



SED

Student Experiment Documentation

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Mission: BEXUS 31

Team Name: MASS

Experiment Title: Manufacturing of Structures in Space

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CHANGE RECORD

Version	Date	Changed chapters	Remarks
0	2019-12-14	New Version	
1	2019-12-15	All Chapters	PDR
2	2019-03-12	Changes in Chapter 3, Minor Changes in Chapter 1.3	Feedback post-PDR. Modified by whole team
2	2020-05-03	Chapters added: 4.4.1, 4.5.3, 4.5.4, 4.7.1, 4.7.2, 4.7.3, 4.7.4, 4.8.1, 4.9.3, 4.9.7, 4.9.6.1, 4.9.6.2, 4.5.2.8, 4.5.2.9, Chapters reworked: Abstract, 2.1, 4.5.2.2, 4.5.2.3, 4.5.5, 4.8, 4.8.2, 4.8.2, 4.4, 4.9.1, 5.1, 5.2, 6.2 Changes in Chapter: 3, 4, 4.3, 4.4, 4.5.1, 4.5.2.4, 4.5.2.5, 4.5.2.6, 4.5.2.10, 4.9, 4.9.4, 4.9.6, 4.5.2.1, 6.1.3, 6.1.2, 6.1.4	CDR Modified by whole team
3	2020-06-26	Chapters added: 4.4.3 Changes in Chapter: 2.1, 2.2, 2.3, 2.4, 6.1.2, 6.1.5, 3.2, 3.3, 4.3, 4.4, 4.4.1, 4.5.3, 4.5.2.3, 4.5.2.6, 4.5.4, 4.5.5, 4.8, 4.8.2, 6.1.3, 4.9.7, 4.9.6.2, 4.9.5, 7.1, 4.9.3, 5.1, 5.2, 6.1.1, 6.1.2, 6.1.4, 4.2.2, 6.3, 7.10	IPR Modified by whole team
4	2021-08-10	Chapters added: 4.6, 4.4.4 Changes in Chapter: 4.4, 1.5.2, 4.1, 3, 4.2.2, 4.3, 4.2.1	EAR Modified by whole team
5	2022-04-24	Chapters added: 7.2, 7.3, 7.4, 7.5, 7.5.1, 7.5.2, 7.5.3, 7.5.4, 7.6.1, 7.6.2, 7.6.3, 7.6.4, 7.7.1, 7.7.2, 7.7.3, 7.7.3, 7.7.4, 7.7.5, 7.7.6, 7.8, 7.9.3, 7.9.1, 7.9.2 Changes in Chapter: 4.2.2, 4.4.1, 7, 5.3, 5.2, 5.1, 8.2 Chapters reworked: 4.6, 4.6.3, 4.6.4, 4.6.5, 7.4, 7.7	Launch Campaign Modified by whole team

PREFACE

MASS (Manufacturing Structures in Space) is a student project at the Munich University of Applied Science. The students are developing a method to inflate and rigidize a structure on board the high-altitude balloon BX31. The two main challenges in designing inflatable structures are the storing and the stabilisation method once the structure is inflated and deployed. The experiment MASS is combining a high efficient storing method with a rigidization method to stabilise the structure in space. During the development of the inflatable and rigidizable structure all relevant information is documented in the SED (Student Experiment Documentation) versions.

ABSTRACT

Launching Satellites into space is an expensive adventure. Every kilogram that can be saved reduces the overall costs of a satellite's launch. Implementing lightweight structures into satellites is very important in today's space engineering. Another factor to decrease the launch costs is the usage of space-saving systems. This means a high stowing efficiency of lightweight structures is beneficial. Therefore, the interest of deployable and inflatable structures for space applications is increasing. All lightweight applications should have a high stowing efficiency, meaning space-saving systems that will enlarge their sizes once deployed in space. To achieve a high stowing efficiency of a stable deployed structure, the packing and the rigidization method of the deployable structure is significant.

MASS is an experiment to test a rigidization method on an inflatable structure for space applications. The technology will be demonstrated on cylindrical shaped structures made of polyester foil on board of the high-altitude balloon BEXUS 31. Flat-folded structures will be inflated and rigidized with an integrated fibre - resin composite that cures once exposed to ultraviolet (UV) radiation. One of the unique developments will be the effective integration of the composite onto the foils. The MASS project will proof the applicability of curing resin to stabilize an inflated structure. The union of resin and fibres can be used for applications in cubesats as well as planetary bases planned in the future.

Das Launchen von Satelliten in den Weltraum ist ein teures Abenteuer. Jedes Kilogramm, das eingespart werden kann, reduziert die Gesamtkosten für den Start eines Satelliten. Die Implementierung von Leichtbaustrukturen in Satelliten ist in der heutigen Raumfahrttechnik sehr wichtig. Ein weiterer Faktor zur Reduktion der Startkosten ist der Einsatz platzsparender Systeme. Dies bedeutet, dass eine hohe Stau-effizienz von Leichtbaustrukturen von Vorteil ist. Daher steigt das Interesse an entfaltbaren und aufblasbaren Strukturen für Weltraumanwendungen. Alle leichten Anwendungen sollten eine hohe Stau-effizienz aufweisen, d.h. platzsparende Systeme, die sich entfalten, sobald sie im Weltraum eingesetzt werden. Um eine hohe Stau-effizienz einer stabilen Einsatzstruktur zu erreichen, ist das Packungs- und Versteifungsverfahren der Einsatzstruktur von Bedeutung.

MASS ist ein Experiment zur Erprobung einer Versteifungsmethode an einer aufblasbaren Struktur für Weltraumanwendungen. Die Technologie wird an zylinderförmigen Strukturen aus Polyesterfolie an Bord des Höhenballons BEXUS 31 demonstriert. Flach gefaltete Strukturen werden aufgeblasen und mit einem integrierten Faser-Harz-Verbundstoff verfestigt, der aushärtet, sobald er ultravioletter Strahlung (UV) ausgesetzt wird. Eine der einzigartigen Entwicklungen wird die effektive Integration des Verbundstoffs auf den Folien sein. Das MASS-Projekt wird die Anwendbarkeit von UV-aushärtenden Harz zur Stabilisierung einer aufgeblasenen Struktur beweisen. Die Verbindung von Harz und Fasern kann für Anwendungen in cubesats und in Zukunft geplanten Planetenbasen genutzt werden.

1 INTRODUCTION

1.1 Scientific/Technical Background

MASS is a follow-up project of the ongoing REXUS mission ‘Additive Manufacturing in Space’ (AIMIS) run by students at MUAS [1]. The development of AIMIS focus on “[...] the extrusion of a photoreactive polymer, also called synthetic resin. This type of plastic cures under the influence of UV light” (<https://aimis-rexus.eu/the-experiment/>, online December 2019). This resin shall be applied as a manufacturing method in space using UV radiation to harden the component. To test this development as an application for the rigidization of an inflating structure, MASS will test the applicability of the resin on conical and cylindrical shaped inflatable structures. The structures are made of a polyester foil that is wrapped with carbon or glass fibres impregnated in the resin. The impregnated fibres form a helix or truss structure around the foil to stabilize the inflated structures. Origami folding patterns were chosen as the packing method for this study due to high storing efficiency compared to other methods and their structural bi-stability, referring to [2], [3], [4] and [5]. A pin puller as the Hold Down And Release Mechanism (HDRM) device, that is provided by Deployables Cubed, will be used to safely hold down the structures during launch and release them in the stratosphere. Key challenges will be the integration and hardening of the fibres to rigidize the structures, developing the inflation method and to fold the structures by not bending the fibres to avoid cracking.

1.2 Mission Statement

The MASS experiment demonstrates the release, inflation and rigidization of cylindrical shaped structures by hardening a resin through ultraviolet radiation in near vacuum conditions. This is to proof the applicability of using a curing resin to stabilize a inflated structure in space.

1.3 Experiment Objectives

The MASS experiment consists of the following primary objectives:

PO1	Cylindrical and conical shaped structures shall be efficiently folded
PO2	The structures shall be inflated during a stratospheric balloon flight
PO3	The inflated structures shall be rigidized once deployed.

The secondary objectives are defined as follows:

SO1	Fibres impregnated in a resin that cures when exposed to UV radiation shall be used as the rigidization method for the inflated structures.
SO2	The curing resin shall be exposed to naturally UV radiation provided by the sun and to artificial UV radiation by Light Emitting Diodes (LEDs)
SO3	Different folding methods shall be applied to the structures and compared with each other with respect to: foldability, time of deployment, rigidizability

1.4 Experiment Concept

The main parts of the experiment are multiple inflatable structures with impregnated fibres to form a stabilising structure. The experiment’s concept is to test the inflation and rigidization of the inflatable structures with various shapes. Cylindrical and conical shaped structures are tested with a UV curing rigidization method that is triggered in two different ways. The natural UV radiation from the sun and artificial UV radiation provided by LEDs shall be tested to cure the resin and rigidize the inflated structures. Cameras are capturing the inflation process,

pressure sensors and accelerometers measure the progression of the pressure and the acceleration of the structure during inflation.

1.5 Team Details

1.5.1 Contact Point




Team Email: mass.bexus@gmail.com


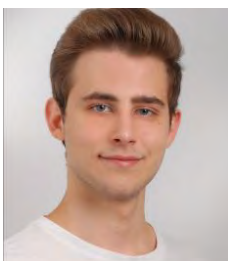

Team leader: Ludwig Staab, Munich University of Applied Science

Postal address: Hochschule München, Lothstr. 34, 80335 Munich, Germany

Contact Number: +49 152 51763280

1.5.2 Team Members

Team member	Background	Field of work
 <p>Ludwig Staab</p>	<p>Aerospace Engineering, Bachelor of Science, 5th year (9th semester), MUAS</p>	<p>Mechanical Engineer Interests: Space and spaceflight, music (playing guitar), motorcycles</p>
 <p>Johannes Ernstberger</p>	<p>Master of Applied Research in Engineering Sciences, 1st year (1st semester) B.Sc. Aerospace Engineering, MUAS Aircraft Mechanic at Airbus Helicopters</p>	<p>Mechanical Engineer Interests: Sport (BJJ, kickboxing), music (playing the trumpet), helicopters, additive manufacturing, machining</p>
 <p>Niklas Fromm</p>	<p>Aerospace Engineering, Bachelor of Science, 5th year (9th semester), MUAS</p>	<p>Mechanical Engineer Interests: Prop- and modelmaking, Space and Spaceflight, 3D Design</p>

 <p>Adrian Hettler</p>	<p>Mechatronics, Master of Engineering, 1st year, MUAS</p>	<p>Mechatronics Engineer Interests: Software reverse engineering, Embedded Systems, Spaceflight</p>
 <p>Petros Karafilis</p>	<p>Aerospace Engineering, Bachelor of Science, 3rd year (5th semester), MUAS</p>	<p>Electrical Engineer Interests: Spaceflight, Motorcycles, Computers (Software and Hardware)</p>
 <p>Carlo Riester</p>	<p>Aerospace Engineering, Master of Science, 2nd year (3rd semester), MUAS</p>	<p>Electrical Engineer Interests: Model Flight, Motorcycles, Space and Spaceflight</p>

Due to the postponement of Bexus Mission 31 team members Pietro Ignoto and Nico Reichenbach had to leave the team.

2 EXPERIMENT REQUIREMENTS AND CONSTRAINTS

2.1 Functional Requirements

ID	Description
FR_01	During ascent the structures shall be securely stored.
FR_02	When the balloon reaches an altitude of 25 km the inflation process shall start.
FR_03	After the inflation process was successful the rigidization of the resin soaked fibre structures shall be accomplished.
FR_04	The rigidization shall be occupied by strong UV light of the LED-segments.
FR_05	Cameras shall record the performance of the inflating structures.
FR_06	The setup shall measure the temperature inside as well outside the structures.
FR_07	The setup shall measure the pressure inside as well outside the structures.
FR_08	The pressure control valve shall be set correctly to the pressure which the structures need to ensure the complete deployment.

2.2 Performance Requirements

ID	Description
PR_01	The resolution of the camera(s) shall be at least 800x600 pixels.
PR_02	Images and Videos captured shall have at least 16-bit colour.
PR_03	Temperature sensors shall be able to record the temperature between -60°C and 40°C .
PR_04	The temperature measurements shall have a minimum sensitivity of $\pm 1^{\circ}\text{C}$.
PR_05	Pressure sensors shall be able to record the measuring values down to 750 Pa.
PR_06	The pressure measurements shall have a minimum sensitivity of $\pm 20\text{ Pa}$.
PR_07	The top part of the inflatable structure shall be positioned with an accuracy $\pm 0.5\text{ cm}$ to the desired target position.
PR_08	The inflation process shall be completed within 30-60 sec.
PR_09	The pressure inside the structures shall be controllable with an accuracy of $\pm 100\text{ Pa}$.
PR_10	Temperature measurements of critical components shall take place at a frequency of at least 0.2Hz.
PR_11	Ambient temperature measurements shall take place at a frequency of 0.2 Hz.
PR_12	Pressure measurements shall be taken at a frequency of 0.1 Hz during the inflation process.

ID	Description
PR_13	The LEDs shall have enough power to start the hardening process of the resin.

2.3 Design Requirements

ID	Description
DR_01	Inflation structures inside the lower box must withstand a temperature range from -30°C to 40°C .
DR_02	Inflation structures in the outside upper box must withstand a temperature range from -60°C to 25°C .
DR_03	Electronic components inside the lower box must be able to operate at temperatures from -30°C to 40°C .
DR_04	Electronic components in the outside upper box must be able to operate at temperatures from -60°C to 25°C .
DR_05	The pneumatic system must be able to operate at temperatures from -60°C to 25°C .
DR_06	Inflation process must be able to operate at temperatures from -60°C to 25°C .
DR_07	The amount of carried pressurized nitrogen shall be enough to completely inflate the 4 structures.
DR_08	The pressure unit shall be designed in such a way that 2 pairs of structures (each consisting of one in the lower box and one in the upper box) can be inflated independently.
DR_09	The LED-segments shall be controllable for on-off-switching via ground station.
DR_10	The experiment shall be developed and positioned so that the 2 outside structures have the possibility to be exposed to the sunlight depending on flight conditions.
DR_11	The lower box shall be designed to regulate the temperature above -30°C .
DR_12	The boxes shall be designed to provide protection of the structures during landing.
DR_13	The experiment shall be designed in such a way that it shall not disturb or harm the gondola or any other experiment.
DR_14	The experiment shall be mounted on the BEXUS gondola so 2 of the 4 structures can inflate inside and the other 2 outside the gondola.
DR_14	No components or parts shall become detached from the experiment at any point during the BEXUS flight.
DR_15	Cameras shall be positioned suitably to capture the whole inflation process.

ID	Description
DR_16	The experiment shall be designed to operate in the vibration profile of the BEXUS balloon with special consideration given to the launch and landing stages.
DR_17	The experiment shall be designed to operate in the pressure profile of the BEXUS balloon.
DR_18	The lower box of the experiment shall contain a guide hole for the power and data cables.
DR_19	The experiment shall be able to get 28.8 V from the BEXUS onboard battery and 21 V from the battered battery.
DR_20	The electrical components shall not draw more than 1,5 A from each battery.
DR_21	The experiment shall not generate more than 45 watts from the BEXUS battery and 30 watts from the battered battery.
DR_22	Communication up down the BEXUS E-Link shall not exceed 500 bps.
DR_23	The whole experiment shall not exceed a maximum weight of 24 kg.

2.4 Operational Requirements

ID	Description
OR_01	The communication between the experiment and ground station shall be executed via E-Link until cutoff.
OR_02	Status of LEDs and pressure temperature values shall be reported to the ground station every 5 seconds.
OR_03	The structures shall be released autonomously at an altitude of 25 km.
OR_04	The inflation process shall start when the gondola reaches a flight altitude of 25 km.
OR_05	The inflation valve shall regulate the pressure autonomously but in case be able to be controlled from the ground station.
OR_06	The experiment LED lights inside the gondola shall be switched on autonomously but in case be able to be controlled from the ground station.
OR_07	All data (including measuring values and recording from the cameras) shall be saved during the flight.
OR_08	All electronic systems shall operate autonomously.
OR_09	The flight altitude shall be at least 25km (low pressure and strong sunlight required for the inflation process and hardening of the structure).

2.5 Constraints

ID	Description
C1	Limited manpower due to team member's full time studies and other university related activities.
C2	Reduced time for experiments and reduced access to labs because of Corona-Pandemic.

3 PROJECT PLANNING

3.1 Work Breakdown Structure

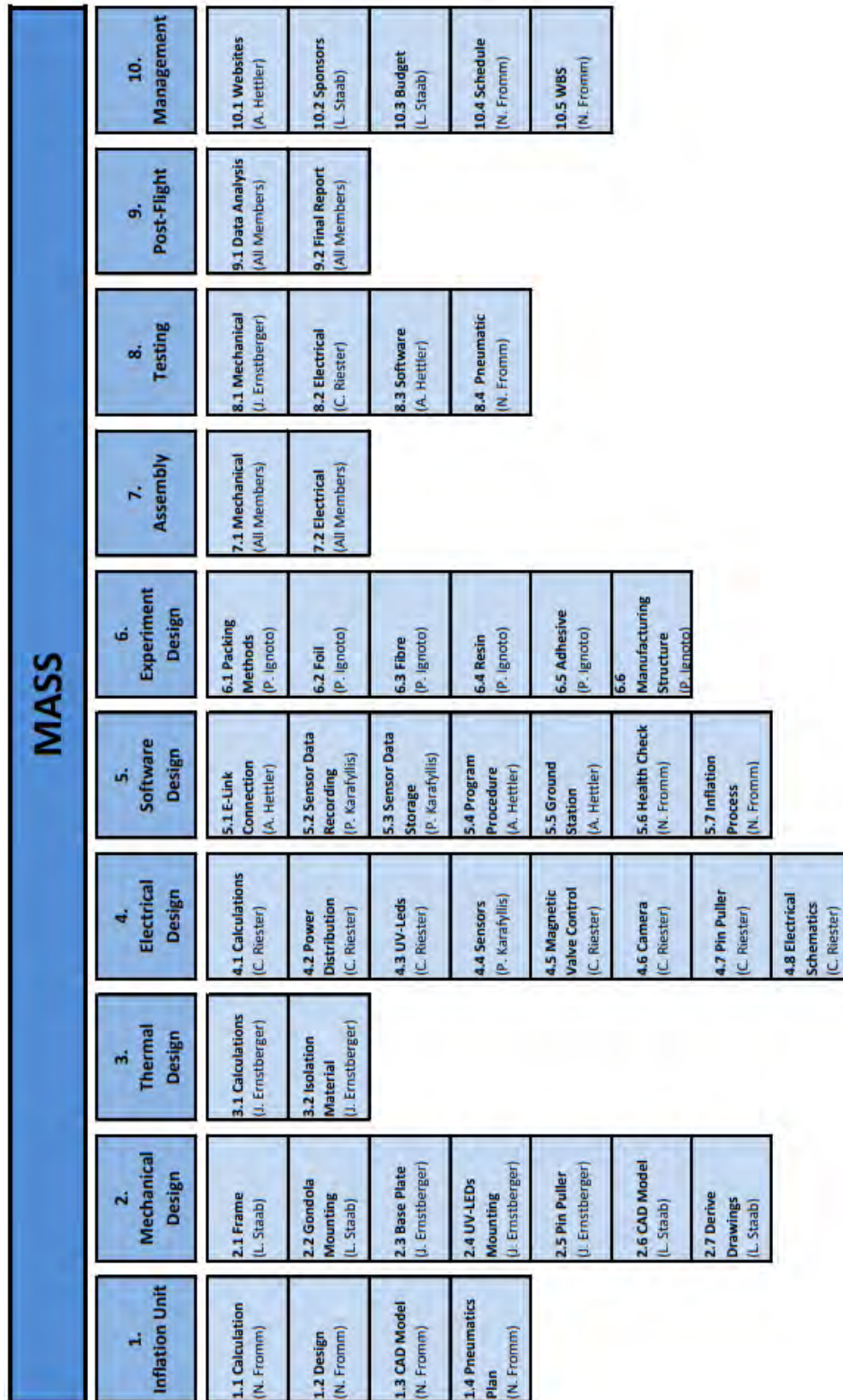


Fig. 3.1: MASS Work Breakdown Structure

3.2 Schedule

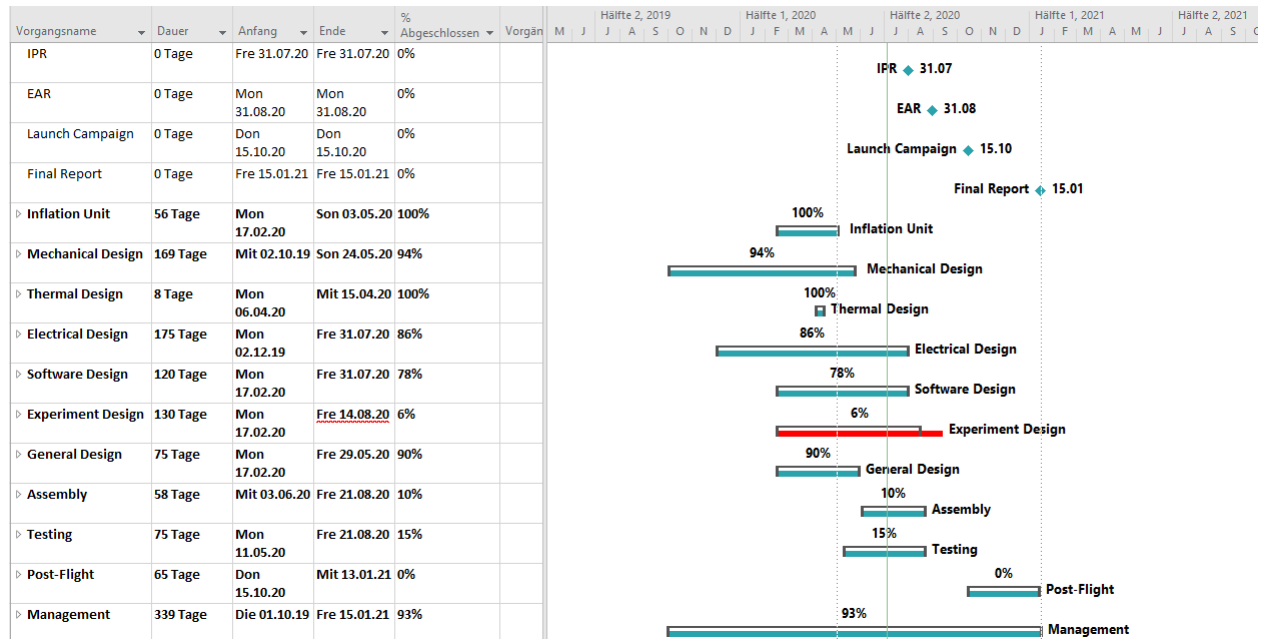


Fig. 3.2: Gantt chart

Due to the outbreak of the Coronavirus our experiment suffered heavy delays regarding the Experiment Design. The assembly of our inflatable structures and the materials, e.g. foil, fibres and spray adhesives heavily depend on thorough testing. The Munich University of applied Sciences shut down for students and has not opened as of 5th of July 2020. All other work packages advance at a good pace, all though small delays were to be expected due to the uncertainty of the situation. The team adapted well to this new situation after a few weeks.

In March 2021 we set up a workshop at the home of one of our team members. This allowed us to advance our Experiment Design and to assemble and test the whole experiment. Due to the uncertainty of the situation week-to-week planning was more effective than planning long term. With only six team members left and no dedicated project manager it was easier and more sensible to spend the available manpower where it was needed. Changes from the IPR were implemented and all open work packages were completed.

Figure 3.2 shows a non detailed version of our original schedule with the planned launch in October 2020. More detailed versions can be found in Appendix A.

3.3 Resources

3.3.1 Manpower

Each work package has a team member assigned to it as seen in Figure 1, which takes responsibility for it. In addition to them other team members aid in development of work packages if additional manpower or expertise is needed. Weekly meetings ensure that everyone stays informed about the status of the project. This allows for easy compensation for temporary loss of manpower due to illness or other complications, since all members stay up to date.

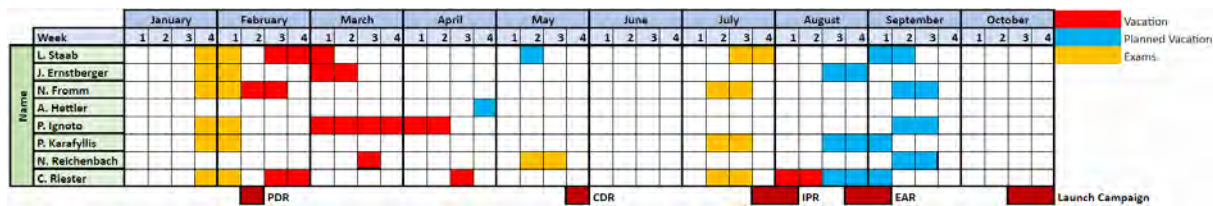


Fig. 3.3: Manpower Chart

A core team of eight students work on the MASS project. This core team is comprised of Adrian Hettler, Nico Reichenbach, Ludwig Staab, Pietro Ignoto, Johannes Ernstberger, Carlo Riester, Petro Karafyllis and Niklas Fromm. Figure 3.3 highlights the transition of personnel and shows the availability of team members. Both Nico Reichenbach and Pietro Ignoto left the team in 2020.

Figure 3.4 shows the amount of work hours individual team members are planning to put into the MASS project. Combining those hours with the amount of weeks that will be worked until the Launch Campaigns begin, and keeping the availability of team members from Figure 3.3 in mind, the MASS team will put a total estimate of around 3200 hours of work into this project.

		h per Week
Name	L. Staab	10
	J. Ernstberger	8+ -
	N. Fromm	10
	A. Hettler	10
	P. Ignoto	10
	P. Karafyllis	8+
	N. Reichenbach	10
	C. Riester	10+ -

Fig. 3.4: time dedicated to project

With the delay of the launch campaign to October 2021 and the aforementioned short term planning the team had more time to work on the experiment. The loss of two team members was compensated by the additional year until launch.

3.3.2 Budget

DLR/ZARM supports the MASS project by purchasing requested items. MUAS supports our project furthermore with an additional 13000€. Deployables Cubed is sponsoring two of their Pin Pullers, equaling additional funding of 4000€. This amounts to a total budget of 17000€ budget. An overview of this projects planned Budget can be seen in table 1.

Table 3.1: Budget overview

Item	Cost	Paid By	Status	Paid	Total
X-Winder filament winding machine	5000€	MUAS	received	5000€	5000€
Inflatable Structures (Foil, Fibre, Resin)	326 €	MUAS 225€, DLR/ZARM 101€	received	5326€	5326€
Electric Components, Sensors, LEDs	1332€	MUAS 290€, DLR/ZARM 1042€	received	6658€	6658€
FESTO Pneumatic Parts	1200€	MUAS 1000€, DLR/ZARM 200€	received	7858€	7858€
Buerkert Pneumatic Parts	200€	MUAS	received	8058€	8058€
Riegler Pneumatic Parts	30€	MUAS	received	8088€	8088€
Other Pneumatic Parts	268€	DLR/ZARM	received	8356€	8356€
Pin Puller	4000€	Deployables Cubed	sponsored	12356€	12356€
Mechanical Parts	788€	DLR/ZARM	received	13144€	13144€
Insulation	100€	DLR/ZARM	estimated	13244€	13244€
3D printed parts	93€	DLR/ZARM	received	13337€	13337€
Safety Equipment	550€	DLR/ZARM	received	13887 €	13887 €

In our current estimate MASS has an additional 3113€ left to be spent on the project. Currently all members intend to attend the launch campaign in October.

The X-Winder is not used by team MASS. Thus it has lost its status as a high value critical item.

3.3.3 External Support

Table 3.2: External Support

Prof. Dr. Markus Pietras	Main MASS Advisor
Dr. Thomas Sinn	Technical Support
Deployables Cubed	Sponsor

One of our main partnerships is Deployables Cubed and its founder Dr. Thomas Sinn. They will provide technical support and share their experience from own REXUS/BEXUS experiments. In addition, they will provide pin pullers for our BEXUS experiment.

MUAS's professors will provide support and guide our BEXUS team through all phases until the end of the project. MUAS allows us to use the following facilities at its campus:

- team workshop with sufficient equipment such as winding machines for manufacturing the truss/helix structure
- MUAS “creative lab” provides access to 3D-printing devices, metalworking and machining tasks.

- Other laboratories including materials technology and polymer technology, accessible through collaborations with other departments at MUAS and industry partners
- small vacuum chamber in which individual components can be tested

AIMIS, a student team from MUAS partaking in REXUS27, offers additional support from their experience with the program.

3.4 Outreach Approach

Disclaimer: Many events our Team planned to attend got cancelled due to Covid-19. Our current outreach plan only consists of social media because of the uncertainty of the situation.

The website for the MASS project has been launched and can be reached through <http://www.massbexus.eu/>. It contains a blog with latest updates on the progress of our development and the gallery is equipped with pictures to follow the hardware design process. Additionally, general info and contact data about the team is provided here.

For more frequent updates, MASS posts on several social media pages and accounts to provide a larger outreach by uploading pictures and video footages. These accounts are aiming for a younger audience with the goal to interest the next generation in scientific projects. To further help us achieve that goal, we are planning to hold talks at local high schools. Currently MASS can be found on the REXUS/BEXUS webpage and the following social media channels:

- <http://rexusbexus.net/>
- <https://www.facebook.com/MASS-Bexus-109982933913101>
- <https://twitter.com/MassBexus>
- <https://www.instagram.com/massbexus/>

<http://rexusbexus.net/>

To communicate news and information about MASS and REXUS/BEXUS to the scientific community, we planed to present a poster with a presentation at the Aerospace Mechanism Symposium in Houston, Texas in May 2020 in front of experts of the space mechanism community. This event has been cancelled due to Covid-19.

3.5 Risk Register

Risk ID

TC - technical/implementation

MS - mission(operational performance)

SF - safety

PE - personnel

MM - managment

Probability (P) A. Minimum - Almost impossible to occur

B. Low - Small chance to occur

C. Medium - Reasonable chance to occur

D. High - Quite likely to occur

E. Maximum - Certain to occur, maybe more than once

Severity (S) 1. Negligible - Minimal or no impact

2. Significant - Leads to reduced experiment performance

3. Major - Leads to failure of subsystem or loss of flight data

4. Critical - Leads to experiment failure or creates minor health hazards

5. Catastrophic - Leads to termination of the REXUS and/or BEXUS programme, damage to vehicle or injury to personnel

The rankings for probability (P) and severity (S) are combined to assess the overall risk classification, ranging from very low to very high and being coloured green, yellow, orange or red according to the SED guidelines

Table 3.3: Risk Register

ID	Risk (and consequence if not obvious)	P	S	P x S	Action
TC10	Video is blurred due to low resolution (<480p)	A	1	very low	Purchase HD Camera (>720p)
TC20	Software failure of on-board data storage	B	2	very low	Testing, Data-Feed to ground
TC30	Hardware failure of storage components	A	2	very low	Testing, Redundancy
TC40	Critical component fails	B	3	low	Keep critical components in stock, redundancy in the system, thoroughly tested components where redundancy is impossible
TC50	Loss of communication with ground station and resulting loss of control over the experiment	A	1	very low	Have an autonomous backup programm once loss of control happened
TC60	Excess of mass or dimension limits	C	1	very low	Monitor mechanical development process, communicate changes early
TC70	Experiment does not fit together for integration	B	2	very low	coordination between working groups and internal reviews
TC80	pressure loss due to leakage in the pressure system, or a bursting inflatable	B	3	low	test system leakage before start, ensure that a failing inflatable doesnt harm the other inflatables
TC90	inflation unit not working	B	4	low	test the inflation unit thoroughly
TC100	camera is not working due to electronic or software failure	B	3	low	testing the camera in various settings (e.g. vacuum chamber)
TC110	Software/Electronics completion issues	B	3	low	Aim for keeping it as simple as possible by focusing on core functions
TC120	Experiment Design completion issues	A	C	very low	X-Winder no longer needed, work was completed outside of MUAS

Table 3.4: Risk Register

ID	Risk (and consequence if not obvious)	P	S	P x S	Action
MS10	Damaging MASS-Structure during mission due to vibration loads	A	3	very low	Vibrations Test
MS20	Temperature falls below survival range of components	A	3		implement isolation and heating; thermal simulation and testing
MS30	component failures due to vacuum	A	3	very low	choosing components built for vacuum, extensive testing of components in a vacuum chamber
MS40	components overheating in thermal vacuum	B	3	low	Extensive thermal tests in a vacuum chamber
MS50	Launch is either too early or too late (outer structures to be cured by sunlight cure too early or not at all)	B	3	low	communicate our launch requirements
MS60	Resin does not cure due to insufficient performance of the LEDs	B	3	low	Extensive testing of the curing process to optimize parameters
MS70	inflated structures are damaged during recovery	D	2	low	Important footage of the inflation process is filmed during the flight, ensure chemical/mechanical comparability with on ground inflated structures
SF10	injury while manufacturing	B	1	very low	use safety equipment, e.g. breathing protection, gloves
SF20	health damage from tests including UV light or spray adhesives	A	3	very low	buy and use safety equipment
SF30	inflatable or pressurized tank explodes due to sudden loss of pressure or tearing	B	3	low	Mechanical tests (test 13) and sufficient safety factor of 2 (i.e. filled with 16 bar)
SF40	box rips off during lift off	A	4	very low	thorough mechanical tests
PE10 (formerly PE20)	Students struggle with workload while carrying on their studies	C	2	low	provide support and flexibility

Table 3.5: Risk Register

ID	Risk (and consequence if not obvious)	P	S	P x S	Action
MM10	not enough budget due miss-planing or sudden need of more funds	A	3	very low	up-to-date budget planning, allocation of funds to projects (i.e. electronics, pneumatics) to ensure no overspending is occurring
MM20	no access to workshops or critical equipment	C	1	very low	workshop outside of MUAS for reliable access
MM30	production problems, ordered items not arriving on time	C	2	low	order items with enough time in mind to accommodate for any delays
MM40	communication problems in the team	B	2	very low	weekly meetings with the team to talk about the status of current work packages

4 EXPERIMENT DESCRIPTION

4.1 Experiment Setup

The experiment consists of four inflatable structures. The structures are made from polyester foil to be inflated onboard the BEXUS balloon. Two structures are mounted inside the gondola and are equipped with LEDs. The other two structures are not equipped with LEDs and shall be integrated on top of the gondola to be inflated outside of the gondola. All four structures are wrapped with fibres that are impregnated in resin, which cures once exposed to UV radiation. The resin of the structures inside the gondola are cured through the artificial UV radiation provided by the LEDs. The structures inflated outside of the gondola are cured through natural UV radiation provided by the sun. During the launch and the ascent of the gondola, all structures are held down by a Hold Down and Release Mechanism (HDRM). To inflate the structures, an inflation unit in the form of a pressure tank is integrated into the experiment. An On-Board Computer (OBC) controls the elements that are involved in the experiment. It triggers the HDRM, the inflation unit and the LEDs through a microcontroller to successfully inflate and rigidize the structure. Throughout the inflation process, cameras are also triggered from the OBC to monitor the inflating procedure. One camera is installed inside the gondola and another camera is installed outside the gondola to capture the inflation process of the two sets of inflatable structures. Pressure sensors and accelerometers are installed onto the inflating structures as well. Besides the camera footage, the measured data from the pressure sensors and accelerometers are stored on the memory of the OBC. In Figure 1 a block diagram shows the experimental setup with the interactions between the subsystems involved.

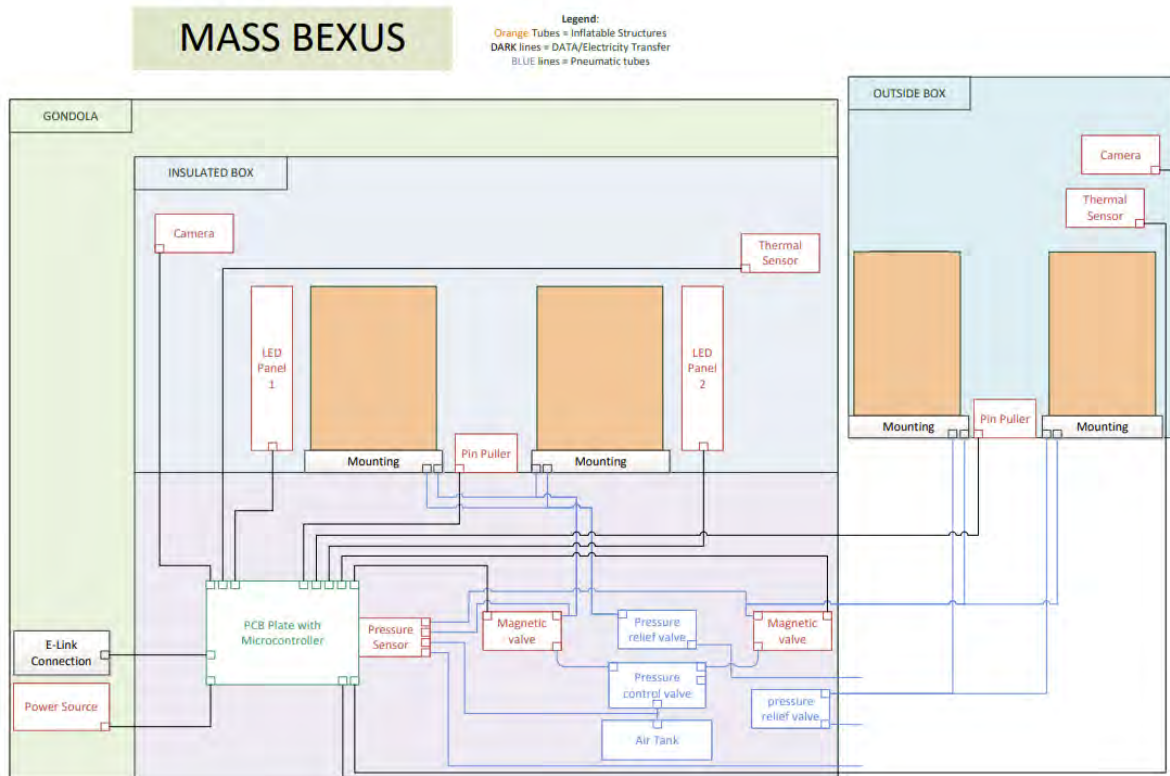


Fig. 4.1: Block Diagram of Experiment Setup

The following figure shows the MASS experiment mounted on the gondola.

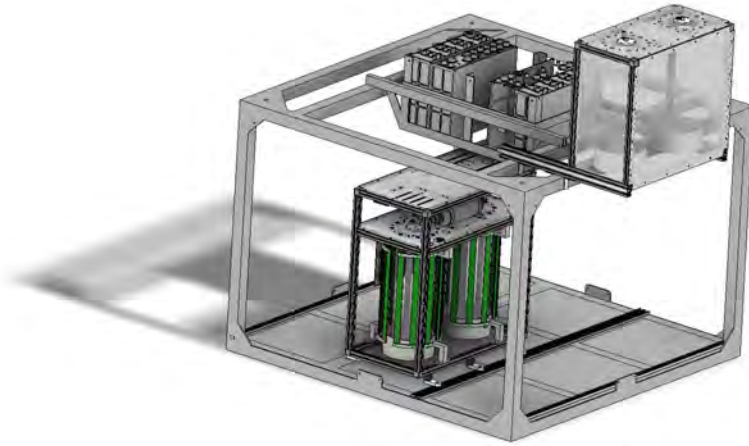


Fig. 4.2: Gondola with Frames and Structures

4.2 Experiment Interfaces

4.2.1 Mechanical

The mechanical interface of the outer experiment box to the gondola consists of two aluminium top hat profiles per one ITEM 40x20 profile, which are the supports of the outer box. These will be screwed together with these profiles via four M5 screws each, which will be screwed into slot nuts fitting the profile. Each slot nut will provide a resistance to dislocation of the upper box into the direction of the mounting profile of 250N. With 4 of these connections per top hat profile a resistance of 1 kN can be realised. With the 4 of these connections the interface is protected against dislocation up to horizontal loads of 4 kN, which gives a safety of 8,15 against a acceleration of 5G into the horizontal direction, which results in a force of 490,5N. Movement along the support beams of the gondola will be prevented via a tight screw clamping of the top hat profiles onto the frame of the gondola. The profiles will be screwed on so tight, that the contact pressure will induce a high enough force to prevent slipping. With a friction coefficient of 0,21 a force of 584N (0,73 MPa contact pressure) in normal direction is to be generated to have high enough static friction to prevent movement along the beams of the gondola.

To guarantee that the clamping of the top hat profiles onto the gondola is tight enough, they will be fitted via aluminum compensation pads/aluminium foil or rubber pads, if the tolerances of the manufacturer are not in our favour.

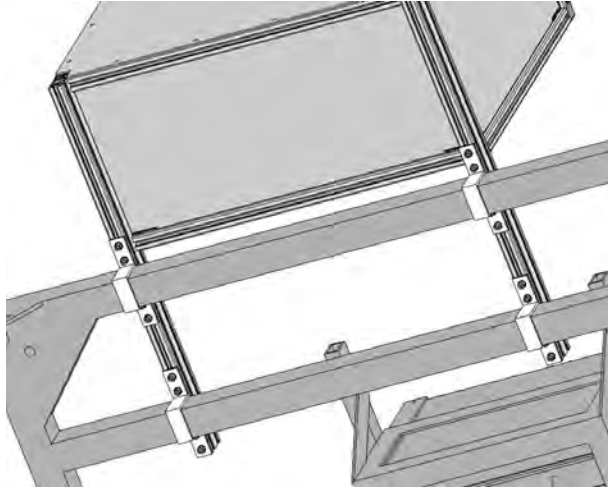


Fig. 4.3: Interface Gondola - Outer Frame



Fig. 4.4: Interface Gondola - Outer Frame (Detail)

The inner box is attached to the rails of the gondola. The connection consists of a rubber buffer and a connecting aluminium plate. The parts are bolted together with M6 screws. The connection to the rail is realized with slot nuts. A total of six connections are implemented.

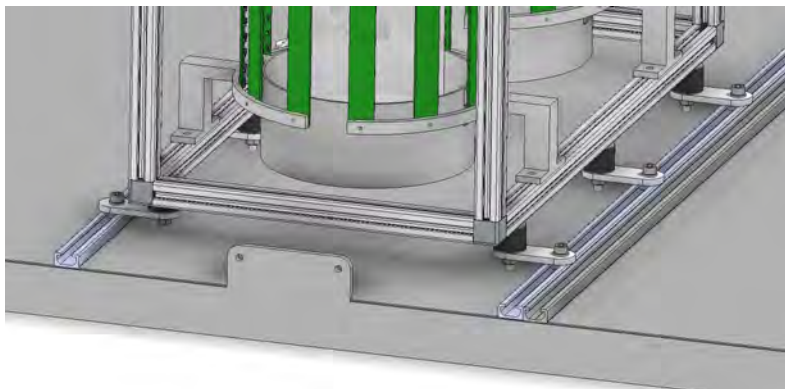


Fig. 4.5: Interface Gondola - Inner Frame

4.2.2 Electrical

A four pin male Amphenol PT02E8-4P connector is used as the electrical power interface to the gondola. A nominal Voltage of 28.8V will be provided by the batteries on the BEXUS gondola. The connector and the pin assignment is shown in figure 4.6.

