	8,14	Retrieved from: http://www.thrustcurve.org/simfilesearch.jsp?id=989
Payload weight (pounds):	12,81	
Liftoff weight (pounds):	53,27	
Number of stages:	1	
Strap-on Booster Cluster:	No	
Propulsion Type:	Solid	
Propulsion Manufacturer:	Commercial	
Kinetic Energy Dart:	No	

Propulsion Systems: (Stage: Manufacturer, Motor, Letter Class, Total Impulse)

1st Stage: Aerotech, M2400T, P Class, 7716.5 Ns

Total Impulse of all Motors: 7716,5 (Ns)

Predicted Flight Data and Analysis

The following stats should be calculated using rocket trajectory software or by hand.

Pro Tip: Reference the Barrowman Equations, know what they are, and know how to use them.

	Measurement	Additional Comments (Optional)
Launch Rail:	ESRA Provide Rail	Rail from http://www.rocketryphotography.com/
Rail Length (feet):	17	
Liftoff Thrust-Weight Ratio:	45,86	N/lbs - RockSim + MatLab Simulation
Launch Rail Departure Velocity (feet/second):	101,14	RockSim + MatLab Simulation
Minimum Static Margin During Boost:	1,76	*Between rail departure and burnout
Maximum Acceleration (G):	11,87	RockSim + MatLab Simulation
Maximum Velocity (feet/second):	1023,89	RockSim + MatLab Simulation
Target Apogee (feet AGL):	10K	
Predicted Apogee (feet AGL):	11242,65	RockSim + MatLab Simulation - Use of Air Brakes*

Payload Information

Payload Description:

The rocket carries two payloads:

1) a 1U cubesat boiler plate payload. It is used not only to achieve the 4kg competition requirement but more over to adjust the whole weight and the center of mass of the rocket if needed. This is achieved by changing the mass of the boiler plate payload with exchangeable plates. Plates of several materials (tungsten, aluminium, plywood) are used to fine adjust the weight. The payload itself can further more be shifted within the internal structure of the rocket to shift the center of mass along the rockets Z-axis.

2) 1,5U cubesat scientific experiment. The goal of this scientific payload experiment is to build a compact, low cost microscope which allows to visualize biological cells during a sounding rocket flight. The microscope including the optical camera, sample, controller and power supply fits into a 1.5-cubesat size unit. The microscope was built by using commercially available off the shelf products and rapid prototyping manufacturing techniques (3D-printing and laser cutting). This payload shows that scientific equipment can be built at low costs by using highly advanced but affordable consumer products and widely available rapid prototyping manufacturing techniques.

Recovery Information

The recovery system consists of a two event parachute ejection system:
1) As the rocket reaches the apogee, a redundant CO2 cartridge will be triggered by the redundant recovery electronics to eject the nose cone from the rocket body. Here, the drogue parachute will be released to lower the descent rate.
2) At 1500ft. AGL, a redundant release device system – the so called tender descender – will be triggered by the redundant recovery electronics to release the main parachute.
Used parts are mostly COTS: Drogue Parachute - Elliptical 24" Parachute from Fruity chutes / Main Parachute - Iris 96" Compact Parachute from Fruity chutes / Flight Computer (Main) - Altimax altimeter from Rocketronics / Flight Computer (Backup) - Marsa54LHD from Marsa Systems / Release Device - L2 Recovery Tether from Fruity Chutes or Servo Release System from Spacetec (Tender Descender) / Deployment system (2x) - Peregrine Raptor CO2 System from Tinder Rocketry / Shock Cords - Nylon shock cords from Fruity chutes. At the apogee, the deployment system will cause the separation of the nose cone and the lower body and the ejection of the drogue parachute. Because of the length of the cords, the main parachute will be held together in the deployment bag inside the rocket. At the second deployment event, the release device will disconnect the cord from the bulkhead, thereby pulling the main parachute out of its bag. The system will be redundant: each computer flight is supplied by two batteries. The main computer will detect the apogee by the accelerometer signal and trigger the CO2 cartridges with 0.5 s delays. The second cartridge is used for redundancy. The backup computer will fire the two cartridges through a timer that will be set according to results of simulations. During the descent, the altimeter of the main computer will detect the altitude. When the preset altitude is reached, two igniters will activate the release device, thereby deploying the main parachute. The backup computer will be set to an altitude 50 m lower to ensure the deployment if the main computer fails. Several ground tests were performed to ensure that the components work properly (e.g. signals from computer flights, triggering of the CO2 cartridge, separation of the rocket, deployment of the drogue parachute, etc.).

Planned Tests

* Please keep brief

Date	Type	Description	Status	Comments
11.18.17	In-Flight	Model Rocket Kits (lvl01)	Successful	Certification Rocket
2.24.18	In-Flight	Model Rocket Kits (lvl01)	Successful	Electronics Test
2.24.18	In-Flight	Model Rocket Kits (lvl01)	Successful	Certification and electronics test
3.24.18	In-Flight	Model Rocket Kits (lvl01)	Successful	Certification and electronics test
3.24.18	In-Flight	Model Rocket Kits (lvl02)	Successful	Recovery System Test
4.28.18	In-Flight	Final Rocket Test Flight	Major Issues	Test launch cancelled due to delivery delay
4.9.18	Ground	ition Rocket Assembly+Disassbembly / Check	Successful	No major or minor Issues
4.9.18	Ground	bsystem Assembly+Disassbembly / Check List T	Successful	No major or minor Issues
4.9.18	Ground	Mass weighing / Weight Test	Successful	Check all estimated masses
5.5.18	Ground	Wind Tunnel Test	Successful	Post-Processing of Data TBD
4.21.18	Ground	Static Firing Test	Successful	Post-Processing of Data TBD
5.12.18	Ground	Recovery Ground Test	Successful	
4.14.18	Ground	Avionics Software Test	TBD	Post-Poned due to lead times
4.14.18	Ground	GPS Test	TBD	Post-Poned due to lead times
4.14.18	Ground	Avionics Lifetime Test	TBD	Post-Poned due to lead times
4.14.18	Ground	Barometer Calibration	TBD	Post-Poned due to lead times
4.23.18	Ground	Shaker Test for Avionics	Major Issues	Test cancelled due to delivery delay
4.9.18	Ground	Air Brakes System Test	Successful	
5.24.18	Ground	Recovery Ground Test	Successful	

Any other pertinent information:

*The team implements a altitude control system: Three air brakes deploying after motor burn out to adjust the apogee.

End of File

D. System Weights, Measures and Performance Data Appendix: Power and Budget Avionics Subsystem

Avionics Budgets

Project TELL

Doc. Reference	TELL_GR06_AVBudgets_02
Author	Raphael Schnider
Date	25-May-2018

Note

Document Change History

Rev. Number	Change Description
Rev. 01	Initial Creation
Rev. 02	Update Power Budget

Abstract

This documet presents the calculations of the power budget and the data budget of the Avionics. The main results are the following:

- The nose cone Avionics consume more energy, about 16 Wh in case of 4 hours on the launchpad
- A 3S 2200 mAh battery is sufficient to power the rocket for 4 hours on the launchpad, even if one cell fails
- During the launch, about 350 kbit/s of data need to be logged per board. In total about 35 MB of data need to be logged per board
- A data throughput to the ground station of about 14 kbit/s is desired. Tests need to be conducted to see if that rate can be achieved
- A data throughput for the intra-rocket communication of about 115 kbit/s is desired. Tests need to be conducted to see if that rate can be achieved

Contents

1 Introduction

The purpose of this document is to show the results of calculations made for power and data of the Avionics. The results are needed to make reasonable choices for the batteries and flash storage. It also shows how much data should be transmitted. If the testing shows that these data rates can not be achieved, the data to be transmitted needs to be reevaluated and priorities must be set.

2 Methodology

2.1 Power Budget

The values for the power consumption were taken from datasheets, as far as available. Some standby currents were not declared in datasheets, they are neglected in the power budget. Once the system is built, these standby currents could be measured and the data budet updated accordingly.
5V supply voltage was assumed for every component. That is, because even if a component only uses only 3.3V supply voltage, the energy consumed by this component will be effectively the same as if it would use 5V, because of the linear voltage regulator that is used to convert 5V to 3.3V.

2.2 Data Budget

The size of data values was taken from datasheets. The sampling rates in the different states are defined in the Software System Specification document [1]. The following time durations were assumed: 4 hours on the launch pad, 10 minutes flight, 1 hour after the flight until recovery.

3 Results

In this section the power budget and data budget are presented

3.1 Power Budget

					Time passed in idle (or off) mode		Time passed at nominal		Time passed at max consumption				
Component	#	Power (idle) [W]	Power (nominal) [W]	Power (max) [W]	Percent of total time (see*) [%]	[min]	Percent of total time (see*) [%]	[min]	Percent of total time (see*) [%]	[min]	Mean power consumpti	Total charge consumed [mAh]	Total energy consumed [mWh]
Microcontroller	1	0,15	0,5	1,25	0	0	100	240	0	0	0,5	180,1801802	2000
Accelerometer	1	0,000105	0,001	0,025	0	0	100	240	0	0	0,001	0,36036036	4
Gyroscope	1	0,00004	0,0165	0,018	0	0	100	240	0	0	0,0165	5,945945946	66
Magnetometer	1	0,000005	0,004285	0,00862	0	0	100	240	0	0	0,004285	1,544144144	17,14
GNSS	2	0	0,16	0,335	0	0	100	240	0	0	0,32	115,3153153	1280
RFmodule (rocket-to-ground)	1	0,0000125	0,2	4,5	0	0	83,75	201	16,25	39	0,89875	323,8738739	3595
WIFI module	1	0,0000075	0,225	0,6	0	0	83,75	201	16,25	39	0,2859375	103,0405405	1143,75
Temperature/Humidity/Pressure	1	0,0000005	0,000018	1,8E-05	0	0	100	240	0	0	0,000018	0,006486486	0,072
Camera	1	0	1,8	2,5	0	0	100	240	0	0	1,8	648,6486486	7200
LED's	0	0	0,1	0,1	0	0	100	240	0	0	0	0	0
External Oscillator	1	0,000075	0,03	0,085	0	0	100	240	0	0	0,03	10,81081081	120
RS232	8	0,0015	0,0015	0,005	0	0	100	240	0	0	0,012	4,324324324	48
Buzzer	1	0	0,045	0,045	0	0	100	240	0	0	0,045	16,21621622	180
Totals:		0,1517455	3,083303	9,47164							3,9134905	1410,206847	15053,962

Figure 1: Power Budget Nose Cone

					Time passed in idle (or off) mode		Time passed at nominal		Time passed at max consumption				
Component	#	Power (idle) [W]	Power (nominal) [W]	Power (max) [W]	Percent of total time (see*) [%]	[min]	Percent of total time (see*) [%]	[min]	Percent of total time (see*) [%]	[min]	Mean power consumptio n [W]	Total charge consumed [mAh]	Total energy consumed [mWh]
Microcontroller	1	0,15	0,5	1,25	0	0	100	240	0	0	0,5	108,1081081	2000
Accelerometer	1	0,000105	0,001	0,025	0	0	100	240	0	0	0,001	0,216216216	4
Gyroscope	1	0,00004	0,0165	0,018	0	0	100	240	0	0	0,0165	3,567567568	66
Magnetometer	1	0,000005	0,004285	0,00862	0	0	100	240	0	0	0,004285	0,926486487	17,14
Barometer (absolute)	1	1,15E-05	0,0032	0,004	0	0	100	240	0	0	0,0032	0,691891892	12,8
Barometer (absolute) Fallback	1	0,000005	0,00006	0,006	0	0	100	240	0	0	0,00006	0,012972973	0,24
Temperature/Humidity/Pressure	1	5E-07	0,000018	1,8E-05	0	0	100	240	0	0	0,000018	0,003891892	0,072
LED's	4	0	0,1	0,1	0	0	100	240	0	0	0,4	86,48648649	1600
External Oscillator	1	0,000075	0,03	0,085	0	0	100	240	0	0	0,03	6,486486486	120
WIFI module	1	7,5E-06	0,6	0,6	0	0	100	240	0	0	0,6	129,7297297	2400
RS232	2	0,0015	0,0015	0,005	0	0	100	240	0	0	0,003	0,648648649	12
Temperature (Motor)	1	0	0	0	0	0	100	240	0	0	0	0	0
CON Motor	1	0	0	36	0	0	99,8611111	239,7	0,1388889	0,3333	0,05	10,81081081	200
Buzzer	1	0	0,045	0,045	0	0	100	240	0	0	0,045	9,72972973	180
Totals:		0,15175	1,301563	38,1466							1,653063	357,419027	6612,252

Figure 2: Power Budget Lower Body

3.2 Data Budget

Component	No/type	Nb	Data size of a significant value (incl. header) [bit]	Nb of measurements needed per seconds [Hz]			Data rate [kbit/s]			Communication interface
				Before launch (on launch pad)	During launch	After hitting the ground	Before launch (on launch pad)	During launch	After hitting the ground	
GNSS (raw data)	neo-m8t	2	1650	0.033333333	10	0.033333333	0.11	33.00	0.11	SPI/I2C
GNSS	neo-m8t	2	64	0.033333333	10	0.033333333	0.00	1.28	0.00	SPI/I2C
Accelerometer	adxl357	1	60	100	1000	0.033333333	6.00	60.00	0.00	I2C/SPI
Gyroscope	ITG-3701	1	48	0.033333333	1000	0.033333333	0.00	48.00	0.00	I2C/SPI
Temperature Sensor	BME280	1	32	0.033333333	10	0.033333333	0.00	0.32	0.00	SPI/I2C
Humidity Sensor	BME280	1	16	0.033333333	10	0.033333333	0.00	0.16	0.00	SPI/I2C
Pressure Sensor	BME280	1	32	0.033333333	100	0.033333333	0.00	3.20	0.00	SPI/I2C
Magnetometer	MMC5883MA	1	16	0.033333333	100	0.033333333	0.00	1.60	0.00	I2C
Batteries voltage measurement		1	14	0.033333333	10	0.033333333	0.00	0.14	0.00	ADC
Position	Processed data	1	96	0	1000	0	0.00	96.00	0.00	-
Rotation	Processed data	1	128	0	100	0	0.00	12.80	0.00	-
Velocity	Processed data	1	96	0	1000	0	0.00	96.00	0.00	-
							6.12	147.70	0.12	

Figure 3: Data Budget Nose Cone

Data logging on flash:						
Logged data:						
Data type	Data rate (reported from above) [kbit/s]					
	Before launch (on	During launch	After landing			
GNSS (raw data)	0.11	33.00	0.11			
GNSS	0.00	1.28	0.00			
Accelerometer	6.00	60.00	0.00			
Gyroscope	0.00	48.00	0.00			
Humidity Sensor	0.00	0.16	0.00			
Temperature Sensor	0.00	0.32	0.00			
Pressure Sensor	0.00	3.20	0.00			
Magnetometer	0.00	1.60	0.00			
Batteries voltage measurement	0.00	0.14	0.00			
Position	0.00	96.00	0.00			
Rotation	0.00	12.80	0.00			
Velocity	0.00	96.00	0.00			
Total:	**6.12**	**352.50**	**0.12**			
Sizing of the flash memory:						
Time [min]	On launch pad	Of flight	After flight			
	240	10	60			
Memory needed [Mbit]	**88.12**	**211.5**	**0.43752**	**Total:**	300.06	Mbit
					37.50735	MByte

Figure 4: Data Logging Nose Cone

Component	No/type	Nb	Data size of a significant value (only raw data) [bit]	Nb of measurements needed per seconds [Hz]			Data rate [kbit/s]			Communication interface
				Before launch (on launch pad)	During launch	After hitting the ground	Before launch (on launch pad)	During launch	After hitting the ground	
Abs. pressure sensor	2SMPB-02E	1	24	0.033333333	100	0.033333333	0.00	2.40	0.00	I2C/SPI
Abs. pressure sensor	LPS22HBTR	1	24	0.033333333	100	0.03333333	0.00	2.40	0.00	I2C/SPI
Accelerometer	adxl357	1	60	100	1000	0.033333333	6.00	60.00	0.00	I2C/SPI
Gyroscope	ITG-3701	1	48	0.033333333	1000	0.033333333	0.00	48.00	0.00	I2C/SPI
Temperature Sensor	BME280	1	32	0.033333333	10	0.033333333	0.00	0.32	0.00	I2C/SPI
Humidity Sensor	BME280	1	16	0.033333333	10	0.033333333	0.00	0.16	0.00	I2C/SPI
Pressure Sensor	BME280	1	32	0.033333333	100	0.033333333	0.00	3.20	0.00	I2C/SPI
Magnetometer	MMC5883MA	1	16	0.033333333	100	0.033333333	0.00	1.60	0.00	I2C
Temperature (Motor)		1	32	0.033333333	100	0.033333333	0.00	3.20	0.00	ADC
Batteries voltage measurement		1	14	0.033333333	10	0.033333333	0.00	0.14	0.00	ADC
Position	Processed data	1	96	0	1000	0	0.00	96.00	0.00	-
Rotation	Processed data	1	128	0	100	0	0.00	12.80	0.00	-
Velocity	Processed data	1	96	0	1000	0	0.00	96.00	0.00	-
							6.01	326.22	0.01	

Figure 5: Data Budget Lower Body

Data logging on flash:						
Logged data:						
Data type	Data rate (reported from above) [kbit/s]					
	Before launch (on	During launch	After landing			
Abs. pressure sensor	0.00	2.40	0.00			
Accelerometer	6.00	60.00	0.00			
Gyroscope	0.00	48.00	0.00			
Temperature	0.00	0.32	0.00			
Humidity Sensor	0.00	0.16	0.00			
Pressure Sensor (Bosch)	0.00	3.20	0.00			
Magnetometer	0.00	1.60	0.00			
Temperature (Motor)	0.00	3.20	0.00			
Batteries voltage measurement	0.00	0.14	0.00			
Position	0.00	96.00	0.00			
Rotation	0.00	12.80	0.00			
Velocity	0.00	96.00	0.00			
Total:	**6.01**	**323.82**	**0.01**			
Sizing of the flash memory:						
Time [min]	On launch pad	Of flight	After flight			
	240	10	60			
Memory needed [Mbit]	**86.50**	**194.292**	**0.03288**	**Total:**	**280.83**	Mbit
					35.10345	Mbyte

Figure 6: Data Logging Lower Body

3.3 Communication Budget

Data transmission to ground station:			
Data type	Data rate (reported from above) [kbit/s]		Ground Transmission Rate [Hz]:
	Before launch (on	During launch	
GNSS	0.13	0.13	1
Accelerometer (NC & LB)	12.00	12.00	100
Gyroscope (NC & LB)	0.96	0.96	10
Magnetometer (NC & LB)	0.03	0.03	1
Pressure (NC & LB)	0.88	0.88	10
Temperature (NC & LB)	0.06	0.06	1
Temperature (Motor)	0.03	0.03	1
Humidity (NC & LB)	0.03	0.03	1
Batteries voltage measurement	0.03	0.03	1
Position	0.96	0.96	5
Rotation	0.64	0.64	5
Velocity	0.48	0.48	5
Total:	**14.16**	**14.16**	

Figure 7: Ground Transmission Rate

Intra-rocket data transmission						
Data type	Data rate (reported from above) [kbit/s]		IR Transmission Rate [Hz]:		Control Sampling Rate [Hz]:	100
	Before launch (on	During launch				
Pressure	0.56	0.56	10		Transmitted to NC for ground transmission	
Temperature	0.03	0.032	1		Transmitted to LB for Control	
Temperature (Motor)	0.03	0.032	1			
Humidity	0.00	0	1			
Accelerometer	6.00	6	100			
Gyroscope	0.05	0.048	1			
Magnetometer	0.02	0.016	1			
Battery voltage measurement	0.01	0.014	1			
GNSS	0.00	0.64	10			
Accelerometer	0.00	60	1000			
Gyroscope	0.00	48	1000			
Total:	6.70	115.34	[kbit/s]			

Figure 8: Intra Rocket Transmission Rate

4 Discussion and Outlook

The results presented in this document give an impression on what to expect from the system. The power budget shows that a 3S 2200 mAh LiPo battery is sufficient to power the Avionics.
The Data budget shows the amount of data to expect. The microcontroller should be able to handle this, and the SD card should be sufficiently fast. By using a 1 GB SD Card, more then enough memory space is provided.

The communication budgets show the desired data throughput rates. If these rates can not be achieved in testing, a reevaluation of what data should be transmitted has to be made.

References

[1] TELL_GD06_SWSysSpecification_02

E. Test Reports: Recovery System Testing No. 01

aris Test Protocol

General Information

Test Information		
TestID	TELL-L-010	
Rocket/Model Name:	Mestral II	
Test Date/Time Time in UTC	24.03.18 0900-1500	
Type (Kit/Mod/Custom):	PML Ultimate Endeavour Modified	
Purpose of Test	Full recovery system test Level 2 Certification	
Test Crew	Alex Schmid (PP,Rocket), Christian Bärtschi (REC), Ferdinand Wittmann (REC)	

Configuration Control

Dimensions/Mass			
Rocket Length:	*2743 mm*	Lift-off weight:	*9840 g*
CG (rel. to top):	*1560 mm*	CP (rel. to top):	*2133 mm*
Rocket diameter:	*156 mm*	Static margin [cal.]:	*2.76*
Motor			
Motor specification:	*K540M*	Manufacturer:	*Aerotech*
Propellant:	*AP/Al (876.7 g)*	Motor Mass:	*1275 g*
Total Impulse [Ns]:	*FILL IN*	Avg. Thrust [N]:	*557.4 N*
Recovery			
Type:	*44" Drogue Chute* *96" Main Chute*	Number of Stages:	Two
Mechanism:	2 Stage Recovery, with a Drogue Ejection, by separating the nose cone from the upper airframe with Co2 and then releasing the Main parachute which is before held in the upper airframe by a release device that then opens through a black powder charge.		

Recovery Avionics	Main Altimeter: Altimax G3, nose cone separation at apogee, release device opening at 400m Redundant Avionics: Altimax Simply nose cone separation 2 sec after apogee		
Avionics			
Av inside (Yes/No):	No	Downlink:	N/A
Board:	N/A	Version:	N/A
Sensors:	N/A		
Software:	N/A		
Control System			
Con inside (Yes/No):	No	Downlink:	N/A
Board:	N/A	Version:	N/A
Sensors:	N/A		
Software:	N/A		

Environment/Facilities

Weather		
Temp: 9 degree	Wind:	Conditions: clear with some clouds
Airspace		
Cernier, CH		

Test Sequence

- Start the briefing
- Go through the checklist of Recovery
- Launch rocket
- Recover the rocket
- Do the debriefing

Limitations:

No limitations are given for the above described system aris **Test Protocol**

To be filled out during the debriefing after the launch.

Boost Phase			
Ignition successful ?:	Yes	Ignition immediate ?:	Yes (within 2 s)
Angle of the pad:	90°		
Stability:	Very stable		
Remarks:	Perfectly straigth ascend		
Coast Phase			
Apogee:	829 m	Maximum velocity:	126 m/s
Remarks:			
Recovery Phase (in air) (RE=Recovery Event)			
RE 1 successful ?:	Yes	RE 2 successful ?:	Yes
		Altitude at RE2 deployment	441 m
Stability of coast:	0	0=stable, 1=slow rotation, 2=fast rotation, 3=uncontrolled	
Remarks::	redundant Co2 failure Rotation of only the rocket, thanks to swivel		
Recovery Phase (on ground)			
Approx horizontal dist.:	approx 300m	Landing site ground:	Grass field
Impact velocity (m/s):	-3 m/s	Descent time (s):	t_apogee: t0+13.16 s t_drogue: t0+13.17 s t_main: t0+40.3 s t_landing : t0+156.3 s
Remarks::			

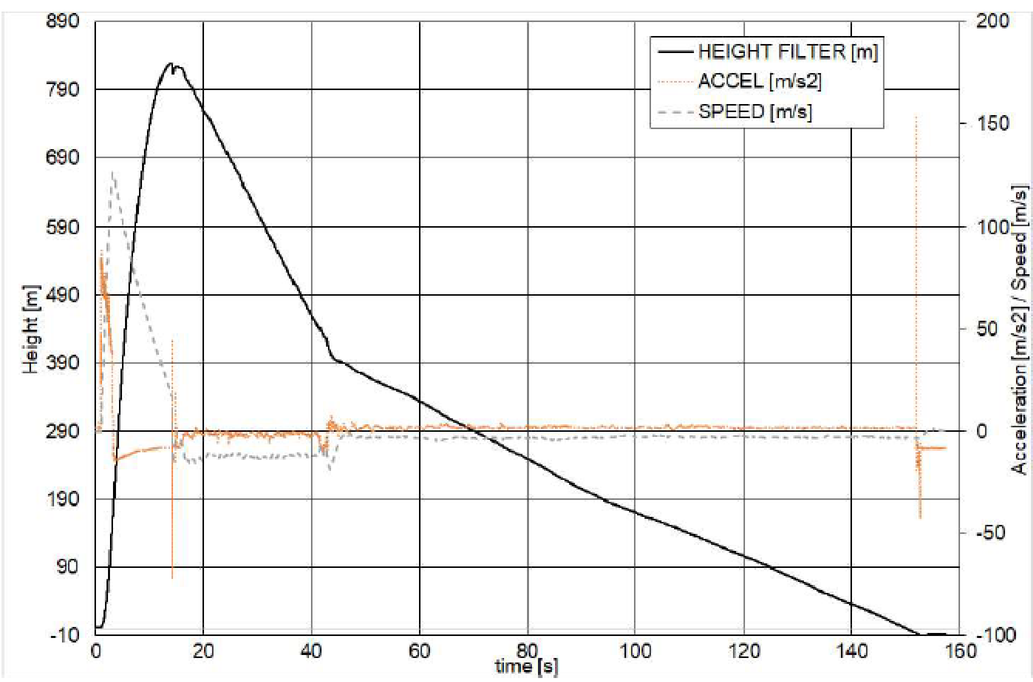
aris **Test Protocol**

Inspection			
Damage:	0	0=dirty, 1=little , 2=severe, 3=critical	
Photos taken ?:	Yes		
Description:	Entanglement of drogue visible in close up		
Overall			
Launch Time:	UTC+2 1545	Flight time [s]:	156.3 s
Apogee (AP) [m]:	Please fill	Source of AP data:	Altimax

Further comments from each subteam:

Recovery:

- Importance of Checklist
- Redundant knowledge of system needed
- wiring diagram as part of checklist



F. Test Reports: Recovery System Testing No. 02

aris **Test Protocol**

General Information

Test Information		
TestID	TELL-G-013	
Test Name:	System Ground Test	
Test Date and Time	12. May 2018	
Test Location	In front of Technopark	
Test Purpose	The recovery system functions as expected on the ground.	
Test Crew	Ferdinand	

Safety considerations

- Release mechanism might open stronger than expected.
- Black Power handling
- CO2 pressure containers handling

Test sequence

- Setup Recovery system

Testing Results

Testing Environment	
Temperature	24 C
Humidity	Dry Weather

Key results	
	Measured values
Time to release drogue	25 sec

Time to release main	50 sec

Testing outcomes.

- Full Assembly Test and nose cone ejection was successful

Things that were not perfect:

- Assembly of the eyebolt - was hard to tighten it through the nylon Tube
- Batterie Wire - too short
- Test: need to learn to interpret the sound signals from the REC avionics

Other notes:

- The package from fruity chutes is a little weird.
    - The parachute bag inside is even shorter and more tight then our other one, it is not functional for the main. But on the other hand with the nylon tube our other bag works just fine
    - We still have only one tender, the shipment did not include another one - could you please order two more as fast as possible the serial tender setup needs to be tested=

Photos

G. Test Reports: Recovery System Testing No. 03

aris **Test Protocol**

General Information

Test Information		
TestID	TELL-G-018	
Test Name:	System Ground Test	
Test Date and Time	25. Mai 2018	
Test Location	In front of Technopark	
Test Purpose	The recovery system functions as expected on the ground.	
Test Crew	Ferdinand	

Safety considerations

- Release mechanism might open stronger than expected.
- Black Power handling
- CO2 pressure containers handling

Test sequence

- Setup Recovery system

Testing Results

Testing Environment	
Temperature	24 C

Humidity	Dry Weather

Key results	
	Measured values
Time to release drogue	25 sec
Time to release main	50 sec

Testing outcomes.

