SED

Student Experiment Documentation

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Mission: REXUS 16

Team Name: HORACE

Experiment Title: Horizon Acquisition Experiment

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1	2013-01-28	All	PDR
1.1	2013-03-26	1.4, 2, 3.3.2, 3.5, 4.3, 4.4, 4.5.2, 4.4.5, 4.7, 4.8, 5.1, 6.3 & minor changes in other chapters	post-PDR, several comments of panel handled, see also appendix A section PDR
2	2013-06-06	2, 3, 4, 5, 6.1.1, 6.2, 6.4, Appendix B,C,D,E,F	CDR
3	2013-09-03	2, 3, 4.3, 4.4, 4.5, 4.6, 5, 6.3 & minor changes in other chapters	post-CDR, all comments of panel handled (see also appendix A section CDR), IPR: • 2 classification of req • 2.2 perf. req for SW • 3 update • 4 more tech. drawings • 4.4 protective window • 4.6 more detailed • 5 update • 6.3 update
4			Pre-Campaign
5			Final report

Abstract: This paper contains the complete documentation of the HORACE-project which is payload on REXUS 16. The current version 3.0 represents the frozen status after CDR, covering all comments/recommendations of the CDR panel and giving the final design and current status of implementation which is to be discussed during IPR.

Keywords: REXUS 16, SED - Student Experiment Documentation, HORACE, Horizon Acquisition Experiment, University of Würzburg,

CONTENTS

ABSTRACT

The aim of the Horizon Acquisition Experiment (HORACE) is to test and demonstrate the capabilities of a new approach for attitude determination, which also works under stress conditions like uncontrolled tumbling or spinning with high rates. Therefore the experiment processes optical data with image processing algorithms on an embedded system, so that the line of horizon is detected in the frames and a vector to the 2D projection of the center of the earth can be calculated.

Unlike existing earth sensing systems using the IR spectrum to detect the earth, HORACE processes video frames of an ordinary camera, which is sensitive to the visible spectrum. Thus, there is strong emphasis on the software components of the system and we imagine a future system which could only be a software package capable enough to use data from existing payload-cameras for attitude determination in emergencies.

During the experiment both video and calculated data are collected to provide qualitative and quantitative evidence about the robustness and accuracy of the horizon acquisition and the calculated earth vector, as well as for the general approach after post flight evaluation.

The flight on REXUS provides a good setting for the experiment, because the launcher’s rotation is similar to uncontrolled tumbling or spinning movements and the reached altitude is high enough to take realistic, space-like images.

HORACE has been initiated by five students of Aerospace Information Technology at University of Würzburg in close cooperation with and support of the Chair of Aerospace Information Technology in October 2012. It will be implemented throughout 2013 and launched in spring 2014 as payload of REXUS 16.

The HORACE team (left to right): Sven Geiger, Arthur Scharf, Florian Wolz, Jochen Barf, Matthias Bergmann, Thomas Rapp

1 INTRODUCTION

1.1 Scientific/Technical Background

As a further step in today's way of technology towards completely autonomous satellites, a satellite's attitude acquisition and control system (AACS) – an essential subsystem – must work autonomously not only during nominal phases of the mission, but also in unexpected situations or emergency cases. These include situations during which the satellite's main AACS is corrupt itself or during which the main AACS's capability does not suffice, e.g. when the satellite is spinning and tumbling uncontrolled at high rates.

To face those situations in the future we envision a sensor system which is autonomously able to (re)acquire a satellite's attitude not only under nominal but also stress conditions mentioned above and which should also be affordable for smaller satellites and missions. In our opinion the best approach would be an horizon acquisition sensor system, as it – unlike many other attitude determination systems (e.g. sun sensors, star cameras etc.) – would work in more situations for following reasons: the central body's (in most cases the earth's) surface looks different to the dark space even during eclipse and it is only hardly probable – nearly impossible – that the satellite would spin and tumble in a mode during which the central body is never visible.

In contrast to existing earth sensors, that detect the earth's IR radiation, HORACE shall use an optical sensor, which is sensitive to the visible spectrum, for the horizon detection to keep expenses low and to emphasis the image processing software-components of the system. So that in a future version with more generic algorithms the system could possibly be only a software package, which is capable enough to use any camera data, e.g. images provided by existing payload-cameras.

1.2 Mission Statement

HORACE on REXUS 16 is a technology demonstration mission for autonomous earth detection on satellites. The aim is to prove or disprove the general technical feasibility of the outlined approach.

During the mission the functionality and robustness of the general approach is tested under realistic, space-like conditions, by means of the HORACE Flight Segment. After post flight evaluation it shall be determined whether the approach of autonomous horizon acquisition with a camera in conjunction with image processing algorithms running on an embedded system connected to the camera is indeed apt to (re)acquire a satellite's attitude under nominal or stress conditions.

1.3 Experiment Objectives

With HORACE, whose development will be part of the mission, the following **primary objectives** shall be reached:

- Investigate whether horizon acquisition can be performed accurately enough for attitude determination.
- Determine whether the very dynamic and time-critical problem can be solved with an embedded system with reasonable time resolution and power consumption.

Secondary objectives are:

- to show physical or systematic limits and problems of the general approach.
- to determine, if a future attitude determination system following the general approach would be applicable also for small satellites.

1.4 Experiment Concept

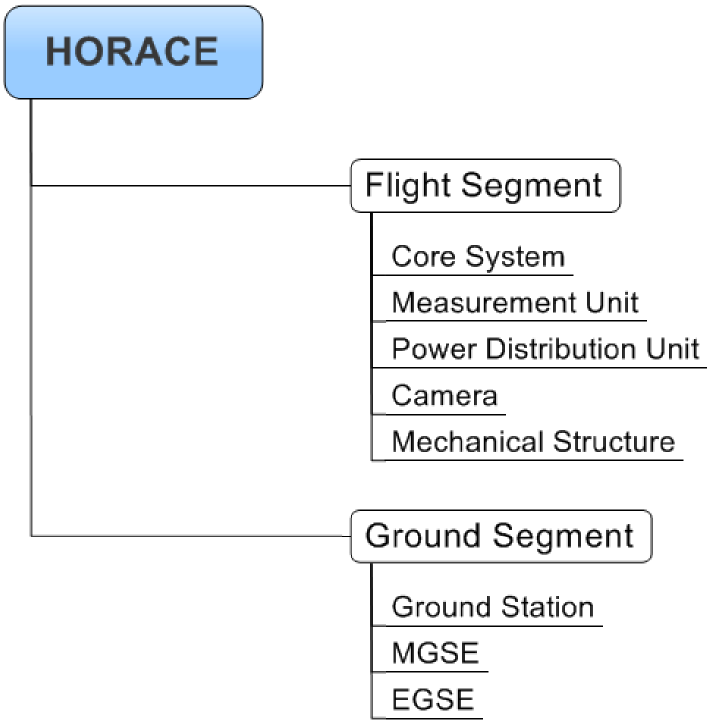

Figure 1-1: Hierarchy of HORACE

The Horizon Acquisition Experiment (HORACE) consists of the Flight Segment (FS), which is carried on the REXUS rocket, performing the actual experiment and the Ground Segment, which are the Ground Station and Ground Support Equipment (both electrical and mechanical).

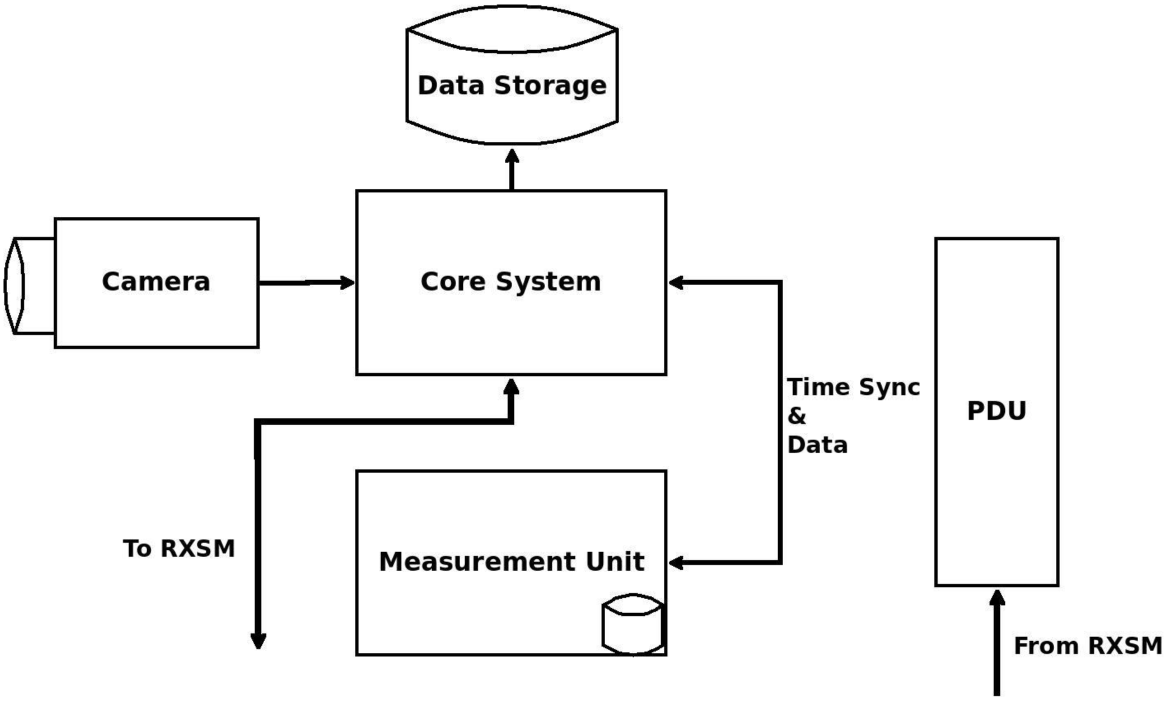

Figure 1-2: Subsystems of Flight Segment

The two key elements of HORACE Flight Segment are its camera and the core system. Furthermore, there is an independent measurement unit and a separate power distribution unit, which is the power interface to RXSM and provides regulated voltages to every component and of course the structure, which mechanically connects the experiment with the vehicle.

All components involved in data handling, the core system and measurement unit, are synchronized with a global time, so that results can be matched for post flight evaluation.

The camera, which observes the outer environment of REXUS, passes its video data to the core system, which directly saves it to data storage and processes it for the horizon acquisition. The results of the calculation are also stored to mass memory. Additionally, the core system represents the data interface to RXSM and passes some of the results of its calculations to RXSM for downlink.

The measurement unit regularly determines and saves health data, like currents and temperatures, autonomously, and in selected software-modes (cf. 4.8.1) provides them for downlink.

The experiment starts at lift off and runs completely autonomously throughout the whole flight. TC is implemented for on-ground testing before launch and flight simulation during implementation/development.

1.5 Team Details

1.5.1 Contact Point

The team's contact person will be the Project Manager Thomas Rapp, whose contact information is as followed:

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1.5.2 Team Members

Thomas Rapp – Project Management

Thomas is the student team leader and therefore responsible for the overall management of the HORACE project. He is in charge of the documentation as well as the project schedule and is the main contact person.

He is also part of the mechanical workgroup and thus involved in the device assembly and mechanical integration of the experiment, focusing on procedures for assembly during launch campaign.

Thomas is in his third undergraduate year of studies of Aerospace Information Technology at University of Würzburg.

Jochen Barf – Algorithmic Development

Jochen's main task is to develop smart algorithms, which detect the horizon in the video frames and to calculate a 2D vector to the earth center, reliably and as fast as possible.

He will also develop the required software components of the ground segment for TM/TC.

Jochen is a student of Aerospace Information Technology at University of Würzburg in his third undergraduate year.

Sven Geiger – Embedded System Development & Porting

It's Sven's job to make sure that Jochen's algorithms will run on the embedded system of the HORACE-System.

He is also responsible for the rest of the embedded programming, which is necessary for the experiment to run properly and assists in the development of the software for ground segment.

Sven is in his third undergraduate year of studies of Aerospace Information Technology at University of Würzburg.

Florian Wolz–Electrical & Mechanical Engineering

As electrical engineer, Florian ensures that every component is supplied with power and that the power consumption is measured and stored correctly.

Together with Matthias and Thomas he also works on the mechanical and thermal design and device assembly.

Florian is a student of Aerospace Information Technology at University of Würzburg in his third undergraduate year.

Matthias Bergmann – Mechanical & Optical Engineering

Matthias joined the team in April 2013 and does the main part of the mechanical and thermal design, including CAD and calculations and device assembly, and is assisted by Florian and Thomas.

He is also in charge of all parts concerning the camera and optics of HORACE.

Matthias is in his third undergraduate year of studies of Aerospace Information Technology at University of Würzburg.

Arthur Scharf – Simulation Environment & Public Outreach

Arthur is mainly responsible for simulation, validation and testing. He therefore will manage the test facilities and procedures and will develop the ground support equipment, which is needed for pre-flight test, to make sure that HORACE is ready for flight.

Besides that, it's Arthur's part to spread information and news about HORACE with his public outreach program.

Arthur is in his third undergraduate year of studies of Aerospace Information Technology at University of Würzburg.

2 EXPERIMENT REQUIREMENTS AND CONSTRAINTS

In this chapter the functional, performance, design and operational requirements are defined, which must be fulfilled to reach the Mission Objectives (cf. 1.3)

All requirements can uniquely be identified with its appropriate number X-Y-Z according to this scheme:

X: F – functional requirement

P – performance requirement

D – design requirement

O – operational requirement

Y: M – mechanical

E – electrical

S – software

Z: consecutive number starting with 01

2.1 Functional Requirements

ID	Requirement text	Respond to
F-E-01	The FS shall observe optically the outer enivronment of the REXUS rocket	
F-E-02	*moved to D-E-06*	
F-E-03	The FS shall distribute power to all subsystems	
F-E-04	*combined with F-E-05 to F-E-06* *moved to D-E-07*	
F-E-05	*combined with F-E-04 to F-E-06* *moved to D-E-08*	
F-E-06	The FS shall measure health data of selected subsystems and at selected points of the experiment	
F-M-01	The mounting of the optical sensor should ensure visibility of the horizon	
F-S-01	The FS shall detect and calculate the line of horizon	
F-S-02	The FS shall calculate the 2D vector to the 2D projection of the earth center	
F-S-03	The FS shall save the experiment data with global timestamp *(combined with F-S-04 & F-S-09;* *original requirement moved to D-S-01)*	

Table 2-1: functional requirements (1/2)

ID	Requirement text	Respond to
F-S-04	*combined with F-S-03 moved to D-S-02*	
F-S-05	*moved to D-S-04*	
F-S-06	*moved to D-S-05*	
F-S-07	*moved to D-S-06*	
F-S-08	*moved to D-S-07*	
F-S-09	*combined with F-S-03 moved to D-S-03*	
F-S-10	The FS shall downlink calculation data during flight	
F-S-11	*moved to D-S-08*	
F-S-12	*moved to D-S-09*	
F-S-13	*moved to D-S-10*	
F-S-14	*moved to D-S-11*	
F-S-15	*moved to D-S-12*	
F-S-16	The FS shall downlink health data during stand-by	

Table 2-2: functional requirements (2/2)

2.2 Performance Requirements

ID	Requirement text	Respond to
	PERFORMANCE REQUIREMENTS	
P-M-01	*moved to D-M-10*	
P-M-02	The horizon may be visible in 70% of the operational time	F-M-01
P-M-03	The horizon should be visible in 50% of the operational time	F-M-01
P-M-04	The horizon shall be visibible in 30% of the operational time	F-M-01
P-E-01	*moved to D-E-10*	
P-E-02	*moved to D-E-11*	
P-E-03	*moved to D-E-12*	
P-E-04	*moved to D-E-13*	
P-E-05	*moved to D-E-14*	
P-E-06	*moved to D-E-15*	
P-E-07	*moved to D-E-16*	
P-E-08	The optical sensor shall be sensitive to the visible spectrum	F-E-01
P-E-09	The optical sensor shall provide an image resolution of 1024px x 768px	F-E-01

Table 2-3: performance requirements (1/3)

ID	Requirement text	Respond to
	PERFORMANCE REQUIREMENTS	
P-E-10	The exposure time of the optical sensor shall be adjustable in a range from 10µsec to 1sec	F-E-01
P-E-11	*moved to D-E-09*	
P-E-12	The optical sensor shall provide sharp pictures at least 0.120sec after full illumination	F-E-01
P-E-13	The MU shall measure temperatures with an accuracy of +/- 0,5°C	D-E-08
P-E-14	The MU shall measure temperatures in a range from -55°C to +125°C	D-E-08
P-E-15	The MU shall measure temperatures with a sample rate of 1Hz	D-E-08
P-E-16	The MU shall measure currents with an accuracy of +/- 100mA	D-E-07
P-E-17	The MU shall measure currents in a range of 0A to 3A	D-E-07
P-E-18	The MU shall measure currents with a sample rate of 100Hz	D-E-07
P-E-19	The data storage of the MU shall have a memory size of 1 Mbyte	D-S-01
P-E-20	The data storage of the MU shall provide a write speed of 2 kbyte/sec	D-S-01
P-E-21	The data storage for the optical raw data shall have a memory size of 45 Gbyte	D-S-03
P-E-22	The data storage for the optical raw data shall provide a write speed of 71 Mbyte/sec	D-S-03
P-E-23	The data storage for the calculated data shall have a memory size of 77 Mbyte	D-S-02
P-E-24	The data storage for the calculated data shall provide a write speed of 130 kbyte/sec	D-S-02
P-S-01	The 2D vector to the earth center should be calculated with 2 digits	F-S-02
P-S-02	The system shall calculate the 2D vector to the earth for every successful horizon detection	F-S-02
P-S-03	The system shall process 30fps for horizon detection	F-S-01

Table 2-4: performance requirements (2/3)

ID	Requirement text	Respond to
	PERFORMANCE REQUIREMENTS	
P-S-04	When the rocket is spinning with low rates (< 0.3Hz) AND if there are no image disturbances[1] the results of horizon acquisition should be successful[2] in 90% of those cases.	F-S-01 F-S-02
P-S-05	When the rocket is spinning with low rates (< 0.3Hz) AND if there are little image disturbances[1] the results of horizon acquisition should be successful[2] in 80% of those cases.	F-S-01 F-S-02
P-S-06	When the rocket is spinning with low rates (< 0.3Hz) AND if there are many image disturbances[1] the results of horizon acquisition should be successful[2] in 50% of those cases.	F-S-01 F-S-02
P-S-07	When the rocket is spinning with high rates (> 1.0Hz) AND if there are no image disturbances[1] the results of horizon acquisition should be successful[2] in 80% of those cases.	F-S-01 F-S-02
P-S-08	When the rocket is spinning with high rates (> 1.0Hz) AND if there are little image disturbances[1] the results of horizon acquisition should be successful[2] in 70% of those cases.	F-S-01 F-S-02
P-S-09	When the rocket is spinning with high rates (> 1.0Hz) AND if there are many image disturbances[1] the results of horizon acquisition should be successful[2] in 30% of those cases.	F-S-01 F-S-02
P-S-10	The amount of false negative horizon acquisitions should be less than 10%.	F-S-01
	[1] Image disturbances are phenomena like: sun in the image, lensflares, too dark or too bright illumination.	
	[2] A horizon acquisition is successful if and only if the ratio between the calculated earth radius and the real earth radius r/R holds $0.9 < r/R < 1.1$ and the error of the calculation of the center of earth e (euclidean distance) related to the real earth radius R holds $e/R < 0.1$	

Table 2-5: performance requirements (3/3)

2.3 Design Requirements

ID	Requirement text	Respond to
	DESIGN REQUIREMENTS	
D-E-01	HORACE shall not electrically harm neither the REXUS rocket nor launcher	C-01
D-E-02	HORACE shall not electrically interfere with other experiments	C-01
D-E-03	HORACE shall be compatible to the REXUS electrical interface according to REXUS manual	C-01
D-E-04	The FS shall use camera(s) as optical sensor(s)	P-E-08
D-E-05	The FS may use 2 cameras (TBC)	P-M-02
D-E-06	The FS shall provide a global timestamp, synchronized to LO *(formerly F-E-02)*	F-S-03
D-E-07	The FS shall measure the power consumption of selected subsystems *(formerly F-E-04)*	F-E-06
D-E-08	The FS shall measure the temperature the CS, PDU & camera hole (for each system) *(formerly F-E-05, now more detailed)*	F-E-06
D-E-09	The optical sensor shall provide the image data as raw data *(formerly P-E-11)*	F-E-01
D-E-10	The PDU shall provide 5V and 12V. *(formerly P-E-01)*	F-E-03
D-E-11	The PDU shall provide currents between 0A and 2.5A *(formerly P-E-02)*	F-E-03
D-E-12	The PDU shall provide voltages with an accuracy of ±5% *(formerly P-E-03)*	F-E-03
D-E-13	The PDU shall provide currents with an accuracy of ±200mA *(formerly P-E-04)*	F-E-03
D-E-14	The PDU shall handle a range of input voltage between 24V and 36V *(formerly P-E-05)*	F-E-03, C-01
D-E-15	The PDU shall handle a range of input current between 0A and 3A *(formerly P-E-06)*	F-E-03, C-01

Table 2-6: design requirements (1/3)

ID	Requirement text	Respond to
	DESIGN REQUIREMENTS	
D-E-15	The PDU shall handle a range of input current between 0A and 3A *(formerly P-E-06)*	F-E-03, C-01
D-E-16	A new timestamp shall be provided with the frequency 10 kHz *(formerly P-E-07)*	D-E-06
D-M-01	HORACE shall not mechanically harm neither the REXUS rocket nor launcher	C-01
D-M-02	HORACE shall not mechanically interfere with other experiments	C-01
D-M-03	HORACE shall be compatible to the REXUS mechanical interface according to REXUS manual	C-01
D-M-04	The core system shall withstand temperature conditions inside the module according to REXUS manual	C-01
D-M-05	The cameras shall withstand temperature conditions at the module's skin according to REXUS manual	C-01
D-M-06	The whole FS shall withstand pressure conditions according to REXUS manual	C-01
D-M-07	The whole FS shall withstand vibration conditions according to REXUS manual	C-01
D-M-08	Connectors shall be easily accessible	O-10
D-M-09	The data storage devices shall be easily accessible	O-11
D-M-10	The optical sensor shall be mounted perpendicular to the z_{BF}-axis *(formerly P-M-01)*	F-M-01
D-S-01	The FS shall save the measurement data with global timestamp *(formerly F-S-03)*	F-S-03
D-S-02	The FS shall save the calculated data with global timestamp *(formerly F-S-04)*	F-S-03
D-S-03	The FS shall save the optical raw data bijectively linked to calculated data *(formerly F-S-09)*	F-S-03
D-S-04	Of the calculated data the FS shall save the 2D vector to the earth center *(formerly F-S-05)*	D-S-02
D-S-05	Of the calculated data the FS shall save the detected horizon line as image data *(formerly F-S-06)*	D-S-02

Table 2-7: design requirements (2/3)

ID	Requirement text	Respond to
	DESIGN REQUIREMENTS	
D-S-06	Of the calculated data the FS shall save the calculated extrapolated horizon (circle) *(formerly F-S-07)*	D-S-02
D-S-07	Of the calculated data the FS shall save the stop of calculation timestamp *(formerly F-S-08)*	D-S-02
D-S-08	During flight in every downlink data frame the starttime of calculation shall be included *(formerly F-S-11)*	F-S-10
D-S-09	During flight in every downlink data frame the image frame number of the processed frame shall be included *(formerly F-S-12)*	F-S-10
D-S-10	During flight in every downlink data frame the 2D vector to the earth center, if cal-culated, shall be included *(formerly F-S-13)*	F-S-10
D-S-11	During flight in every downlink data frame the extrapolated horizon (circle), if cal-culated, shall be included *(formerly F-S-14)*	F-S-10
D-S-12	During flight in every downlink data frame the stop of calculation timestamp should be included *(formerly F-S-15)*	F-S-10
D-S-13	The FS shall downlink received signals (echo) during stand-by	F-S-16
D-S-14	The FS shall downlink the self-check status during stand-by	F-S-16
D-S-15	The FS shall downlink the temperature during stand-by	F-S-16

Table 2-8: design requirements (3/3)

2.4 Operational Requirements

ID	Requirement text	Respond to
O-01	The FS shall operate fully autonomously during flight	C-01
O-02	HORACE shall accept a request for radio silence at any time while on the launch pad	C-01
O-03	The FS shall survive several power-on-off switching cycles during launch preparation	C-01
O-04	The FS shall start the video record latest at 0sec (lift-off)	D-S-03
O-05	The FS shall be shut down completely after 600sec	F-S-03
O-06	The FS shall be testable with EGSE	
O-07	FS shall accept a start command from the EGSE	
O-08	The received downlink data shall be saved by the groundsegment	F-S-10
O-09	The groundsegment shall allow realtime monitoring of the received downlink data	F-S-10
O-10	The data storage devices shall be removed directly after recovery	F-S-03
O-11	The integration and assembly of the FS in the module shall be simple	

Table 2-9: operational requirements

2.5 Constraints

ID	Requirement text	Respond to
C-01	The FS of HORACE is payload of REXUS16	

Table 2-10: constraints

3 PROJECT PLANNING

3.1 Work Breakdown Structure (WBS)

In the WBS all work packages for HORACE are listed below. In Figure 3-1 a broad overview and in the following figures a more detailed breakdown are given. An even more detailed version can be found in Appendix C . Already finished work packages are written in italics.