Pin A: +
Pin B: - , do not connect to chassis or ground
Pin C: empty
Pin D: empty



Fig. 4.6: Amphenol PT02E8-4P

To connect the experiment to the E-Link telemetry system a Amphenol RJF21B connector is used. The connector is shown in figure 4.7.

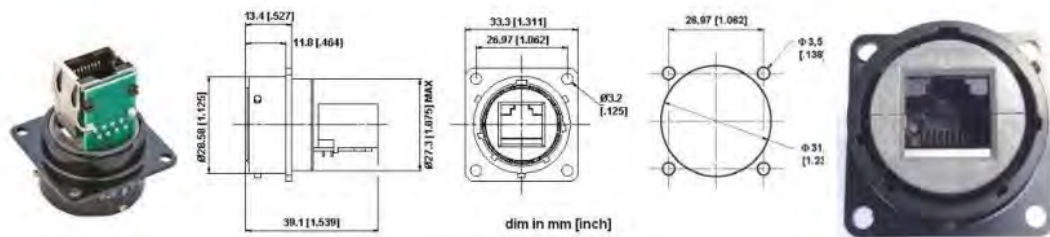


Fig. 4.7: Amphenol RJF21B

In Fig.4.8 and Fig.4.9 is shown the position of the Power-connector 4.6 and the E-Link telemetry system 4.7



Fig. 4.8: connector

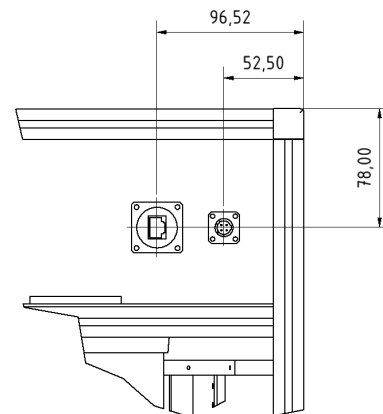


Fig. 4.9: connector

4.3 Experiment Components

Components	Estimated mass (IPR)	Actual mass (measured)
Upper Frame (including Plexiglas)	5 kg	4,7kg
Interface for upper frame	2,0 kg	0,3kg
Lower Frame	4,7 kg	4,8 kg
Isolation	1,8 kg	1,8 kg
Inflatable Structure - Polyester foil - Fibers - Resin - Base plate - Top plate	4 x 1,0 kg = 4,0 kg	4 x 0,55kg = 2,2kg
Inflation Unit	3,3 kg	3,8kg
Eletrical components: - Camera (2x) - Microcontroller - LEDs - Batteries - Sensors	2,0 kg	2kg
HDRM	-	2 x 0,3kg = 0,6kg
Total Mass	22,8 kg	20,2 kg + 10%

Table 4.1: Mass estimations of components.

Experiment mass	20,2 kg + 10%
Upper Frame	6,4 kg
Lower Frame (including interface)	13,8 kg
Experiment dimensions:	.
Upper Frame	505mm x 247mm x 442mm
Lower Frame	592mm x 342 x 604mm
Experiment expected CoG (Centre of gravity) position (measured from CoG of gondola)	545mm x 70mm x 205mm

Table 4.2: Experiment summary table.

4.4 Mechanical Design

4.4.1 Inflation Unit

All pneumatic elements will be mounted on a 1.5mm aluminium plate from the opposite side as pictured in Figure 4.10. Two cylinder clamps hold the tank. T-Connectors and tubes are secured by using cable ties where necessary.

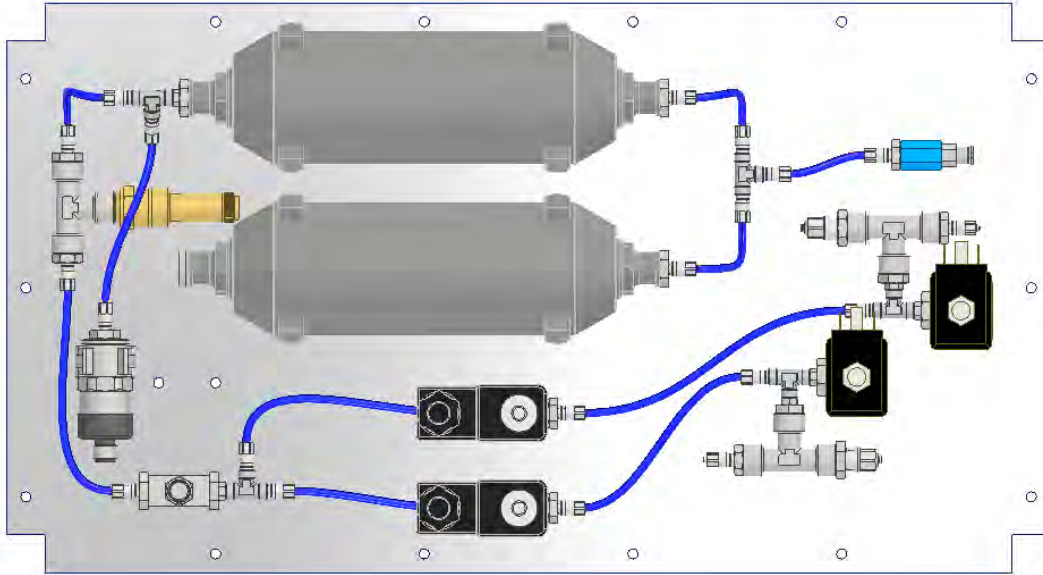


Fig. 4.10: CAD model of the Inflation Unit.

The experiment is designed, that our structure will inflate due to a differential pressure. For that we are considering to provide pressurized gas in form of dry nitrogen to prevent icing of valves. Previous BEXUS missions measured an external pressure of 11 hPa during flight phase, hence that we only need a minimal pressure vessel to perform the inflation. Testing showed that a differential pressure of 100hPa is sufficient to completely inflate the structure. In Figure 4.10 the setup of the inflation unit is pictured. Two tanks provide the necessary volume of dry nitrogen. Pressure inside the inflatable structures will be regulated by opening the VZWD magnetic valves in short bursts.

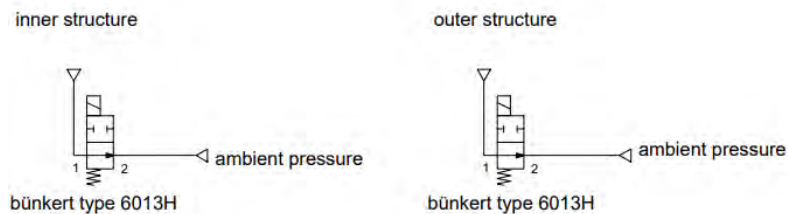


Fig. 4.11: pneumatics schematic for pressure equalization.

The pneumatic system provides pressure equalization during ascent as well as during descent as seen in Figure 4.11 to avoid damage to the structures. During flight the pressure system provides inflation of all four structures as seen in Figure 4.12. Pressure is measured at the pressurized tanks, the inner and outer structures and the atmospheric pressure. The magnetic valves used

in the inflation process are normally closed. Those for equalization are normally opened to allow for equalization to happen even after experiment cutoff.

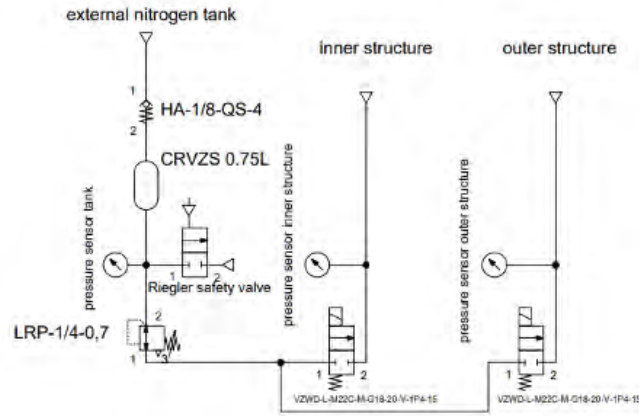


Fig. 4.12: pneumatics schematic for inflation.

The pressure tanks are filled with dry nitrogen at nominal 8 bar. For vacuum isothermal inflation estimated 3,1 litres of nitrogen are required to achieve a pressure of 100 hPa in all four structures. One 0,75L tank contains 6 litres of nitrogen at 8 bar. Testing during the Thermal Vacuum Week at ZARM showed that approximately 0.2 litres of dry nitrogen were sufficient for inflation with an ambient pressure of 11 mbar. The tanks can be refilled from external nitrogen tanks via 4mm tubes. During refill the nitrogen goes through a filter to avoid particles getting in our inflation unit that may damage any components. All components have been changed to vacuum-suitable ones.

Name	Part Num.	Description	Quantity
PAN-MF-4X0,75-SW	570357	4mm tubing	10m
PAN-MF-6X1-SW	570358	6mm tubing	1m
CRVZS-0.75	160235	pressure tank	2
GRO-1/8-B	151216	throttle valve	1
VZWD-L-M22C-M-G18-20-V-1P4-15	1491827	magnetic valve	2
buerkert Plunger valve	6013-H	magnetic valve	2
HA-1/8-QS-4	153446	non-return valve	1
QM-1/8-1/8	2254	sleeve	1
NPFC-T-3G14-F	8030236	T-connector G1/4"	3
NPFC-R-G18-M5-MF	8030307	adapter	5
NPFC-R-G14-M5-MF	8069229	adapter	13
NPCK-C-D-M5-K4	1857681	screw tube fixation	31
riegler Sicherheitsventil DN8, Messing, G1/4	104007	safety valve	1
B-1/4	3569	B-blanking plug	1
NPFK-C-D-G18-K6	1366257	screw tube fixation	2
NPFC-R-G14-G18-MF	8030308	adapter	2
NPFC-D-2M5-M	8030267	double nipple	6
T 50 MSV	T 50 MSV	T-connector M5	7

Table 4.3: part list MASS Inflation Unit

4.4.2 Inner and Outer Box

The experiment is split up into an Inner and an Outer Box. The Inner Box provides an insulated environment to house the OBC, the batteries and all critical pneumatics components. Additionally it includes two inflatable structures that will be cured by activating UV-LEDs during flight. Both the Inner and Outer Box are constructed from ITEM black aluminium profiles that were chosen because of their relative light weight and modularity. Dimensions (excluding the 20mm thick insulation all around the box) can be seen in figure 4.13.

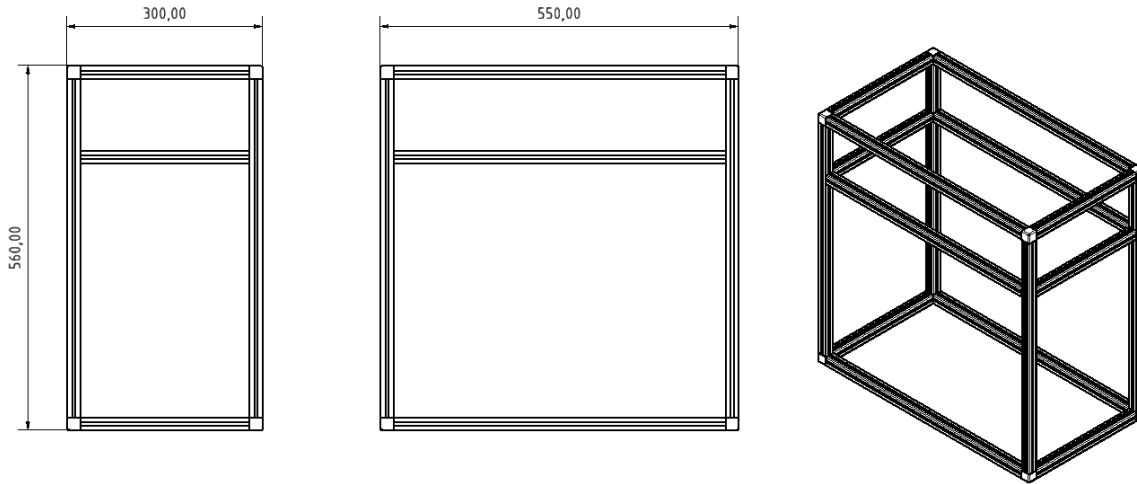


Fig. 4.13: Dimensions of the Inner Box

Two 1.5mm thick aluminium sheets are screwed to M5 blocks to allow for easier assembly. One sheet serves as the interface to the inflation unit, another as baseplate for both inflatable structures.

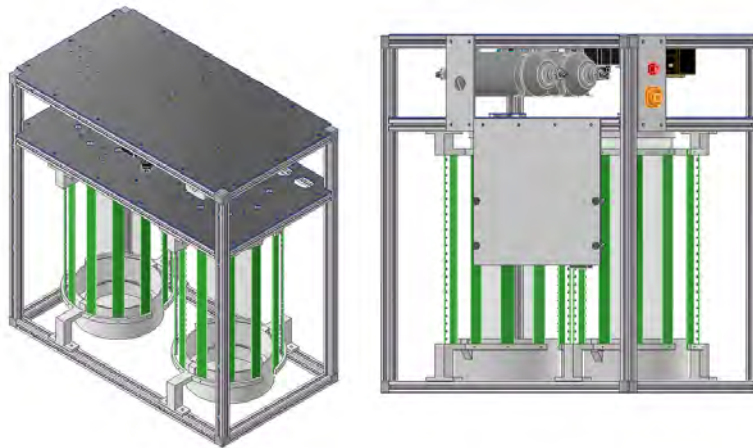


Fig. 4.14: Inner Box Assembled

Several 3D-printed PETG plates and mountings are attached with M5 blocks. 20mm Insulation is attached with plastic screws to the frame, with included cut outs for all interfaces. ITEM aluminium profiles are screwed with either M5 blocks or with appropriate corner pieces as can be seen in figure 4.15.

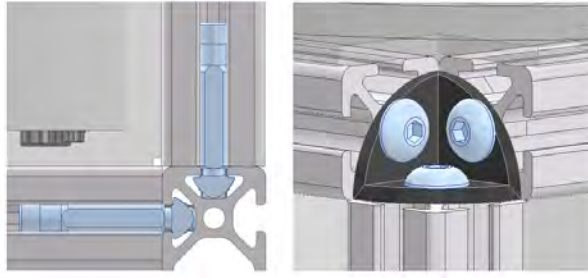


Fig. 4.15: ITEM profile connections

The Outer Box consists of a similar framework as the Inner Box. Notably two of the lower frame pieces are 40x20 instead of 20x20 in dimension to ensure a strong connection to the gondola. To allow sunlight to cure the inflatable structures inside the Outer Box Polycarbonate plates are used instead of styrofoam to trap as much heat as possible inside the box.

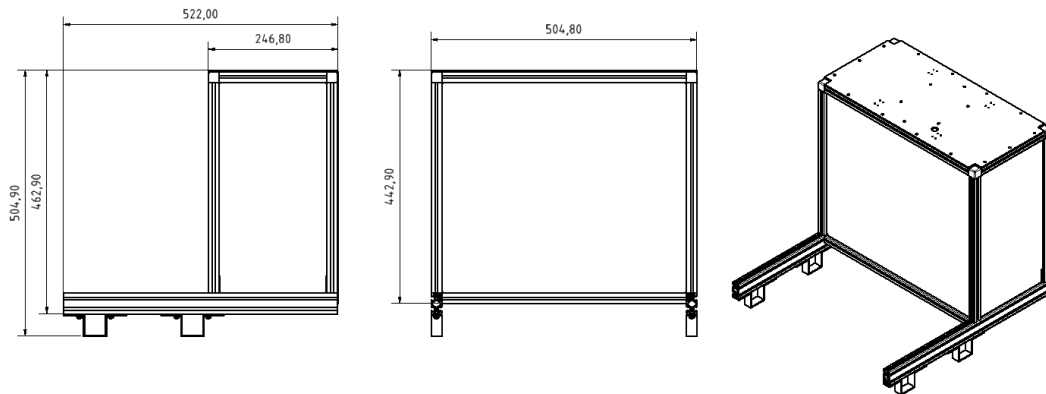


Fig. 4.16: Dimensions of the Outer Box

These PC-Plates are clamped to the box as seen in figure 4.17. Two PC plates are screwed to M5 blocks instead of clamping to allow for easier access and assembly of the box. Figure 4.18 shows a hook that is screwed to one of the 40x20 ITEM profiles to allow a safety cable to be attached.

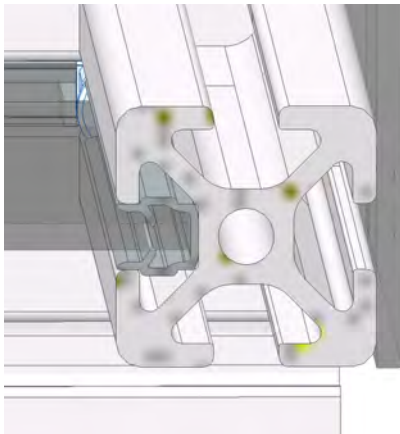


Fig. 4.17: clamping of PC plates

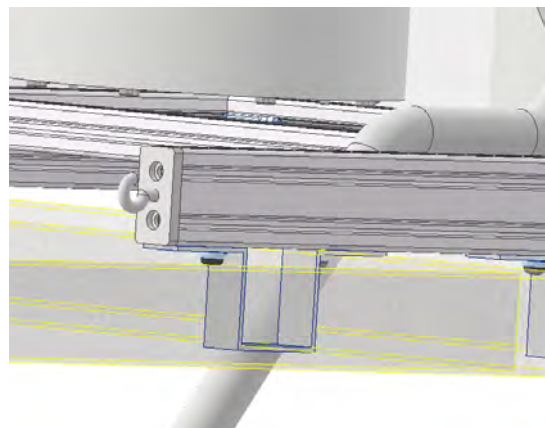


Fig. 4.18: hook for safety cable

4.4.3 FEM Simulation

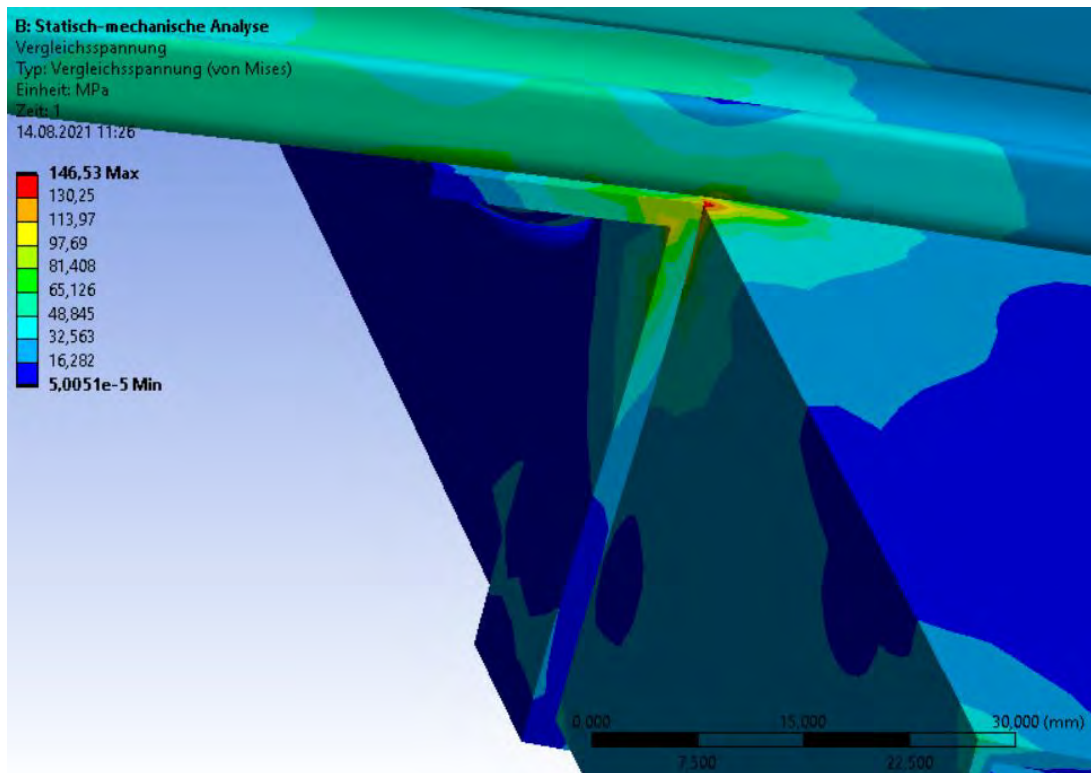


Fig. 4.19: FEM simulation with vertical and horizontal load on gondola interface

The maximum tension occurs in the support beam of the gondola. With a maximum tension of 146,33 MPa, including the safety factor of x1,5, the emerging stress is well within the material boundaries for the gondola and the interface for the outer experiment box.

- **Materials**

Name	Aluminium 6061	
General	Mass Density	2,7g/cm ³
	Yield Strength	275 Mpa
	Ultimate Tensile Strength	310 Mpa
Stress	Young's Modulus	68,9 Gpa
	Poisson's Ratio	0,33 ul
	Shear Modulus	25,9023 Gpa
Part Name(s)	HutprofilKasten4020 item_0037004_Profil_5_40x 20	

Fig. 4.20: Aluminium

Name	Steel, Mild	
General	Mass Density	7,85g/cm ³
	Yield Strength	207 MPa
	Ultimate Tensile Strength	345 MPa
Stress	Young's Modulus	220 GPa
	Poisson's Ratio	0,275 ul
	Shear Modulus	86,2745 Gpa
Part Name(s)	ISO 7380-1 M5x16 item_0044444_Nutscheibe_6_D5 item_0037001_Nutenstein_5_St_ M5	

Fig. 4.21: Steel

- **Parameter for determination**

- m = weight interface = 10 kg
- g = gravitational constant = 9.81 kg/s²
- mul = design for max. vertical acceleration during landing = x10

d) mul_1 = design for max. horizontal acceleration during landing = x5

e) s = safety = x1.5

$$\Rightarrow \prod \text{ total force through vertical acceleration} = m \cdot g \cdot mul \cdot s = 1471.5N$$

$$\Rightarrow \prod \text{ total force through horizontal acceleration} = m \cdot g \cdot mul_1 \cdot s = 735.75N$$

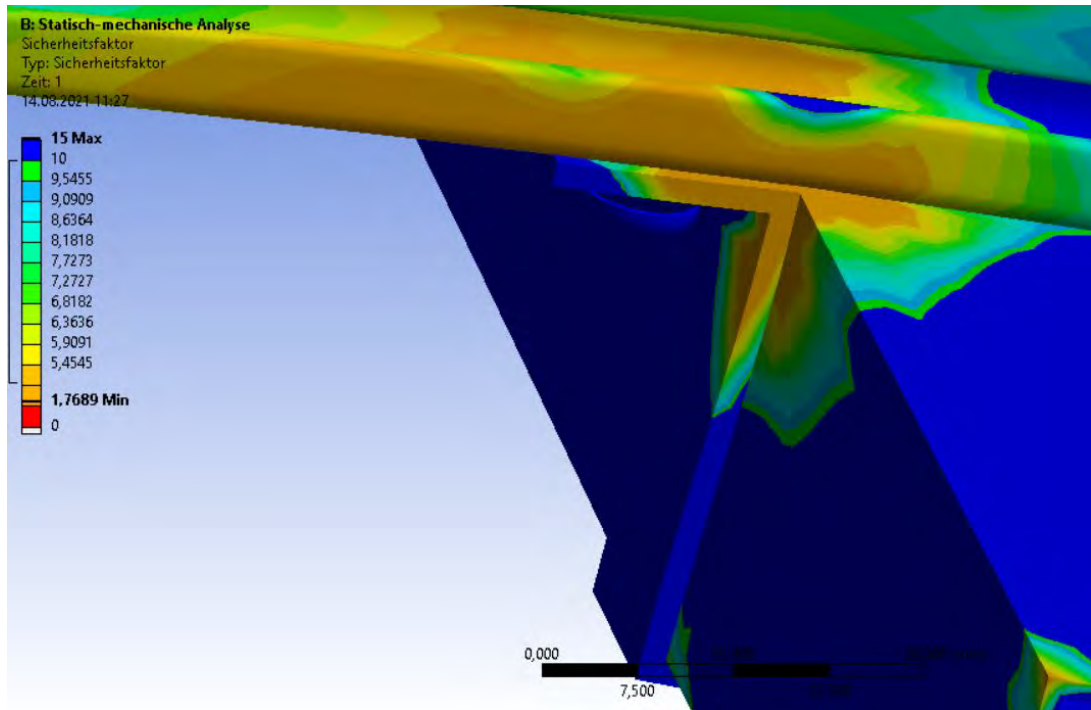


Fig. 4.22: Safety vertical and horizontal loading

In this simulation only one interface was determined, the total weight was divided by 2 and again shifted onto the connections.

\Rightarrow a total force for the Vertical load is 735.75 N

\Rightarrow a total force for the Horizontal load is 367.875 N

In image Fig.4.23 the displacement and the torsion of the interface beam is visible.

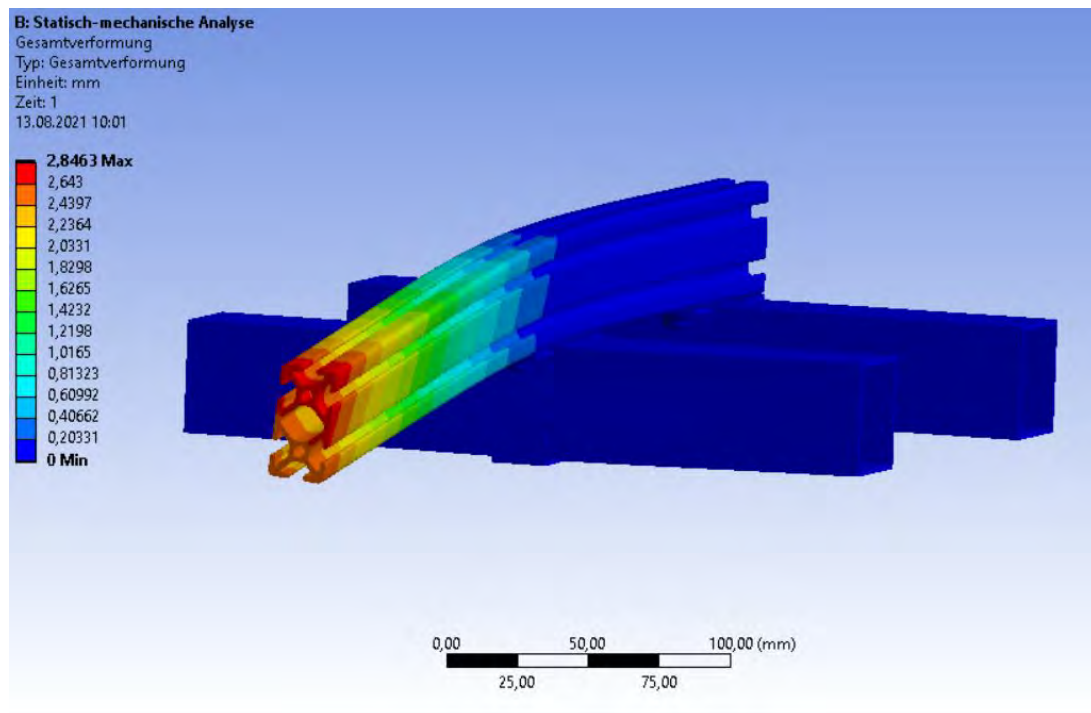


Fig. 4.23: Excursion in x-,y-direction and torsion

FEM - Analysis	
Key Figures	Solution
Max. Equivalent Stress	146,53 MPa
Min. Safety Factor	1,77
Max. Deformation	2,84 mm

4.4.4 Hold Down and Release Mechanism

The HDRM secures that the inflatable structures remain stationary until a release signal is sent. A spring-loaded aluminium fork that is itself held in place by a pin puller supplied and sponsored by Deployables Cubed blocks movement of an inflatable structure in all axis. Figure 4.24 shows an assembled HDRM.

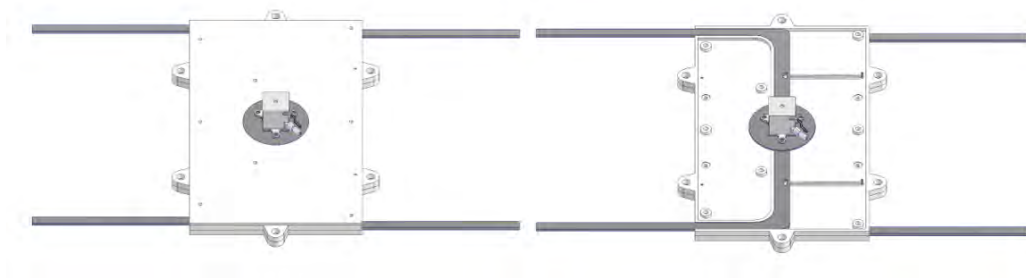


Fig. 4.24: HDRM with and without top plate

One Pin Puller per HDRM locks two aluminium forks on different heights in place until an electric signal is sent that pulls the pin which in turn releases the aluminium forks. Figure 4.25 shows a sectional view of that mechanism.

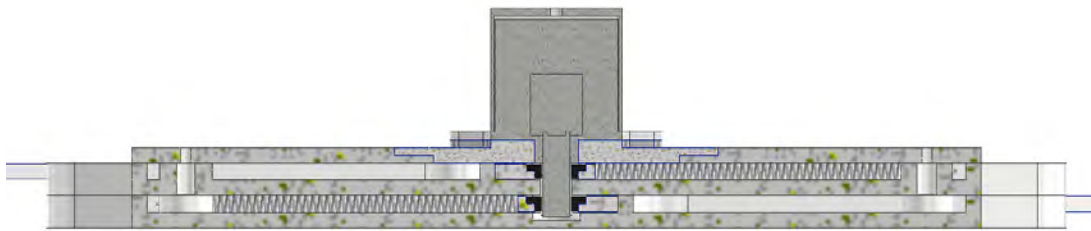


Fig. 4.25: Sectional view of the pin puller mechanism

The aluminium forks fit in slots of the inflatable structure and retract because of two 5 Newton springs pulling them back towards the HDRM housing.

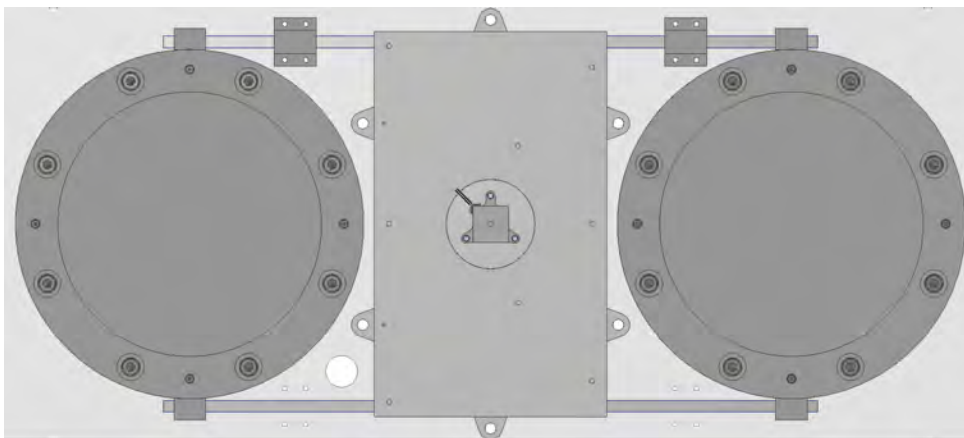


Fig. 4.26: Top view of the aluminium forks holding the inflatable structures in place

4.5 Electronics Design

4.5.1 Structure

The electrical design is separated into two main parts, power distribution and data transmission. The general design can be seen in Figure 4.1. The block diagram shows all main components, power and data lines. In the following each is getting explained in more detail.

4.5.2 Components

4.5.2.1 CPU Board The electronic core of the experiment is the CPU board with the uC, it will control the entire data flow. This requires a high number of clock cycles per second with a large bit count per operation. For these reasons, the MBed uC was chosen. Against the background of the Experimenters University and former Experiments a MBed uC of the company STM will be used. The chosen uC is the NUCLEO-F767ZI. It provides the experiment with a powerful processing unit and enough pins to connect each function of the experiment.

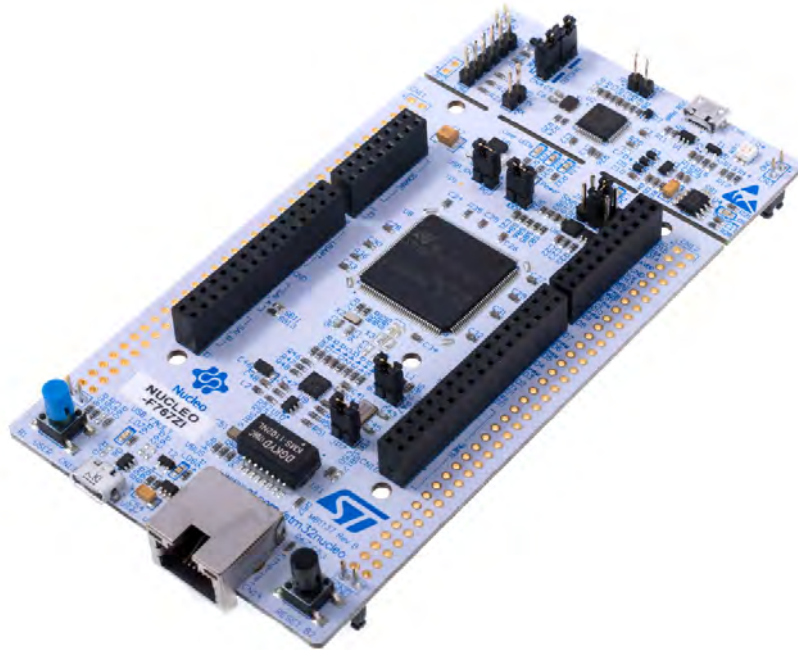


Fig. 4.27: Nucleo F767ZI

4.5.2.2 LEDs MASS uses UV-LEDs to cure resin. The LEDs in use have a wavelength of 365nm, which is ideal for resins curing. Each LED is drawing 20mA at 3.3V, this results in a power consumption of 66mW and can output 13mW of radiant flux with a angle of attack of 150 deg.



Fig. 4.28: Kingbright ATS2012UV365

The resin, DELO Photobond GB310, requires $200mW/cm^2$ of flux for 20s for hardening. As time is not of the essence the hardening time is extended to one hour. This means that a flux of $1.11mW/cm^2$ is required for one hour.

To ensure even illumination a total of 216 LEDs are mounted on 18 PCB strips around each inflatable structure. Three parallel sets of four in series connected LEDs are used. Each pcb draws a current of 60mA at 13.2V.

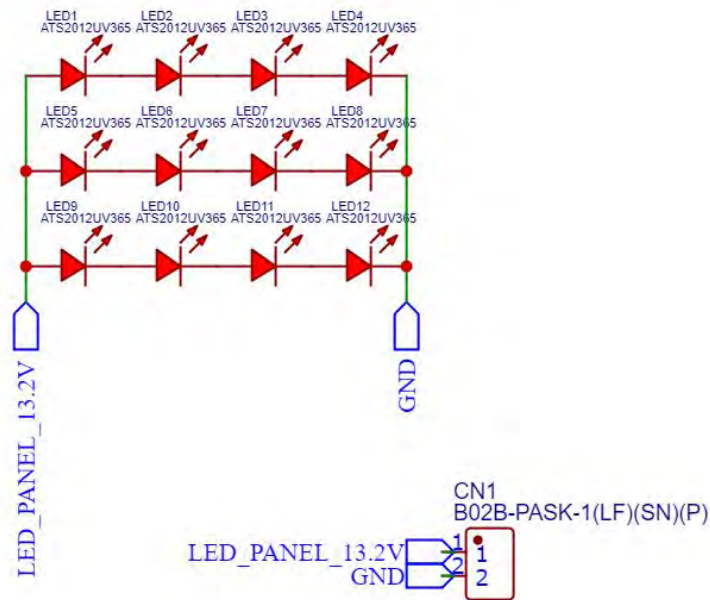


Fig. 4.29: LED Schematic



Fig. 4.30: Single LED Panel

The LEDs consume a total of 30W for both structures.

4.5.2.3 Inflation Unit The magnetic valves will get activated by the switches described in Chapter 4.34. Two types of valves are used. Both need a voltage of 24V DC, they differentiate in Power consumption (6,8W & 8W). A Total of 4 Valves are used, this amounts to a total power consumption of 29,6W.

4.5.2.4 Memory Units Due to multiple data inputs and high data rates coming from the controller, it is necessary that the memory has a high write speed. For an optimal redundant result, twice the amount of collected data is provided as free writable memory space. In total, three memory cards are used. One for the data acquisition and one for each camera. The memory cards used in cameras have a capacity of 64GB each. This is enough for a recording time of around 4 hours. The memory card used for data storage has a capacity of 16GB and is connected to the SPI bus of the mC.

4.5.2.5 Camera The MASS Experiment is mainly a functionality test / technology demonstration. Two Runcam Split Micro 3 cameras, one for each Experiment position, are used to record the inflation and the curing of the resin impregnated folding structures. The Field of View of each Camera will cover two inflatable structures. They are able to record 1080p at 60 fps and only require a power of 3.25W. The data is stored on the SD-Card, inserted into the camera.

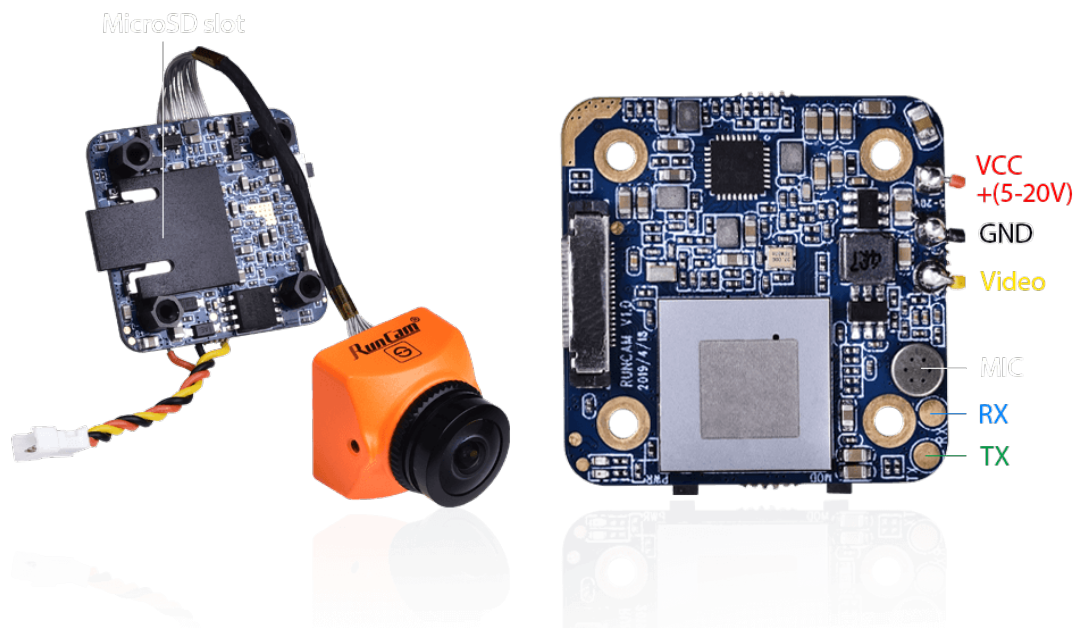


Fig. 4.31: Runcam Split Micro 3

4.5.2.6 Sensors To evaluate the experiment, sensors are used in addition to the video recording of the process to collect experimental data.

Thermal Sensors

To measure the exact temperature in each experiment box two NTC-Thermistors are used. They are connected to an ADC which converts the analog voltage to an I2C Signal. The temperature range is -55°C to $+250^{\circ}\text{C}$.

Pressure Sensors

A total of 4 pressure sensors are used to record the tank pressure, the ambient pressure and the pressure in the inflated structures. They get directly connected to the tubes of

the inflation unit. Absolute pressure is being measured. The analog output voltage gets converted by an 16 bit ADC.



Fig. 4.32: HSCDANN030PAAA5

Current/Voltage Sensor

To measure the currently drawn current a HAL current sensor is being used. The voltage is measured by a voltage divider and ADC. With this information the power consumption can be calculated, further more it can be used to check if e.g. the LEDs are turned on.

Real time clock

To create a experiment time line a RTC is being used. It gets started at lift off and counts the time passed. It gets backed up by a lithium 3.3V button cell.

4.5.2.7 Pin Puller To release the inflatable structures pin pullers are being used. They only need to be activated once. The actuation time is 2.5 seconds @ 1.4A & 1.5V. The voltage is achieved with the use of a series resistor at which the voltage is decreased from 12V to 1.5V. The required power is 16.8W. In the resistor 14.7W is dissipated though heat. To reduce the peak power the pin pullers don't get activated at the same time.

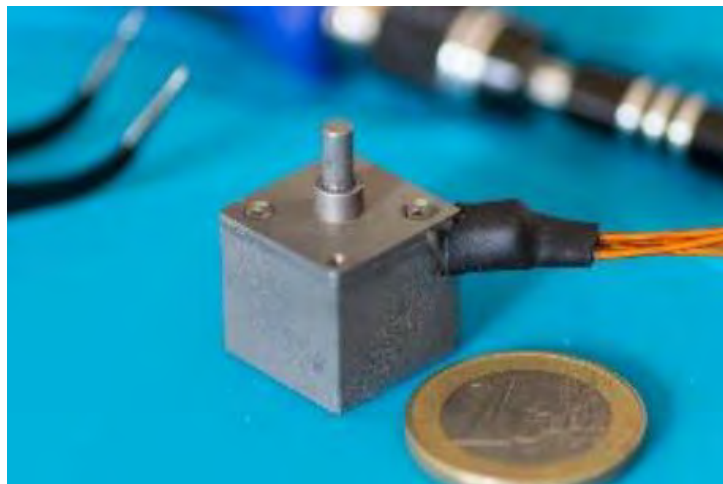


Fig. 4.33: Pin Puller

4.5.2.8 Switches Switches are required to trigger valves, pin puller and LEDs with the mC. They are realised with a Smart Highside Power Switch and a logic level transistor. The GPIO output of the mC can control the switch.

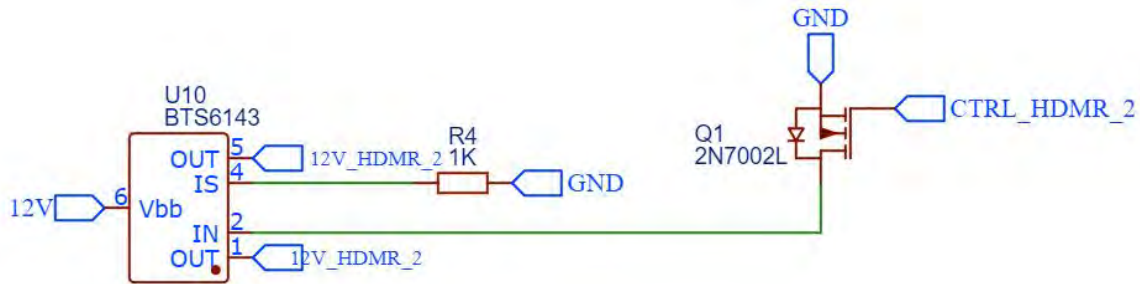


Fig. 4.34: Switches

If the Input is connected to GND the power switch turns on.