First Ground Test:

- Failed, because the recovery was not correctly assembled and not airtight

Second Ground Test:

- Full Assembly Test and nose cone ejection was successful

Things that were not perfect:

- Test: need to learn to interpret the sound signals from the REC avionics
- Dual Tender setup might lead to the ignitor been ripped out of the avionics

Solution:

cut one ignitor in half and connect it with wire connector that separates, when force is applied

Photos

H. Test Reports: SRAD Propulsion System Testing

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I. Test Reports: SRAD Pressure Vessel Testing

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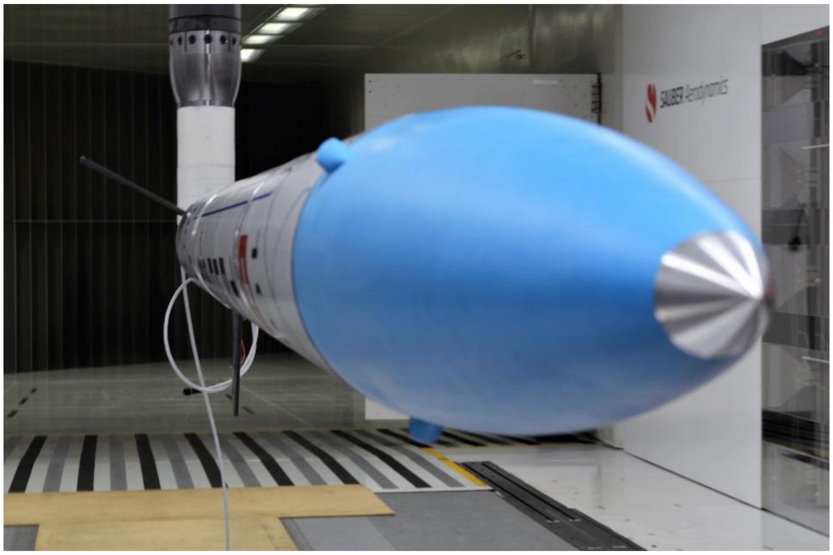
J. Test Reports: Wind Tunnel Testing at Sauber Aerodynamics

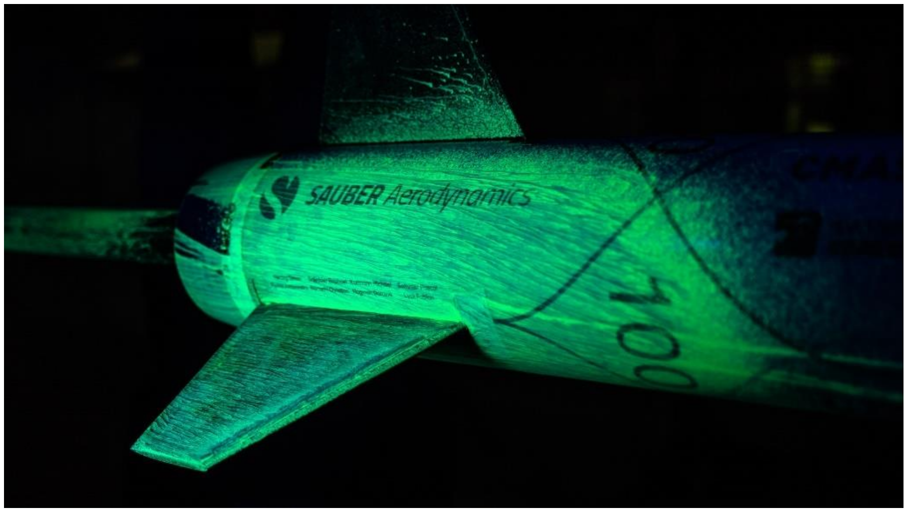
In collaboration with the rocket team from the university EPFL (ERT) a wind tunnel test at the facilities of Sauber Aerodynamics in Hinwil was possible.

Tested was the rocket with different configurations of the following three parameters:

- Wind speed
- Angle of attack
- Air Brake deployment

The results are currently being post-processed. Furthermore, a test run to compare the drag of the rocket was made once with and once without launch buttons. Additionally, FlowVis was applied to the rocket to visualize the aerodynamical flow.




SAUBER Aerodynamics

K. Hazard Analysis Appendix

The following materials used in TELL were identified as hazardous:

1. COTS Motor M2400
2. CO2 Cartridges for nose cone deployment and drogue parachute deployment
3. Tender Descender filled with black powder for main parachute release

After the identification of the hazardous materials, the following measurements and mitigations can be described:

Item	**COTS Motor M2400**
Description	This solid COTS motor is used for TELL at the competition in the US.
Mitigation / Analysis	• The motor is pre-ordered and will be picked up on the US site from MotoJoe to minimize handling and transportation. • Motor handling will only take place in dedicated areas at the competition • The Code of Conduct for high per rocketry launches and motor storage, NFPA1127, was read by the team members • Therefore, safety procedures according to NFPA1127 will be followed • Several team members got a level I certification during test flights in Switzerland in cooperation with ARGOS (Swiss Rocketry Association, http://www.argoshpr.ch) • One team member chosen to handle the competition motor acquired a level II certification during testing in Switzerland in cooperation with ARGOS (Swiss Rocketry Association, http://www.argoshpr.ch)

Item	**CO2 Cartridges**
Description	25g cartridges are used for the deployment of the nose cone and the drogue parachute deployment.
Mitigation / Analysis	• The cartridges are COTS products used for refilling bike tyres and similar items and therefore not to be seen as severe risk • There will be no transport from Switzerland to the US to ensure safety. Cartridges for the competition will be bought in th US while the handling will be trained in Switzerland • Checklists for the handling are created • Several ground tests are performed so the recovery responsible gets to know how to handle the cartridges

Item	**Tender Descender with Black Powder Filling**
Description	The tender descender is the COTS mechanism used to release the main parachute and works with black powder.
Mitigation / Analysis	• The tender descenders are COTS products especially made for rocket system with several guidelines to be found online from vendors • Therefore, the team was able to create checklists for the system TELL • Several ground tests are performed so the recovery responsible gets to know how to handle the tender descender system • There will be no transport of black power from Switzerland to the US to ensure safety. Black powder for the competition will be bought in th US while the handling will be trained in Switzerland

L. Risk Assessment Appendix

General Risk Assessment

Date	15-Mar-2018
Revision No.	01

ID	Description	Potential Failure Mode and Effects	Project Phase	Severity	Likeli-hood	Criticality	Prevention Method(s)	Recommended Action(s)	Responsible Person
TELL_01	Work force availability	Team consists of students: Lack of time and capacity leads to uncompleted work	All	Undesirable	Definite	Extreme	Weekly team meetings and general meetings to assess current work state	Communicate lack of work forces - recruit early enough	CEO CTO Team Leaders
TELL_02	Misscommunication	Needs and interfaces will not be detected - "I'm not in charge" opinion	All	Intolerable	Likely	Extreme	Weekly team meetings and general meetings to assess current work state	Use means of communications and show up on meetings and work shops	All
TELL_03	Deadlines	Other team members rely on work of other subteams to complete their work	All	Intolerable	Seldom	High	Weekly team meetings and general meetings to assess current work state	Use means of communications and show up on meetings and work shops Keep track of mile stones	CEO CTO
TELL_04	Requirements tracking	If requirements are not met team might lose points at challenge	Design Phase	Intolerable	Unlikely	High	Requirements List	Do requirements reviews Recheck designs	CTO
TELL_05	Matching of interfaces	Only thinking in own system: End-assembly will not work / Interfaces won't match	Design Phase	Intolerable	Likely	Extreme	Requirements List	Use means of communications and show up on meetings and work shops Do requirements reviews Recheck designs	CTO Team Leaders
TELL_06	Technical Procedures	Unclear procedures cause chaos and inefficient work and frustration	Assembly, Testing and Launch	Undesirable	Likely	Extreme	Design and plan in advance to make procedures as easy as	Write check lists for all procedures (assembly, testing and launch)	CTO Team Leaders
TELL_07	Operational Procedures	Unclear procedures cause chaos and inefficient work and frustration	All	Undesirable	Likely	Extreme	Define work flows for certain procedures	Part ordering and manufacturing procedures to be determined	Operations Team ST Team
TELL_08	Lead times	Items/Parts arrive too late	Ordering / Manufacturing	Intolerable	Likely	Extreme	Detect to be ordered parts early	Order as early as possible	Operations Team Team Leaders
TELL_09	Tools and work stations	Needed tools not available Place to work at not available	Manufacturing	Intolerable	Occasional	Extreme	Detect needed tools and work stations	Order / book as early as possible	Operations Team

RISK ASSESSMENT PROPULSION: COTS MOTOR HANDLING

ID	RISK DESCRIPTION	SEVERITY	LIKELIHOOD	RISK LEVEL	ACTIONS TO BE TAKEN
PP_01	Motor not available at the comeptition	Intolerable	Occasional	EXTREME	Contact Moto Joe early and make sure he has the M2500T-P at the competition reserved for us
PP_02	Ignition failure	Intolerable	Likely	EXTREME	Follow the instructions on Igniter mounting thouroughly Use 2 igniters
PP_03	Motor failure	Intolerable	Unlikely	HIGH	Check the grain for cracks before inserting it into the liner Inspect the Housing and the closures before mounting
PP_04	Motor thrust deviates from simulation	Undesirable	Occasional	EXTREME	Test flight to prove simulations
PP_05	Motor doesn't fit	Intolerable	Occasional	EXTREME	Recheck design of lower structure

System-FMECA

Subsystem	Recovery
Date	04-Jan-2018
Revision No.	01

1	2	3	4	5	8	10	11	15	18
ID	Item / Part	Function	Potential Failure Mode	Potential Effect(s) of Failure	Potential Cause(s) of Failure	Criticality	Current Design Control: Prevention Method(s)	Recommended Action(s)	Responsible Person
REC_01	Batteries	Supply the computer flights	1) Battery get discharged prematurely 2) Batery gets disconnected	1) The power supply to the computer flight stops	Battery was not totally charged	Low	1) Totally 4 batteries installed, 2 for each computer 2) Use new batteries for the launch 3) The computer flight has a special capacitor that allows the signal to be triggered even without power supply	1) Verify that batteries are charged before the launch	1) "launcher" 2) SE
REC_02	Computer flight	Sending activation signal for the ejection of the parachutes	1) Computer gets disconnected 2) Apogee not detected	1) The parachutes are not ejected	Computer not properly programmed/connected/mounted	High	1) Two computer flights installed for redundancy, one of which set with a timer instead of acelerometer	1) Testing computer flights to build experience	1) "launcher"
REC_03	Igniters	Receive signal from computer flight and trigger CO2 cartridge and release device	1) Igniters gets disconnected	1) The parachutes are not ejected	Low quality of igniters or not properly connected	Medium	1) Install two igniters in parallel for redundancy	1) Ground tests to build experience	1) "launcher" 2) team leader REC
REC_04	CO2 system	Triggered by igniters, builds up pressure in the recovery bay to separate the rocket	1) Not enough pressure is built 2) CO2 does not fire	1) Separation of nosecone does not take place	1) CO2 system not correctly mounted 2) CO2 cartridge was leaking	High	1) There are two cartridges for redundancy	1) Weight cartridge before mounting to be sure it is not partially empty	1) "launcher" 2) SE
REC_05	Recovery bay	Air-tight environment needed for the pressure build-up by CO2 and to separate the nosecone	1) Not enough pressure is built	1) Separation of nosecone does not take place	1) Recovery bay or the bulkhead were not properly air-tight	High		1) Launch test TELL before competition 2) Ground test on model to test the concept of bulkhead	1) "launcher" 2) team leader REC 3) ST team
REC_06	Shear pins	Keep the nosecone connected until the pressure build-up in the recovery bay	1) Shear pins fail prematurely due to outside decrease of pressure with the altitude or due to inertial forces 2) Shear pins do not break when pressure is built up at the apogee	1) Separation of nosecone does not take place 2) Rocket separates prematurely during ascent	1) Wrong number of shear pins installed 2) Small hole for pressure equilibrium with the height not dimentioned correctly	High		1) Use recommended shear pins and use on-line calculator to design the number of shear pins 2) Ground test	1) "launcher" 2) team leader REC
REC_07	Drogue Parachute	Decrease descent rate and stabilize rocket	1) Parachute not deployed correctly	1) Rocket does not slow down enough and the main parachute will not be able to be pulled out	1) cord entanglement 2) Parachute cords were not connected properly	High	1) Drogue parachute very hardly should get entangled according to design	1) Ground tests	1) "launcher" 2) team leader REC
REC_08	Drogue parachute shock cords	Carry the load of the drogue patachute opening	1) Failure	1) The drogue parachute will get disconnected from the rocket and recovery will fail	1) Tolerable load of cords was too low	High	1) Shock cords selected with supplier based on the opening shock loads and safety factors	1) Launch test TELL before competition	1) "launcher"
REC_09	Release device	Holding the main parachute inside the recovey bay until the second event at 500 m AGL	1) Release did not withstand the drogue chute shock load	1) Main parachute deployed prematurely	1) Release mechanism did not work according to supplier specifications 2) Drogue parachute shock load estimated with an error larger than one order of magnitude	Low		1) Ground tests 2) Launch test TELL before competition	1) "launcher" 2) team leader REC
REC_10	Release device	Release the main parachute at the second event at 500 m AGL	1) Release device did not release the main parachute	1) Main parachute not deployed	1) Release mechanism did not work according to supplier specifications 2) Other components in the the recovery bay prevented the correct functioning	High		1) Ground tests 2) Launch test TELL before competition	1) "launcher" 2) team leader REC 3) SE 4) AV team
REC_11	Main parachute cords	Carry the load of the main parachute opening	1) Failure 2) Entanglement	1) The main parachute will get disconnected from the rocket and recovery will fail 2) The main parachute will not be deployed correctly and the recovery will fail	1) Not correct folding of cords 2) cord did not withstand shock load	Extreme	1) Shock cords selected with supplier based on the opening shock loads and safety factors 2) Shock cords will be folded with the main parachute bag according to detailed guidelines from the supplier	1) Ground tests 2) Launch test TELL before competition	1) "launcher" 2) team leader REC
REC_12	Swivel links	Release torque from cords and withstand opening shocks	1) Normal shock too big	1) One or more shock cords could be disconnected from the rocket	1) Swivel links were not designed for that load 2) Swivel links were not properly screwed on the bulkhead	Medium		1) Ensure with ST team that the connection of the swivel links to the bulkhead are safe	1) team leader REC 2) SE 3) ST team
REC_13	Screws in connection of the CO2 system to the bulkhead	Keep the CO2 bottles connected at the bulkhead	1) Failure of the screws	1) The CO2 will not flow to the recovery bay	1) The CO2 system was not properly connected to the bulkhea	High		1) Ensure with ST team that the connection of the swivel links to the bulkhead are safe	1) team leader REC 2) SE 3) ST team

System-FMECA

Subsystem	Avionics
Date	04-Mar-2018
Revision No.	01

ID	Item / Part	Function	Potential Failure Mode	Potential Effect(s) of Failure	Mission Phase	Potential Cause(s) of Failure	Criticality	Current Design Control: Prevention Method(s)	Recommended Action(s)	Responsible Person
AV_01	Software	Process in real time	Can't process all functions at once	Not all tasks can be executed or are executed too late	All	Not enough computing power	EXTREME	Chose microcontroller with high performance Simplify control algorithms	Assign priorities to software tasks Testing	1) Raphael 2) Fabian for Motor control
AV_02	Software	Detect Mission Phases	Doesn't detect critical mission points	No sampling No sign for air brakes	All	Failure in software implementation	HIGH	Skip states if software gets stuck	Testing with simulated data Testing with launches	1) Raphael
AV_03	Telemetry Signal	Send position	Signal jamming Range to low Rocket orientation	No correct position sent Sampling and video recording starts not at t=-30	All	Interference from in-rocket components or materials or surroundings Selection of wrong module Rocket trajectory	HIGH	Shielding of rocket electronics Spatial separtion of high frequency components Choose module with max legally allowed radiation power	Testing	1) Pascal
AV_04	WLAN connection	Intra-Rocket communication	Interference / material influences	No communication No sensor redundancy for control No data from LB AV to ground station	All	Interference from in-rocket components or materials	HIGH	Only parachutes in between	Communication test	1) Raphael 2) Alessandro
AV_05	Battery	Power source	Not enough energy	Failure of control and avionics	All	Turned on to early Misscalculated power budget	HIGH	Battery selection (if 1 of 5 cells fails the other still work) Use low power mode before start Only turn on if necessary	Recalculate power budget Verify power budget with measurements	1) Alessandro
AV_06	Hardware	Resist surrounding conditions	Doesn't withstand heat and humidity	Failure of control and avionics	All	Miss selection of hardware components Defined range not like reality	HIGH	Mechanical protection of electronic hardware Monitoring of surroundings	Climate chamber testing	1) Alessandro
AV_07	Hardware	Ensure performance of all components	Wrong PCB assembly	Failure of control and avionics	Design / Assembly	Selfmade component - risk of missassembly	EXTREME	Check how components have to be assembled in data sheets	Testing	1) Alessandro
AV_08	PCB	Ensure performance of all components	Wrong PCB design	Failure of control and avionics	Design / Assembly	Wrong design not detected before producing	HIGH	Recheck team intern Recheck by expert?	Find an expert for re-check	1) Alessandro
AV_09	GPS	Send position	No satellite connection Time till first fix too long	Recovery failure No GPS data	All	GPS turned on too late Rocket orientation	HIGH	Two GPS antennas	Run GPS earlier before launch pad (during assembly)	1) Raphael

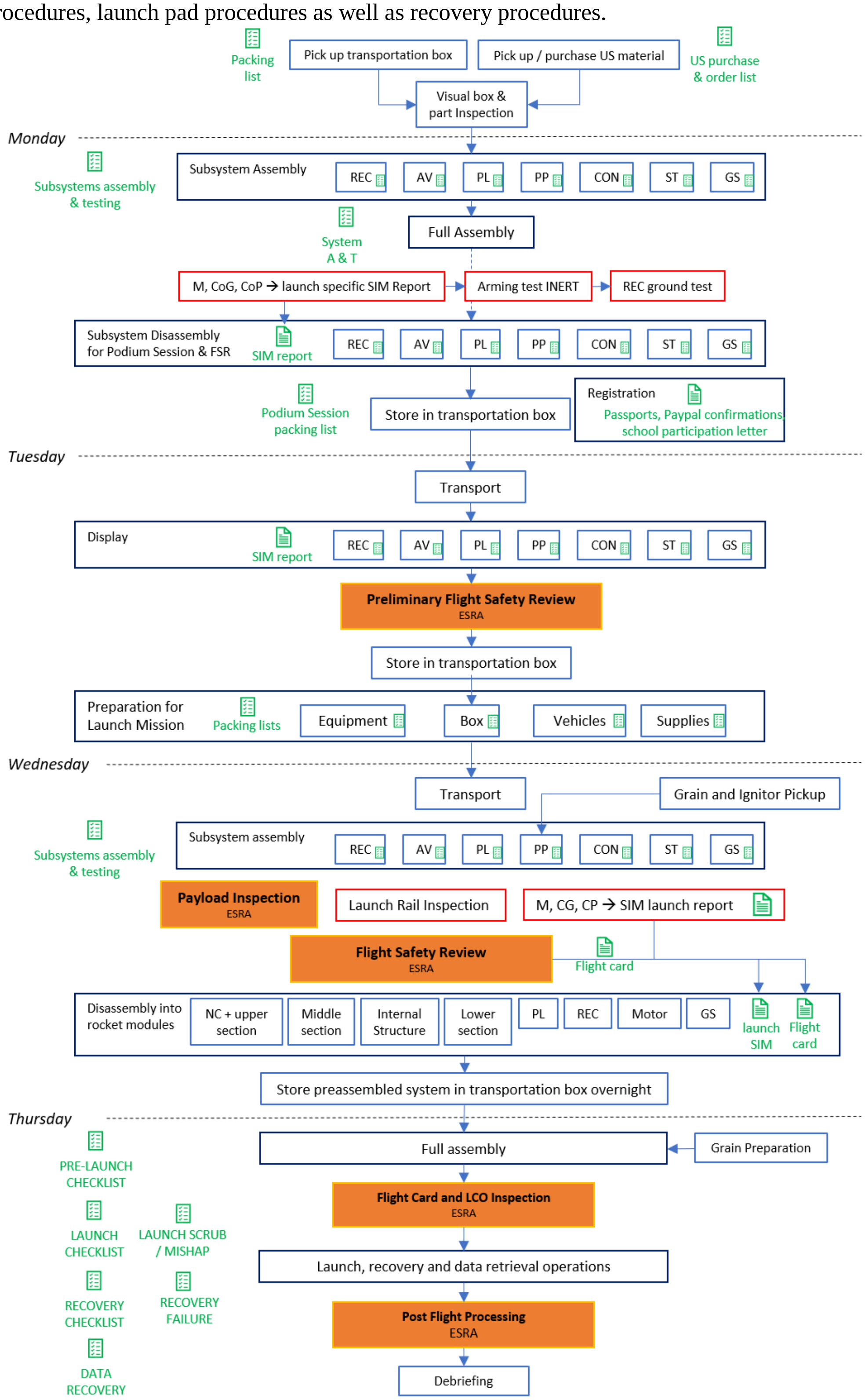
System-FMECA

Subsystem	Control
Date	04-Mar-2018
Revision No.	01

ID	Item / Part	Function	Potential Failure Mode	Potential Effect(s) of Failure	Mission Phase	Potential Cause(s) of Failure	Criticality	Current Design Control: Prevention Method(s)	Current Design Control: Detection Method(s)	Recommended Action(s)
CON_01	Controller	Compute the correct airbrake position	1) Overshooting 2) Oscillations 3) Premature deployment	1) An overcorrection, i.e. too much braking could result in not reaching the apogee. 2) Overshooting of the target airbrakes position can result in oscillations, reducing the accuracy of the control algorithms. 3) The airbrakes deploying too early at high windspeeds, which are not tested in the windtunnel, may cause undershoot in the final altitude.	Ascent	Badly tuned controller. Inaccurate altitude estimate. Software redundant securities failures.	High	Test the control algorithm on the simulation with different failure scenarios. Tune the controller using flight data. Accurate tests on the windtunnel.	State estimation module providing accurate altitude. Redundant securities. Conservative and safe control inputs.	1) Test the algorithms with failure scenarios in the simulation. 2) Windtunnel tests and previous launch data used to tune the controller.
CON_02a	Motor Controller	Actuate the airbrakes to the desired position	Delayed actuation Inconsistent actuation	The motor control algorithm could become unstable or inaccurate, leading to bad apogee accuracy.	Ascent	Inaccurate motor controller Too high motor load Not enough cooling of the controller Unexpected motor behaviour Badly tuned PID	High	Thoroughly tested on ground, windtunnel and launch tests. Minimal, conservative and safe control inputs.	Can be detected automatically during flight by comparing motor position measurement with expectations based on control input.	1) Tests on the ground, windtunnel and launches.
CON_02b	Motor Controller	Actuate the airbrakes to the desired position	Unintended actuation Overheating	Preemptive actuation may result in structural disintegration. Too much load, or increased ambient temperature could lead to overheating and thus degrading performance of the controller. Excessive overheating could increase the ambient temperature within the avionics bay to unsafe levels, causing the avionics to fail. This would result in failure to trigger the payload. Unintended actuation could deplete the avionics battery, causing the avionics to fail.	Ascent	Inaccurate motor controller Too high motor load Not enough cooling of the controller	High	The power supply system is implemented with redundancy featuring a multitude of battery cells. Shut off motor controller in case of excessive heating.	Can be detected automatically during flight by comparing motor position measurement with expectations based on control input. Cannot be prevented if motor controller malfunctions.	1) Actively monitor the motor controller temperature
CON_03	Power Supply	Supply the motor and the controller with sufficient power	1) Power breakdown 2) Lack of power	1) Blackout of the controller could result in any amount of over- or underbrakeing and thus over- or undershooting the apogee. 2) A lack of power could result in bad motor performance.	Ascent	Battery failureBroken wiresBroken power cont	Medium	The power supply system is implemented with redundancy featuring a multitude of battery cells. Soldered connections are held to a high standard.	No RF connection and no airbrake movement.	1) Check critical power connections for robustness. 2) Don't use brand new batteries to make sure there are no manufacturing errors.
CON_04	Trajectory Estimation / Sensor Fusion	Fuse the sensor data to obtain an accurate estimate of the current position, velocity and attitude	Wrong state estimation	Unexpected sensor measurements (increased noise, bias, ...) will reduce the precision of the state estimate or lead to failure. Wrong state estimation could lead to early payload ejection.	Ascent	Vibrations Hardware failure Excessive sensor noise	Extreme	Test of the algorithms in simulations and previous test launches sensors data. Sensor fusion can handle sensor errors by design.	Sensor data from test flights will show most sensor errors. The variance of the current state and altitude estimates computed by the algorithm can detect unexpected sensor measurements.	1) Test the algorithms with failure scenarios in the simulation. 2) Previous launch data used to tune the algorithms and expected precision.
CON_05	Linear Guides	Guide the airbrake plates stiffly and smoothly along their path.	1) Getting stuck	1) If the linear guides get stuck the airbrakes are locked in some position which will result in under- or overshooting the apogee.	Ascent	Unexpectedly high loads on brake plates and their supportive structure. Wrong or no greasing of the linear guides. Dirty or sand in the linear guides. Misalignement of linear guides and gear racks.	Medium	Make design considerations for larger forces than expected -> Safety factor. Lock screws with loctite. Prevent dirt from entering the rocket by closing the airbrakes when landing and for transportation. Grease linear guides with high temperature grease. Carefully align linear guides and test.	Test the linear guides with the expected load in a ground test. Test rocket performance under the influence of vibration.	1) Check the susceptibility of the linear guides to jamming
CON_06	Airbrake Plates	Serve as a control surface, increasing the drag force on the rocket.	1) Fluttering, vibration 2) Structural disintegration 3) Induction of roll	1) Unpredicted fluttering or vibrations might lose screws, change the system dynamics, change the motor performance. 2) Structural failure of the brake plates leads to asymetrical braking and a possible destabilization of the rocket. 3) If the airbrake plates are asymetrical they might lead to an accelleration of the rocket in roll direction and have unwanted affects on the dynamics of the rocket and on the onboard measurement devies.	Ascent	Unexpectedly high loads Manufacturing failures Design failures	High	Oversized linear guides and mounting should assure structural stability.	Wind tunnel, load and vibration tests. Finite element method analysis of structural elements. Computational fluid dynamics simulation to estimate forces.	
CON_07	Gear and rack	Transmit the motor force to the air brake plates.	1) Getting stuck 2) Structural disintegration 3) Increased friction	1) If the linear guides get stuck the airbrakes are locked in some position which will result in under- or overshooting the apogee. 2) If gear or rack brake under too much stress one or several brake plates will not be actuateable anymore which can result in asymetrical braking and thus destabilization of the rocket. 3) If gear and rack have more friction than accounted for the dynamics of the system might be different resulting in actuation inaccuracies.	Ascent	Unexpectedly high loads on brake plates and their supportive structure. Loosing of the shaft to collar connection. Dirty or sand on the gears. Misalignement of linear guides and gear racks.	High	Overdesigned gear and rack system to hold up to higher forces than expected. The system is kept as simple as possible to reduce points of failure.	Wind tunnel, vibration and load tests. Finite element method analysis of structural elements. Computational fluid dynamics simulation to estimate forces.	
CON_08	Motor	Drives the air brakes	1) Breakdown due to lack of power or hardware error	It may not be possible to retract the air brakes.	Ascent	Excessive vibrations Heat overload Faulty motor controller	High	An oversized and well tested COTS motor should be very reliable.	Motor stress tests during vibration and heat tests.	1) Check with manufacturer to assure motor is used correctly.

M. Assembly, Preflight and Launch Checklists Appendix

The following pages show the check lists for the competition The first picture shows the procedures for all competition days. Green markings show where check lists have to be used or reports or other documentations have to be ready. Check lists were created for packing of items, purchasing and ordering, pre-assembly procedures, assembly procedures, launch pad procedures as well as recovery procedures.