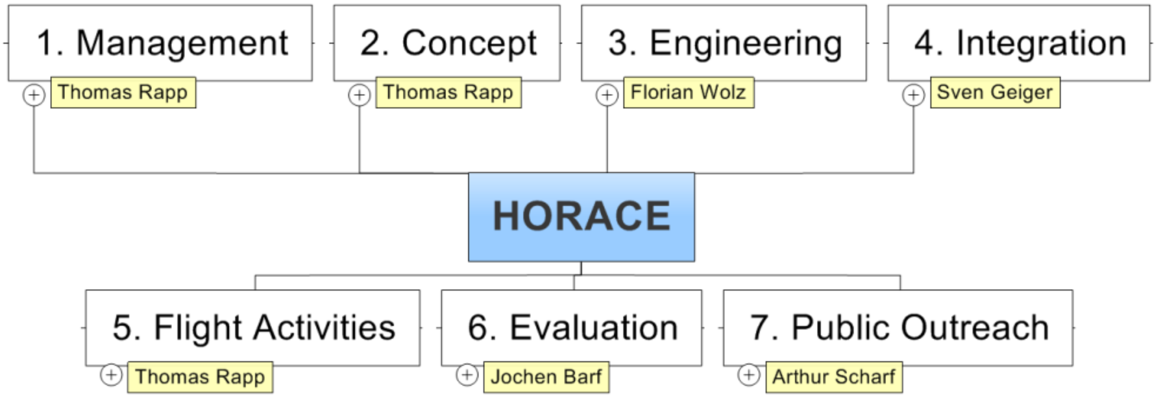


Figure 3-1: WBS overview

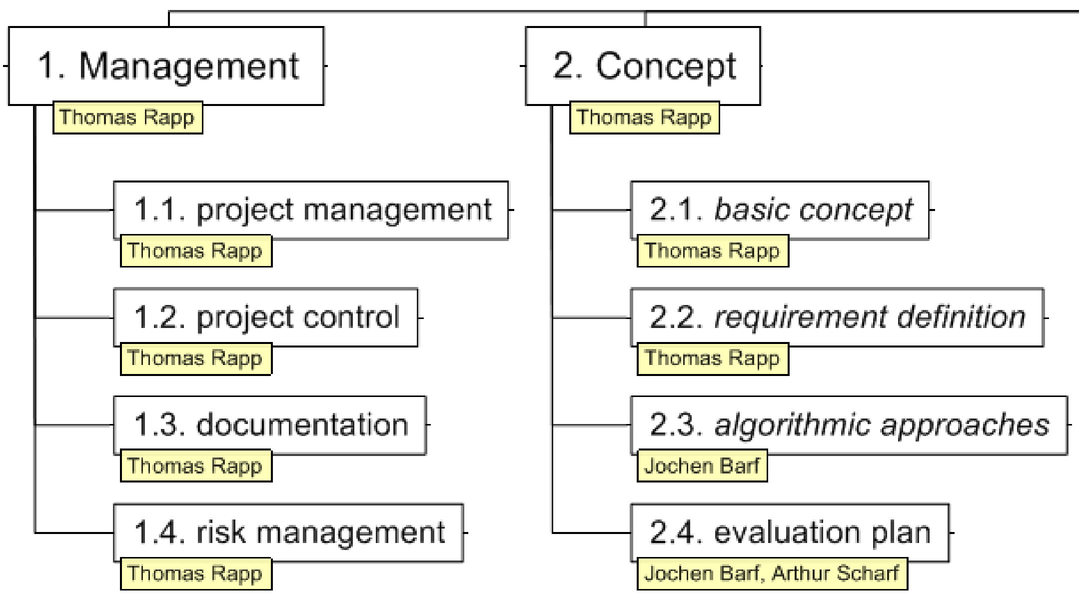


Figure 3-2: detailed WBS Management & Concept

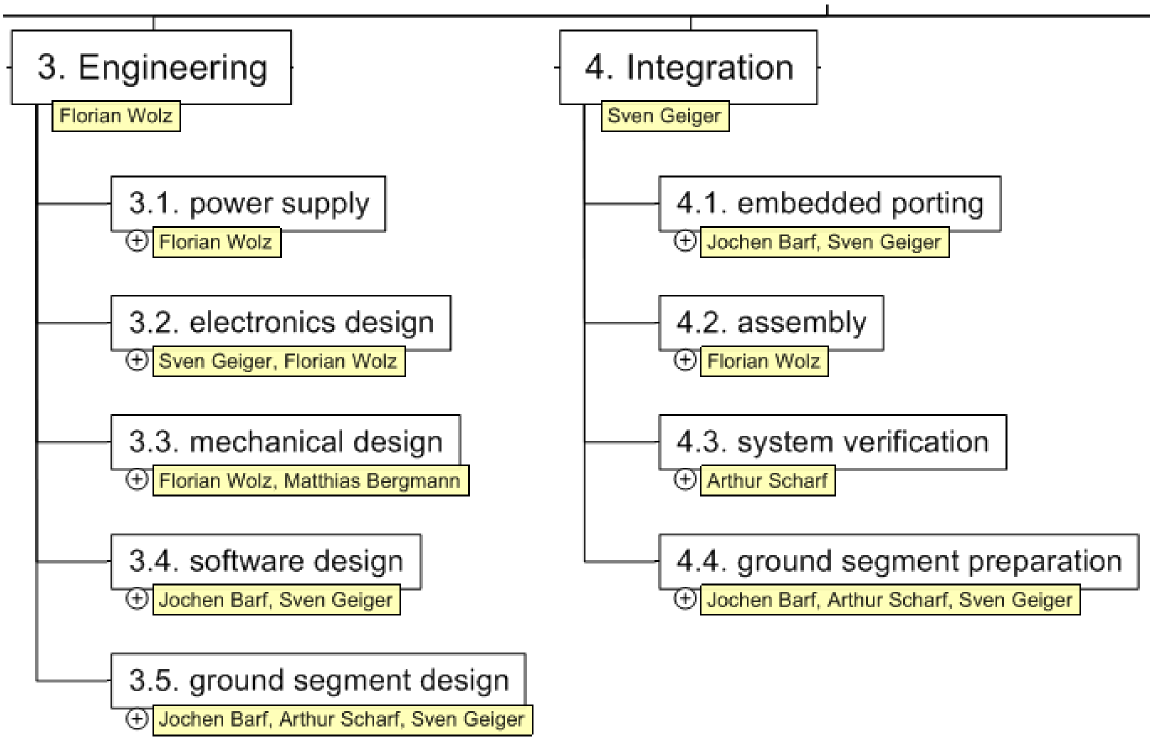


Figure 3-3: detailed WBS Engineering & Integration

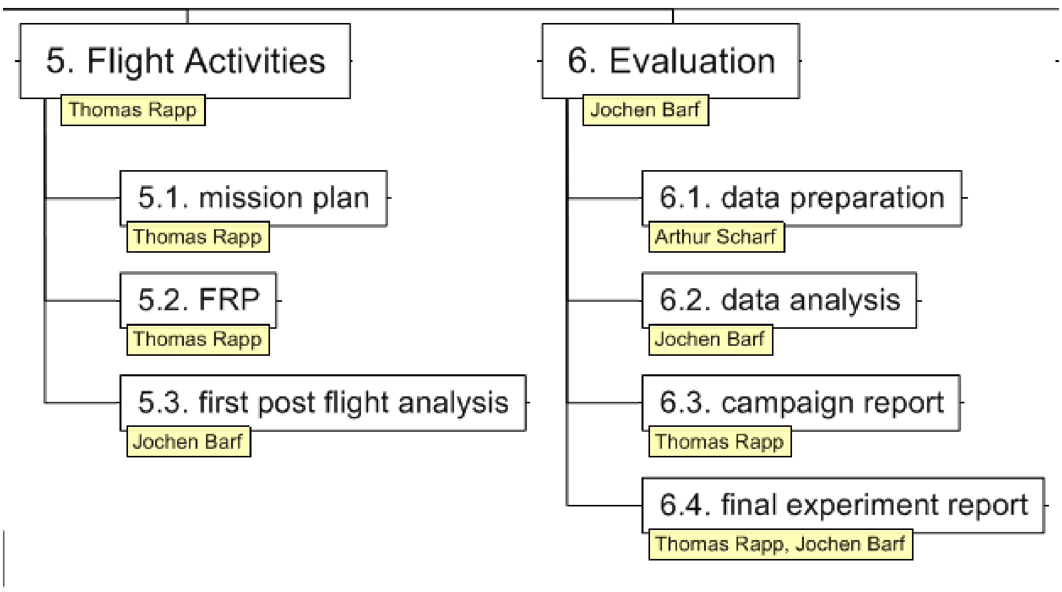


Figure 3-4: detailed WBS Flight Activities & Evaluation

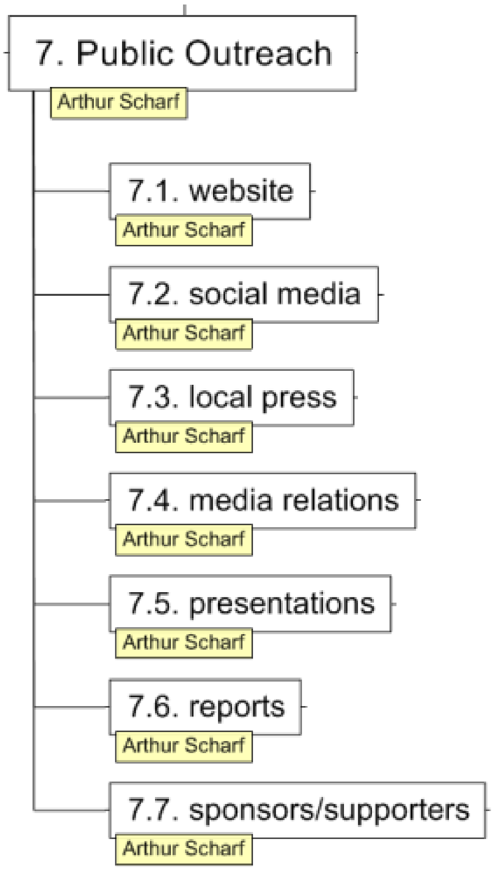


Figure 3-5: detailed WBS Public Outreach

3.2 Schedule

At this point in time, the project is delayed for about three weeks due to the intense work of nearly the complete team on a solution for thermal protection of the optical system, what was imposed as condition for passing the CDR by the review board. Thus, the work on the RIDs, in particular the protective window, retarded the beginning of the integration, which, however, until then progresses well. The solution for the protective window is not yet finished completely, but progresses in parallel with the rest of the integration. All components, except some spare items, the protective windows and professional made PCBs for the PDU, are delivered and therefore no further delays due to component purchase are expected. Also the algorithmic development progresses well, as recently major problems have been solved, and as the embedded porting is much simpler, the delay from CDR-level is nearly caught up. All in all, even the delay of three weeks does not severely affect the overall project progress. The current schedule for the whole project is shown in the following figure. The complete schedule with more detailed information, in particular for the upcoming implementation & simulation phase, is available in Appendix C .

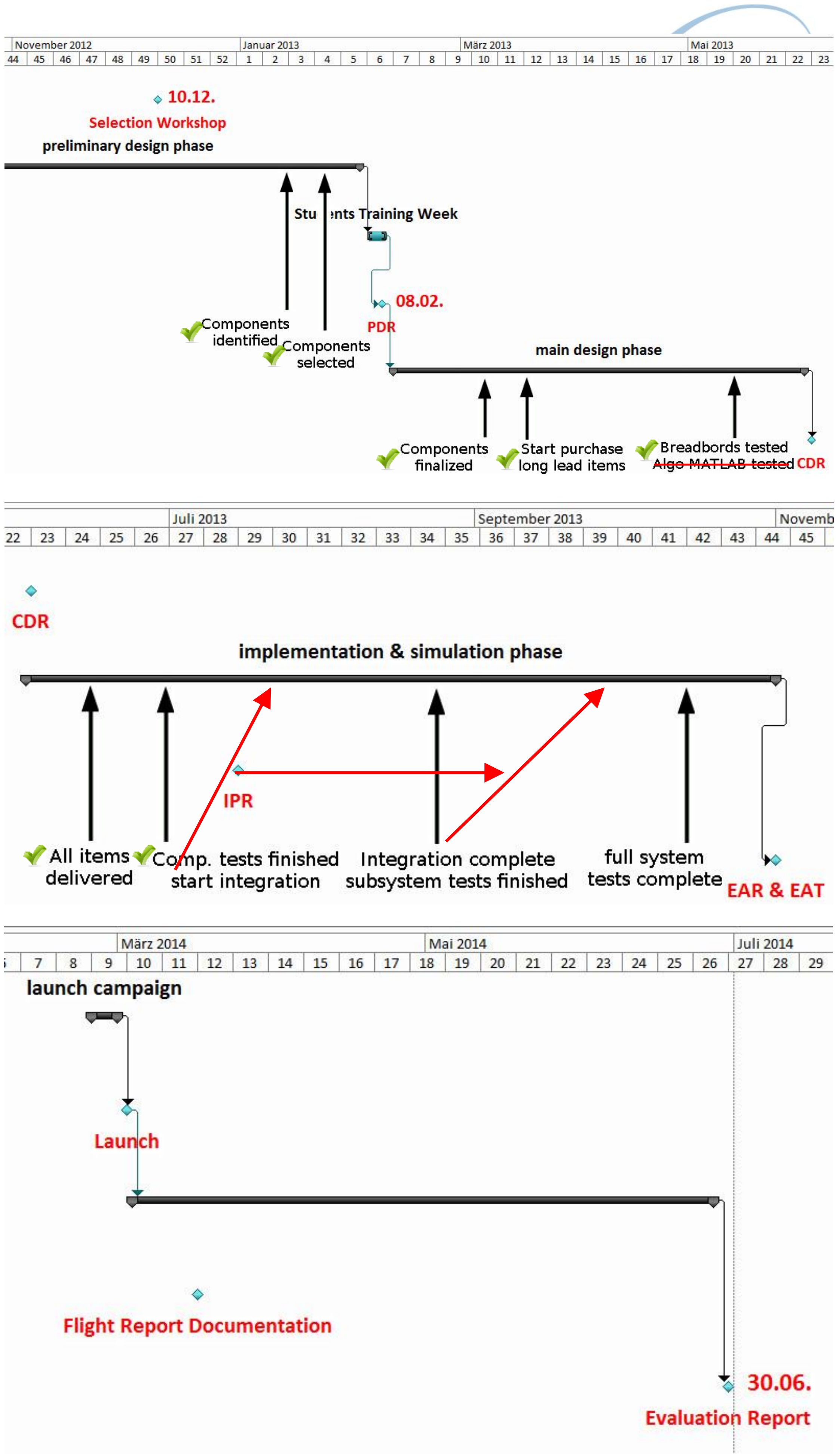


Figure 3-6: HORACE roadmap from initialisation to end of project

3.3 Resources

3.3.1 Manpower

As of now, the allocation of specific work packages and tasks to the team members has been completed (cf. 3.1) according to the disposition of fields of work (cf. 1.5.2).

The “Project Management” work package is assigned to Thomas Rapp, the team leader, who is ultimately also in charge of the “Concept” WP and “Flight Activities” WP, even though all team members work on sub-packages of them.

The “Engineering” WP and “Integration” WP, as well as the sub-packages concerning the electronics and mechanics of HORACE, are strongly related to each other. Following the focus, which is a bit different and the team members’ fields of work, “Engineering” is assigned to Florian Wolz and “Integration” to Sven Geiger. The sub-package “mechanical design” is completely assigned to Matthias Bergmann, who will take miscellaneous tasks and share workload with other team members on demand, when his main work packages are completed.

Jochen Barf is responsible for the software design of the flight segment, as well as of the ground segment, which is divided to several main work packages. As he thus is most familiar with the algorithm for horizon detection best, the “Evaluation” WP is also allocated to him.

The whole verification, testing and simulation of the experiment that are again divided to several main work packages are Arthur Scharf’s job. Additionally, he is in charge of the complete “Public Outreach” WP with all its sub-packages.

Currently, each team member can contribute approximately 10-15h/week for HORACE and all six team members plan to be active and available during all design, implementation, testing and operational phases of the experiment.

There are some fellow students, who are generally interested in HORACE (but not yet part of it for various reasons).These could possibly be incorporated into the team if necessary.

3.3.2 Budget

On the next page the budget plan for HORACE is given. As some minor values and travel expenses are yet only estimated (marked red), but the selection of components is finished except for the protective window, a margin of 20% is added. The calculation already includes spare respectively test items for critical and long lead items (core system, camera, lenses).

ID	Component	Sponsors	Status	No.	Single cost [EUR]	Total Cost [EUR]
Electronics						
1	Camera mvBlueCOUGAR-X102b	1x DLR 2x ZARM	1x delivered, 2x to be delivered	3	600,00	1.800,00
2	MIO-2260 with Intel Atom N455 1,66GHz	1x DLR, 1x JMU	2x delivered, 1x to be ordered	3	214,00	642,00
3	SDRAM 2GB DDR3 667MHz SO-DIMM	1x JMU	2x to be ordered, 1x delivered	3	40,00	120,00
4	Arduino Leonardo	3x EXP-TECH	3x delivered	3	0,00	0,00
5	Arduino SD shield	3x EXP-TECH	3x delivered	3	0,00	0,00
6	current sensor ACS712	2x Watterott	2x delivered	2	0,00	0,00
7	temperature sensor DS18B20	12x Watterott	12x delivered	12	3,38	40,56
8	SSDNow V+ 200 (SVP200S3/120G), 2.5"	3x DLR	3x delivered	4	99,44	397,76
9	Micro SD 2GB Class 2	2x JMU	2x delivered	2	4,40	8,80
10	CF Card 600x 8GB (TS8GCF600)	3x DLR	3x delivered	4	30,00	120,00
11	LM2596 DC/DC regulator module	9x JMU	9x delivered	9		0,00
12	PDU PCB board		3x to be ordered	3	70,00	210,00
13	RS-232 TTL Module for Arduino	3x JMU	2x delivered, 1x to be ordered	3	0,00	0,00
14	wiring / connectors	JMU, DLR	mostly delivered	1	200,00	200,00
Mechanical						
15	main structure		to be manufactured	1	100,00	100,00
16	lens + adapter ring	1x JMU, 2x ZARM	3x delivered	3	28,00	84,00
17	mounting support (screws)	Gedex	mostly delivered	1		0,00
18	protective window & mounting		to be ordered	2	300,00	600,00
Ground Support						
19	laptop		2x to be ordered	2	300,00	600,00
20	power supply		available at JMU	0	0,00	0,00
21	tools		available in team			0,00
Other						
22	CDR - travel expenses for 6th team member	JMU		1	0,00	0,00
23	Launch campaign - travel expenses for 5th & 6th team member			2	970,00	1.940,00
	SUM [EUR]					**6.863,12**
	Margin			**20%**		**1.372,62**
	TOTAL BUDGET [EUR]					**8.235,74**

Table 3-1: HORACE budget plan

3.3.3 External Support

The HORACE team is continuously seeking for external supporters for experiment realization, especially regarding technical and management expertise, hardware provisions and sponsoring as well as financial support.

Currently the team is generously supported by:

- The Chair of Aerospace Information Technology at University of Würzburg. In particular Prof. Dr. Hakan Kayal and Dipl.-Inf. Gerhard Fellinger support the team with technical and management expertise. Furthermore, the Chair of Aerospace Information Technology provides access to local facilities and expertise from other projects as well as logistic and financial support for HORACE.
- Alexander Bucher, designer from Munich, who designed the HORACE logo.
- EXP GmbH, an electronics shop from Saarbrücken generously sponsored three Arduino Leonardos and fitting SD-card-shields, which are used for the Measurement Unit of HORACE.
- Watterott electronic GmbH from Leinefelde handsomely sponsored all temperature and current sensors, which are used by the Measurement Unit to collect housekeeping data.
- Firma Gedex-Service from Erkrath sponsored the majority of the needed screws, washers and nuts.
- va-Q-tec AG from Würzburg generously provided their thermal chamber for testing our components at -40°C.

3.4 Outreach Approach

Since public outreach is a very important part of the HORACE-project we are going to involve a broad spectrum of news-spreading media. We will broadcast news the old-fashioned way via newspaper, especially the local newspaper “MainPost” in Würzburg. Also, we will be highly integrated in digital media like social websites etc. and we will be present at University’s both daily routine and special events to increase public awareness of our activities.

To reach this approach we will have to diversify what kind of information we will provide in which case. For that we spotted three parts of news-distribution, the scientific news services and University, local newspaper / TV broadcasts and the presence on the internet.

3.4.1 Scientific news services and University

As proposed in SED v1.0, we released an article about our experiment through the scientific news services of our University, to describe and share our progress we made with the experiment (see Appendix B for links to the articles). Further articles are planned for October and for March 2014, to present the outcome of our experiment.

Additionally, presentations at University of Würzburg, which already were part of our outreach approach, will be continued.

On January 16th, 2013 two of our team members presented the concept and first details about our experiment to a group of students and on January 22th, 2013 our team leader held a presentation in front of a European audience to get them a glimpse into what projects our university is involved in. On May, 27th Thomas and Jochen presented in front of an English class, to describe the experiment objectives and to arouse more interest for what we are doing.

Additionally we are in touch with our Supervisor to organize a lecture about the experiment. Potential dates to present our work progress to other interested students and people are at the end of June or the beginning of October. This presentation will probably take place within the so-called „Schnupperwoche“, a special week in which school-leavers who are interested in studying at the University of Würzburg can get a view into some student projects.

Furthermore, the experiment will be presented at the „Tag der Physik“, an open house day at the end of June where different science projects are presented to a broad local, also non-university audience. At this presentation we will especially concentrate on technical aspects and technical capability of the system. Another presentation, in which we will focus on the algorithm and other aspects of the software, will be held at the „Tag der Informatik“, a computer science day at our university.

For all presentations we will also prepare some gimmicks (e.g. posters and stickers/badges).

3.4.2 Local Publicity

To publicize the experiment regionally we will release some information about HORACE at the local newspaper called „MainPost“.

Additionally, we plan to print and distribute some informational posters in selected public places including our university.

3.4.3 Web presence

The Web presence of HORACE is one of the major public outreach tools, and divided into two parts.

First, we have the main website to keep our audience up to date about our development progress on a regularly basis and later. Afterwards outcome and results analysis of the experiment come to the fore.

The website also features a download section, where the documentation will be made available for the public and a sponsor section, the sponsors are broken down. For people who are interested in the experiment and want to get in touch with our team, the website also provides a contact section.

The other part of our web presence is the presence on social media like Facebook, Twitter, Google+ etc. Here we will publish short status updates and news at a regular basis to keep the virality of the project as high as possible and to reach a broad audience. Preferably, images or videos shall be uploaded to these pages since they are more likely to be watched than status updates consisting of plain text.