4.5.2.9 Video Decoder A video decoder is used to convert the analog PAL composite video signal to a digital 8-Bit 4:2:2 YCbCr DCMI signal.

4.5.2.10 Cables and Connectors The cables used must withstand a wide range of conditions. For this particular reason, enameled wires or film-wrapped solid wires should be used. D-Sub Connectors are being used for internal connections.

4.5.3 Data system

The following figure clarifies the data structure of the experiment.

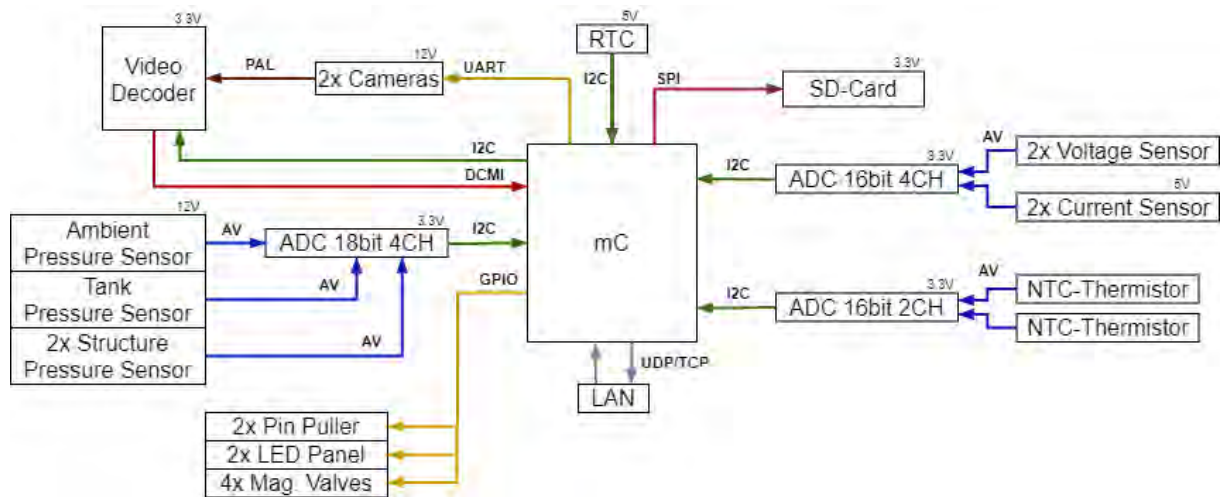


Fig. 4.35: Data systems

All of the I2C devices use the same Bus. This is possible because they have a different slave address.

4.5.4 Arrangement

The components are mounted on a 4 layer pcb. For a better signal integrity the signal traces are routed on the top and bottom layer. The middle layers are used for ground- and power. The microcontroller is mounted on top of the pcb with standard pin headers.

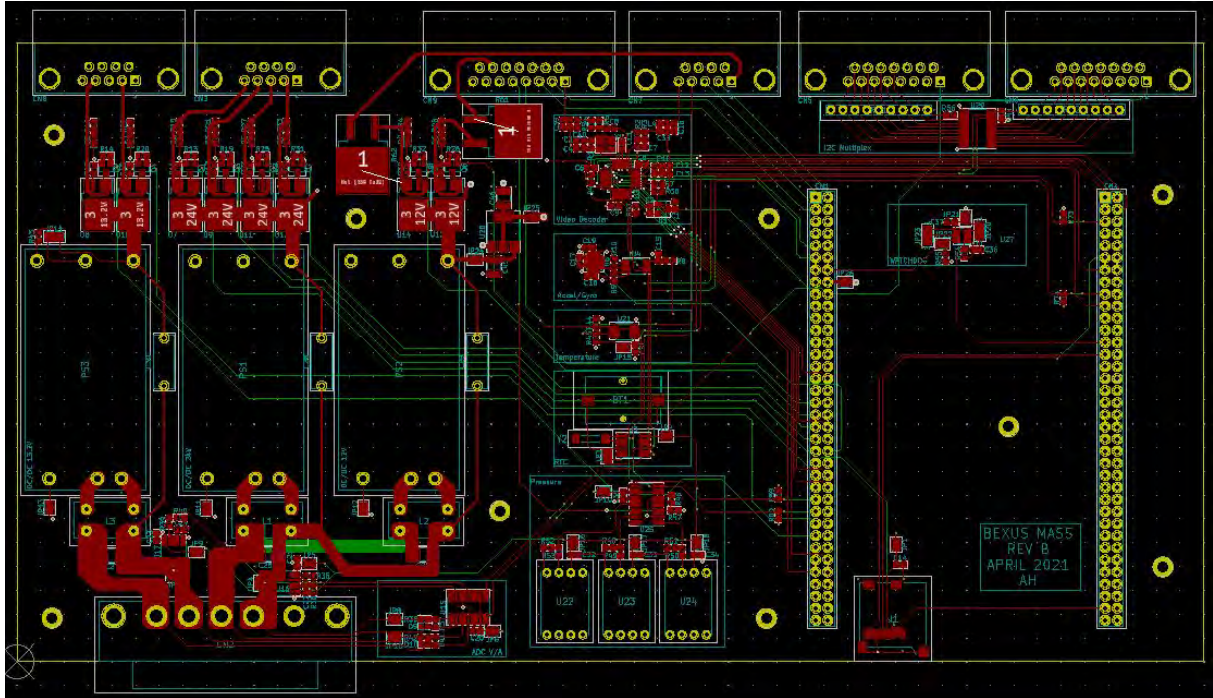


Fig. 4.36: PCB shield

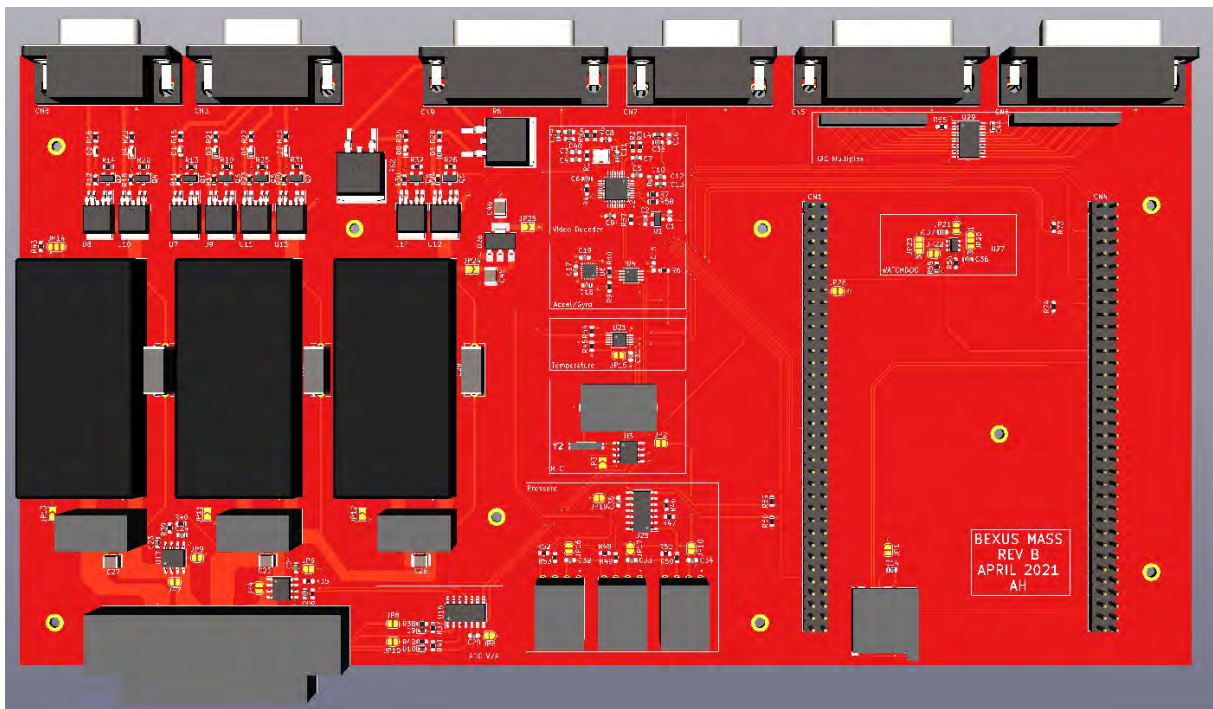


Fig. 4.37: PCB 3D-View

4.5.5 Electrical Data

Component	Part Nr.	Number	Manufacturer	Power in ea.
Microcontroller	NUCLEO-F767ZI	1	STM	5W
LED	ATS2012365UV	288	Kingbright	66mW
NTC-Thermistor	B57540G1103F000	2	EPCOS	
Preassure Sensor	HSCDANN030PAAA5	3	NXP	
Preassure Sensor	SSCDANN150PAAB5	1	NXP	
RTC	DS1307+	1	MAXIM	
Current sensor	ACS712ELCTR-05B-T	1	ALLEGRO	
ADC 4CH 16bit	MCP3428E/SL	1	MICROCHIP	
ADC 2CH 16bit	MCP3426A1-E/SN	2	MICROCHIP	
Camera	Runcam split micro 3	2	Runcam	3.5W
Video Decoder	TVP5150AM1IPBS	1	TI	
DC/DC 40W / 12V	TEN40-2412WIE	1	TRACO POWER	
DC/DC 40W / 24V	TEN40-2415WIE	1	TRACO POWER	

Table 4.4: Used components

Note: The power estimation of sensors, etc. is included in the power estimation of the micro-controller.

4.6 Experiment Design

This chapter describes the design of the inflatable rigidizable structures.

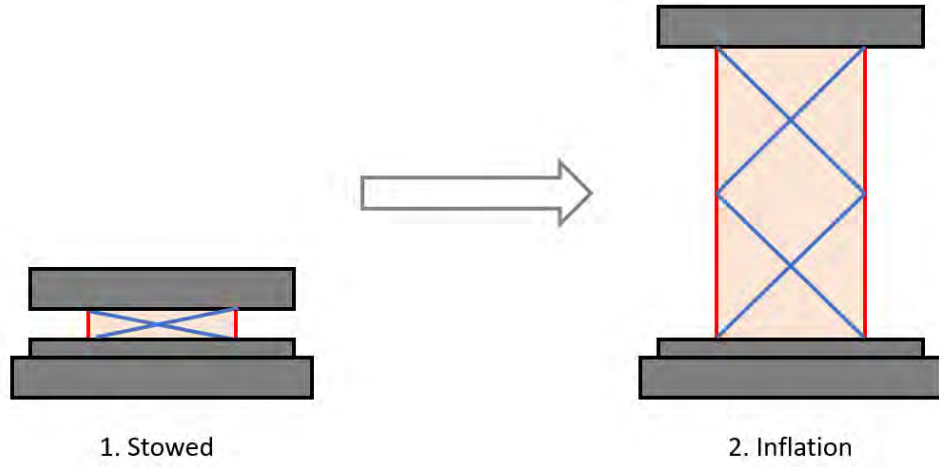


Fig. 4.38: Principle of the inflatable structures

As shown in figure 4.38, the goal is to create a inflatable, packagable cylindrical structure. The packaging method, rigidization method, sealing lid design and assembly is described in the following sections.

4.6.1 Packaging Method

Twisted Buckling Cylinders are origami structures that are folded in their two-dimensional (2D) form as described in Hunt and Ario (2004) and Liu et al. (2015). In Figure 4.39 folding pattern is shown for a twisted buckling cylinder. The solid lines indicate the mountain fold lines and the dashed lines are valley fold lines to be folded in its two-dimensional shape. The angles alpha (α) and beta (β) in Figure 4.39 have to be chosen to fulfil the conditions of closeability and flat-foldability.

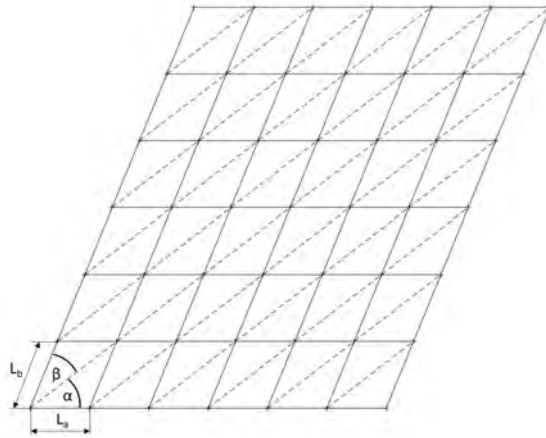


Fig. 4.39: Origami folding pattern for a twisted buckling cylinder structure.

The condition of closability means that the 2D folded sheet should be moldable into its three-dimensional (3D) form as pictured in Figure 4.40. Figure 4.40 shows the flat-folded cylinder that meets the condition of flat-foldability. This condition is a mathematical correlation between the angles of the fold lines joining at each node in the folding pattern to meet the flat-foldability of the 3D structure. Figure 4.40, Figure 4.41 and Figure 4.42 show a photo series of an unbuckling flat-foldable origami cylinder that was folded according to the crease pattern pictured in Figure 4.39.



Fig. 4.40: Flat-folded twist buckling origami cylinder.



Fig. 4.41: Unbuckling cylinder.



Fig. 4.42: Unbuckled cylinder.

Besides packing, inflating and rigidizing cylindrical structures, conical shaped structures shall be flat-folded and stored based on origami folding patterns as well. A transformation method, developed by Ishida et al. (2014), to transform folding patterns for cylindrical structures into folding patterns for conical shaped structures are considered for packaging the conical structures. Modelling foldable conical structures using conformal mapping is the baseline for this approach. As described in Ishida et al. (2014), conformal mapping are transformations of coordinate systems by maintaining “ [...] the regularity of fold lines.” (Ishida et al., 2014). This means the nodes would be transformed, but the angles between the fold lines would stay the same. As a result of that, the fold lines would transform from straight lines into curved fold lines which is not possible to fold. Therefore, for our approach the nodes of the folding patterns for cylindrical structures are transformed based on the transformation of fluid flows with circulation. The transformed coordinates will then be connected with straight lines and create the new fold lines. This creates new angles (α' , β' , α'' and β'') within the cells of the folding patterns but results in a foldable pattern. In Figure 4.43 a transformed folding pattern for conical shaped structures is pictured.

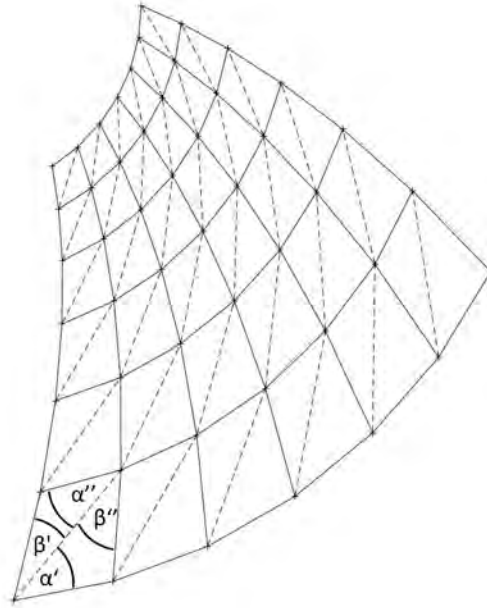


Fig. 4.43: Folding pattern for a conical shaped structure to be flat-folded.

As for the cylindrical structures, the conical folding pattern is folded in its 2D shape (solid lines are mountain fold lines and dashed lines are valley fold lines) and closed along its longitudinal side. Fig. 4.44, Figure 4.45 and Fig. 4.46 show a photo series of an unbuckling flat-foldable origami cone that was folded according to the crease pattern pictured in Figure 4.43.



Fig. 4.44: Flat-folded twist buckling origami cylinder.



Fig. 4.45: Unbuckling cylinder.



Fig. 4.46: Unbuckled cylinder.

MASS BEXUS will only use cylindrical shapes and no conical shapes for easier manufacturing and time saving purposes. Conical structures could be implemented with little additional work.

4.6.2 Rigidization Method

To stabilize the structure once it is inflated, the UV-curing resin shall be integrated to avoid the structure from collapsing. Performed breadboard tests demonstrated a stable structure as long as the valley fold lines are secured from buckling once the structure is completely deployed. This can be achieved by placing the resin along the valley fold lines with an adhesive layer protruding the fold line. Additionally, the fold line can be supported with fibres to prevent buckling after the structure has been deployed. The curing fold lines are indicated in Figure 4.47.

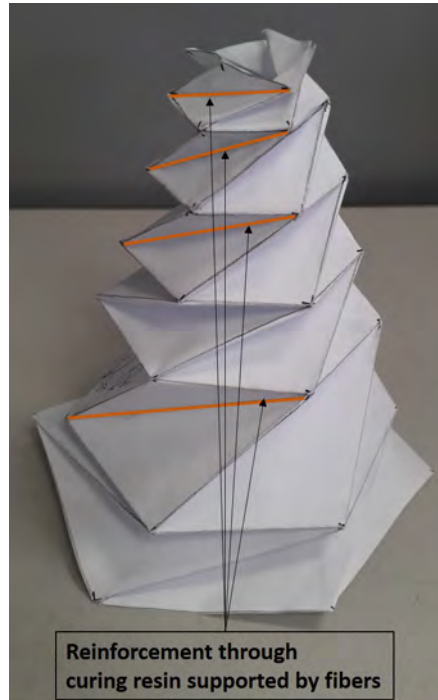


Fig. 4.47: Rigidizing the valley fold lines through curing resin (orange).

Testing has shown this method to be prone to compression and torsion. An additional layer or resin soaked fibres perpendicular to the fibres along the valley fold lines that connects the mountain fold lines corner points as seen in figure ?? improve the structure by a lot. Testing showed that additional fibres could be added for increased mechanical strength.

After experimenting with different resins "ELEGOO ABS-like resin" combined with glass fibres delivered satisfactory results. Other, more expensive resins differed in viscosity and curing time, which were the most important aspects for this experiment. Out of the different resins that were tested the ELEGOO resin was the best compromise between being easy to apply to a cylindrically shaped foil with a brush but being viscous enough to stay in place. The comparably low toxicity and affordable price were other factors in favor of the ELEGOO resin. It also has a fast curing time and is easy to work with. Early tests with the ELEGOO resin and aramid-, carbon- and glass fibre showed that glass fibres cured significantly faster than the alternatives. Combining the very fast curing time with the greater flexibility of glass fibres especially compared to carbon fibres made them the optimal choice for the experiment.



Fig. 4.48: Rigidized structure with aramid fibres



Fig. 4.49: Rigidized structure with carbon fibres

4.6.3 Lid design

Additive manufactured lids are used to be able to mount, store and seal the assembled inflatable structures. They are built from PETG, as the material possesses the right properties and is printable without any problems. Several team members own 3D printers privately which was ideal for rapid prototyping and reducing manufacturing costs, especially compared to milled aluminium parts.

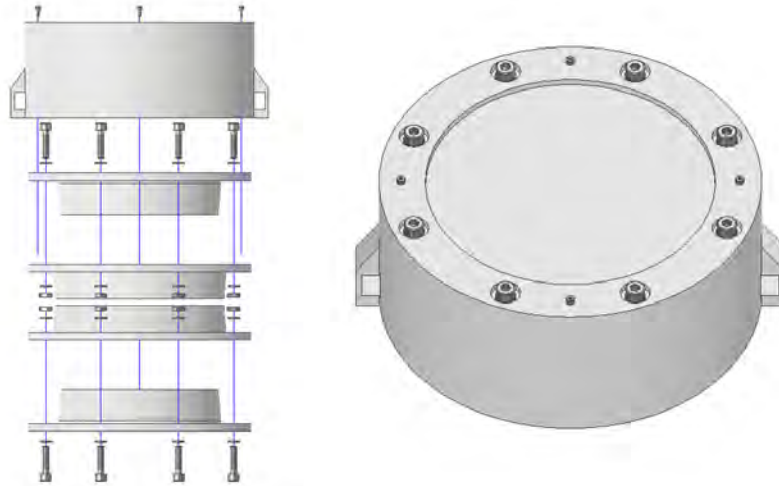


Fig. 4.50: Exploded and assembled sealing lid design

The lids are attached to the top and bottom opening of the cylinder. The carrier foil and fibres are fastened to the lids by conical clamping. Additionally, the top lid includes a cover that encloses the entire structure. The purpose of the cover is to shield the UV-resin from any unwanted UV radiation and it also provides the slots where the fork of the release mechanism

sits. The two clamping rings are fastened to each other by a total of eight screws. A O-ring is used to seal the gap between the two parts, the location is shown in figure 4.51.



Fig. 4.51: Sealing ring location

The slot for the sealing ring is milled instead of relying on the FDM printer to get the necessary surface properties to ensure a tight seal.

4.6.4 Inflatable Structure

This chapter describes the composition and assembly of the inflatable structures. As shown in figure 4.52, the base of the structures consists of a $30\mu\text{m}$ mylar carrier foil that is folded as described in section 4.6.1. On top of the folded, cylindrical foil a layer of spray adhesive is applied. The product name of the used spray adhesive is: 3M Hi-Tack 71, its industrial grade and is usually used for layering prepreg composites. The same adhesive is used to glue the foil into a cylindrical shape. On top of the adhesive, the soaked glass fibres are applied, as described in section 4.6.2 in a cross hatching manner. To prevent the inflatable structure from sticking together a second, thinner unfolded foil is wrapped around the assembled structure.



Fig. 4.52: Principle of the inflatable structures

The thickness of the foils were determined by several tests. The thickness of the carrier foil is mainly dependent on the diameter of the inflatable structure. A thickness of $30\mu m$ was ideal for a structure diameter of 115mm. The height of the structures is 350mm. With changes to the folding pattern, smaller or larger structures can be produced.

4.6.5 Testing and Development

This section shows some of the testing and development process of the inflatable structures. Figures 4.53, 4.54, 4.55, 4.56 and 4.57 show some of the initial concepts.



Fig. 4.53: Structure closed



Fig. 4.54: Structure starting to inflate



Fig. 4.55: Structure starting to inflate



Fig. 4.56: Structure half inflated



Fig. 4.57: Structure half inflated

Due to problems with sealing and mounting, it was decided that a conical clamps would be best to hold the foil in place. Additionally the filament of the 3D printer was changed from PLA to PETG due to need for the material to withstand direct sun exposition. First concepts of the conical clamping are shown in figure 4.58.



Fig. 4.58: Old sealing design

To ensure a leakproof design, pressure tests were performed under water. A water test of one of the earlier designs is shown in figure 4.59.



Fig. 4.59: Pressure test with water

Figures 4.60 and 4.61 show the final design. The inflatable structure is marked in red. This design was achieved after a couple of iterations. It achieves all the necessary requirements. It clamps the inflatable structures, it keeps a tight seal, it shield the structures from UV-radiation, it is compatible with the release mechanism and it's fairly easy to install.

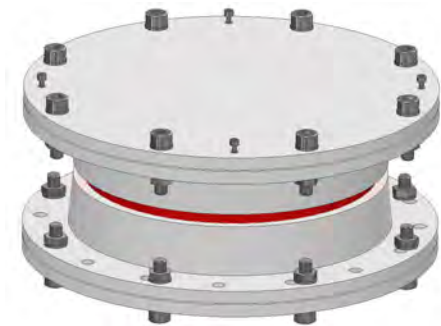


Fig. 4.60: Structure without UV-lid. Foil is coloured red for better visibility.



Fig. 4.61: Sectional view of the of the fully assembled inflatable structure in closed position

4.7 Thermal Design

4.7.1 General environment condition

- a) Accommodation: The two experiment setups from the Team will be mounted inside the BEXUS-Gondola and on the outside as well.
- b) At that time, it is not sure if our flight will take place at day or night. Therefore, the calculations and the technical configuration will be made for the worst case with the lowest temperatures.
- c) According to the given inputs, the following lowest temperatures can be expected:

Table 4.5: Expected Temperatures

Lowest Temperatures	Exp. setup inside gondola	Exp. setup outside gondola
Day Launch	-48°C	-60°C
Night Launch	-55°C	-80°C

4.7.2 Solar constant

Until the destination height is reached both experiments have to be protected from the sunlight to prevent a curing process at an early stage. The inner experiment will be protected the whole flight with a thermal isolation (See Fig.2). Due to that the canvas cover of the BEXUS gondola will be attached. The outer structures will be protected with top covers until that time the final height is reached and they are inflated, so the sunlight can start the curing process. The side walls consist of UV-light permeable PC.

The solar irradiance at the ESRANGE latitude and launch campaign in October can be extracted from the following figure:

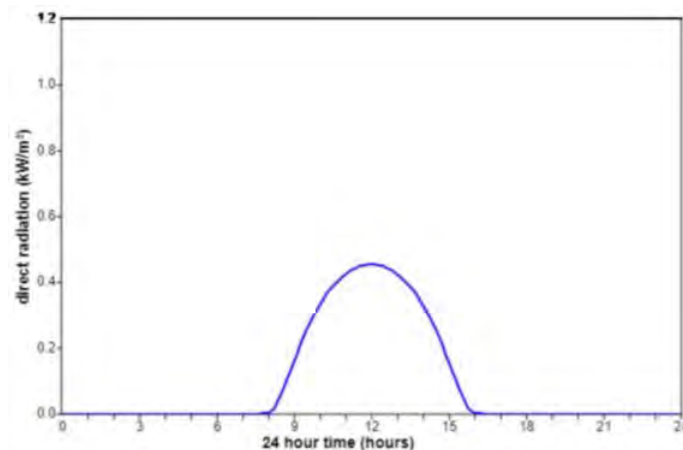


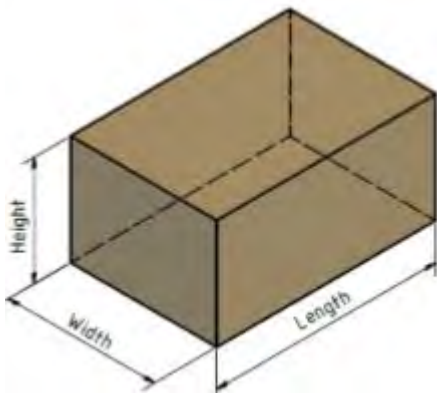
Fig. 4.62: Solar irradiance over the day.

As already mentioned, it is not clear at which time our flight will take place currently. To be on the safe side, the solar irradiance will be neglected for the first calculations.

An additional irradiance would only lead to a higher temperature inside our experiment-boxes and depending on our used resin this would actually have some advantages.

4.7.3 Properties of the Experiment-setup

a) Dimensions of the surrounding housing



$$H \text{ Height} = 1,02 \text{ m}$$

$$W \text{ Width} = 0,4 \text{ m}$$

$$L \text{ Length} = 0,65 \text{ m}$$

Calculation of the surrounding surface:

$$A = 2 \cdot (H \cdot W + H \cdot L + W \cdot L)[m^2]$$

Fig. 4.63: Experiment housing

b) Insulation and used materials

Beside the thermal conductivity of the material it is also necessary to consider the density of the chosen material to achieve the goal of a light experiment weight. In the following table the densities of the given (standard) materials are added:

Table 4.6: isolation-materials and their properties

Materials	Thermal Conductivity	Density
	$W/(m^2 \cdot K)$	kg/m^3
Polystyrene PS	0,030 - 0.034	1050
Polyethylen	0.032 – 0.040	914 - 960
Pertinax	0.350 – 0.390	1650 - 1850
Rubber	0.120 – 0.190	920 - 960
Stainless steel (1.4301 - V2A)	15 - 21	7900
Aluminum	210 - 230	2700

c) Internal heat / electronical heat dissipation

The expected power of our electronical installations varies over the time. The most heat dissipation appears in the inner experiment when our UV-LEDs are switched on. In the outer experiment, that dissipation is not present. Similar to the solar irradiance, the heat dissipation is neglected in the first stage of the calculations and will be added afterwards. Until further tests have been made, the expected heat of all electronical components is set to:

$$\dot{Q}_{el} = 10W$$

d) The wanted inner temperature of our experiments (inside and outside of the BEXUS gondola) is room temperature (approximately 15 °C). This temperature is recommended in the data sheet of our resign.

4.7.4 Thermal Calculations

To simplify the heat transfer calculation the whole flight was divided in three phases. For every single area of our boxes the heat transfer will be determined, due to the fact, that everyone has different boundary conditions:

Table 4.7: flight phases and their properties

	Phase I (Ground)	Phase II (Ascent)	Phase III (Float)
Temperature	-15°C	Varies during that phase, depending on the height	-80°C
Time	Several hours	1,5 hours	1 - 5 hours
Heat transfer type	Stationary and convective	Stationary and convective	Stationary and convective
Heat transfer	Constant	Varies during the phase, depending on the change in temperature	Constant
Additional given information	-	Ascent speed $v_{steig} = 5\text{m/s}$ Only minor changes in altitude ($\pm 200\text{m}$)	

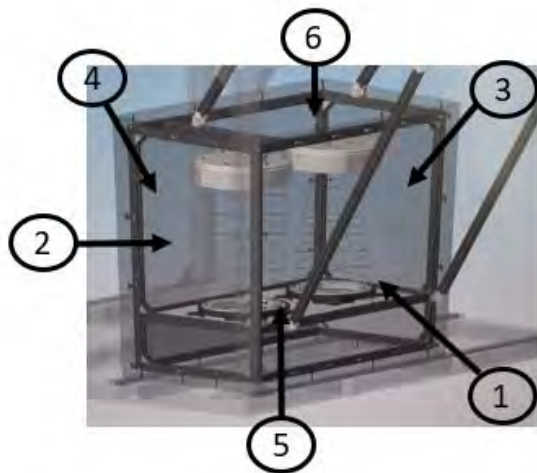


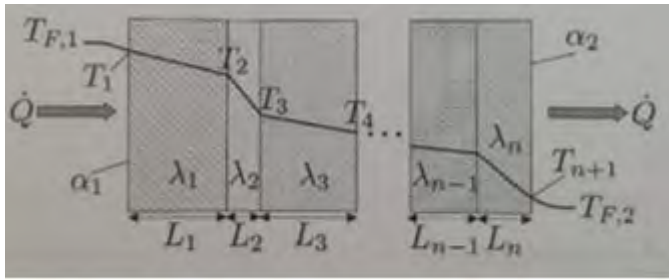
Fig. 4.64: Definition of the areas

Area	Description
1	Right hand side of the BEXUS gondola
2	Front side of the gondola
3	Opposite side area 2
4	Opposite side area 1
5	Bottom side of our experiment
6	Top side of our experiment

Table 4.8: Definiton of the areas

The stationary heat transfer can be determined by the following equations:

$$\dot{Q} = k \cdot (T_{F1} - T_{F2}) \cdot A$$



\dot{Q} = heat flow [W]
 k = heat transmission coefficient [$W/(m^2 \cdot K)$]
 T_{F1} = inner Temperature [K]
 T_{F2} = outer Temperature [K]
 A = area [m^2]

Fig. 4.65: Model for the thermal calculations

with:

$$k = \frac{1}{\alpha_1} + \frac{L_1}{\lambda_1} + \frac{L_2}{\lambda_2} + \frac{L_3}{\lambda_3} + \dots + \frac{1}{\alpha_2}$$

α_i = heat transfer coefficient [$W/(m^2 \cdot K)$]

L_i = length of the individual layer [m]

λ_i = thermal conductivity [$W/(m \cdot K)$]

The convective heat transfer is determined with the same equations, but the heat transfer coefficient (α) for the areas where an airflow exists, has to be calculated with the Nußelt-Number:

$$Nu = \sqrt{Nu_{lam}^2 + Nu_{turb}^2}$$

Nu = Nußelt-Number [-]

Nu_{lam} = laminar area of the Nußelt-Number [-]

Nu_{turb} = turbulent area of the Nußelt-Number [-]

$$Nu_{lam} = 0.664 \cdot Re^{\frac{1}{2}} \cdot Pr^{\frac{1}{3}}$$

$$Nu_{turb} = \frac{0.037 \cdot Re^{0.8} \cdot Pr}{1 + 2.44 \cdot Re^{-0.1} \cdot (Pr^{\frac{2}{3}} - 1)}$$

Re = Reynolds-Number [-]

Pr = Prandtls-Number [-]

$$Re = \frac{v_f \cdot L}{\nu}$$

v_f = velocity of the flowing fluid (in this case the airflow) [m/s]

L = characteristic length [m]

ν = kinematic viscosity of the fluid [m^2/s]

$$Pr = \frac{\nu}{a_{Pr}}$$

with:

$$a_{Pr} = \frac{\lambda}{\rho \cdot c_p}$$

λ = thermal conductivity of the flowing fluid [$W/(m \cdot K)$]

ρ = density of the flowing fluid [kg/m^3]

c_p = specific heat capacity at constant pressure [$J/(kg \cdot K)$]

For the range of validity of:

$$\begin{aligned}10 < Re < 10^7 \\0.6 < Pr < 2000\end{aligned}$$

the Nußelt-Number can be determined by:

$$Nu = \frac{\alpha \cdot L}{\lambda}$$

converted to the searched value results in:

$$\alpha = \frac{Nu \cdot \lambda}{L}$$

In the first attempt for all variable's values were allocated to determine the heat flow and with the time for the single phases the required energy amount was calculated.

4.7.4.1 Flight Phase I (Ground) The following parameters and suggestions were used for this phase:

Parameter	Area 1	Area2	Area 3	Area 4	Area 5	Area 6
$T_{F1} [K]$	288.15					
$T_{F2} [K]$	258.15					
$A [m^2]$	0.663	0.408	0.408	0.663	0.26	0.26
$\alpha_1 \left[\frac{W}{m^2 * K} \right]$	2	2	2	2	2	2
$\alpha_2 \left[\frac{W}{m^2 * K} \right]$	2	2	2	2	2	2
$\lambda_{iso} \left[\frac{W}{m * K} \right]$	0.04	0.04	0.04	0.04	0.04	0.04
$\lambda_{air} \left[\frac{W}{m * K} \right]$	0.02	0.02	0.02	0.02	0.02	0.02
$\lambda_{cover} \left[\frac{W}{m * K} \right]$	0.02	0.02	-	-	0.02	-
$\lambda_{base} \left[\frac{W}{m * K} \right]$	-	-	-	-	17	-
$L_{iso} [m]$	0.02	0.02	0.02	0.02	0.02	0.02
$L_{base} [m]$	-	-	-	-	0.01	-
$L_{air} [m]$	0.003	0.003	-	-	0.129	-
$L_{cover} [m]$	0.002	0.002	-	-	0.002	-

Fig. 4.66: Parameters Flight Phase I (Ground)

- the preparation of the experiment was made at room temperature
- the air inside the gondola is the same as on the outside
- there is a possible small air gab between the isolation and the canvas cover
- only at area 1,2 and 5 the canvas cover is present, the other areas lead to the inside of the gondola
- the base-plate where the structures are mounted is made of carbon-fibre reinforced plastic

4.7.4.2 Flight Phase II (Ascent) The following parameters and suggestions were used for this phase:

Parameter	Area 1	Area2	Area 3	Area 4	Area 5	Area 6
$T_{F1} [K]$	15°C (288.15 K)					
$T_{F2} [K]$	n.c.		-	-	n.c.	-
$T_{iG} [K]$	-	-	n.c.	n.c.	-	n.c.
$A [m^2]$	0.663	0.408	0.408	0.663	0.26	0.26
$\alpha_1 \left[\frac{W}{m^2 * K} \right]$	2	2	2	2	2	2
$\alpha_2 \left[\frac{W}{m^2 * K} \right]$	n.c.		2	2	n.c.	2
$\lambda_{iso} \left[\frac{W}{m * K} \right]$	0.04	0.04	0.04	0.04	0.04	0.04
$\lambda_{air} \left[\frac{W}{m * K} \right]$	0.02	0.02	0.02	0.02	0.02	0.02
$\lambda_{cover} \left[\frac{W}{m * K} \right]$	0.02	0.02	-	-	0.02	-
$\lambda_{base} \left[\frac{W}{m * K} \right]$	-	-	-	-	17	-
$L_{iso} [m]$	0.02	0.02	0.02	0.02	0.02	0.02
$L_{base} [m]$	-	-	-	-	0.01	-
$L_{air} [m]$	0.003	0.003	-	-	0.129	-
$L_{cover} [m]$	0.002	0.002	-	-	0.002	-

Fig. 4.67: Parameters Flight Phase II (Ascent)

- the temperature is not constant (n.c.) during the ascent and is calculated following the model of the international standard atmosphere (ISA DIN 5450/ISO2533) after it reaches the -15°C on the ground (until that, the outside temperature is suggested as constant)
- area 1,2,5 face the calculated outside temperature (T_{F2})
- area 3,4 and 6 face the temperature inside the gondola (T_{iG}) which is assumed to be 10 K higher than the outside temperature
- area 1,2 and 5 face a flowing air on the outside → convective heat flow; for those areas, the value for α_2 variates during the ascent too and has to be calculated with the Nußelt-number
- ascent up to the maximum height of 30km

During that phase some parameters of the heat flow calculations (e.g. the temperature and density of the air) change and have to be calculated. Those parameters are dependent of the belonging temperature which itself is dependent from the height during most of the time. The height can easily be calculated, since the velocity of ascent is known.

$$h(t) = v_{steig} \cdot t$$

$$v_{steig} = \text{ascent velocity} = 5 \frac{m}{s}$$

The following figures and tables show the formulas and assign them to the respective time period during the ascent phase:

$$T_h = T_A + a \cdot (h - h_A)$$

$$p_h = p_A \cdot \left(\frac{T_h}{T_A} \right)^{-\frac{g_0}{a \cdot R}}$$

$$\rho_h = \rho_A \cdot \left(\frac{T_h}{T_A} \right)^{-\left[\frac{g_0}{a \cdot R} + 1 \right]}$$

$$T_h = T_A = \text{const.}$$

$$p_h = p_A \cdot e^{-\left(\frac{g_0}{R \cdot T_A} \right) (h - h_A)}$$

$$\rho_h = \rho_A \cdot e^{-\left(\frac{g_0}{R \cdot T_A} \right) (h - h_A)}$$

Fig. 4.68: Formulas for changing temperature Fig. 4.69: Formulas for constant temperature

	Höhenintervall h [m]	h_A [m]	T_A [K]	p_A [Pa]	ρ_A [kg/m ³]	a [K/m]
1	$-5 \cdot 10^3 - 11 \cdot 10^3$	0	288,15	101325	1,2250	$-6,5 \cdot 10^{-3}$
2	$11 \cdot 10^3 - 20 \cdot 10^3$	$11 \cdot 10^3$	216,65	22632	0,3639	0,0
3	$20 \cdot 10^3 - 32 \cdot 10^3$	$20 \cdot 10^3$	216,65	5475	0,0880	$+1,0 \cdot 10^{-3}$
4	$32 \cdot 10^3 - 47 \cdot 10^3$	$32 \cdot 10^3$	228,65	868	0,0132	$+2,8 \cdot 10^{-3}$
5	$47 \cdot 10^3 - 52 \cdot 10^3$	$47 \cdot 10^3$	270,65	111	0,0014	0,0
6	$52 \cdot 10^3 - 61 \cdot 10^3$	$52 \cdot 10^3$	270,65	59	0,0008	$-2,0 \cdot 10^{-3}$
7	$61 \cdot 10^3 - 79 \cdot 10^3$	$61 \cdot 10^3$	252,65	18	0,0002	$-4,0 \cdot 10^{-3}$
8	$79 \cdot 10^3 - 88 \cdot 10^3$	$79 \cdot 10^3$	180,65	1	$1,9 \cdot 10^{-5}$	0,0

Fig. 4.70: Parameters for the temperature calculation

Table 4.9: Assignment time, height, and formulas

Time sec.	Height km	Formulas	Note
$0 < t < 900$	$0 < h < 4.5$	-	values for density etc. are constant ($T = -15^\circ\text{C}$)
$900 < t < 2200$	$4.5 < h < 11$	Fig. 54	Fig. 56. line 1
$2200 < t < 4000$	$11 < h < 20$	Fig. 55	Fig. 56 line 2
$4000 < t < 6000$	$20 < h < 30$	Fig. 54	Fig. 56 line 3

4.7.4.3 Flight Phase III (Float) The following parameters and suggestions were used for this phase:

Parameter	Area 1	Area2	Area 3	Area 4	Area 5	Area 6
$T_{F1} [K]$	15°C (288.15 K)					
$T_{F2} [K]$	-80°C	-80°C	-55°C	-55°C	-80°C	-55°C
$A [m^2]$	0.663	0.408	0.408	0.663	0.26	0.26
$\alpha_1 [\frac{W}{m^2 * K}]$	2	2	2	2	2	2
$\alpha_2 [\frac{W}{m^2 * K}]$	2	2	2	2	2	2
$\lambda_{iso} [\frac{W}{m * K}]$	0.04	0.04	0.04	0.04	0.04	0.04
$\lambda_{air} [\frac{W}{m * K}]$	0.02	0.02	0.02	0.02	0.02	0.02
$\lambda_{cover} [\frac{W}{m * K}]$	0.02	0.02	-	-	0.02	-
$\lambda_{base} [\frac{W}{m * K}]$	-	-	-	-	17	-
$L_{iso} [m]$	0.02	0.02	0.02	0.02	0.02	0.02
$L_{base} [m]$	-	-	-	-	0.01	-
$L_{air} [m]$	0.003	0.003	-	-	0.129	-
$L_{cover} [m]$	0.002	0.002	-	-	0.002	-

Fig. 4.71: Parameters Flight Phase III (Float)

- lowest given temperatures inside and outside the gondola are used
- small variations of the height will have no effect on the temperature

4.7.4.4 Comparison of the calculations To see if the calculated temperatures and other suggestions are reliable, they are compared to given inside and outside temperatures in the BEXUS user manual. Due to the fact, that only the graphs were given, the data were approximated by straights:

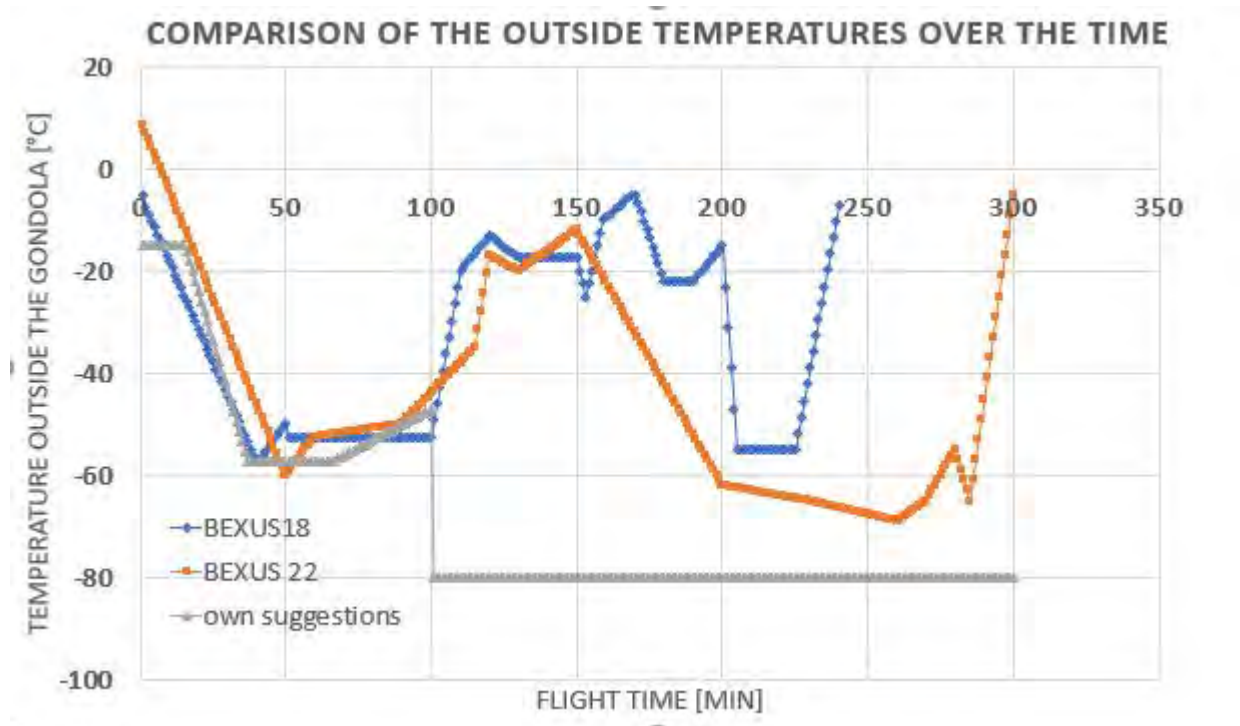


Fig. 4.72: Comparison of the outside temperatures

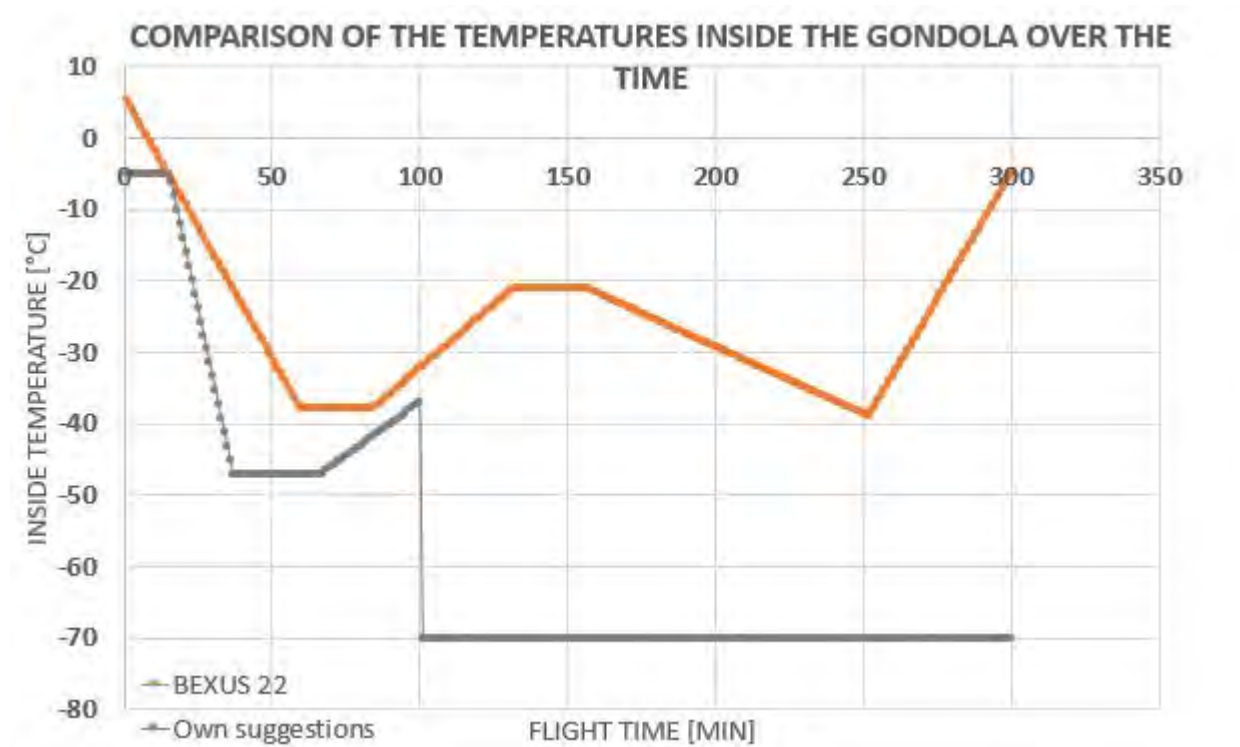


Fig. 4.73: Comparison of the inside temperatures

All calculations were made with a MATLAB script and evaluated with Excel. For the assumptions made in 4.6.4.1 till 4.6.4.3, the following results were determined:

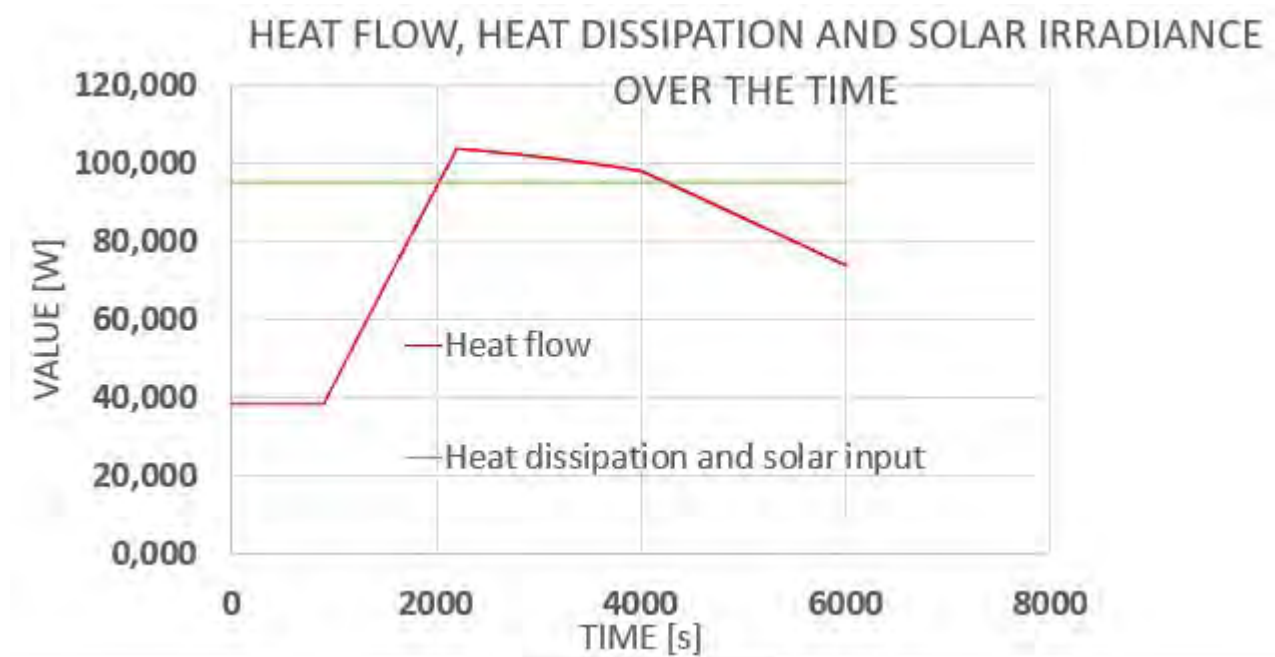


Fig. 4.74: Heat flow and heat dissipation over the time

The solar irradiation was assumed to be in average $100W/m^2$ which has an affect on area 1 and area 2. This calculations were made for the inner experiment. The outer experiment will face an bigger airflow but also will have a significant bigger solar irradiation. Apart from this the used material for the side walls of the outer experiment will have approximately the same thermal conductivity as our isolation of the inner experiment.

Until further test have been made or other results will be achieved our isolation (specified in the following) is expected to be sufficient for both experiments. In the worst case, additional heat sources can be placed inside the boxes. Due to the fact, that we have a little bit more power that actually needed (mentioned in the next Chapter 4.7). Therefore we have the option to use that additional power to heat or we can place heat sources which are independent from the power supply.

4.7.5 Insulation and attachment

The insulation consists of a 2 cm thick plate made of PS (styrofoam), which is fastened with screws around the lower frame to store the heat in the frame to maintain a constant temperature of 15 °C (4.7.3 d)) inside both boxes and to protect it from environmental influences. To protect the soft and fragil styrofoam again a 1mm thick PVC plate will be added at the outer side. Additionally the single PS and PVC plates as well as the screws can be assembled with with an appropriate sealing compound (Silicone). This will ensure an area-wide fixaton of the plates, secures the screws against loosening and fills the gaps between the single plates. For the thermal vacuum test this sealant will not be used to guarantee an easier disassembly. The sealant will only be used if the tests show, that too much heat will be dissipated. If necessary all side parts will be assembled in advance except of the one at area 1 (4.64 to be safe that the sealing has sufficient time to cure. Side insulation 1 will be mounted in the last minutes to provide access to our structures, electric and pneumatic until the very end. This side has been choosen because of it's good accessability. It will be fixed with a *Loctite 242* as well as the screws. This adhesive / sealant has been selected because of its fast curing and the possibility to disassemble it without much effort. However, the manufacturer states that the compatibility of this adhesive with our insulation must be checked. The insulation are shown in Figure 4.75 and the attachment Figure 4.76.

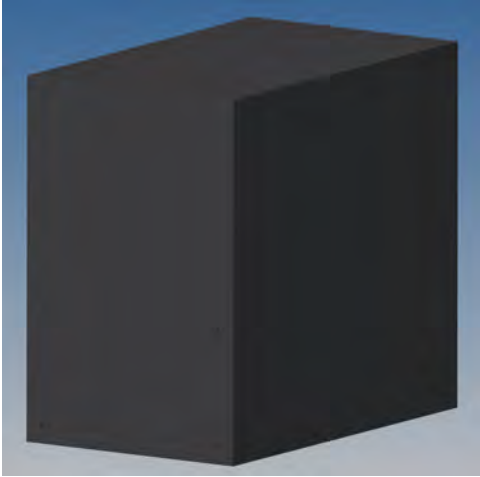


Fig. 4.75: Insulation lower Frame

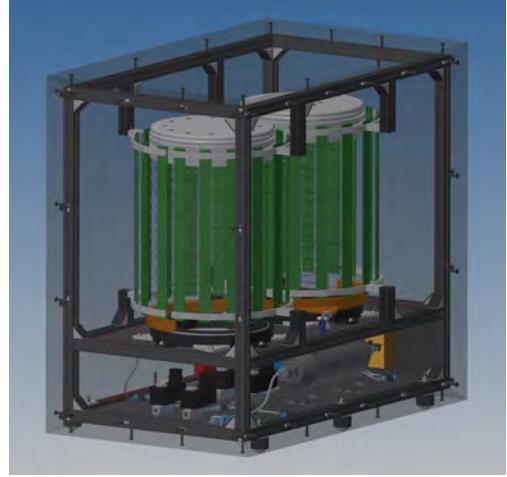


Fig. 4.76: Lower frame (old setup) with transparent insulation

The insulation can be cut out for the electrical interface and the E-Link connections as well as for the connection between the two experiment setups. Due to the fact that the pressurised air resservior and the electronic supply is based in the inner experiment frame a connection has to be established. Occurring gaps can be filled with temperature resistant sealing compound for example a silicone sealing. Most of them have a temperature span until -60°C . This should be more than sufficient for the inner experiemnt. The outter experiment requires much less interfaces than the inner one but has to withstand a significant lower temperature than the inner experiment. Therefore the used sealing compound for the inner experiment has to be combined with a o-ring or fibre sealing. Optionally a hard seal made of PVC can be integrated. This combination has to be tested as well.

4.8 Power System

MASS uses more power than the BEXUS battery can provide, that's why an extra battery pack, consisting of 6 SAFT LSH20 batteries in series, is used. The LEDs get powered by the extra battery pack, everything else is supplied by the BEXUS battery.

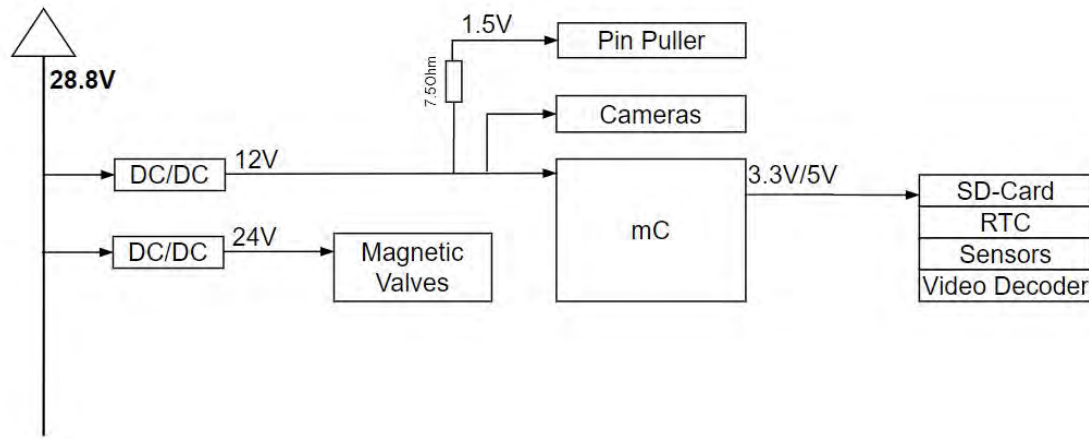


Fig. 4.77: Power system BEXUS battery

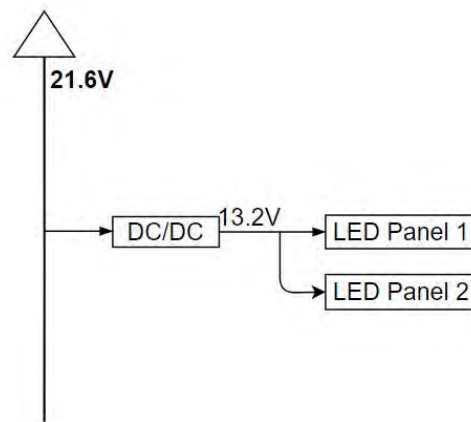


Fig. 4.78: Power system EXTRA battery

MASS uses a total of 3 DC/DC step down converters that transform the battery voltage to 12V (mC, pin puller, cameras), 13.2V (LEDs) and 24V (magnetic valves). The conversion to 3.3V and 5V for sensors and other low power devices is done internally by the mC.

Besides the the 3.3V button cell no other extra batteries are required. Converters from the company "TRACO POWER" are used. They are easy to use and don't need a lot of additional components and have with, 89%, a high efficiency.



Fig. 4.79: TRACO POWER DC/DC

Component	Voltage (V)	Current (A)	Power (W)
Microcontroller	12	0.42	5W
Inflation Unit	24V	2x 0.283A + 2x0.333A	2x 6.8W + 2x 8W
HDRM	12V (2.5sec actuation)	1.4A	16.8W
UV-LEDs	13.2V	2.16A	30W
Cameras	12V	2x 0.29A	2x 3.5W

Table 4.10: Power consumption / component

4.8.1 Power Consumption

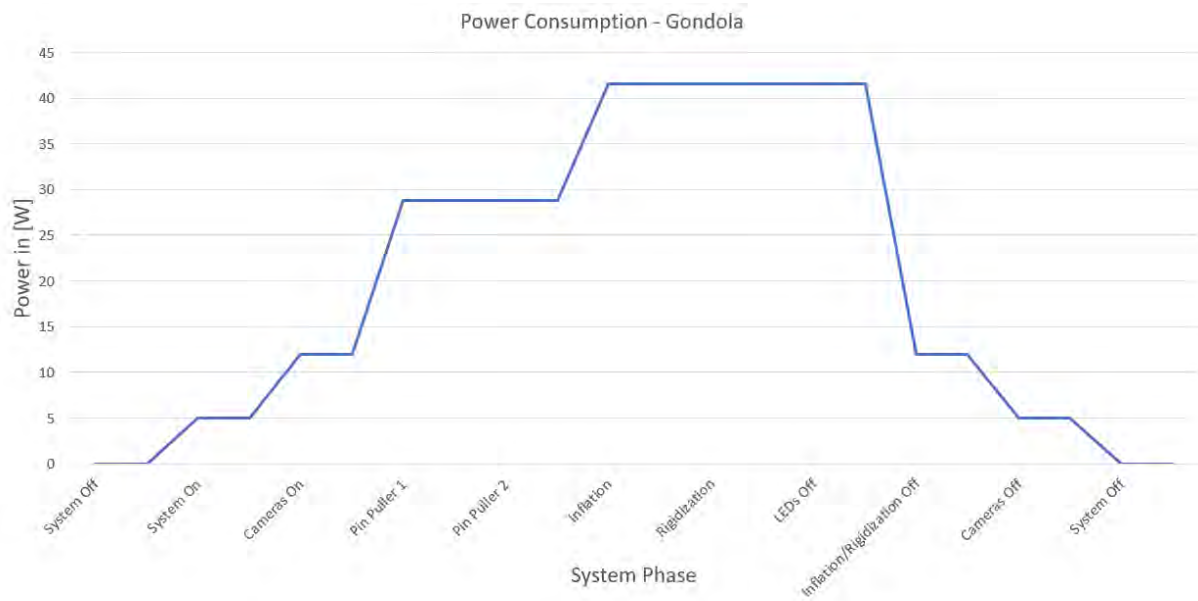


Fig. 4.80: Power Consumption - Gondola

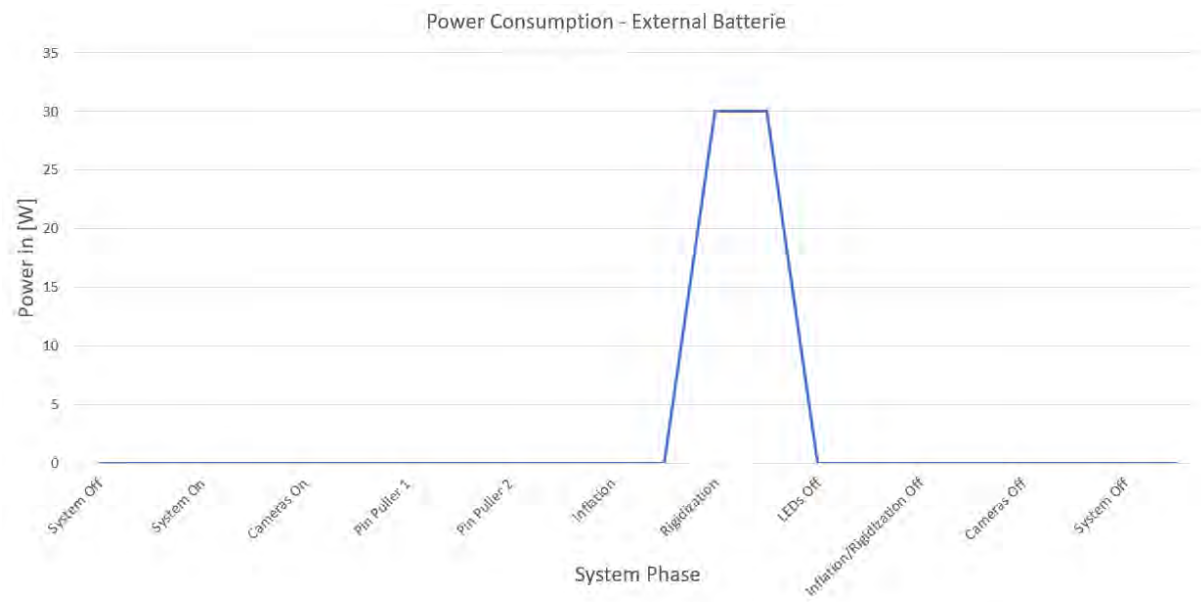


Fig. 4.81: Power Consumption - Battery

Calculation Power Consumption - Gondola			
Component	Run Time[h]	Power[W]	Energy [Wh]
Microcontroller	5	5	25
Cameras	5	7	35
Pin Puller	2.5 [sec] x 2	16.8	7/300
Inflation Unit (Magnetic Valves, 2x6,8W & 2x8W)	3	29.6	88.8
		Sum:	148.8
Calculation Power Consumption - Battery			
Component	Run Time[h]	Power[W]	Energy [Wh]
UV-LEDs	3	30	90
		Sum:	90

Table 4.11: Power consumption Gondola/Battery

4.8.2 Reverse polarity protection

To protect the circuit from reverse polarity a p-channel MOSFET is used.

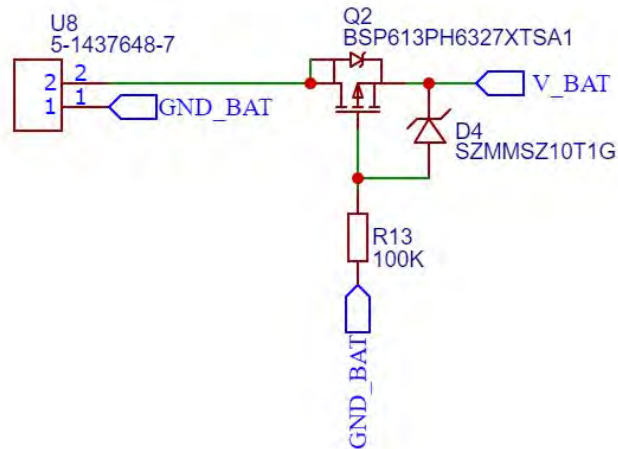


Fig. 4.82: RPP circuit

4.9 Software Design

The software design is divided into multiple subsystems. Recording of sensor data, storage of sensor and other data (on board & on ground), the inflation process, the timing of processes, the ground station and the communication between ground station and experiment. Each subgroup is self-contained and intrinsically testable, which means that the development process can take place in parallel and the impact on components upon failure is limited.

4.9.1 General Design

MASS uses a STM32 NUCLEO-F767ZI Microcontroller, described in chapter 4.5.2.1, which doesn't require a dedicated operating system. It also provides the necessary signal protocol interfaces, e.g. I^2C , SPI, UART, DCMI as well as a Ethernet port. The mC is responsible for all on board systems and procedures.

Programming languages to be used are C/C++ for the mC and C# for the ground station. To keep the workload low standard libraries and open source projects are used if possible.

The software is maintained in a Git repository, to provide all team members with access and up to date code.

<https://github.com/AdrianHettler>

4.9.2 Sensor Data Acquisition and Storage

MASS uses different types of sensors, described in chapter 4.5.2.6. All of them use I^2C as serial communication protocol, I^2C is an easy to implement protocol, it is less susceptible to noise and is better for long distance signal transmission than for example SPI. Even though its much slower than SPI its sufficient for our application. Each Sensor has it's own I^2C slave address to allow for individual readings. The sensor data will get processed in the mC and stored on a micro SD card, which is connected to the mC by SPI. The data is stored in two files simultaneously

4.9.3 Video Data Acquisition and Storage

As described in section 4.5.2.5, MASS uses RunCam Split 3 Micro cameras. These will be controlled by UART serial communication, e.g. start/stop recording. The video data will be stored on a 64GB Class 10 micro SD card, which is plugged into the cameras pcb board. The file format is .mov. Furthermore the RunCam Split 3 Micro has a TV-output channel, which outputs NTSC or PAL analog composite video. As described in section 4.5.2.5 it will be decoded to a DCMI digital 8-Bit 4:2:2 YCbCr video signal. The video data will be buffered in the SDRAM of the mC and sent to the ground station in multiple packets. This acts as a make shift slightly delayed live video feed.

4.9.4 Inflation Process

The inflation process is controlled by the mC. During ascent and descent the system does not need to be controlled, since the valves used for pressure equalization are normally opened. When flight phase starts all four magnetic valves will be continually activated. To ensure a stable inflation of our Structures the valves will be opened during the entire flight phase. At Experiment Cutoff all valves will be closed to allow for the entire experiment to shut down. Pressure equalization valves will go back into their open state to ensure that the inflatable structures do not get damaged from the higher differential pressure when back at ground level.

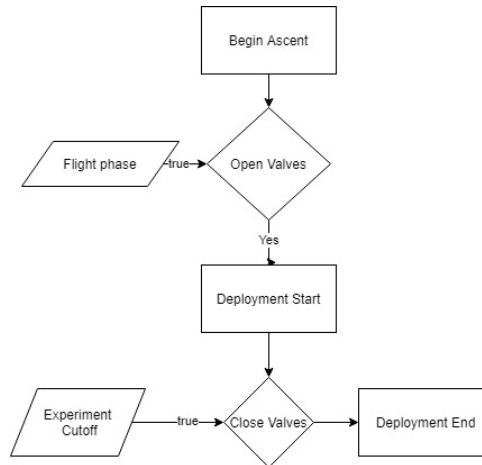


Fig. 4.83: Inflation process flow

4.9.5 Procedure

In the following the software procedure is getting explained. MASS will be operated manually, with an autonomous backup in the case connection to the gondola is lost. In the following flow chart the software procedure of the mcu is displayed,

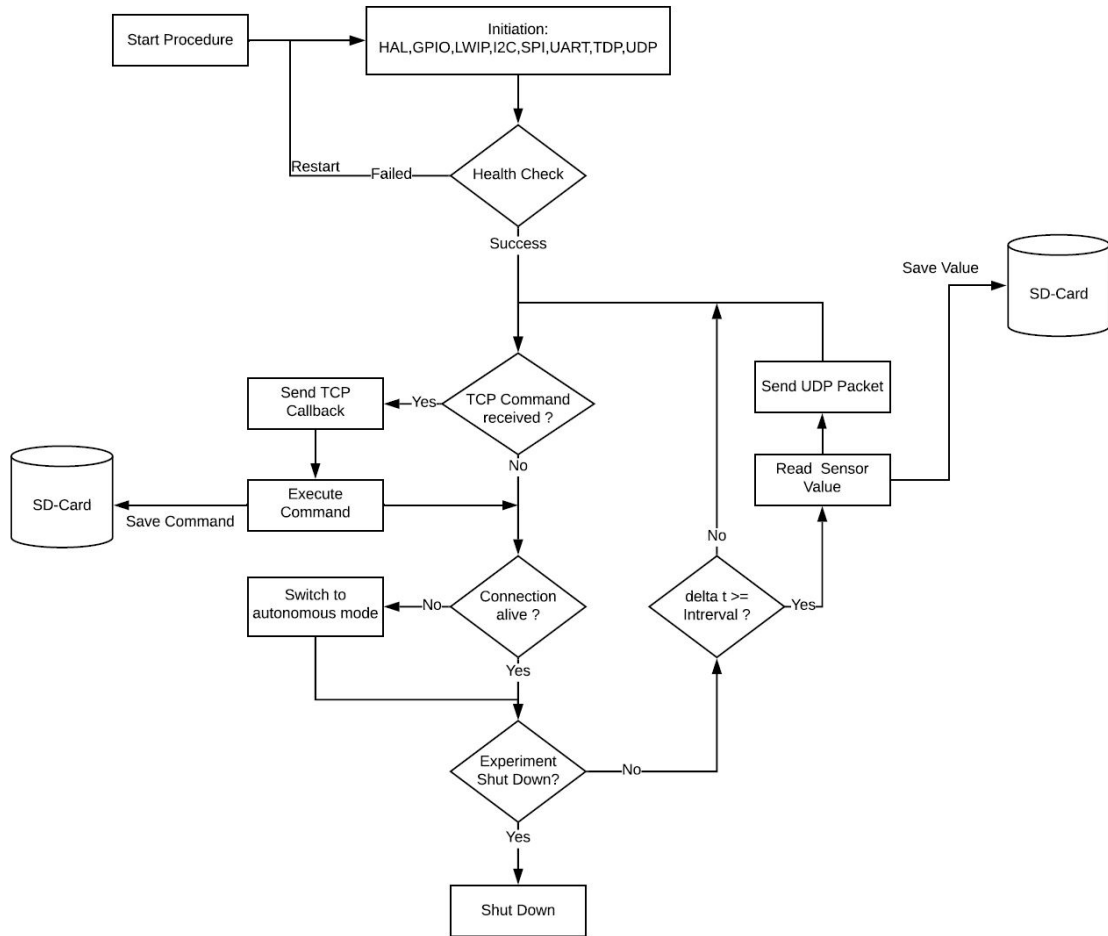


Fig. 4.84: Software Procedure MCU

The Microcontroller runs single threaded, with the use of timings. Sensor values are not getting read every time, they only get queried in defined intervals. The received TCP command packet includes a messaged id which is getting filtered in a switch case to find out the correct operation. When no ping request is received in a predefined time the experiment switches to autonomous mode.

In the following flow chart the software procedure of the ground station is explained.

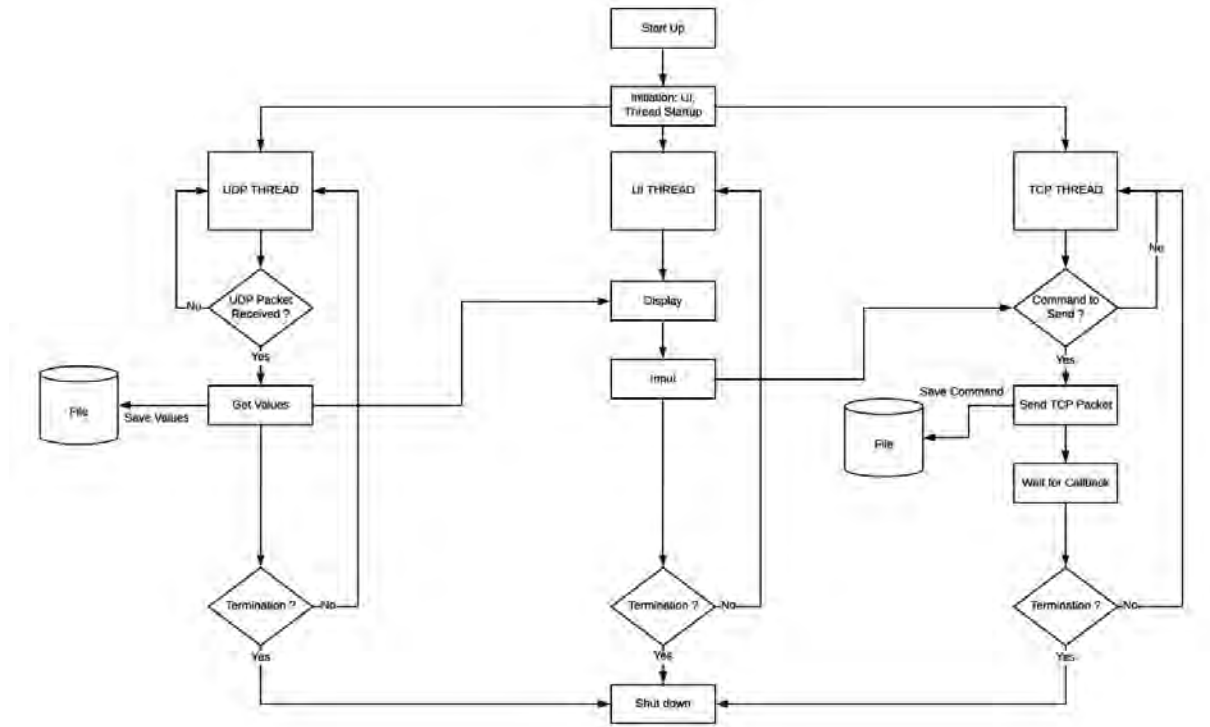


Fig. 4.85: Software Procedure GS

The ground station runs multi threaded. The UDP thread checks if a usp packet is received, gets the values with the help of the included message id, saves the value to a file and changes the value in the UI. The UI thread displays the UI and is responsible for user input. User commands are saved in an array, so that they can be processed one after the other and no command is lost. The TCP Thread checks if there are values in the command array. If there are values to be sent, it creates a packet, sends it and waits for an answer by the experiment.

4.9.6 Communication

The specified E-Link connection is used for data transfer between experiment and ground station. UDP and TCP connection protocols are being used to transfer data and commands. TCP is used for uplink, because it guarantees that the receiver, in our case the experiment, receives the correct data packets. This guarantees the reliability that is required for the transfer of commands. If for example the checksum of the received packet doesn't match the data, the same packet is sent again. UDP is used for downlink, as it doesn't matter if 1 out of 1000 data packets gets lost. Instead of TCP there is no handshake taking place, if a faulty packet is detected it gets discarded.

The widely used open-source TCP/IP stack lwIP (lightweight IP) is used. It is designed for embedded systems and provides all the underlying TCP/UDP functions. Furthermore it comes with ICMP echo protocol, which allows to ping the mC to get a response time.

MASS needs two IPs, one for the mC and one for the ground station.

4.9.6.1 Message Layout

Each message/packet has the following layout:

<UDP/TCP header><ID><DATA>

UDP/TCP header	default TCP/UDP header	20-60 byte / 8 byte
ID	message ID, containing specific function of command	1 byte
DATA	data byte array	variable

4.9.6.2 Messages

System commands:

ID	Data	Protocol	Info
1 - OK	INT8 message_id	TCP/UDP	Sent to confirm a command, data will be id of command
2 - TCP/UDP Ping	-	TCP	TCP/UDP connection check, responded with TCP/UDP Pong
3 - TCP Pong	-	TCP	Response to TCP/UDP Ping
4 - UDP Pong	-	UDP	Response to TCP/UDP Ping
5 - Reset	-	TCP	Message to reset mC, must be received two times.
254 - Error	INT8 error_code LONG timestamp	TCP	Error message & timestamp

Experiment commands:

20 - EXP Init	-	TCP	Used to reset system clock
21 - EXP Release Structures	INT8 structure	TCP	Data is a bitshifted byte to send info which structure gets released. E.g. 00001011 Release of Structure 1,2 and 4
22 - EXP Start Inflation	INT8 structure	TCP	Data is a bitshifted byte to send info which structures to inflate
23 - EXP UV ON	INT8 structure	TCP	Data is a bitshifted byte to send info which LEDs of structure to activate
24 - EXP UV OFF	INT8 structure	TCP	Data is a bitshifted byte to send info which LEDs of structure to deactivate
25 - EXP CAM START	INT8 cam_id	TCP	
26 - EXP CAM STOP	INT8 cam_id	TCP	

Downlink Data:

100 - Data environmental	float env_temp_outside float env_temp_inside float env_pressure	UDP	Environmental data of experiment: temperature, pressure
101 - Data power	float volt- age_bexus_bat float volt- age_extra_bat float cur- rent_bexus_bat float cur- rent_extra_bat	UDP	Power data (Voltage/Current)
102 - Data pneumatics	float pressure_tank float pres- sure_inside_structures float pres- sure_outside_structures	UDP	Pneumatics data (Pressure)

4.9.7 Ground Station

The ground station is used to send commands to the experiment and to receive data. It's written in C# and uses windows forms for the user interface.

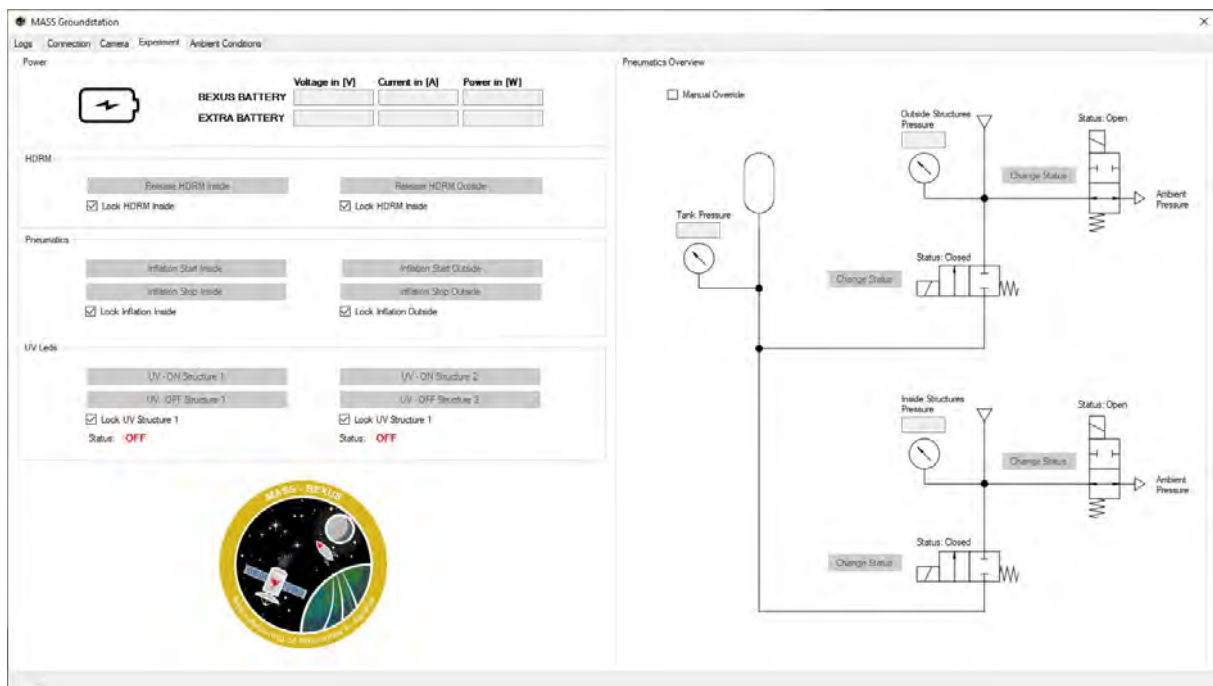


Fig. 4.86: Ground station

To avoid missfires, all buttons are additionally secured by a lock checkbox. In checked state this prevents the press of buttons.

4.10 Ground Support Equipment

Aside of standard tools, there were only two specially developed ground support equipment pieces made.

The first one is a simple winding device used for sealing the foil with spray adhesive, and later on as support for maintaining a round shaped form during application of the fibers to the foil. At last, the thinner sealing foil has been applied as the structure was still positioned in the winding device. The picture below shows described winding device, the knurled screws are for dismantling purposes of the inflatable structure and guide the PVC-cylinder.



Fig. 4.87: Winding device

The second used ground support equipment is a CNC-cut PVC sheet for marking the correct origami folding lines of the tested structures onto the carrier foil prior to folding. This eases the process of folding to a significant degree, as there is no need for measuring and marking line by line onto the foil. The image below shows the PVC marking-sheet with a standard Edding Pen for size comparison.

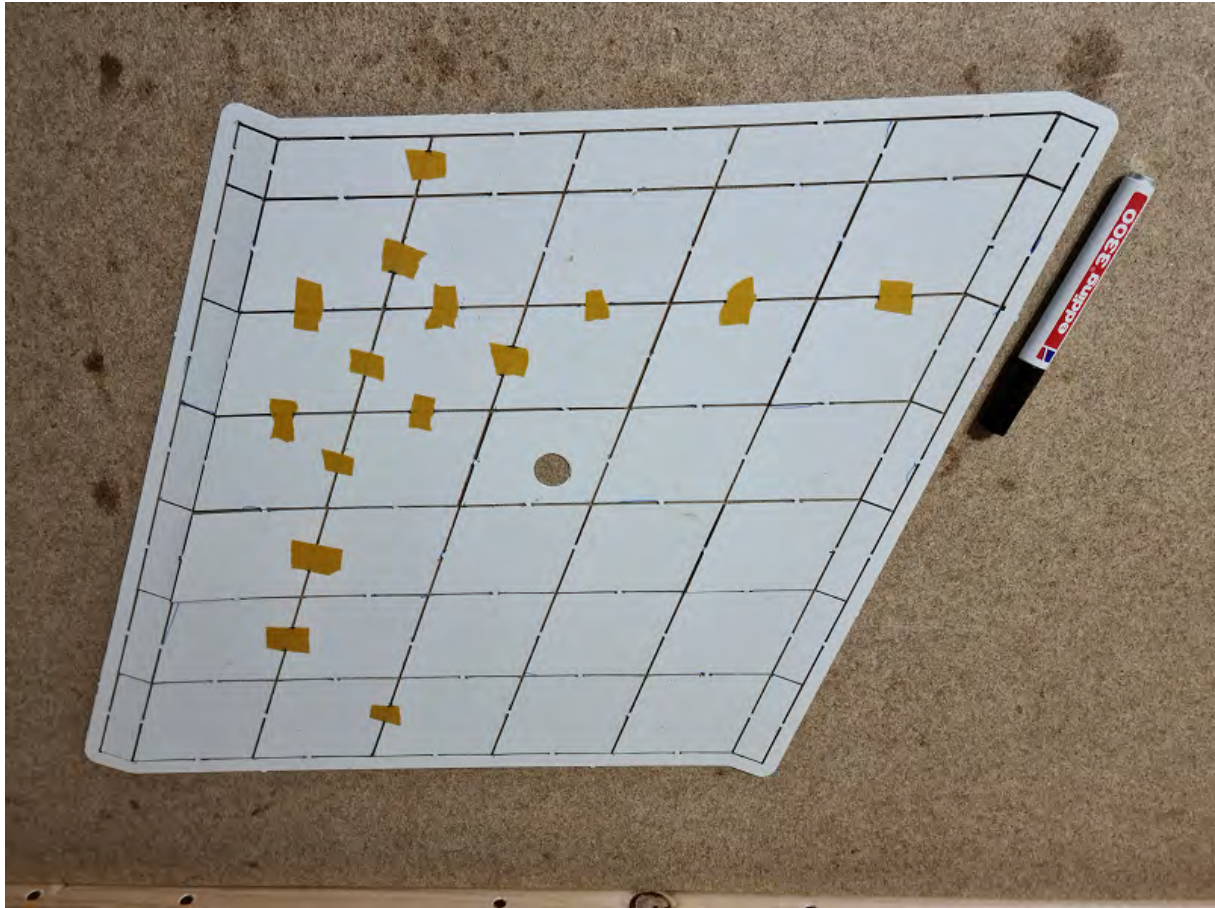


Fig. 4.88: PVC marking-sheet

5 EXPERIMENT VERIFICATION AND TESTING

The verification methods used in this section comply with the established verification methods of the ECSS-E-ST-10-02C [2]:

- Verification by review-of-design (R)
- Verification by inspection (I)
- Verification by analysis (A)
- Verification by similarity (S)
- Verification by test (T)

The abbreviations used in this section are as follows (see also Page 148):

- tbd - to be done
- pd - partially done
- d - done

5.1 Verification Matrix

The following table lists all the requirements from section 2 and the verification method used to verify them.