The team is currently still working on their check lists as several learnings are to be implemented which will come up during the weeks before the competition, when assembly and disassembly will be trained. Below are examples of how the check lists are constructed:

REC Recovery Checklist

Item #	Item	Phase	T-[hh:mm:ss]	Countdown	Task	Nominal value	if non-nominal	System relevai
057	REC-057	Assembly	02:00:00	T-02 h 0 min	Connect MdfPlate with Bulkhead witch 4x m3 * 25 screws			
056	REC-056	Assembly	01:30:00	T-01 h 30 min	Attach Batteries 4x			
059	REC-059	Assembly	01:29:00	T-01 h 29 min	Attach Board from Avionics			
060	REC-060	Assembly	01:28:00	T-01 h 28 min	Attach Recovery Electronic			
061	REC-061	Assembly	01:27:00	T-01 h 27 min	Screw Recovery Bay onto the bulkead 4x m4 * 16			
062	REC-062	Assembly	01:20:00	T-01 h 20 min	Load both Raptors(Lube thread and exhaust ports)			
066	REC-066	Assembly	23:59:00	T-23 h 59 min	Attach both Raptors 8x m3 * 12			
068	REC-068	Assembly	01:30:00	T-01 h 30 min	Connect Ignitor for Co2 with Recovery Avionics			
075	REC-075	Assembly	22:00:00	T-22 h 0 min	Connect lower end of parachute bag to	Ready for launch sign	hold until nominal	
076	REC-076	Assembly	02:00:00	T-02 h 0 min	attach both tender in serial			
077	REC-077	Assembly	01:45:00	T-01 h 45 min	yellow wires one up one down			
078	REC-078	Assembly	01:45:00	T-01 h 45 min	connect middle quickling - swivel - big quickling - eyebolt			
081	REC-081	Assembly	01:00:00	T-01 h 0 min	attach quicklink bottom and top of main shock cord			
082	REC-082	Assembly	00:01:20	T-1 min	connect main shock cord at the end of parachute lines			
083	REC-083	Assembly	00:45:00	T-45 min	connect the top op the parachute (a little loop in the inside of t			
084	REC-084	Assembly	00:30:00	T-30 min	fold parachute cylindrically and then fold the lines correctly att			

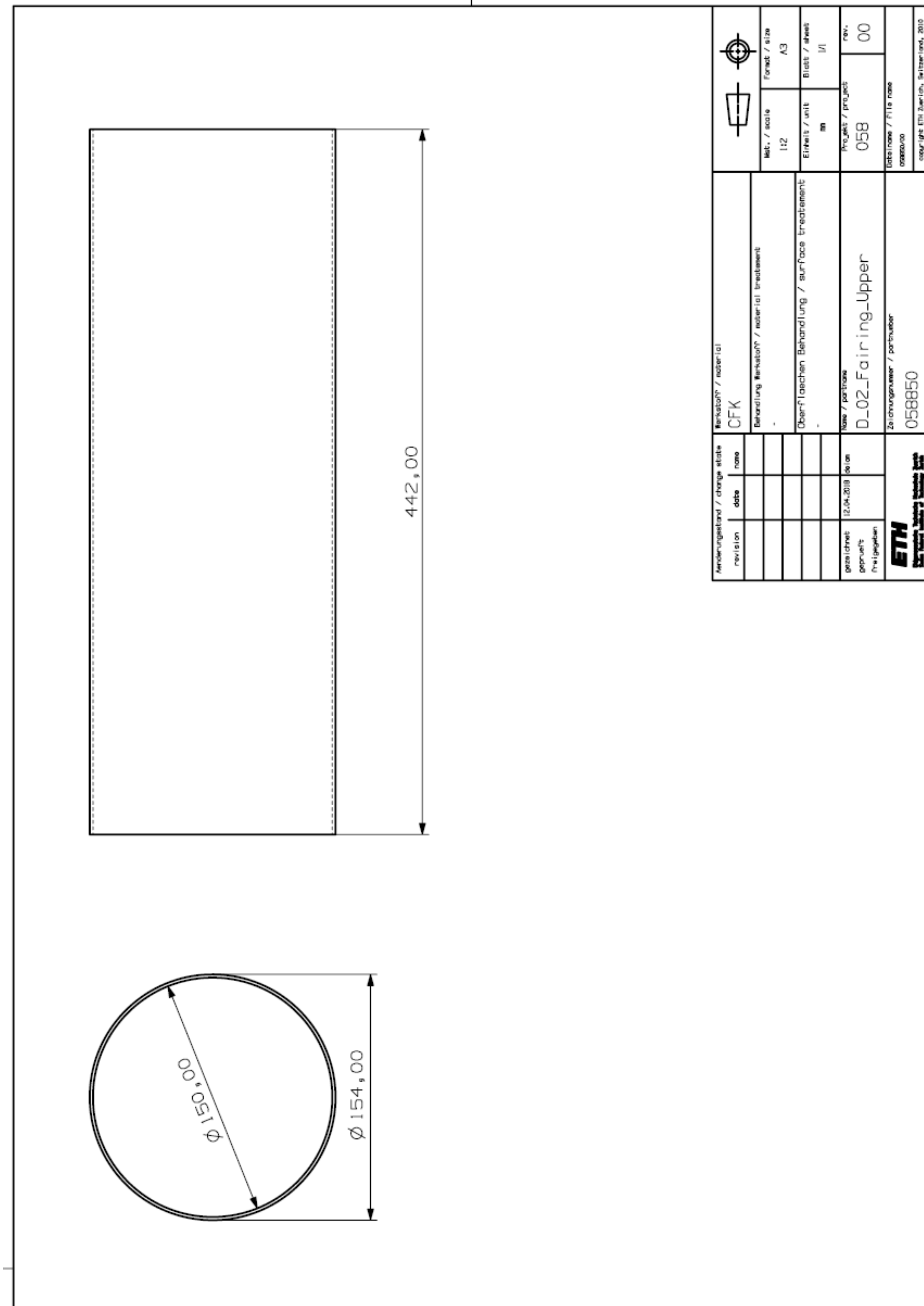
AV Avionics Checklist

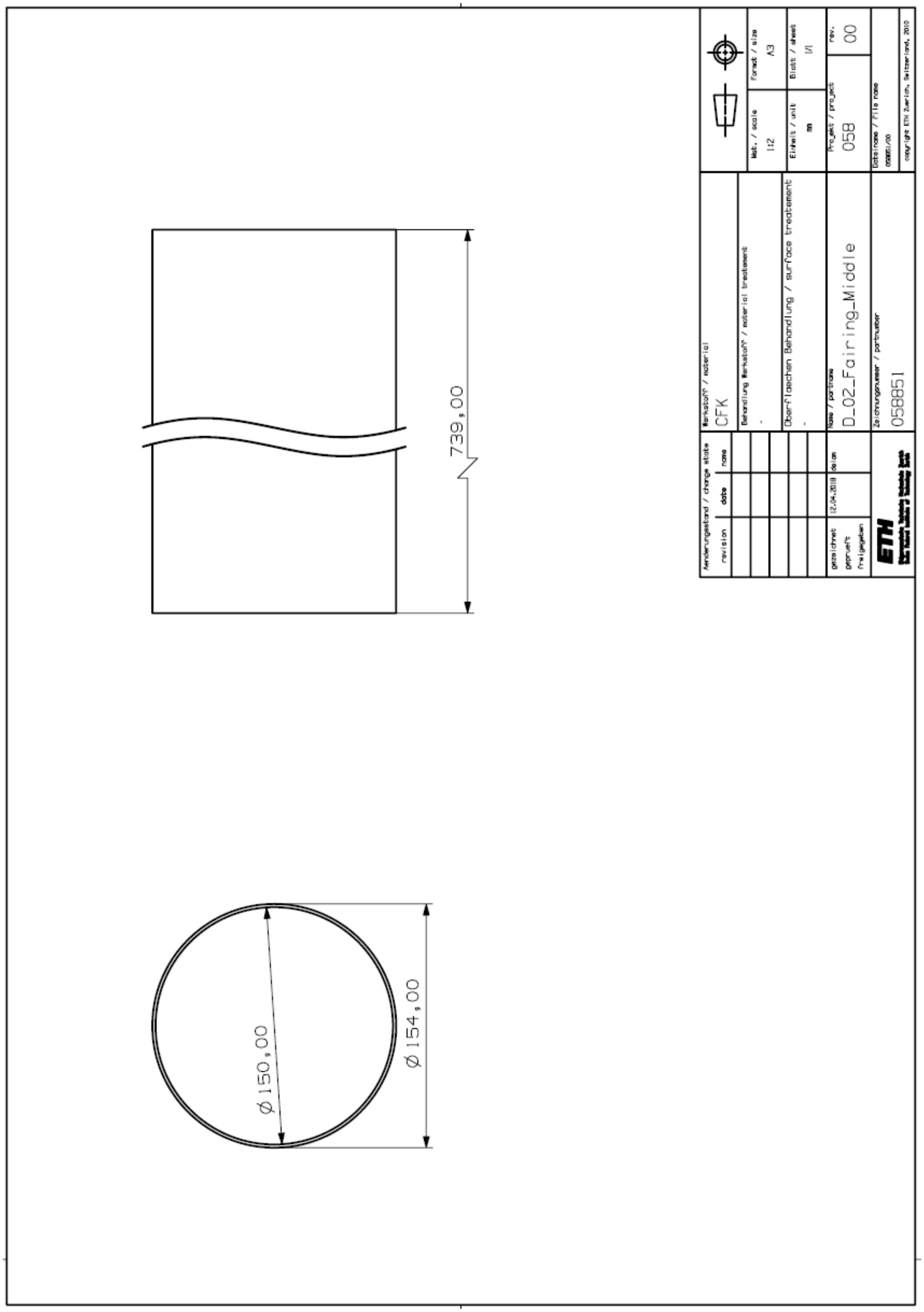
Item #	Item	Phase	T-[hh:mm:ss]	Countdown	Task	Nominal value	if non-nominal	System relevan
000	AV-000	Packing List	00:00:00	T-0 s	Battery incl. Backup for Nosecone	Packed, 3.7V/cell	notify Chief Mission C	
002	AV-002	Packing List	00:00:00	T-0 s	SD card incl. Backup for NC and LB(4)	packed	notify Chief Mission C	
003	AV-003	Packing List	00:00:00	T-0 s	Battery charger	Packed	notify Chief Mission C	
004	AV-004	Packing List	00:00:00	T-0 s	sd card to usb adapter (2*)	packed	notify Chief Mission Oper	
005	AV-005	Packing List	00:00:00	T-0 s	NC main sensor board & backup	packed	notify Chief Mission Oper	
006	AV-006	Packing List	00:00:00	T-0 s	2x GPS board & backup	packed	notify Chief Mission Oper	
007	AV-007	Packing List	00:00:00	T-0 s	2x WiFi board & backup	packed	notify Chief Mission Oper	
008	AV-008	Packing List	00:00:00	T-0 s	rs232 cable *6	packed	notify Chief Mission Oper	
009	AV-009	Packing List	00:00:00	T-0 s	Raspberry Pi Zero	packed	notify Chief Mission Oper	
010	AV-010	Packing List	00:00:00	T-0 s	Raspberry Spy Cam	packed	notify Chief Mission Oper	
011	AV-011	Packing List	00:00:00	T-0 s	Ground Com Antenna & backup	packed	notify Chief Mission Oper	
012	AV-012	Packing List	00:00:00	T-0 s	3x Wifi Antenna	packed	notify Chief Mission Oper	
013	AV-013	Packing List	00:00:00	T-0 s	3x GPS Antenna	packed	notify Chief Mission Oper	
014	AV-014	Packing List	00:00:00	T-0 s	NC mechanical holder	packed	notify Chief Mission Oper	
015	AV-015	Packing List	00:00:00	T-0 s	Ground Com board	packed	notify Chief Mission Oper	
016	AV-016	Packing List	00:00:00	T-0 s	buck converter (2*)	packed	notify Chief Mission Oper	
017	AV-017	Packing List	00:00:00	T-0 s	ground comm & wifi anenna cable * 4	packed	notify Chief Mission C	
018	AV-018	Packing List	00:00:00	T-0 s	extension boards power cable(nc)	packed	notify Chief Mission Oper	
019	AV-019	Packing List	00:00:00	T-0 s	mainboard power cable	packed	notify Chief Mission Oper	
020	AV-020	Packing List	00:00:00	T-0 s	buck converter to raspberry power cable	packed	notify Chief Mission Operator	
021	AV-021	Packing List	00:00:00	T-0 s	data cable mainboard to buck converter	packed	notify Chief Mission Oper	
022	AV-022	Packing List	00:00:00	T-0 s	external led (3)	packed	notify Chief Mission Oper	

AV Avionics Checklist

Item #	Item	Phase	T-[hh:mm:ss]	Countdown	Task	Nominal value	if non-nominal	System relevan
111	AV-111	Assembly	01:00:00	T-01 h 0 min	check if connection to control can be established	connection success	hold until nominal	
112	AV-112	Assembly	01:00:00	T-01 h 0 min	check if connection to payload can be established	connection success	hold until nominal	
113	AV-113	Assembly	01:00:00	T-01 h 0 min	check if connection to temperature sensor can be established	connection success	notify Chief Mission C	
114	AV-114	Assembly	01:00:00	T-01 h 0 min	check if connection between avionics can be established	connection success	notify Chief Mission C	
115	AV-115	Assembly	01:00:00	T-01 h 0 min	check ground communication link	connection success	hold until nominal	
116	AV-116	Assembly	01:00:00	T-01 h 0 min	Activate GPS modules	GPS fix acquired	notify Chief Mission C	
117	AV-117	Assembly	01:00:00	T-01 h 0 min	Check battery voltage	4.2V/cell	notify Chief Mission C	
118	AV-118	Launchpad	00:10:00	T-10 min	Run CON self-test	Test passed, visuall	hold until nominal	
119	AV-119	Launchpad	00:10:00	T-10 min	Run Sensor self-test	Test passed, good	hold until nominal	
120	AV-120	Launchpad	00:01:00	T-1 min	switch state to pre launch	feedback that state	notify Launch control	
121	AV-121	Launchpad	00:10:00		Arm the upper and lower avionics	arming leds are on	notify Launch control	
122	AV-122	Recovery	00:05:00	T+5 min	Report last known GPS position		notify Chief Mission C	
123	AV-123	Recovery	01:00:00	T+01 h 0 min	Turn off all avionics	avionics off (led off)	hold until nominal	
124	AV-124	Recovery	01:02:00	T+01 h 2 min	remove sd cards from lb, nc and raspberry	sd card carried by a	hold until nominal	
125	AV-125	Recovery	01:05:00	T+01 h 5 min	Carry avionics back to base camp	avionics back at bas	hold until nominal	
126	AV-126	Recovery	01:30:00	T+01 h 30 min	copy all data from the 3 sd cards to 2 different laptops	copy of data on 2 la	hold until nominal	
127	AV-127	Post flight ana	02:00:00	T-02 h 0 min	provide flight data to simulations team	simulations team ha	hold until nominal	
128	AV-128	Post flight ana	02:05:00	T-02 h 5 min	analyse temperature data	always <75° C	notify Chief Mission C	
129	AV-129	Post flight ana	12:00:00	T-12 h 0 min	save copy of data to the aris database	data in aris databas	notify Chief Mission C	
130	AV-130	In Flight	00:00:00	T+0 s	hold antenna into direction of rocket	ground station recie	hold until nominal	

N. Engineering Drawing Appendix

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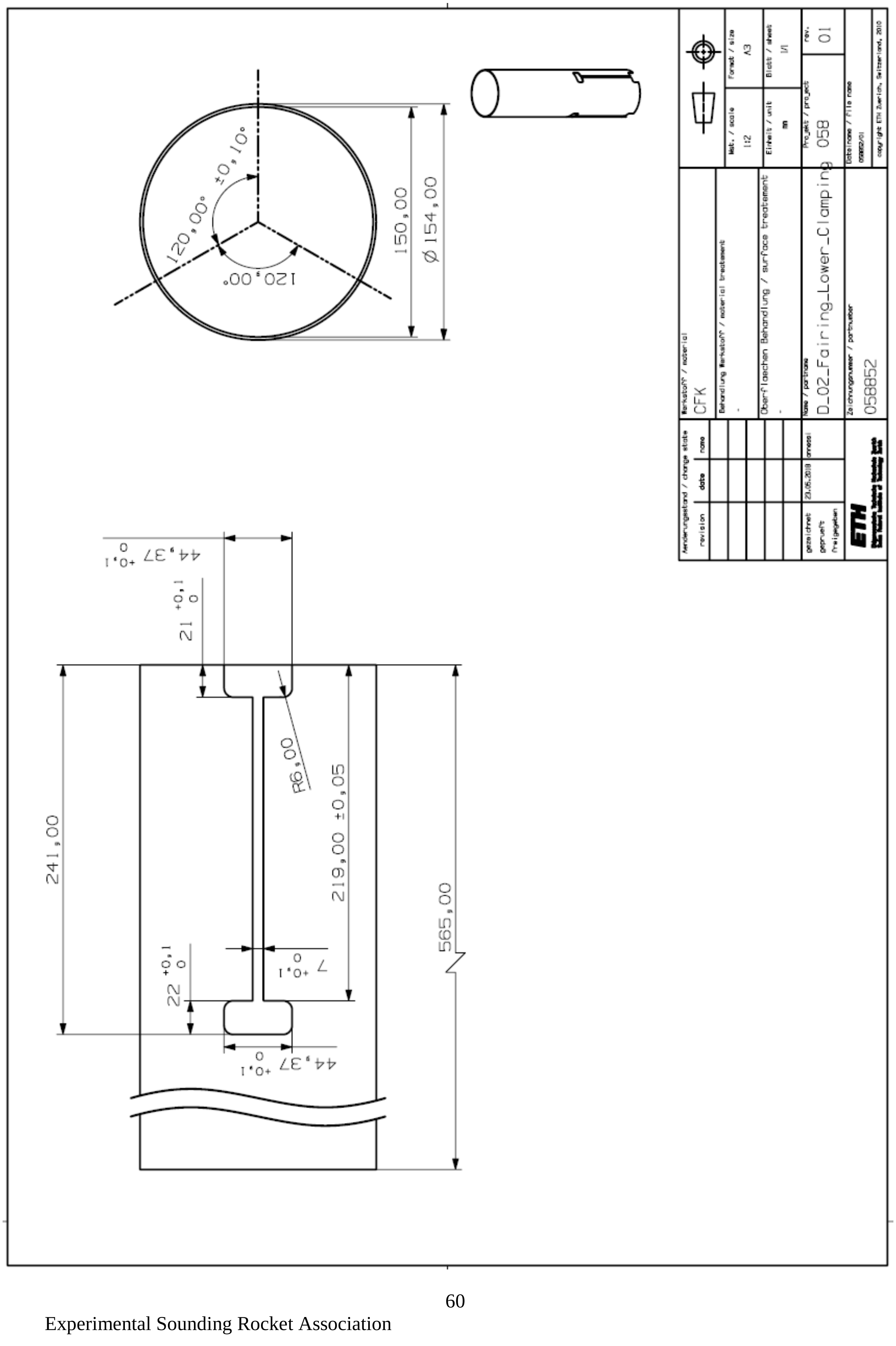
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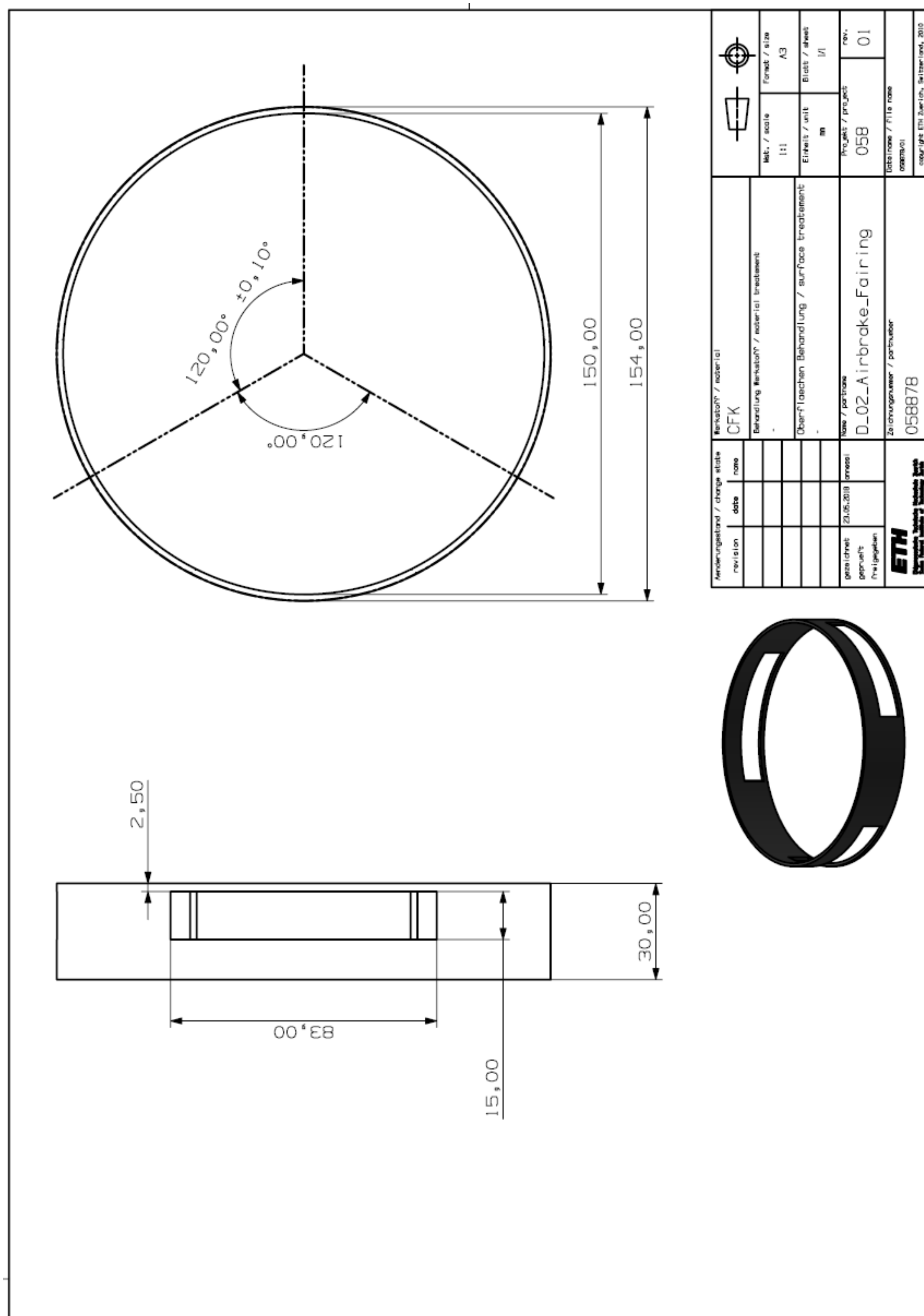

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CFK
Oberflaechen Behandlung / surface treatement
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Projekt / project
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rev.
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Einheit / unit
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Blatt / sheet
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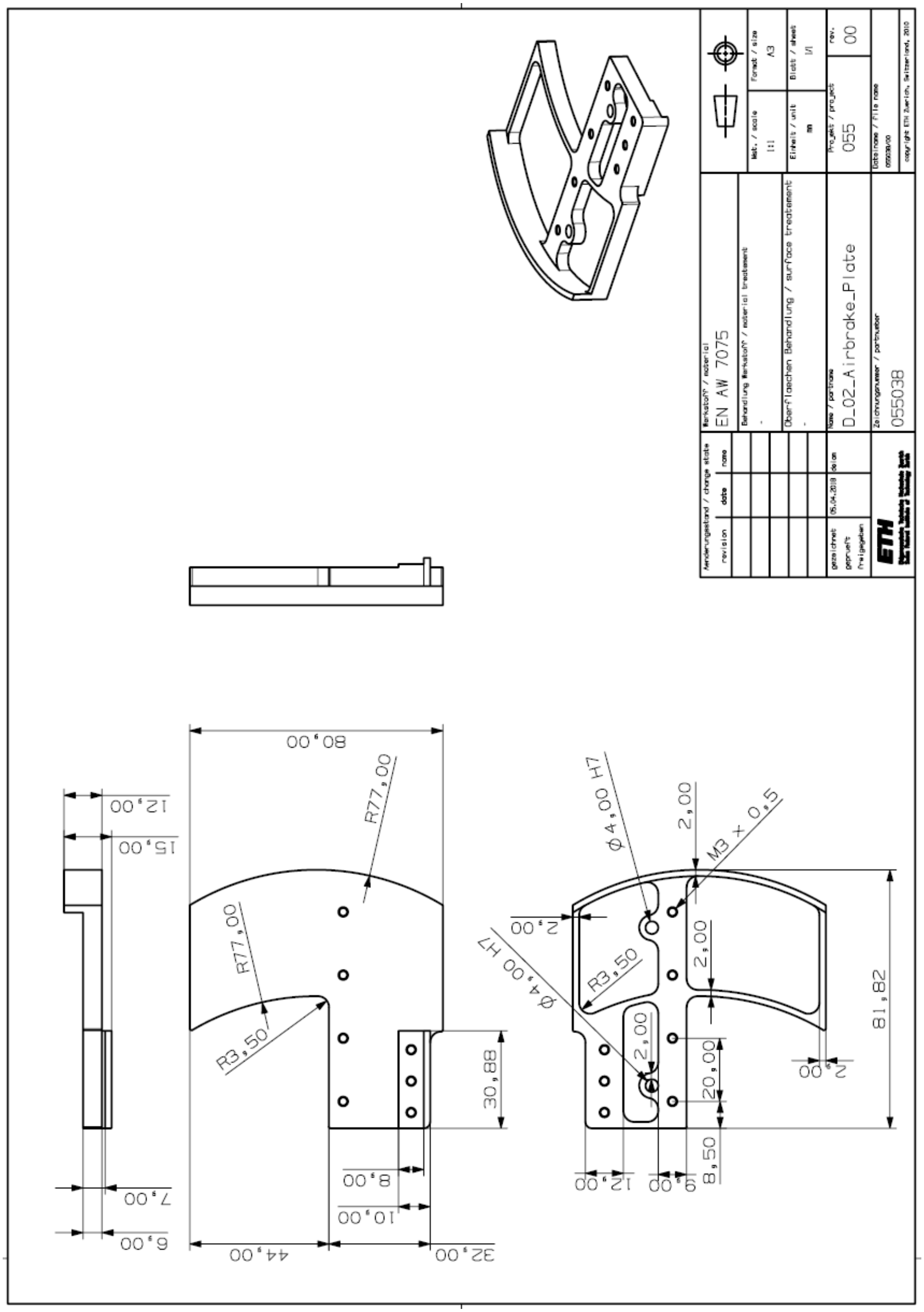
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Pro_jekt / project
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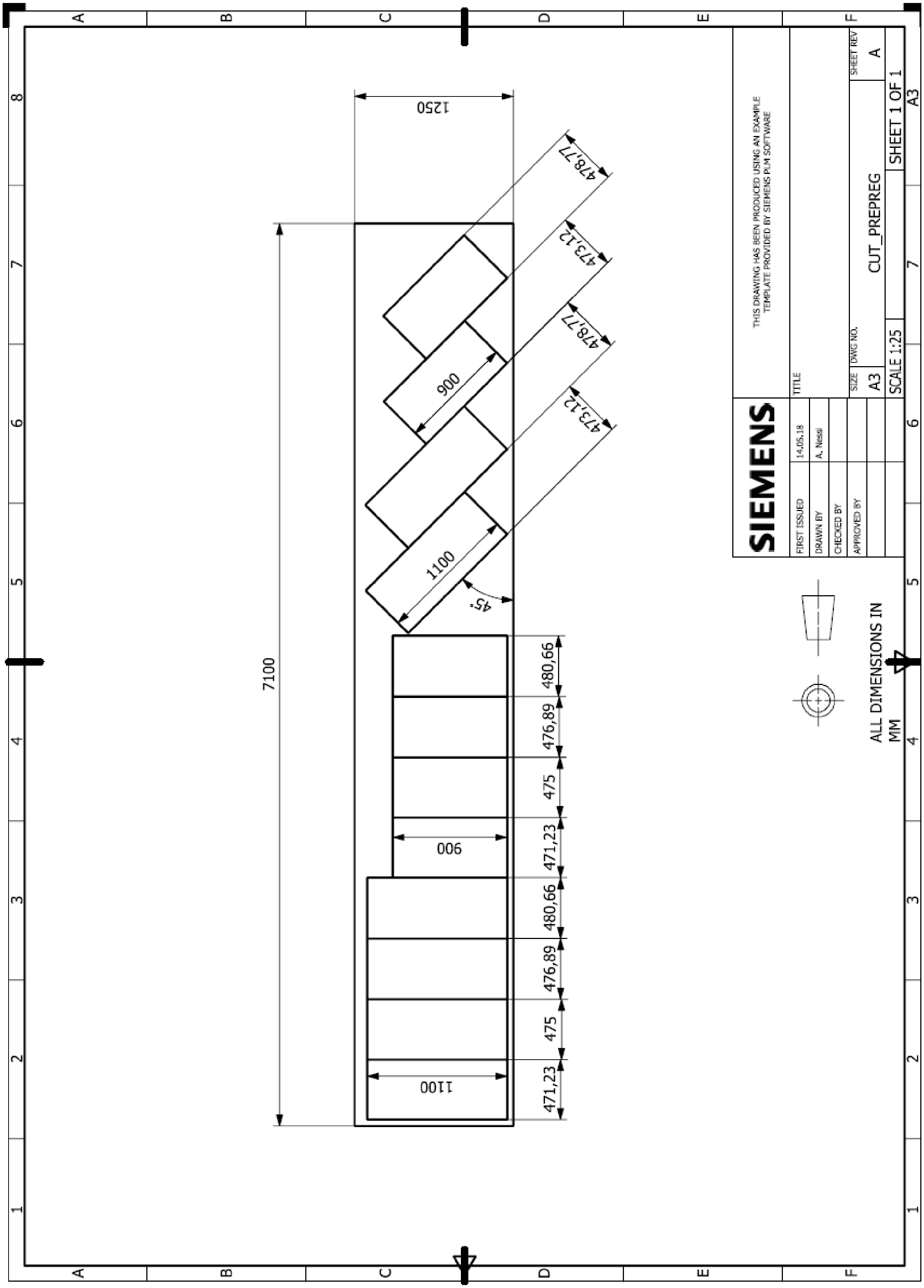
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SIEMENS
FIRST ISSUED 14.05.18
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CHECKED BY
APPROVED BY
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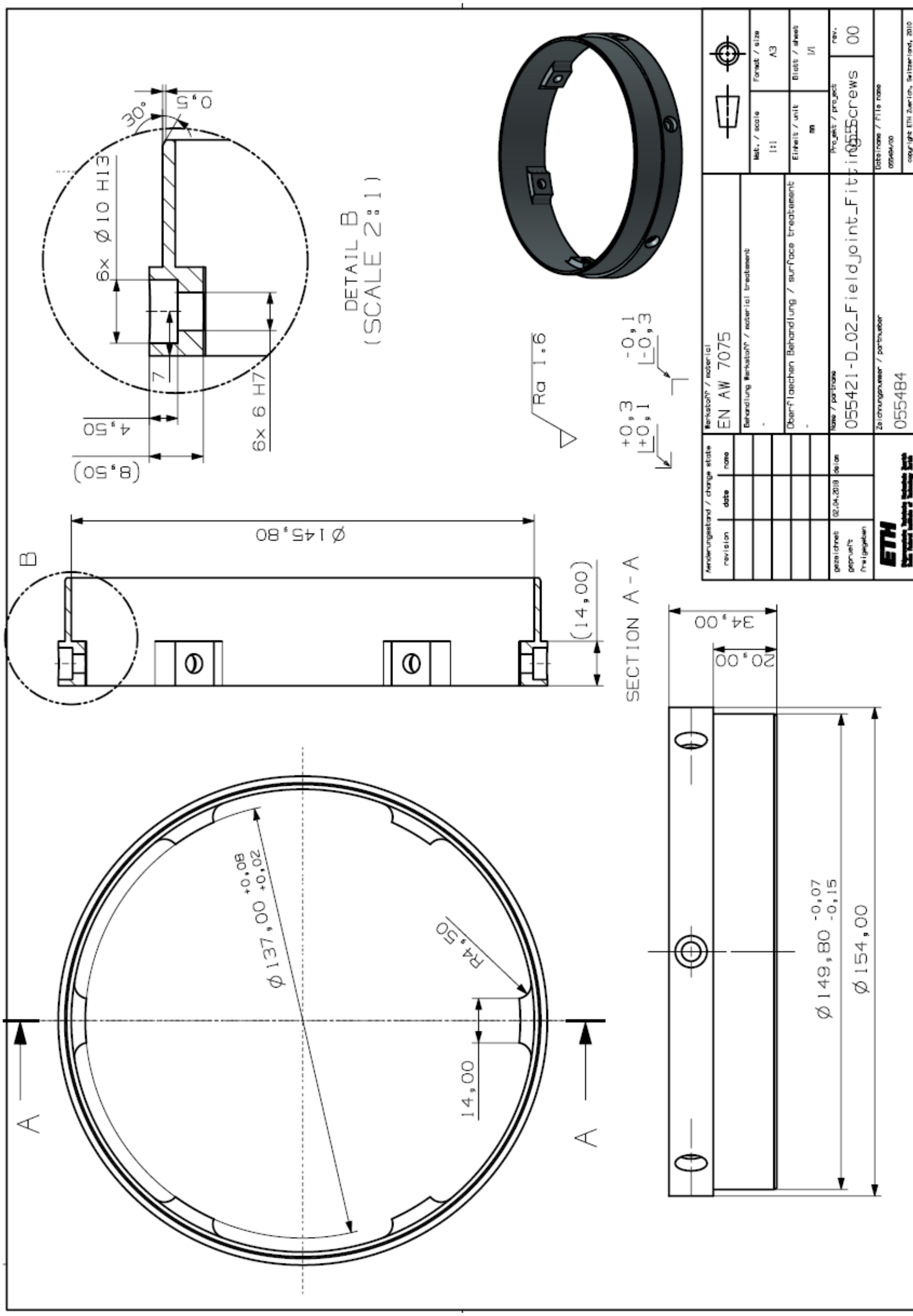
ALL DIMENSIONS IN MM