3.5 Risk Register

Risk ID
TC – technical/implementation
MS – mission
SF – safety
VE – vehicle
PE – personnel
EN – environmental

ID	Risk (& consequences)	P	S	PxS	Action
MS-010	*deleted, redundant to TC120*				
MS-020	LO-signal missed	B	4	low	> Use redundancy > Use SOE as backup
MS-030	*deleted, redundant to TC160*				
MS-040	camera does not resist temperature conditions	B	3	low	> thermal tests > isolation
MS-050	Horizon less than 50% of time visible	B	3	low	> use 2 cameras
MS-060	lenses or filters get fogged in the cold during CD	C	1	very low	> damp will evaporate during flight due to vaccum
MS-070	systems don't start up during CD due to low temperatures	B	3	low	> thermal tests > ask for heating by Service System
MS-080	fligh segment overheats during flight	B	3	low	> thermo-vacuum tests > passive cooling of hot parts
MS-090	protective window gets fogged or dirty during integration, testing or CD	C	2	low	> protection foil, removed as short as possible before flight
MS-091	remainder of MS-090	A	2	very low	
MS-100	protective window gets fogged or dirty during flight	B	2	very low	> fog will evaporate due to vaccuum
PE-010	team member not available during launch campaign	B	4	low	> creating detailed operation lists > recruit fellow students
PE-020	team member cannot work for a periode	C	2	low	> documentation > person proxy list
PE-030	fatal communication problems	B	3	low	> take care of each other > respectful discussions > frequent social activities
PE-031	remainder of PE30	A	3	very low	> mediation with supervisors

Table 3-2: risk register (1/3)

ID	Risk (& consequences)	P	S	PxS	Action
TC-010	camera can not provide sharp pictures fast enough after full illumination	D	2	low	> early illumination tests with camera
TC-020	electical connection between camera and core system gets lost	C	4	medium	> vibration tests > secure connectors
TC-021	remainder of TC-020	A	4	very low	
TC-030	electical connection between camera and video storage gets lost	C	3	low	> vibration tests > secure connectors
TC-040	MU software fails during flight	B	3	low	> software tests
TC-050	system damaged during implementation/shipping	C	4	medium	> have always spare HW componets (reorder spare items immediately, if one comp is damaged)
TC-051	remainder of TC-050	A	4	very low	
TC-060	camera does not resist pressure conditions	C	4	medium	> vacuum tests
TC-061	remainder of TC-060	A	4	very low	
TC-070	loss of developement data	B	3	low	> do regular backups > save in cloud
TC-080	manufacturer does not provide / cannot deliver hardware	B	2	very low	> order camera at other manufacturers
TC-090	*split up*				
TC-100	loss of downlink data caused by a software malfunction	B	2	low	> software tests (code coverage)
TC-110	loss of measurement data caused by a software malfunction	B	3	low	> software tests (code coverage)
TC-120	loss of calculated data caused by a software malfunction	B	4	low	> software tests (code coverage)
TC-130	loss of video data caused by a software malfunction	B	3	low	> software tests (code coverage)

Table 3-3: risk register (2/3)

ID	Risk (& consequences)	P	S	PxS	Action
TC-140	loss of measurement data caused by a mechanical influence	C	3	low	> recovery procedure > integration procedure > backup after recovery > complete shutdown before landing > secure mounting of memory device
TC-150	loss of calculated data caused by a mechanical influence	C	4	medium	> recovery procedure > integration procedure > backup after recovery > complete shutdown before landing > secure mounting of memory device
TC-151	remainder of TC-150	A	4	very low	
TC-160	loss of video data caused by a mechanical influence	C	3	low	> recovery procedure > integration procedure > backup after recovery > complete shutdown before landing > secure mounting of memory device
TC-170	hot gas inrush through unportected camera holes	C	4	medium	> protect holes with fin > close gap with adapter
TC-171	remainder of TC-170	A	4	very low	
TC-180	hot gas flow damages lens	B	4	low	> protect lens with fin
VE-010	Experiment can not be recovered or mass storage is destroyed during landing	B	4	low	> downlink minimum data
VE-020	camera gets loose from structure	C	4	medium	> vibration tests > secure mounting
VE-021	remainder of VE-020	A	4	very low	

Table 3-4: risk register (3/3)

4 EXPERIMENT DESCRIPTION

4.1 Experiment Setup

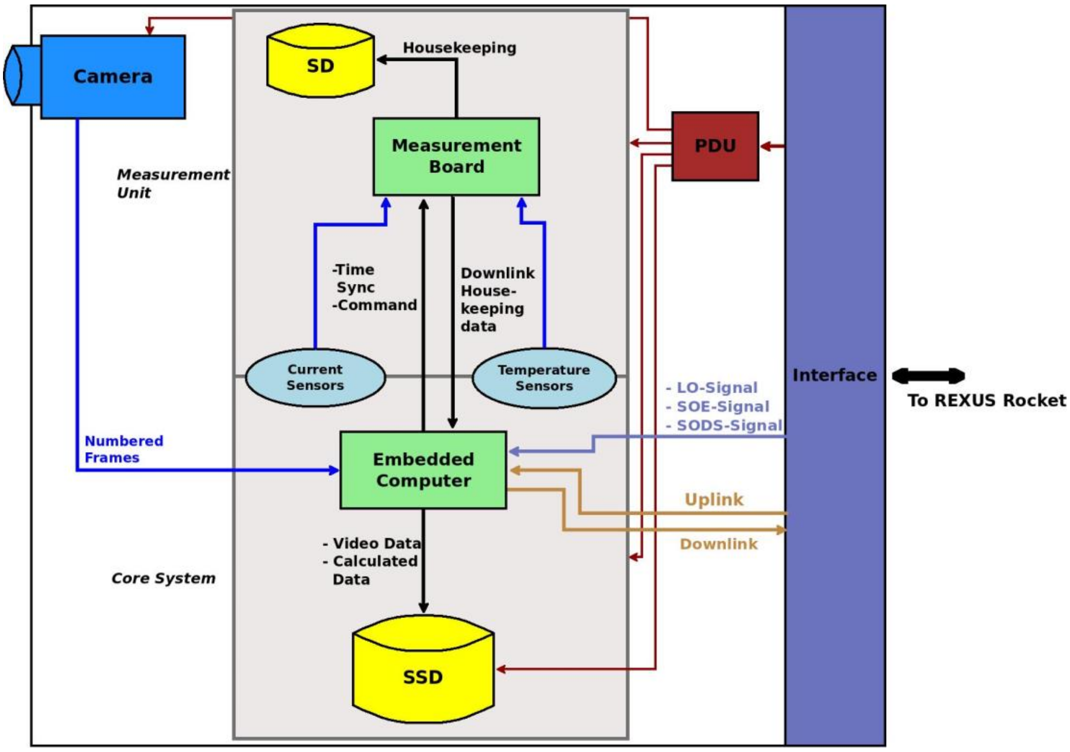


Figure 4-1: Flight Segment – experiment setup

As already given in Chapter 1.4 the subsystems of the Flight Segment are the core system, the camera, the PDU, the measurement unit and the structure.

The camera passes its image data of the outer environment of the REXUS rocket to the core system with an unique frame number via GigE-Vision interface.

The core system receives the numbered frames from the camera via GigE-Vision interface provided by the embedded computer and saves it via SATA to a fast mass memory (SSD). In a second step, image processing algorithms for horizon detection and the calculation of the 2D vector to the earth center run on the core system. The frame number of every processed frame is saved together with the global timestamp and the results of the calculations to another file on the SSD – so that bijective matching of the video data with the calculations is ensured. The global timestamp is reset at lift-off by the core system and is provided by an internal timer of the embedded computer.

Meanwhile, synchronized with the global timestamp, the measurement unit, which is an Arduino Leonardo, extended with a SD-shield, regularly measures the current consumed of each core system and the temperature at six points of the experiment – at the lens, PDU and core system of each of the two identical systems. The measurements with the global timestamp are stored on a SD-card within the measurement unit. During stand-by and shutdown-mode (cf. 4.8.1) the measurements are also passed to RXSM downlink via the core system using the RS-232 interfaces of both subsystems.

The PDU continuously provides the needed voltages for every single component throughout the whole experiment – from power ON (T-600s) to power OFF (T+600s), by regulating down the voltage provided by RXSM.

The electrical interface to RXSM is realized with a D-SUB 15 connector on side of RXSM and optocoupler circuits, which are located on the PDU-carrier-board, to process and forward the signals to the core system and the measurement unit. As besides the LO- and SODS-signal other signals are not needed for the flight segment, the SOE-signal is used as redundancy, if the LO-signal was missed. The downlink stream is directly conditioned and the uplink stream is interpreted by the core system. So the corresponding pins are connected via bidirectional RS-422 to RS-232 converter, also located on the PDU-carrier-board, to a serial interface of the core system.

The main structure, which is the mechanical interface to REXUS, are bulkhead mounted aluminium cases, in which all unprotected components except the camera and connecting wires are stored. The camera is directly mounted to the bulkhead with an aluminium mounting frame and observes the outer environment through a hole in the outer hull of REXUS. The thermal analysis has shown that no protecting window, which would impair video data, is necessary. To prevent hot gases from flowing directly on the lens, an aerodynamic fin is mounted on the module's outer skin. Additionally, an aluminium adapter is placed in the module to close the gap between the module's skin and the lens without obstructing the camera's field of view.

Originally, it was planned to match the calculated data also with recorded flight data of flight dynamics for post flight evaluation. But that data cannot be provided by RXSM with the needed accuracy and would only bring new information about the experiment's performance, if the video data was lost. Furthermore, if an own recording system was designed and implemented, in case of loss of data, it would be very likely that also (parts of) the flight dynamic data would be lost. Thus it was decided that no such recording system will be implemented and that one will forego the matching of the calculated data with data of flight dynamics.

As already discussed on PDR level, it is planned to let **two identical systems** fly in the same module. Unlike the demand of the PDR panel to implement own auxiliary power units to mitigate the problem that with two systems HORACE would consume too much power and thus exceed the total power budget of REXUS, some changes in the electrical design (cf. 4.5) are introduced, which led to lower power consumption (cf. 4.7). As it has not yet been confirmed by EuroLaunch, if that approach solves the problem adequately, the decision to fly two systems **stays preliminary**. If it is declined by EuroLaunch, HORACE **will not implement own auxiliary power units, but only fly one system.**

4.2 Experiment Interfaces

4.2.1 Mechanical

HORACE will feature a main structure with one single bulkhead loaded from both sides to store all components. Components with unprotected electrical parts or parts which emit high temperatures are stored in aluminium boxes mounted onto the bulkhead; others, like the camera are directly mounted onto the bulkhead with a bracket to secure its connection. The highest parts are mounted on the lower side of the bulkhead, while the lower parts are mounted onto the upper side. Additionally, the setup is built highly symmetrical to ensure that the center of gravity is very near the z_{BF}-axis of the rocket.

For each camera a hole in the outer structure of the REXUS rocket is needed as optical interface. To protect the experiment from hot gases those holes are closed with protective windows which are mounted to the rocket's skin.

With a total height of 77mm, the assembly fits into a 120mm long module, regarding the restrictions for gaps of 10mm and 20mm to the lower and upper end of the module.

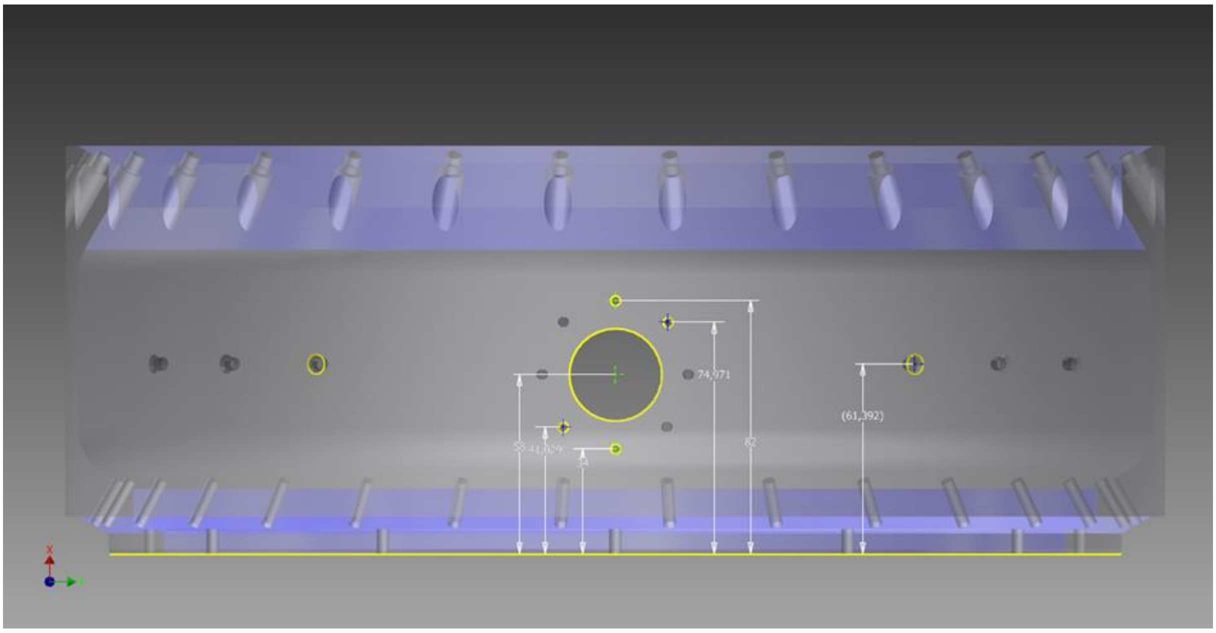


Figure 4-2: required modifications (holes) of the 120mm module

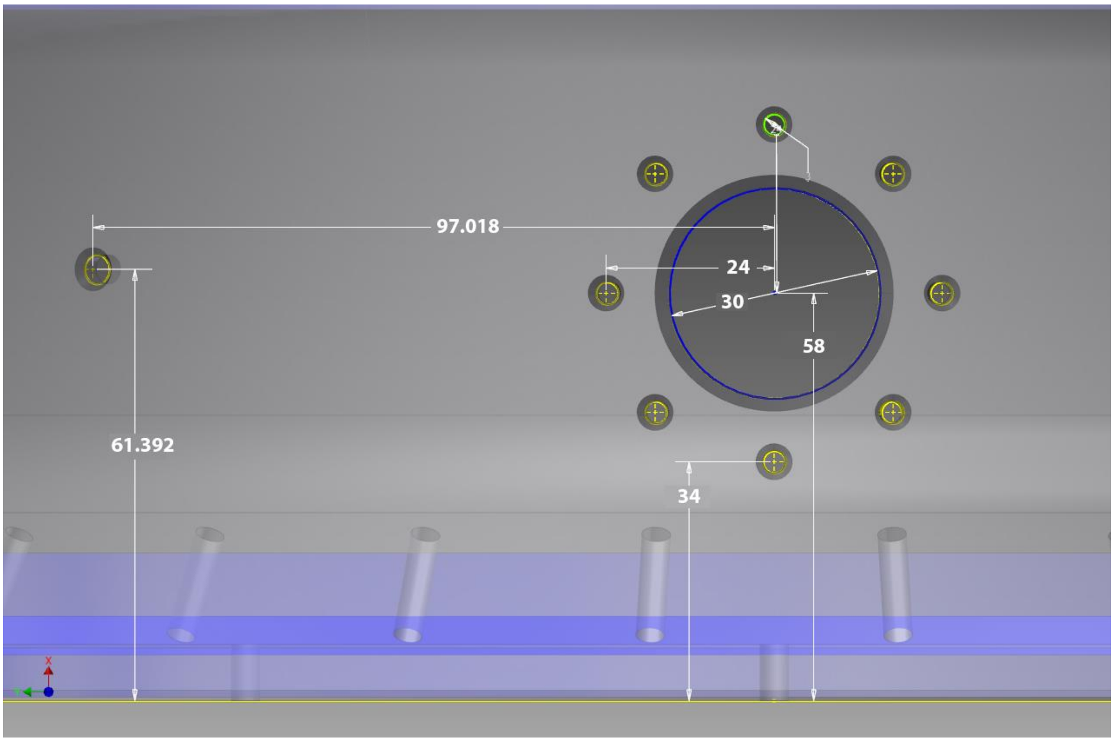


Figure 4-3: detailed view of bores in the module

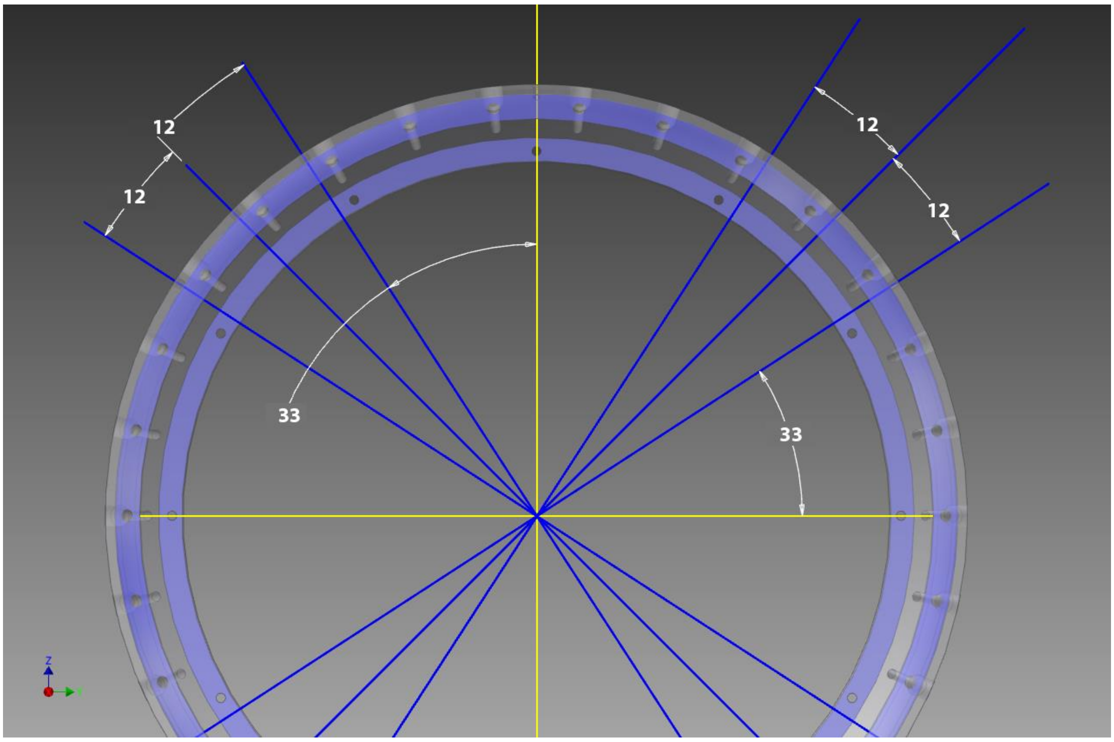


Figure 4-4: top view of the module with angles of bores indicated

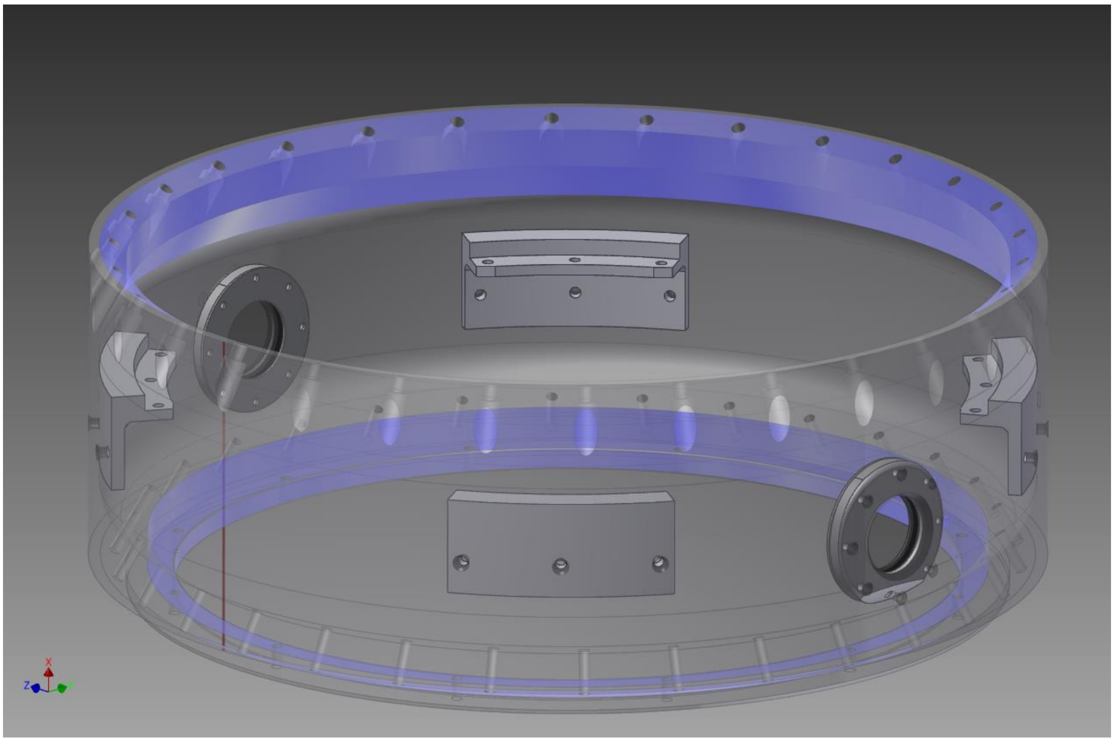


Figure 4-5: module with brackets and protective windows

Two holes are needed at a 90° and 270° angle from the 0°-line with a diameter of 30mm at a height of 58mm from the bottom line to the holes' center for the cameras. Around these holes 8 bores with a diameter of 3.2mm in 45° steps are required, which were originally designated for fins and aluminium adapters, but are now used to mount the protective windows. Thus, this design change does not affect the mechanical interface to the REXUS rocket at all.

For the mounting of the bulkhead, using the default brackets, 12 bores with a diameter of 4mm placed at a height of 61.4mm from the bottom line are needed. The middle bores are orientated at a 45°, 135°, 225° and 315° angle from the 0°-line. (for more CAD-drawings cf. Appendix E)

Mechanical stress analysis for the modified module showed that no further measures are necessary to guarantee stability of the module (cf. Appendix E)

4.2.2 Electrical

The HORACE flight segment will use the power provided by RXSM, and does not use own auxiliary power supply. The unregulated voltage between 24V and 36V is taken to the experiment via the D-Sub 15 connector and converted continuously to the needed operating voltages of all electrical components by the PDU (cf. 4.5.4) throughout the whole experiment operating time (from T-600 to T+600).

HORACE will consume about 67W on average if two identical core systems are flown, respectively 35W for one system (both including 50% margin).

The signals sent to HORACE from RXSM, LO-signal, SOE-signal and SODS-signal, are processed by a separate signal interface, which is physically located on the PDU-carrier-board. The interface uses optocouplers to ensure galvanic separation of the experiment and RXSM and to provide the signals to every component. The core system is therefore directly connected to the interface and is directly triggered by the incoming signals, which are then forwarded to the MU. As the LO- and SODS-signal are actually the only needed signals, the SOE-signal is implemented as redundancy if the LO-signal was missed because of technical malfunction, and is sent to HORACE with few seconds delay to lift-off (cf. 4.8.1).

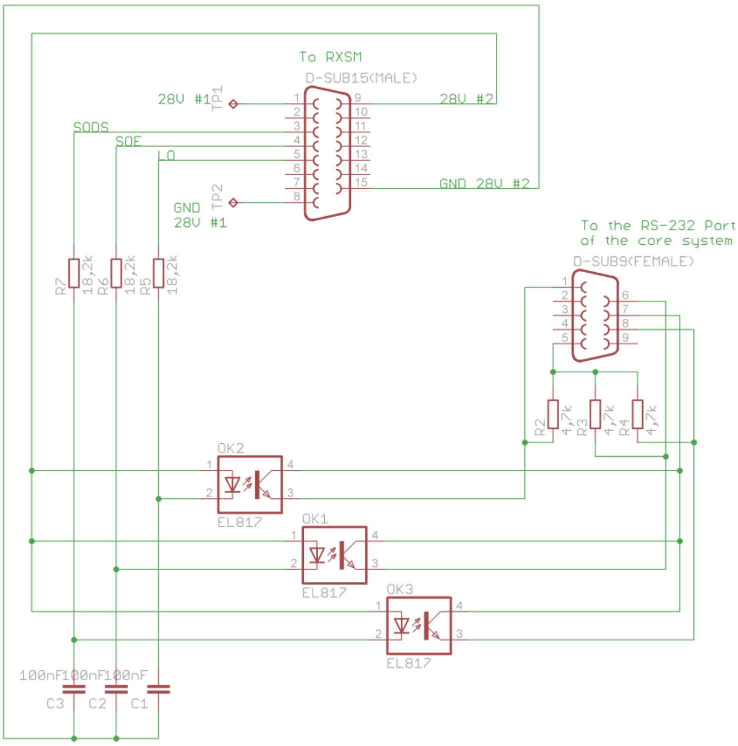


Figure 4-6: signal interface

The core system implements the up- and downlink interface to RXSM according to the RS-422 standard defined in the REXUS manual via one of its RS-232 interfaces. Therefore the RS-232 to RS-422 converter MAX488CSA is used as shown below. More information about data interfaces can be found in 4.2.4.

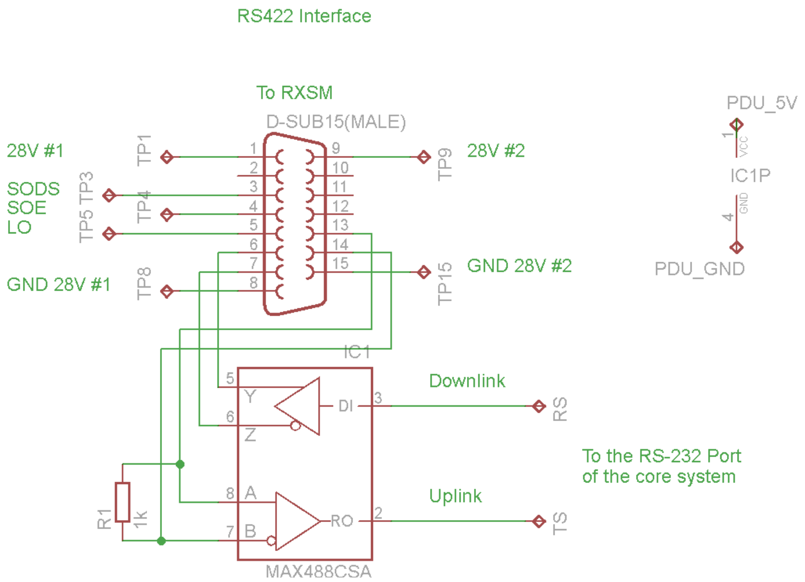


Figure 4-7: electronic schematic TM/TC interface

The figures next pages show the complete electronic schematics of the PDU-carrier-board which implements all electrical interfaces. Its PCB-layout can be found in Appendix F .

If two identical systems are flown, also two electrical interfaces to RXSM are needed.