ID	Requirement Text	Method	Reference	Status	Verification Result
FR_01	First securely store (during ascent), then inflate and rigidize 4 resin soaked fibre structures	T,R	Test 7, Test 9	pd	partially successful
FR_02	Cameras shall record the inflation process and performance of the inflating structures	R,T	Test 6	d	successful
FR_03	The setup shall measure temperature and pressure inside as well as outside the structures	R,T	Test 4	d	successful
FR_04	The structures shall be inflated to their final form	A,T	Test 3, Test 8	d	successful

Continued on next page

ID	Requirement Text	Method	Reference	Status	Verification Result
FR_05	The pressure inside the structures shall be regulated to control the inflation process and ensure complete deployment of the structures	R,A,T	Test 3,2	d	successful
FR_06	The setup shall provide a sufficient amount of pressurized Nitrogen	R,A		d	successful
PR_01	The resolution of the camera(s) shall be at least 800x600 pixels	R		d	successful
PR_02	Images and Videos captured shall have at least 16-bit colour	R		d	successful
PR_03	Temperature sensors shall be able to record measuring values between -60°C and 40°C	R,T	Test 1, Test 4	pd	partially successful
PR_04	The temperature measurements shall have a minimum sensitivity of $\pm 1^{\circ}\text{C}$	R,T	Test 1	d	successful
PR_05	Pressure sensors shall be able to record the measuring values down to 750 Pa	R,T	Test 1, Test 4	d	successful
PR_06	The pressure measurements shall have a minimum sensitivity of ± 20 Pa	R,T	Test 1	d	successful
Continued on next page					

ID	Requirement Text	Method	Reference	Status	Verification Result
PR_07	The top part of the inflatable structure shall be positioned with an accuracy of $\pm 0,5$ cm to the desired target position	R,T	Test 2	d	successful
PR_08	Inflation process shall be completed within 20-30 sec	A,T	Test 5	d	successful
PR_09	The pressure inside the structures shall be controllable with an accuracy of ± 100 Pa	R,T	Test 3	d	successful
DR_01	Inflation structures must withstand a temperature range from -60°C to 25°C	A,R,T	Test 4	d	successful
DR_02	Electronic components inside the lower box must be able to operate at temperatures from -30°C to 40°C	R,T,A	Test 4	d	successful
DR_03	Mechanisms must be able to operate at temperatures from -60°C to 25°C	A,T	Test 4	d	successful
DR_04	Inflation process must be able to operate at temperatures from -60°C to 25°C	R		d	successful
Continued on next page					

ID	Requirement Text	Method	Reference	Status	Verification Result
DR_05	The amount of carried pressurized nitrogen shall be enough to completely inflate the 4 structures	A		d	successful
DR_06	The pressure unit shall be designed in such a way that 2 pairs of structures (each consisting of one in the lower box and one in the upper box) can be inflated independently	R		d	successful
DR_07	The LED-segments shall be controllable for on-off-switching via ground station	R,T	Test 9	d	successful
DR_08	The experiment shall be developed and positioned so that the 2 outside structures have the possibility to be exposed to the sunlight depending on flight conditions	R		d	successful
DR_09	The lower box shall be designed to regulate the temperature above -30°C	A,R,T	Test 10	pd	partially successful
DR_10	The boxes shall be designed to provide protection of the structures during landing	A,R		d	successful
Continued on next page					

ID	Requirement Text	Method	Reference	Status	Verification Result
DR_11	The experiment shall be designed in such a way that it shall not disturb or harm the gondola or any other experiment	R		d	successful
DR_12	The experiment shall be mounted on the BEXUS gondola so 2 of the 4 structures can inflate inside and the other 2 outside the gondola	R		d	successful
DR_13	No components or parts shall become detached from the experiment at any point during the BEXUS flight	R,T	Test 11	pd	partially successful
DR_14	Cameras shall be positioned suitably to capture the whole inflation process	R		d	successful
OR_01	The communication between the experiment and ground station shall be executed via E-Link until cutoff	R		d	successful
OR_02	Status of LEDs, pressure and temperature values shall be reported to the ground station every 5 seconds	R,T	Test 9, Test 10	d	successful
OR_03	The structures shall be released autonomously at an altitude of 25 km	R,T	Test 7, Test 10	d	successful
Continued on next page					

ID	Requirement Text	Method	Reference	Status	Verification Result
OR_04	The inflation process shall start when the gondola reaches a flight altitude of 25 km	R,T	Test 10	d	successful
OR_05	The inflation valve shall regulate the pressure autonomously but in case be able to be controlled from the ground station	R,T	Test 7	d	partially successful
OR_06	The experiment LED lights inside the gondola shall be switched on autonomously but in case be able to be controlled from the ground station	R,T	Test 7	d	partially successful
OR_07	All data (including measuring values and recording from the cameras) shall be saved during the flight	R,T	Test 7, Test 9	d	successful
OR_08	All electronic systems shall operate autonomously	R,T	Test 7, Test 9	d	partially successful
OR_09	The flight altitude shall be at least 25km (low pressure and strong sunlight required for the inflation process and hardening of the structure)	R		d	successful

5.2 Verification Plan

Test Number	1
Test Type	thermal
Test Facility	ZARM Bremen (thermal-vacuum week)
Tested Item	thermal and pressure sensors
Model	protoflight
Procedure, Test Level & duration	sensors measurements will be compared to reference values to see if the sensors work properly in every state of the flight
Test Campaign Duration	1/2 day
Test Campaign Date	2021/08/16
Test Completed	yes
Requirements Verified	PR_03, PR_04, PR_05, PR_06

Test Number	2
Test Type	mechanical, electrical
Test Facility	Private Workshop
Tested Item	pressure vessels, pressure valve (inflation unit)
Model	protoflight
Procedure, Test Level & duration	Dummy of inflation model will be inflated, differential pressure values will be recorded and compared to defined values
Test Campaign Duration	1/2 day
Test Campaign Date	2021/06/09
Test Completed	yes
Requirements Verified	FR_05, PR_07

Test Number	3
Test Type	mechanical
Test Facility	Private Workshop
Tested Item	inflation model and mechanism
Model	protoflight
Procedure, Test Level & duration	Desired inflation model will be inflated and checked if it inflates according to our designed inflation process after and during inflation, it will also be checked if any deviation from the desired shape occur. Due to that it will be checked what the critical components are. 15 hours
Test Campaign Duration	2-3 days
Test Campaign Date	2021/05 - 2021/06
Test Completed	yes
Requirements Verified	FR_04, FR_05, PR_09

Test Number	4
Test Type	thermal
Test Facility	ZARM Bremen (thermal-vacuum week)
Tested Item	electronics and inflation model and inflation mechanism
Model	protoflight
Procedure, Test Level & duration	Test items will be tested for functionality at room temperature or in a heated environment, afterwards they will be placed in a thermal vacuum chamber for circa 5 hours and will be tested for functionality after being cooled down completely. 8 hours
Test Campaign Duration	2 days
Test Campaign Date	2021/08/16
Test Completed	yes
Requirements Verified	FR_03, DR_01, DR_02, DR_03

Test Number	5
Test Type	mechanical
Test Facility	Private Workshop
Tested Item	inflation model and mechanism
Model	protoflight
Procedure, Test Level & duration	Desired inflation model will be inflated and checked if it inflates in our defined time limit, 2-3 hours
Test Campaign Duration	1 day
Test Campaign Date	2021/06 - 2021/07
Test Completed	yes
Requirements Verified	PR_08

Test Number	6
Test Type	mechanical/ electrical
Test Facility	Private Workshop
Tested Item	all mechanical and electrical components
Model	prototype
Procedure, Test Level & duration	To ensure that the whole process works autonomically one dummy will be assembled and the experiment simulated. During this Test, the whole pneumatic System, the control System, the structure packing, the Sensor read-outs and the LED bank will be tested thoroughly 20 hours
Test Campaign Duration	2-3 days
Test Campaign Date	2021/08/06
Test Completed	yes
Requirements Verified	Fr_02

Test Number	7
Test Type	electric
Test Facility	Private Workshop
Tested Item	electronic, especially microcontroller
Model	protoflight and qualification model
Procedure, Test Level & duration	We will simulate the whole experiment for the control system. Due to that, the data storage is also included. The System has to perform a whole Experiment run, including a test of current consumption of the Pinpuller. During this time there should be no Power outage, the Data and the Video data has to be stored properly and the video feed should work. 8 hours
Test Campaign Duration	2-3 days
Test Campaign Date	2021/08/06
Test Completed	yes
Requirements Verified	FR_01, OR_03, OR_05, OR_06, OR_07, OR_08

Test Number	8
Test Type	mechanical
Test Facility	Private Workshop
Tested Item	inflation unit
Model	protoflight
Procedure, Test Level & duration	Desired inflation model will be inflated and checked if inflation of the model is completed, 2 hours
Test Campaign Duration	1 day
Test Campaign Date	10.06.2021
Test Completed	yes
Requirements Verified	FR_04

Test Number	9
Test Type	functionality
Test Facility	ZARM Bremen (thermal-vacuum week)
Tested Item	complete system
Model	protoflight & flight
Procedure, Test Level & Duration	Model will be set up and connected via cable to the ground station. Then it has to run a full system test and multiple inflation cycles. After successful testing the model will be unplugged from the ground station and will have to run a system test and another inflation cycle under flight conditions. 8 hours
Test Campaign Duration	2-3 day
Test Campaign Date	2021/08/16
Test Completed	yes
Requirements Verified	FR_01, DR_07, OR_02, OR_07, OR_08

Test Number	10
Test Type	environmental/thermal
Test Facility	ZARM Bremen (thermal-vacuum week)
Tested Item	complete system
Model	protoflight
Procedure, Test Level & duration	Model will be placed inside a vacuum test chamber. After this model also has to carry out a full system test under flight conditions while being exposed to vacuum conditions. Behavior of the experiment will be analysed and used to improve and fine-tune the system. 3 hours
Test Campaign Duration	1 day
Test Campaign Date	2021/08/16
Test Completed	yes
Requirements Verified	DR_09, OR_02, OR_03, OR_04

Test Number	11
Test Type	environmental
Test Facility	Private Workshop
Tested Item	complete system
Model	flight
Procedure, Test Level & duration	Model will be hung up on a rope to be able to free-swing. Model then has to run a full system test and one inflation cycle while being swung around. Flight Model will then be put on a DIY Vibration Table and has to perform a system Test While being exposed to hand made vibrations. 6 hours
Test Campaign Duration	1 day
Test Campaign Date	2021/08/11
Test Completed	yes
Requirements Verified	DR_13

Test Number	12
Test Type	mechanical
Test Facility	Private Workshop
Tested Item	Pinpuller
Model	Pinpuller
Procedure, Test Level & duration	Pinpuller will be tested in terms of actuation Force, bearable axial and radial loads while being still able to work, Power Consumption and mountability
Test Campaign Duration	3 day
Test Campaign Date	20.07.2021
Test Completed	yes
Requirements Verified	Part Testing of Pinpuller

5.3 Verification Results

Verification number	1
Test Number / Type of test	2 / mechanical
Facility	Private workshop
Verified item	Pressure valves
Verification description	Different structure types were inflated and checked if the pneumatic setup works properly. in addition, the pneumatic assembly is checked for leakage
Expected results	It was expected, that a differential pressure of approximately 0.5bar is needed to inflate the structures. Due to that it was expected that a pressure loss of approximately 2bar will occur over the time of 8 hours.
Obtained Results	The different structures (different types of fibres (CFK, GFK, AFK) and different folding methods) were inflated completely. During a period of 3 hours a pressure loss of 1.2bar was measured.
Conclusions	The current set values are appropriate to guarantee a complete inflation of the structures. Nevertheless, the pressure vessel is filled with more than 8bar (approximately 10bar). This is to ensure that important minutes are gained for inflation. However, too high a filling pressure is not used, as otherwise the pressure loss that occurs would only increase due to the existing leakage.



Fig. 5.1: Strucutre with Aramid fibres inflated



Fig. 5.2: Strucutre with Carbon fibres inflated

Verification number	2
Test Number / Type of test	3 / mechanical
Facility	Private Workshop
Verified item	Inflatable Structures
Verification description	Different arrangements of the filaments were tried out in order to check with which laying method the best and most stable structures can be achieved.
Expected results	It was assumed that a better cylinder shape would be achieved with a purely helical lay-up. Contrary with a laying method where the fibres cross each other more stable structures can be built.
Obtained Results	With the helical lay-up the inflated structure geometry has more similarities with a cylinder than the crossed lay-up. In contrast, more stable structures are created with the crossed laying method.
Conclusions	To ensure that the inflated structures can survive even a harsh landing, the crossed lay-up will be applied for the final inflation. The primary goal is to study the physical properties of the structure after the flight and not to produce geometrically perfect components. It was shown that the same differential pressure is sufficient to inflate both structures.



Fig. 5.3: Structure Assembly with Aramid fibres with crossing lay-up



Fig. 5.4: Structure Assembly with Aramid fibres with helical lay-up

Verification number	3
Test Number / Type of test	5 / mechanical
Facility	Private Workshop
Verified item	Inflation Process
Verification description	Different structure types (varying folding methods and fibre materials) were produced and inflated to see what differential pressure is needed and how long the process needs.
Expected results	It was assumed that for all structure types the differential pressure for the inflation process as well as the needed time is approximately the same
Obtained Results	The inflation process for all different types takes between 10 and 15 seconds.
Conclusions	The time estimated before the experiments will be significantly undercut. Therefore, the time factor in the inflation process will not be the critical value.



Fig. 5.5: Inflation process (Left:nearly completely folded; Middle: Half inflated; Right: Completely inflated)

Verification number	4
Test Number / Type of test	7 / electronic
Facility	Private Workshop
Verified item	microcontroller / software compatibility
Verification description	Each software function is tested. The software is started in debug mode and is checked for possible exceptions.
Expected results	No exceptions should get thrown and every software function should work nominally.
Obtained Results	No exceptions were thrown and every software function worked nominally.
Conclusions	Because of unexpected exceptions that would normally not occur, exception handling was implemented.

Verification number	5
Test Number / Type of test	8 / mechanical
Facility	Private Workshop
Verified item	Inflatable Structures
Verification description	The structures were inflated and cured under the influence of the sun.
Expected results	It is assumed that the structures will be nearly completely cured after two hours only to the influence of the sun.
Obtained Results	The structures were completely cured after less than 10 minutes.
Conclusions	The time estimated before the experiments will be significantly undercut. Therefore, the time factor in the curing process will not be the critical value too.

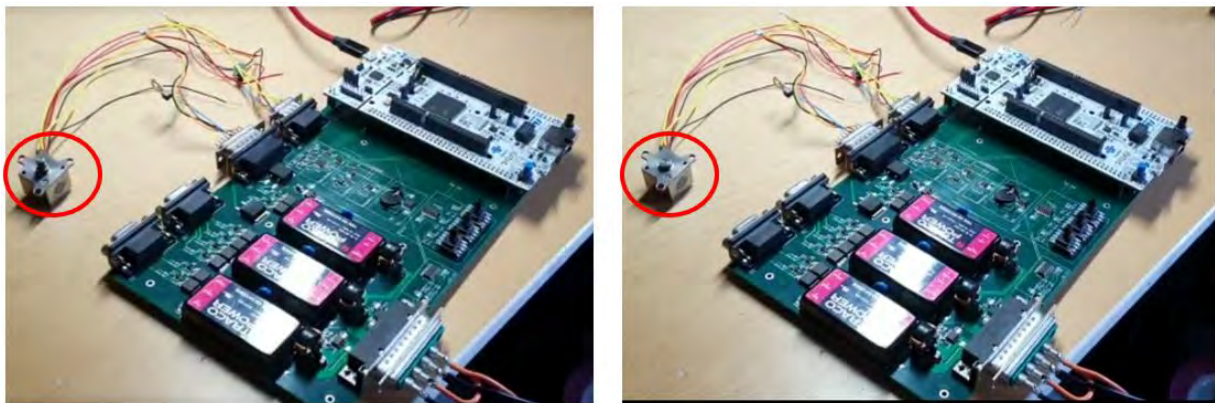


Fig. 5.6: Pin-Puller and the electrical interface



Fig. 5.7: Pin-Puller connected to electrical interface an HDRM

Verification number	6
Test Number / Type of test	12 / mechanical and electrical
Facility	Private Workshop
Verified item	Pin-Puller
Verification description	The pin puller was connected to electrical interface to check the power consumption. Additionally the pin puller was connected to the HDRM to check if the structures can be safely released.
Expected results	It is assumed, that the power consumption is $\sim 10W$. Furthermore it is expected that the HDRM work as in 4.24 depicted.
Obtained Results	The average power consumption of the pin puller was $\sim 10W$. Moreover, the springs operated by it are strong enough to ensure a release of the structures for the inflation process
Conclusions	The pin puller works as expected without any difficulties. To prevent over current a software check was implemented that only one pin puller could be operated at once.

Verification number	7
Test Number / Type of test	11 / mechanical / environmental
Facility	Private workshop
Verified item	complete system
Verification description	Model will be hung up on a rope to be able to free-swing. Model then has to run a full system test and one inflation cycle while being swung around. Flight Model will then be put on a DIY Vibration Table and has to perform a system Test while being exposed to hand made vibrations.
Expected results	No damage to the experiment was expected.
Obtained Results	No damage to the experiment was observed.
Conclusions	Mechanical loads during flight will not damage our experiment.

Verification number	8
Test Number / Type of test	1 / thermal
Facility	ZARM Bremen (thermal-vacuum week)
Verified item	sensors
Verification description	Own recorded sensor measurements were compared to the thermal-vacuum-chamber sensors during the entire test run
Expected results	Sensors will have to be calibrated but should fulfill the requirements
Obtained Results	The pressure sensors differed by a few HPa compared to the thermal-vacuum chamber measurements. Due to an electrical layout error the temperature sensors shut off at 15° C.
Conclusions	The problem regarding the temperature sensors is easy to fix. The sensors are accurate enough and work properly.

Verification number	9
Test Number / Type of test	4 / thermal
Facility	ZARM Bremen (thermal-vacuum week)
Verified item	electronics, inflation model and inflation mechanism
Verification description	After the experiment cooled down to expected flight-level in the thermal-vacuum chamber a full health check and inflation test was done.
Expected results	One camera was expected to overheat due to the low pressure environment and the missing cooling from convection because of that. Furthermore we expected problems with the air trapped between the two foils used for the inflatable structure in a near vacuum environment.
Obtained Results	The expected camera did overheat during the first test run, but took no lasting damage from it. For a second test run we added a heatbridge with aluminum tape connecting the camera and the colder aluminum frame which cooled the camera down sufficiently. The trapped air in the inflatable structure did not cause any problems.
Conclusions	The electronics, inflatable structure and inflation mechanism work as intended in the expected flight environment.

Verification number	10
Test Number / Type of test	6 / mechanical / electrical
Facility	Private workshop
Verified item	all mechanical and electrical components
Verification description	Thorough testing of all experiment functions, electronics and software to ensure that no unexpected experiment behavior occurs during flight.
Expected results	Experiment performs as intended.
Obtained Results	The experiment performed mostly as intended and expected, everything that did not was improved upon, especially the HDRM.
Conclusions	The experiment is will work as intended during flight.

Verification number	11
Test Number / Type of test	9 / functionality
Facility	ZARM Bremen (thermal-vacuum week)
Verified item	complete system
Verification description	After the experiment cooled down to expected flight-level in the thermal-vacuum chamber a full health check and inflation test was done.
Expected results	After the first thermal-vacuum test everything was expected to work. Additional thermal sensors from ZARM were added to get more data for analysis.
Obtained Results	Everything performed as expected.
Conclusions	The complete system is functional and all primary and most of the secondary objectives of Team MASS are expected to be achieved.

Verification number	12
Test Number / Type of test	10 / environmental/thermal
Facility	ZARM Bremen (thermal-vacuum week)
Verified item	complete system
Verification description	After the experiment cooled down to expected flight-level in the thermal-vacuum chamber a full health check and inflation test was done.
Expected results	The HDRM only releases partially reliably - 3/4 structures reliably released during testing before the vacuum chamber. Everything else was expected to work as intended.
Obtained Results	The HDRM did not release all structures. Everything else worked as intended.
Conclusions	The springs used in the HDRM will be replaced by stronger ones. The design will be improved slightly by making it easier to arm the mechanism by adding handles. With the changes we expect all four structures to be released. All primary objectives will still be achieved even if one of the four structures does not release.

6 LAUNCH CAMPAIGN PREPARATION

6.1 Input for the Campaign / Flight Requirement Plans

6.1.1 Dimensions and Mass

Components	Estimated mass
Outside Frame (including Plexiglas)	5,8 kg
Interface for upper frame	0,3 kg
Inside Frame	6,5 kg
Isolation	1,8 kg
Inflatable Structure - Polyester foil - Fibers - Resin - Base plate - Top plate	4 x 0,55 kg = 2,2 kg
Inflation Unit	3,8 kg
Eletrical components: - Camera (2x) - Microcontroller - LEDs - Batteries - Sensors	2,0 kg
Heat pads	0,2 kg
Total Mass	23,2 kg

Table 6.1: Mass estimations of components.

Experiment mass	23,2 kg (measured during EAR)
Outside Frame	6,9 kg
Inside Frame (including interface)	16,3 kg
Experiment dimensions:	.
Outside Frame	506mm x 245mm x 465mm
Inside Frame	598mm x 350mm x 608mm
Experiment expected CoG (Centre of gravity) position (measured from CoG of gondola)	

Table 6.2: Experiment summary table.

6.1.2 Safety Risks

This table details the possibility of interference with other experiments in the BEXUS gondola and possible safety risks when manufacturing and integrating the final build

Risk	Key Characteristics	Mitigation
Bursting Pressure Container	Festo 16 bar (8 bar used)	Safety Factors (2), pressure test @16bar
UV-curing resin	under 100ml, no toxic fumes	not accessible in stored position, harmless in cured state
Structure outside gondola	Mass 5 Kg	additional safety line
Interface outside gondola	Mass 1,2 Kg	additional safety line
Handling of N2 bottle	200bar pressure	use of pressure regulator
Filling of N2 tank	overpressure >8bar	supervised by SSC Staff, overpressure valve

Table 6.3: Experiment safety risks

6.1.3 Electrical Interfaces

BEXUS Electrical Interfaces	
E-link Interface: E-link required? Yes	
Number of E-link interfaces:	1
Number of required IP addresses:	2
Data rate – downlink (max. and average):	500/200 bytes/s
Data rate – uplink (max. and average):	200/50 bytes/s
Interface type (RS-232, Ethernet):	Ethernet
Power system: Gondola power required? Yes	
Peak power and current consumption:	41,6W + 30W*
Average power and current consumption:	42W
Total power and current consumption after lift-off	240Wh
Power system: Experiment includes batteries?	Yes

Table 6.4: Electrical interfaces applicable to BEXUS

*41,6W BEXUS battery, 30W extra battery (6x SAFT LSH-20)

6.1.4 Launch Site Requirements

- A dark (no sunlight) well ventilated room with a table.
- Work safety equipment for all present team members (safety goggles, L and XL nitril gloves)
- At least three tables (~2m x 1m)
- Four chairs
- A powersupply (DC ~ 30V / 100W output)
- Power outlets for computer equipment / multi-outlet power strip
- Ethernet cable
- A multimeter
- A standard toolbox
- Two Open-end wrench set (metric / 6 - 19)
- Open-end wrench Size 32
- Battery-powered screwdriver with reciever for nuts
- Drill set (diameter: 2.5; 3; 4.5; 5.5; 6.5; 8; 10.5 [mm])
- Two Inbus key sets
- Two flashlights for inspection at the end
- Two steel scales (500mm)
- Two hammers (one plastic, one steel)
- A hand deburrer
- A warding file set
- Adhesive tape (50mm)
- Double sided adhesive tape (~50mm)
- Kapton tape (~30mm)
- Aceton (1l)
- Side cutter
- Wire stripper
- A soldering iron
- Solder wire
- Paper towels (~500 sheets)
- Covering foil (~3m x 2m)
- Leak detection spray
- Standard pressurized nitrogen gas bottle(5-10l/200bar), connecting thread W 24,32 x 1/14" - DIN 477

6.1.5 Flight Requirements

The balloon shall reach at least 25 km of altitude above ground level. This floating altitude should be maintained for at least 1 hours to provide enough time to cure the resin. MASS uses UV light from the sun to cure the resin, therefore it is absolutely necessary to float during daylight. To ensure maximum intensity of the sunlight during the experiment, the ascend should not start too early before sunrise. The float phase should be between 9AM - 4PM.

6.1.6 Accommodation Requirements

The Sun should be able to shine on all sides of the deployed upper structures. That is why MASS should be positioned on top of the gondola. The two fully inflated upper structures will deploy out of the gondola, the two lower structures will be deployed in the main structure, as they get rigidized by UV-LEDS and do not need the sun to harden.

6.2 Preparation and Test Activities at Esrange

Time/Day	Main Task	Description	Responsible	Duration [h:m]
Day 1	Day of Arrival	-	-	-
Day 2	Experiment Preparation	Mounting of both boxes on gondola, testing/fitting of interfaces, connecting/mounting, cables/tubes/structures	whole Team	approx. 270 min
Day 2	Pneumatic test	Pressure valves tests, inflation pressure control, inflating test structures	Niklas Fromm & Adrian Hettler	approx. 120 min
Day 3	Software and electronics test	Connection tests, sensor calibration/tests, video recording, local memory, pin puller	Adrian Hettler	approx. 180 min
Day 3	Ground station and connection test	Remote control, correct data transfer	Adrian Hettler	approx. 60 min.
Day 3	Final testrun	Combination test and test release mechanism	whole Team	approx. 120 min

Table 6.5: List of planned activities

6.3 Timeline for Countdown and Flight

Time (S)	Signal	Function
T - 5h	Pressurisation*	Pressurisation of N2 tank
T - 4h	-	Start of countdown
T - 3h:50m	Power on	Health check
T - 1h:30m	RTC Sync	Exp. time sync.
T - 0h	Lift off	-
T + 1m	Start of data storage	The experiments start to collect data
T + 1h	Altitude > 25 km	-
T + 1h:15m	Inflation	Release and inflation of the structure.
T + 1h:20m	Inflation Complete	Structure is fully inflated
T + 1h:25m	Begin Curing	Curing process starts
T + 2h:25m	End Curing	Structure is fully cured
T + 2h:30m	Stop data storage	Exp will no longer collect data.
T + 2h:35m	Experiment shutdown	Experiment shutdown
T + 5h	Balloon cut-down	
T + 5h:30m	Gondola Landing	End of mission

Table 6.6: Example of timeline of the experiment events

* To avoid the need of late access the pressurisation of N2 tanks will be carried out before hand.

7 DATA ANALYSIS AND RESULTS

7.1 Data Analysis Plan

MASS is a technology demonstration. That's why the analysis has to show the functionality of the experiment.

The main question is: Does this technology work ? This can be easily verified by the inflated hardened structures. Even if, because of an unexpected hard impact, the structures get destroyed, camera footage can be used to determine the success of the experiment.

The hardened structures and camera footage will be inspected for performance and appearance in the first iteration step. This verifies the successful packing and inflation of the structures.

Another important aspect is the comparison of the structures. Different hardening methods and shapes are drawn in comparison.

In a more detailed iteration the fibers are examined. Mechanical properties (stiffness, rigidity, hardness) will be checked. Another important point is the location of the fibers on the inflated foil.

All the data collected during the experiment will be used for future adaptations and adjustments of the experiment. To build a functional in-space manufacturing technique.

7.2 Thermal Vacuum Week

During Thermal Vacuum Week (TVW) at ZARM in August 2021 the experiment was tested in a thermal vacuum chamber for the first time. During preparation for the test the experiment was tested thoroughly which showed the Hold Down and Release Mechanism to be not sufficiently reliable for use during the launch campaign and even the thermal vacuum test. The aluminium fork used in the HDRM was not stiff enough for the weight of the inflatable structures. This bent the fork which increased the necessary strength of the spring mechanism to reliably retract the fork and release the structures. Several small iterations of improvements to the design were tested during the TVW which improved the HDRM greatly. For the launch campaign the springs were increased in size which proved to make the HDRM fail-proof during testing.

During the first thermal vacuum test the structures released but were already partly cured before inflation began. Suspected reasons for that were either the low temperatures around -30°C which impacted the properties of the resin, or contamination of UV light that somehow started to cure the resin. Due to time constraints those phenomena had to be tested after the TVW.

Except for the camera in the inner box the experiment performed well regarding its thermal properties. The mentioned camera overheated and shut down but was not permanently damaged. A heat bridge made from copper tape from the camera's pcb to the aluminium frame helped cooling the overheating camera, which was tested in a second thermal vacuum test.

7.3 Launch Campaign

After arriving at Kiruna the experiment was thoroughly checked to ensure nothing was damaged during transportation. The Video Decoder got damaged during transport for which no spare part was available. This reduced the video quality the ground station received, but since the video files were also saved on SD cards aboard the gondola which could be analysed after recovery it did not impact experiment performance.

The improved Hold Down and Release mechanism was mounted and thoroughly tested to ensure a reliable release of the four inflatable structures. The night before the launch the inflatable structures were assembled and mounted to reduce the possibility of UV-contamination of the UV-curing resin used on the structures. To aid in protecting the structures reflective tape was used to hinder stray UV-light to reach the resin.



Fig. 7.1: Assembled Structure

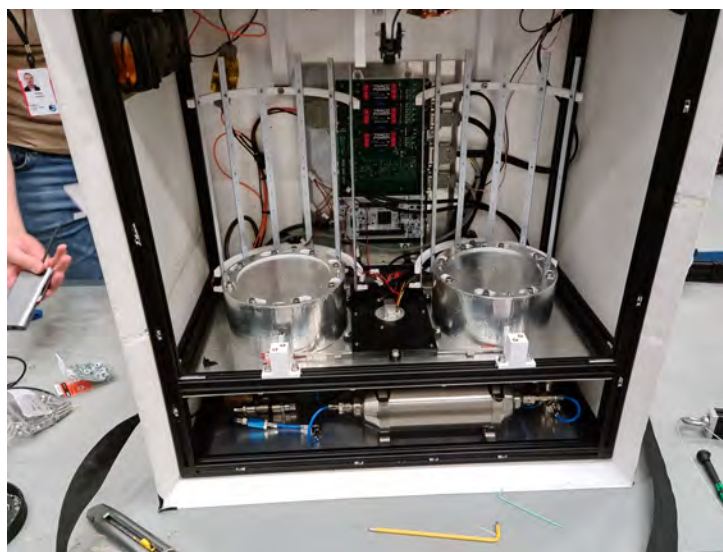


Fig. 7.2: Inside of the experiment after mounting

7.4 Post-Flight Activities

As the gondola had been successfully recovered by the SSC personnel, the experiment was visually inspected for damage. The figure below shows the gondola after recovery with the experiments still mounted:



Fig. 7.3: Gondola after recovery

Close-up of the outer box with both structures, left with resin, right one without:



Fig. 7.4: Gondola after recovery

Close-up of the inner box opened with both structures:



Fig. 7.5: Gondola after recovery

After the first inspection, both experiment boxes were dismounted from the gondola, and positioned on a table for further disassembly:

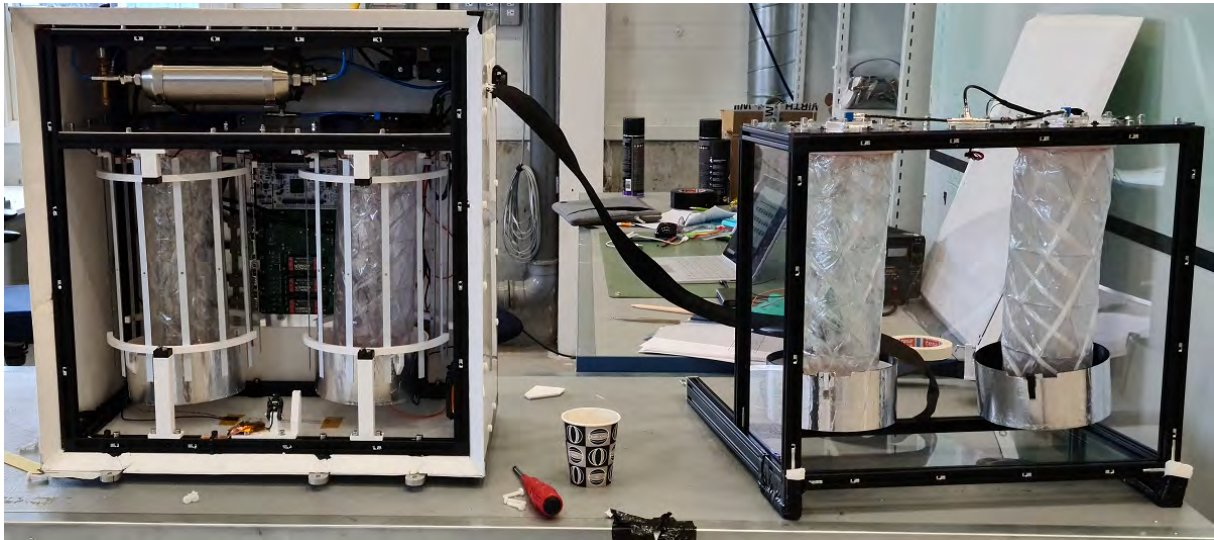


Fig. 7.6: Gondola after recovery

The first inspection showed that every structures was deployed, inflated and fully hardened. The last step during the launch campaign was to close up the experiment boxes again and to prepare them for shipping back to Germany. It should be noted, that the structures were not protected in any way during transport, and remained in their mounted position as seen in the figures above. Later back at the workshop, it showed that the structures were not damaged during transport.

7.5 Flight Performance

A lot of data was gathered during flight, which includes temperature, pressure, power consumption and a video recording of the experiment. The data will be shown in the following chapters.

7.5.1 Temperature Profile

The Temperature profile is shown in figure 7.7. The temperature was stored in an interval of 5 seconds during the entire time the experiment was powered.

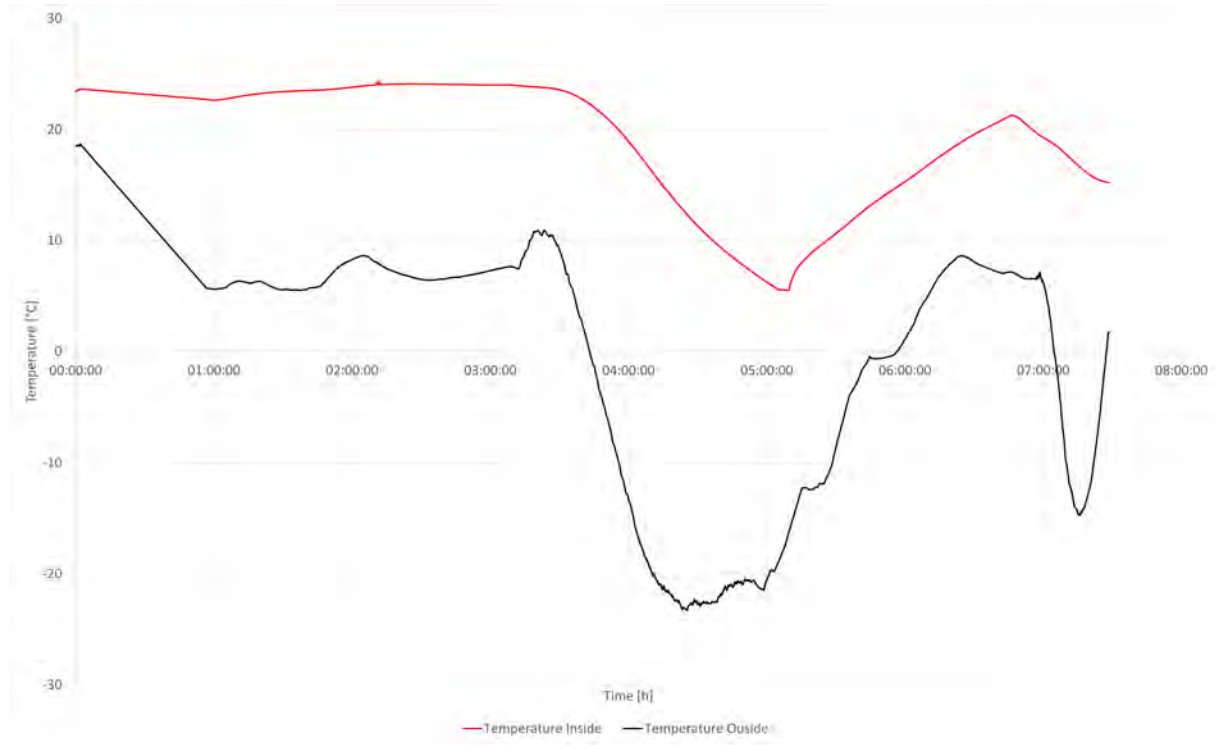


Fig. 7.7: Temperature Profile

Two different temperatures were recorded. The temperature of the insulated box, located inside of the gondola and the temperature of the uninsulated outside box. The temperature of the inside box stayed constant at about 24°C during preparations until lift off. After lift off the temperature decreased to 6°C , due to the low ambient temperature. Once the UV-LEDs were turned on, the temperature increased again. The outside box wasn't insulated, and did therefore decrease to the ambient temperature of the launch pad. Due to changing sun conditions, the temperature fluctuated from 6°C to about 10°C . After lift off the temperature decreased to a minimum of -23°C . After the minimum was reached, the temperature increased again. This was because the cloud layer was breached and the sun was shining on the black anodized aluminum profiles. The aluminum profiles heated up the experiment by heat radiation. Furthermore heat transfer by convection decreased to almost zero, because of the low air pressure. That's why the temperature of the outside box increased to about 8°C , even though the ambient temperature was much lower. This effect was expected.

7.5.2 Ambient Pressure Profile

The ambient pressure Profile is shown in figure 7.8. Furthermore the flight profile can be derived from this graph. Lift off was 3 hours and 10 minutes after the experiment was powered on. The floating phase was reached after about 2 hours and lasted for 1 hour and 45 minutes.

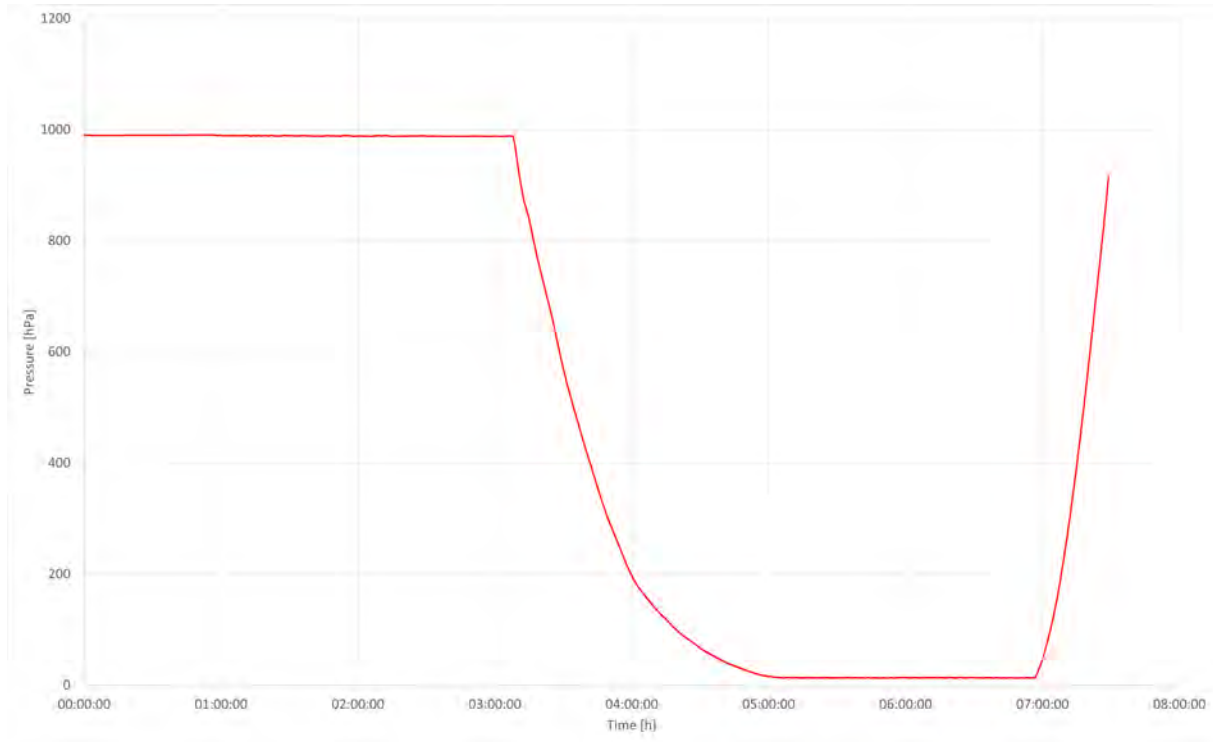


Fig. 7.8: Pressure profile

7.5.3 Experiment Pressure

Figure 7.9 shows the tank pressure over the entire flight. The first happened because of the failing auto inflation. Too much nitrogen was flowing into the structures. The exact problem was stated in chapter 7.6.3. The other drops in pressure happened during inflation of the other structures.

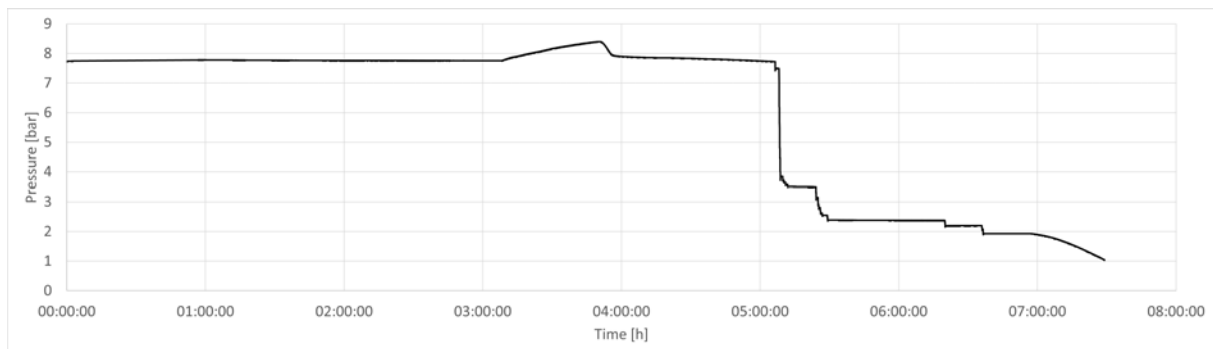


Fig. 7.9: Tank pressure

Figure 7.10 shows the pressure inside of the different structures during inflation. It can be seen that the structures did not hold the pressure well. After the pulsed inflation the pressure inside of the structures equalized to the ambient pressure. This was expected and did not affect the outcome of the inflated structures, as the cylindrical shape was maintained. The structure pressure was also measured shortly after the valve and not directly inside of the structures, this led to additional inaccuracies.