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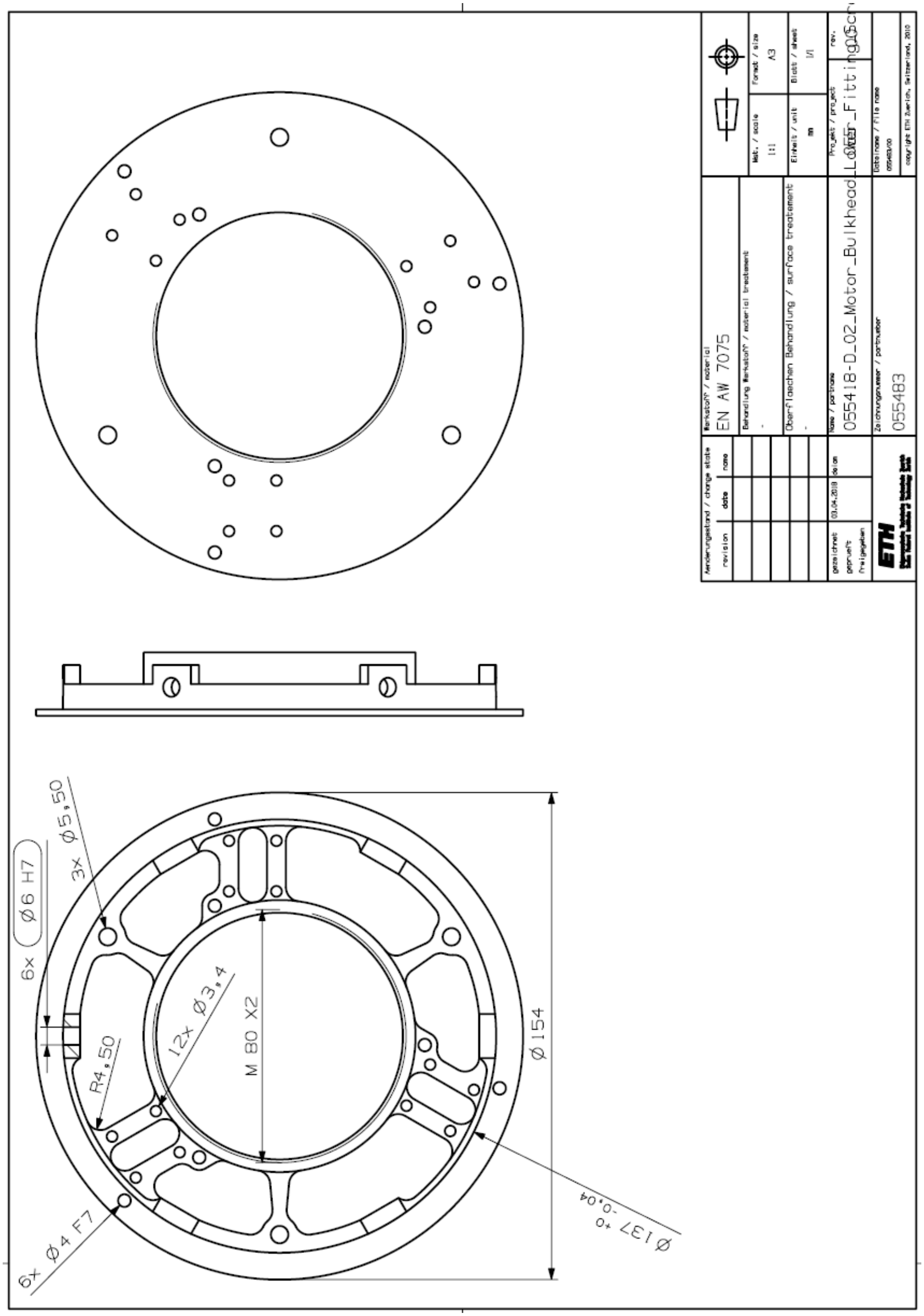
ETH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R4,50
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Ø154
Ø137 +0 -0,04
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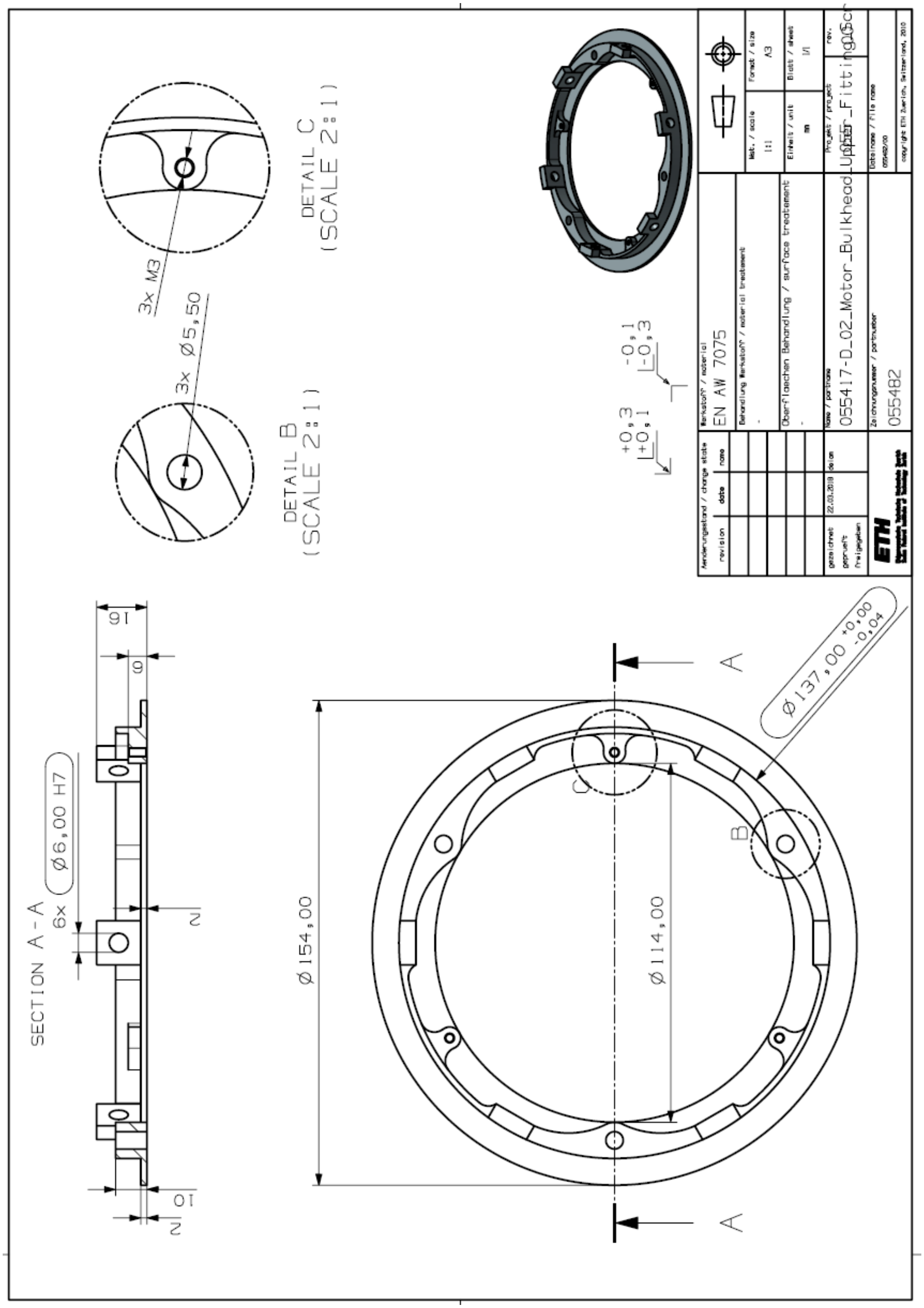
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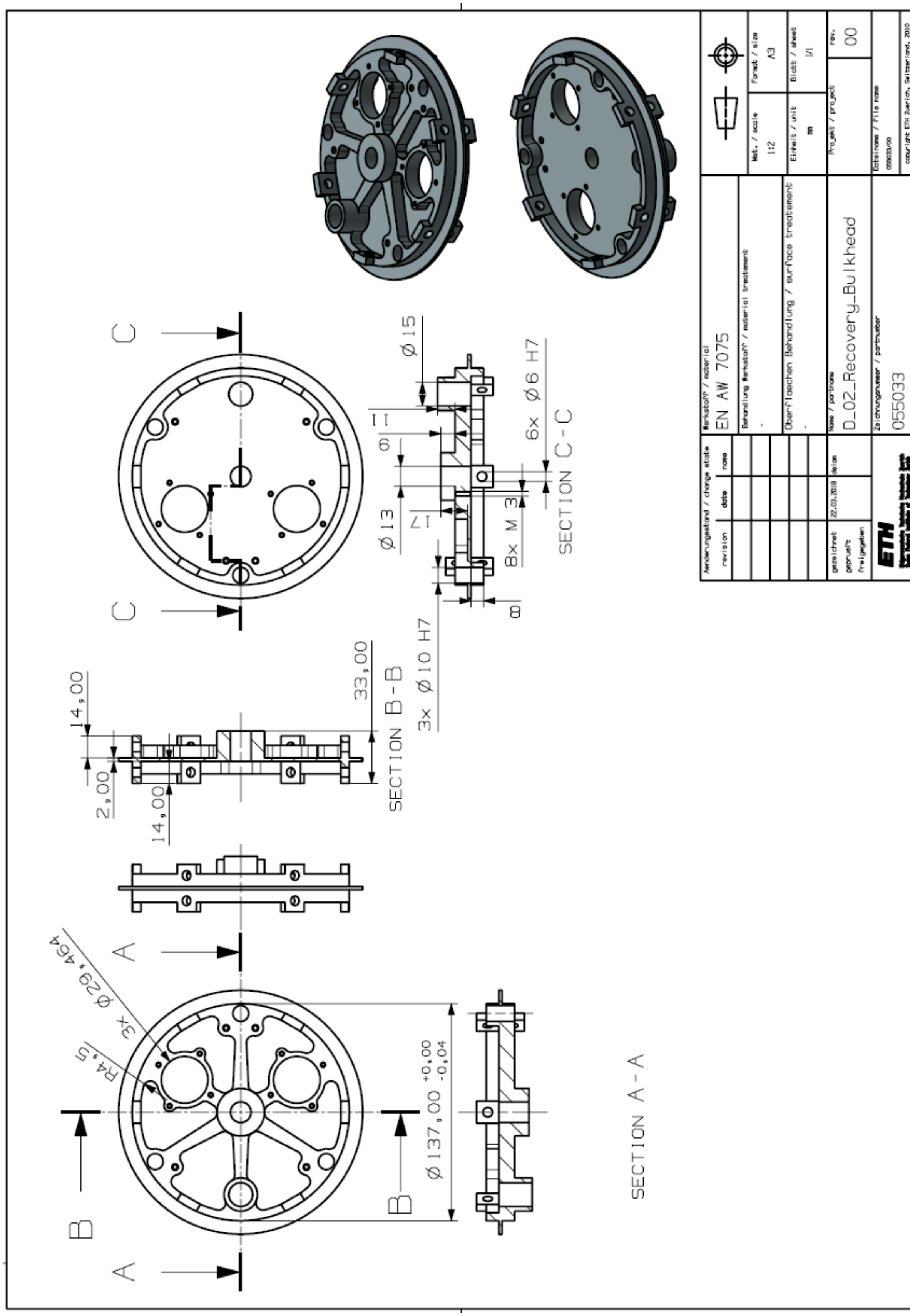

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SECTION B-B
SECTION C-C
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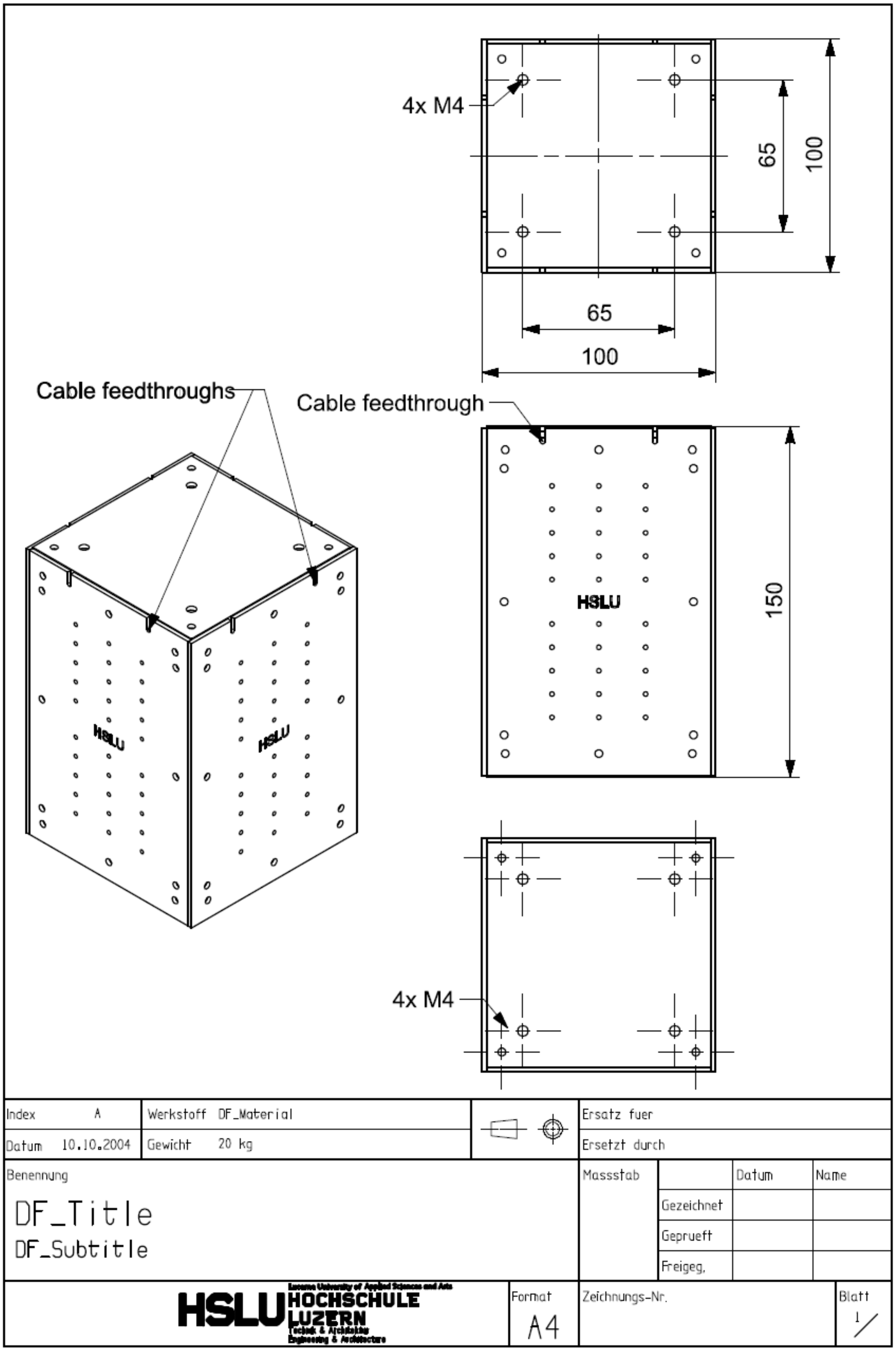

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Ersetzt durch
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Freigeg.
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Zeichnungs-Nr.
Blatt
1/

O. Management Appendix: Stakeholder Analysis

The first step in the stakeholder analysis is the identification of the stakeholders. The Main stakeholders are:

- Competition Body
- Student Team
- University
- Partner Universities
- Sponsors
    - Sponsors providing the funds for the development/production
    - Sponsor providing the funds for the competition logistics
- Partner Labs
- Team Mentors
- Advisors
- Media
- ARGOS (Advanced Rocketry Group of Switzerland)

Additional stakeholders with whom the team does not interact until the competition are:

- Competition Sponsors
- Volunteers (pad support, runners)
- Judges

After the identification of the stakeholders, we further analyze them by determining their role, needs and objectives. This analysis is summarized in Table 6. Stakeholder Overview.

Table 6. Stakeholder Overview

Stakeholder	**Their role, needs and objective**
IREC Competition Organizer	Their *role* is to organize the competition, create the necessary format and define basic requirements the teams need to fulfill.
	Their *needs* are advertising the competition, have many teams from different countries, arrange facilities for the launch and, attract volunteers and sponsors
	Their *objective* is to have a successful competition, increase their public visibility while promoting their goals
Team Sponsors	Their *role* is to provide the funds and sometimes assist with production by providing the equipment and technical expertise.
	Their *needs* are to interact with the team and make sure the team is sufficiently prepared to enter the competition.
	Their *objective* is to increase the visibility of the company/facility as well as attract new potential clients and employees.
Home University (ETH Zurich)	Their *role* is to provide the support and facilities to the team, possibly motivate the participation by enabling the students to earn credits and contribute to funding the project.
	Their *needs* are to have a student team acquiring new skills and implementing the knowledge already acquired.
	Their *objective* is to advance the teams understanding of the field and promote the project.
Partner University	Their *role* is to provide additional support facilities and funding.
	Their *needs* are to have the interaction with the team, build up a relationship to other participating Universities and define the areas of contribution
	Their *objective* is to help the team advance the project
Partner Labs	Their *role* is to provide the support to the team by providing the necessary equipment expertise and facilities.

	Their *needs* are to interact with the team and organize their involvement.
	Their *objective* is to contribute to the success of the team while possibly advertising their lab and obtaining some data from the main product
Faculty Advisors	Their *role* is to provide technical expertise to the team, to oversee the progress and help with possible issues.
	Their *needs* are to train/advise the students to come up with a good and competitive design, to help with team formation and assignment separation.
	Their *objective* is to have a successful team competing and applying the knowledge acquired during their studies.
Team Mentors	Their *role* is to organize and lead the team, to separate the tasks, to set immediate goals and objectives, track the progress.
	Their *needs* are to interact with the team members, organize regular meeting and reviews.
	Their *objective* is to have a well-organized team and meet the deadlines imposed by the competition.
Media	Their *role* is to inform the public about the competition and capture most important events happening in and around the same.
	Their *needs* are to interact with competition organizers and the teams, conduct interviews and to visually capture the competition.
	Their *objective* is to have interesting story which will captivate the audience and attract more viewers.
ARGOS	Their *role* is to organize the test launch in Switzerland.
	Their *needs* are to have many people attending and further increase the popularity of the model rocketry.
	Their *objective* is to facilitate the test launch.

The next step in the stakeholder analysis is to determine how each stakeholder influences the team. Therefore, we analyzed the values the team gets from each stakeholder. The complete analysis of the value flow is presented in Table 7. Stakeholder Value Flow.

Table 7. Stakeholder Value Flow

To Stakeholder	Value flow	From Stakeholder
IREC Competition Organizers	Financial flow	Sponsors
	Publicity	Media
	Work force	Volunteers
	Intellectual flow	Student Teams
	Competition Venue	Spaceport America
Team Sponsors	Public Visibility	Student Teams/ Media
	Media Attention	Media
Home University	Motivated Students	Student Teams
	Public Visibility	Media
	New Ideas Concepts	Student Teams
Partner Universities	New Ideas Concepts	Student Teams
	Public Visibility	Media
Partner Labs	New Ideas/ Concepts	Student Teams
	Possible experiment data	Student Teams
	Public Visibility	Media
Faculty Advisors	Motivated Students	Student Teams
	New Ideas/ Concepts	
Team Mentors	Intellectual effort	Student Teams
Media	Interesting Story	Student Teams
		Competition Organizer
ARGOS	New Partners	Student Teams
	Visibility in new environment	University

	Media exposure	Media
Student Team	Organization/ Leadership	Team Mentors
	Intellectual support	Faculty Advisors
	Public Visibility	Media
	Facilities/ Equipment	Home University
		Partner Labs
		Partner Universities
	Funding	Home University
		Sponsors
	Competition Requirements/ Goals	Competition Organizers

As a last step in the analysis we mapped the main stakeholders according their Power/influence and Interest/impact to visualize which stakeholders we need to manage closely and which ones we can only monitor. This helps to identify the workload for each stakeholder. The result is presented in Figure 39.

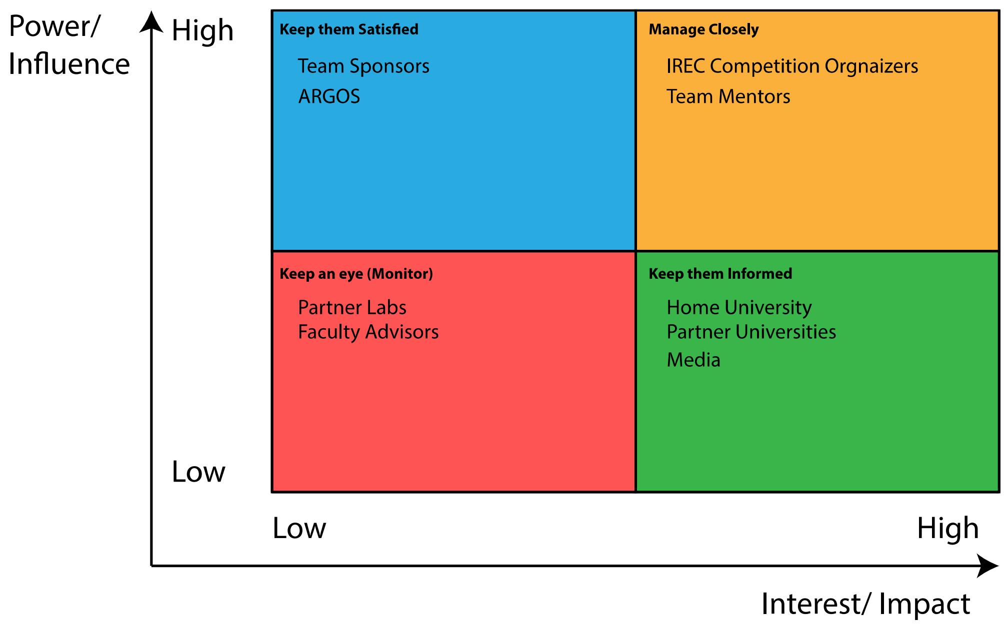


Figure 39. Power/ Influence vs. Interest/Impact mapping of main stakeholders

P. Requirements Appendix

The following pages show the requirments created for mission TELL.