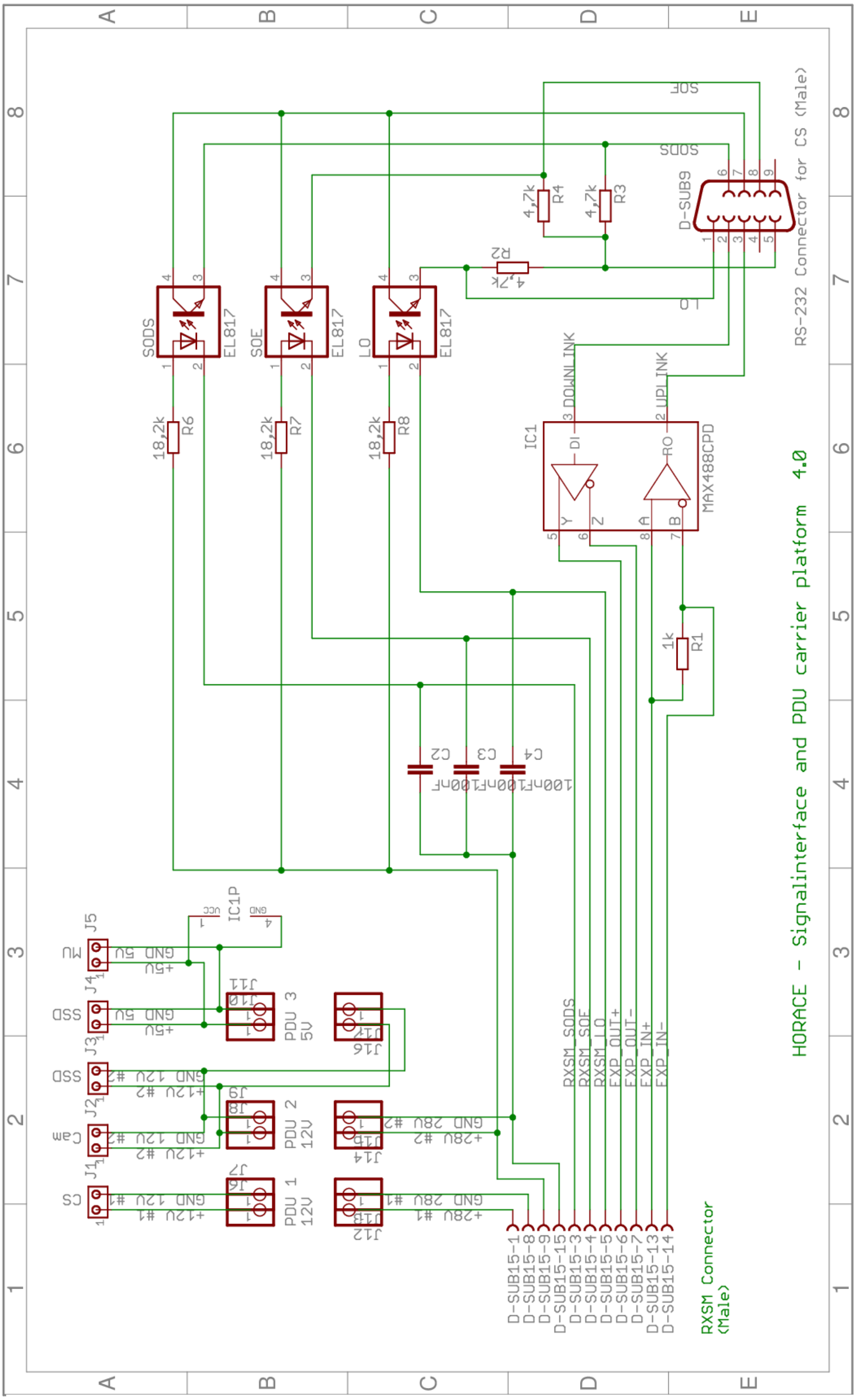


Figure 4-8: electronics schematic for complete PDU-carrier-board (including signal & TM/TC interface)

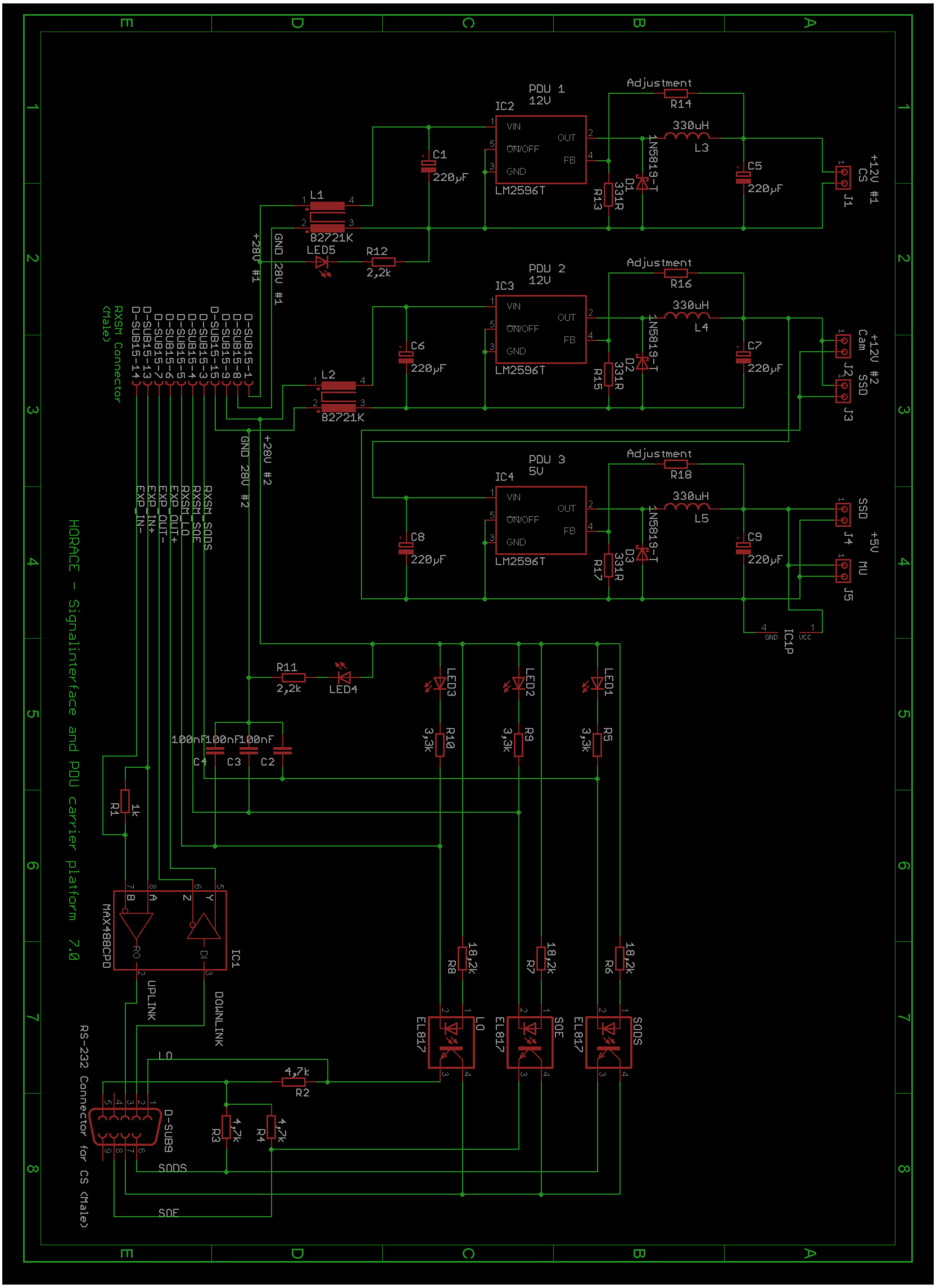


Figure 4-9: full electrical interface (modules on carrier board)

4.2.3 Thermal

There are 6 components (2x camera, 2x CS, 2x PDU) which can heat up their environment, 4 of them can generate temperatures up to a peak value of 60°C (2xCS and 2xPDU) which will only be reached under maximum workload.

The 2 other components are the two cameras, which only heat up to a maximum of 35°C under full stress.

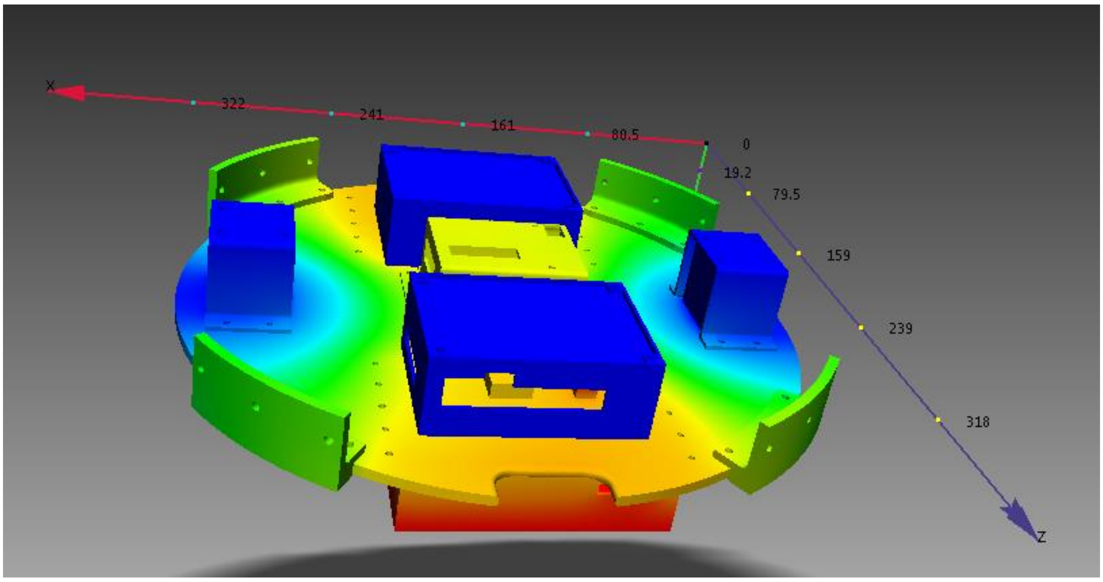


Figure 4-10: heat distribution in the flight segment in vacuum, regarding only internal heat sources; button-up view; blue=35°C, red=60°C

External heat sources are the module itself, either through heating up by air-friction or hot gas inrush through the camera holes. To prevent hot gas inrush, the holes for the cameras are mechanically closed with protective windows.

Heatsinks are mounted onto the parts which generate the most heat (PDU and CS). Additionally, to further decrease the overall temperature the heatsinks are thermally connected to the casings, which are connected to the bulkhead. Thus the complete structure can serve as a heatsink. The expected overall increase in temperature is in the required ranges stated in the REXUS manual.

For the complete simulation report see Appendix E .

4.2.4 Data Interfaces

In order to gain safe and reliable data and signal interfaces both to RXSM and for intra-experimental communication, protocols will be implemented for each RS-232 interface of the core system. The core system conditions the data to be sent to ground station via the RXSM telemetry infrastructure, as well as TC is implemented by the RS-232 interface of the core system. TC is used for on ground commanding and pre-campaign testing/verification. During flight TC is not needed for operational functions, although it is implemented for testing.

Take note that in this chapter, only protocols for transmitting and receiving are described on a low level, e.g. formatting and failure recognizing. For more information about the transmitted data packages see 4.8.2.

For definition of “master core system”, resp. “slave core system” see 4.5.2

4.2.4.1 First RS-232 of Master/Slave CS

The following protocols are implemented to the first RS-232 interface of both master and slave core systems.

CS → RXSM

Used for downlink data packages, according to software mode (cf. 4.8.2).
Baud rate: 38.4 kbit/s
Format: 8 bits, 1 start and stop bit, no parity
Used Pins: TX-pin for transmitting downlink protocol frames.

The header-information of the downlink protocol frame consists of a synchronisation word, a message counter and the current software mode. The synchronisation word indicates a new protocol frame in order to decode the protocol frames on ground. Since the data package size and division is depending on the software mode (cf. 4.8.2), this information is essential for decoding downlinked data. The message counter provides checking whether information was lost during transmission. For failure recognizing a checksum and also a cyclic redundancy check is implemented.
As required in REXUS manual a gap of 3ms between two following protocol frames will be implemented.

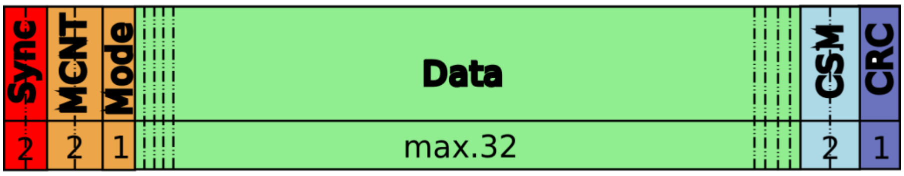


Figure 4-11: protocol frame CS → RXSM

Sync: synchronisation word
Mode: software mode of the core system
MCNT: message counter
Data: data package depending on software mode (cf. 4.8.2)
Checksum: sum of all data bytes
CRC: cyclic redundancy check

RXSM → CS

Used for on-ground uplink and receiving LO, SOE, SODS
Baud rate: 38.4 kbit/s
Format: 8 bits, 1 start and stop bit, no parity
Used Pins: RX-pin for receiving uplink protocol frames.
CD-pin for trapping LO-signal.
DSR-pin for trapping SOE-signal.
CTS-pin for trapping SODS-signal.

In addition to a simple 8-bit command word, that is decoded on the core system, also an synchronisation word and an cyclic redundancy check provide a save commanding of the experiment on ground. While the synchronisation word is used to be sure that actually a TC was sent, the cyclic redundancy check ensures that a correct command was gained. Besides TC also the different signals provided by RXSM will be trapped with this interface. To prevent glitches on the signal line being misinterpreted as signals (as a rising edge event occurs), the CS waits for a falling edge event for 15ms before accepting the signal.

Sync	Command	CRC
2	1	1

Figure 4-12: protocol frame RXSM → CS

Sync: synchronisation word
Command: telecommand word
CRC: cyclic redundancy check

4.2.4.2 Second RS-232 of Master CS only

The following protocols are implemented on the second RS-232 interface of only the master core system, but not (respectively implemented but deactivated) on the slave core system.

MasterCS → MU

Used for TC- and signal forwarding, as well as providing time synchronisation.
Baud rate: 38.4 kbit/s
Format: 8 bits, 1 start and stop bit, no parity
Used Pins: TX-pin on CS for transmitting protocol frames.
CD-pin on CS for forwarding LO, SOE and SODS-Signal.
DSR-pin on CS for sending time pulse.

RX-pin on MU for receiving protocol frames.
CD-pin on MU for trapping forwarded LO, SOE, SODS-signal.
DSR-pin on MU for capturing time pulse.

The synchronisation word indicates a new protocol frame, while a checksum is used for failure recognition.

While the data package contains the current time of the core system, also a pulse on the DSR-pin is sent when transmitting this protocol frame. This provides an accurate time synchronisation between the core system and the MU.

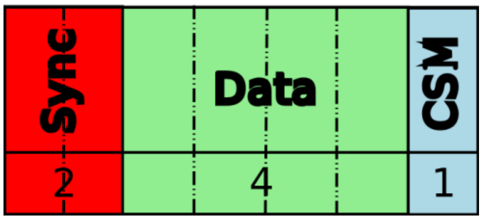


Figure 4-13: protocol frame MasterCS → MU

Sync: synchronisation word
Data: data package including command and time (cf. 4.8.2)
Checksum: sum of all data bytes

MU → MasterCS

Use: forward housekeeping data for downlink
Baud rate: 38.4 kbit/s
Format: 8 bits, 1 start and stop bit, no parity
Used Pins: TX-pin on MU for transmitting protocol frame.
RX-pin on CS for receiving protocol frame.

Like in other protocols the synchronisation word is used to identify new protocol frames and the checksum for failure recognition.

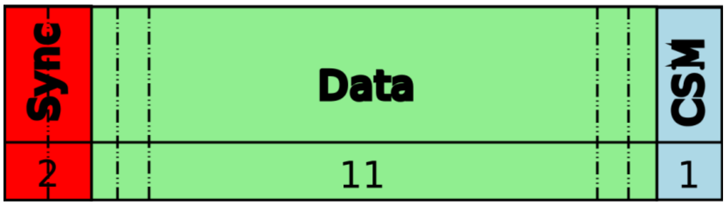


Figure 4-14: protocol frame MU → MasterCS

Sync: synchronisation word
Data: data package (cf. 4.8.2)
Checksum: sum of all data bytes

4.2.4.3 Others

Camera → CS

The data interface from the camera to the core system to transfer the image data is implemented using the standardized GigE-vision protocol.

CS → SSD

The data interface from the core system to the SSD to write video and calculated data is implemented using the standardized SATA protocol.

MU → SD

The data interface from the MU to the SD to write housekeeping data is implemented using the standardized SPI protocol.

Sensors → MU

The data interface from the digital sensors to the MU to read the raw housekeeping data is implemented using the standardized OneWire protocol.

The figure given below shows an overview of all electrical and data interfaces, as well as the used cabling and connectors.

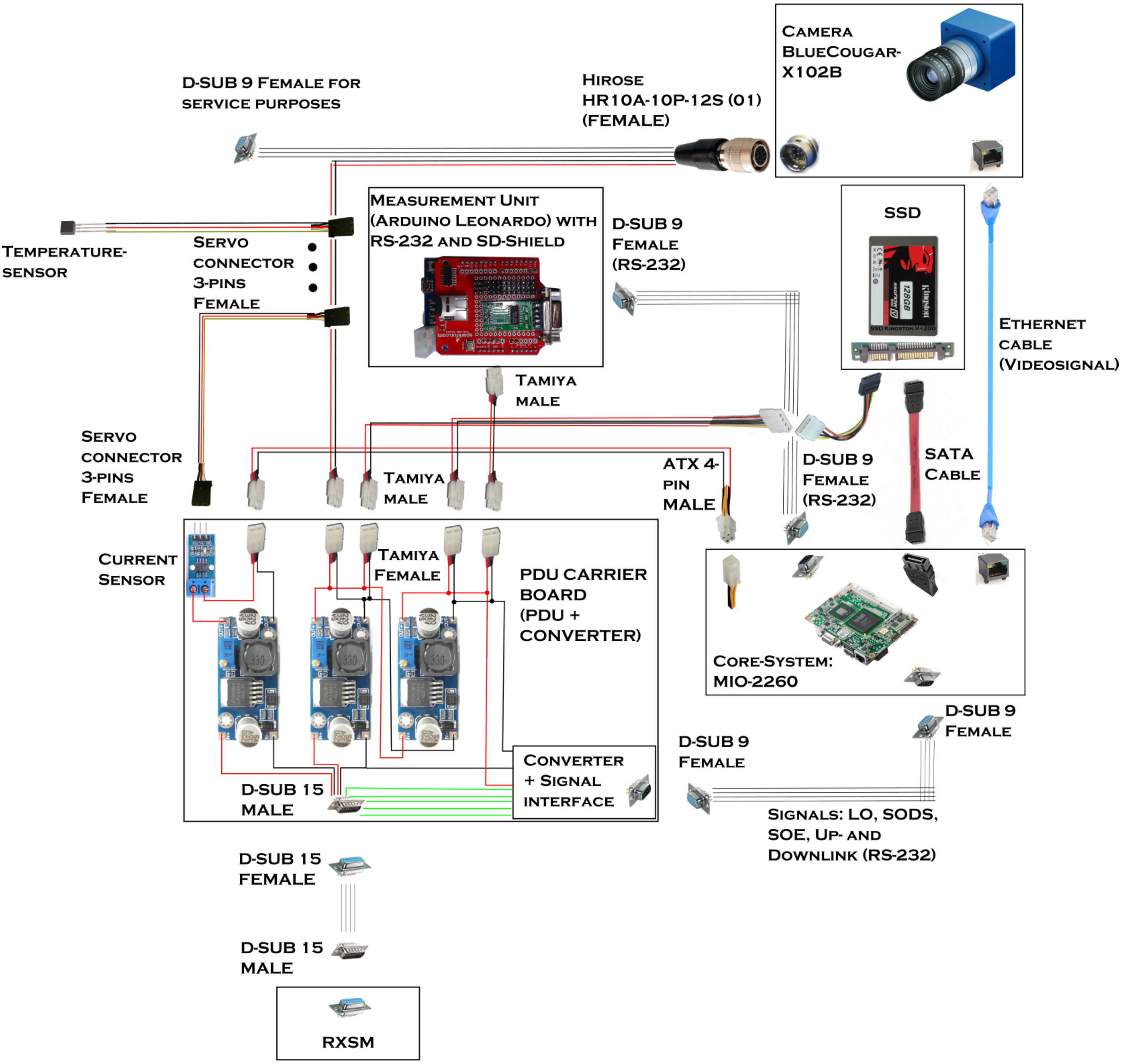


Figure 4-15: overview of electrical & data interfaces, cabling & connectors

4.3 Experiment Components

ID	Component	Manufacturer	Status	Comment
Electronics				
1	Camera mvBlueCOUGAR-X102b	Matrix Vision	1x delivered, 2x to be delivered	
2	MIO-2260 with Intel Atom N455 1,66GHz	Advantech	2x delivered, 1x to be ordered	
3	SDRAM 2GB DDR3 667MHz SO-DIMM		2x to be ordered, 1x delivered	
4	Arduino Leonardo	Arduino	3x delivered	
5	Arduino SD shield	Arduino	3x delivered	
6	current sensor ACS712	Allegro MicroSystems Inc.	2x delivered	
7	temperature sensor DS18B20	Maxim Integrated	12x delivered	
8	SSDNow V+ 200 (SVP200S3/120G), 2.5"	Kingston	3x delivered	
9	Micro SD 2GB Class 2	SanDisk	2x delivered	
10	CF Card 600x 8GB (TS8GCF600)	Transcend	3x delivered	
11	LM2596 DC/DC regulator module	Linear Technology	9x delivered	
12	PDU PCB board		3x to be ordered	
13	RS-232 TTL Module for Arduino		2x delivered, 1x to be ordered	
14	wiring / connectors	several	mostly delivered	
Mechanical				
15	main structure	JMU workshop	to be manufactured	
16	lens + adapter ring		3x delivered	
17	mounting support (screws)	several	mostly delivered	
18	protective window & mounting	Schott?	to be ordered	
Ground Support				
19	laptop	e.g. IBM Lenovo	2x to be ordered	serial interface needed; older models suffice
20	power supply	--	available at JMU	
21	tools	--	available in team	

Table 4-1: experiment components

Experiment mass (in kg):	7.65kg (for 2 systems, including 10% margin, including module)
Experiment dimensions (in m):	0.318 m x 0.348 m x 0.0799m
Experiment footprint area (in m^2):	0.038 m^2
Experiment volume (in m^3):	$1.1 \cdot 10^{-3}$ m^3
Experiment expected COG (centre of gravity) position:	coordinate system: axes parallel to BF, origin on z_{BF} in lowest plane of module: x=0.0mm y=0.0mm z=66.6mm; ±<10mm each axis

Table 4-2: Experiment summary table

4.4 Mechanical Design

The two main functions of the mechanical design of HORACE are tight and safe mounting for a safe flight, as well as the guarantee of good visibility of the horizon for the cameras. Figure 4-16 below shows the mechanical setup of HORACE within the 120mm-module.

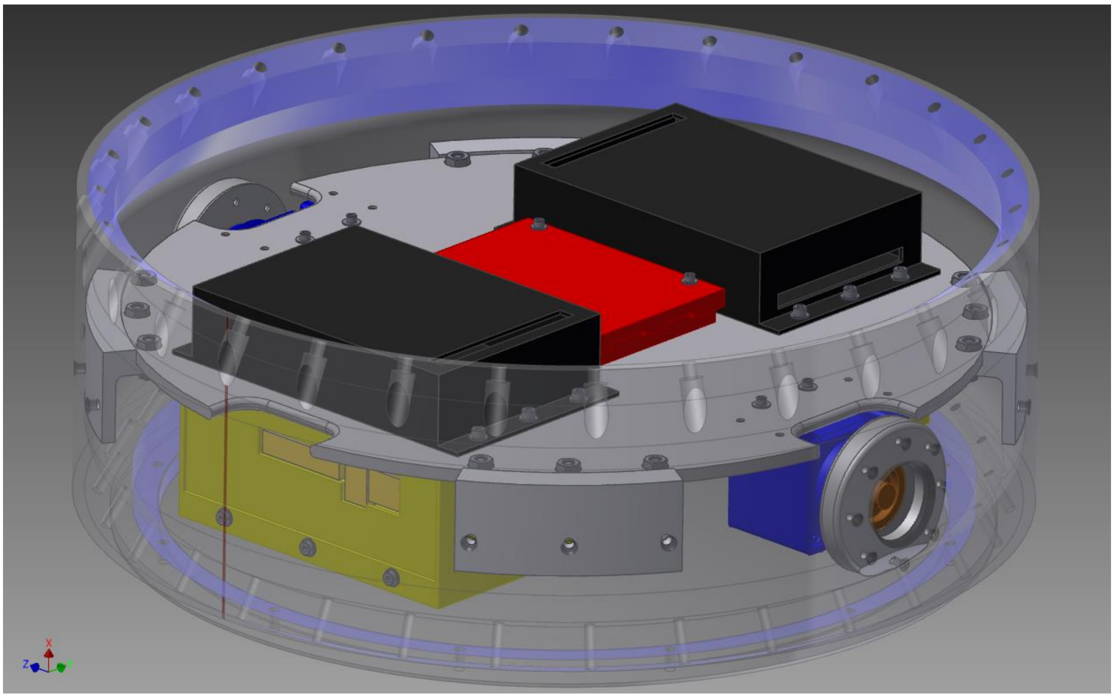


Figure 4-16: 3D-view of flight segment setup

For easy and fast integration to the module and good utilization of the available volume every single component for two identical experiment systems is mounted onto both sides of the 4mm bulkhead of the experiment's main structure, which itself is mounted to the module with the standardized brackets and bolts. The bores are at a height of 61.4mm from the lowest surface of the module.

To have easy access to the data storage devices before integration in the module and during disassembly they are not boxed. Wiring within the module is supposed to be done through the cable feedthroughs of the bulkhead plate. The specific location of each component shown in Figure 4-18 & Figure 4-19 shall ensure a good utilization of volume and footprint area, as well as best possible symmetrical assembly to keep the center of gravity near the rockets z_{BF}-axis (see Figure 4-19).

Also the two cameras are mounted to the main structure symmetrically and so that their view axes are anti-parallel. Thus, in most cases if the horizon cannot be seen by one camera it is visible for the other one. Additionally to increase the mounting stability the cameras are mounted with brackets. Both cameras are supposed to have no direct contact to the rocket skin for thermal reasons and are protected by two windows which do not affect the cameras' field of view. (cf. also Appendix A – RID-report for protective window).

The windows are, due to the material's good optical and thermal characteristics, made of borosilicate, also known as Duran. The glass itself is cylindrical with a height of 3mm and a diameter of 40mm (cf. Figure 4-25). To mount the glass onto the module, it is embedded in a socket, which itself is curved on the side which is in direct contact to the module (cf. Figure 4-21, Figure 4-22, Figure 4-23).

Inside the socket, the glasses are reinforced with a silicon seal, to buffer the vibrations of the rocket and guarantee tight mounting (cf. Figure 4-24).

The socket will use the mounting points originally designated for the conical adapter and the fins. Thus the design change does not affect the mechanical interface to the REXUS rocket.

The components are mostly fixed with M3 and M4 screws (brackets). To secure the connections, locknuts are used in combination with Loctite.

More exported CAD-drawings as well as the original CAD-files and reports of stress analysis can be found in Appendix E .