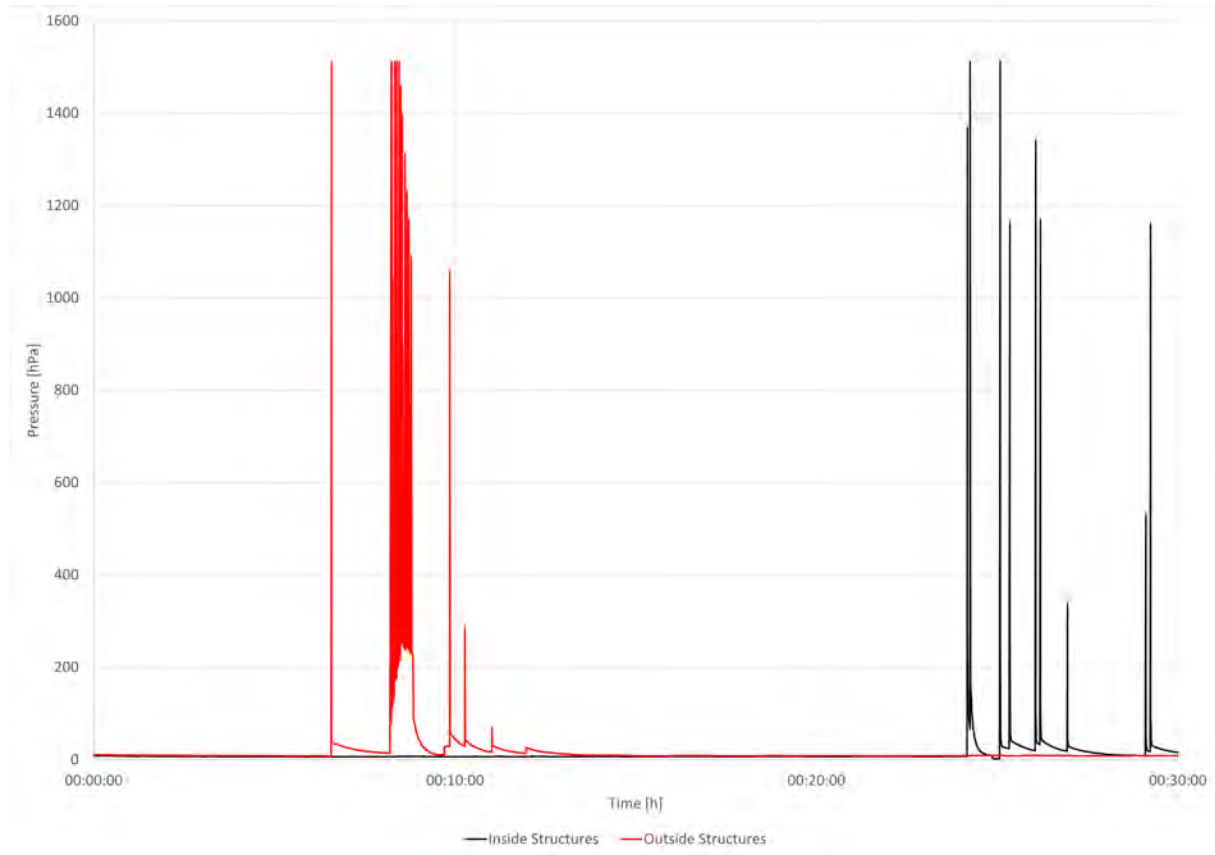


Fig. 7.10: Pressure in structures

7.5.4 Power Consumption

The voltage profile is shown in figure 7.11. The voltage drop is explained by the changing resistance in the circuit under load. The experiment was initially powered by an external power supply, that's why the voltage is different in the beginning.



Fig. 7.11: Voltage profile

Figure 7.12 shows the drawn power over time. The spikes show when the different consumers were switched on (valves, pin puller). The maximum current that was drawn was 1.55A. The total power consumption was 57Wh from the REXUS battery and 46Wh from the extra battery. This corresponds to a total battery usage of about 20%.

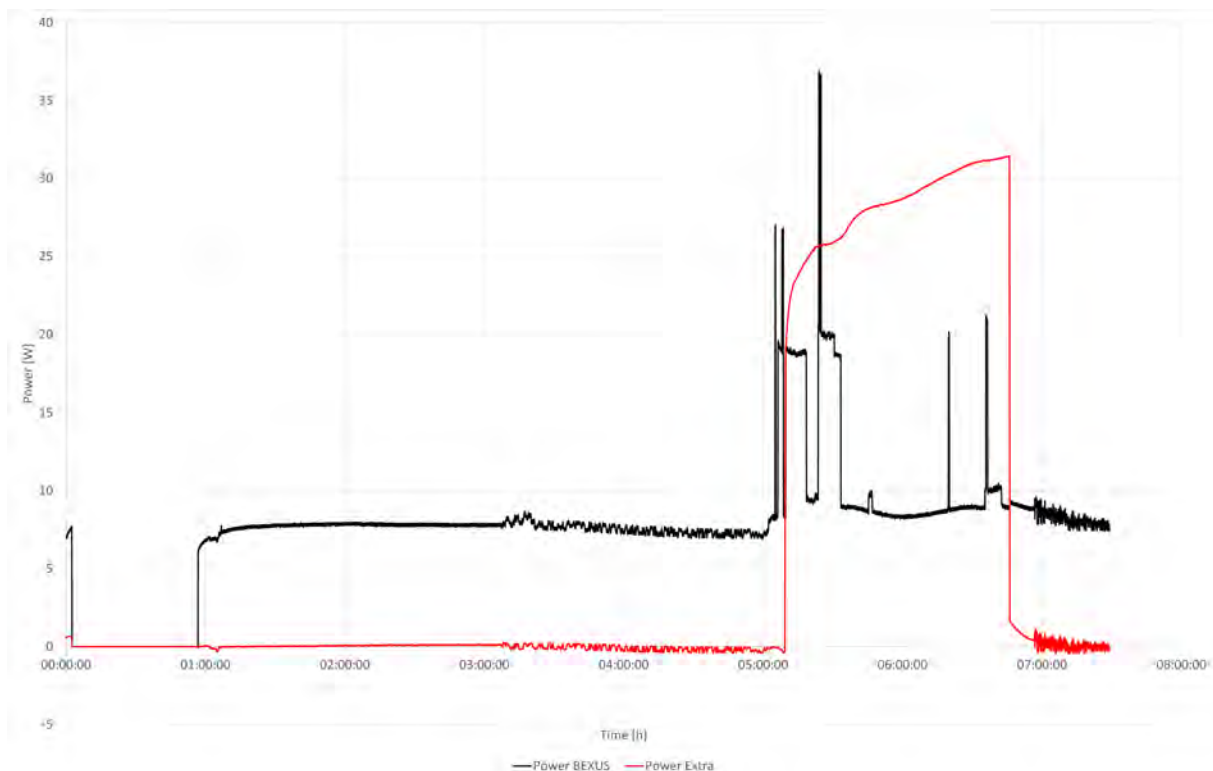


Fig. 7.12: Power profile

7.6 Failure and Malfunctions

The malfunctions that did and did not affect the performance of the experiment are listed in this chapter.

7.6.1 Video-decoder

As described in chapter 7.3, the video decoder was damaged during transport. The decoder is used to translate the analog video signal of the cameras into a digital signal. The damage did not affect the performance of the experiment, as it still was partly working. The quality was good enough to check the deployment process. The video footage was additionally saved without fault on an sd-card for later review.



Fig. 7.13: Working

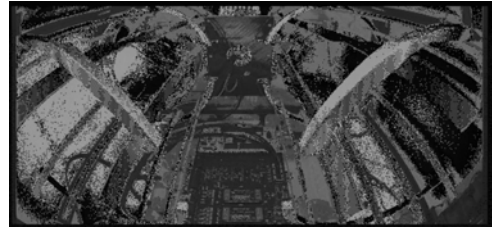


Fig. 7.14: Damaged

7.6.2 Battery-pack

To power the UV-leds, a external battery-pack was used. The battery-pack consisted of 6 SAFT LSH-20 batteries that were soldered in series. All batteries were checked before the soldering process started. After the soldering was finished two single batteries malfunctioned in the pack. The voltage of the single faulty cells read zero and high impedance was measured. This happened two times during the launch campaign preparation and one time during the thermal vacuum week. After changing the faulty batteries a working battery-pack could be produced. After consulting experts from ZARM and SSC a decisive error was not discovered. It was suspected that some cells were faulty.

7.6.3 Auto Inflation

The auto inflation worked on the principle of the differential pressure between the structures and the ambient pressure. A constant excess pressure of 100mbar should be maintained. But because the structures were not as air tight as in non vacuum conditions, the auto inflation used way to much of the tank pressure. Luckily this was detected fast enough and the structures were inflated manually.

7.6.4 Delamination of structures

The cause of the delamination could be tracked to a bug in the software. The microcontroller did reset during the automated inflation process. Consequently, all the valves returned to their initial states. This resulted in a sudden decrease in pressure inside of the structures, following delamination. The two figures below show the difference of one of the outer structures without delamination, and one of the inner structures with delamination. The delamination can mainly be noticed on the inner carrier foil, it only slightly affected the glass fibre. It wasn't detectable on the outside cover foil.

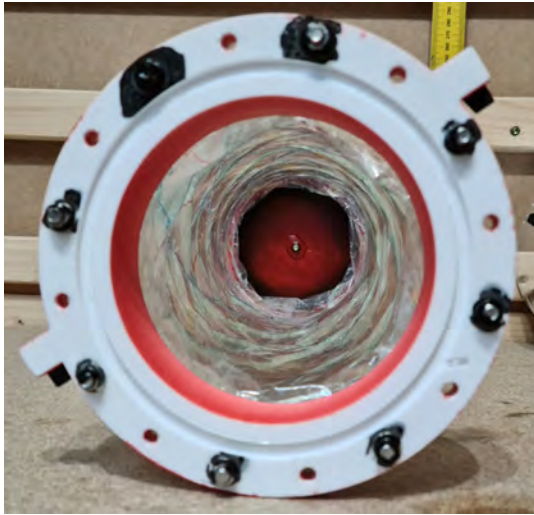


Fig. 7.15: Structure without delamination

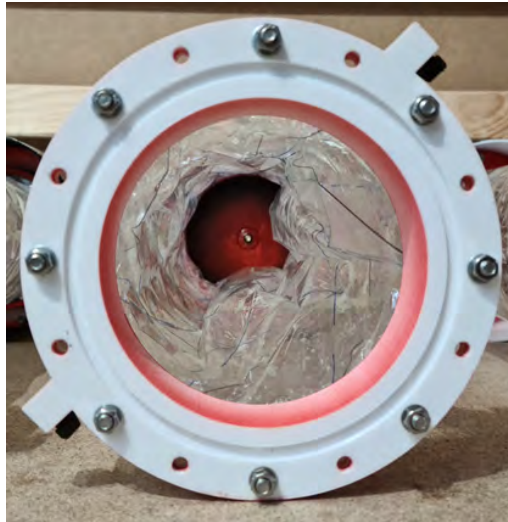


Fig. 7.16: Structure with delamination

7.7 Results

After the recovery, disassembly and inspection of the experiment, it can be stated that all primary and secondary Objectives, except for the thirist secondary objective were fully or partially successful. The MASS-experiment on BEXUS 31 proved that fiber-foil composite structures can be inflated to a predefined geometrical shape and cured through sunlight in high altitude conditions (27 km). It was also shown, that origami folding patterns are suitable for this application.

7.7.1 PO1: Cylindrical and conical shaped structures shall be efficiently folded

As mentioned in 4.6, the objective was partially fulfilled. Due to the pandemic situation, and therefore lack of team members, access to a workshop and time, only cylindrical structures were used in the final experiment. But prototyping proved, that conical shapes can also be implemented with minimal adjustments to the manufacturing process.

7.7.2 PO2: The structures shall be inflated during a stratospheric balloon flight

This Objective was successfully fulfilled. All 4 structures were deployed and inflated during flight as planned. The video recording showed that the inflation happened in a controlled manner, without colliding against each other or the experiment box. The figures below show footage from the cameras of the outer and inner box during inflation.



Fig. 7.17: Stored structures outside

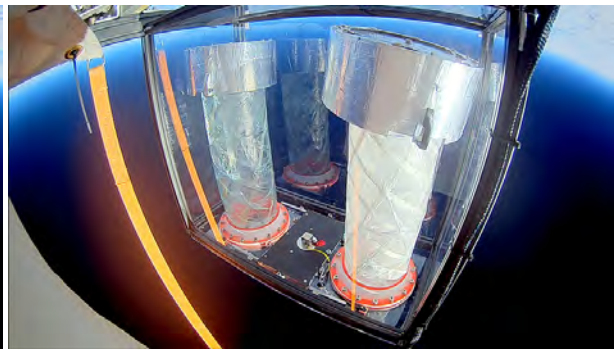


Fig. 7.18: Inflated structures outside



Fig. 7.19: Stored structures inside



Fig. 7.20: Inflated structures inside with UV LED's on

The video footage of in inflation can be accessed from this link: <https://www.youtube.com/watch?v=SgM9u3Y9wTc>

7.7.3 PO3: The inflated structures shall be rigidized once deployed

This Objective was successfully fulfilled, as all three resin impregnated structure were rigidized as planned. The disassembled structures are shown in figure 7.21.



Fig. 7.21: All 4 structures disassembled at the workshop

The two structures on the left are from the outside box, the other two were inflated in the inner box. The second one from the left is the control structure without resin which can be clearly identified through the different optical appearance. Figures 7.22, 7.23, 7.24 and 7.25 show the inside view of the structures. The cause of the delamination shown in figures 7.24 and 7.25 was described in section 7.6.4. The delamination did not affect the rigidization process.



Fig. 7.22: Structure 1 outside with resin

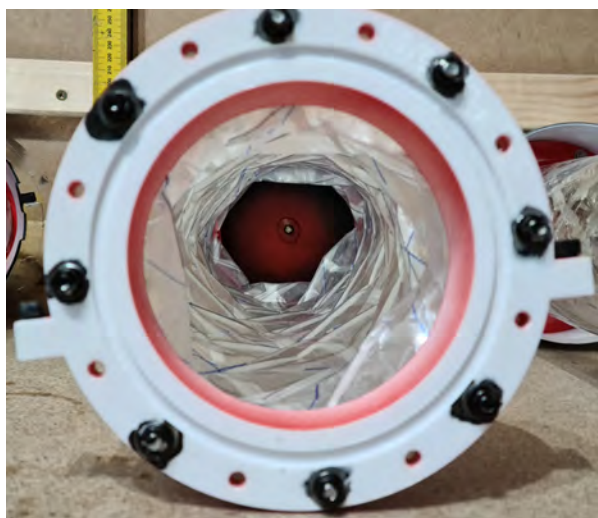


Fig. 7.23: Structure 2 outside without resin



Fig. 7.24: Structure 3 inside with resin and de-

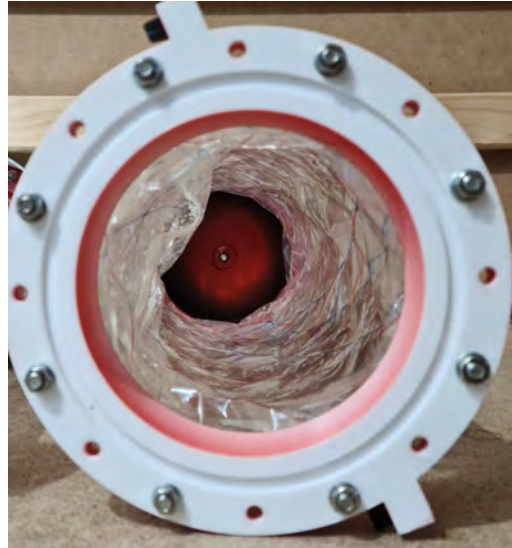


Fig. 7.25: Structure 4 inside with resin and de-

7.7.4 SO1: Fibres impregnated in a resin that cures when exposed to UV radiation shall be used as the rigidization method for the inflated structures

This objective was fulfilled, as the resin used for the experiment cured as planned during the float phase of the gondola.

7.7.5 SO2: The curing resin shall be exposed to naturally UV radiation provided by the sun and to artificial UV radiation by Light Emitting Diodes (LEDs)

This objective was fulfilled. Observation during flight, and examination after disassembly showed that the resin cured equally well both inside the inner experiment box with the LED's and in the outer box with natural UV-radiation due to sun light.

7.7.6 SO3: Different folding methods shall be applied to the structures and compared with each other with respect to: foldability, time of deployment, rigidizability

This objective was not fulfilled, since the experiment used the same folding method/pattern for all 4 structures. It was decided that only the twist buckling origami pattern is to be used, as it works best for cylinders. Additionally it has great flat folding properties and is fairly easy to manufacture.

7.8 Static load test

After the launch campaign, a static load test was performed to investigate the mechanical strength of the structures. Due to the previously described issue regarding delamination, only one perfectly inflated structure was cured during the experiment. Therefore, the quasi static load test was performed on one of the inner structures to preserve the only structure without defects.

The structure was put under an increasing load until failure using different steel weights found in the workshop. Permanent deformation occurred at a weight of 7.8 kg (76.6N), as the rigidized fibres broke. To ensure a more equally distributed force, a wooden plate was put between the end of the structure and the weight's.

Figure 7.26 shows the setup of the load test. The strong deformation of the structure is clearly visible.



Fig. 7.26: Static load test

The test showed that the fibre-foil structures can take a significant load compared to their size and weight. Therefore their possible applications could not only include one of defining geometric shapes but also carrying loads. The mechanical strength can be increased by using different and more fibres.

7.9 Outlook

7.9.1 Improvement of experiment and recommendations

The sealing rings for the inflatable structures are one aspect that would improve the performance of the experiment. As the pressure diagrams show earlier in this chapter the pressure loss after inflating the structures is quite dramatic. Reducing that pressure loss increases the safety margin of the dry nitrogen reserve and helps in achieving a cylindrical shape.

The HDRM went through many iterations and worked reliably in the flight model, but is unnecessarily complicated and susceptible for faults. Designing a simpler and more reliable HDRM for easier arming of the structures and more reliable release is recommended.

Accessibility of the experiment is the biggest topic that needs improvement. The umbilical that connected both boxes should be detachable for easier transportation. Having enough space to mount structures and reach important areas of the experiment with tools would improve handling and allow for easier maintenance.

7.9.2 Planned presentations and publications

Publications: The team submitted an abstract to the *25th ESA Symposium on European Rocket and Balloon Programmes and Related Research*. A scientific paper will be published in 2022 following the symposium.

Presentations: MASS held a presentation at AIRTEC 2021 in november in Munich. A presentation will also be held at the 25th ESA Symposium on European Rocket and Balloon Programmes and Related Research.

7.9.3 Conclusion

In summery, this document described the development, tests and subsequent successful flight of the MASS experiment. The experiment showed that origami folded, inflatable and rigidizable structures can be successfully used in high altitude conditions. As described in chapter 7.7, all of the important mission objectives were successfully executed. Over the course of the last two year all of the MASS team members learned so many new things that will benefit us greatly. We are truly grateful to have been part of the REXUS/BEXUS program. Additionally we want to thank the REXUS/BEXUS organizers for helping us every step of the way and making this experience possible.

7.10 Lessons Learned

7.10.1 General

- Documentation takes a lot of time.
- Communication can sometimes be difficult, say exactly what you mean.
- Always be truth full if you run into a problem.
- Communication with the supervisor can sometimes be tricky.
- Always backup your data
- The scheduling of appointments can be difficult, especially when living in different time zones.
- Needed Man Power is most of the underestimated during planning
- Communication is the key to a successful collaboration.
- Sticking to agreed deadlines prevents too much time from being wasted.
- Even if a larger number of team members makes organization more difficult, the necessary creative input is still increased.
- Bring spare components for everything.
- Building Prototypes as soon as possible shows design faults in an early stage.
- Testing after every major modification of a system is very important to identify problems clearly.
- Keeping notes of made changes and reasons for them made.

7.10.2 Electronics

- Always double check your hardware order.
- Always check the availability of hardware.
- Hardware could be sold out in the future.
- It's often easier to build a breadboard prototype, instead of only reading datasheets.
- Check voltage of hardware, not every component needs 3,3V.
- You shouldn't run high amounts of Power on 0,2mm Traces.
- SMD parts can be soldered without an expensive reflow oven.
- Once you've overcome the first hurdle, electronics is actually fun.
- Always double check the power consumption.
- You should avoid small SMD components.

7.10.3 Software

- Software libraries can simplify a lot of things and save time.
- Software libraries can contain errors.
- Exception handling is very important.
- Error solving can take a lot of time, especially with small errors.
- It's often easier to create a theoretical software model first, instead of jumping straight into coding.
- You are not the first person that encountered a specific problem, there are online bulletin boards (stackoverflow) that often provide solutions.
- The revert function in GitHub is extremely useful.
- Use comments to explain software functions, this helps when you come back to this part of the code a month later.
- Working with a new system (e.g. microcontroller) is time consuming.

7.10.4 Project Management

- Project Management is a full-time job, one person should be responsible for just that.
- Regularly scheduled meetings are very important to keep the team members engaged.
- Have enough time for delays in your schedule.
- Keep track of exactly how much budget is left.
- Check in with team members if they get their work done in time, or if they need help.
- Develop an outreach-plan and stick to it.
- Assign team members to outreach activities, and talk about planned activities.
- Don't underestimate the number of active team members needed.

7.10.5 Mechanical

- The stiffness of mechanical parts is often the most critical characteristic
- Checking for sufficient clearance for mounting during designing the mechanical layout is important, especially providing enough space for needed tools e.g. pliers or drivers
- Ground support equipment can often ease the mounting process significantly (e.g. for pre-loading the HDRM)
- Ground support equipment can often ease the manufacturing process significantly, so it is beneficial to invest enough time in developing them
- Inflating an undefined structure is not possible
- 3d printed floor and top panels are stable and consistent
- When using 3d printed parts, it is essential to keep track of the process parameters and materials to suit the application

- post-processing of the 3d structure necessary
- Post-processing of the 3d-printed structure are necessary when sealing parts are made due to manufacturing imperfections
- Mylar foil is easily static loaded, which makes folding difficult
- assembling the foil with 3d structure not so easy
- Low stiffness components need a lot of testing to function reliably.
- Not increasing weight during development is difficult.
- Inflatable UV-cured resin-fibre structures are stiff structures.

7.10.6 Simulation

- Simulation requires experience
- It is difficult to set the boundary conditions
- screws or washers cause strong peaks of tension

7.10.7 Thermal

- Beside the computation, simulations can provide a first point of reference for a plausibility check.
- Insulation's which are built up in layers result in a lower heat flow and thus heat loss (onion principle). Furthermore, thermal bridges can be minimized.
- A calculation based on the assumption of a one-dimensional heat flow only represents the reality to a limited extent and thus only provides limited target-oriented results.

8 ABBREVIATIONS AND REFERENCES

8.1 Abbreviations

AIT	Assembly, Integration and Test
asap	as soon as possible
CAD	Computer Aided Design
CDR	Critical Design Review
CGG	Cold Gas Generator
COG	Centre of Gravity
CRP	Campaign Requirement Plan
DLR	Deutsches Zentrum für Luft- und Raumfahrt
EAT	Experiment Acceptance Test
EAR	Experiment Acceptance Review
ECTS	European Credit Transfer System
EIT	Electrical Interface Test
EPM	Espace Project Manager
ESA	European Space Agency
Espace	Espace Space Center
ESTEC	European Space Research and Technology Centre, ESA (NL)
ESW	Experiment Selection Workshop
FAR	Flight Acceptance Review
FDM	Fused Deposition Modeling
FST	Flight Simulation Test
FRP	Flight Requirement Plan
FRR	Flight Readiness Review
GSE	Ground Support Equipment
HDRM	Hold Down and Release Mechanism
HK	House Keeping
H/W	Hardware
ICD	Interface Control Document
I/F	Interface
IPR	Integration Progress Review
LO	Lift Off
LT	Local Time
LOS	Line of Sight
mC	microcontroller
Mbps	Mega Bits per second
MFH	Mission Flight Handbook
MORABA	Mobile Raketen Basis (DLR, EuroLaunch)
OP	Oberpfaffenhofen, DLR Center
PCB	Printed Circuit Board (electronic card)
PDR	Preliminary Design Review
PST	Payload System Test
PT	Pressure Tank
RBF	Remove Before Flight
SED	Student Experiment Documentation
SNSA	Swedish National Space Agency
SODS	Start Of Data Storage
SOE	Start Of Experiment
SSC	Swedish Space Corporation
STW	Student Training Week

S/W	Software
T	Time before and after launch noted with + or -
TBC	To be confirmed
TBD	To be determined
WBS	Work Breakdown Structure
ZARM	Zentrum für Angewandte Raumfahrttechnologie und Mikrogravitation

8.2 References

References

- Hunt, G. W. and Ario, I. (2004). Twist buckling and the foldable cylinder: an exercise in origami. *International Journal of Non-Linear Mechanics*, 40(6):833–843.
- Ishida, S., Nojima, T., and Hagiwara, I. (2014). Mathematical approach to model foldable conical structures using conformal mapping. *Journal of mechanical design*, 136(9):091007.
- Liu, X., Yao, S., and Georgakopoulos, S. V. (2015). Reconfigurable origami equiangular conical spiral antenna. In *2015 IEEE International Symposium on Antennas and Propagation & USNC/URSI National Radio Science Meeting*, pages 2263–2264. IEEE.

Appendix A - Experiment Reviews

	REXUS/BEXUS Experiment Acceptance Review	Experiment Team:	MASS
		Vehicle and Flight number:	BEXUS31
Location: ZARM, Bremen		Date: 20th September 2021	
<div><div><div>Deutsches Zentrum für Luft- und Raumfahrt e.V. in der Helmholtz-Gemeinschaft</div></div><div><div>Rymdstyrelsen Swedish National Space Agency</div></div><div></div><div></div><div></div></div>			

Review Board Members:

Torsten Lutz (ZARM)

Experiment Team Members:

- Niklas Fromm
- Adrian Hettler

Summary of Main Actions for the Experiment Team:

1. Provide checklist for flight preparation and post flight activities
2. Ensure correct and updated inputs in the Chapter 6 in SED
3. Prepare shipping (address, contact person, list of content) to and from ESRANGE

Address:

SSC
ESRANGE Space Center
c/o Armelle Frenea-Schmidt, Maria Snäll
phone: +46 730 879 144
SE-981 91 Jukkasjärvi
Sweden

4. GSP-Q: Please provide the Ground Safety Plan to SSC (Armelle Frenea-Schmidt). This document is important for defining the ground safety during the campaign. All inputs will be presented to the Safety board at Esrangle.
5. different spring sets are available for the campaign for use in the release mechanism.

Review Result: pass / conditional pass / fail

Next SED version 5 due 31st January 2020 (3months after launch campaign)

1 General

1.1 Presentation

Experiment and its function was presented during TV Test. –o.k.

1.2 SED (editorial)

No comments

	<h1>REXUS/BEXUS</h1> <h2>Experiment Acceptance Review</h2>	Experiment Team:	MASS
		Vehicle and Flight number:	BEXUS31
Location: ZARM, Bremen		Date: 20th September 2021	
<div><div><p>Deutsches Zentrum für Luft- und Raumfahrt e.V. in der Helmholtz-Gemeinschaft</p></div><div><p>Rymdstyrelsen Swedish National Space Agency</p></div><div></div><div></div><div></div></div>			

2 REQUIREMENTS AND CONSTRAINTS

3 PROJECT PLANNING

3.1 WBS

3.2 Schedule

3.3 Resources

3.4 Outreach

3.5 Risks

	REXUS/BEXUS Experiment Acceptance Review	Experiment Team:	MASS
		Vehicle and Flight number:	BEXUS31
Location: ZARM, Bremen		Date: 20th September 2021	
<div><div><div>Deutsches Zentrum für Luft- und Raumfahrt e.V. in der Helmholtz-Gemeinschaft</div></div><div><div>Rymdstyrelsen Swedish National Space Agency</div></div><div></div><div></div><div></div></div>			

4 EXPERIMENT

4.1 Mechanics

REMARK: Slide Nuts and M6 screws are used for mounting the inside box on gondola rails. Square clamps for the outside box. –o.k.

4.2 Electronics

REMARK: Electronics are extensively tested -o.k.

4.3 Thermal

REMARK: Thermal test has shown that heat pads must be used. Both inside and outside box. So that the resin does not freeze.

4.4 Software

REMARK: GS ok. some details are still to be improved –o.k.

REMARK: Spare Laptop for GS available –o.k.

REMARK: SW on flight model is finalized –o.k.

REMARK: Sw is resistant to disconnection. No data loss –o.k.

5 VERIFICATION AND TESTING

5.1 Verification Matrix

5.2 Testplan

- Longtime test over 12h – o.k
- Tightness test for pressure tanks. -o.k.
- Luftmengen test –o.k.
- Connection abort test finalized –o.k.
- Unter- Überspannungstest : 12V-35V

6 LAUNCH CAMPAIGN PREPARATION

REMARK: pressure vessel. Documents are held for the campaign.

REMARK: SED: revise chapter 6: late access needed for closing venting holes.

REMARK: Start using checklists for pre and post flight activities. Normally one person checks the list, another person does the task. Take photos during the process to make sure, you didn't forget anything.

REMARK: There will be a Flight Readiness Review the night before launch, where every team will present what they did to achieve flight readiness and what they still have to do before launch.

REMARK: The recovery team will need an instruction (printed on A5) with photos. This can be printed in Kiruna.

REMARK: After the flight there will be a post flight meeting, where each team will present their first results and further steps.

	REXUS/BEXUS Experiment Acceptance Review	Experiment Team:	MASS
		Vehicle and Flight number:	BEXUS31
Location: ZARM, Bremen		Date: 20th September 2021	
<div><div><div>Deutsches Zentrum für Luft- und Raumfahrt e.V. in der Helmholtz-Gemeinschaft</div></div><div><div>Rymdstyrelsen Swedish National Space Agency</div></div><div></div><div></div><div></div></div>			

7 Thermal-Vacuum-Test Campaign

1. Test day:

- Camera inner box becomes too hot.
- Temp of el components o.k.
- If experiment is started too late and without heat pads: resin frozen.
- Parameter confirmation: pressure in the tank completely sufficient.
- Spring sets for the release mechanism are not strong enough.

2. Tes day:

- Heat pads tested. working well.
- Baseplate mainly determines the temperature in the structure.
- Camera with copper heat pipe connected to thermal sink.

Mass: inside box: 16,3 kg
 outside box: 6,9 kg

Dimensions: inside box: L: 598mm W: 350mm H: 608mm without rails
 outside box: L: 506mm W: 245mm H: 465mm without rails

Mechanical interface:

- Fixation of setup onto the rails of the gondola with the help of slide nuts and M6x16 screws and washers.
- Rubber bumpers integrated into insulation cover –ok
- Square clamps for the outside box

Check thermal cover: ok

Electrical interfaces: LAN- (a-code) and power-plug ok

- 28V; 0.300 A when powered on –ok Max 1,56 A incl all valves.
- Communication – ok
- Power range tested: 12V..35V –ok
- Bandwith on LAN is tested: < 0,2 Kbyte/s. in the range of several minutes as much data rate as possible to download images from inflation (describe in chapter 6 SED).

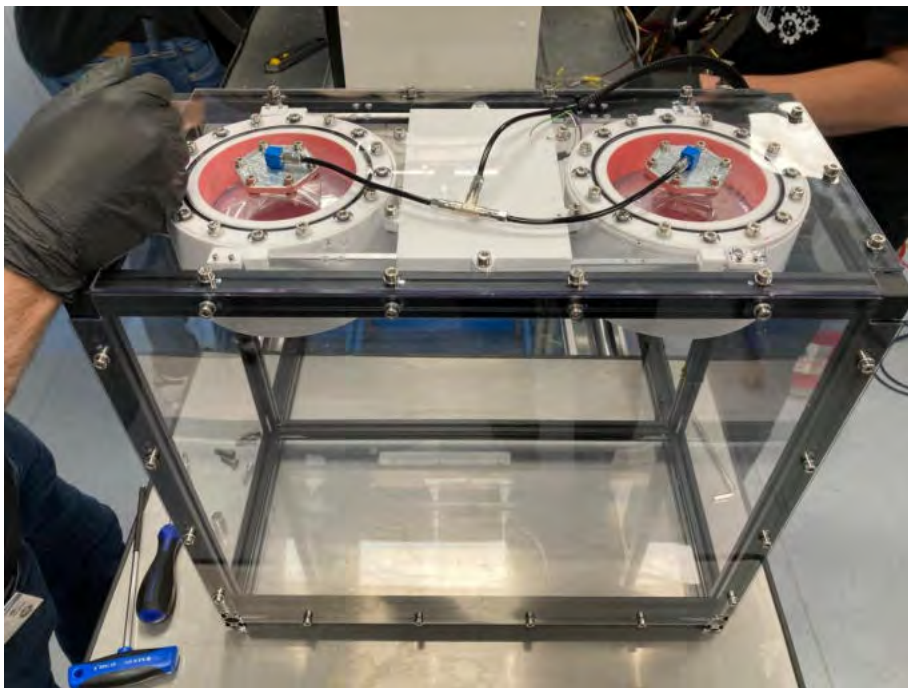
mages:

	REXUS/BEXUS Experiment Acceptance Review	Experiment Team:	MASS
		Vehicle and Flight number:	BEXUS31
Location: ZARM, Bremen		Date: 20th September 2021	
<div><div><p>Deutsches Zentrum für Luft- und Raumfahrt e.V. in der Helmholtz-Gemeinschaft</p></div><div><p>Rymdstyrelsen Swedish National Space Agency</p></div><div></div><div></div><div></div></div>			



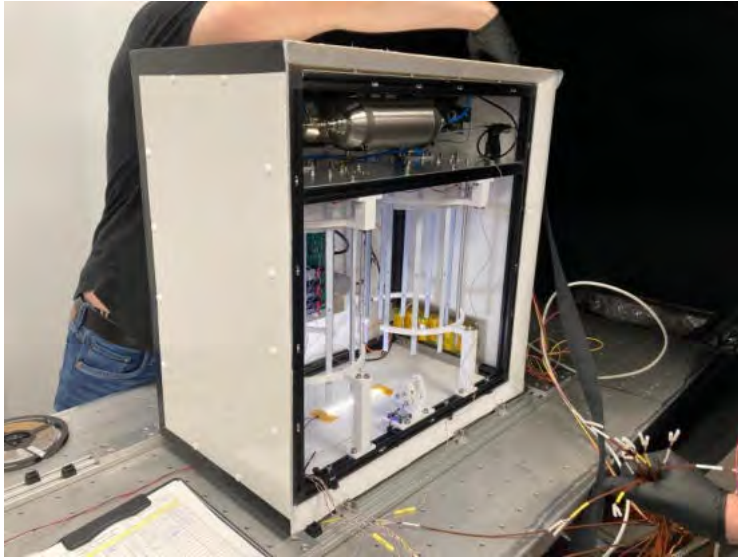
Team during integration of the experiment on the cold plate

Team during integration of the

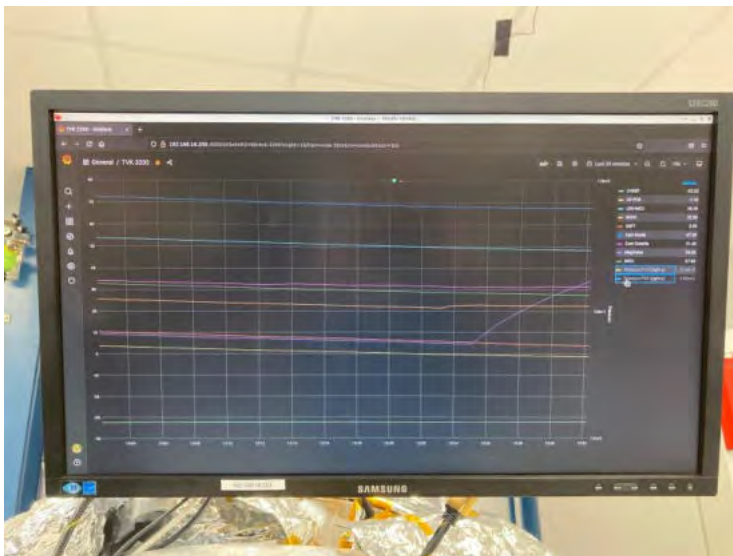


outer box

	REXUS/BEXUS Experiment Acceptance Review	Experiment Team:	MASS
		Vehicle and Flight number:	BEXUS31
Location: ZARM, Bremen		Date: 20th September 2021	
<div><div><p>Deutsches Zentrum für Luft- und Raumfahrt e.V. in der Helmholtz-Gemeinschaft</p></div><div><p>Rymdstyrelsen Swedish National Space Agency</p></div><div></div><div></div><div></div></div>			

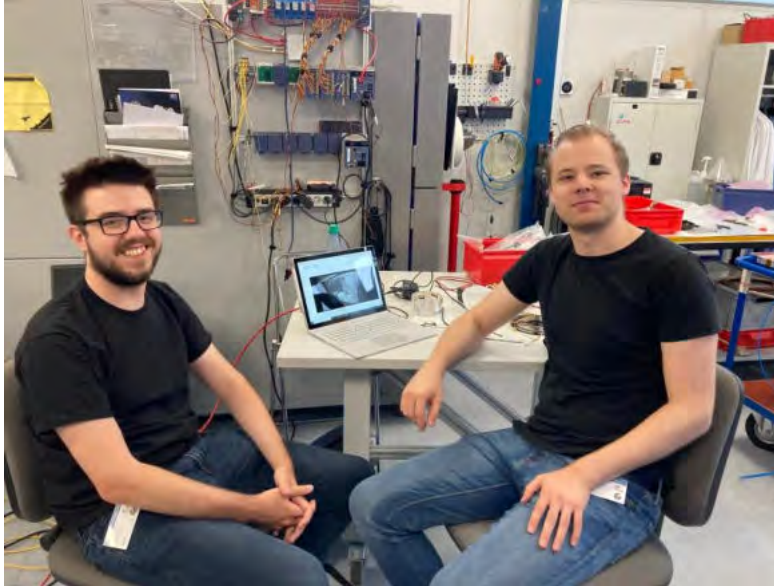


inner box



temperature lines during TV Test

	REXUS/BEXUS Experiment Acceptance Review	Experiment Team:	MASS
		Vehicle and Flight number:	BEXUS31
Location: ZARM, Bremen		Date: 20th September 2021	
<div><div><p>Deutsches Zentrum für Luft- und Raumfahrt e.V. in der Helmholtz-Gemeinschaft</p></div><div><p>Rymdstyrelsen Swedish National Space Agency</p></div><div></div><div></div><div></div></div>			



Team during TV Test

	REXUS/BEXUS Integration Progress Review	Experiment Team:	MASS
		Vehicle and Flight number:	BEXUS 31
Location: SSC ESRANGE		Date: 10Feb20	
<div><div><div>Deutsches Zentrum für Luft- und Raumfahrt e.V. in der Helmholtz-Gemeinschaft</div></div><div><div>Rymdstyrelsen Swedish National Space Agency</div></div><div></div><div></div><div></div></div>			

Review Board Members:

Dieter Bischoff (ZARM)
Simon Mawn (ZARM) chair
Michael Becker (DLR)
Katharina Schütttauf (MORABA)
Armelle Frenea-Schmidt (SSC)

Maria Snäll (SSC)
Kent Andersson (SSC)

Elisabeth Berka (ZARM)

Experiment Team Members:

Ludwig Staab (team leader)
Carlo Riester
Petros Karafyllis
Adrian Hettler

Summary of Main Actions for the Experiment Team:

1. Electronics: Implement interfaces for actors and sensors; Calculate the power distribution
2. Mechanical: Include interfaces to gondola; Design the pressure system
3. Provide a thermal design

Review Result: ~~pass~~ / conditional pass / fail

Next SED version 2 due 4th May 2020

Explanation of the Report:

In the following document the board member comments are sorted by the chapters of the SED beginning with SED chapter 2. Comments are divided into RIDS and Remarks:

- **RID** (Review Items Discrepancy) is the mechanism used to record questions or identified problems and solutions arising from examination of the review documentation and discussion. They are issues, identified by a reviewer, that are not compliant with a requirement, a review objective or a design goal. A red RID will be followed up during the next project steps by the organizers and must be fulfilled by the team in order to pass the review.
- **Remarks** contain considerations a team should make and recommendations from the board members

1 General

1.1 Presentation

REMARK: Good presentation, good transition to BEXUS

REMARK: First state briefly what your experiment wants to achieve

1.2 SED (editorial)

REMARK: Document approved by the team leader is not a good idea

RID: Version number and file name inconsistent on front page

RID: Document type: Spec -> SED

REMARK: Abstract very factual. Explaining why you are doing it could make it a little more interesting.

RID: Include an abstract in German as well

	REXUS/BEXUS Integration Progress Review	Experiment Team:	MASS
		Vehicle and Flight number:	BEXUS 31
Location: SSC ESRANGE		Date: 10Feb20	
<div><div><div>Deutsches Zentrum für Luft- und Raumfahrt e.V. in der Helmholtz-Gemeinschaft</div></div><div><div>Rymdstyrelsen Swedish National Space Agency</div></div><div></div><div></div><div></div></div>			

- REMARK: Mission statement and objectives are very clear. Mission statement could be expanded with some of the 'why?' (justification)
- REMARK: PO2 – instead of “near vacuum conditions” -> “on a stratospheric balloon flight)
- RID: Figures are not completely visible (e.g. Figure 3.3)
- RID: Section 4.2.3 and 4.2.4 can be deleted if not used
- RID: List of abbreviations: SNSB -> SNSA; SSC is missing
- RID: Mechanical design still leaves a lot of unanswered questions
- RID: Divide the scientific part from the subsystems (mechanical)
- RID: Thermal design not available
- REMARK: It is recommended to investigate previous work from RXXB teams (PICARD RX19, InTex (BX21), StrathSat-R7R2 (RX13/RX15), iSEDE (BX16))

2 REQUIREMENTS AND CONSTRAINTS

- RID: Functional requirement – need to be worked on;
Main function: deployment and rigidizing as top-level function is missing
- REMARK: Shape alteration mentioned for the first time in functional requirement
- RID: Specify “communication to balloon”
- RID: FR_02 – Wording: “Sensors cannot record data.” Better: “The setup shall measure the temperature” or “The setup shall measure the pressure.”
- RID: FR_03 – Design req.
- RID: FR_04 – Design req.; Instead: “Setup shall regulate the working pressure.” – as functional req.; define properly
- RID: FR_06 – Specify/Think about wording
- RID: FR_07 – Is not a useful requirement nor a function.
- REMARK: Performance req. – might need more, most are good
- RID: PR_03 – Design req., shall be split up into multiple requirements
- RID: PR_04 – Expand the lowest temperature down to -60°C
- RID: PR_05 – Why did you choose such a bad accuracy?
- RID: PR_06 – Wording – “down to” instead of “up” to 750Pa.
- RID: PR_08 – Which part of the inflatable structure?
- RID: PR_10 – Not a useful requirement (strong enough for what?) – The system should any way use the E-Link connection.
- RID: DR_01 – Duplicate of PR_03
- REMARK: DR_04: Just consider that the BEXUS launch is unguided. So, the duration of how long a setup will face to the sun directly is unknown.
- RID: Design requirements – Add: “The setup shall be designed to work within the pressure profile of BEXUS.” Also include requirements for operation/survivability of mechanical environment.
- RID: OR_01 – You should use the E-Link. It will not be stable until landing but should be stable until cut-off and then very often to +/- 2 km altitude (line of site).
- RID: OR_02 – What is a critical component and what will be reported about it?
- RID: OR_08 – Design req.
- RID: C2 – not a constraint

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3 PROJECT PLANNING

3.1 WBS

RID: Please assign a responsible team member to all work packages (WP). This way you won't forget a WP.