ID	Source	SIM	ST	PP	REC	AV	PL	CON	OPS/ LOG	MAN	Requirement Description	Compliance	Source	Reasoning & Comments	Last Updated by
Functional		x	x	x	x	x	x	x	x	x					
F1.	**SE**			**X**					**X**		**Rocket shall take off with a full COTS motor**	**Compliant**	**For categories see IREC Rules & Req. Doc 03/06/2017 Section 2.0**		**19.03.2018**
F2.	**IREC**		**X**		**X**						**Rocket shall be landed with a dual event recovery system**	**Compliant**	**IREC Design, Test & Evaluation Guide 02/17/2017 Section 3.1**	**Ground Tests conducted**	**20.05.2018**
F2.1	SE				X				X		Initial deployment system shall consist of a COTS drogue parachute	Compliant		Simplification of system	20.05.2018
F2.1.1	IREC				X						Initial deployment event shall occur at or near apogee and stabilize the vehicle's attitude (prevent tumbling) during descent	Compliant	IREC Design, Test & Evaluation Guide 02/17/2017 Section 3.1.1.1		20.05.2018
F2.1.2	IREC				X						Initial deployment event shall reduce its descent rate enough to permit the main deployment event yet not so much as to exacerbate wind drift (eg between 75 and 150 ft/s [23-46 m/s]).	To be verified	IREC Design, Test & Evaluation Guide 02/17/2017 Section 3.1.1.1		19.03.2018
F2.1.3	SE		X		X						Initial parachute opening shock shall be smaller than TBD g	To be verified		Structural integrity	19.03.2018
F2.1.4	SE		X		X						Initial parachute is deployed by separating the nose cone from the rocket main structure	Compliant		Ground Tests conducted	20.05.2018
F2.2	SE				X				X		Main deployment system shall consist of a COTS main parachute	Compliant		Simplification of system	19.03.2018
F2.2.1	IREC				X						The main deployment event shall occur at an altitude no higher than 1,500 ft (457 m) AGL and	Compliant	IREC Design, Test & Evaluation Guide 02/17/2017 Section 3.1.1.2		20.05.2018
F2.2.2	IREC		X		X						The main deployment event shall reduce the vehicle's descent rate sufficiently to prevent excessive damage upon impact with ground (ie less than 30 ft/s [9 m/s]])	Compliant	IREC Design, Test & Evaluation Guide 02/17/2017 Section 3.1.1.2	TELL-L-010	30.03.2018
F2.2.3	SE		X		X						Main parachute opening shock shall be smaller than TBD g	To be verified		Structural integrity	19.03.2018
F2.2.4	IREC				X						Main parachute colour shall be drastically different than initial parachute colour	Compliant	IREC Design, Test & Evaluation Guide 02/17/2017 Section 3.1.3		19.03.2018
F2.2.5	SE		X		X						Main parachute is deployed by separating the nose cone of the rocket main structure	Compliant		Ground Tests conducted	20.05.2018
F2.3	SE				X		X				Rocket shall recover itself independent of any active or passive payload function(s).	Compliant	IREC Rules & Req. Doc 03/06/2017 Section 2.3.2		20.05.2018
F2.4	SE		X		X	X	X				Rocket shall separate in maximum 3 parts	Compliant		Only two	20.05.2018
F2.4.1	SE		X								Any separated launch vehicle part shall be connected structurally to the launch vehicle's recovery system directly or indirectly	Compliant			19.03.2018

ID	Source	SIM	ST	PP	REC	AV	PL	CON	OPS/LOG	MAN	Requirement Description	Compliance	Source	Reasoning & Comments	Last Updated by
F4.	**IREC**		**x**			**x**					**Each seperable launch vehicle part shall carry a radio beacon or similar transmitter aboard**	**Compliant**	**IREC Rules & Req. Doc 03/06/2017 Section 2.5**	**IREC rules&requirements section 2.5 only 1 for the rocket**	**19.03.2018**
F4.1	SE		x			x					At least one part of the launch vehicle shall contain and transmit GPS postion to a ground station	Compliant			20.05.2018
F5.	**IREC**						**x**				**Any deployable payloads shall carry a radio beacon or similar transmitter aboard each independently recovered assembly**	**Compliant**	**IREC Rules & Req. Doc 03/06/2017 Section 2.5**	**No deployable PL in the system**	**20.05.2018**
F6.	**IREC**		**x**			**x**			**x**		**Launch vehicles shall carry a COTS barometric pressure altimeter with on-board data storage**	**Compliant**	**IREC Rules & Req. Doc 03/06/2017 Section 2.6**	**independet COTS barometer unit with serial interface for communication with ground station**	**19.03.2018**
F6.1	SE		x			x					Barometric pressure altimeter shall deliver accurate measurement results	To be verified			19.03.2018
F6.1.1	SE		x			x					Multiple venting holes shall be symetrically placed on the barometric pressure altimeter chamber	To be verified		No outside airflow influence for pressure stability	19.03.2018
F6.1.2	SE		x	x		x					Barometric pressure altimeter chamber shall be air tight sealed from any motor exhaust gases	Compliant			20.05.2018
F6.1.3	SE		x			x					Position of barometric pressure altimeter chamber shall be at least 5 calibres below any outer diameter change of the launch vehicle	Compliant		No influence of underpressure area due to diameter changes	20.05.2018
F6.1.4	SE	x	x								Below the nosecone shall be no diameter changes of the airframe	Compliant			20.05.2018
F6.1.4.1.	*SE*		*x*								*Diameter below the nosecone shall be 150 mm(internal)*	*Compliant*			*20.05.2018*
F6.1.5	SE	x	x			x		x			Airbrakes should be mounted 1 calibre below the barometric pressure altimeter	Compliant			20.05.2018
F6.1.6	SE					x					Data shall be logged on an on-board data storage	Compliant		Independent of the functionality and performance of the SRAD avionics	20.05.2018
F6.1.7	IREC		x			x					Altitude logging system shall be mounted to the launch vehicle and not the payload	Compliant	IREC Rules & Req. Doc 03/06/2017 Section 2.6		20.05.2018
F7.	**IREC**		**x**		**x**						**All launched components shall be recovered**	**Compliant**	**IREC Rules & Req. Doc 03/06/2017 Section 2.8.1.4**		**20.05.2018**
F8.	**SE**							**x**			**Rocket shall control apogee height AGL**	**Compliant**		**With air brakes**	**20.05.2018**
F9.	**IREC**	**x**						**x**			**Rocket shall be naturally stable during ascent**	**Compliant**	**IREC Design, Test & Evaluation Guide 02/17/2017 Section 8.1**		**25.05.2018**
F9.1	IREC	x					x	x			launch vehicles entered into the IREC need not be stable without the required payload mass on-board.	Compliant			25.05.2018
F9.2	SE	x				x		x			Launch vehicle shall be naturally stable with implemented control system in any position	Compliant			25.05.2018

ID	Source	SIM	ST	PP	REC	AV	PL	CON	OPS/ LOG	MAN	Requirement Description	Compliance	Source	Reasoning & Comments	Last Updated by
F9.2.1	IREC		X			X		X			Control actuator systems (CAS) shall mechanically lock in a neutral state whenever either an abort signal is received for any reason, primary system power is lost, or the launch vehicle's attitude exceeds 30° from its launch elevation.	Compliant	IREC Design, Test & Evaluation Guide 11/22/2017 Section 5.3	What exactly is a neutral position? Suggestion: Neutral position = position where rocket is still stable	25.05.2018
F9.2.2	IREC	X				X		X			No moment shall be applied to the launch vehicle whenever either an abort signal is received, primary system power is lost, or the launch vehicle's attitude exceeds 30° from its origin	Compliant	IREC Design, Test & Evaluation Guide 02/17/2017 Section 5.3		25.05.2018
F9.2.3	IREC					X		X			All active control systems should comply with requirements and goals for "redundant electronics" and "safety critical wiring" as recovery systems	Compliant	IREC Design, Test & Evaluation Guide 11/22/2017 Section 5.5		25.05.2018
F9.2.4	IREC					X		X			Flight control systems are exempt from the requirement for COTS redundancy, given that such components are generally unavailable as COTS to the amateur high-power rocketry community.	Compliant	IREC Design, Test & Evaluation Guide 02/17/2017 Section 5.4	in relation to recovery requirements	25.05.2018
F9.2.5	IREC					X		X			All stored-energy devices used in an active flight control system (aka energetics) shall comply with the energetic device requirements defined in Section 4.0 of the IREC Design, Test & Evaluation Guide 02/17/2017	Compliant	IREC Design, Test & Evaluation Guide 02/17/2017 Section 5.5		25.05.2018
F10.	**IREC**		**X**								**Launch vehicle shall be adequately vented**	**Compliant**	**IREC Design, Test & Evaluation Guide 02/17/2017 Section 6.1**	**Venting holes for AV and REC**	**20.05.2018**
F10.1	IREC		X								A 1/8 to 3/16 inchhole shall be drilled in the booster section just behind the nosecone or payload shoulder area.	To be verified	IREC Design, Test & Evaluation Guide 02/17/2017 Section 6.1		19.03.2018
F11.	**IREC**	**X**	**X**								**Launch vehicles shall withstand the operating stresses and retain structural integrity under the conditions encountered during handling as well as rocket flight.**	**Compliant**	**IREC Design, Test & Evaluation Guide 02/17/2017 Section 6.2**	**FEM verified**	**20.05.2018**
F11.1	IREC		X	X	X	X	X	X	X	X	PVC (and similar low-temperature polymers), Public Missiles Ltd. (PML) Quantum Tube, and stainless steel components shall not be used in any structural (ie load bearing) capacity, most notably as load bearing eyebolts, launch vehicle airframes, or propulsion system combustion chambers.	Compliant	IREC Design, Test & Evaluation Guide 11/22/2017 Section 6.2.1		20.05.2018
F11.2	IREC		X								All load bearing eye bolts shall be steel and of the closed-eye, forged type – NOT of the open eye, bent wire type.	Compliant	IREC Design, Test & Evaluation Guide 02/17/2017 Section 6.2.2		20.05.2018
F11.3	IREC		X								All load bearing eyebolts and U-Bolts shall be steel (other than stainless). This requirement extends to any bolt and eye-nut assembly used in place of an eyebolt.	Compliant	IREC Design, Test & Evaluation Guide 11/22/2017 Section 6.2.2		20.05.2018

ID	Source	SIM	ST	PP	REC	AV	PL	CON	OPS/ LOG	MAN	Requirement Description	Compliance	Source	Reasoning & Comments	Last Updated by
F11.4	IREC		X								Airframe joints which implement "coupling tubes" should be designed such that the coupling tube extends no less than one body caliber on either side of the joint – measured from the separation plane	Compliant	IREC Design, Test & Evaluation Guide 02/17/2017 Section 6.2.3		20.05.2018
F11.5	IREC		X								Launch lugs (aka rail guides) shall implement "hard points" for mechanical attachment to the launch vehicle airframe.	Compliant	IREC Design, Test & Evaluation Guide 02/17/2017 Section 6.2.4		25.05.2018
F11.5.1	IREC		X								The aft most launch lug shall support the launch vehicle's fully loaded launch weight while vertical	Compliant	IREC Design, Test & Evaluation Guide 02/17/2017 Section 6.2.4		25.05.2018
F11.5.2	SE		X								Launch lugs shall be compatible with the launch rail	Compliant			25.05.2018
F11.5.3	SE	X	X								Launch lug shall not interfere with flow measurement devices and infect stability	Compliant		Used the airfoil shape to minimize drag	25.05.2018
F12.	**SE**					**X**					**Telemetry shall deliver system status and main events to the ground station and main events from pre-launch to recovery**	**To be verified**			**19.03.2018**
F12.1	SE					X					Telemetry shall deliver confirmation of launch, apogee, payload ejection, first recovery event, main recovery event, touch down	To be verified		launch: accelerometer; apogee: barometer; payload ejection: ?; first recovery event: contact measurement?; main recovery event: accelerometer; touch down: accelerometer	19.03.2018
F12.2	SE					X					Telemetry shall deliver touch down position of the rocket with an accuracy of 50m	To be verified		gps	19.03.2018
F12.3	SE					X					Telemetry shall deliver status of all ejection and seperation mechanisms	To be verified		separation mechanisms: contacts	19.03.2018
F12.4	SE					X					Telemetry shall deliver battery status of LB avionics and NC avionics	To be verified		to be discussed after recovery design finishded	19.03.2018
F12.5	SE					X					Telemetry shall deliver altitude	To be verified			19.03.2018
F12.5.1	SE					X					During ascent: Telemetry shall deliver altitude every 0,1 second	To be verified			19.03.2018
F12.5.2	SE					X					During descent: Telemetry shall deliver altitude every 0,5 second	To be verified			19.03.2018
F12.5.3	SE					X					Ground station shall deliver velocity with provided altitude, angle and time	To be verified			19.03.2018
F12.6	SE					X					Telemetry shall provide temperature and pressure data from the nosecone, LB avionics and the motor	To be verified		sensors outside of motor and getting data through interpolation/simulation	19.03.2018
F12.6.1	SE					X					Pre-Launch: Every 30s	To be verified			19.03.2018
F12.6.2	SE					X					Count Down and ascent: Every 0,1s	To be verified			19.03.2018

ID	Source	SIM	ST	PP	REC	AV	PL	CON	OPS/ LOG	MAN	Requirement Description	Compliance	Source	Reasoning & Comments	Last Updated by
F12.6.3	SE					X					During descent: Every 0,5 second	To be verified			19.03.2018
F12.6.4	SE					X					After touch down: Every 30s	To be verified			19.03.2018
F12.7	SE					X					Telemetry may deliver images	Compliant			25.05.2018
F12.8	SE		X			X					The Avionics should be in the nosecone (non-conducting material for communication) AND above the motor (logging of temperature from motor and pressure)	Compliant			25.05.2018
F13.	**SE**		**X**			**X**					**REQUIREMENT DELETED: ~~All system batteries shall be fed and connected to an external source until launch~~**	**Deleted**		**also recovery**	**19.03.2018**
F14.	**SE**					**X**					**All sensor data shall be logged and saved on board**	**To be verified**		**For redundancy**	**25.05.2018**
F14.1	SE					X					During pre-launch data shall be logged and saved on board	To be verified			25.05.2018
F14.1	SE					X					Temperature shall be logged and saved on board every 30s	To be verified			25.05.2018
F14.2	SE					X					Pressure shall be logged and saved on board every 30s	To be verified			25.05.2018
F14.3	SE					X					Altitude shall be logged and saved on board every 30s	To be verified			25.05.2018
F14.2	SE					X					After arming until launch detection all sensor data shall be logged and saved on board	To be verified			25.05.2018
F14.1	SE					X					At least 30s before launch data shall be recorded (previous data can be overwritten, buffer)	To be verified			19.03.2018
F14.3	SE					X					During ascent until apogee all sensor data shall be logged and saved on board every 0,01s	To be verified			19.03.2018
F14.4	SE					X					From apogee to touch down all sensor data shall be logged and saved on board every 0,1s	To be verified			19.03.2018
F14.5	SE					X					From touch down to recovery all sensor data shall be logged and saved on board every 30s	To be verified			19.03.2018
F14.6	SE		X			X					Camera data shall be logged and saved seperately on board	To be verified			19.03.2018
F14.6.1	SE		X		X	X					~~Main recovery process shall be video recorded on board~~	Deleted			25.05.2018
F14.6.2	SE		X			X	X				REQUIREMENT DELTED: ~~Payload ejection shall be video recorded on board~~	Deleted			25.05.2018
F14.6.3	SE	X	X			X					At least one camera shall video record the flight	Compliant			25.05.2018
F14.6.3.1.	*SE*		*X*			*X*					*The camera shall point downwards along the rocket z-axis*	*Compliant*			*25.05.2018*
F14.6.3.2.	*SE*		*X*			*X*					*The external camera mounting shall have a minimum influence on the aerodynamics*	*Compliant*			*25.05.2018*
F14.6.3.3.	*SE*		*X*			*X*					*All external cameras shall be arranged radial symmetrical or have a symmetrical aerodynamic compensator*	*Compliant*			*25.05.2018*
F15.	**SE**					**X**	**X**				**~~Ejection system of the payload shall be triggered by flight avionics~~**	**Deleted**		**detect apogee**	**19.03.2018**
F15.1	SE					X	X				~~Payload ejection shall be triggered automatically~~	Deleted			25.05.2018
F16.	**Theo**		**X**		**X**	**X**					**REQUIREMENT DELETED: ~~The rocket shall send a visual signal (e.g. smoke bomb) before touch down~~**	**Deleted**		**For recover the landed rocket, AV could provide the signal for smoke bomb -> after touchdown also possible?**	**19.03.2018**
F16.1	Theo		X		X	X					REQUIREMENT DELETED: ~~Any such system shall comply with all competition regulations (ask Theo)~~	Deleted			19.03.2018

ID	Source	SIM	ST	PP	REC	AV	PL	CON	OPS/ LOG	MAN	Requirement Description	Compliance	Source	Reasoning & Comments	Last Updated by
F17.	IREC	X	X	X							Launch vehicles shall nominally launch at an elevation angle of 84° ±1° and a launch azimuth defined by competition officials at the IREC	To be verified	IREC Design, Test & Evaluation Guide 02/17/2017 Section 8.1		19.03.2018
F18.	SE			X							Test bench for motor development shall be built	Compliant			19.03.2018
Performance Requirements		X	X	X	X	X	X	X	X	X					
P1.	IREC	X	X	X		X		X			Rocket shall reach target apogee	To be verified	IREC Rules & Req. Doc 03/06/2017 Section 2.0		19.03.2018
P1.1	SE	X	X	X		X		X			Rocket shall reach target apogee within margin limits (2-5% accuracy)	To be verified			19.03.2018
P2.	IREC		X				X				Launch vehicle shall carry no less than 8.8 lb of payload to the apogee	Compliant	IREC Rules & Req. Doc 03/06/2017 Section 2.3		25.05.2018
P3.	FAA / IREC			X							Launch vehicles shall not exceed an installed total impulse of 9,208 pound-seconds/40,960 Newton-seconds (FAA Class 2 Amateur Rocket)	Compliant			25.05.2018
P3.1	SE			X					X	X	The propulsion responsible team member at the competition shall have at least a TRIPOLI level 2 certification	Compliant		Safety and Insurance Issue	20.05.2018
P6.	SE	X	X	X							Motor performance shall provide 7700 Ns	Compliant			25.05.2018
P7.	IREC					X					Performance of electronics shall be ensured	To be verified			19.03.2018
P7.1	IREC				X						Launch vehicles and payload shall implement redundant recovery system electronics	Compliant	IREC Design, Test & Evaluation Guide 02/17/2017 Section 3.3		20.05.2018
P7.1.1	IREC				X						Recovery system shall include redundant sensors/flight computers	Compliant	IREC Design, Test & Evaluation Guide 02/17/2017 Section 3.3		19.03.2018
P7.1.1.1.	*IREC*				*X*				*X*		*At least one redundant recovery system electronics subsystems shall implement a COTS flight computer.*	*Compliant*	*IREC Design, Test & Evaluation Guide 02/17/2017 Section 3.3.1*		19.03.2018
P7.1.1.2.	*SE*				*X*				*X*		*The recovery system electronics flight computers shall be disimillar*	*Compliant*			19.03.2018
P7.1.2	IREC				X						Recovery system shall include redundant "electric initiators"	Compliant	IREC Design, Test & Evaluation Guide 02/17/2017 Section 3.3		19.03.2018
P7.1.3	IREC				X	X					Recovery system shall include redundant power supply	Compliant	IREC Design, Test & Evaluation Guide 02/17/2017 Section 3.3		19.03.2018
P7.1.3.1.	*SE*				*X*	*X*					*Life endurance of ~~the recovery~~ and avionics batteries shall be 4hrs at 80°C (at launchpad)*	*To be verified*			20.05.2018
P7.1.3.2.	*SE*										*Life endurance of the recovery and avionics batteries should be at least 1hr after landing*	*To be verified*			19.03.2018
P7.1.3.3.	*SE*										*Recovery and avionics battery shall work at lowest temperature limit (testing in Switzerland)*	*To be verified*			19.03.2018

ID	Source	SIM	ST	PP	REC	AV	PL	CON	OPS/LOG	MAN	Requirement Description	Compliance	Source	Reasoning & Comments	Last Updated by
P7.2	IREC		X		X	X					All safety critical wiring should follow the safety critical wiring guidelines described in Appendix B of the IREC Design, Test & Evaluation Guide 02/17/2017	Compliant	IREC Design, Test & Evaluation Guide 02/17/2017 Section 3.4		25.05.2018
P7.3	IREC		X		X	X					All safety critical wiring shall implement a cable management solution (e.g. wire ties, wiring, harnesses, cable raceways)	Compliant	IREC Design, Test & Evaluation Guide 02/17/2017 Section 3.4.1		25.05.2018
P7.4	IREC		X		X	X					small amount of slack should be provided to prevent unintentional de-mating due to expected launch loads transferred into wiring/cables at physical interfaces	Compliant	IREC Design, Test & Evaluation Guide 02/17/2017 Section 3.4.1		25.05.2018
P7.5	IREC		X		X	X					All safety critical wiring/cable connections shall be sufficiently secure as to prevent de-mating due to expected launch loads	Compliant	IREC Design, Test & Evaluation Guide 02/17/2017 Section 3.4.1	Tug test to be performed	25.05.2018
P7.6	SE		X		X	X					All electronics shall function under the expected TBD shock and vibrations	Compliant		make measurements AV components withstand 16g (according to data sheets) expect for GSP	25.05.2018
P8.					**X**	**X**	**X**				**Recovery and avionics system performance of launch vehicle and payload shall be ensured**	**To be verified**		**Avionics performance still open**	**25.05.2018**
P8.1	IREC		X		X	X	X				Ground test of the recovery and avionics systems shall be performed and documented	Compliant	IREC Design, Test & Evaluation Guide 02/17/2017 Section 3.6.1		25.05.2018
P8.1.1	SE		X		X	X	X				Recovery and avionics electronics shall be fully included in the ground test	Closed		Avionics was not included as not available by then	25.05.2018
P8.2	SE		X		X	X	X				At least one drop Test of the recovery and avionics systems shall be performed and documented	Closed			25.05.2018
P8.2.1	SE		X		X	X	X				Recovery and avionics electronics shall be fully included in the drop test	Closed			25.05.2018
P8.3	IREC				X	X	X				At least one flight test of the recovery and avionics systems shall be performed and documented	Closed	IREC Design, Test & Evaluation Guide 02/17/2017 Section 3.6.2		25.05.2018
P8.3.1	SE				X	X	X				Recovery and avionics electronics shall be fully included in the flight test	Closed			25.05.2018

ID	Source	SIM	ST	PP	REC	AV	PL	CON	OPS/LOG	MAN	Requirement Description	Compliance	Source	Reasoning & Comments	Last Updated by
P9.	IREC	X		X							Launch vehicles shall have sufficient velocity upon "departing the launch rail".	Compliant	IREC Design, Test & Evaluation Guide 02/17/2017 Section 8.2	Alternatively, the team may use detailed analysis to prove stability is achieved at a lower rail departure velocity (greater than 50 ft/s [15.24 m/s]) either theoretically (eg computer simulation) or empirically (eg flight testing). Teams	25.05.2018
P9.1	IREC	X		X							Acceleration shall be achieved within launch rail length (5.5m)	Compliant	IREC Design, Test & Evaluation Guide 02/17/2017 Section 8.2		25.05.2018
P10.	IREC	X	X					X			Static margin during ascent shall be at least 1,5 body calibers	Compliant	IREC Design, Test & Evaluation Guide 22/11/2017 Section 8.3	regardless of CG movement due to depleting consumables and shifting center of pressure (CP) location due to wave drag effects	25.05.2018
P11.	IREC	X	X					X			Static stability margin during ascent shall not be significantly greater than 2 body calibers (eg greater than 6 body calibers)	Compliant	IREC Design, Test & Evaluation Guide 22/11/2017 Section 8.4		25.05.2018
P12.	SE					X					Telemetry range shall be at least 10km	To be verified		Discuss in PDR	19.03.2018
P13.	SE				X						Initial recovery event shall take place at latest TBD seconds after apogee	To be verified		Need time from SIM	19.03.2018
P13.1	SE				X						Main recovery event shall take place TBD seconds after apogee	To be verified			19.03.2018
P13.2	SE				X						In any case the main recovery shall take place TBD seconds after apogee	To be verified		For example initial recovery fails	19.03.2018
P14.	SE		X		X						Rocket body shall withstand the landing shocks from TBD N	Compliant			25.05.2018
P15.	SE				X		X				Correct folding of parachutes shall be ensured	Compliant			20.05.2018
P15.1	SE				X		X				Successfull folding and deployment shall be tested at least 2 times	Compliant			20.05.2018
P15.2	SE				X		X				At least 2 persons shall be successfully able to fold and deploy those tests	Compliant			20.05.2018
P16.	IREC		X								Airframe coloration should be adjusted to competition environment	Compliant			20.05.2018
P16.1	IREC		X								Coloration should be mostly in white or lighter tinted colors (eg yellow, red, orange, etc.).	Compliant		airframes are especially conducive to mitigating some of the solar heating experienced in the IREC launch environment.	20.05.2018

ID	Source	SIM	ST	PP	REC	AV	PL	CON	OPS/ LOG	MAN	Requirement Description	Compliance	Source	Reasoning & Comments	Last Updated by
P16.2	IREC		X								High-visibility schemes (eg high-contrast black, orange, red, etc…) and roll patterns (eg contrasting stripes, "V" or "Z" marks, etc..) should be used.	Closed		Those may allow ground-based observers to more easily track and record the launch vehicle's trajectory with high-power optics.	25.05.2018
Interface Requirements		X	X	X	X	X	X	X	X	X					14.01.2018
I1.	**IREC**		**X**				**X**				**Payload shall be replaceable by ballast of the same mass with no change to the rocket's trajectory**	**Compliant**	**IREC Rules & Req. Doc 03/06/2017 Section 2.3**		**20.05.2018**
I2.	**IREC**		**X**				**X**				**Payload shall not be inextricably connected to the launch vehicle**	**Compliant**	**IREC Rules & Req. Doc 03/06/2017 Section 2.3.3**		**20.05.2018**
I2.1	IREC		X				X				Payload may connect to other payload associated components (eg leads to sensors located variously throughout the airframe, deployment mechanisms, etc…) when integrated with the launch vehicle	Compliant	IREC Rules & Req. Doc 03/06/2017 Section 2.3.4		20.05.2018
I2.1.1	IREC						X				Those associated components shall not be accounted to the payload mass	Compliant	IREC Rules & Req. Doc 03/06/2017 Section 2.3.4		20.05.2018
I3.	**IREC**		**X**				**X**				**Payload geometry shall have CubeSat standard**	**Compliant**	**IREC Rules & Req. Doc 03/06/2017 Section 2.3.4**		**20.05.2018**
I3.1	SE		X				X				Outer mold line of the payload is described by 3U	Compliant	IREC Rules & Req. Doc 03/06/2017 Section 2.3.4		20.05.2018
I4.	**SE**		**X**	**X**	**X**	**X**	**X**	**X**			**Every subcomponent shall be disassembled, exchanged and reassembled in a given time**	**Compliant**			**20.05.2018**
I4.1	SE		X	X	X	X	X	X			Disassembly shall be trained at least once before the competition	Compliant			20.05.2018
I4.2	SE		X	X	X	X	X	X			For each disassembly/reassembly a check list ensuring functionality of the subsystem shall be provided	Compliant			20.05.2018
I5.	**SE**			**X**					**X**		**Ignition of the propellant shall be conducted by a COTS ignitor**	**Compliant**			**20.05.2018**
I5.1	IREC			X							The arming system shall not be software based	Compliant	IREC Design, Test & Evaluation Guide 02/17/2017 Section 2.2		20.05.2018
I5.1.1	IREC			X							All ground-started propulsion system ignition circuits/sequences shall not be "armed" until all personnel are at least 50 ft (15 m) away from the launch vehicle	Compliant	IREC Design, Test & Evaluation Guide 02/17/2017 Section 2.2.1		20.05.2018
I5.2	SE			X						X	To ignite the provided arming system by ARGOS and IREC shall be used	Compliant			20.05.2018
I7.	**IREC**		**X**				**X**				**All energetics of launch vehicle and payload (ignitors, pyrogens, springs, pressure vessels) shall be armed only in the launch position**	**Compliant**	**IREC Design, Test & Evaluation Guide 02/17/2017 Section 4.1**		**20.05.2018**
I7.1	SE		X			X	X				Arming shall be detectable	Compliant			20.05.2018

ID	Source	SIM	ST	PP	REC	AV	PL	CON	OPS/LOG	MAN	Requirement Description	Compliance	Source	Reasoning & Comments	Last Updated by
I7.1.1	SE		X			X					The NC avionics and LB avionics each shall deliver an audible feedback	Compliant		not sensor but boards-> PDR	20.05.2018
I7.1.2	SE		X			X					Arming shall occur with haptical feedback (e.g. button, pin ...)	Compliant			20.05.2018
I7.2	IREC		X	X		X	X				Two separate events shall be required to release the energy	Compliant	IREC Design, Test & Evaluation Guide 02/17/2017 Section 4.1		20.05.2018
I7.3	IREC		X	X		X	X				All energetic device arming features shall be externally accessible/controllable	Compliant	IREC Design, Test & Evaluation Guide 02/17/2017 Section 4.1.1		20.05.2018
I7.3.1	IREC		X			X	X				All energetic device arming features shall be located on the airframe	Compliant	IREC Design, Test & Evaluation Guide 02/17/2017 Section 4.1.2		20.05.2018
I8.	**SE**	**X**	**X**	**X**	**X**	**X**	**X**	**X**			**All weights shall be evenly distributed along circumference and the radius of the rocket body**	**Compliant**			**20.05.2018**
I8.1	SE	X	X	X	X	X	X	X			Center of mass of any subsystem shall be on the rocket z-axis	Compliant			20.05.2018
I8.1.1	SE	X	X								Interface shall be reserved to compensate center of mass deviations from the z-axis	Compliant			20.05.2018
I9.	**SE**	**X**	**X**								**Balast interface shall be reserved to shift the center of mass along the z-axis by adding balast**	**Compliant**			**20.05.2018**
I9.2	SE	X	X								Simulations shall define optimal positions for these balast interfaces	Closed			25.05.2018
I10.	**SE**		**X**		**X**						**The rocket body shall withstand the parachute opening shock of at least 3,7kN**	**Compliant**		**Value from project RORO**	**25.05.2018**
I11.	**SE**		**X**	**X**	**X**	**X**	**X**	**X**			**Launch vehicle shall not exceed a mass of 30 kg**	**Compliant**			**20.05.2018**
I12.	**SE**	**X**	**X**								**Launch vehicle shall have a minimial drag during ascent**	**Compliant**			**25.05.2018**
I13.	**AV**		**X**			**X**					**The nosecone shall support the avionics and electronics**	**Compliant**			**20.05.2018**
I13	AV		X			X					The nosecone shall be made out of non-conducting material to be able to transceive radio waves	Compliant	Avionics	Antennas must be able to send signal.	20.05.2018
I14	AV		X			X					The nosecone shall be splitted during the first recovery event (GPS antenna has to face the sky, only possible with two antennas during ascent and descent due to different orientation of the nosecone)	Compliant	Avionics		20.05.2018
I15	**IREC**				**X**						**The recovery system rigging (eg parachute lines, risers, shock chords, etc...) shall implement swivel links at connections to relieve torsion as the specific design demands.**	Compliant	**IREC Design, Test & Evaluation Guide 11/22/2017 Section 3.1.4**		**20.05.2018**
Operational Requirements		**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**					
O1.	**IREC**									**X**	**Teams shall consist of members who were matriculated undergraduate or graduate students during the previous academic year from one or more academic institutions**	**Compliant**	**IREC Rules & Req. Doc 03/06/2017 Section 2.2**		**20.05.2018**
O2.	**IREC**									**X**	**Each team shall submit no more than one project into the IREC**	**Compliant**	**IREC Rules & Req. Doc 03/06/2017 Section 2.2**		**20.05.2018**
O3.	**IREC**									**X**	**A hazard analysis shall be performed for documentation**	**Compliant**	**IREC Rules & Req. Doc 03/06/2017 Section 2.7.2.8**	**Responsible: Q**	**20.05.2018**