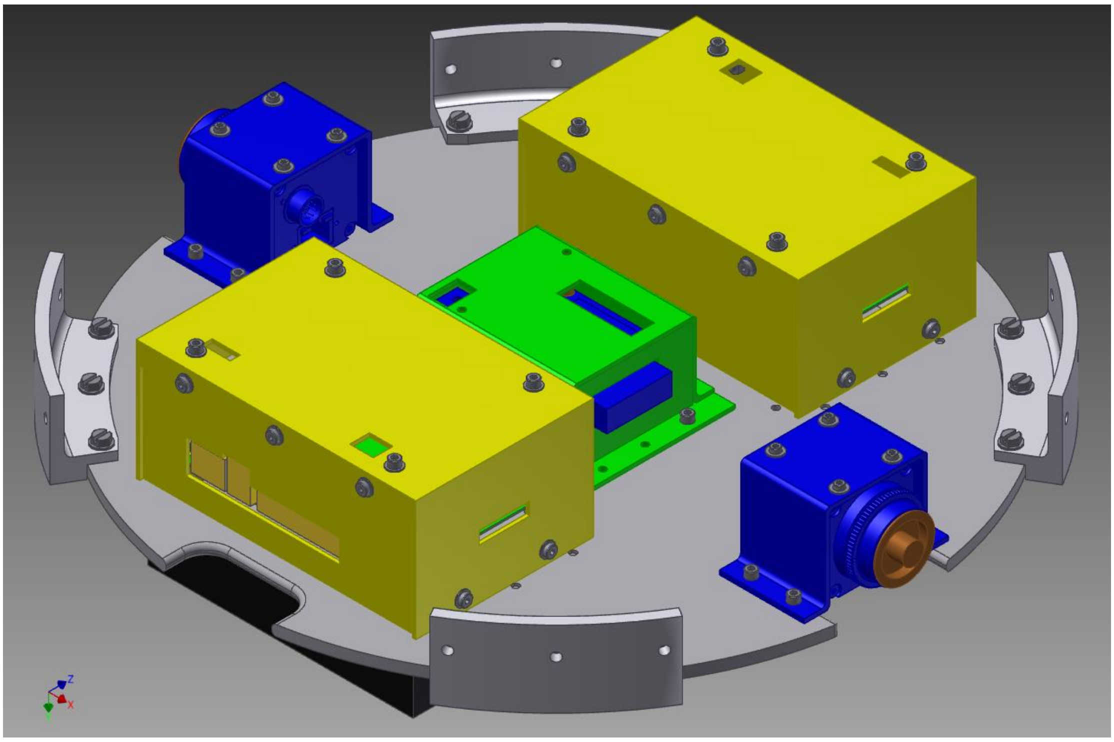


Figure 4-17: 3D-view of flight segment setup without module

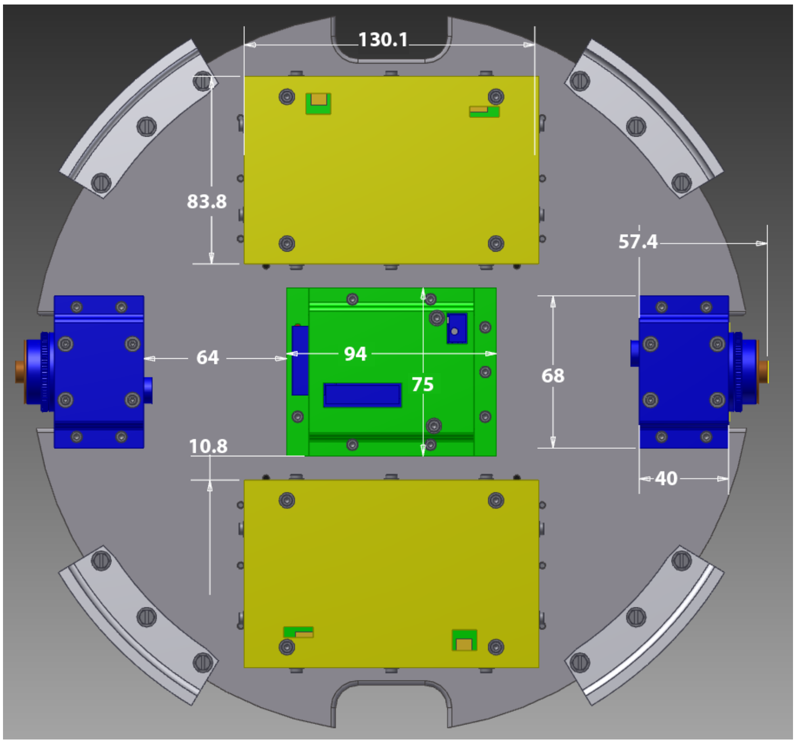


Figure 4-18: bottom-up-view; grey - bulkhead, brackets; blue: cameras with brackets; yellow - core systems; green - measurement unit

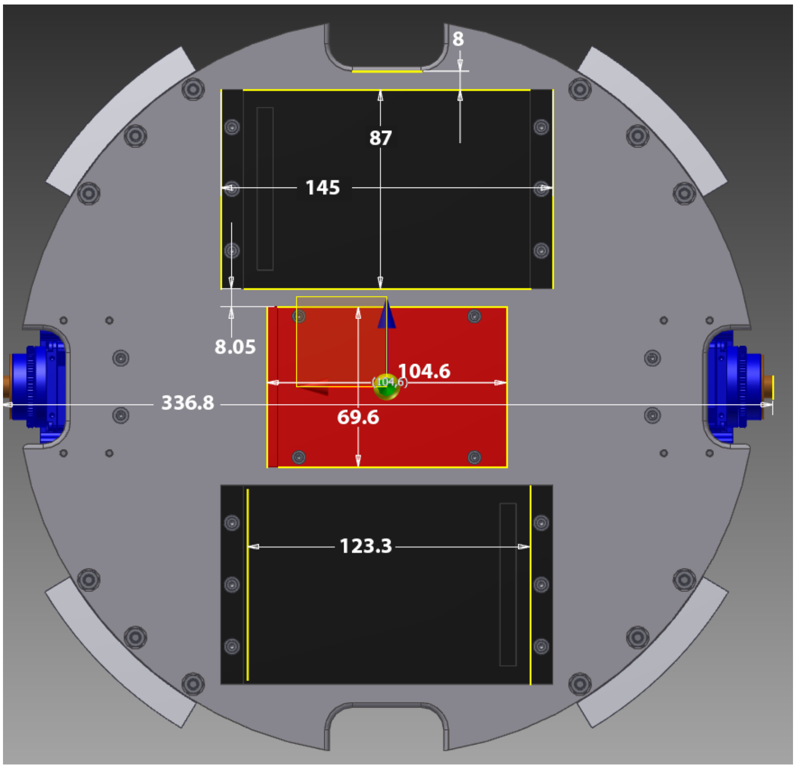


Figure 4-19: top-down view with COG: black - PDUs; red - SSDs

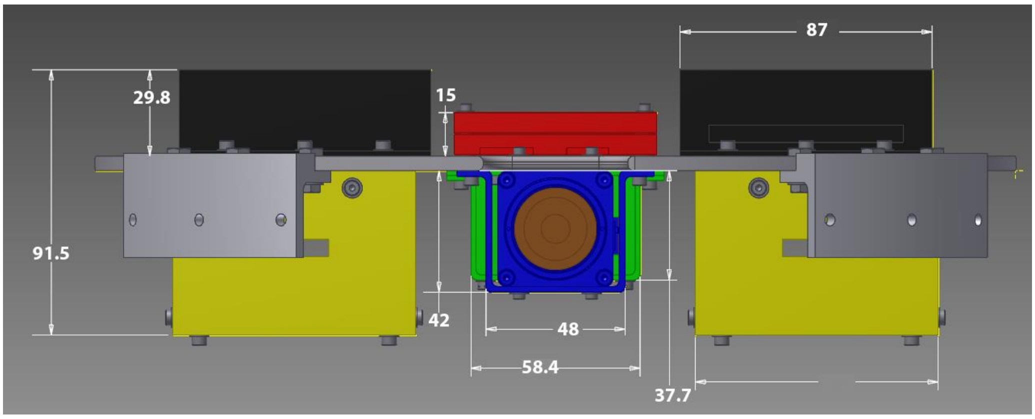


Figure 4-20: side view

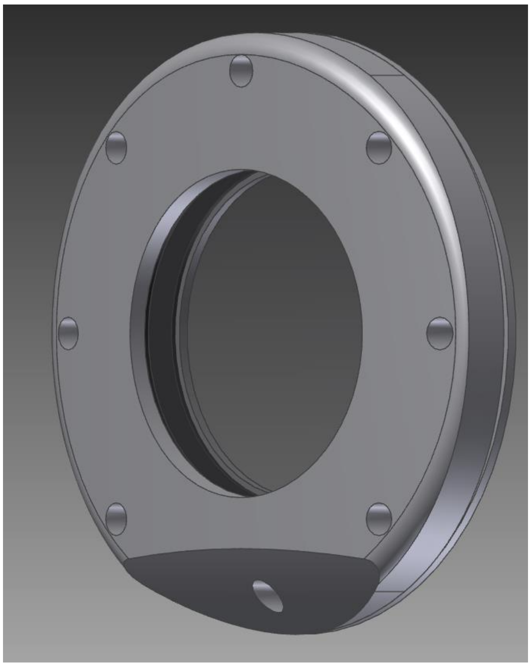


Figure 4-22: detailed view protective window

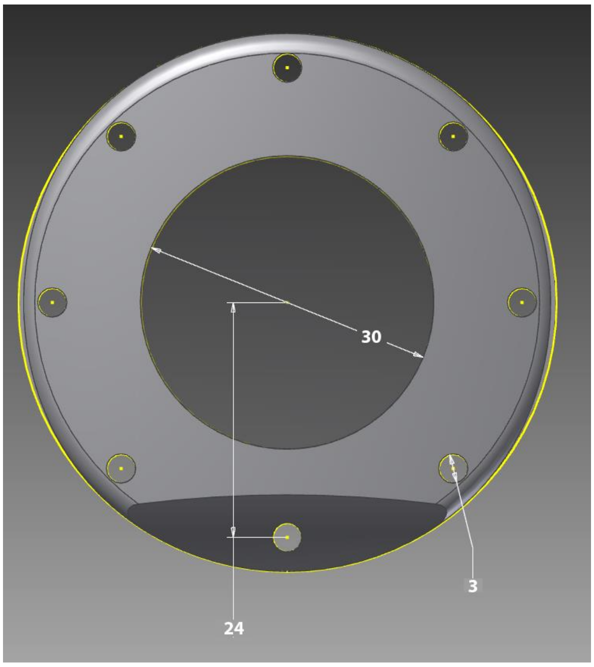


Figure 4-21: front view protective window with measures

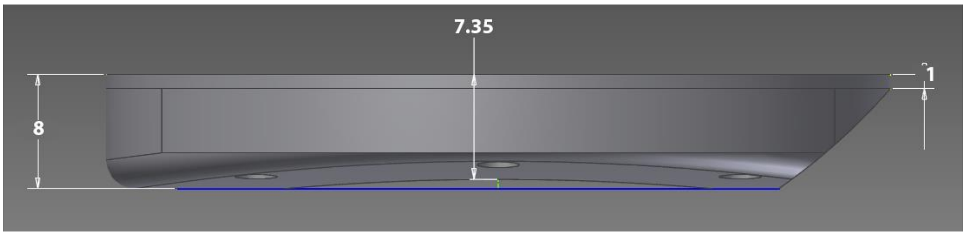
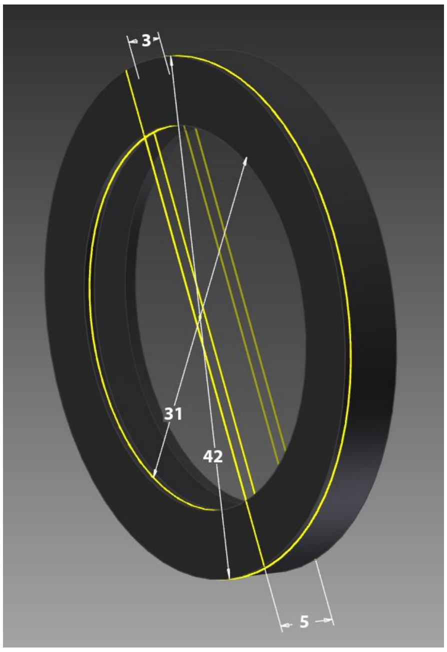


Figure 4-23: side view protective window



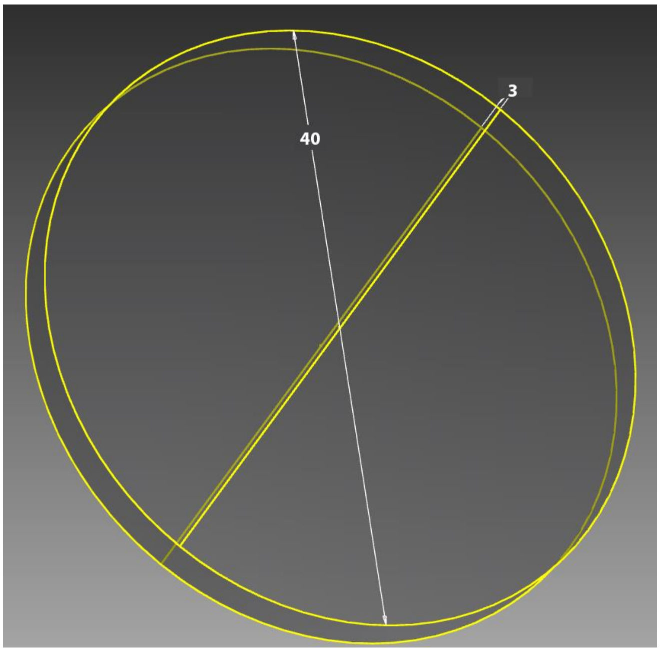


Figure 4-24: glass of protective window with silicon seal

Figure 4-25: pure glass of protective window

ID	Component	Flight No.	Dimensions	Single mass [kg]	Flight mass [kg]
Electronics					
1	Camera mvBlueCOUGAR-X102b	2	39.8mm x 39.8mm x 35mm	0,1100	0,2200
2	MIO-2260 with Intel Atom N455 1,66GHz	2	100mm x 72 mm x 34mm	0,2000	0,4000
3	SDRAM 2GB DDR3 667MHz SO-DIMM	2		0,0500	0,1000
4	Arduino Leonardo	1	69mm x 53mm x 12mm	0,0190	0,0190
5	Arduino SD shield	1	61mm x 53mm x 5mm	0,0150	0,0150
6	current sensor ACS712	2	35mm x 15mm x 15mm	0,0040	0,0080
7	temperature sensor DS18B20	6	19mm x 4mm x 3mm	0,0003	0,0018
8	SSDNow V+ 200 (SVP200S3/120G), 2.5"	2	100mm x 69.85mm x 7mm	0,0923	0,1846
9	Micro SD 2GB Class 2	1	11mm x 15mm x 1mm	0,0005	0,0005
10	CF Card 600x 8GB (TS8GCF600)	2		0,0140	0,0280
11	LM2596 DC/DC regulator module	6	45mm x 20mm x 15mm	0,0120	0,0720
12	PDU PCB board	2	120mm x 85mm x 28mm	0,1500	0,3000
13	RS-232 TTL Module for Arduino	1	40mm x 30mm x 12mm	0,0040	0,0040
14	wiring / connectors	1		0,2000	0,2000
Mechanical					
15	main structure	1		1,5000	1,5000
16	lens + adapter ring	2	ca. 25mm x Ø ca. 20mm	0,0200	0,0400
17	mounting support (screws)	1		0,1400	0,1400
18	protective window & mounting	2		0,1000	
	SUM [kg]				**3,2329**
	Margin	**10%**			**0,3233**
	TOTAL MASS [kg]				**3,5562**

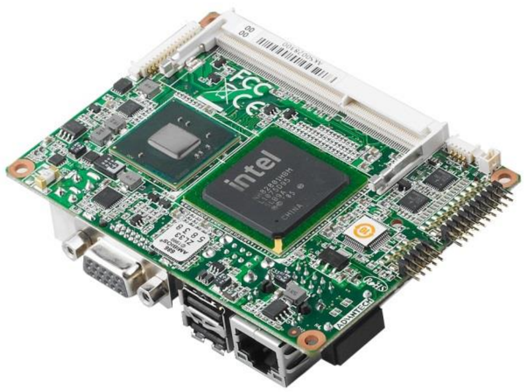
Table 4-3: components mass & dimensions (estimated values marked red)

4.5 Electronics Design

4.5.1 Camera

The camera which observes the outer environment is the industrial CMOS camera mvBlueCOUGAR-X102b manufactured by Matrix Vision. It provides the image data as consecutively and uniquely numbered frames via GigE-Vision interface to the core system. This interface provides a fast data throughput to the core system also for frames with high resolution. Through the integrated FPGA during implementation various settings, like exposure time, resolution and frame rate can be programmed. With those variable settings it is possible to adjust the frames exactly to the needs of the algorithm even in a later development process. Is it planned to set a frame rate of 30fps, an 8bit coloured resolution of 1024px x 768px. With a global shutter and a maximal blindness of 1/8.333s after full illumination good pictures can be provided also under rough conditions (high spinning rates, looking regularly into sun). As soft criterion the good documentation, available drivers, as well as the good support of the manufacturer even beforehand lead to the decision of this model.

4.5.2 Core System



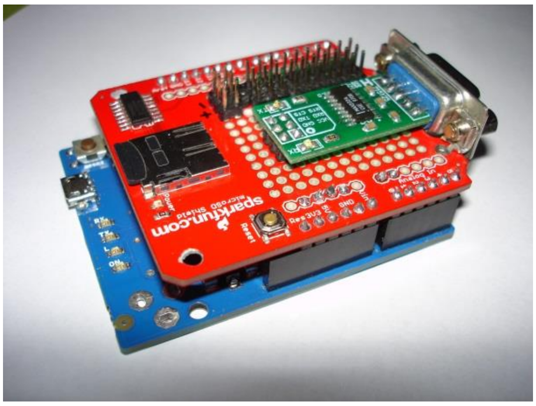
On the core system, which is the embedded computer Pico-ITX MIO-2260 with an Intel Atom CPU, the actual experiment – image processing and horizon detection – is performed (cf. 4.8). Therefore it receives the provided video data via the GigE interface, which is then directly stored to the SSD via SATA-interface. Furthermore it processes the video data and saves the calculated data to the SSD. By saving both the global timestamp and the consecutive unique frame number for every processed frame, it is ensured that all collected data can be matched bijectively for post-flight evaluation (cf. 4.8.2).

Additionally, the core system controls all subsystems and therefore communicates with the RXSM and the other subsystems. The communication for up- and downlink via RXSM is implemented according to the RS-422 standard defined in the REXUS manual by using the I/O transceiver extension chip MAX488 and the first RS-232 interface of the core system. This interface is also used to process the signals provided by RXSM. Communication with the MU is implemented by using the second RS-232 interface of the embedded computer. Thus also housekeeping data provided by the MU can be downlinked, as well as commands can be forwarded to the MU.

As also in the case of two core system setups only one MU is integrated (cf. 4.5.3), only one of the two core systems is linked to the MU and thus has access to the provided data and has to control the MU. If distinction of both core systems is needed, the core system linked to the MU is called master core system (in figures also abbreviated as “MasterCS” or indicated by an “M”); the other one is called slave core system (respectively “SlaveCS”, “S”).

The master core system additionally provides time synchronization with the MU, as specified in 4.2.4.2.

4.5.3 Measurement Unit



The MU is an Arduino Leonardo Board with an Atmel ATmega32U4 microcontroller, shouldered with a SD-card shield. It measures regularly temperatures with DS18B20 digital temperature sensors from Maxim Integrated (range from -55°C to +125°C with a sensitivity of +/- 0.5°C) six points of the experiment (lens, CS, PDU each system) and current of the core systems with the ACS712 current sensors, produced by Allegro (range from -5A to 5A with sensitivity of 185mV/A) and saves the measured data with the global timestamp to its SD-storage. Also in the case of two identical core system setups only one MU is integrated. During stand-by- and shutdown-mode (cf. 4.8.1) the measured data is passed to RXSM downlink via the core system using the RS-232 interface implemented by the RS-232 TTL converter placed on the SD-shield.

The Arduino Leonardo is ideal to read out sensors with little power consumption and a simple interface to the core system can be implemented. Additionally, the platform is well documented and many extensions (like the SD-shield) are available.

4.5.4 Power Distribution Unit

The power distribution is performed with a set of DC/DC regulators LM2596, produced by Linear Technology – one for each needed voltage. The modules are able to handle the unregulated input voltage from RXSM of 24V to 36V and provide very stable voltages and currents. The operating temperature range is between -40°C and +125°C, so the modules might have to be cooled by a link to passive heatsinks or to the bulkhead. Each PDU for one system consists of three regulator modules, which are placed on the PDU-carrier-board (for complete electronics schematics cf. 4.2.2 and Appendix F).

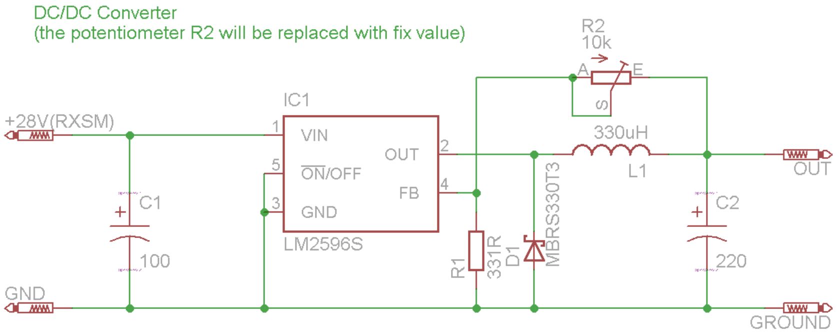


Figure 4-27: electronics schematic for one DC/DC converter module

The first module, PDU-1, provides 12V power only to the core system and uses the first 28V power line provided by RXSM. The second module, PDU-2 converts the 28V provided by the second power line of RXSM, also to a 12V output to supply the camera and the SSD. Additionally, the third module, PDU-3, is also powered by PDU-2 and converts the 12V-output of PDU-2 to 5V, which supply the MU, the SSD, as well as the RS-422 to RS-232 converter placed on the PDU carrier board.

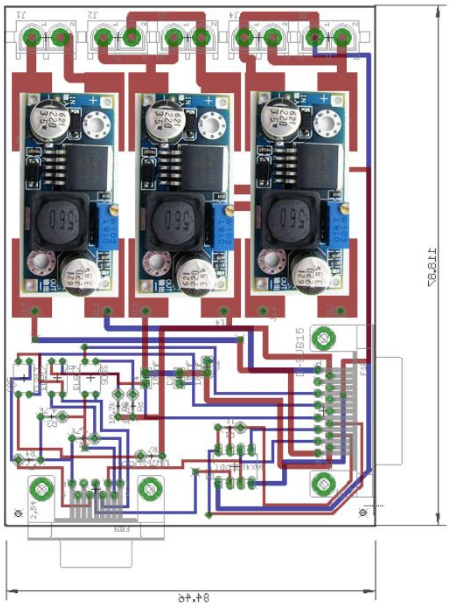


Figure 4-28: PDU modules placed on the carrier board

The used stepdown regulator chip LM2596 is very power efficient and provides enough current for the system. In addition, with the given circuit the voltage can be adjusted very accurately.

4.6 Thermal Design

Phase	Shipping	Integr.	Roll-out	to T-20m	T-20m to T-10m	T-10m to LO	Flight	Post-Flight
Temp.	-40°C	+20°C	-40°C	+17°C	-40°C to +20°C	-40°C to +20°C	+20°C to +45°C	-30°C to 0°C
Exp. time	∞	∞	10min	∞	10min	10min	10min	3hours

Table 4-4: Expected temperature ranges inside the module and exposure times (according to flight profile of RX10 and RX11 and REXUS manual)

Temp/Component	Storage Temperature	Operating Temperature
OPTICAL SYSTEM		
Camera	-20°C to 60°C	0°C to 45°C
MEASUREMENT UNIT		
Arduino Leonardo	n.a.	-40°C to 85°C
SD-shield	n.a.	n.a.
RS232-TTL	-65°C to 160°C	-40°C to 85°C
micro SD-card	n.a.	n.a.
temp. sensor	-55°C to 125°C	-55°C to 125°C
current sensor	-65°C to 170°C	-40°C to 85°C
CORE SYSTEM		
embedded PC	-40°C to 85°C	0°C to 60°C
RAM	n.a.	n.a.
CF-card	-40°C to 85°C	-25°C to 85°C
SSD	-40°C to 85°C	0°C to 85°C
POWER DISTRIBUTION UNIT		
DC/DC converter	-65°C to 150°C	-40°C to 125°C
MAX488	-65°C to 160°C	-40°C to 85°C
optocoupler	-55°C to 125°C	-55°C to 120°C

Table 4-5: Operational and storage ranges of the components (according to datasheets)

Phase/Comp.	Shipping	Integr.	Roll-out	to T-20m	T-20 to T-10m	T-10m to LO	Flight	Post-Flight
Camera	6)		1)		1)	2)	3)	4)
Arduino								
SD-shield	7)	7)	7)	7)	7)	7)	7)	7)
RS232-TTL								
micro-SD	7)	7)	7)	7)	7)	7)	7)	7)
temp. sensor								
current sens.								
emb. PC						2)		
RAM	7)	7)	7)	7)	7)	7)	7)	7)
CF-card						2)		
SSD						2) 5)		
DC/DC conv.								
MAX488								
optocoupler								

Table 4-6: comparison matrix of expected and specified temperatures

The comparison of specified temperature ranges to the expected ones shows that there are 3 components, whose temperature ranges partly are outside the expected ranges or don't overlap completely – the camera, the core system and SSD.