RID: Include post flight activities and electrical fabrication (ordering PCBs, etc.).

3.2 Schedule

REMARK: Reasonable Gantt chart based on WBS. But it is not very conservative. Project planning must be realistic, therefore put a buffer in each task (e.g. testing).

RID: Important events are missing (CDR, IPR, etc.); Schedule until SED v5.

3.3 Resources

RID: Manpower nicely displayed. Provide an easy comparison to the schedule.

RID: Budget – Financial support from DLR/ZARM. Provide information what is sponsored.

REMARK: Think of travel costs, also for additional (non-sponsored) students.

REMARK: High value critical item (X-winder filament winding machine) – assume this is not to be flown? What happens if it's damaged or delayed?

3.4 Outreach

REMARK: Webpage – Good first start; Facebook – Empty (no posts so far; until 29th Jan.). Implement an outreach plan, including social and traditional media.

RID: Name all sponsors on your website. Follow the outreach guidelines found on the team site (with regards to using organiser's logos).

REMARK: Logo still contains a rocket -> perhaps adapt it

3.5 Risks

REMARK: Delete general comments from the template

RID: Risk always include a cause and consequences (e.g. missing in TC50 "critical component fails" – very general, therefore finding a specific mitigation is impossible. By the way: The action will not help in case of a systematic failure)

REMARK: A lot of risks with a severity of 5, which is very unlikely for most. Except for SF40, which is only a 3.

RID: Missing risks: inflation not working, structures leaking, operation (launch time), management (budget, schedule), box rips off during lift off, etc.

RID: TC70 – Probability too low, severity too high

RID: TC80 – Other action necessary -> tolerances

RID: MS20 – Severity is not 5; Action should be a good thermal design including thorough testing.

RID: MS30 – Severity is not 5; Action – first correct choice of suitable components.

RID: PE 10 – so far it means: "very likely to occur and has a huge impact on BEXUS program, damage to the vehicle or injury to the personnel"

RID: Sf10 – better actions can be found (e.g. breathing protection, skin protection)

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4 EXPERIMENT

4.1 Mechanics

RID: Interface – The attachment of the structure to the gondola is not optimal concerning stiffness and vibration issues. Consider separating the two boxes and explain how you can fixate them to the gondola.

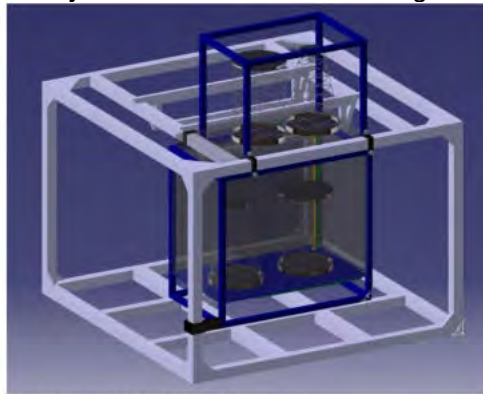


Figure 4.2: Gondola with frame and structures.

REMARK: Good that you deliver many 3d views and images which explains a lot

RID: Choose the resin asap – early thorough testing (curing process dependant on flux; consider using LEDs)

RID: Specify important details:

- What is the expected pressure you need for the inflation of all four folded structures?
- What is the calculated amount of gas needed? What kind of gas is required – Air, N₂?
- What is the preferred gas source (pressurized bottle or gas generator)? What is the type and performance of the gas source?
- What about requirements regarding the tubing? Could they be flexible plastic tubes, or do they have to be built out of steel?
- What about connections between pressure reservoir, valves, and structures?
- How will the gas inlet into the structures look like? Describe refill and filtering.
- How will the gas flow be regulated/measured (orifice or flow regulator)?
- How will the structures be sealed and what is the value of acceptable leakage?
- Is there any safety valve to prevent overpressure?
- Is there any possibility for refilling the pressure after tests and before launch?
- Is there any particle filter in the system foreseen to prevent malfunctions of valves and nozzles?
- How are the components fixated inside the main structure?
- What material will be used for the main structure (strut profiles or others)?
- What sensors/cameras are you going to use and how and where will they be implemented?
- Apart from the pressure reservoir there will not be any airtight housing?
- What is the type of pin puller (page 23, figure 4.1) and what will it be used for? Generally, if there are moving parts you need to describe their activities during launch.
- Provide details about the mockup LED arrangement.

REMARK: The experiment mass will be around 12 kg so the rack structure must be able to carry the loads during launch (Transport by HERCULES: Expect 5g₀ in z-axis; Parachute opening: 5g₀ in xy-axis and about 10g₀ in z-axis).

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REMARK: Good manufacturer for pneumatics is Festo
<https://www.festo.com/>)

REMARK: What kind of UV radiation is needed for hardening the resin? What wavelength?
Plan to measure flux in- and outside to be able to compare.

4.2 Electronics

REMARK: A lot is missing in the electronics chapter. It needs a lot of work.

RID: Include block diagrams and schematics.

RID: Where are the electronic interfaces located? How do you connect the microcontroller to the sensors, LED or valves?

REMARK: Refrain from using a fuse. They often only add another source of error.

REMARK: Recommendations for cameras – RunCam, independent cameras

RID: According to your power budget, an additional battery is not necessary.
Recalculate to be sure.

4.3 Thermal

REMARK: Good that you made a first definition of a wanted temperature range to keep.
Where does the range of 0°C to +40°C come from?

RID: You are going to implement a PUR insulation with a thickness of 50mm. Why?
Where is a first basic calculation to confirm that thickness? Maybe you won't need as much.

RID: How will the thermal cover out of PUR be attached to the structure? And how will feedthroughs (for the clamps) be realised?

RID: Where is a first list of components and their temperature working ranges?

RID: You are going to heat the setup with sodium acetate trihydrate (SAT). What amount are you going to implement and what temperatures will be reached with this action?

RID: Different from the description in the SED you cannot regulate the temperature with SAT during flight – furthermore you just can set a more comfortable offset of inner temperature at beginning of the launch by this action.

REMARK: The activation of SAT in late access needs to be tested before, because the substance needs oxygen from the surrounding air to start the heating process and this could take a while depending on the effective surfaces in contact with surrounding O₂ of the atmosphere.

RID: The upper both structures will need UV radiation directly from the sun for the hardening process. How are they heated/housed finally? What about a thermal cover built out of acryl glass? This material is highly permeable for UV wavelength from 250nm on and 92% permeable for IR.

RID: Where is a consideration about how to use/distribute the electrical heat dissipation of around 25W?

4.4 Software

REMARK: Inflation process – using pressure sensor information is a good idea, maybe also consider getting a feedback to the process (“structure is inflated”)

RID: Process flow is very general (e.g. Ground station (GS), sensor data, loops and sequences) -> Consider all parts and connect them, then think about how to implement them.

REMARK: Safety should be the lowest priority. Prioritize functionality.

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REMARK: You will lose communication after cut-down. There should be a possibility to turn the experiment off manually. Maybe have a fallback routine (autonomously).

5 VERIFICATION AND TESTING

5.1 Verification Matrix

RID: Subsystem testing is good, but lack of full system and environmental testing

RID: Inspection is often misused (e.g. You can inspect whether the window is clean but not if the sensor can measure $\pm 40^{\circ}\text{C}$)

5.2 Test Plan, Verification Plan

REMARK: Well done

REMARK: Low pressure test could be performed during thermal vacuum test week at ZARM in Bremen.

6 LAUNCH CAMPAIGN PREPARATION

RID: Ensure that inputs in chapter 6 are the same as in the chapters before. Closer to campaign any info from chapter 6 will be used for preparing the CRP (Campaign Requirements Plan). So far there are different inputs regarding the power consumption (17W in chapter 6 vs. 25 W + something in Chapter 4.7).

REMARK: The camera footage from the top container may not be used if pictures of the antenna are included. Needs to be checked after the flight.

RID: Safety risks – pressure container (include pressure, qualification, etc.); resin (chemical risk)

RID: Safety risk: Every component fixated outside of the gondola needs to be secured with an additional safety line which could be a steel cable or a flexible rope (like Dyneema). Therefore you need to provide fixation spot(s) like eyelets or drillings.

RID: State how much nitrogen will be needed

REMARK: Flight requirements – Flight is only guaranteed for an hour. Define exactly what your experiment requires. If you state you require a flight at noon, the launch window decreases. Include a minimum and maximum requirement.

REMARK: Late access – you need a good reason for a late access. Define the maximum time before lift-off that you can work with. Maybe pressurisation can be done before the countdown.

RID: Go more into detail in chapter 6.2 and 6.3. Concentrate on your own tasks and not on the vehicle.

REMARK: Post-flight activities suggest you want to investigate the inflatables after flight – how do you guarantee they are not damaged on landing or recovery? Is a quick or dedicated recovery required?

RID: Include a data analysis plan.

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Review Board Members:

Dieter Bischoff (ZARM)
Simon Mawn (ZARM) chair
Michael Becker (DLR)
Katharina Schütttauf (MORABA)
Armelle Frenea-Schmidt (SSC)
Maria Snäll (SSC)

Giorgio Parzianello (ESA)
Koen DeBeule (ESA)
Paolo Concari (ESA)

Elisabeth Berka (ZARM, minutes)

Experiment Team Members:

Adrian Hettler
Nico Reichenbach

Niklas Fromm
Johannes Ernstberger

Summary of Main Actions for the Experiment Team:

1. Work on your mechanical design (accessibility, pressure system, support boom).
2. Decide on a resin and start testing.

Review Result: pass / conditional pass / fail

Next SED version 3 due to one week before IPR

Explanation of the Report:

In the following document the board member comments are sorted by the chapters of the SED beginning with SED chapter 2. Comments are divided into RIDS and Remarks:

- **RID** (Review Items Discrepancy) is the mechanism used to record questions or identified problems and solutions arising from examination of the review documentation and discussion. They are issues, identified by a reviewer, that are not compliant with a requirement, a review objective or a design goal. A red RID will be followed up during the next project steps by the organizers and must be fulfilled by the team in order to pass the review.
- **Remarks** contain considerations a team should make and recommendations from the board members

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1 General

1.1 Presentation

REMARK: Good presentation

1.2 SED (editorial)

REMARK: Document ID: "v2-0" not "v2"

REMARK: Missing footer

REMARK: Appendix bookmarks do not work

REMARK: Don't use a new numbering scheme for new document versions, because it is not possible to follow the changes.

REMARK: Block diagram in figure 5, p.14 needs arrows to indicate the relations/ functions.

REMARK: List of abbreviations – SNSB is SNSA (Agency instead of Board), SSC is missing.

REMARK: Include table "Mass and Dimensions" in chapter 6 instead of a link to chapter 4.3, because we will take the inputs from chapter 6 to generate the Campaign Requirement Plan (CRP).

REMARK: Try to use a comprehensive numbering scheme for the complete document (e.g. Chapter 4 – Table 4.1)

2 REQUIREMENTS AND CONSTRAINTS

REMARK: Good rework of this section, but please keep the numbering scheme next time and mark changes and continue to work on this chapter.

REMARK: Some classifications mistakes (compare PR3 with DR1-4)

REMARK: Several functional requirements are missing/combined.

RID: FR_01 – combination of several functions with different verification methods (secure storage, deployment, rigidization)

REMARK: FR_02 – correct

RID: FR_03 – Split into temperature & pressure requirement

RID: FR_04 – obvious, delete; or specify "final form" with accuracy in different axes (if you care) -> Right now PR_07 is the only requirement specifying it

RID: FR_06 – not a function (function is everything your experiment is going to do, this basically just good engineering)

REMARK: Performance requirements are good, but you are missing some measurement frequencies or intervals.

REMARK: PR_08 – Make sure that your requirements are consistent.

RID: Design requirements – you are missing the general vehicle compliances:

- Environment (temperature, pressure, vibration, shock).
- Interface properties (footprint, weight, voltage, peak current, power, data rate)
- Interface physical (rails, bolts, power connector, data connector)

RID: DR_07 – first time LED segments are mentioned -> shows that a function and corresponding performances are missing

REMARK: OR_02 – Make sure that the low frequency is enough since the inflation process is over after just 25 seconds.

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3 PROJECT PLANNING

3.1 WBS

REMARK: There have been no updates since PDR

3.2 Schedule

REMARK: Good workable Gantt chart, but not all work packages have been transferred from the WBS.

REMARK: Consider further refinement of the AITV stage, including predecessors & successors (interdependencies) and critical path mapping (especially useful when considering C19 delays).

REMARK: Consider adding a progress line (comparing progress vs. current date)

3.3 Resources

REMARK: Manpower – it could be helpful to compare available manpower with needed manpower to identify critical time periods and to adjust planning.

RID: Budget – include travel costs (rough estimations) especially for non-sponsored students

REMARK: DLR/ZARM doesn't sponsor money, it sponsors items

REMARK: Not including "Paid by" information on not yet ordered items can be risky.

3.4 Outreach

REMARK: Website has a good clean look and has an intuitive navigation

REMARK: Images/videos are better than huge text blocks to explain the experiment

RID: Include a link to the REXUS/BEXUS webpage & please update the ESA logo on your website.

RID: There have been no updates since December/January. Consider using a tool like Hootsuite to post across multiple social medias with one post.

REMARK: Facebook – complete the "about" section, less followers/likes than team member -> increase effort here

REMARK: Consider a long-term outreach plan, including visits, conferences and traditional media (newspapers, etc.)

3.5 Risks

REMARK: Only low risks which is untypical for the stage of your project. Consider project management risks like your PE10 (this one has already reduced, why? Is your SW on such a good way?)

REMARK: There are no changes in probability or severity since the PDR, why? Haven't you worked on your experiment and your risk elimination? (e.g. TC10)

RID: Cause of the risks are missing and therefore appropriate counter measures can't be found, e.g. TC80, MS40

RID: Make your countermeasures more detailed (e.g. "aim for keeping it as simple as possible")

RID: TC40 – Severity is quite low

RID: TC60 – low severity, but your mass is already on the edge -> reconsider

RID: PE10 – wrong category

RID: SF30 – please note your correct safety factor; specify the test (test number)

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RID: PDR comment not included "Missing risks: inflation not working, structures leaking, operation (launch time), management (budget, schedule), box rips off during lift off, etc."

RID: Risks regarding C19 missing, Management risks missing (no workshops, production problems, communication problems inside the team)

4 EXPERIMENT

4.1 Mechanics

REMARK: Interface to the gondola is well described.

RID: Access to the rubber bumpers is covered by the setup.

RID: Clamp (lower clamp) of the upper box is not optimal and shall be attached to the rail of the gondola to ensure form fit and to avoid interference with crash pad of the gondola. -> ask Dieter Bischoff from ZARM for advice

REMARK: Because of safety reasons any component, mounted outside the gondola, needs to be secured additionally with a safety line. Therefore, you already provided eyelets where we can attach the safety line – good.

REMARK: The implementation of the electronics/PCBs is missing. How and where will the components be fixated/supported inside?

REMARK: Where are the electrical interfaces (LAN, power plug) located? Ensure a good accessibility.

REMARK: How are the interfaces in between the both boxes realised? Is there a special cable protection required?

RID: The used pressure regulator is not suitable for vacuum usage. There is a certain pressure required for the regulation. You should ask the supplier of pneumatics for suitable components.

RID: Please do not use the shown plug-in connectors, because they are not suitable for usage in vacuum either. Better are the ones with screwed tube fixation.

RID: How do you control the pressure? Use safety valves/check valves for over pressure.

RID: Provide check valve and suitable feed through for filling/refill connection. Include a filtering system (best way in the filling device).

RID: The environmental pressure depends on the altitude and can vary in between 10 to 17hPa. The pressure system should be able to adjust/provide the required difference of 50 hPa for deployment activities.

REMARK: Consider accessibility for the connectors (power, E-Link) as they will be plugged and unplugged often.

RID: Think through refilling processes and how easy you can access critical parts of the experiment in case of leakage. Find a way where you don't have to disassemble and reassemble the complete experiment every time.

REMARK: Are the LEDs UV and visible? Can the cameras see inside the box?

RID: Provide further information on the release system using the pin puller as it could be a critical component.

RID: Be consistent with your mass (i.e. difference in presentation and SED)

REMARK: Is the plexiglass UV transparent?

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- REMARK: The current support boom for the upper box is interfering with the crash bed of the gondola. Is it a problem to move it to the other side/a couple of centimetres? There might also be interference with tension lines.
- REMARK: The bottom side of the boom is currently clamped. For a better force distribution try adding more surface by using a plate.
- REMARK: The long boom connected to a small clamping area will result in strong torque forces on the box section during landing. Consider adding controlled break points.
- REMARK: Consider stickiness of the used resin and how this might affect the unfolding procedure.

4.2 Electronics

- REMARK: 4.7 PWR System – MC, cameras and Pin puller PWR is in sum 28,8W (plus SD-card, RTC, sensors, video decoder). This is near the max PWR (*converter*) (30W) of the TRACO DCDC converter. Note the danger of the boot process when the voltage drops (maybe search for a different converter)
- REMARK: Detailed overview fig 5 and good experiment description (no superfluous text)
- REMARK: Don't be afraid of micro buttons and switches on board of electronics. They can only get activated if something pushes on them. Don't need replacement. Soldering them only harms board reliability.
- REMARK: Good overview fig 50 but GPIO is missing (Pin Puller, LEDs...)
- REMARK: The transport/shipping of batteries is quite difficult.
- REMARK: Try measuring the UV intensity of the LEDs for calibration. Come up with a method if there are no suitable sensors (e.g. UV reactive paper) or contact ZARM for help.
- RID: Test the I2C line already on breadboard level to check whether you are pushing too much load on the bus.

4.3 Thermal

- REMARK: Very detailed calculations and considerations. Very good chapter.
- REMARK: Please describe the attachment of the surrounding thermal cover. You need to avoid heat bridges and should ensure insulated feedthroughs of electronic interfaces as well.
- REMARK: What are the estimated temperatures inside the boxes? The cameras will need a certain temperature range.
- RID: How high is the heat dissipation of the LED panel? This needs to be tested.

4.4 Software

- REMARK: Nice using Github. But so far, its only GS software from February in your git-repo.
- REMARK: CONSIDER OPERATING YOUR EXPERIMENT MANUALLY! In case your sensor is wrong and opens your pullers accidentally its game over for your experiment! If you do it manually you have full control. In case of communication lost you can have a fall-back routine which operates the pullers.
- REMARK: If controlled in auto mode – How do you know about different stages (ascent, descent, flight phase, deployment start)? If you control these states manually,

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- please provide a command list. This list is also important for your team to know what's going on during experiment flight.
- REMARK: Rudimental modularisation of the needed tasks. No interfaces between modules described. How will you code with different programmers?
- RID: No implementation concept described so far. Single loop? Multithreading? How will you implement and how are the interaction between tasks?
- REMARK: No clear specification for sw. If you do not specify clear goals for your sw you will have a long phase implementing changes. Sometimes a wrong sw architecture can lead to not usable sw. Consider describing the process field and how the sw is embedded and specify clear requirements.
- REMARK: Data Acquisition – Please make considerations about the used file system on SD card. Prefer a journal file system if possible, in order to have a chance to rescue data in case of a file system failure.
- REMARK: Consider generating more than one file. Generating more files is more reliable in case of corruption.
- REMARK: Don't use SD cards with different types. Fly with SD types which you used for tests. Add the SD card status on a checklist.

5 VERIFICATION AND TESTING

5.1 Verification Matrix

- REMARK: Analysis are computer calculations and simulations. You sometimes use A wrongly, where it is not possible, e.g. OR_06, OR_07, OR_08.
- RID: FR_03 – at least tested
- RID: PR_07 – should also be tested on ground
- RID: OR_09 – Inspection impossible, or are you flying on the balloon as well?

5.2 Test Plan, Verification Plan

- REMARK: When using different models (flight and qualification), be aware of their differences and how you can compare test results.
- REMARK: The test descriptions are very general and need further refinement. Otherwise you might undertest without realising (e.g. Test 6, Test 7)
- REMARK: Test 10 and Test 13 are both thermal vacuum tests. One probably can be skipped because of the situation (restricted access to test facilities/labs etc).
- RID: Test 12: Drop test is too much and not suitable. Please do not destroy your experiment. We recommend a calculation/preparation of the deceleration distance/test pad first.
- RID: The pin puller mechanism should be tested thoroughly, also consider power chain and possibly mechanical differences/loads.
- REMARK: Pin puller operation may limit current to microcontroller (powerline) – what if the MC resets when the pin puller is actuated?
- REMARK: Recommendation – Also have a final verification of pin puller connection at the campaign (continuity test/inspection of connection and cabling).
- REMARK: Vibration testing in the launch configuration is recommended as the upper box will vibrate more.

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REMARK: Limitation of cold testing with convection vs. thermal vacuum testing – consider this and use analysis as a secondary verification for operation in low temperature.

REMARK: If you numbered your different analysis like the tests, you would notice that some are not possible

6 LAUNCH CAMPAIGN PREPARATION

RID: 6.1.1 – You have a high increase in mass since PDR. This should not increase any further. Include the “Dimensions and Mass” table.

REMARK: 6.1.2 Safety Risks – Your risk descriptions are very general. Be more precise!

RID: Bursting pressure container – write down the safety factor and add more actions (e.g. test).

REMARK: Include information about the used resin (data sheet, quantity needed, is there risk for staff etc.)

REMARK: Nitrogen usage must be declared in this chapter. Handling of the bottle is a safety risk.

REMARK: Safety line for the outer box needed which is already implemented in the design. Information needs to be included here as well.

REMARK: Include information about the batteries, also important for recovery.

REMARK: Filling the tank to 8 Bar needs to be supervised -> safety

REMARK: 6.1.3 Electrical Interfaces – Be prepared that bandwidth might be limited.

REMARK: 6.1.5 Flight Requirements – Do you require a specific sun angle? The sun will rise before 8 AM. If you only require sunlight during float, the balloon can launch earlier.

REMARK: 6.2 Preparation – The order is unclear. Include uplink commands.

RID: 6.3 Timeline CD & Flight – Describe your late access procedure (what are you doing? When? Who?) -> specify when is the latest you need to fill the tank before lift-off. This is also important in case of a delay due to weather changes.

REMARK: Add when you will measure and when you will stop measuring in your timeline.

REMARK: Tip: do RTC sync and SODS at least T-45min (better T-90min)

REMARK: 6.4 Recovery – Include a recovery procedure. Should the recovery team remove your samples/anything specific from your experiment before putting the gondola on the truck?

RID: You will need a photo permit for your outside camera.

REMARK: The balloon will probably be cut down after around 3-4 hours.

REMARK: Chapter 7 – No data analysis plan/post flight analysis; no lessons learned (i.e. trainings week?)

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Review Board Members:

Dieter Bischoff (ZARM)
Simon Mawn (ZARM) chair
Michael Becker (DLR)
Katharina Schütttauf (MORABA)
Armelle Frenea-Schmidt (SSC)

Maria Snäll (SSC)
Kent Andersson (SSC)
Elisabeth Berka (ZARM)

Experiment Team Members:

Ludwig Staab (team leader)
Carlo Riester
Petros Karafyllis
Adrian Hettler

Summary of Main Actions for the Experiment Team:

1. Electronics: Implement interfaces for actors and sensors; Calculate the power distribution
2. Mechanical: Include interfaces to gondola; Design the pressure system
3. Provide a thermal design

Review Result: ~~pass~~ / conditional pass / fail

Next SED version 2 due 4th May 2020

Explanation of the Report:

In the following document the board member comments are sorted by the chapters of the SED beginning with SED chapter 2. Comments are divided into RIDS and Remarks:

- **RID** (Review Items Discrepancy) is the mechanism used to record questions or identified problems and solutions arising from examination of the review documentation and discussion. They are issues, identified by a reviewer, that are not compliant with a requirement, a review objective or a design goal. A red RID will be followed up during the next project steps by the organizers and must be fulfilled by the team in order to pass the review.
- **Remarks** contain considerations a team should make and recommendations from the board members

1 General

1.1 Presentation

REMARK: Good presentation, good transition to BEXUS

REMARK: First state briefly what your experiment wants to achieve

1.2 SED (editorial)

REMARK: Document approved by the team leader is not a good idea

RID: Version number and file name inconsistent on front page

RID: Document type: Spec -> SED

REMARK: Abstract very factual. Explaining why you are doing it could make it a little more interesting.

RID: Include an abstract in German as well

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- REMARK: Mission statement and objectives are very clear. Mission statement could be expanded with some of the 'why?' (justification)
- REMARK: PO2 – instead of “near vacuum conditions” -> “on a stratospheric balloon flight)
- RID: Figures are not completely visible (e.g. Figure 3.3)
- RID: Section 4.2.3 and 4.2.4 can be deleted if not used
- RID: List of abbreviations: SNSB -> SNSA; SSC is missing
- RID: Mechanical design still leaves a lot of unanswered questions
- RID: Divide the scientific part from the subsystems (mechanical)
- RID: Thermal design not available
- REMARK: It is recommended to investigate previous work from RXXB teams (PICARD RX19, InTex (BX21), StrathSat-R7R2 (RX13/RX15), iSEDE (BX16))

2 REQUIREMENTS AND CONSTRAINTS

- RID: Functional requirement – need to be worked on;
Main function: deployment and rigidizing as top-level function is missing
- REMARK: Shape alteration mentioned for the first time in functional requirement
- RID: Specify “communication to balloon”
- RID: FR_02 – Wording: “Sensors cannot record data.” Better: “The setup shall measure the temperature” or “The setup shall measure the pressure.”
- RID: FR_03 – Design req.
- RID: FR_04 – Design req.; Instead: “Setup shall regulate the working pressure.” – as functional req.; define properly
- RID: FR_06 – Specify/Think about wording
- RID: FR_07 – Is not a useful requirement nor a function.
- REMARK: Performance req. – might need more, most are good
- RID: PR_03 – Design req., shall be split up into multiple requirements
- RID: PR_04 – Expand the lowest temperature down to -60°C
- RID: PR_05 – Why did you choose such a bad accuracy?
- RID: PR_06 – Wording – “down to” instead of “up” to 750Pa.
- RID: PR_08 – Which part of the inflatable structure?
- RID: PR_10 – Not a useful requirement (strong enough for what?) – The system should any way use the E-Link connection.
- RID: DR_01 – Duplicate of PR_03
- REMARK: DR_04: Just consider that the BEXUS launch is unguided. So, the duration of how long a setup will face to the sun directly is unknown.
- RID: Design requirements – Add: “The setup shall be designed to work within the pressure profile of BEXUS.” Also include requirements for operation/ survivability of mechanical environment.
- RID: OR_01 – You should use the E-Link. It will not be stable until landing but should be stable until cut-off and then very often to +/- 2 km altitude (line of site).
- RID: OR_02 – What is a critical component and what will be reported about it?
- RID: OR_08 – Design req.
- RID: C2 – not a constraint

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3 PROJECT PLANNING

3.1 WBS

RID: Please assign a responsible team member to all work packages (WP). This way you won't forget a WP.

RID: Include post flight activities and electrical fabrication (ordering PCBs, etc.).

3.2 Schedule

REMARK: Reasonable Gantt chart based on WBS. But it is not very conservative. Project planning must be realistic, therefore put a buffer in each task (e.g. testing).

RID: Important events are missing (CDR, IPR, etc.); Schedule until SED v5.

3.3 Resources

RID: Manpower nicely displayed. Provide an easy comparison to the schedule.

RID: Budget – Financial support from DLR/ZARM. Provide information what is sponsored.

REMARK: Think of travel costs, also for additional (non-sponsored) students.

REMARK: High value critical item (X-winder filament winding machine) – assume this is not to be flown? What happens if it's damaged or delayed?

3.4 Outreach

REMARK: Webpage – Good first start; Facebook – Empty (no posts so far; until 29th Jan.). Implement an outreach plan, including social and traditional media.

RID: Name all sponsors on your website. Follow the outreach guidelines found on the team site (with regards to using organiser's logos).

REMARK: Logo still contains a rocket -> perhaps adapt it

3.5 Risks

REMARK: Delete general comments from the template

RID: Risk always include a cause and consequences (e.g. missing in TC50 "critical component fails" – very general, therefore finding a specific mitigation is impossible. By the way: The action will not help in case of a systematic failure)

REMARK: A lot of risks with a severity of 5, which is very unlikely for most. Except for SF40, which is only a 3.

RID: Missing risks: inflation not working, structures leaking, operation (launch time), management (budget, schedule), box rips off during lift off, etc.

RID: TC70 – Probability too low, severity too high

RID: TC80 – Other action necessary -> tolerances

RID: MS20 – Severity is not 5; Action should be a good thermal design including thorough testing.

RID: MS30 – Severity is not 5; Action – first correct choice of suitable components.

RID: PE 10 – so far it means: "very likely to occur and has a huge impact on BEXUS program, damage to the vehicle or injury to the personnel"

RID: Sf10 – better actions can be found (e.g. breathing protection, skin protection)

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4 EXPERIMENT

4.1 Mechanics

RID: Interface – The attachment of the structure to the gondola is not optimal concerning stiffness and vibration issues. Consider separating the two boxes and explain how you can fixate them to the gondola.

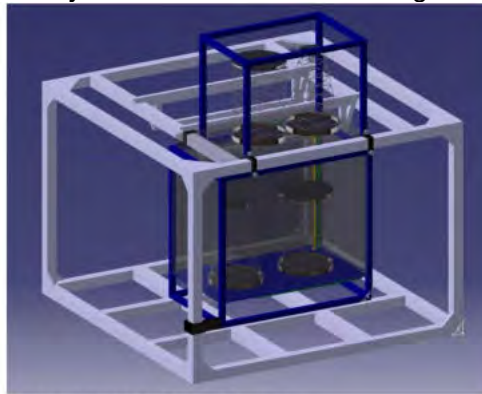


Figure 4.2: Gondola with frame and structures.

REMARK: Good that you deliver many 3d views and images which explains a lot

RID: Choose the resin asap – early thorough testing (curing process dependant on flux; consider using LEDs)

RID: Specify important details:

- What is the expected pressure you need for the inflation of all four folded structures?
- What is the calculated amount of gas needed? What kind of gas is required – Air, N₂?
- What is the preferred gas source (pressurized bottle or gas generator)? What is the type and performance of the gas source?
- What about requirements regarding the tubing? Could they be flexible plastic tubes, or do they have to be built out of steel?
- What about connections between pressure reservoir, valves, and structures?
- How will the gas inlet into the structures look like? Describe refill and filtering.
- How will the gas flow be regulated/measured (orifice or flow regulator)?
- How will the structures be sealed and what is the value of acceptable leakage?
- Is there any safety valve to prevent overpressure?
- Is there any possibility for refilling the pressure after tests and before launch?
- Is there any particle filter in the system foreseen to prevent malfunctions of valves and nozzles?
- How are the components fixated inside the main structure?
- What material will be used for the main structure (strut profiles or others)?
- What sensors/cameras are you going to use and how and where will they be implemented?
- Apart from the pressure reservoir there will not be any airtight housing?
- What is the type of pin puller (page 23, figure 4.1) and what will it be used for? Generally, if there are moving parts you need to describe their activities during launch.
- Provide details about the mockup LED arrangement.

REMARK: The experiment mass will be around 12 kg so the rack structure must be able to carry the loads during launch (Transport by HERCULES: Expect 5g₀ in z-axis; Parachute opening: 5g₀ in xy-axis and about 10g₀ in z-axis).

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REMARK: Good manufacturer for pneumatics is Festo
<https://www.festo.com/>)

REMARK: What kind of UV radiation is needed for hardening the resin? What wavelength?
Plan to measure flux in- and outside to be able to compare.

4.2 Electronics

REMARK: A lot is missing in the electronics chapter. It needs a lot of work.

RID: Include block diagrams and schematics.

RID: Where are the electronic interfaces located? How do you connect the microcontroller to the sensors, LED or valves?

REMARK: Refrain from using a fuse. They often only add another source of error.

REMARK: Recommendations for cameras – RunCam, independent cameras

RID: According to your power budget, an additional battery is not necessary.
Recalculate to be sure.

4.3 Thermal

REMARK: Good that you made a first definition of a wanted temperature range to keep.
Where does the range of 0°C to +40°C come from?

RID: You are going to implement a PUR insulation with a thickness of 50mm. Why?
Where is a first basic calculation to confirm that thickness? Maybe you won't need as much.

RID: How will the thermal cover out of PUR be attached to the structure? And how will feedthroughs (for the clamps) be realised?

RID: Where is a first list of components and their temperature working ranges?

RID: You are going to heat the setup with sodium acetate trihydrate (SAT). What amount are you going to implement and what temperatures will be reached with this action?

RID: Different from the description in the SED you cannot regulate the temperature with SAT during flight – furthermore you just can set a more comfortable offset of inner temperature at beginning of the launch by this action.

REMARK: The activation of SAT in late access needs to be tested before, because the substance needs oxygen from the surrounding air to start the heating process and this could take a while depending on the effective surfaces in contact with surrounding O₂ of the atmosphere.

RID: The upper both structures will need UV radiation directly from the sun for the hardening process. How are they heated/housed finally? What about a thermal cover built out of acryl glass? This material is highly permeable for UV wavelength from 250nm on and 92% permeable for IR.

RID: Where is a consideration about how to use/distribute the electrical heat dissipation of around 25W?

4.4 Software

REMARK: Inflation process – using pressure sensor information is a good idea, maybe also consider getting a feedback to the process (“structure is inflated”)

RID: Process flow is very general (e.g. Ground station (GS), sensor data, loops and sequences) -> Consider all parts and connect them, then think about how to implement them.

REMARK: Safety should be the lowest priority. Prioritize functionality.

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REMARK: You will lose communication after cut-down. There should be a possibility to turn the experiment off manually. Maybe have a fallback routine (autonomously).

5 VERIFICATION AND TESTING

5.1 Verification Matrix

RID: Subsystem testing is good, but lack of full system and environmental testing

RID: Inspection is often misused (e.g. You can inspect whether the window is clean but not if the sensor can measure $\pm 40^{\circ}\text{C}$)

5.2 Test Plan, Verification Plan

REMARK: Well done

REMARK: Low pressure test could be performed during thermal vacuum test week at ZARM in Bremen.

6 LAUNCH CAMPAIGN PREPARATION

RID: Ensure that inputs in chapter 6 are the same as in the chapters before. Closer to campaign any info from chapter 6 will be used for preparing the CRP (Campaign Requirements Plan). So far there are different inputs regarding the power consumption (17W in chapter 6 vs. 25 W + something in Chapter 4.7).

REMARK: The camera footage from the top container may not be used if pictures of the antenna are included. Needs to be checked after the flight.

RID: Safety risks – pressure container (include pressure, qualification, etc.); resin (chemical risk)

RID: Safety risk: Every component fixated outside of the gondola needs to be secured with an additional safety line which could be a steel cable or a flexible rope (like Dyneema). Therefore you need to provide fixation spot(s) like eyelets or drillings.

RID: State how much nitrogen will be needed

REMARK: Flight requirements – Flight is only guaranteed for an hour. Define exactly what your experiment requires. If you state you require a flight at noon, the launch window decreases. Include a minimum and maximum requirement.

REMARK: Late access – you need a good reason for a late access. Define the maximum time before lift-off that you can work with. Maybe pressurisation can be done before the countdown.

RID: Go more into detail in chapter 6.2 and 6.3. Concentrate on your own tasks and not on the vehicle.

REMARK: Post-flight activities suggest you want to investigate the inflatables after flight – how do you guarantee they are not damaged on landing or recovery? Is a quick or dedicated recovery required?

RID: Include a data analysis plan.

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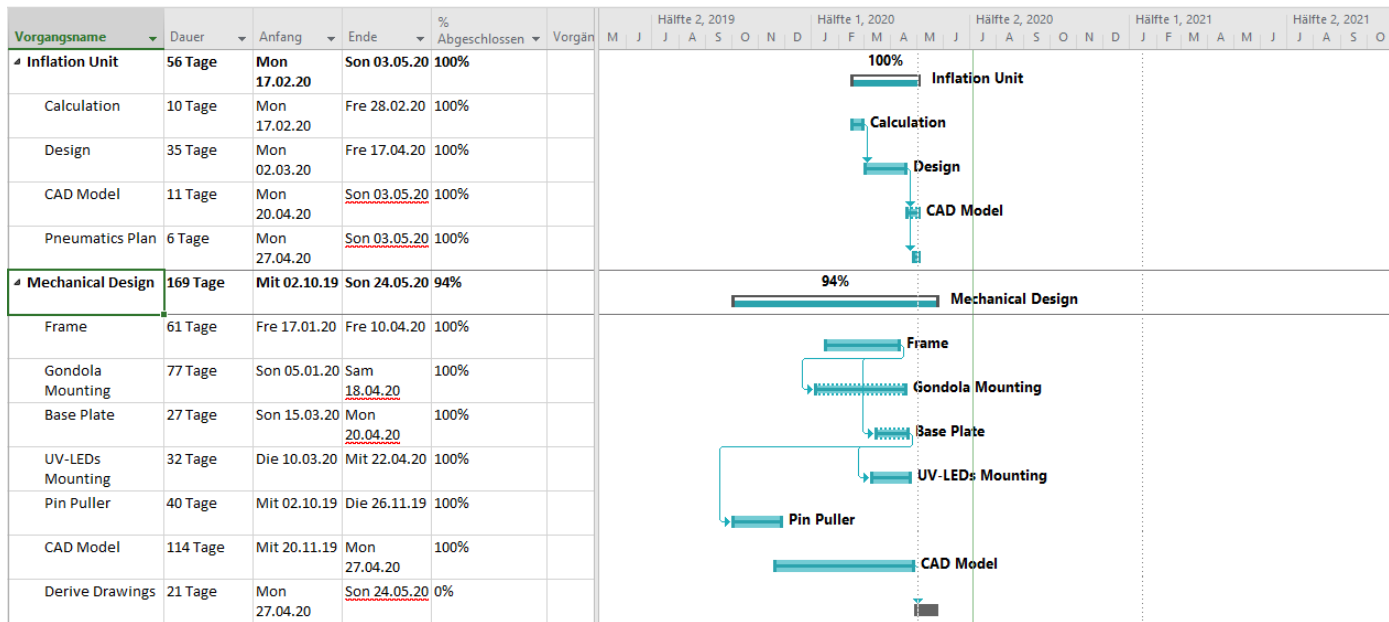