ID	Source	SIM	ST	PP	REC	AV	PL	CON	OPS/ LOG	MAN	Requirement Description	Compliance	Source	Reasoning & Comments	Last Updated by
O3.1	SE	X	X	X	X	X	X	X			A hazard analysis shall be made by every subsystem	Compliant			20.05.2018
O4.	**IREC**									**X**	**A risk assessment shall be performed for documentation**	**Compliant**	**IREC Rules & Req. Doc 03/06/2017 Section 2.7.2.9**	**Responsible: Q**	**20.05.2018**
O4.1	SE	X	X	X	X	X	X	X			A risk assessment shall be made by every subsystem	Compliant			20.05.2018
O5.	**SE**									**X**	**A FMECA shall be made**	**Compliant**		**Responsible: Q (work together with subteam leaders)**	**20.05.2018**
O6.	**IREC**	**X**	**X**	**X**	**X**	**X**	**X**	**X**		**X**	**Project Technical Report shall be submitted in time**	**Compliant**	**IREC Rules & Req. Doc 03/06/2017 Section 2.9**		**25.05.2018**
O7.	**IREC**									**X**	**eligible team member representatives shall be sent to the Spaceport America Cup.**	**Compliant**	**IREC Rules & Req. Doc 03/06/2017 Section 2.9**		**20.05.2018**
O8.	**SE**									**X**	**Members participating in procedures shall attend briefing and debriefing**	**Compliant**			**20.05.2018**
O9.	**SE**						**X**				**Payload shall participate in SDL Payload Challenge**	**Compliant**			**20.05.2018**
Safety Requirements		X	X	X	X	X	X	X	X	X					
S1.	**SE**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**Safety concept shall be implemented**	**Compliant**			**20.05.2018**
S1.1	SE	X	X	X	X	X	X	X	X	X	**Only authorized and trained personnel are allowed to use and have access to specific facilities (workshops, use of machines, …)**	Compliant			20.05.2018
S2.	**IREC**			**X**						**X**	**Non-toxic propellants shall be used. Ammonium perchlorate composite propellant (APCP), potassium nitrate and sugar (aka "rocket candy"), nitrous oxide, liquid oxygen (LOX), hydrogen peroxide, kerosene, propane, alcohol, and similar, are all considered non-toxic**	**Compliant**	**IREC Design, Test & Evaluation Guide 02/17/2017 Section 2.1**		**20.05.2018**
S3.	**IREC**				**X**						**The recovery system shall implement adequate protection (eg fire resistant material, pistons, etc...)**	**Compliant**	**IREC Design, Test & Evaluation Guide 02/17/2017 Section 3.1.2**	**to prevent hot ejection gases (if implemented) from causing burn damage to retaining chords, parachutes, and other vital components as the specific design demands.**	**25.05.2018**
Legal Requirements		X	X	X	X	X	X	X	X	X					
L1.	**IREC**		**X**			**X**				**X**	**Payloads shall not contain significant quantities of lead or any other hazardous materials**	**Compliant**	**IREC Rules & Req. Doc 03/06/2017 Section 2.3.5**		**20.05.2018**
L2.	**IREC**		**X**	**X**			**X**			**X**	**Payload shall not contain any radioactive materials or vertebrate animals**	**Compliant**	**IREC Rules & Req. Doc 03/06/2017 Section 2.3.5**		**20.05.2018**
L3.	**IREC**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**Teams shall comply with all rules, regulations, and best practices imposed by the authorities at their chosen test location(s)**	**Compliant**	**IREC Design, Test & Evaluation Guide 02/17/2017 Section 2.4**		**20.05.2018**

ID	Source	SIM	ST	PP	REC	AV	PL	CON	OPS/	LOG	MAN	Requirement Description	Compliance	Source	Reasoning & Comments	Last Updated by
L3.1	SE			X								Handling of propellants shall comply with Swiss handling and transportation regulations of dangerous goods	Compliant			20.05.2018
L3.2	SE			X								Transportation of propellants shall comply with Swiss and US laws	Compliant			20.05.2018
L4.	**SE**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**		**X**	**All separated tests should be completed by 01 April**	**Closed**	**IREC Design, Test & Evaluation Guide 02/17/2017 Section 2.4**	**In order to be ready for test launch**	**25.05.2018**
L5.	**IREC**										**X**	**The team's Team ID (a number assigned by ESRA prior to the IREC), project name, and academic affiliation(s) shall be clearly identified on the launch vehicle airframe.**	**Compliant**	**IREC Design, Test & Evaluation Guide 02/17/2017 Section 6.3**		**20.05.2018**
L6.	**IREC**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**		**X**	**Teams shall comply with all rules, regulations, and best practices imposed by the authorities at their chosen workshops, facilities, equipment and tools**	**Compliant**	**IREC Design, Test & Evaluation Guide 02/17/2017 Section 2.4**		**20.05.2018**

Q. Propulsion System Appendix: Thrust Force Calculation

The motor has to accelerate the rocket to at least 30.48 m/s before leaving the launch rail. In a first calculation, it is assumed that aerodynamic forces and mass losses are relatively small compared to the motor performance during launch rail phase and are therefore neglected. To determine the required thrust, Newton's second law and gravity force is applied:

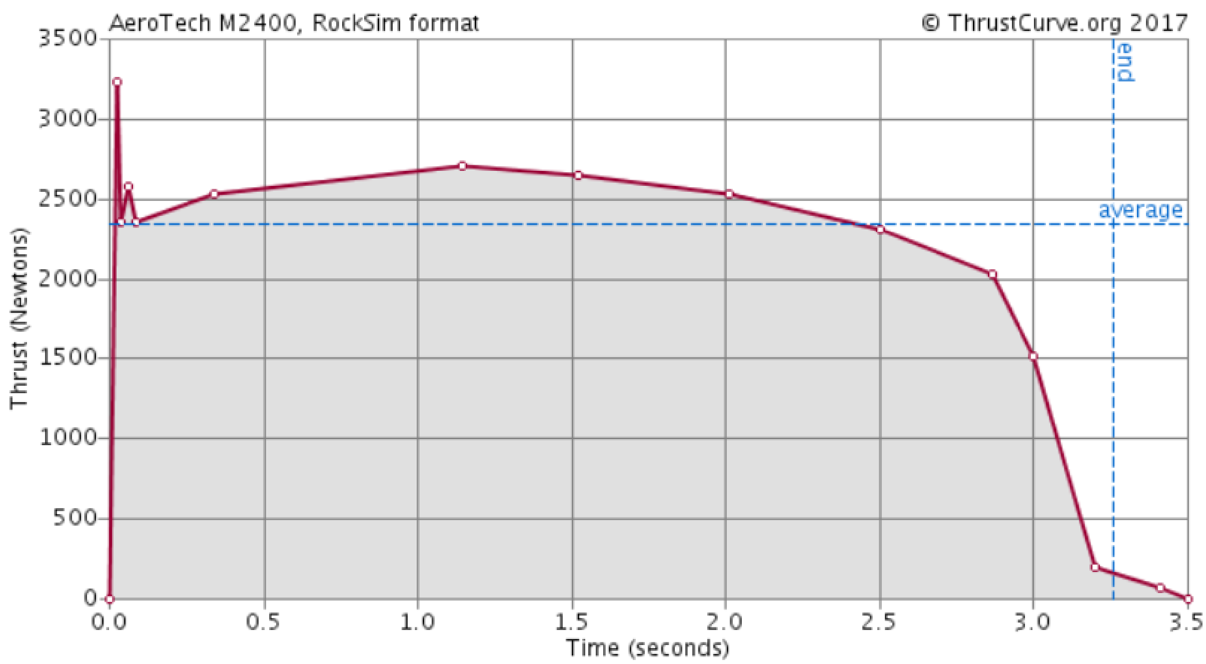
$$F_{req} = F_T + F_G = m \cdot a + m \cdot 9.81 \frac{m}{s^2}$$

By using simple laws of motion, the values for the launch rail s=5.5 m,v=30.48 m/s and the budgeted lift-off weight of m=22.3 kg the necessary thrust force is determined to be:

$$F = m\left(\frac{v^2}{2s} + g\right) = 22.3\,\mathrm{kg} \cdot \left(\frac{\left(30.48\,\frac{\mathrm{m}}{\mathrm{s}}\right)^2}{2 \cdot 5.5\,\mathrm{m}} + 9.81\frac{\mathrm{m}}{\mathrm{s}^2}\right) = 2102\,\mathrm{N}$$

R. Propulsion System Appendix: Thrust Curve M2400

Thrust curve retrieved from: http://www.thrustcurve.org/simfilesearch.jsp?id=989



S. Aerostructures System Appendix: Inner Structure – Dimensioning of the Rods: Minimum Diamater

Mass of attached systems:

- Payload, maximum 4.5kg
- Avionics, maximum 1kg

$5.5kg \cdot g \approx 54N$

Assumed acceleration a at parachute deployment:

- Assumed maximum force at parachute deployment: $9kN$
- Assumed Weight of rocket at parachute deployment: $25kg$

$a = \frac{9kn}{25kg} \approx 36g$

Maximum load on rod at parachute deployment:
$F = 54N \cdot 36g \approx 1950N$

Rod, Tensile Strength (from catalogue) $= 1400MPa$

Minimum Rod Diameter:
Factor of Safety $= 2$
$A_{min,tensile} = \frac{F.S \cdot 1950N}{1400MPa} \approx 2.8mm^2$

Elongation at Parachute Deployment:

- Elongtation at break ϵ_{max} (from catalogue): 0.015
- Maximum Load F at parachute deployment: $1950N$
- Modulus in tension E (from catalogue): $130GPa$

$\sigma_{max} = E \cdot \epsilon_{max} = 1950MPa$

$\sigma = \frac{F}{A_{min,tensile}} \approx 700MPa$
$\sigma < \sigma_{max}$

Tensile strength is more critical than elongation.

Theoretically a rod transverse section of 2.8mm^2 would be sufficient to withstand the occurring loads. Due to manufacturing and handling constraints a larger rod diameter rod is recommended. This is furthermore beneficial to evade vibrations.
A rod diameter of 6mm is recommended. This maximizes the clamping surface for the rod clamp without violating the build volume constraints.

T. Aerostructures System Appendix: Inner Structure – Friction Clamping Ring and Rod

- Payload, maximum 4.5kg
- Avionics, maximum 1kg

Payload module has highest mass, therefore critical clamping force calculates with an acceleration at parachute deployment of $a = 36g$:
$F_{Friction,tot} = m_{Payload} \cdot a = 4.5kg \cdot 36g \approx 1600N$

The internal structure consists of three rods, therefore the total needed friction force of the clamps is divided by three:
$F_{Friction,Min,SingleClamp} = F_{Friction,tot} \cdot \frac{1}{3} \approx 550N$

No exact value for friction coefficient for aluminium - carbon fiber/epoxy matrix found in literature, assumption that friction will be better than aluminium - aluminium (dry) due to the material pairing of plastic and aluminium. As worst case scenario $\mu = 0.21$ is chosen (alu-alu, dry).

$F_{Friction,Min,SingleClamp} = \mu \cdot F_N$
With a factor of safety $F.S. = 2$ the normal force $F_{N,min}$ reads as follows:
$F_{N,min} = \frac{F_{Friction,Min,SingleClamp} \cdot F.S.}{\mu} \approx 5250N$

Clamping ring can be simplified as two halfshells connected by a hinge (see fig. xx). The minimum preload force on the bolt can then be calculated as follows:

$$F_{min,preload} = F_N \frac{l_1}{l_2} = 5250N \frac{5}{10.5} = 2500N$$

Bonding joint rod - T-sleeve

$$\frac{F}{b \cdot l_u} = \tau_{B,real}$$

$\tau_{B,real} = f_Q \cdot f_W \cdot \tau B$
$f_Q = 0.8; f_W = 0.66$

Glue: DP 760.0050 (Swisscomposite catalogue)
$\tau_B = 24MPa$ at 80°C

$\tau_{B,real} = 0.8 \cdot 0.66 \cdot 24 = 12.672 Mpa$

$l_{u,T} = 25mm$
$b_T = 6mm \cdot \pi = 18.85mm$

$F_{max,T} = \tau_{B,real} \cdot l_{u,T} \cdot b_T = 5971,54N$

The bonding joint of one rod with its T-sleeve can withstand ≈ 5900N, which is exceeding for the expected shock load of 1950N at parachute deployment due to the weight of the attached payload and avionics module.

Formula for bonding joint from skript of the course "Leichtbau" at ETHZ, fall semester 2016.

U. Aerostructures System Appendix: Finite Elemente Analysis

During flight the following two phases will be the events, where the most critical load cases for the different parts can be expected.

- Motor burn (critical parts: bulkheads, inner structure, fairing)
- Main parachute deployment: (critical parts: bulkheads, inner structure)

Regarding these phases more than one load case for each part of the rocket is possible. But interesting for the analysis are the critical ones. To get the critical load case for every part a simple flux of force for the rocket can help to identify the critical ones. Comparing the two flight phases with each other the following critical load cases can be found:

- Motor burn: upper and lower motor bulkhead with connection, buckling of the fairing
- Main parachute deployment: recovery bulkhead, inner structure, field joint

The following data is used for the simulations.

Safety factor: 1.5

Motor burn
Motor: Aerotech M2400
Average Thrust: 2400N
Maximum Thrust: 3401.6N -> **5100N** with safety factor
Expected acceleration: 14g

Main Parachute opening
Maximum shock: 5000N -> **7500N** with safety factor
Expected acceleration: 24g

Rocket Mass
With propellant: 24.5kg
Without propellant: 21kg
Weight inner structure with parts: 6kg -> **2200N** with safety factor (main parachute deployment)
Weight lower structure with parts (without propellant): 8kg -> **3000N** with safety factor (main parachute deployment)
Estimated weight recovery and nosecone with parts: 6kg -> **1300N** with safety factor (motor burn)
Material
Aluminum 7075
Yield strength: 485MPa
Ultimate strength: 549MPa

Aluminum 6082
Yield strength: 255MPa
Ultimate strength: 310MPa

Fitting screw (Steel 012.9/12.9)
Yield strength: 1080MPa
Ultimate strength: 1200MPa

Carbon fibre
Fibre tensile strength: 4385MPa
Fibre tensile modulus: 231GPa

S235JR
Yield strength: 185MPa
Ultimate strength: 340MPa

Upper and lower motor bulkhead (load case: motor burn)
The Structure consists of the three parts: the two bulkheads, which are made of aluminum 7075 and the shells, which are made of aluminum 6082. For the analysis the expected maximum thrust of the rocket motor is applied with safety

factor 1.5 (5100N). The force is applied at the lower motor bulkhead via motor adapter (not shown in Figure 1) at the center. The upper motor bulkhead is fixed at the field joint connection, assuming that all the thrust of the motor is transmitted through the structure.

In Figure 1 the resulting stress distribution is shown. Comparing the maximum stress with the yield strength of the used materials, one can see that the structure can withstand the loads. Stress peaks can be found at the lower edges of the screw shells.

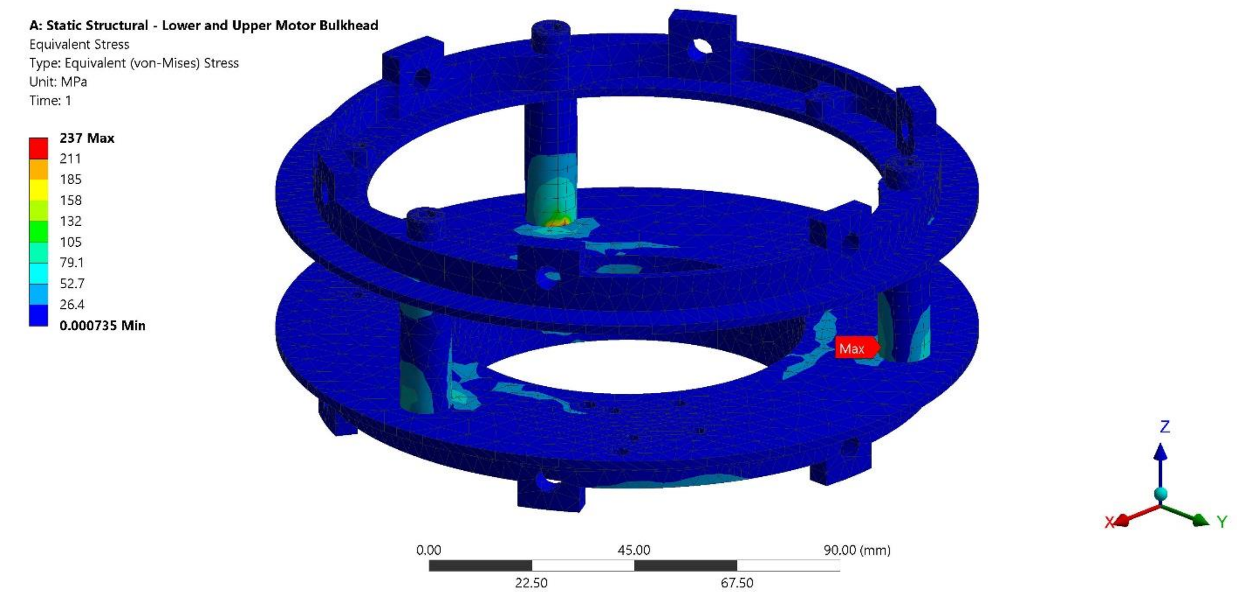


Figure 1: Stress distribution of lower and upper motor bulkhead with screw shells (the connection between upper and lower motor bulkhead) during motor burn (critical load case for these parts). Stress peaks can be found at the lower end of the screw shells.

Fairing (load case: motor burn)

For the buckling analysis the fairing of the middle section is used, because it is the longest one and has to withstand the largest forces. During flight the middle fairing has to carry the load of the inner structure and recovery and nosecone section. For simplification it is assumed that the total thrust of the rocket motor is transmitted through the middle fairing, which is too conservative. For the analysis itself a force (compression) of 1N is applied on one end to get directly the necessary forces for buckling. The other end of the tube is fixed again. The boundary conditions are not directly applied at the tube but via field joints (not shown in Figure 2 and 3). For the tube 6 layers were used (layup 0 45 0 0 45 0).

The simulated forces are exceeding the range of the expected forces by far. For this reason, it is also not a problem that our assumptions for the expected forces are too conservative.

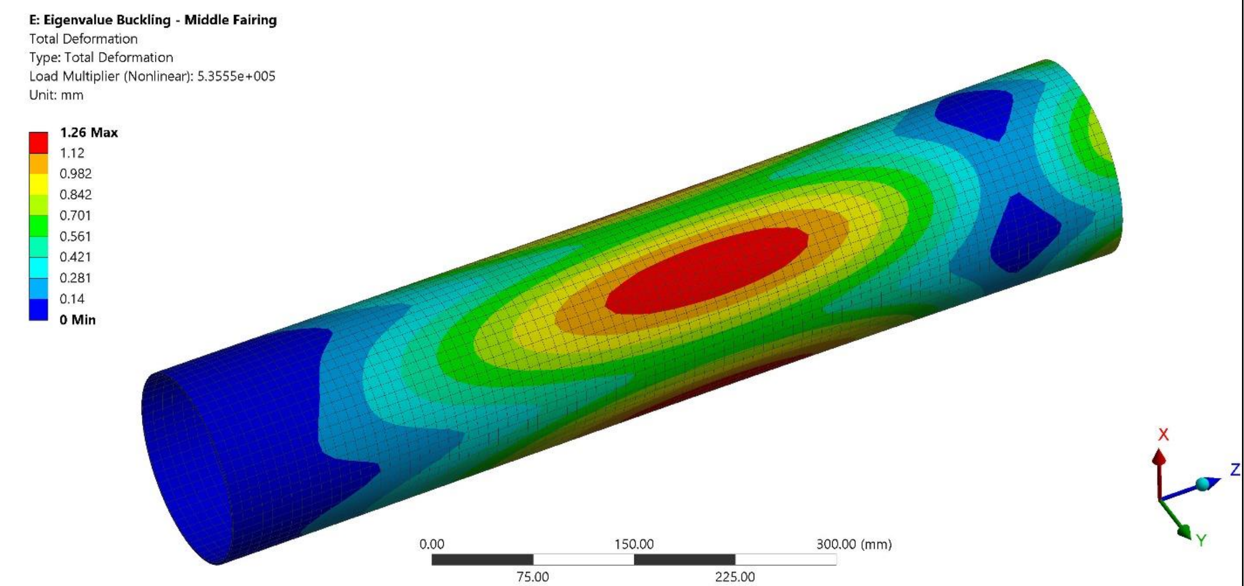


Figure 2: Displacement distribution of the first buckling mode. A load of approximately 535500N is necessary for this mode, which is about 100 times larger than the expected load, which guarantees us that no buckling will occur.

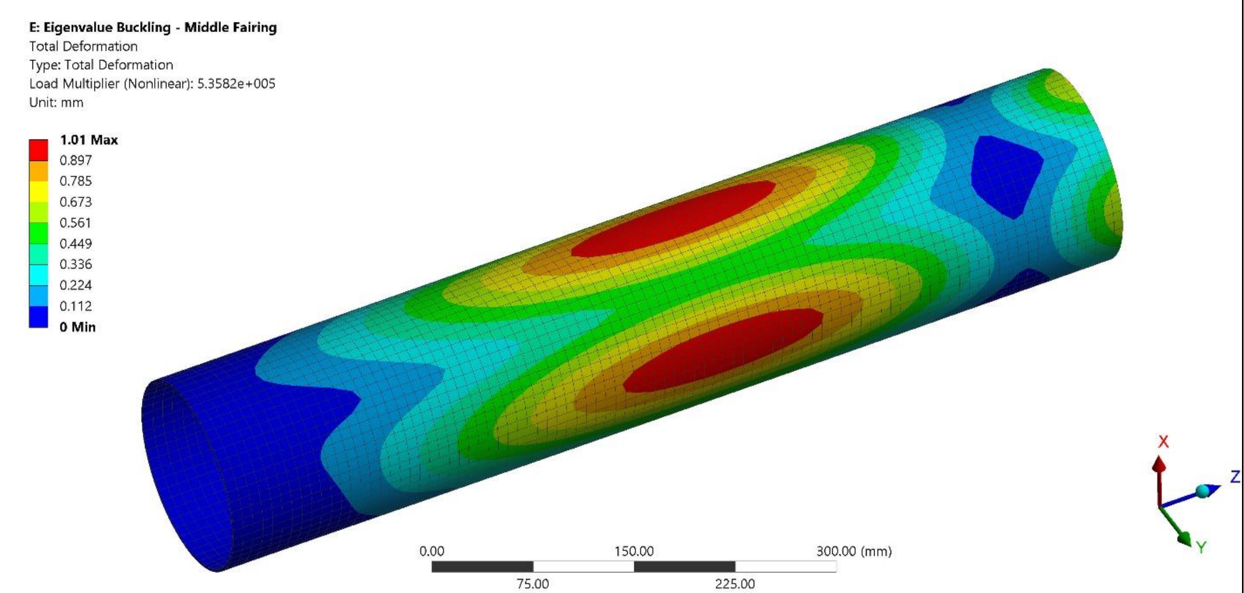


Figure 3: Displacement distribution of the second buckling mode. A load of approximately 535800N is necessary for this mode, which is about 100 times larger than the expected load, which guarantees us that no buckling will occur.

Recovery bulkhead (load case: main parachute deployment)
The recovery bulkhead is made of aluminum 7075. For the analysis a safety factor of 1.5 is applied to the expected opening shock of 5000N. The load (7500N) is applied on the parachute attachment point (hole in the center). In fact the loads there would be smaller due to the missing weight of recovery and nosecone. The bulkhead is fixed at the connection points for the inner structure and the middle fairing (lower ring with radial holes). These are also the connections where the largest amount of the opening shock is transmitted.

The analysis shows that the recovery bulkhead can withstand the expected loads of the main parachute opening. Stress peaks can be found at the edges of the reinforcement beams.

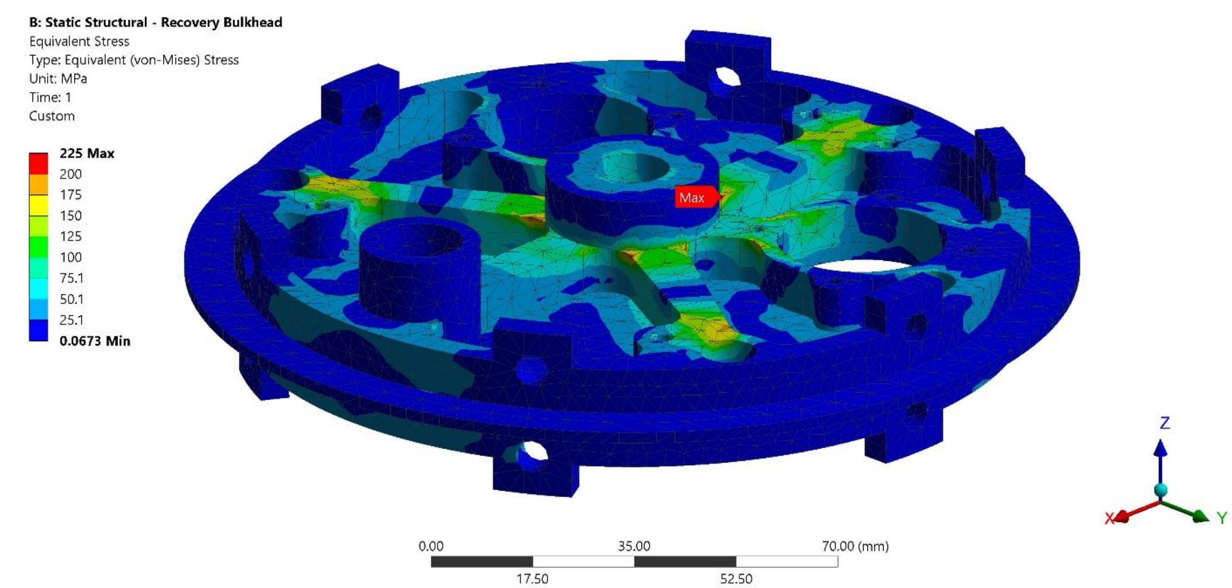


Figure 4: Stress distribution recovery bulkhead, where the recovery system and the inner structure are attached. The simulation shows the stress distribution during the main parachute deployment (critical load case for these parts). Stress peaks can be found at the upper edges of the reinforcement beams.

Inner structure (load case: main parachute deployment)
For the inner structure it is important to check if it is able to carry the load of the attached rocket parts. The critical load case is during main parachute deployment. Assuming an acceleration of 24g and a safety factor of 1.5 it has to withstand a maximum force of 2200N. The carbon fiber rods are bonded inside the t-shells (S235JR) and additionally fixed with clamp rings. For the simulation the recovery bulkhead is fixed at the parachute attachment point and a load is applied at the end of the carbon fiber rods. For the contact between t-shells and recovery bulkhead frictional contacts are used.
The simulation shows that the structure can withstand the parachute opening shock. Stress peaks are found on the outer wall of the recovery bulkhead, because of the thin wall thickness.