All those discrepancies will be tested carefully, but they are not considered critical for the following reasons.

1) The cameras' storage temperature range isn't as low as the minimum possible temperature, but electronic problems are not expected as the exposure time is short. More critical is the risk of the lenses or filters growing damp in the cold. As this dampness will evaporate and thus the lenses and filters will be clear again, when the rockets starts climbing up the atmosphere and pressure sinks, no obstruction of the experiment's performance is expected.
2) During this phase the systems are already running, and thus all electrical components will heat up the module. If needed additional workload can be put to the core system via TC to increase the temperature even more. Thus the most critical moment will be starting up the experiment at T-10min, when it's cold and cannot heat itself. As during this phase low levels of heating can be provided by the Service System and as the experiment will be monitored precisely at the

ground station, also that issue is not considered to be critical, but will be tested even more carefully.

3) In fact the cameras' operating temperature does overlap with the expected range for flight. But as the cameras are very close – but not thermally coupled – to the rocket's skin and no information of the exact point of measurement for the RX10/11 flight profile is available, the camera's behavior at high temperatures will be tested carefully.
4) This discrepancy is absolutely uncritical for the experiment as after switching off the experiment at T+600s the cameras won't be needed anymore and being damaged after flight won't obstruct the experiments results or performance.
5) Low temperatures may slightly affect the SSDs function, in particular the write speed. But during count-down no high speed data link to the SSD is needed and as the components will heat up (as mentioned in 2), this discrepancy is also considered not to be critical. If the tests proved the opposite the SSDs can simply be replaced by industrial grade models with operating ranges starting from -40°C – which are on the other hand much more expensive and therefore not yet selected.
6) The discrepancy between the minimum storage temperature of the cameras and the worst case temperature during the long period of shipping can be handled with proper packaging and insulation. Nevertheless, the camera will also be tested for low storage temperatures and large exposure periods.
7) Neither for the RAM, SD-shield nor micro-SD-card datasheets are available. Thus, although no electrical problems are expected, those components will be tested carefully and have possibly to be replaced with more expensive industrial components.

With the low expected ambient temperatures in Esrange, electrical components heating up, while working is an advantage on ground, but can lead to overheating during flight, especially as cooling by convection is not possible due to the vacuum environment.
Therefore a thermal analysis with the following methodology was performed to examine the heat dissipation within the flight segment.

The components' temperature was measured at 1bar and 21°C ambient temperature, respectively estimated where components weren't available so far, first being powered on but idling and secondly under maximum load. The table below gives the end temperatures after 15min. Those absolute temperatures are of course not representative for vacuum conditions, as the components were passively cooled by convection, but give the relative temperature distribution.

	Idle	**Maximum Load**
camera	25°C	35°C
PDU	30°C	55°C
core system	30°C	60°C
SSD	21°C	< 31°C

Table 4-7: measured/ estimated temperatures (1bar, 21°C ambient)

As all electrical components are mostly built of the same materials and similar in size, their heat radiation capacity is considered to be equal.

In a further step a numerical simulation of heat distribution in the module over time for vacuum conditions and 15 minutes was performed, with the above determined relative temperature distribution as input. Thus the results indicate the relative heat distribution for vacuum conditions and the components working with maximum load and so show the hot parts within the flight segment which need to be cooled (cf. Figure 4-29).

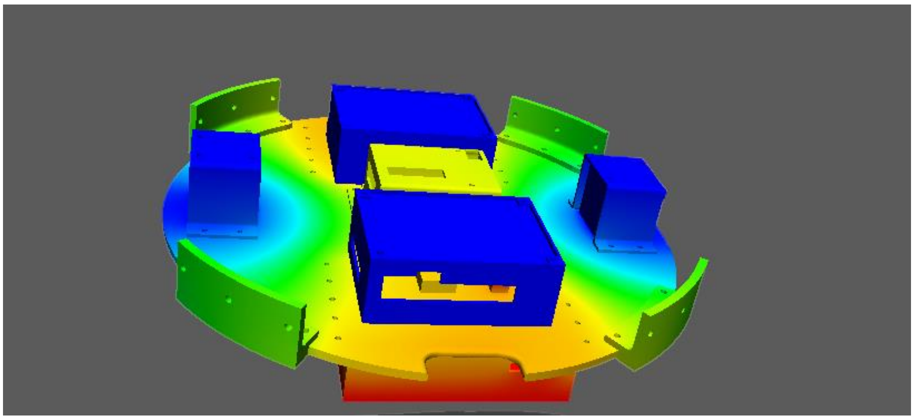


Figure 4-29: result of temperature simulation

As consequence of this analysis passive heatsinks are placed onto the PDU and the core system, which are themselves thermally coupled also to the casing, respectively to the bulkhead and thus the complete structure is used as heatsink to dissipate the heat during flight, whereas the impact of the cameras and SSDs heating up is negligible.

Hence the flight is short and the heat takes time to spread, no significant heating of the rocket's structure or other experiments is expected, even if it is used as heatsink.

To monitor the experiment's temperature during CD and flight, the MU collects housekeeping from temperature sensors at six distinct points of the experiment (cf. 4.5.3) and downlinks the data to the ground. Temperatures are measured at:

- 2x at the skin at the protective window (one sensor each window)
- 2x core system (one each system)
- 2x PDU (one each system)

As the given calculations are very basic and come with many assumptions, the thermal design will be carefully regarded and tested throughout the complete integration process (e.g. both a thermographic camera and thermo-vacuum chamber are available at JMU).

4.7 Power System

The complete power, consumed by the HORACE flight segment, is drawn from the RXSM, which provides maximum 84W (3A @ 28V). The power budget of HORACE is expected as shown below, both for one and two systems. As some values are only estimated (marked red) at the current stage, a margin of 50% is added. Components indicating a consumption of 0W are directly supplied by their carrier-component, thus no extra consumption must be added.

ID	Component	Flight No.	Voltage [V]	Current [A]	Single power [W]	Flight power [W]
Electronics						
1	Camera mvBlueCOUGAR-X102b	2	5,0000	0,8000	4,00	8,00
2	MIO-2260 with Intel Atom N455 1,66GHz	2	12,0000	0,8600	10,32	20,64
3	SDRAM 2GB DDR3 667MHz SO-DIMM	2	0,0000	0,0000	0,00	0,00
4	Arduino Leonardo	1	5,0000	0,4000	2,00	2,00
5	Arduino SD shield	1	0,0000	0,0000	0,00	0,00
6	current sensor ACS712	2	0,0000	0,0000	0,00	0,00
7	temperature sensor DS18B20	6	0,0000	0,0000	0,00	0,00
8	SSDNow V+ 200 (SVP200S3/120G), 2.5"	2	2,0650	1,0000	2,07	4,13
9	Micro SD 2GB Class 2	1	0,0000	0,0000	0,00	0,00
10	CF Card 600x 8GB (TS8GCF600)	2	0,0000	0,0000	0,00	0,00
11	LM2596 DC/DC regulator module	6			0,00	0,00
12	PDU PCB board	2			5,00	10,00
13	RS-232 TTL Module for Arduino	1	0,0000	0,0000	0,00	0,00
14	wiring / connectors	1			0,00	0,00
	SUM one system [W]					**23,39**
	Margin	**50%**				**11,69**
	TOTAL CONSUMPTION one system [W]					**35,08**
	SUM two systems [W]					**44,77**
	Margin	**50%**				**22,39**
	TOTAL CONSUMPTION two systems [W]					**67,16**

Table 4-8: HORACE power budget

4.8 Software Design

4.8.1 Software Modes

There are three software modes, “stand-by”, “flight-mode” and “shut-down”.

After power on the flight segment is in stand-by mode. By receiving the LO-signal (or the redundant SOE-signal) the mode will be switched to the flight-mode. When the internal clock reaches T_S (T+590s) the mode is changed to shut-down.

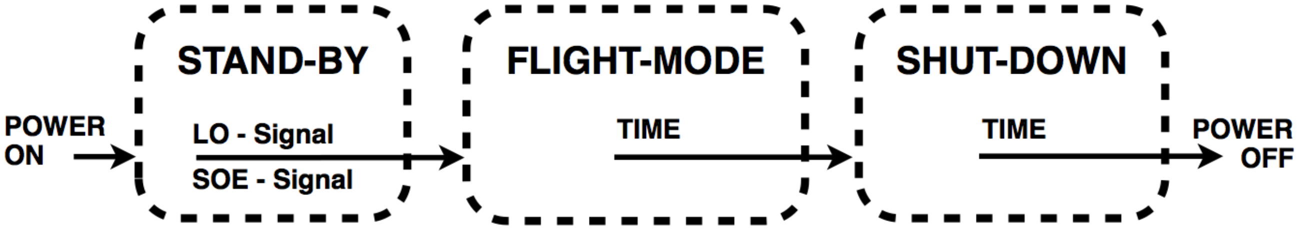


Figure 4-30: software modes

4.8.1.1 Stand-by

Several tasks start simultaneously after switching.

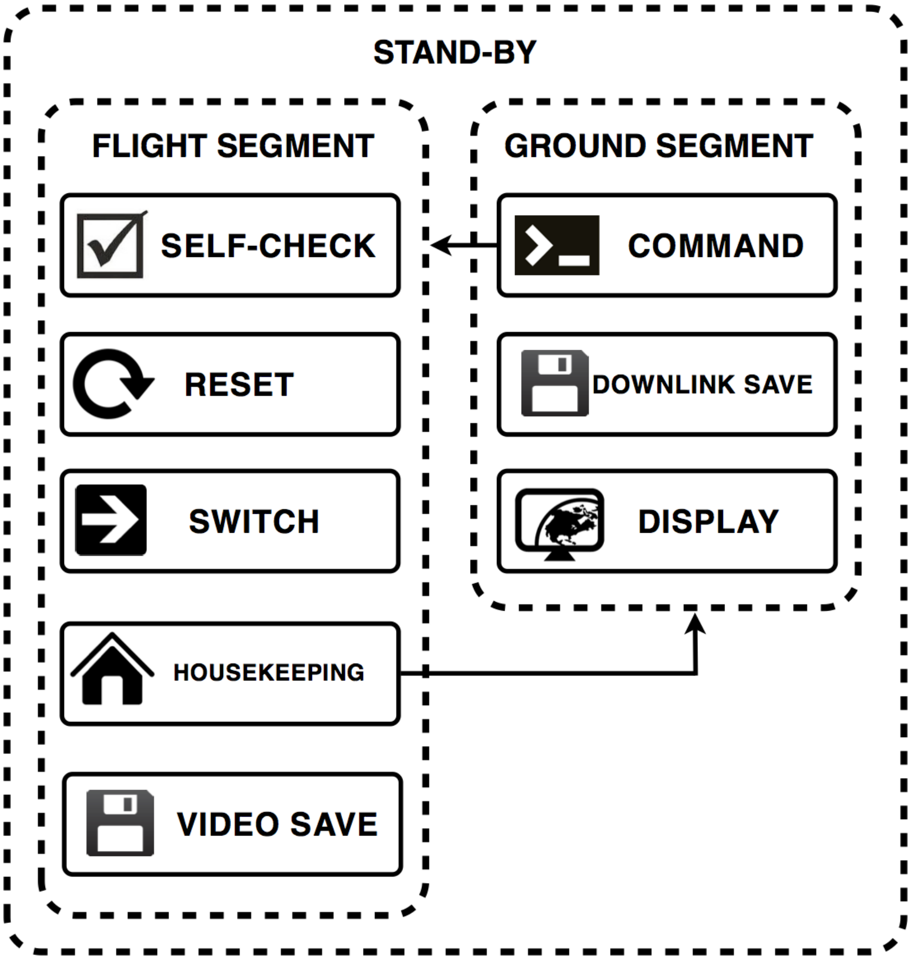


Figure 4-31: tasks stand-by mode

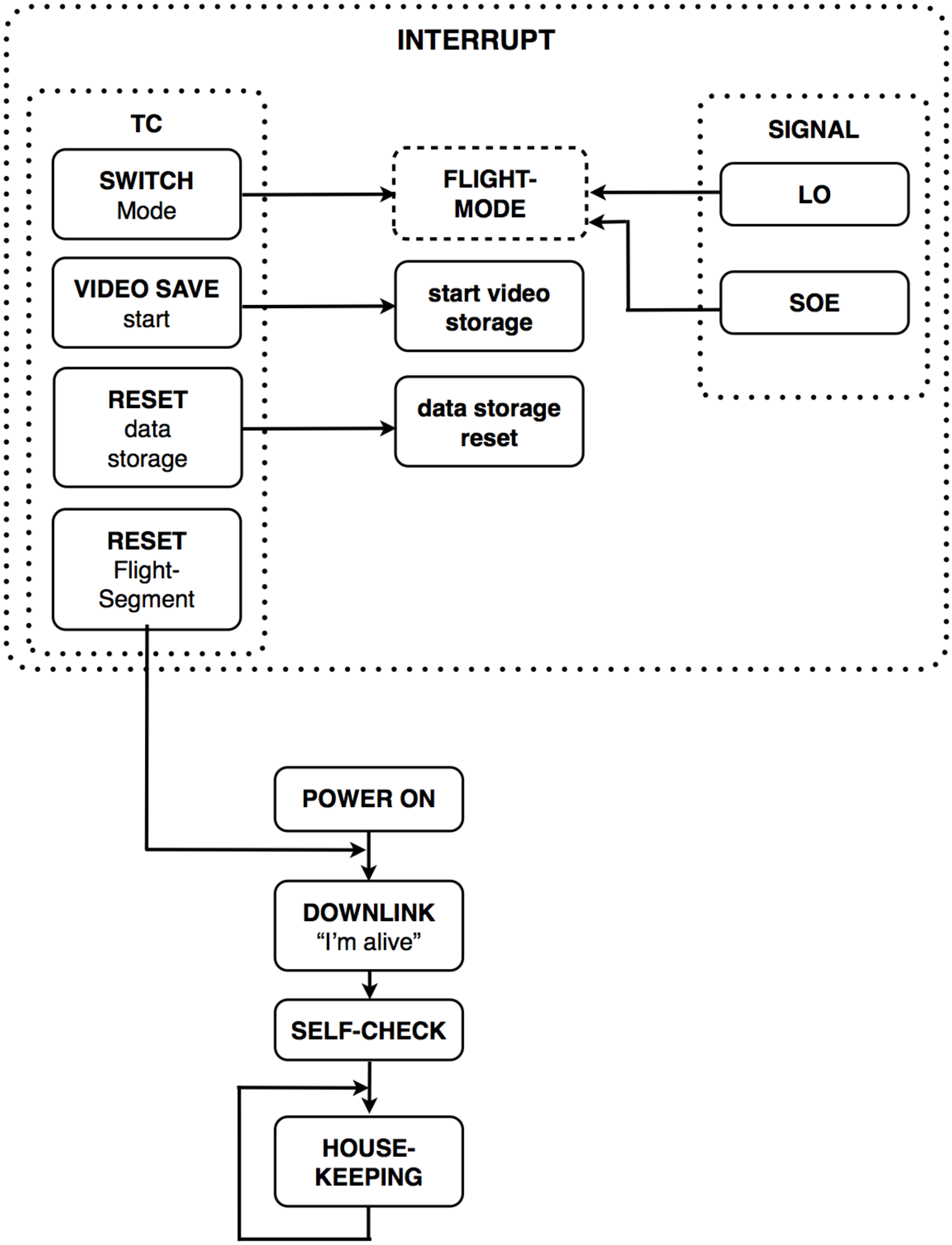


Figure 4-32: flow chart of stand-by-mode

Self-Check

Several subsystems are checked for operational reliability.

Reset

The data storage reset is executed by TC and deletes all saved data. This reset is needed to make sure that important data can’t be overwritten and there is enough free space on the data storage device.

Switch
This task waits for the LO- and the SOE-signal and changes to flight-mode after receiving.

Housekeeping
This task collects the information, forms it into the Stand-By Downlink Data Package and sends it to the ground station. Included are temperature, currents, signals and checks.

Video Save
Video saving is started by TC. This task has the sole function to add the unique frame number to the received video data and save them to memory.

Command
This task captures manual TC and sends them to the flight segment, where the commands are executed.

Downlink Save
The received data is saved to downlink memory.

Display
The housekeeping data is displayed on a screen, according to the specifications of the ground station software in 4.9.3.

4.8.1.2 Flight Mode

Several tasks start working simultaneously and directly after switching:

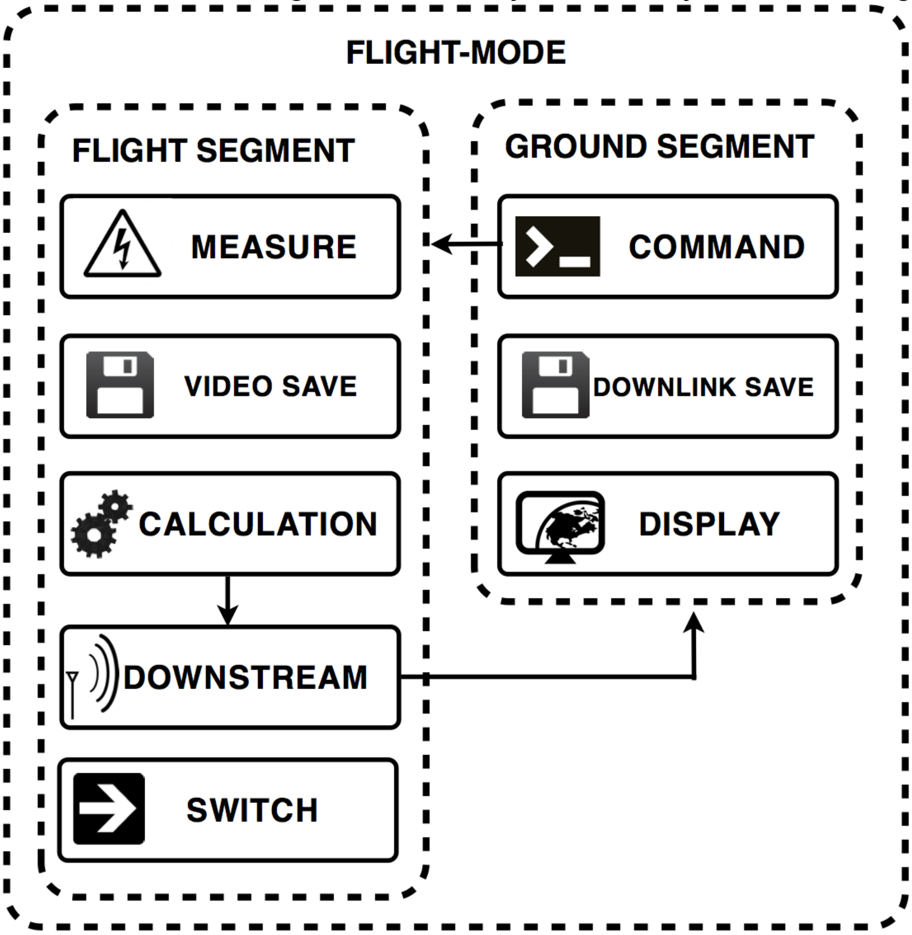


Figure 4-33: tasks flight mode

Measure
The measure task receives data from the current and temperature sensors, adds the global timestamp and saves them to memory.

Video Save
This task has the sole function to add the unique frame number to the received video data and save them to memory.

Calculation
The first part of the calculation is a threshold filter, which decides if a pixel is bright or dark by comparing it to a parameter called threshold-value and assigns its corresponding value. An edge detection marks the borders of bright and dark areas in the resulting picture. Therefore it uses the parameters low-threshold-value and high-threshold-value. Now, as edges are found, the line detection searches for a line by extrapolating edges beginning at the border of the frame. Here the parameter range affects the decision which pixel belongs to the horizon line. After the curve of the horizon has been detected the vector to the 2D projection of the earth is calculated by finding the center of the circle which is determined by the curve.

During and after each calculation selected data (specified in 4.8.3) is sent to the downstream and saved to memory.

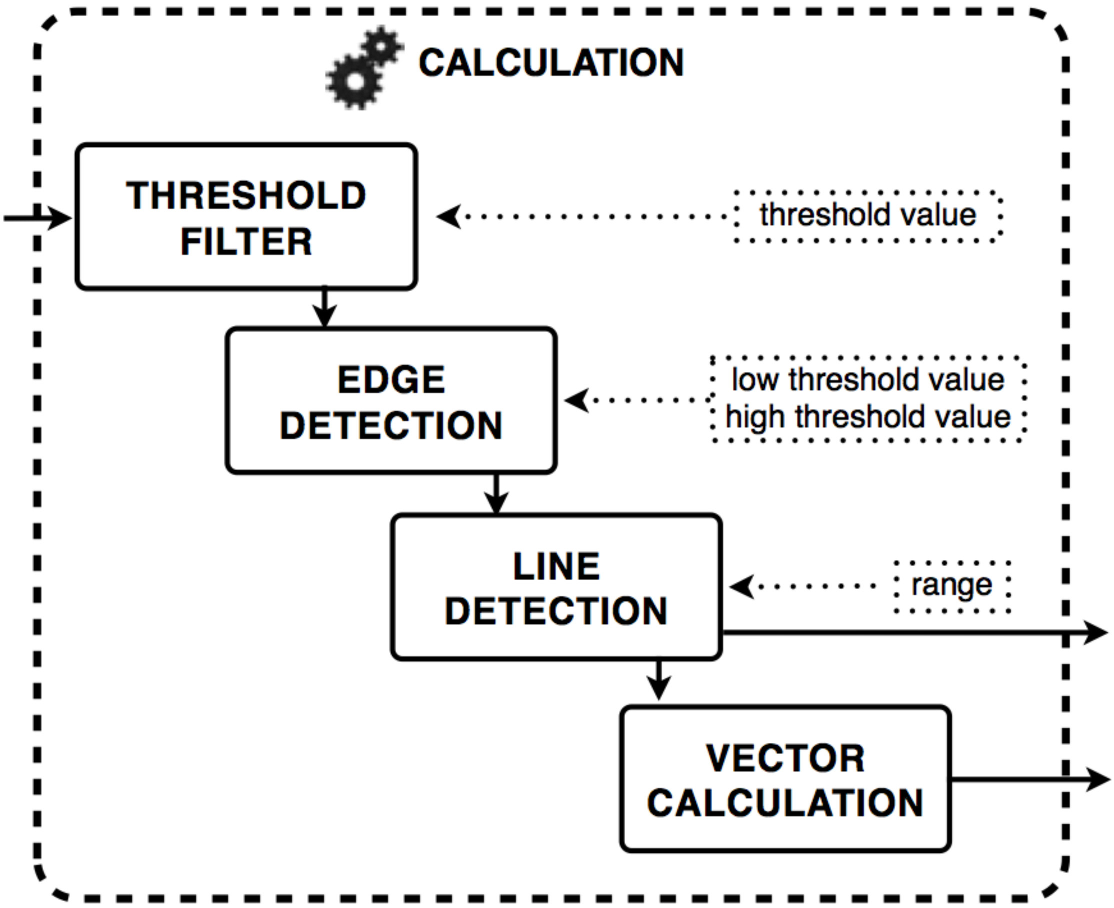


Figure 4-34: flow chart of calculation

Downstream
This task running on the flight segment selects calculated data packages, forms them into downlink packages and sends them to the RXSM.

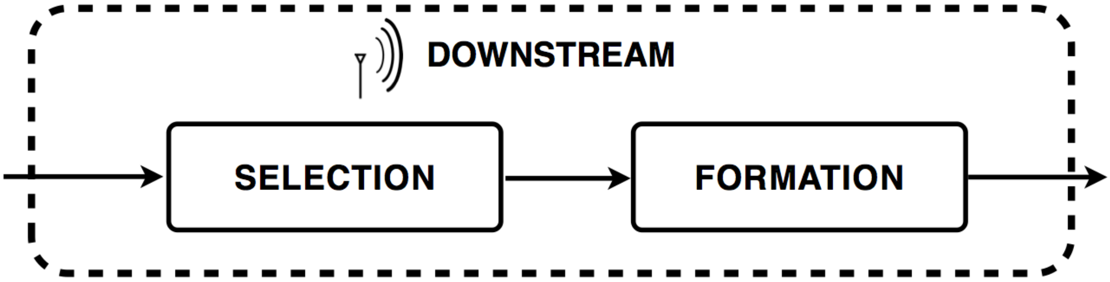


Figure 4-35: data flow downstream

Switch
At T_S (T+590s) this task changes the mode to shut-down.

Command
For testing and in the case that there is an uplink available this task captures manual TC and sends them to the flight segment, where the commands are executed. During flight, it is not necessary for the operational functions.

Downlink Save
This task running on the ground station has the sole function to save the received downlink data to memory.

Display
The ground station displays the received downlink data according to the specifications of ground station software in 4.9.3.