Fig. 8.1: Detailed View of the Schedule

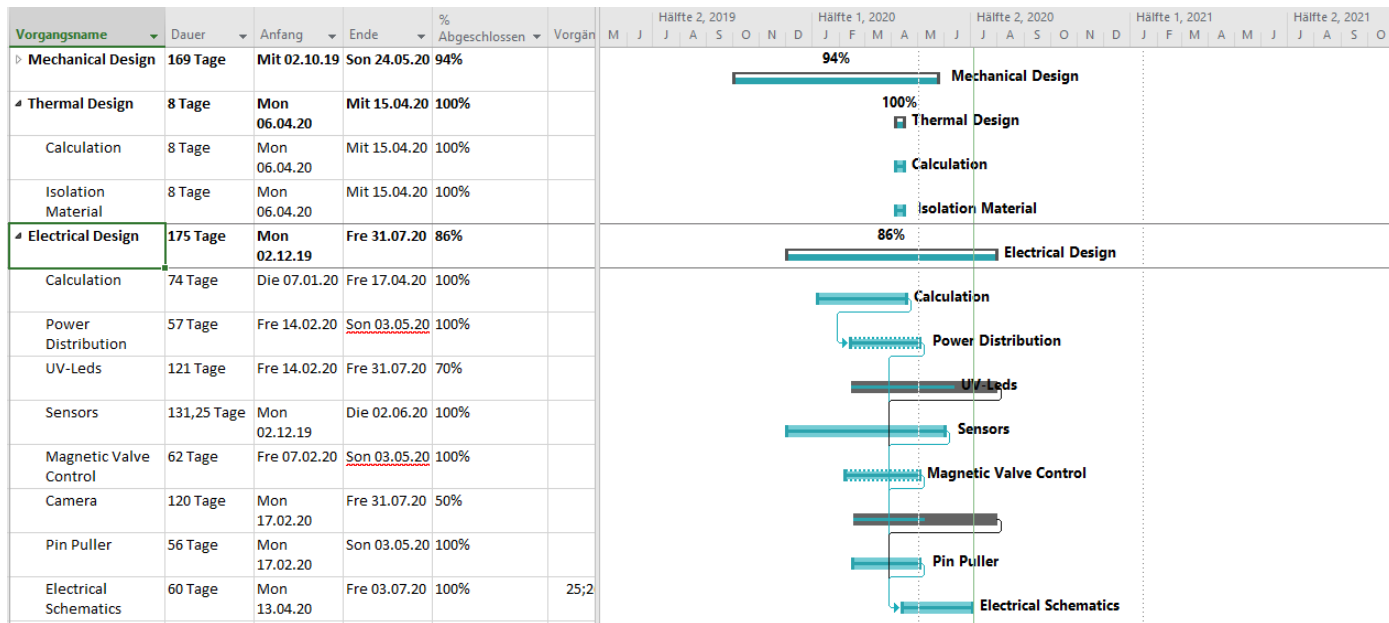


Fig. 8.2: Detailed View of the Schedule

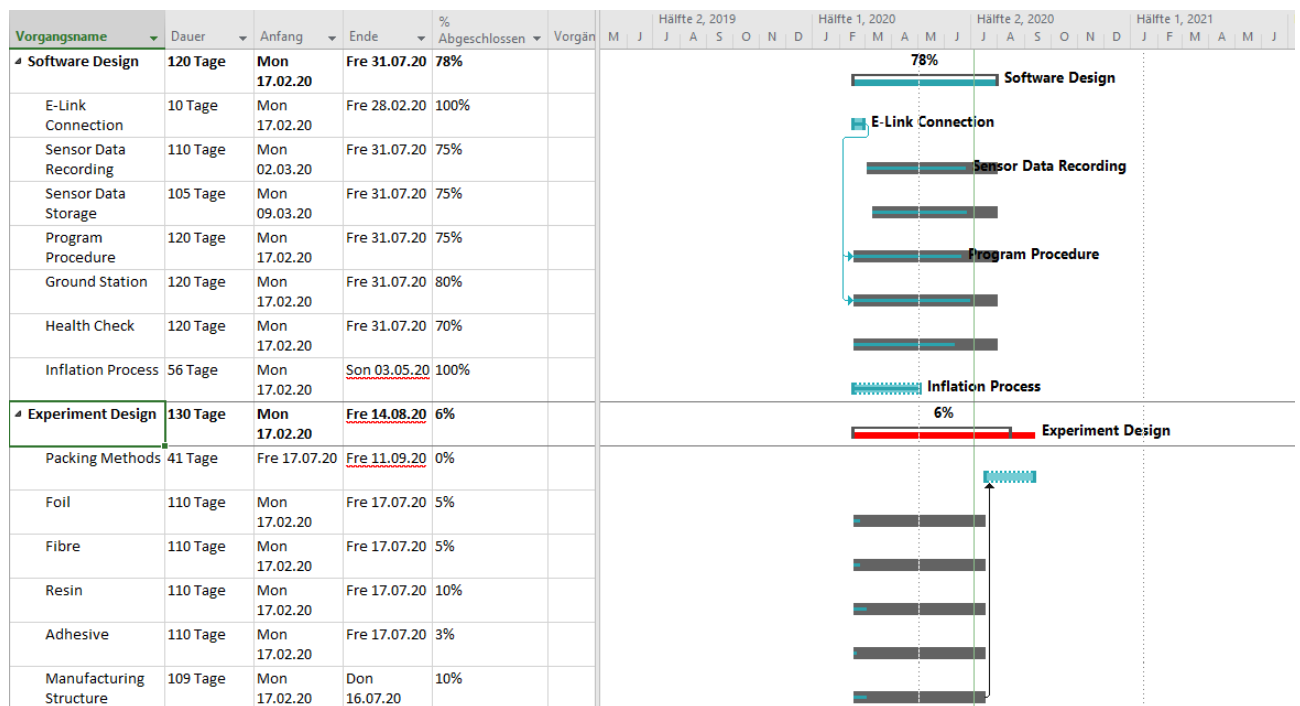


Fig. 8.3: Detailed View of the Schedule

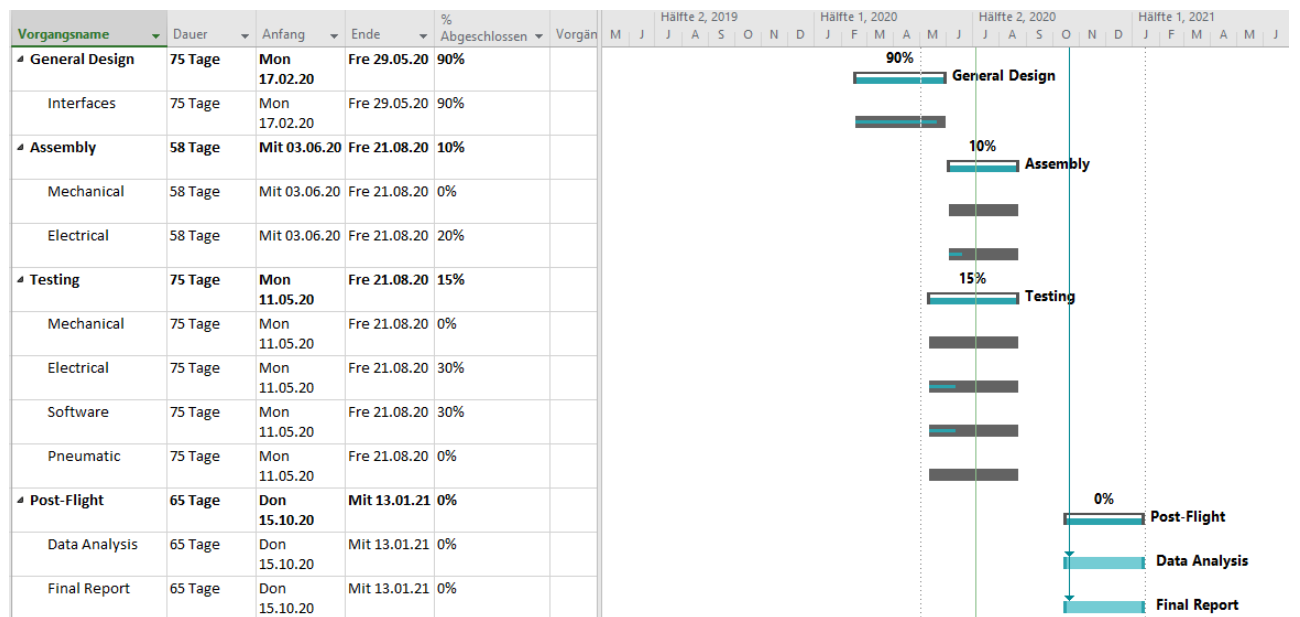


Fig. 8.4: Detailed View of the Schedule

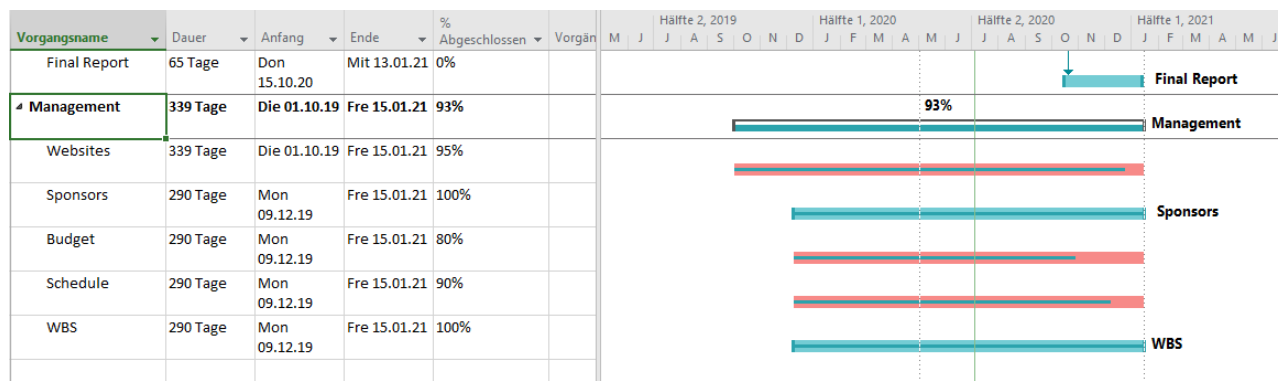


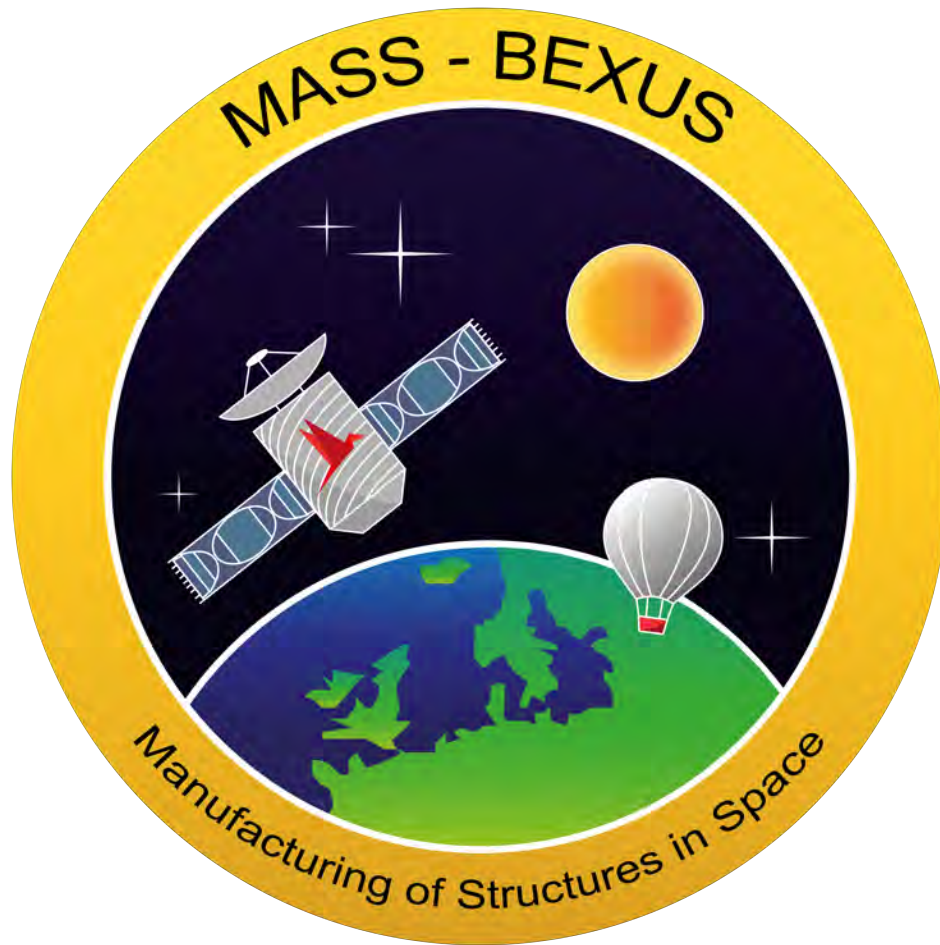
Fig. 8.5: Detailed View of the Schedule

Appendix B - Outreach and Media Coverage

Online presence

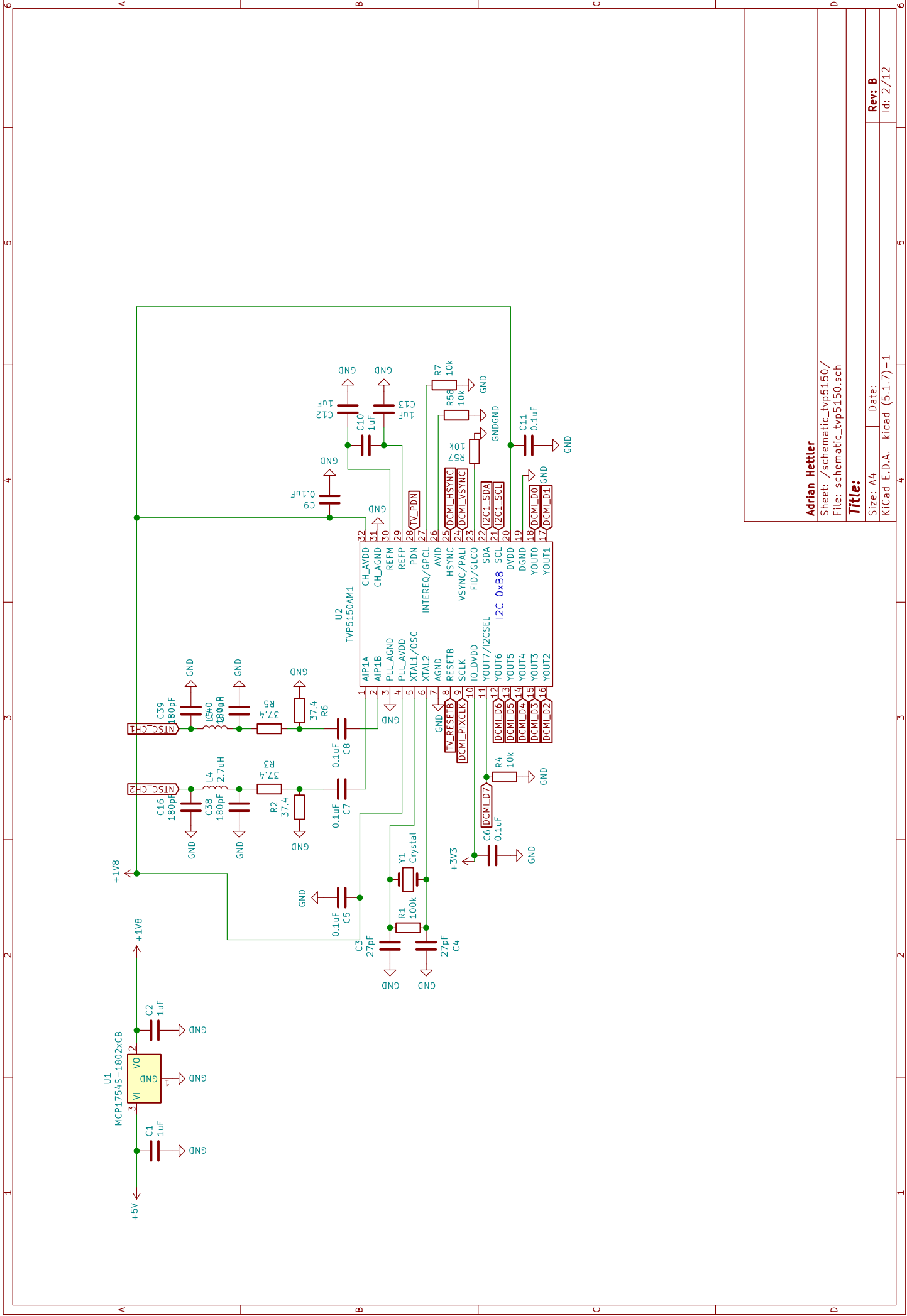
- Facebook page: <https://www.facebook.com/people/Mass-ReXus/100042185382368>
- Webside: <http://www.mass-bexus.eu/>
- Instagram: <https://www.instagram.com/massbexus/>

Logo



Appendix C - Additional Technical Information

1		2	3	4	5
A	Sheet: schematic_tvp5150	Sheet: schematic_sd_rtc	Sheet: schematic_icm-20948	Sheet: schematic_current_volt	Sheet: schematic_temp
	Video Decoder File: schematic_tvp5150.sch I2C1 0x88	SD/RTC File: schematic_sd_rtc.sch I2C1 0x68	Accel/Gyro File: schematic_icm-20948.sch I2C1 0x69	Current/Voltage File: schematic_current_volt.sch I2C1 0x6E	Temperature File: schematic_temp.sch I2C2 0x68
B	Sheet: schematic_switches	Sheet: schematic_dc_dc	Sheet: schematic_connector	Sheet: schematic_watchdog	Sheet: schematic_i2c_multiplexer
	Switches File: schematic_switches.sch	DC/DC File: schematic_dc_dc.sch	Connector File: schematic_connector.sch	Watchdog File: schematic_watchdog.sch	I2C Multiplexer File: schematic_i2c_multiplexer.sch I2C 0x70
C					
D	Adrian Hettler				
	Sheet: /				
	File: pcb_shield.sch				
	Title:				
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Adrian Hettler

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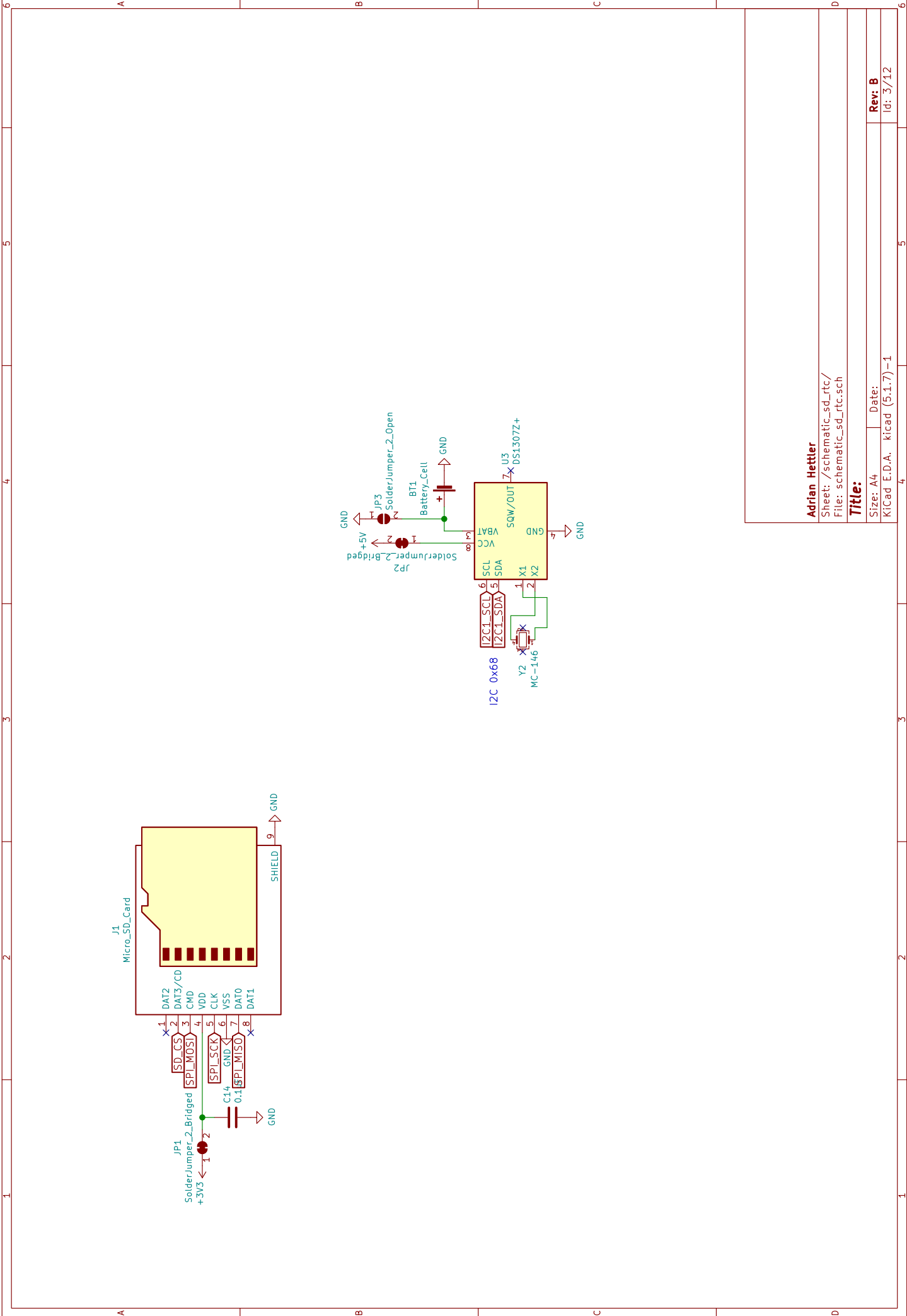
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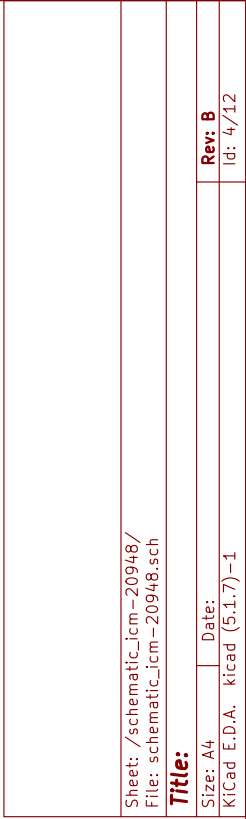
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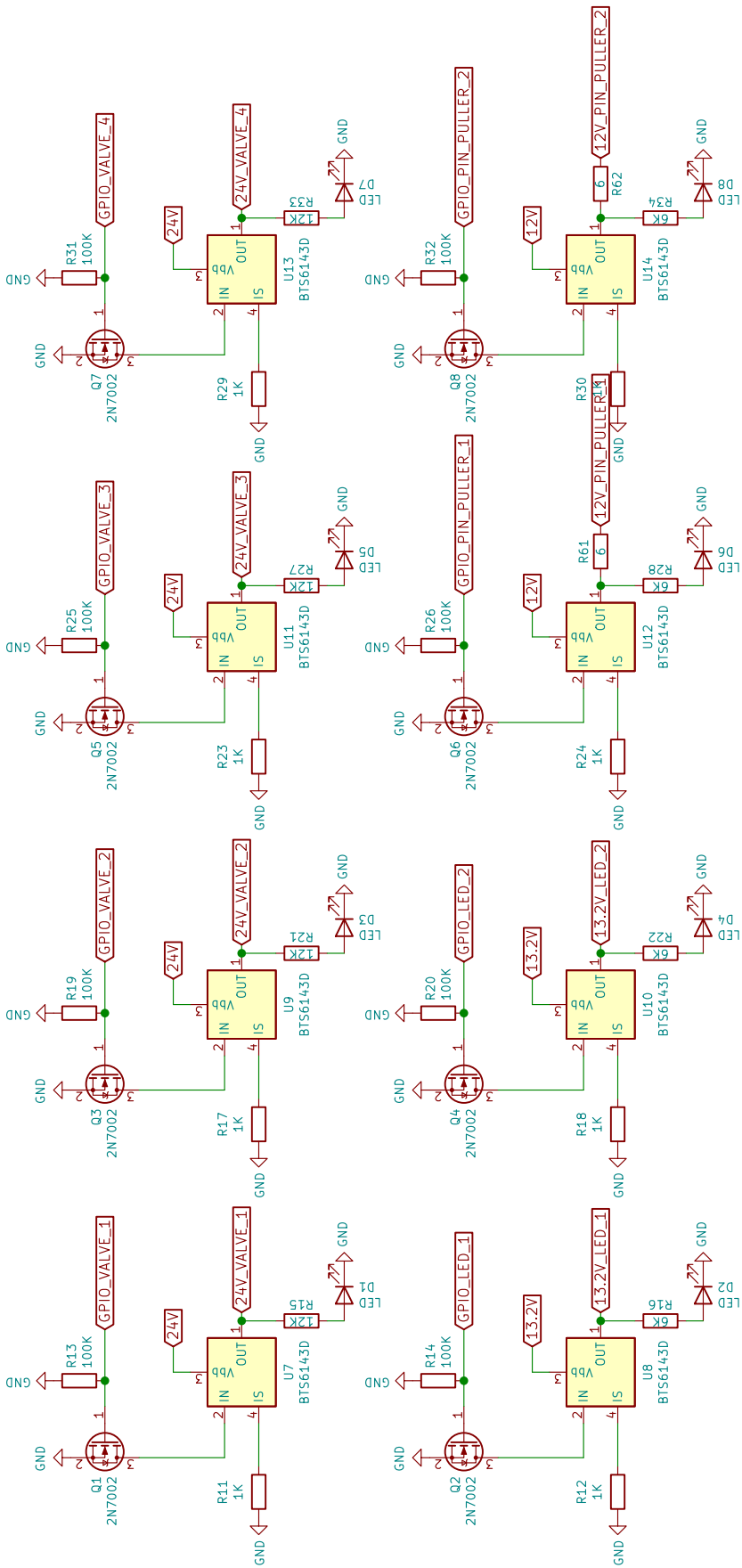
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LED KG DELL51.22-JGKH-24



Sheet: /schematic_switches/
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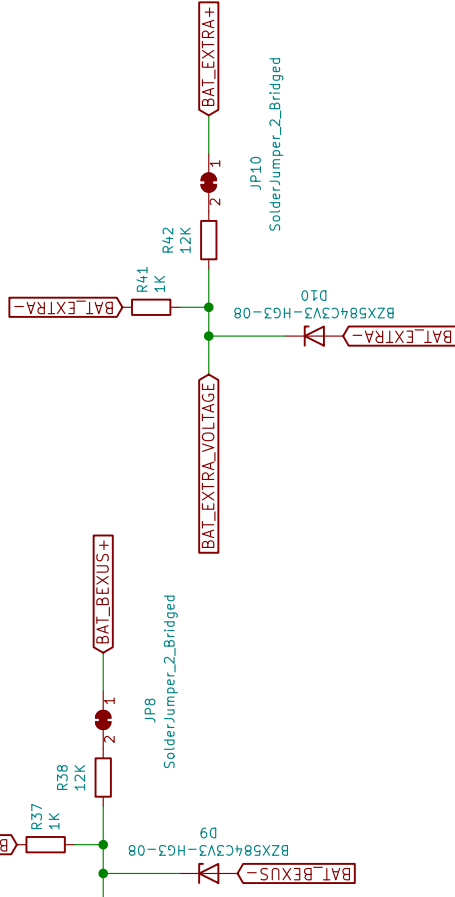
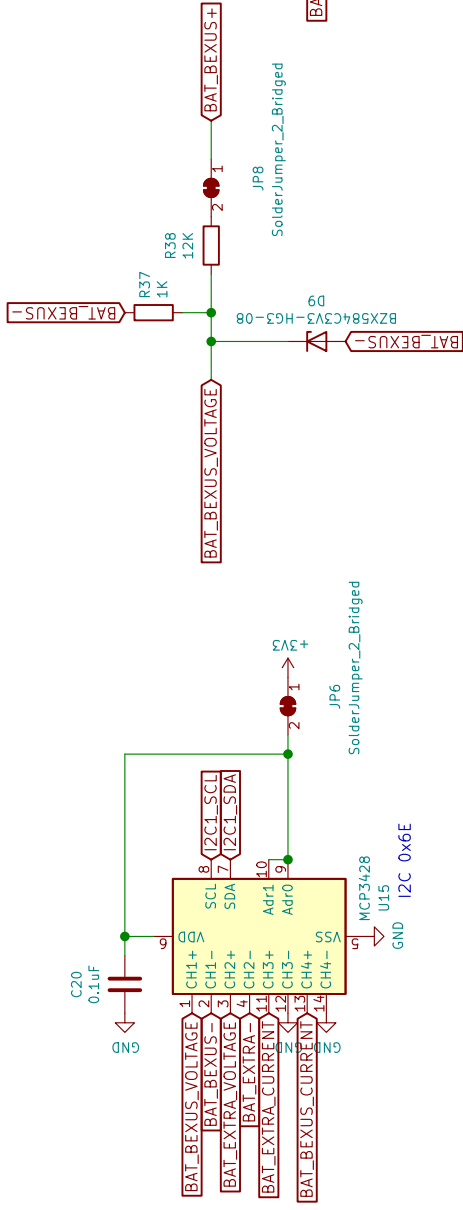
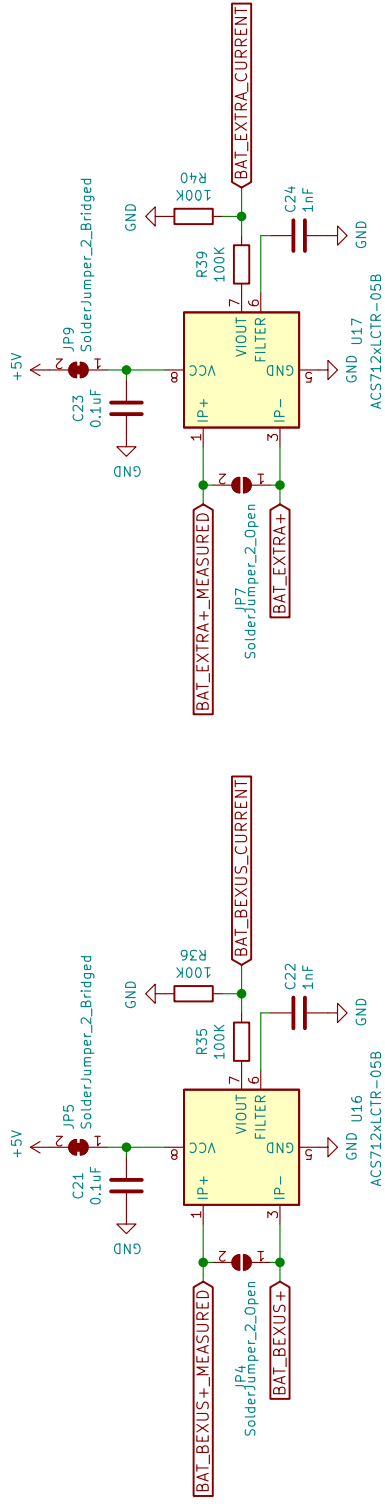


TABLE 5-3: ADDRESS BITS VS. ADDRESS SELECTION PINS FOR (MCP3427 AND MCP3428 (MCP3401 NOTE 4, 2, 3)

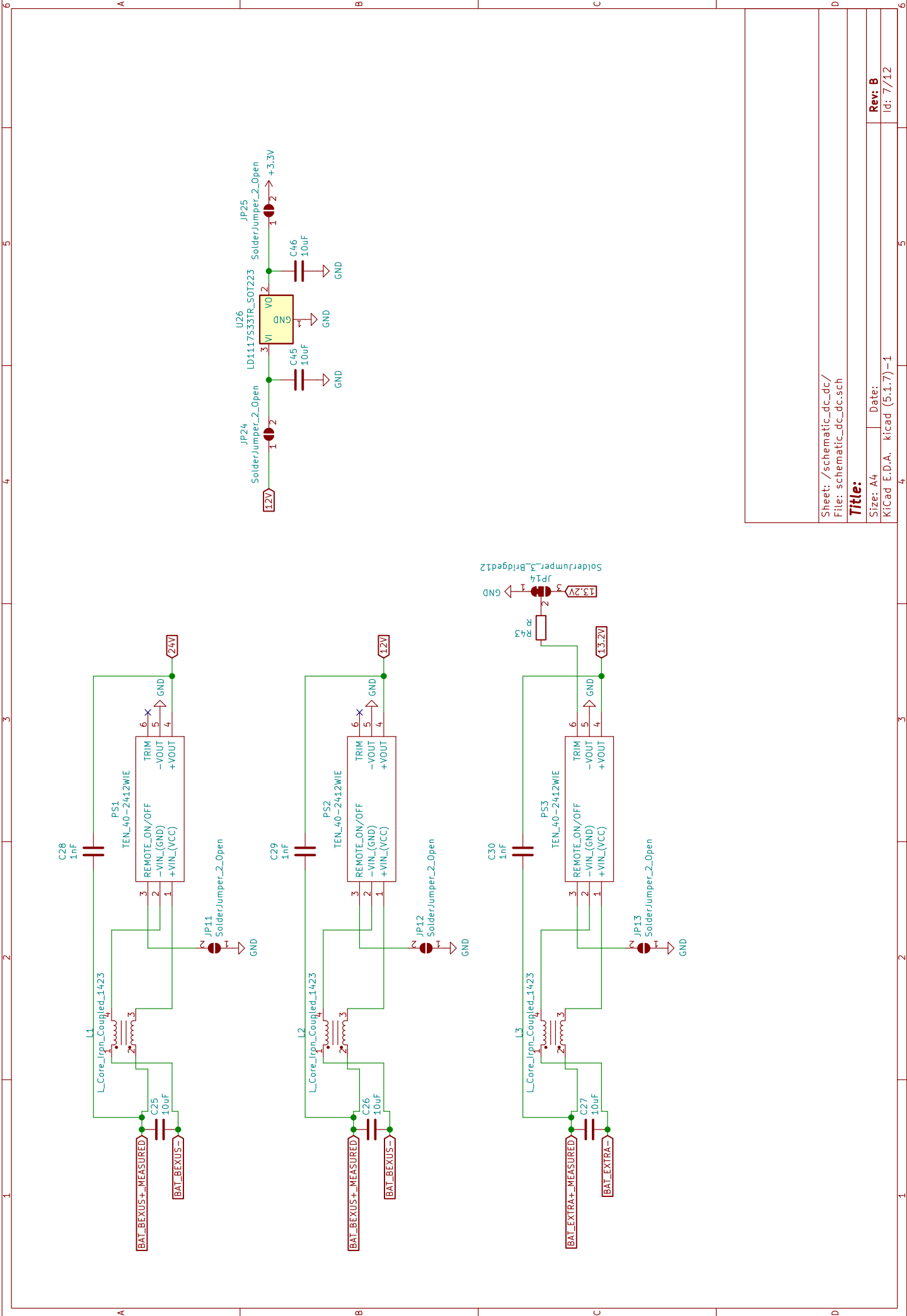
i2C Device Address Bits	Logic Status of Address Selection Pins					
	A2	A1	A0	Addr Pin	Addr Pin	Addr Pin
0	0	0	0	0 (Addr_Low)	0 (Addr_Low)	0 (Addr_Low)
1	0	0	1	0 (Addr_Low)	0 (Addr_Low)	Float
2	0	1	0	0 (Addr_Low)	0 (Addr_Low)	1 (Addr_High)
3	0	1	0	0 (Addr_Low)	1 (Addr_High)	0 (Addr_Low)
4	0	1	1	0 (Addr_Low)	1 (Addr_High)	Float
5	1	0	0	1 (Addr_High)	0 (Addr_Low)	1 (Addr_High)
6	1	0	1	1 (Addr_High)	0 (Addr_Low)	0 (Addr_Low)
7	1	1	0	1 (Addr_High)	1 (Addr_High)	0 (Addr_Low)
8	1	1	1	1 (Addr_High)	1 (Addr_High)	Float
9	0	0	0	Float	Float	Float

Note 1: Float: (a) Leave pin without connecting to anything (left floating), or (b) apply Add_Float voltage.

2: The user can tie the pins to V_{SS} or V_{DD} :

- Tie to V_{SS} for Addr_Low
- Tie to V_{DD} for Addr_High

3: See Addr_Low, Addr_High, and Add_Float parameters in **Electrical Characteristics Table**.



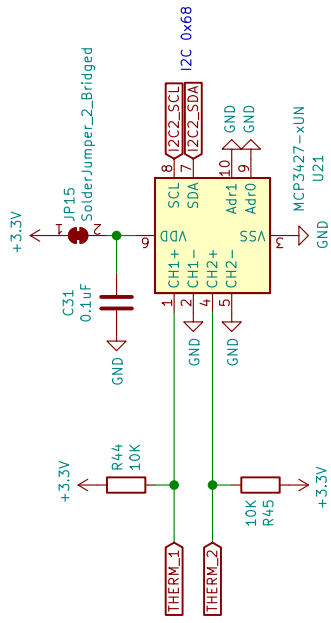


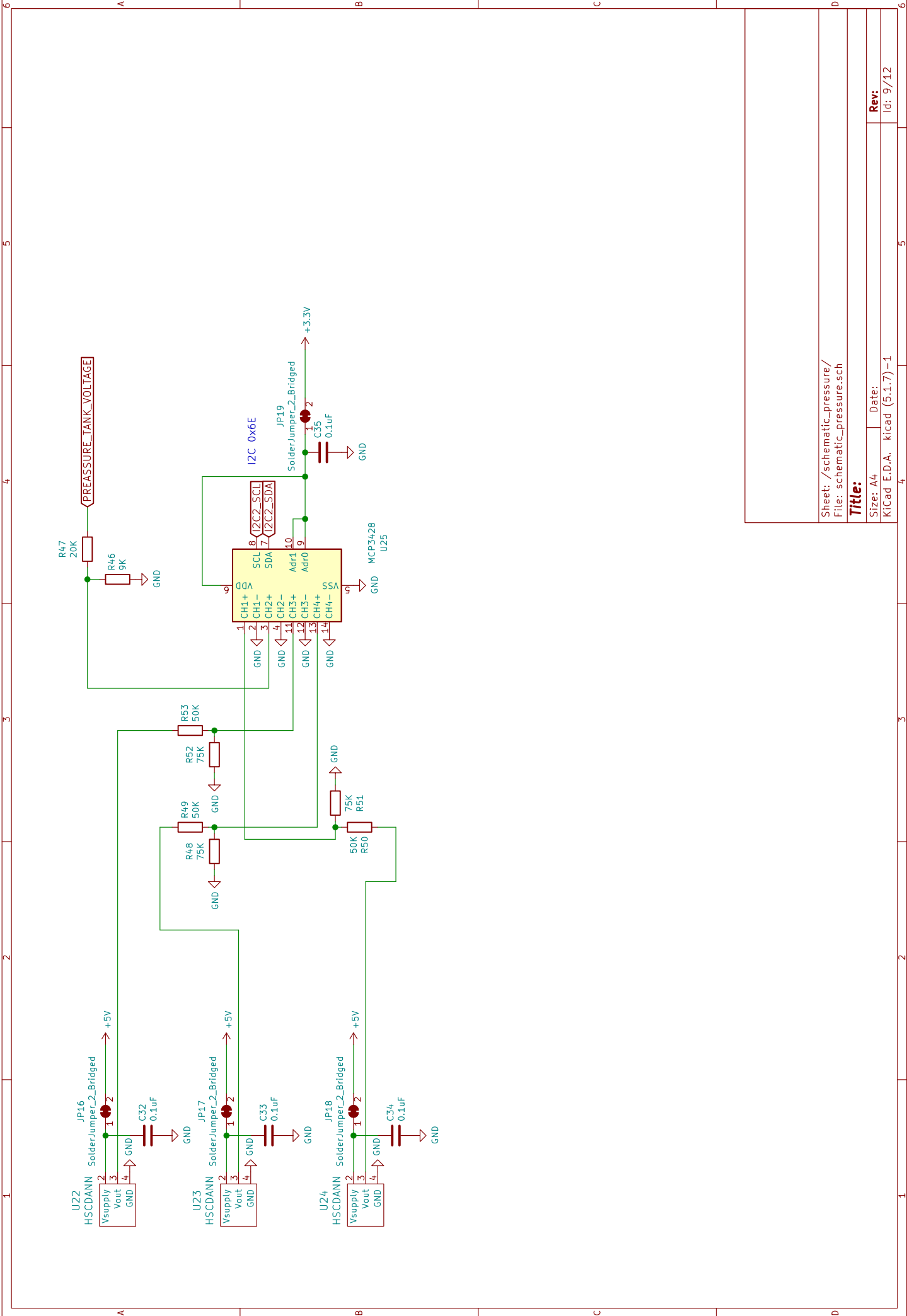
TABLE 5-3: ADDRESS BITS VS. ADDRESS SELECTION PINS FOR (MCP3427 AND MCP3428 ONLY) (NOTE 1, 2, 3)

PC Device Address Bits	A2	A1	A0	Logic Status of Address Selection Pin	Addr Pin	Addr Pin
0	0	0	0	0 (Addr _{Low})	0 (Addr _{Low})	0 (Addr _{Low})
1	0	0	1	0 (Addr _{Low})	1 (Addr _{High})	Float
2	0	1	0	1 (Addr _{High})	0 (Addr _{Low})	1 (Addr _{High})
3	0	1	1	1 (Addr _{High})	1 (Addr _{High})	Float
4	1	0	0	1 (Addr _{High})	0 (Addr _{Low})	1 (Addr _{High})
5	1	0	1	1 (Addr _{High})	1 (Addr _{High})	Float
6	1	1	0	1 (Addr _{High})	0 (Addr _{Low})	1 (Addr _{High})
7	1	1	1	1 (Addr _{High})	1 (Addr _{High})	Float

Note 1: (a) Leave pin without connecting to V_{SS} or V_{DD}.
 (b) Float.
 (c) Supply.

Note 2: The user can tie the pins to V_{SS} or V_{DD}:
 - Tie to V_{SS} for Addr_{Low}
 - Tie to V_{DD} for Addr_{High}

Note 3: See Addr_{Low}, Addr_{High} and [Electrical Characteristics Table](#)



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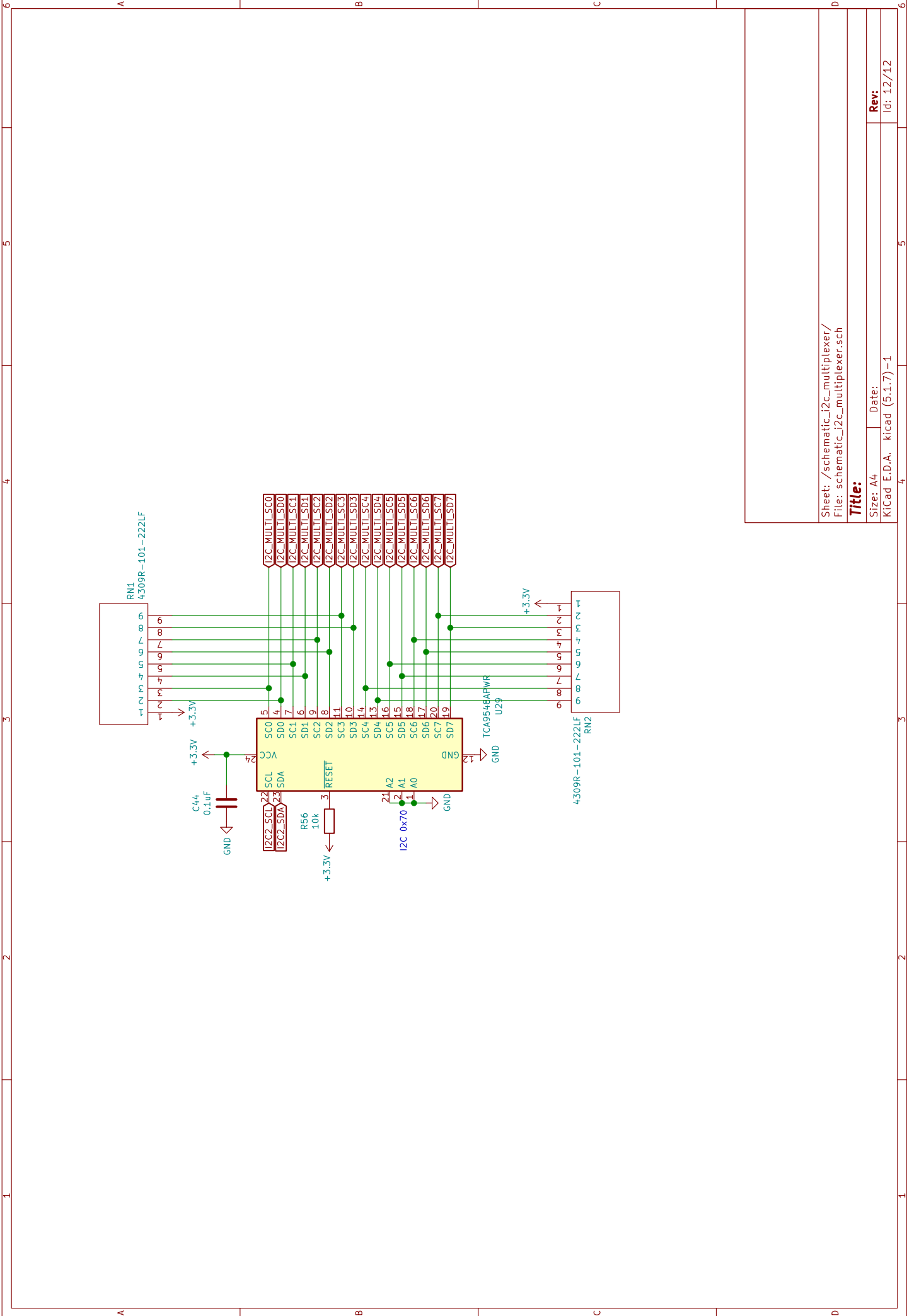
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Appendix D - Checklists

Checklist Components

Team MASS

PNEUMATICS	
visual inspection	
check if all valves open and close before tank is filled	
fill tank to 8 bar	
check for possible leaks	
check volumetric flow, adjust using throttle	
tighten throttle nut	

ELECTRIC & SOFTWARE	
visual inspection	
ensure that power switch is turned off	
check battery voltage	
connect power and lan line	
turn on power switch	
ensure that the micro controller is running on the correct version of the software	
check connection with ground station	
check plausability of sensor data measurements (voltage, current, pressure, temperature)	
check camera live view	
check cammera command communication	
check data on SD-card	
check that log file is created with sensor data	
check if commands from ground station work	

Checklist Structure Assembly

Team MASS

Structure	1	2	3	4
mark folding lines on 30µm foil using template				
add additional diagonal lines				
cut the 30µm foil to shape				
fold structure				
create a cylindrical shape using spray adhesive				
toughen the folding lines by putting weight on the folded down structure				
attach glass fibres in a cross pattern using spray-adhesive				
move to a dark room with no ambient UV-light				
cut the 12µm foil to size				
put on safety equipment (gloves, mask)				
soak glass fibres in UV-curing resin				
wrap the structure with 12µm foil				
slide one lid over the structure, put in O-ring				
clamp foil between two lids, tighten with screws				
repeat on other side				
attach UV-protection				
toughen folding lines again				

Checklist Assembly

Team MASS

remove all four UV-Panels	
replace zip ties and mount battery pack	
mount HDRM	
replace temperature sensor on HDRM	
replace fuse	
mount PCB	
connect wiring PCB -> HDRM	
connect D-Sub connectors to PCB	
connect wiring of lower two UV-Panels	
mount two lower UV-Panels	
mount two inflatable structures	
arm HDRM	
connect wiring of upper two UV-Panels	
mount upper two UV-Panels	
mount insulation	