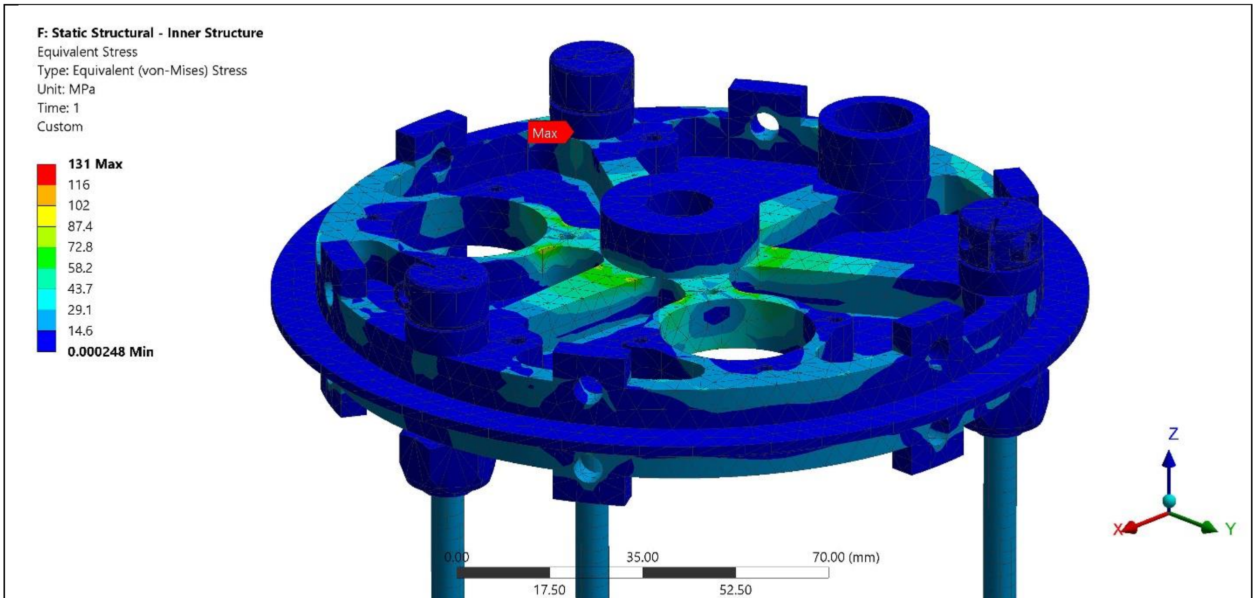


Figure 5: Stress distribution recovery bulkhead with attached inner structure. The simulation shows the stress distribution for the resulting force for the inner structure during the main parachute deployment (critical load case for this part). Stress peaks can be found at the thin wall around the attachment points for the inner structure.

Field joint (load case: main parachute deployment)

The fairings are attached to the bulkhead via field joints. For this purpose, fittings screws are used, which allow to transmit shear forces. The overall rocket contains four of these field joints, of which the most critical one is simulated to guarantee that all the field joints can withstand the loads. The critical field joint load is during the main parachute deployment. With an acceleration of approximately 24g and a safety factor of 1.5 a maximum force of 3000N is transmitted via field joint. For the simulation the recovery bulkhead is fixed at the parachute attachment and the force is applied at the field joint. For the contact region between field join, bulkhead and fitting screws frictional contact properties are used.

As it can be seen in Figure 7 the stress distribution in the field joint connection is within the acceptable range. The stress peaks can be explained with numerical errors in the contact region. Due to nonlinear contact behavior these errors must be expected. For this reason, this simulation results have to be regarded with care.

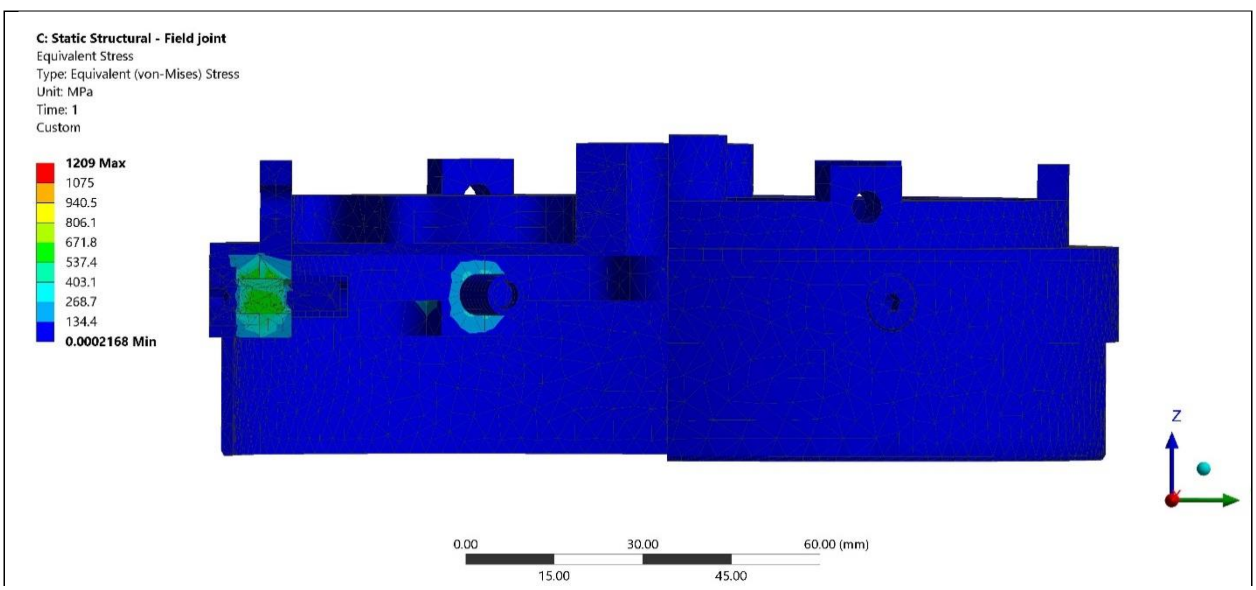


Figure 6: Stress distribution of the field joint during the main parachute deployment (critical load case). The stress peaks on the color bar are caused by numerical errors in the contact region.

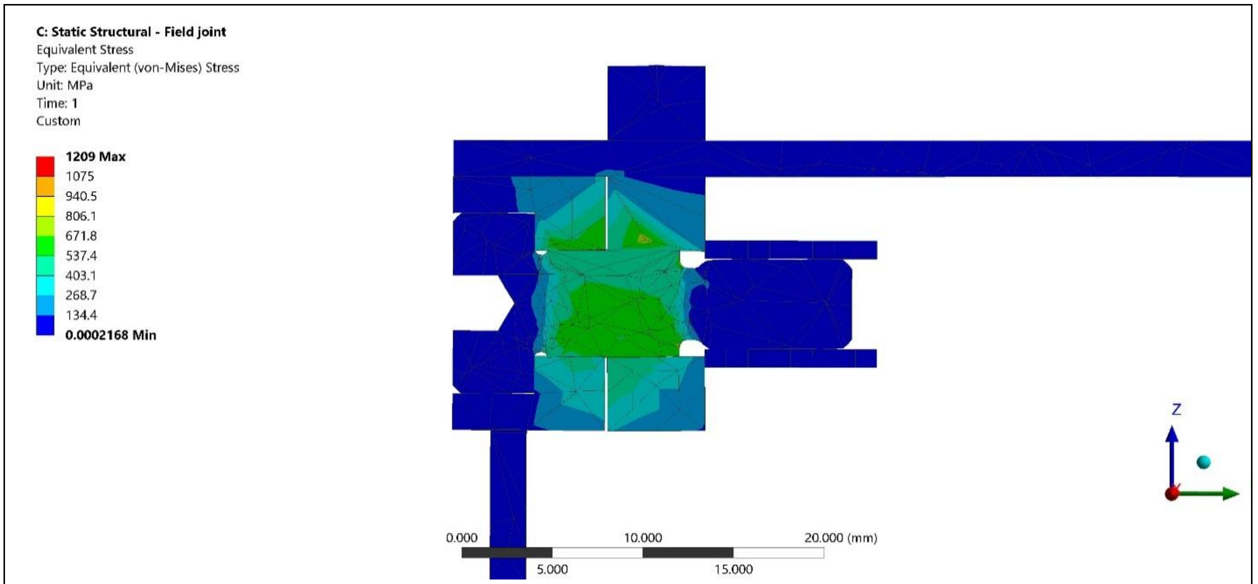


Figure 7: Detailed view of the stress distribution on the field joint during the main parachute deployment (critical load case). According to the color bar the stress distribution is around the yield strength of the used materials. The results have to be treated with care because numerical errors have to be considered in the contact region.

V. Recovery System Appendix: Dimensioning of Venting Holes

Dimensioning of venting holes for ensuring altimeter accuracy during flight

A maximum allowed error of h_{err} 20 m altitude is specified as requirement.

$$h_{err} = 20\ m$$

This corresponds to a pressure of aboutΔP = 240 Pa

$$\Delta P = \rho g h_{err}$$

The maximum rate of change in pressure ΔPm of about 3600 Pa/s based on maximum velocity of V_{max} of 300 m/s:

$$\Delta Pm = \rho g V_{max}$$

Following the approached described in www.cusf.co.uk/category/rocket-calculations/ the area required to vent a volume of about 0.02 m3 is:

$$A = \frac{\Delta Pm\ Volume}{RT\rho\sqrt{\frac{2\Delta P}{\rho}}\ C_D} = 52\ mm2$$

Which corresponds to 3 holes of about 5 mm diameter.

Dimensioning of venting holes to prevent premature ejection of the nosecone

The maximum pressure difference pulling the nosecone happens at the apogee, where the external pressure is the minimum. The pressure inside is supposed to be as at the ground. The force pulling the nosecone would be, without venting holes:

Density*3000 m* g * pi * D*D/4 = 635 N = 65 kg

With the same approach used for the altimeter venting holes, we can ensure that the force on the nosecone will be less than 1 kg by installing venting holes. This translates in a pressure of

$$\Delta P = 550\ Pa$$

and a requirement of 3 holes with a diameter of about 4 mm.

The system is then ground tested in two ways:

- We ensure that the nosecone is not pulled out by a weight of 5 kg at least. In this way we ensure that a pressure difference 5 times higher than 550 Pa will not pull the nosecone away
- We ensure that the CO2 system is still able to eject the nosecone despite the presence of the venting holes

W. Avionics System Appendix: Avionics Software

The following pages are part of Raphael Schniders Semester Project “Multisensor acquisition system for educational and competition rockets” at ETH Zurich.

Hardware System Overview

Project TELL

Doc. Reference	TELL_GD06_HWSysOverview_02
Author	Raphael Schnider, Anna Kiener
Date	25-May-2018

Note

Document Change History

Rev. Number	Change Description
Rev. 01	Initial Creation
Rev. 02	Add Power Supply Concept, Update Camera Concept

Contents

1 Document Purpose

This document shall give an overview of the Avionics hardware components and placement in the TELL rocket.
First, A general overview with the placement of the Avionics hardware will be presented. Then a detailed list of the main components and an architecutre overview will be presented.

2 Document Scope

This document is valid for the project TELL 2017/2018, participating in the SpacePort America Cup 2018. It defines the general architecture and placement in the TELL rocket of the Avionics hardware.

3 Overview

This section shall give a general overview of the main requirements and purpose, main design decisions, as well as an overview of the placement, of the Avionics hardware.
There are 2 Avionics sections in TELL: in the nose cone (NC) and the lower body (LB) of the TELL rocket. The hardware shall be almost identical. The only big difference is that the NC Avionics has ground-communication and GPS, and the LB Avionics includes pressure sensors.

3.1 Requirements and Purpose

The main requirements for the Avionics hardware are the following:

- Needs to be work for temperatures up to 75 degrees
- Architecture of the two Avionics flight computers should be as similar as possible to simplify software development
- Needs to provide suitable interfaces for debugging, as well as assembly and arming at the competition

3.2 Main Design Decisions

The main design decisions made in the hardware architecture are the following:

- **Split design:** The design uses two independent avionics parts in the nose cone (NC AV) and lower body (LB AV) of the TELL rocket. The reason is the following:
  - NC Avionics: The ground-communication and GPS antennas need to be placed in the NC because it is the only part of the rocket that is built out of material that is not interfering with RF communication.
  - LB Avionics: The COTS barometer for altitude measurements (IREC requirement) needs to be placed at least 5 diameter units behind the NC (less flow induced pressure differences). An Avionics part in the LB also simplifies measurements from the motor and and controlling the Air brakes.
- **Modularity:** Hardware design was made with the goal to provide modularity. GPS and RF modules are placed on a separate PCB which allows incremental improvements on just a subset of the hardware components, and also makes development and testing efforts simpler.

3.3 Placement Overview

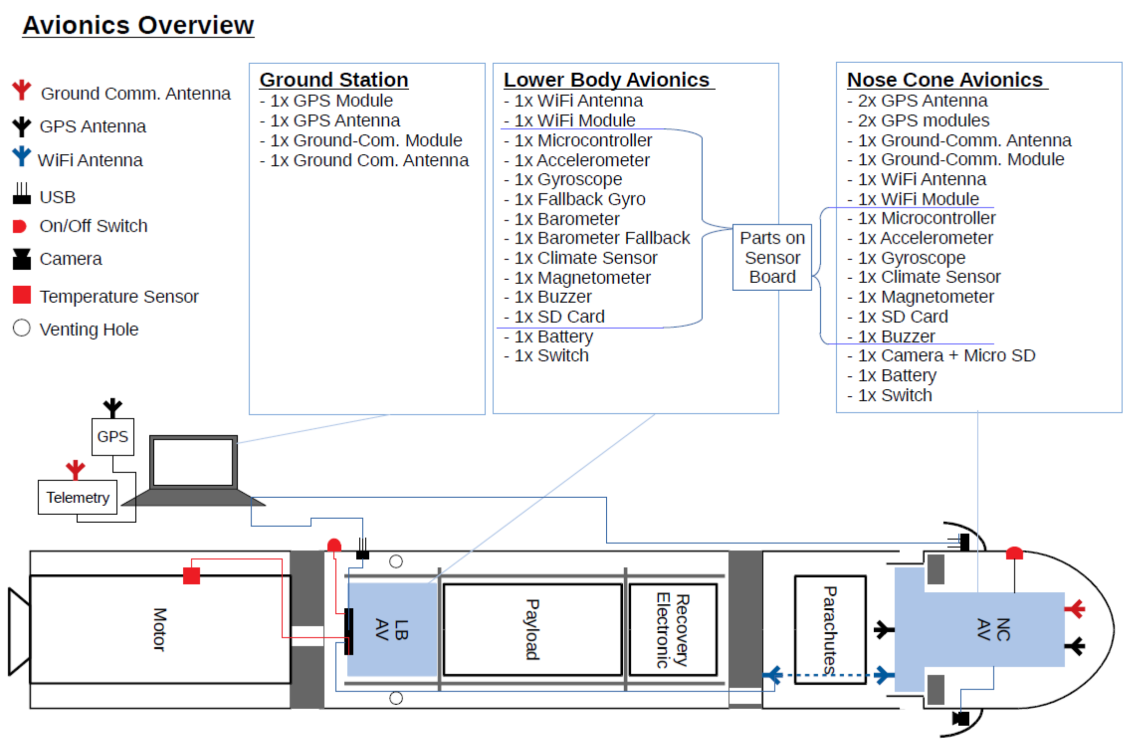


Figure 1: Avionics System Overview

4 Main Concepts

This section explains the main concepts elaborated for the Avionics of TELL.

4.1 Telemetry Concept

The telemetry frequency band is limited by regulations. Therefore the 915 MHz (USA) and 868 MHz (Europe) band will be used. As the frequencies are different,the communication modules need to be exchanged between testing (CH) and the competition (USA). These bands provide up to 40 km transmission range in line-of-sight conditions. The influence of the rocket body on the range has to be determined by testing.
Because of the complex regulations, the importance of the downlink and the lack of a communication expert it was decided to use a COTS XBee module which is available for both frequencies.
The main body of the rocket is possibly made from a conducting material and is not suited for radio communication. Therefore the communication module will be placed in the nosecone, made from a non-conducting material.

4.2 GPS Concept

A simple one-chip GPS solution should provides about 10m accuracy, which is sufficient for the final recovery. With a second GPS station on the ground, the position of the rocket can be calculated

to ¡1m accuracy by differential post-processing. An online high-precision solution will be developed in the future. The modular design makes it easy to exchange the GPS module if the high-precision solution is finished in time for the competition.
After apogee the nosecone will face to the ground. To enable connection to the GNSS satellites, the nosecone shall be separated after apogee. A second GPS module and antenna at the bottom of the nosecone ensures that there is a GPS signal also during descent. By using 2 GPS modules and antennas, the possibility that both modules or antennas face the ground after landing is reduced.

4.3 Camera Concept

A small camera will be employed, placed on the side of the nose cone facing the ground. Therefore a small hole in the nose cone is needed. The camera will be covered with a bulge to minimize the aerodynamic impact.

4.4 Intra-rocket Communication Concept

The two avionics parts in the nose cone and the lower body need a way to communicate. To ensure a reliable separation of the nose cone after apgoee, the decision was made to not use a cable connection, but also RF communication using the 2.4 GHz frequency. The antennas are placed on either side of the separation plane, one at the bottom of the nose cone and one on top of the recovery bulkhead in the recovery bay. This gives a distance of only a few cm between the antennas and it is assumed that this should work fine.

4.5 Power Supply Concept

Each of the two avionics sections has its independent power supply. The 11,1 V battery is attached to the main sensor board, which distributes power to all other boards.

4.6 Redundancy Concept

As there are two avionics parts which are almost identical and can operate independently, most components are redundant. Also, the battery of each part is chosen such that one cell is redundant. However, there are a few components that are a single point of failure for certain functionalities:

- **Telemetry module:** A failure results in unavailability of ground communication
- **Intra-rocket communication module:** If one of the two modules failes, intra-rocket communication is unavailable
- **Camera:** If the cameras fails, there is no video recording
- **NC Microcontroller:** A failure of the microcontroller in the nose cone would make GPS data and telmetry unavailable
- **LB Microcontroller:** A failure of the micrcontroller in the lower body would make accurate barometer data and Air brake control unavailable

5 Components

This section specifes the main components used and gives an overview of the hardware architecture.

5.1 Nose Cone Avionics

The nose cone avionics contains the following boards:

Board	#
Main Sensor Board	1
Ground Communication Board	1
Intra Rocket Communication Board	1
GPS Board	2
Camera Board	1

Table 1: Nose Cone Avionics Boards

5.1.1 Main Sensor Board

Component	#	Type
Microcontroller	1	STM32F407
SD Card	1	
Magnetometer	1	MMC5883MA
Accelerometer	1	ADXL357
Gyroscope	1	ITG-3701
Climate Sensor	1	BME280
Battery	1	Swaytronic LiPo 3S 11.1V 2200mAh 35C/70C XT60

Table 2: Sensor Board Components Nose Cone

5.1.2 Ground Communication Board

Component	#	Type
Ground communication module	1	XB8X-DMRS-001/XBP9X-DMRS-001
Ground communication antena	1	

Table 3: Ground Communication Board Components

5.1.3 Intra Rocket Communication Board

Component	#	Type
Intra rocket communication module	1	XBP24CZ7RIS-004
Intra rocket communication antenna	1	A24-HASM-450

Table 4: Intra Rocket Communication Board Components

5.1.4 GPS Board

Component	#	Type
GPS module	2	neo-m8t
GPS antenna	2	ANN-MS

Table 5: GPS Board Components

5.1.5 Camera Board

Component	#	Type
Camera	1	Raspberry Pi + Spy Cam

Table 6: Camera Board Components

5.2 Lower Body Avionics

The lower body avionics contains the following boards:

Board	#
Main Sensor Board	1
Intra Rocket Communication Board	1

Table 7: Lower Body Avionics Boards

5.2.1 Main Sensor Board

Component	#	Type
Microcontroller	1	STM32F407
SD Card	1	
Magnetometer	1	MMC5883MA
Accelerometer	1	ADXL357
Gyroscope	1	ITG-3701
Climate Sensor	1	BME280
1st Barometer	1	2SMPB-02E
2nd Barometer	1	LPS22HBTR
Battery	1	Swaytronic LiPo 3S 11.1V 2200mAh 35C/70C XT60

Table 8: Sensor Board Components Lower Body

5.2.2 Intra Rocket Communication Board

Component	#	Type
Intra rocket communication module	1	XBP24CZ7RIS-004
Intra rocket communication antenna	1	A24-HASM-450

Table 9: Intra Rocket Communication Board Components

5.3 Ground Station

Component	#	Type
Laptop	1	Any
Communication module	1	digi xbee sx rf modem
Communication antenna	1	A09-Y11NF
GPS module	1	neo-m8t
GPS antenna	1	ANN-MS

Table 10: Main Components Ground Station

5.4 Architecture Overview

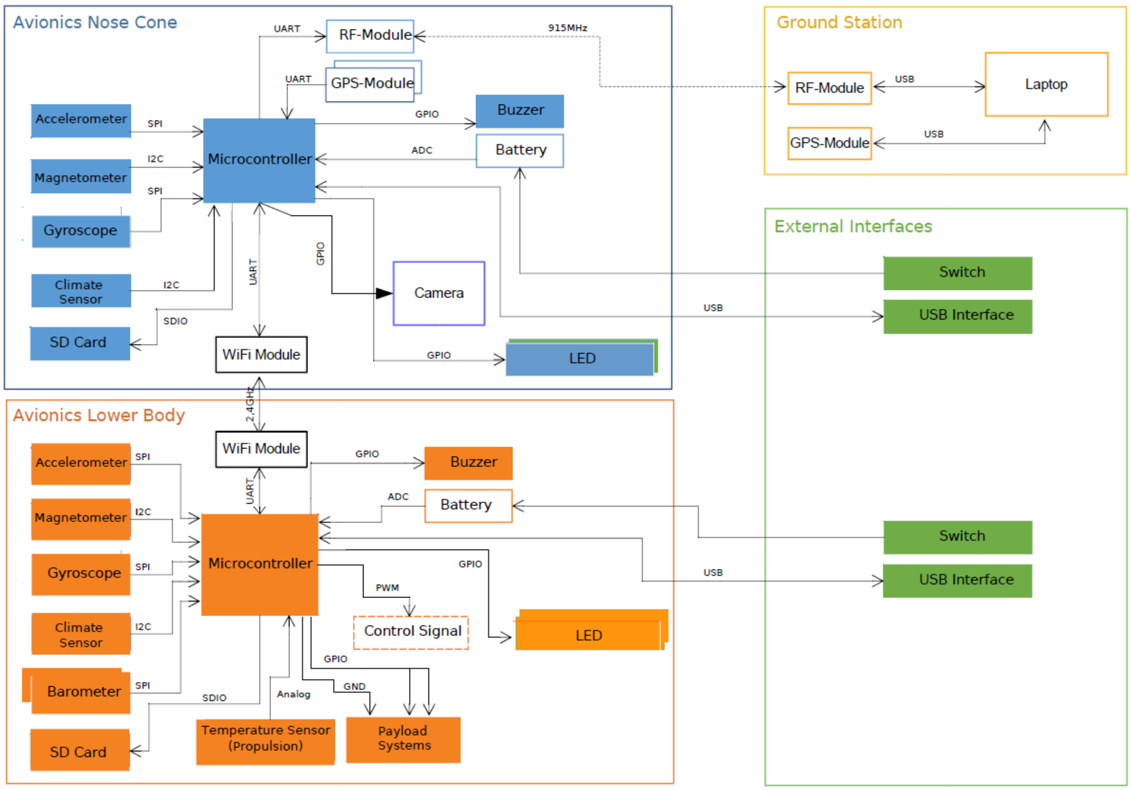


Figure 2: Avionics System Architecture Overview

Software System Specification

Project TELL

Doc. Reference	TELL_GD06_SWSysSpecification_02
Author	Raphael Schnider
Date	25-May-2018

Note

Document Change History

Rev. Number	Change Description
Rev. 01	Initial Creation
Rev. 02	Update Task priorities and FSM

Contents

1 Document Purpose

This document shall specify the architecture of the Software running embedded on the Avionics hardware in the TELL rocket.
First, A general overview of the Software will be given. Then the task model and the software states will be specified.

2 Document Scope

This document is valid for the project TELL 2017/2018, participating in the SpacePort America Cup 2018. It defines the general architecture of the Avionics and Control Software running on the Avionics hardware.

3 Overview

This section shall give a general overview of the main requirements and purpose, as well as the main design decisions, of the Avionics software.
There are 2 Avionics sections in TELL: in the nose cone (NC) and the lower body (LB) of the TELL rocket. The software shall be almost identical. The difference is that the NC Avionics has ground-communication and GPS, and the LB Avionics has 2 barometers and is responsible for controlling the Airbrakes.

3.1 Requirements and Purpose

The main requirements for the Avionics software are the following:

- Sampling of Sensor values and storing them to flash storage. In different flight phases, different sampling rates shall be applied. A more detailed specification will follow later in this document.
- Sensor fusion to process the sensor values
- Detection of flight events like start, apogee, landing etc.
- Transmission of data and events to a ground station
- Intra-rocket communication to share data and events between the two Avionics parts
- Using the processed data to control the Airbrakes of the TELL rocket

3.2 Main Design Decisions

The two main decisions made in the software architecture are the following:

- Because the software needs real-time properties, a real-time operating system (RTOS) is used. Currently FreeRTOS[1] is used.
- The software has different requirements and tasks during different phases of the flight. Therefore, a finite state machine (FSM) is used to control the software (e.g. different sampling rates in different states).

4 Task Model

This section specifies the RTOS tasks and their interactions. It is slightly different for the nose cone (NC) and the lower body (LB). In the figures, a node represents a task, and an arrow represents some kind of inter process communication (IPC).

4.1 Nose Cone

The tasks and their inter process communication (IPC) are visualized in the following figure:

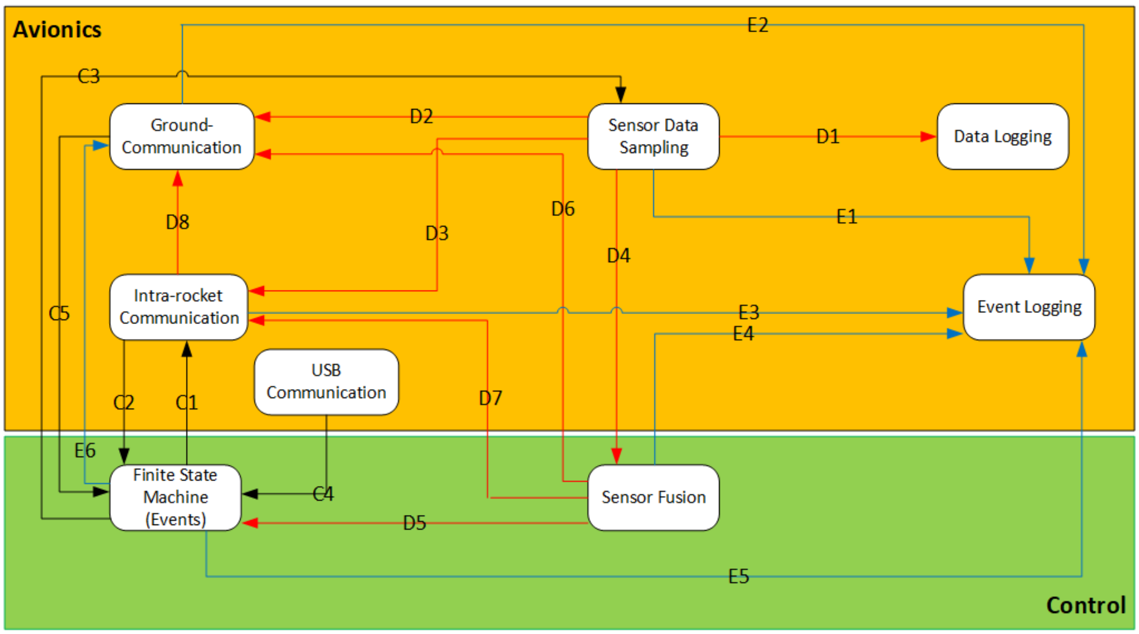


Figure 1: NC Task Model. Legend: Red arrows for data, blue arrows for events, black arrows for state control

The following two tables specify the different tasks and arrows.