4.8.1.3 Shut-Down

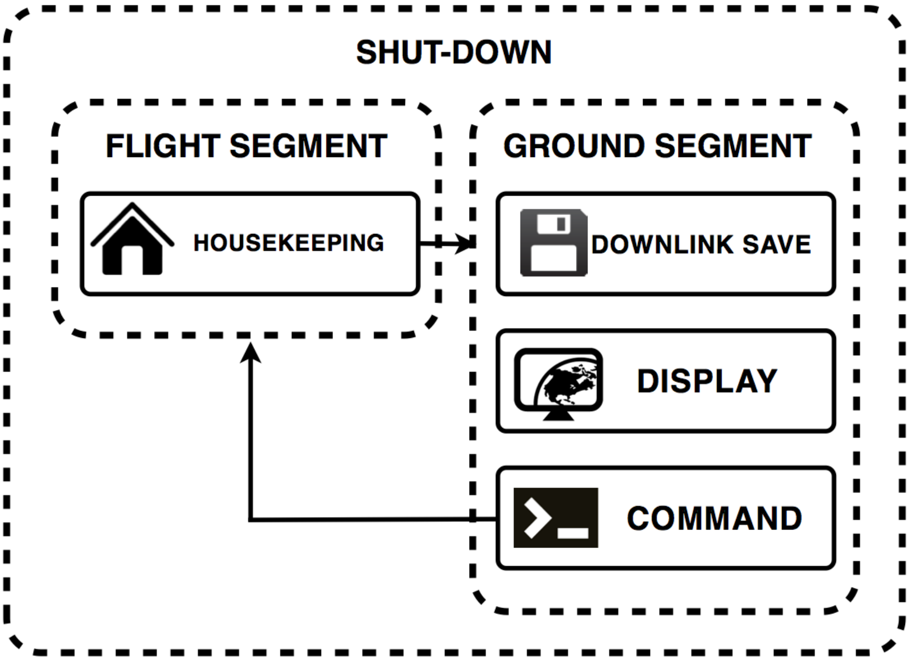


Figure 4-36: tasks shut-down

Housekeeping

This task collects the information, forms it into the Stand-By Downlink Data Package and sends it to the ground station. Included are temperature, currents, signals and checks.

Command

For testing and in the case that there is an uplink available this task captures manual TC and sends them to the flight segment, where the commands are executed. It is not necessary for the operational functions.

Downlink Save

The received data is saved to downlink memory.

Display

The housekeeping data is displayed on a screen according to the specifications of ground station software in 4.9.3.

4.8.2 Data Handling

One stream of the raw video data is directly saved to the video memory, the other one supplies the calculation process. Calculated data packages are both saved to calculation memory, and sent to the downstream. Downlink packages received in the ground station are displayed and saved to downlink memory. The measurement data from current and temperature sensors is processed in the measure task and saved to the measurement memory.

The numbers in the following packages are the bytes the section named above needs with the convention k=1000, M=1000k and G=1000M. M and S indicate the system (Master/Slave) and the numbers in the names indicate the sensor.

Measurement Data Package

Sync	Time	Current M	Temp M1	Temp M2	Temp M3	Current S	Temp S1	Temp S2	Temp S3	Sum
1	3	2	2	2	2	2	2	2	2	3

MU-To-MasterCS Data Package

Time	Current M	Temp M1	Temp M2	Temp M3	Current S	Temp S1	Temp S2	Temp S3
3	2	2	2	2	2	2	2	2

MasterCS-To-MU Data Package

Command	Time
1	3

Figure 4-37: definition of data packages (1/2)

Calculation Data Package

Sync	Frame	Start Time	Stop Time	Extrapolated Horizon	Vector	Horizon Line	Sum
1	2	3	3	8	8	4,2 k	3

Flight-Mode Downlink Data Package

Frame	Start Time	Stop Time	Vector	Extrapolated Horizon
2	3	3	8	8

Stand-By Downlink Data Package

Echo	Signals	Checks	Temp M1	Temp M2	Temp M3	Temp S1	Temp S2	Temp S3	Current M	Current S
1	1	1	2	2	2	2	2	2	2	2

Shut-Down Downlink Data Package

Tasks	Temp M1	Temp M2	Temp M3	Temp S1	Temp S2	Temp S3	Current M	Current S
1	2	2	2	2	2	2	2	2

Video Data Package

Sync	Frame	Video Frame	Sum
1	2	2,36 M	3

Figure 4-38: definition of data packages (2/2)

Memory	Data amount 1	adding *)
Measurement	900 kbyte	480 kbyte
Video	46,02 Gbyte	46,02 Gbyte
Calculation	76,1 Mbyte	76,1 Mbyte
Downlink	626,4 kbyte	52,8 kbyte
Sum	46,10 Gbyte	46,10 Gbyte
	total *)	92,20 Gbyte

Table 4-9: data amount *) if two core systems are flown

Case	Required bandwidth
minimum	240 byte/s
normal	870 byte/s
maximum	870 byte/s

Table 4-10: required bandwidth for downlink

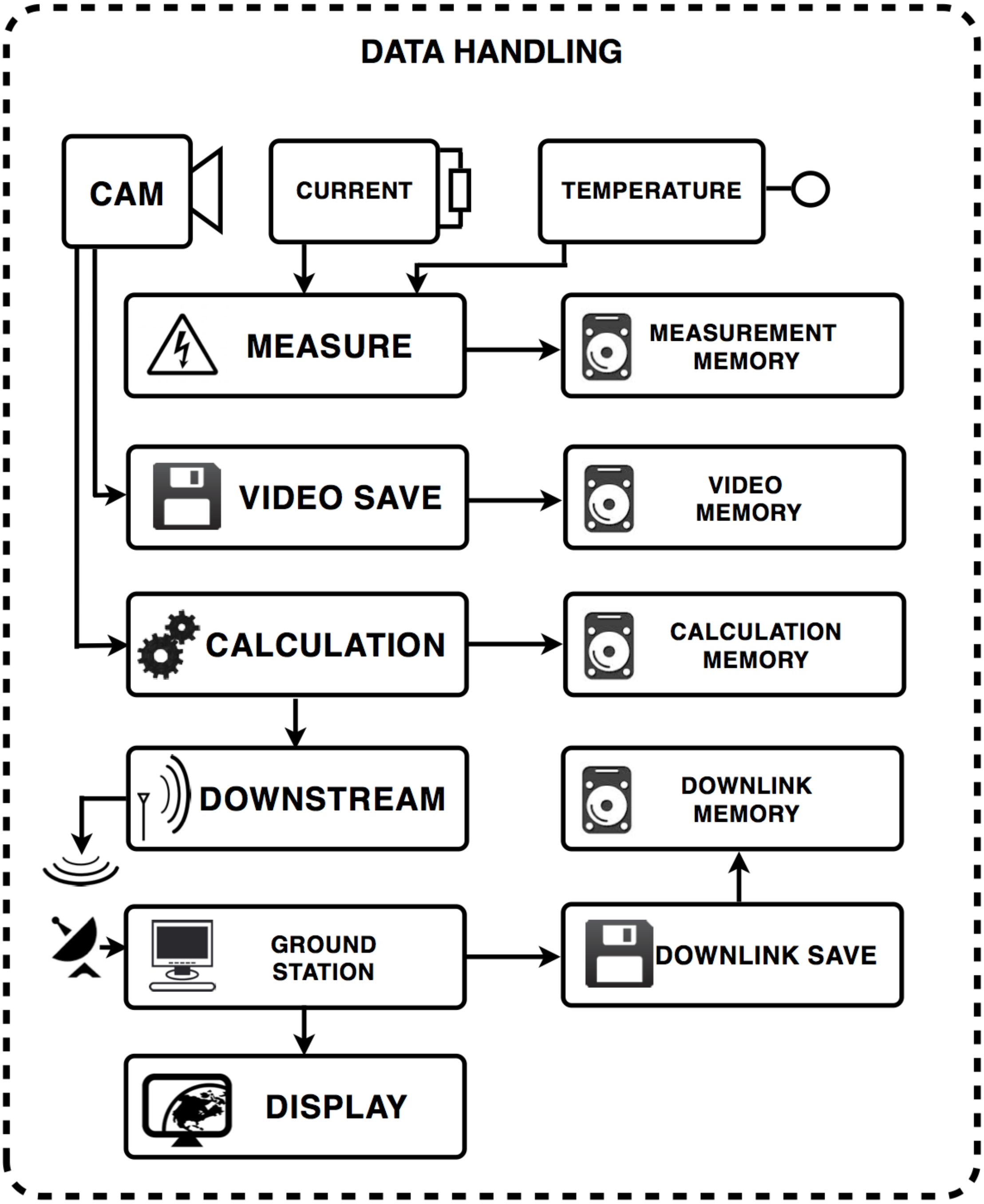


Figure 4-39: data handling

4.8.3 Development

In order to develop the horizon detection algorithm the open source framework openCV is used. To implement the algorithm in C++ the development environment XCode is chosen.
The application running on the ground station will also be implemented in Python and is fully specified in 4.9.3.

4.9 Ground Support Equipment

The HORACE ground support equipment includes all needed technical and organisational tools to prepare and operate the experiment during launch campaign. At the current stage the following minimum support items have been identified so far. This preliminary list will increase and get more detailed during implementation and testing.

4.9.1 EGSE

To test, modify and prepare the experiment there are one or two notebooks with the needed interfaces software (possibly special developed, cf. 4.8.3) and cables.

Additionally a 24V-36 DC power supply is used for testing.

During development and implementation an RXSM simulator device is used for testing. So far this device can simulate the signals sent by RXSM and will be extended concerning supported features throughout implementation phase.

For each data memory device as well as critical components of the flight segment there will be another one as backup.

4.9.2 MGSE

For correct assembly and disassembly the flight segment into the REXUS module, there is a toolkit with several needed tools.

4.9.3 Ground Station

The ground station consists of two notebooks, one for each of the identical systems, both using the same software for up- and downlink. Both are connected to the Science-Net using the RS-232 interface. The three main tasks are: saving downlink data, displaying downlink data and sending telecommands on ground.

To fulfil those tasks, special software with the following features is developed (cf. also 4.8.3)

Save

The raw downlink-data is saved automatically on the notebook’s hard drive to a file whose name and path can be set in the preferences of the ground station software.

Display

To display the data, it is parsed and shown on a GUI. As there are different modes of the core system, also the ground station represents them with different views, which show only information, available and necessary for the current state of countdown and flight. A status bar indicates whether the connection to the system is established and which of both systems is connected (either master core system or slave core system).

View for Stand-By Mode:
In this view, while the rocket is still on ground, information of the current state (e.g. bootup-information, self-check results) of the core system is printed to a scrollable text-area, using colours to indicate success and failures.

Additionally, the housekeeping data, collected by the MU, is continuously displayed, if the ground station is linked to the master core system, indicating unexpected or out-of-range values with colours. As the slave core system can't access the housekeeping data, the corresponding area on the GUI is left blank for the ground station linked to the slave.

To send TC a terminal is used. It is both possible to manually type commands or use buttons to copy predefined commands to the terminal. For security, every command must be confirmed with a click to the "Send"-button, to avoid sending (wrong) commands by accident. Critical commands, like "restart" need to be additionally confirmed on the terminal ("Are you sure?"). Furthermore, manual typing/editing commands in the terminal can be disabled, so that only the commands predefined on the buttons can be accessed, to prevent spelling mistakes or entering wrong commands during stress situations (hot countdown).

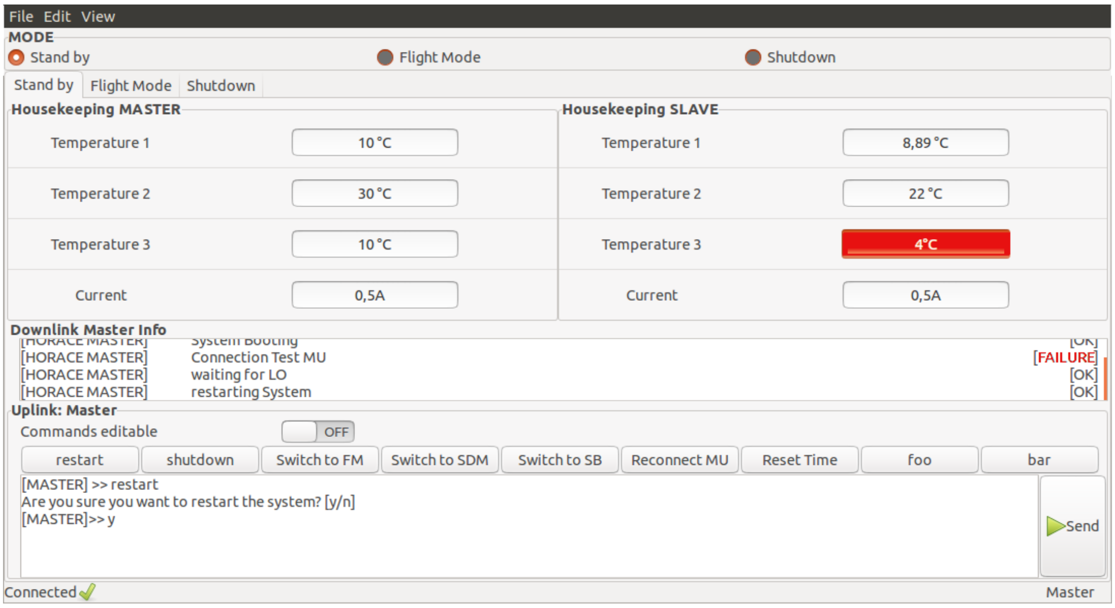


Figure 4-40: screenshot of the GUI prototype for stand-by view

Flight Mode:
In this view the results of the algorithm, which are continuously downlinked during flight, will be displayed. The calculation time is displayed in a plot, as well as calculation results and vector data are given as numerical or graphical output.

Shutdown:
The status of the shutdown procedure is printed to a scrollable text-area, using colours to indicate success and failure, in this view. For the master system additionally housekeeping data, provided by MU is displayed.

Command

The ground station software parses the text-commands input via the GUI, translates them to the corresponding byte-command, conditions them according to the uplink protocol (cf. 4.2.4) and sends them via the RS-232 interface to the Science-Net for uplink.

5 EXPERIMENT VERIFICATION AND TESTING

5.1 Verification Matrix

ID	Requirement text	Verification	Status
	FUNCTIONAL REQUIREMENTS		
F-E-01	The FS shall observe optically the outer enivronment of the REXUS rocket	R, I	TBD
F-E-02	*moved to D-E-06*	-/-	
F-E-03	The FS shall distribute power to all subsystems	R, T	TBD
F-E-04	*combined with F-E-05 to F-E-06 moved to D-E-07*	-/-	
F-E-05	*combined with F-E-04 to F-E-06 moved to D-E-08*	-/-	
F-E-06	The FS shall measure health data of selected subsystems and at selected points of the experiment	R	TBD
F-M-01	The mounting of the optical sensor should ensure visibility of the horizon	R	TBD
F-S-01	The FS shall detect and calculate the line of horizon	R,T	TBD
F-S-02	The FS shall calculate the 2D vector to the 2D projection of the earth center	R, T	TBD
F-S-03	The FS shall save the experiment data with global timestamp *(combined with F-S-04 & F-S-09; original requirement moved to D-S-01)*	R, T	TBD
F-S-04	*combined with F-S-03 moved to D-S-02*	-/-	
F-S-05	*moved to D-S-04*	-/-	
F-S-06	*moved to D-S-05*	-/-	
F-S-07	*moved to D-S-06*	-/-	
F-S-08	*moved to D-S-07*	-/-	
F-S-09	*combined with F-S-03 moved to D-S-03*	-/-	
F-S-10	The FS shall downlink calculation data during flight	R	TBD
F-S-11	*moved to D-S-08*	-/-	
F-S-12	*moved to D-S-09*	-/-	
F-S-13	*moved to D-S-10*	-/-	
F-S-14	*moved to D-S-11*	-/-	
F-S-15	*moved to D-S-12*	-/-	
F-S-16	The FS shall downlink health data during stand-by	R	TBD

Table 5-1: verification matrix (1/7)

ID	Requirement text	Verification	Status
	PERFORMANCE REQUIREMENTS		
P-M-01	*moved to D-M-10*	-/-	
P-M-02	The horizon may be visible in 70% of the operational time	A	TBD
P-M-03	The horizon should be visible in 50% of the operational time	A	TBD
P-M-04	The horizon shall be visibible in 30% of the operational time	A	TBD
P-E-01	*moved to D-E-10*	-/-	
P-E-02	*moved to D-E-11*	-/-	
P-E-03	*moved to D-E-12*	-/-	
P-E-04	*moved to D-E-13*	-/-	
P-E-05	*moved to D-E-14*	-/-	
P-E-06	*moved to D-E-15*	-/-	
P-E-07	*moved to D-E-16*	-/-	
P-E-08	The optical sensor shall be sensitive to the visible spectrum	R	TBD
P-E-09	The optical sensor shall provide an image resolution of 1024px x 768px	R	TBD
P-E-10	The exposure time of the optical sensor shall be adjustable in a range from 10µsec to 1sec	R	TBD
P-E-11	*moved to D-E-09*	-/-	
P-E-12	The optical sensor shall provide sharp pictures at least 0.120sec after full illumination	T	TBD
P-E-13	The MU shall measure temperatures with an accuracy of +/- 0,5°C	R	TBD
P-E-14	The MU shall measure temperatures in a range from -55°C to +125°C	R	TBD
P-E-15	The MU shall measure temperatures with a sample rate of 1Hz	R	TBD
P-E-16	The MU shall measure currents with an accuracy of +/- 100mA	R	TBD
P-E-17	The MU shall measure currents in a range of 0A to 3A	R	TBD
P-E-18	The MU shall measure currents with a sample rate of 100Hz	R	TBD

Table 5-2: verification matrix (2/7)

ID	Requirement text	Verification	Status
	PERFORMANCE REQUIREMENTS		
P-E-19	The data storage of the MU shall have a memory size of 1 Mbyte	R, T	✔see TR4.1
P-E-20	The data storage of the MU shall provide a write speed of 2 kbyte/sec	T	✔see TR4.1
P-E-21	The data storage for the optical raw data shall have a memory size of 45 Gbyte	R, T	✔see TR4.1
P-E-22	The data storage for the optical raw data shall provide a write speed of 71 Mbyte/sec	T	✔see TR4.1
P-E-23	The data storage for the calculated data shall have a memory size of 77 Mbyte	R, T	✔see TR4.1
P-E-24	The data storage for the calculated data shall provide a write speed of 130 kbyte/sec	T	✔see TR4.1
P-S-01	The 2D vector to the earth center should be calculated with 2 digits	R	TBD
P-S-02	The system shall calculate the 2D vector to the earth for every successful horizon detection	R, T	TBD
P-S-03	The system shall process 30fps for horizon detection	R	TBD
P-S-04	When the rocket is spinning with low rates (< 0.3Hz) AND if there are no image disturbances[1] the results of horizon acquisition should be successful[2] in 90% of those cases.	T	TBD
P-S-05	When the rocket is spinning with low rates (< 0.3Hz) AND if there are little image disturbances[1] the results of horizon acquisition should be successful[2] in 80% of those cases.	T	TBD
P-S-06	When the rocket is spinning with low rates (< 0.3Hz) AND if there are many image disturbances[1] the results of horizon acquisition should be successful[2] in 50% of those cases.	T	TBD
P-S-07	When the rocket is spinning with high rates (> 1.0Hz) AND if there are no image disturbances[1] the results of horizon acquisition should be successful[2] in 80% of those cases.	T	TBD

Table 5-3: verification matrix (3/7)

ID	Requirement text	Verification	Status
	PERFORMANCE REQUIREMENTS		
P-S-08	When the rocket is spinning with high rates (> 1.0Hz) AND if there are little image disturbances[1] the results of horizon acquisition should be successful[2] in 70% of those cases.	T	TBD
P-S-09	When the rocket is spinning with high rates (> 1.0Hz) AND if there are many image disturbances[1] the results of horizon acquisition should be successful[2] in 30% of those cases.	T	TBD
P-S-10	The amount of false negative horizon acquisitions should be less than 10%.	T	TBD
	[1] Image disturbances are phenomena like: sun in the image, lensflares, too dark or too bright illumination.		
	[2] A horizon acquisition is successful if and only if the ratio between the calculated earth radius and the real earth radius r/R holds $0.9 < r/R < 1.1$ and the error of the calculation of the center of earth e (euclidean distance) related to the real earth radius R holds $e/R < 0.1$		
	DESIGN REQUIREMENTS		
D-E-01	HORACE shall not electrically harm neither the REXUS rocket nor launcher	R	TBD
D-E-02	HORACE shall not electrically interfere with other experiments	R	TBD
D-E-03	HORACE shall be compatible to the REXUS electrical interface according to REXUS manual	R	TBD
D-E-04	The FS shall use camera(s) as optical sensor(s)	I	TBD
D-E-05	The FS may use 2 cameras (TBC)	I	TBD
D-E-06	The FS shall provide a global timestamp, synchronized to LO *(formerly F-E-02)*	R	TBD
D-E-07	The FS shall measure the power consumption of selected subsystems *(formerly F-E-04)*	R	TBD

Table 5-4: verification matrix (4/7)

ID	Requirement text	Verification	Status
	DESIGN REQUIREMENTS		
D-E-08	The FS shall measure the temperature the CS, PDU & camera hole (for each system) *(formerly F-E-05, now more detailed)*	R	TBD
D-E-09	The optical sensor shall provide the image data as raw data *(formerly P-E-11)*	R	TBD
D-E-10	The PDU shall provide 5V and 12V. *(formerly P-E-01)*	R, T	TBD
D-E-11	The PDU shall provide currents between 0A and 2.5A *(formerly P-E-02)*	R, T	TBD
D-E-12	The PDU shall provide voltages with an accuracy of ±5% *(formerly P-E-03)*	T	TBD
D-E-13	The PDU shall provide currents with an accuracy of ±200mA *(formerly P-E-04)*	T	TBD
D-E-14	The PDU shall handle a range of input voltage between 24V and 36V *(formerly P-E-05)*	R, T	TBD
D-E-15	The PDU shall handle a range of input current between 0A and 3A *(formerly P-E-06)*	R, T	TBD
D-E-16	A new timestamp shall be provided with the frequency 10 kHz *(formerly P-E-07)*	R, T	TBD
D-M-01	HORACE shall not mechanically harm neither the REXUS rocket nor launcher	R	TBD
D-M-02	HORACE shall not mechanically interfere with other experiments	R	TBD
D-M-03	HORACE shall be compatible to the REXUS mechanical interface according to REXUS manual	R	TBD
D-M-04	The core system shall withstand temperature conditions inside the module according to REXUS manual	T	TBD
D-M-05	The cameras shall withstand temperature conditions at the module's skin according to REXUS manual	T	✔see TR2.3, TR2.2

Table 5-5: verification matrix (5/7)

ID	Requirement text	Verification	Status
	DESIGN REQUIREMENTS		
D-M-06	The whole FS shall withstand pressure conditions according to REXUS manual	T	TBD
D-M-07	The whole FS shall withstand vibration conditions according to REXUS manual	A, T	TBD
D-M-08	Connectors shall be easily accessible	R, I	TBD
D-M-09	The data storage devices shall be easily accessible	R, I	TBD
D-M-10	The optical sensor shall be mounted perpendicular to the z_{BF}-axis *(formerly P-M-01)*	R, I	TBD
D-S-01	The FS shall save the measurement data with global timestamp *(formerly F-S-03)*	R, T	TBD
D-S-02	The FS shall save the calculated data with global timestamp *(formerly F-S-04)*	R, T	TBD
D-S-03	The FS shall save the optical raw data bijectively linked to calculated data *(formerly F-S-09)*	R, T	TBD
D-S-04	Of the calculated data the FS shall save the 2D vector to the earth center *(formerly F-S-05)*	R	TBD
D-S-05	Of the calculated data the FS shall save the detected horizon line as image data *(formerly F-S-06)*	R	TBD
D-S-06	Of the calculated data the FS shall save the calculated extrapolated horizon (circle) *(formerly F-S-07)*	R	TBD
D-S-07	Of the calculated data the FS shall save the stop of calculation timestamp *(formerly F-S-08)*	R	TBD
D-S-08	During flight in every downlink data frame the starttime of calculation shall be included *(formerly F-S-11)*	R	TBD
D-S-09	During flight in every downlink data frame the image frame number of the processed frame shall be included *(formerly F-S-12)*	R	TBD
D-S-10	During flight in every downlink data frame the 2D vector to the earth center, if cal-culated, shall be included *(formerly F-S-13)*	R	TBD

Table 5-6: verification matrix (6/7)

ID	Requirement text	Verification	Status
	DESIGN REQUIREMENTS		
D-S-11	During flight in every downlink data frame the extrapolated horizon (circle), if cal-culated, shall be included *(formerly F-S-14)*	R	TBD
D-S-12	During flight in every downlink data frame the stop of calculation timestamp should be included *(formerly F-S-15)*	R	TBD
D-S-13	The FS shall downlink received signals (echo) during stand-by	R, T	TBD
D-S-14	The FS shall downlink the self-check status during stand-by	R, T	TBD
D-S-15	The FS shall downlink the temperature during stand-by	R, T	TBD
	OPERATIONAL REQUIREMENTS		
O-01	The FS shall operate fully autonomously during flight	T	TBD
O-02	HORACE shall accept a request for radio silence at any time while on the launch pad	R, T	TBD
O-03	The FS shall survive several power-on-off switching cycles during launch preparation	T	TBD
O-04	The FS shall start the video record latest at 0sec (lift-off)	R, T	TBD
O-05	The FS shall be shut down completely after 600sec	R	TBD
O-06	The FS shall be testable with EGSE	T	TBD
O-07	FS shall accept a start command from the EGSE	R, T	TBD
O-08	The received downlink data shall be saved by the groundsegment	T	TBD
O-09	The groundsegment shall allow realtime monitoring of the received downlink data	R, T	TBD
O-10	The data storage devices shall be removed directly after recovery	R	TBD
O-11	The integration and assembly of the FS in the module shall be simple	R, T	TBD

Table 5-7: verification matrix (7/7)

More detailed information about verification (e.g. verification objectives, pass/fail criteria, verification levels) is available in Appendix C .