Task	Description
Sensor Data Sampling	Task responsible to collect measurement data from the sensors. The sampling rates are different depending on the state.
Data Logging	Task responsible to store the collected measurement data to the flash memory
Event Logging	Task responsible to store the detected events to the flash memory. Events could either be flight events (e.g. apogee) or error/exceptional events from tasks or components (e.g. telemetry link down)
Ground Communication	Task responsible to transmit data and event information to the ground station
Intra-rocket Communication	Task responsible to exchange data and event information with the LB Avionics
USB Communication	Task responsible to handle USB communication. This task shall make it possible to change the state as well as perform status checks and read the recorded data
Finite State Machine	Task responsible for updating the state of the finite state machine (FSM). Flight events need to be detected from the data and cause a state transition. Also actions that need to be performed in a certain state need to be handled by this task (e.g. payload ejection)
Sensor Fusion	Task responsible to process the measurement data and perform sensor fusion to deliver more accurate results

Table 1: Description of the Tasks

IPC	Description
D1	Sensor data to be saved on the flash memory
D2	Sensor data to be transmitted to the ground station
D3	Sensor data to be transmitted to the LB Avionics, which can be used by the control algorithm
D4	Sensor data to be used for the sensor fusion
D5	Processed data to detect events and determine the state
D6	Processed data to be transmitted to the ground station
D7	Processed data to be transmitted to the LB Avionics, which can be used by the control algorithm
D8	Data received from the LB Avionics which are forwarded to the ground station
E1	Exceptional events from data sampling to be saved on the flash memory (e.g. deadline miss)
E2	Exceptional events from ground communication to be saved on the flash memory (e.g. link down)
E3	Exceptional events from intra-rocket communication to be saved on the flash memory (e.g. link down)
E4	Error events from sensor fusion to be saved on the flash memory
E5	Detected flight events to be saved on the flash memory
E6	Detected flight events to be transmitted to the ground station
C1	State control information to be transmitted to the LB Avionics
C2	State control information received from LB Avionics
C3	State control information to adjust the sampling rate
C4	State control information received from USB Communication
C5	State control information received from the ground station

Table 2: Description of the IPC

4.2 Lower Body

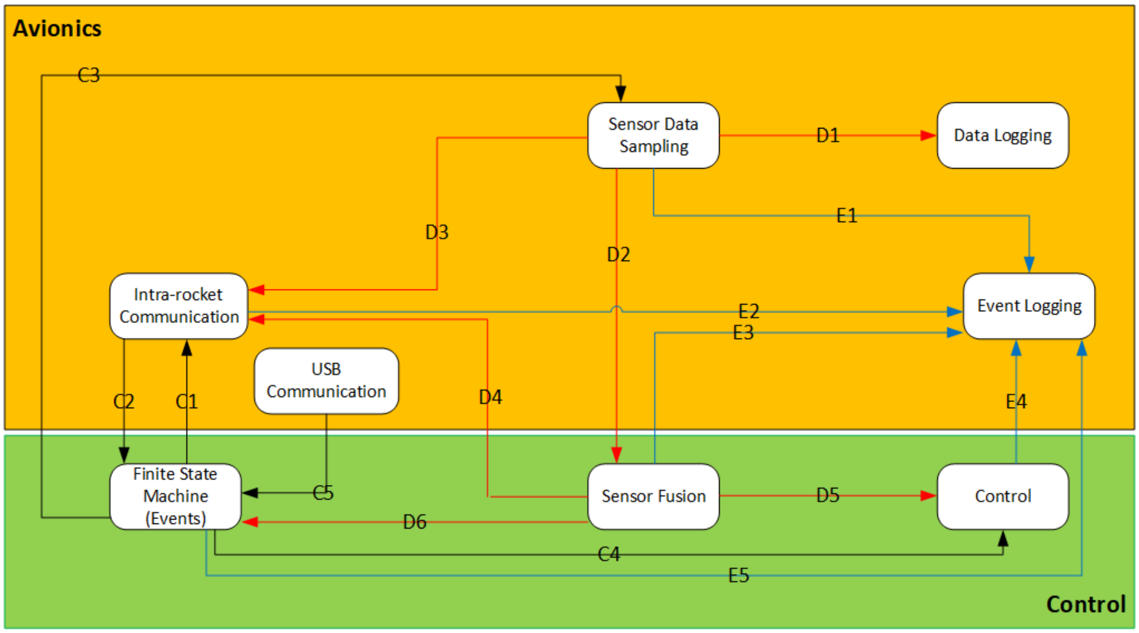


Figure 2: LB Task Model. Legend: Red arrows for data, blue arrows for events, black arrows for state control

The following two tables specify the different tasks and arrows.

Task	Description
Sensor Data Sampling	Task responsible to collect measurement data from the sensors. The sampling rates are different depending on the state.
Data Logging	Task responsible to store the collected measurement data to the flash memory
Event Logging	Task responsible to store the detected events to the flash memory. Events could either be flight events (e.g. apogee) or error/exceptional events from tasks or components (e.g. telemetry link down)
Intra-rocket Communication	Task responsible to exchange data and event information with the NC Avionics
USB Communication	Task responsible to handle USB communication. This task shall make it possible to change the state as well as perform status checks and read the recorded data
Finite State Machine	Task responsible for updating the state of the finite state machine (FSM). Flight events need to be detected from the data and cause a state transition. Also actions that need to be performed in a certain state need to be handled by this task (e.g. payload ejection)
Sensor Fusion	Task responsible to process the measurement data and perform sensor fusion to deliver more accurate results
Control	Task responsible to evaluate the processed data and control the motor of the Air brakes. This task is only running in the motor burnout phase of the flight

Table 3: Description of the Tasks

IPC	Description
D1	Sensor data to be saved on the flash memory
D2	Sensor data to be used for the sensor fusion
D3	Sensor data to be transmitted to the NC Avionics from where they are forwarded to the ground station
D4	Processed data to be transmitted to the NC Avionics from where they are forwarded to the ground station
D5	Processed data to be evaluated by the control algorithm
D6	Processed data to detect events and determine the state
E1	Exceptional events from data sampling to be saved on the flash memory (e.g. deadline miss)
E2	Exceptional events from intra-rocket communication to be saved on the flash memory (e.g. link down)
E3	Error events from sensor fusion to be saved on the flash memory
E4	Error events from control task to be saved on the flash memory
E5	Detected flight events to be saved on the flash memory
C1	State control information to be transmitted to the NC Avionics
C2	State control information received from NC Avionics
C3	State control information to adjust the sampling rate
C4	State control information to run or disable the control task
C5	State control information received from USB Communication

Table 4: Description of the IPC

4.3 Task Priorities

In case the flight computer is not able to complete all tasks in time, task priorities are used. The following table specifies the priority for each task, a lower number means higher priority.

Task	Priority
USB Communication	1
Data Logging	2
Event Logging	3
Sensor Data Sampling	4
Sensor Fusion	5
Finite State Machine	6
Control	7
Ground Communication	8
Intra-rocket Communication	9

Table 5: Task Priorities

5 Finite State Machine

This section specifies the finite state machine (FSM) that will be implemented. First an overview is presented, then a description of all states and transitions are given, and the different sampling rates in each state are defined. Both Avionics parts (NC and LB) run the same FSM. The two parts can exchange information about state transitions that occur, to help keeping the correct state if an event is undetected by one of the two flight computers.

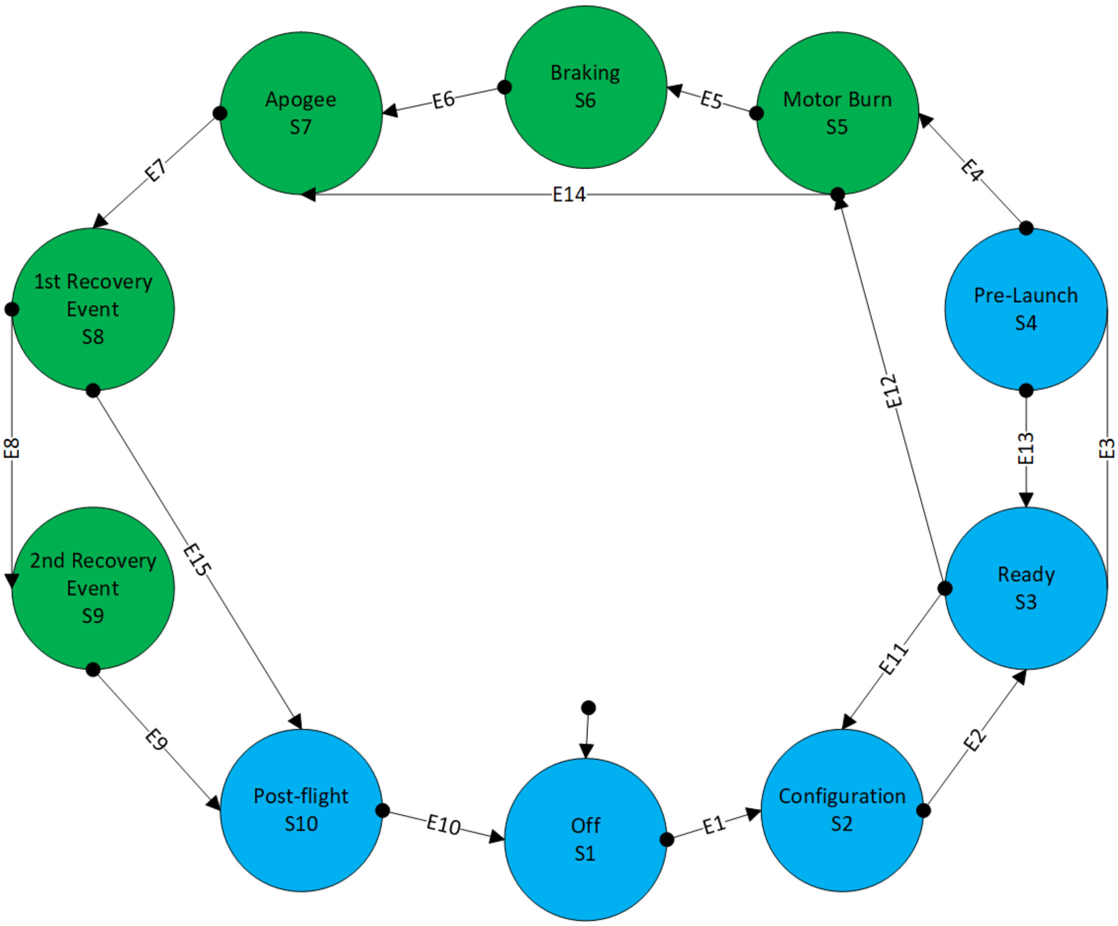


Figure 3: Avionics Finite State Machine. Legend: Blue nodes represent ground states, green nodes represent flight states, arrows represent state transitions

5.1 FSM States

The following table gives a short description of all states of the FSM. All flight events that need to be detected result in a state transition. Of course it is possible to reach S1 from any state using the power switch.

State	Description
S1	**Off State:** This is the initial state, when the complete system is turned off
S2	**Configuration State:** In this state all components that need configuration right before the launch are configured. Currently this is only planned for the GPS module, all other components are turned off to save energy. Also test routines can be run in this state
S3	**Ready State:** The system is ready for launch. All components are turned on, but sampling and ground transmission happens only with low frequency. Only accelerometer runs at high sampling rate to detect a launch
S4	**Pre-Launch State:** System expects a launch in the next 90 seconds. Full sampling, camera and payload experiment are started
S5	**Motor Burn State:** Launch was detected and motor burn phase is still ongoing. Full sampling, payload experiment and camera are started, in case S4 was missed
S6	**Braking State:** Motor burnout was detected and rocket is still ascending. Only in this state the control task is allowed to run and perform braking using the Air brakes
S7	**Apogee State:** Apogee was detected. Disable Air brake control
S8	**1st Recovery Event State:** First Recovery Event was detected (drogue parachute). Log the event and stop the payload experiment
S9	**2nd Recovery Event State:** Second Recovery Event (main parachute) was detected. No specific action needs to be performed, except logging of the event
S10	**Post-flight State:** Landing of the rocket was detected. Sampling and transmission rates can be reduced, camera is turned off

Table 6: FSM State Descriptions

5.2 FSM Transitions

The following table gives a description of all the possible state transitions. Transitions generally correspond to an event or a timeout.

Transition	Event/Description
E1	Power switch is used to turn the system on
E2	Command to switch to Ready state is received on the USB interface
E3	Command to switch to Pre-Launch state is received via telemetry
E4	Start detected
E5	Motor burnout detected, or timeout occured
E6	Apogee detected
E7	First Recovery Event detected, or timeout occured
E8	Second Recovery Event detected
E9	Landing detected
E10	Power switch used to turn the system off
E11	Command via USB or telemetry to go back to configuration mode, to save energy
E12	Start detected before system is in Pre-Launch state. This transition needs to be possible in case there is a failure of the telemetry link
E13	Command via USB or telemetry to go back to ready state, to save energy
E14	Apogee detected before motor burnout was detected or timeout occured. This transition needs to be possible in case the motor burnout can not be detected and timeouts are chosen badly
E15	Landing was detected before the detection of the 2nd Recovery Event

Table 7: FSM State Transition Descriptions

5.3 State Dependent Task Activities

The following table specifies the different sensor sampling rates in the different states.

Sensor	S2	S3	S4-S11	S12
Humidity	0 Hz	1/30 Hz	10 Hz	1/30 Hz
Temperature	0 Hz	1/30 Hz	10 Hz	1/30 Hz
Pressure	0 Hz	1/30 Hz	100 Hz	1/30 Hz
Accelerometer	0 Hz	100 Hz	500 Hz	1/30 Hz
Gyroscope	0 Hz	1/30 Hz	500 Hz	1/30 Hz
Magnetometer	0 Hz	1/30 Hz	10 Hz	1/30 Hz
GPS	0 Hz	1/30 Hz	5 Hz	1/30 Hz
Motor Temperature	0 Hz	1/30 Hz	10 Hz	1/30 Hz
Battery Status	0 Hz	1/30 Hz	10 Hz	1/30 Hz

Table 8: FSM State Dependent Sampling Rates

The following table specifies the activity of the other tasks in the different states

Task	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12
Ground Communication	Off	Off	On	On	On	On	On	On	On	On	On	On
Intra-rocket Communication	Off	Off	On	On	On	On	On	On	On	On	On	On
USB Communication	Off	On	On	On	On	On	On	On	On	On	On	On
Data Logging	Off	Off	On	On	On	On	On	On	On	On	On	On
Event Logging	Off	On	On	On	On	On	On	On	On	On	On	On
Sensor Fusion	Off	Off	On	On	On	On	On	On	On	On	On	Off
FSM	Off	On	On	On	On	On	On	On	On	On	On	On
Control	Off	Off	Off	Off	On	Off	Off	Off	Off	Off	Off	Off

Table 9: FSM State Dependent Task Activities

References

[1] FreeRTOS Open Source Real Time Operating System
URL: https://www.freertos.org/ [cited 3 March 2018].

X. Management Appendix: Management Summary

Project Objectives

TELL was the very first project lead by the newly founded student association ARIS (Akademische Raumfahrt Initiative Schweiz). ARIS was founded at ETH and HSLU and aims to engage students of all disciplines in aerospace related projects in close collaboration with academia and industry. Our ultimate goal is to bring together research, education, and industry in the field of aerospace technology and promote Swiss engineering excellence on a global stage. To realize this ambitious goal we worked closely with the EPFL Rocket Team (ERT). With ARIS we have the ambition to create a framework for a generation of students to come in order to allow them to pursue sophisticated aerospace projects. The main objectives from the management perspective were defined with that in mind and were the following:

- Establish and test a functioning project structure easy to adopt for future projects
- Establish manufacturing and testing infrastructure
- Locally root aerospace projects at the university of ETH and HSLU under the association ARIS
- Build up a network of industry partners
- Obtain a high degree of academic integration
- Transfer knowledge successfully to future student teams
- Inspire the next generation of students

Management Challenges

Although TELL was ARIS' first project, there was no lack of interested students as aerospace projects are an attractive opportunity for students to apply their theoretical knowledge. With somewhat limited possibilities for students to earn university credits the decision was made to build a large team and divide the tasks among the subteam members. Indeed many students were more than happy to volunteer their free time but that free time was limited. There were a few unintended consequences with that decision.

- Coordination cost in and among the subteams proved to be very high.
- During the semester it became apparent that some team members had to put in more effort than others. Keeping motivation and commitment to the project intact was demanding.
- The large non technical subteam, although needed in this first project for the set up of the association and infrastructure was questioned by the technical subteams, putting a strain on the overall team.
- A particular challenge our large team faced was communicating a clear division of tasks and the members responsible for each task were unclear.
- As a result, team leaders felt it was necessary to involve themselves more into the technical details and neglected managing the interfacing of subteams.

Project Timeline

ARIS and its project TELL was officially kicked-off in mid October. Concept studies on a system and subsystem level were conducted and synchronised until the preliminary design review

(PDR) with academic and industrial partners in December 2018. In a further step, the systems were detailed and prototyped and scrutinised at the critical design review CDR in mid-March. Even though the main manufacturing phase was planned to start before CDR already, it was delayed due to exam sessions in february and started only after CDR. This resulted in a delay of many other activities, including a full system test launch before shipping the rocket. Throughout the whole year several Tripoli launch opportunities were exploited to test subsystems such as recovery and avionics on. In parallel, a partner network across academia and industry was established across Switzerland.

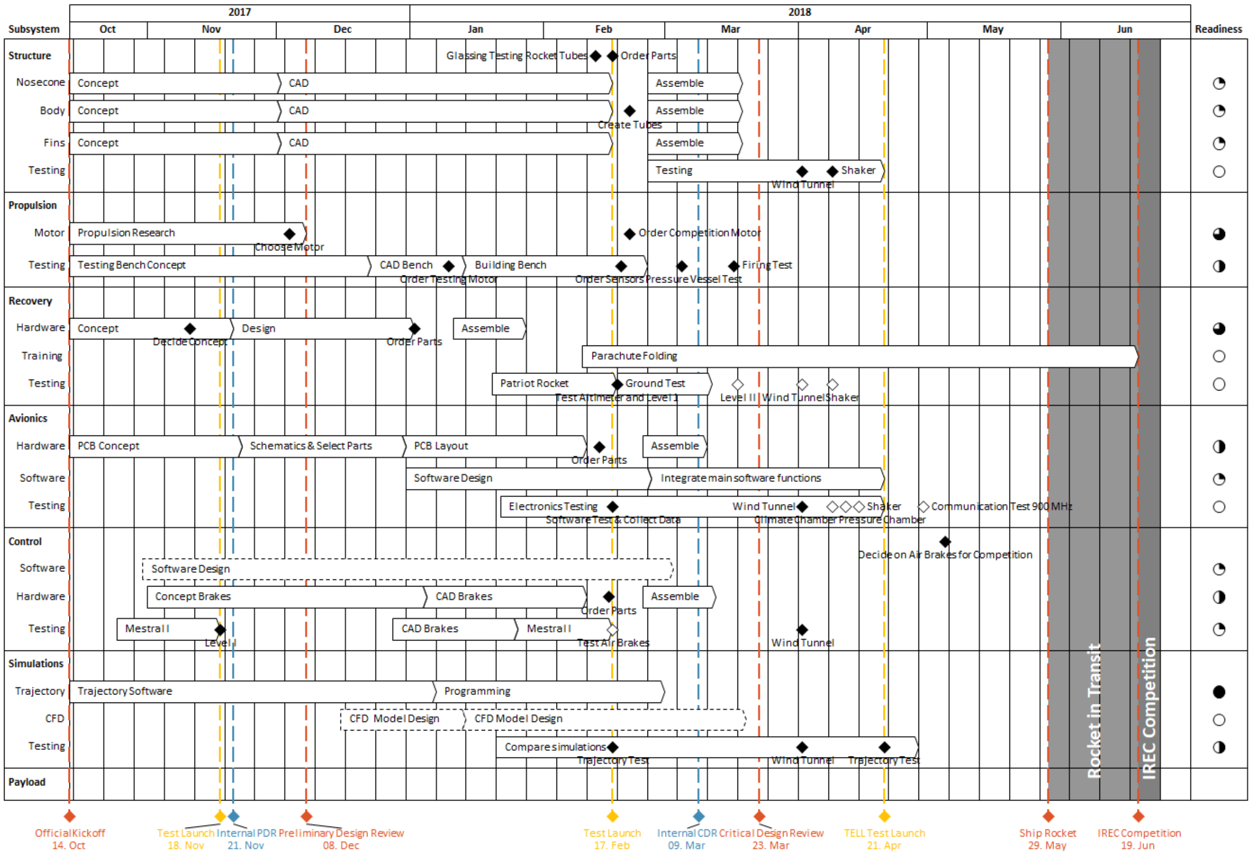


Fig. XY: Original top level project plan.

Sponsoring

As promoting Swiss engineering excellence is one of ARIS' stated goals most companies approached for sponsoring were Swiss. SMEs in Switzerland operate at a very high standard, perfectly suited for aerospace applications. Over the coming years our aspiration is to ensure companies become aware opportunities in the steadily growing sector of civilian space industry. The early beginnings of what in the future is going to be a sound network of industry partners has been established.

Academic Partners:

Laboratory of Composite Materials and Adaptive Structures (CMAS), ETH Zürich	Supervising Institute

HSLU Technik & Architektur - Departement Maschinentechnik	Secondary supervising institute
HSLU Technik & Architektur - Departement Elektrotechnik	Secondary supervising institute
HSLU Technik & Architektur - CC Bioscience and Medical Engineering	Payload Manufacturing
Student Project House (SPH, ETH Zürich	Infrastructure
Swiss Space Center	

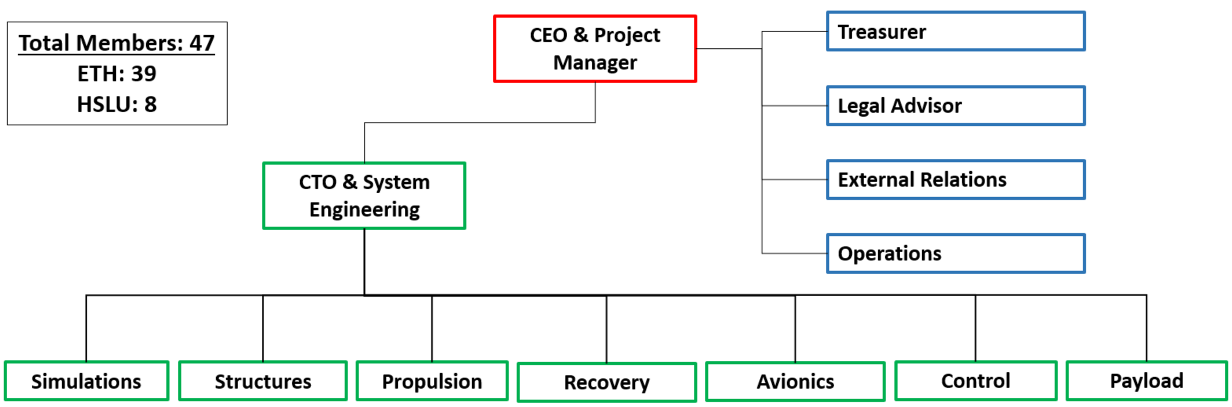
Industry Partners

RUAG Space	Manufacturing & Financial support
Sauber Aerodynamics	Windtunnel testing
Maxon Motor	Electronic components
Allega	Manufacturing material
Bossard	Manufacturing material
Ceratizit	Manufacturing material
Cimform AG	Manufacturing
EVS	Marketing
HABA	Manufacturing material
Kaiser+Kraft	Infrastructure
KiFa	Logistic support
Kuehne + Nagel	Logistic support
libs	Manufacturing
Marsa Systems	Electronic components
Mädler	Electronic components
Mouser	Electronic components
Müller&Paparis	Legal support
PB Swiss Tools	Tools
Qualicut	Manufacturing

Schneeberger	Manufacturing material
Sigg	Marketing
STA Travels	Logistic support
Suter Kunststoffe	Manufacturing material
Swaytronic	Electronic components
Swissbit	Electronic components
Würth Electronics	Electronic components

Team Structure

The team was structured as follows:



The large project team of 47 active members is composed of a technical and a management group. Lead by the project manager and chief technical officer seven subteams were formed according to the sub-system layout of the rocket. Each team is lead by a team leader that has the responsibility of coordinating with the other subteam leaders. About a quarter of the project team is engaged in operations and the business side of the project to establish the general association frame. As the competition is being held in the US, large logistic and financial efforts were crucial to the success of the project. To ensure successful participation to the competition, a strong bond to academic, industrial and private partners was required to complete the project. It was therefore important to find sponsors that were not only willing to help on the technical side but also on the logistics side. The main incentive for these companies to support the project was

- the direct access to capable engineers in the team,
- the visibility of the project at the university, and
- potential national or even international media coverage.

A strong marketing and external relations team was therefore essential alongside the operations team to ensure the project could see the light of day. The share of members on the business side of ARIS is expected to somewhat decrease as the association becomes more established.

A particular organisational decision that had a key impact was the separation of the weekly management meeting and the weekly technical meeting, with only a few members attending both. This had both positive and negative effects. One major improvement gained from this decision was the ability to conduct more efficient meetings. After the split, management information that directly concerned the technical team was shared on Slack or by the management members present at the technical meeting and vice versa. However, one negative impact of this split was the creation of a camaraderie gap between the management team and the technical team. The management team should not be too far removed from the technical team and, although this set-up ended up working well enough, it could be improved. In the future we plan on solving this issue by making sure the management team takes on smaller technical responsibilities as they all have the relevant education to do so. A larger area where everyone can work side by side will also most likely reduce this camaraderie gap.

Strategies for Knowledge Transfer

Knowledge transfer needs to happen on two levels: from team member to team member and from year to year.

Knowledge transfer between team members

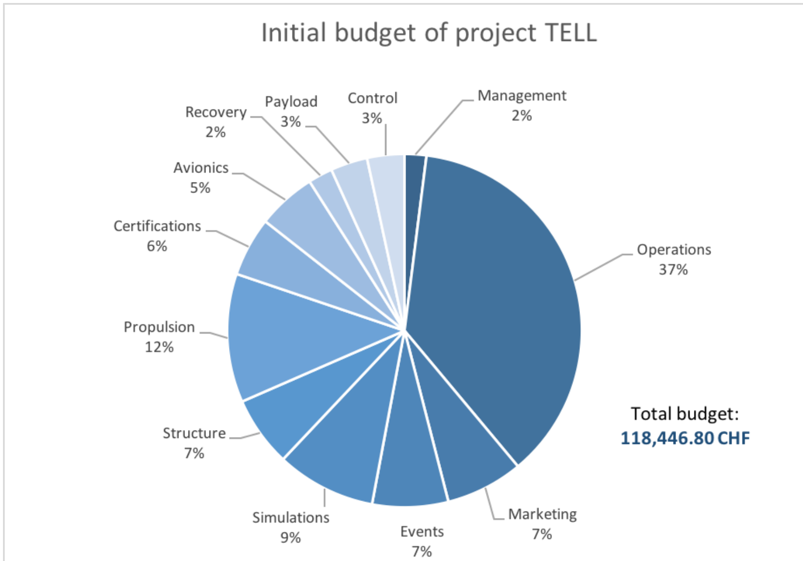
One of the main challenges for ARIS is that students are participating in parallel to their studies and are not able to obtain credits for their efforts. While many students are motivated to volunteer their free time, this poses a hurdle as it means that every student cannot dedicate equal amounts of time to the project. Moreover, there were times, during exam periods for example, where a lot of students could not, understandably so, focus as much on the project. As all students have exams at the same time, this lead to periods of time with significantly decreased activity. All these factors combined mean that the time each student can contribute is diminished and this requires more students to fulfill all responsibilities. The more people participate in a project, the more difficult it is to coordinate their efforts and ensure that knowledge is shared.

To mitigate this problem and facilitate informal transfer of information, we worked hard to find locations around the university where all the subteams could work together. Although we have come a long way, at the end of this first year this problem is not yet entirely solved, as the offices we have obtained are not big enough for the whole team. However, we are currently working with ETH Zurich to obtain more space. We hope adding office space will improve our knowledge transfer across subteams in the following years.

Knowledge transfer between projects

The second challenge of knowledge transfer results from the turnover of team members year after year. To ensure the success of building upon previous years' knowledge we will be implementing two strategies. The first one is related to documentation. Our team this year will be required to document the work they have done for this project in an organized manner. This will allow future students to learn and build upon what was done in previous years. The second strategy will be to ensure that at least one student per subteam stays on the team as a coach to next year's corresponding sub team. This role will not require a large time commitment from the participating students and will ensure that the new team receives appropriate support. Our goal with these processes is to learn from our mistakes and avoid repeating them in the future.

Financial overview



Project TELL's budget arises to 118,446.80 CHF. This budget was based on last year's project RORO as well as on estimations of required supplies made by the individual subteams. This budget was split into cash budget and "in kind" contributions and is used both for estimating the cash sponsoring required as well as for the allocation of funds to the correct subteams without overspending. It can be noted in the figure above that the largest part of the expenses are for operations. This is due to two factors. First, the USA logistics expenses were very high as transatlantic flights are very expensive. Second, ARIS was founded less than a year ago, which meant that there were no existing tools or infrastructure that could be used, most had to be acquired. This should not be the case in the following years and we expect the operations budget to be lower as a result. The budget was slightly readjusted during the project but this was mainly done by slightly adjusting the amounts allocated to each subteam as actual expenses became more clear. The total budget, however, remained as it was calculated from the start and we can proudly state that it was possible to find the required funds and keep the expenses within this frame so far.