5.2 Test Plan

Test Number	1.1
Test type	Vacuum Test
Test facility	University of Wuerzburg
Tested item	Power Modules
Test level/ procedure and duration	The power modules will be tested under low pressure conditions (< 0.5 mbar) according to the REXUS manual chapter 9.1 to verify that the capacitors on the power modules withstand low-pressure conditions.
Test campaign duration	approx. 1 day
Status	Done, 20Jun13

Test Number	1.2
Test type	Vacuum Test / Stress Test
Test facility	University of Wuerzburg
Tested item	Power Distribution Unit
Test level/ procedure and duration	The PDU will be tested under low pressure conditions (< 0.5 mbar) according to the REXUS manual chapter 9.1 and beneath an electronic load similar to the electronic load which arises during operation of the FS.
Test campaign duration	approx. 1 day
Status	Planned for 05Sep13

Test Number	2.1
Test type	Thermal Test
Status	Combined with 5.2 and 5.3 to Test Number 5.4

Test Number	2.2
Test type	Thermal Test
Test facility	University of Wuerzburg
Tested item	Lens
Test level/	The Lens shall be tested under temperature conditions

procedure and duration	as occur on the skin at the outside of the rocket, according to the REXUS manual chapter 6.1.3.
Test campaign duration	approx. 1 day
Status	Done, 27Jul13

Test Number	2.3
Test type	Thermal Test
Test facility	University of Wuerzburg
Tested item	Camera System
Test level/ procedure and duration	The Camera System shall be tested under temperature conditions as occur on the skin at the outside of the rocket, according to the REXUS manual chapter 6.1.3, to determine if the camera is working without a protective glass.
Test campaign duration	approx. 1 day
Status	Done, 07Aug13

Test Number	2.4 – not needed, verification method was changed to Review of Design only!
Test type	Thermal Test
Status	Cancelled

Test Number	2.5
Test type	Thermal Test
Test facility	University of Wuerzburg
Tested item	System Level Test
Test level/ procedure and duration	The whole System shall be tested in a Climate Chamber at -40°C to verify the System is able to power up at such temperature conditions, as occur during the test campaign in Kiruna, too.
Test campaign duration	approx. 1 day
Status	Planned for 06Sep13

Test Number	3.1
Test type	Functionality Test
Test facility	University of Wuerzburg
Tested item	Software of the Core System
Test level/ procedure and duration	Verify that Measurement data, calculated data and optical raw data are saved with global timestamp.
Test campaign duration	approx. 1 day
Status	Open, planned for end of September

Test Number	3.2
Test type	Functionality Test
Test facility	University of Wuerzburg
Tested item	Software of the GSE
Test level/ procedure and duration	Verify that the Ground Support Equipment is compatible to the FS and is capable of controlling the FS.
Test campaign duration	approx. 1 day
Status	Open, planned for end of September

Test Number	3.3
Test type	Functionality Test
Test facility	University of Wuerzburg
Tested item	Software of the Core System
Test level/ procedure and duration	A Simulation of the flight will be performed to test the Core System's capability to run the developed Horizon-Detection Algorithm.
Test campaign duration	approx. 1 day
Status	Open, planned for mid of September

Test Number	3.4
Test type	Functionality Test

Test facility	University of Wuerzburg
Tested item	System Level Test
Test level/ procedure and duration	Verify that the Flight System is compatible to the REXUS interface by testing with a REXUS simulator
Test campaign duration	approx. 1 day
Status	Open, planned for mid of September

Test Number	4.1
Test type	Performance Test
Test facility	University of Wuerzburg
Tested item	Data Storage
Test level/ procedure and duration	Memory size and write speed of data storage devices shall be tested according to Performance Requirements P-E-19 to P-E-24
Test campaign duration	approx. 1 day
Status	Done, 30Aug13

Test Number	4.2
Test type	Performance Test
Test facility	University of Wuerzburg
Tested item	Power Distribution Unit
Test level/ procedure and duration	Verify that PDU provides Voltage and Current with a specific accuracy according to Requirements P-E-01 to P-E-06
Test campaign duration	approx. 1 day
Status	Open, planned for end of August.

Test Number	4.3
Test type	Performance Test
Test facility	University of Wuerzburg
Tested item	Camera System

Test level/ procedure and duration	Verify that the Camera provides an image resolution of 1024x768px and is able to provide sharp pictures at least 0.12sec after full illumination. The protecting glass must be used in this test to verify there are no severe impacts or distortions on image quality caused by the protecting glass.
Test campaign duration	approx. 1 day
Status	Open, planned for beginning of September

Test Number	4.4
Test type	Performance Test
Test facility	University of Wuerzburg
Tested item	System Level Test
Test level/ procedure and duration	A simulation of the flight shall be run to confirm that the Flight Segment is able to operate fully autonomously during a flight simulation. The image data also shall be simulated (via ASAP Simulator or Beamer)
Test campaign duration	Approx. 2 days
Status	Open, planned for mid/end of September

Test Number	5.1
Test type	Thermal vacuum
Status	edited and moved to Test Number 2.4

Test Number	5.2
Test type	Thermal vacuum
Status	Combined with 2.1 and 5.3 to Test Number 5.4

Test Number	5.3
Test type	Thermal vacuum
Status	Combined with 2.1 and 5.2 to Test Number 5.4

Test Number	5.4
Test type	Thermal vacuum
Test facility	University of Wuerzburg
Tested item	System Level Test
Test level/ procedure and duration	The whole System (consisting of PDU, MU, CS and Camera System) shall be tested under flight conditions according to REXUS manual Chapter 9.1 and 9.2.
Test campaign duration	approx. 2 days
Status	Open, planned for mid of September

Test Number	6.1 – not needed anymore!
Test type	vibration
Test level/ procedure and duration	Qualification Level
Status	Will not be done

Test Number	6.2
Test type	vibration
Test facility	DLR Bremen
Tested item	System Level Test
Test level/ procedure and duration	Acceptance Level The whole system shall be mounted on a vibration table and vibration in X,Y and Z axis must be performed according to REXUS manual chapter 9.3.1.
Test campaign duration	TBD
Status	Open

Test Number	7.1
Test type	Performance Test
Test facility	University of Wuerzburg
Tested item	System Level Test
Test level/	The whole system shall be disassembled and

procedure and duration	assembled according to the “Integration and assembly procedure” to verify the assembly procedure is simple and without fault.
Test campaign duration	approx. 2 days
Status	Open, planned for end of September

Test Number	8.1
Test type	Transport
Test facility	University of Wuerzburg
Tested item	System Level Test
Test level/ procedure and duration	The whole system shall be put in similar conditions as occur during transport of the experiment from Bremen to Kiruna. It shall be verified that there is no damage to any component even the transport conditions are rough.
Test campaign duration	approx. 2 days
Status	Open, planned for end of September

5.3 Test Results

The test results can be found separately in a zip-file on the Teamsite which contains following items:

Index	**Filename**	**Description**
1	RX16_HORACE_TR1.1_v1.0_21Jun13.pdf	Test Report for Test #1.1
2	RX16_HORACE_TR2.2_v1.0_30Jul13.pdf	Test Report for Test #2.2
3	RX16_HORACE_TR2.3_v1.0_07Aug13.pdf	Test Report for Test #2.3
4	RX16_HORACE_TR4.1_v1.0_02Sep13.pdf	Test Report for Test #4.1

6 LAUNCH CAMPAIGN PREPARATION

6.1 Input for the Campaign / Flight Requirement Plans

6.1.1 Dimensions and mass

Experiment mass (in kg):	7.65kg (for 2 systems, including 10% margin, including module)
Experiment dimensions (in m):	0.318 m x 0.348 m x 0.0799m
Experiment footprint area (in m^2):	0.038 m^2
Experiment volume (in m^3):	1.1*10-3 m^3
Experiment expected COG (centre of gravity) position:	coordinate system: axes parallel to BF, origin on z_{BF} in lowest plane of module: x=0.0mm y=0.0mm z=66.6mm; ±<10mm each axis

Table 6-1: Experiment mass and volume

6.1.2 Safety risks

Except from usual risks associated with electricity HORACE entails no special safety risks, neither for personnel nor the REXUS rocket.

6.1.3 Electrical interfaces

REXUS Electrical Interfaces		
Service module interface required? Yes		
	Number of service module interfaces:	2 x 1 **)
	TV channel required?	No
Up-/Downlink (RS-422) required? Yes		
	Data rate - downlink:	2x 5.3Kbit/s **)
	Data rate – uplink	0Kbit/s
Power system: Service module power required? Yes		
	Peak power consumption:	35W *); 67.2W**)

	Average power consumption:	35W*); 67.2W **) (incl.50% margin)
	Total power consumption after lift-off(until T+600s)	5.8Wh *); 11.2Wh **)
	Power ON	T-600s
	Power OFF	T+600s
	Battery recharging through service module:	No
Experiment signals: Signals from service module required? Yes		
	LO:	Yes
	SOE:	T+2s
	SODS:	T+3s

*) If one core system is flown.

**) If two core systems are flown.

Table 6-2: Electrical Interfaces to REXUS

6.1.4 Launch Site Requirements

At the launch site the following equipment shall be provided:

- 3 desks/tables
- 6 chairs
- 10x power outlet (230V, 50Hz)
- 1 whiteboard/flipchart with pencils (&magnets)
- power supply 24V-36V DC for testing
- Internet access

6.2 Preparation and Test Activities at Esrange

With the following plan for preparation and test activities at Esrange during the days right before launch, it shall be ensured, that the experiment survived the transport to Esrange, is working properly and is well prepared for the flight.

The given plan will be extended and get more detailed, as well as procedures for single activities will be defined, by experiences gathered during implementation.

As soon as possible, latest on Day 2 of the launch campaign, one shall start unpacking the experiment and perform visual inspection of all components. Obviously damaged ones are immediately exchanged with spare items. After inspection for each subsystem several tests and check-out procedures are performed, to ensure proper functionality of each subsystem, respectively to detect failures early. When all subsystem test and check-outs are passed, the experiment is assembled in the module, latest during Day 3, to perform full system tests and check-outs.

Properly prepared one will go on with the compulsory tests and flight simulation together with the other experiments already connected to and communicating via RXSM (Day 3 & 4).

As the last step before final assembly of the complete payload, all screws are checked, locked and glued irreversibly, as well as all electrical connections are checked and fixated irreversibly (latest end of Day 4), what will be followed by the Flight Acceptance Review.

Before roll-out, the Flight Readiness Review will be held, and the launch preparations end with the compulsory test CD – nominally during Day 7.

Latest possible before launch the protection foils of the cameras are removed.

6.3 Timeline for Countdown and Flight

This chapter gives a rough timeline of activities, processes and signals/ actions of RXSM (written in red capitals) for countdown and flight. The timeline will be extended and specified more detailed in upcoming SED versions.
RBFs: As short as possible before flight, the protection foils of the cameras' windows have to be removed.

Time	Subsystem	Action
-600	RXSM	POWER ON
	FS-PDU	distribute power to all subsystems
	FS-all	start all subsystems
	GS-TM	start monitoring & saving received TM
-540	FS-all	start self-checks; send life&health data regularly
	GS-TM	monitor self-checks & life/health data
	GS-TC	command self-checks
-420	FS-all	self-checks finished
	GS-TC	clear/reset data storages (manually)
-60	GS-TC	command start video record
	FS-CS	start video record (triggered by TC)
	GS-TM	monitor video recording
+0	RXSM	LO
	FS-CS	synchronize clock
	FS-CS	start & save calculations
	FS-MU	start saving measurement data
+2	RXSM	SOE (as redundancy to LO)
+590	FS-all	stop saving; safe system shutdown
+600	RXSM	POWER OFF

Table 6-3: timeline for countdown and flight

6.4 Post Flight Activities

Directly after flight, the received and saved downlink data will be backed up to external data storage devices to prevent loss of data by accident.

While waiting for recovery, first brief evaluations of the downlink data are performed to estimate the experiments performance, which will be presented during Post Flight Meeting.

As first action of disassembly the Flight Segment's data storage devices are removed carefully and immediately backed up. Afterwards the complete Flight Segment is disassembled step by step and all components inspected. Disassembly and inspection are well-documented regarding check-lists and including photos.

Finally all components and the complete equipment is packed and prepared for transportation following packing procedures.

7 DATA ANALYSIS PLAN

7.1 Data Analysis Plan

During the post flight analysis the calculated data will be both matched with the recorded video data and collected housekeeping data as well as with flight data collected by RXSM and data from pre-flight simulations and tests.

Therefore the calculated data will be visualised, layered in the video data with video editing software and evaluated frame by frame manually or with special software, whereas the matching of the RXSM and housekeeping data to the calculated data will most likely be performed by using spread sheets.

So all data will be analysed regarding the following aspects:

- Calculate deviation of detected horizon compared with visible horizon in video frames
- Calculate deviation of calculated earth vector compared with vector calculated with RXSM-data
- Determine limits of spinning rates for successful horizon acquisition
- Calculate ratio of correctly processed frames per second
- Did false positives occur? Detect reasons.
- Did false negatives occur? Detect reasons.
- Calculate ratio of successful horizon detections to frames on which horizon is indeed visible
- Evaluate correlations between power consumption and algorithmic activities and spinning rates
- Evaluate power consumption as important parameter for later operational use

With this data analysis and evaluation finally both qualitative and quantitative evidence about the general technical feasibility, robustness and accuracy of autonomous horizon detection following the outlined approach will be provided.

8 ABBREVIATIONS AND REFERENCES

8.1 Abbreviations

This section contains a list of all abbreviations used in the document.

AIT	Assembly, Integration and Test
asap	as soon as possible
BO	Bonn, DLR, German Space Agency
BR	Bremen, DLR Institute of Space Systems
CDR	Critical Design Review
COG	Centre of gravity
CRP	Campaign Requirement Plan
CS	Core System
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	Esrange Project Manager
ESA	European Space Agency
Esrange	Esrange Space Center
ESTEC	European Space Research and Technology Centre, ESA (NL)
ESW	Experiment Selection Workshop
FAR	Flight Acceptance Review
FS	HORACE Flight Segment
FST	Flight Simulation Test
FRP	Flight Requirement Plan
FRR	Flight Readiness Review
GSE	Ground Support Equipment
HK	House Keeping
H/W	Hardware
ICD	Interface Control Document
I/F	Interface
IPR	Interim Progress Review
JMU	Julius-Maximilians-Universität Würzburg
LO	Lift Off
LT	Local Time
LOS	Line of sight
Mbps	Mega Bits per second
MFH	Mission Flight Handbook

MORABA	Mobile Raketen Basis (DLR, EuroLaunch)
MU	Measurement Unit
OP	Oberpfaffenhofen, DLR Center
PCB	Printed Circuit Board (electronic card)
PDR	Preliminary Design Review
PDU	Power Distribution Unit
PST	Payload System Test
SED	Student Experiment Documentation
SNSB	Swedish National Space Board
SODS	Start Of Data Storage
SOE	Start Of Experiment
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
WP	work package

8.2 References

(Books, Paper, Proceedings)

[1] EuroLaunch: **REXUS User Manual** (2012)

8.3 List of Figures and Tables

APPENDIX A – EXPERIMENT REVIEWS

Comments of the Selection Board on proposal:

Comments on the REXUS-Proposal „HORACE“
• We got the proposal from the students´ supervisor. Within the REXUS/BEXUS programme the student team has to represent the experiment by themselves (selection workshop, reviews, launch campaign).
• Looking at available videos from previous rocket campaigns you should convince us that you can perform a reasonable horizon acquisition with your approach (camera + image processing). http://www.explore-rexus.de/
• Why do need an uplink? Note: On REXUS, an uplink is not normally available during flight!
• What is the reason to measure power consumption?
• The team should add a mechanical engineer.
• The outreach activities should be extended. For instance, the video could be uploaded on Youtube, and you should present your results in, e.g., seminars. Which team member is responsible for public outreach?
• Give some more details on the algorithms and the planned evaluation during the presentation.

Comments on the presentation during Selection Workshop in Bonn

- Consider that the Earth is not always “blue” and the sky is not always “black”.
- Consider using movies from other teams to test the algorithm.
- After the flight, housekeeping data from the rocket can be provided to support the evaluation.
- Consider including more than one camera.
- Tests on turning tables should be carried out.
- Consider that the camera can be exposed directly to sun.
- Consider to reduce/avoid sun reflections around and inside the hatch (e. g. surface treatment).
- Consider comments already given with the workshop invitation.

Comments and recommendations of the PDR-panel

More detailed information/discussion and response of the team about the RIDs is available on the Team Site (file: RX16_HORACE_RID-PDR-v1.0_21Mar13.pdf)

- **Requirements and constraints***(SED chapter 2)*
  - 21 functional requirements, appears to be far too many
  - Focus on functions that people would like to know from the experiment
  - Some performance requirements are very open
  - Be careful with the difference between performance and design requirements
  - Can include should, shall, may in the requirements to build on the objectives in the requirements
  - Careful with definitions of your experiment name
  - Operational requirements very good
  - Careful with the words launcher and vehicle
  - 2nd performance requirement – how do you actually achieve a 70% if you are treating the systems as redundant. Team – they are independent
- **Mechanics***(SED chapter 4.2.1 & 4.4)*
  - Team doesn't have a mechanical engineer currently
  - If parts break off from the rocket, that can influence flight dynamics
  - So team should be able to prove somehow that the system is fastened well and strong enough
  - Consider working on both sides of a single bulkhead rather than using two bulkheads
  - Box your electronic boards up to protect them
  - Team is looking at just holes
  - This would mean hot gas coming in on entry
  - Team needs to think on how large these holes are for the correct angle of view
  - Brackets are upside down
  - Cable feedthrough is needed at 180° for both bulkheads if used
- **Electronics and data management***(SED chapter 4.2.2, 4.2.3, 4.5 & 4.7)*
  - Interface to REXUS is ok
  - Power consumption is unclear right now
  - DCDC converters would be more efficient
  - With a second camera, more power required could exceed the budget
  - Team = perhaps power consumption is much higher than earlier

- Input to power has a large capacitor which should be removed if not valid
- Power consumption is at limit but with a 25% margin, be careful of DCDC converter efficiency
- COTs board with unnecessary components that are unlikely to perform or survive for a rocket launch
- Important to make sure they are safe enough for the launch
- Long boards need to be supported against bending stresses
- Better if the power solution is worked on sooner rather than later since it can be messy to implement at a late stage
- Team must implement batteries or use just a single unit
- Power system and batteries will influence all other systems and so a decision should be made quickly for this

- **Thermal***(SED chapter 4.2.4 & 4.6)*
    - Not much there right now (Nice that team was able to identify this)
    - Environment considered and the Component ranges should be added in this section
    - Thermal experiment interface deleted, please put it back in
    - Hot gas inrush - needs to be looked at carefully
    - Power dissipation of the FPGA will need to be checked and tested very carefully
- **Software***(SED chapter 4.8)*
    - Should switch to experiment phase before lift-off so that it can be checked out thoroughly
    - Look to use SOE and SODS before or after lift-off so that you can better test your experiment
    - How do you ensure that none of the data is corrupted during shutdown
    - Processers need to be brought to safe mode directly before switch-off
    - Look for the data packages to use bytes rather than bits as this can be easier to implement but could also be adapted
    - Please implement an uplink capability for on-ground testing
    - Use this for a memory reset function
    - You have very nice diagrams but halfway between block diagrams and flow diagrams, good to be careful with this but diagrams are generally clear and informative
- **Verification and testing***(SED chapter 5)*
    - Some items are analysis but are actually review of design
    - Analysis is used a little too often

- Some of the testing is actually not reflected in the verification matrix
    - Verification methodology is ok but make sure you treat the whole spectrum of verification methods
    - Software testing should be considerably increased
    - Look into cold coverage factor for software
- **Safety and risk analysis***(SED chapter 3.4)*
    - Be careful with severity, 5 is very high
    - Risk analysis should be reviewed in detail
- **Launch and operations***(SED chapter 6)*
    - Power on T-1200s, should be T-600s
    - Chapter 6.3 is missing, missing timeline
    - What do you want do to do before flight
    - Which housekeeping data do you need from EuroLaunch
    - Bring with you switches
    - WLAN must be off for radio silence
    - If batteries are used, this experiment needs to be able to be switched to a dead payload functionality
    - Consider the inclusion of the battery possibility now as it is easier to remove later. If both systems are used, it looks necessary to include the batteries
- **Organization, project planning & outreach***(SED ch. 3.1, 3.2 & 3.3)*
    - Team looks to still have the lack of mechanical engineering (Team – can't find one in Wurzburg due to lack of faculty there)
    - Could look at working with the SpaceMasters students in some capacity
    - Outreach has begun well and it is hoped that the team keeps this up
    - Updates and outreach should continue after the launch

Comments and recommendations of the CDR-panel:

More detailed information/discussion and response of the team about the RIDs is available on the Team Site:

RX16_HORACE_CDR_RID_01_v1.1_08Aug13_final.pdf
RX16_HORACE_RID_CDR_others_v1.0_25Aug13.pdf

- **Requirements and constraints** *(SED chapter 2)*
    - Some classifications are not correct. The requirements P-E-01 to P-E-08 are all design requirements, not performance requirements.

  - **Performance requirements should reflect to goals of what the system has to achieve.**
  - For example: Output of power supply is a design requirement, not a performance requirement.
  - P-E-12: has been clarified
  - D-E-09: has been clarified
- **Mechanics** *(SED chapter 4.2.1 & 4.4)*
  - Major topic: Camera covers/fins
  - **If an element is protruding from the skin, this element will in fact get hot.**
  - **Consider turbulences that can occur due to the fins.**
  - **Fins are not completely wrong, but might not be completely useful either.** It is recommended that the fins on the outside are removed.
  - **The panel suggest finding a different protective solution flush with the skin.**
  - Protection with a cover usually is for the ascent phase only.
  - **Aluminium or other metals will be very bright in the camera; make sure to render the surface less reflective.**
  - **There is a lack of mechanical overview drawings.**
  - Use of helicoils on the bulkhead is suggested (do not use nuts). Self-locking helicoils might also be an option, depending on order of assembly.
- **Electronics and data management** *(SED chapter 4.2.2, 4.2.3, 4.5 & 4.7)*
  - Interface circuits are implemented correctly.
  - Team has decided not to use batteries.
  - **Filtering of the 28V of REXUS is missing. Include inductivity/choke/input filter.**
  - **Overall power consumption is permissible for two interfaces; this is however subject to global system design decisions.**
  - In worst case scenario, second camera system can be driven in a lower power mode.
  - Second experiment connector is requested, there will be a second cable.
  - **Team will start integrating two systems and wait for EuroLaunch feedback on the availability of experiment connectors. Team would rather drop second system than implement batteries.**

  - Ripple should be measured on the input line, clarify it again.
  - Data rate for uplink: 38.4 kbit/s
- **Thermal** *(SED chapter 4.2.4 & 4.6)*
  - **Include 'shipping' as a thermal environment for the camera.**
  - **Full component list with thermal boundary missing.**
  - Approach is quite solid.
- **Software** *(SED chapter 4.8)*
  - Edge detection currently implemented in C on Linux, will then move to flight hardware.
  - Implement proper shutdown procedure on the Linux system.
  - Fast start-up time of system is good.
  - **SOE signal 10s before lift-off is a risk. There is no chance to stop launch sequence at this point.**
  - Consider pushing a button yourself on the ground station instead of SOE.
- **Verification and testing** *(SED chapter 5)*
  - Compatibility to the launcher/vehicle shall be tested, not only reviewed.
  - Excellent thermal-vacuum test plan.
  - Very good test plan in general.
  - **Consider and test the dynamic exposure setting of the camera.**
- **Safety and risk analysis** *(SED chapter 3.4)*
  - No safety issues seen with the experiment.
- **Launch and operations** *(SED chapter 6)*
  - No specific comments.
  - Does not use the SOE signal 10s before LO.
- **Organisation, project planning & outreach** *(SED chapters 3.1, 3.2 & 3.3)*
  - Correct the order of sponsor on your webpage.
  - Good that there is current information.
  - Impressed by the project management, it was very clear (Gantt, WBS, etc. clear)
  - Include a sponsorship in the component list.
  - IPR is scheduled too early.

APPENDIX B – OUTREACH AND MEDIA COVERAGE

B.1 Weblinks

Ref. #	Link
1	www.horace-rexus.de
2	www.facebook.com/horace.rexus
3	www.youtube.com/user/horacerexus
4	www.gplus.to/horacerexus
5	www.twitter.com/horace_rexus
6	http://www8.informatik.uni-wuerzburg.de/mitarbeiter/kayal0/student_projects/horace/
7	http://de.wikipedia.org/wiki/HORACE
8	http://www.presse.uni-wuerzburg.de/einblick/single/artikel/nach-600-s/
9	http://idw-online.de/pages/de/news524349
10	http://www.scinexx.de/business-15805-2013-03-20.html
11	http://www.pressrelations.de/new/standard/dereferrer.cfm?r=526654

B.2 Logo

We designed two Logos for the HORACE project. One for general use in publications or presentations, and a mission patch for "personal use", like labels, T-shirt imprints etc.

Mission Patch

HORACE Logo

B.3 Poster

We designed the poster shown below, which supports our presentations, e.g. on information stands, and is hung up at the floors of the Chair of Aerospace Information Technology.

B.4 Presentations

Presentations held by team members about HORACE.

Date	Event/ Occasion /Auditorium
16.01.13	Seminar “Avionic Devices” for Aerospace Information Technology students at University of Würzburg
22.01.13	Meeting of German-Polish cooperation board for nano-satellites at University of Würzburg
09.02.13	Presentation for all other RXBX-teams during STW
27.05.13	Presentation in the context of English course “English for Academic Purposes” (students of all fields of study attending) at University of Würzburg

APPENDIX C – PROJECT MANAGEMENT

This appendix contains additional information about project management and can be found separately in a zip-file with the following contents:

Index	Filename	Description
1	RX16_HORACE_SED_v2.0_APPENDIX_C_1_full_WBS_01Jun13.pdf	Full WBS (interactive PDF)
2	RX16_HORACE_SED_v3.0_APPENDIX_C_2_schedule_02Sep13.mpp	Complete Schedule (MS Project 2010)
3	RX16_HORACE_SED_v2.0_APPENDIX_C_3_Verification_Objectives_02Sep13.pdf	Verification Objectives

APPENDIX D – DATASHEETS

The appendix can be found separately on the Teamsite as zip-file with the content given below:

D.1 Datasheets

Index	Filename	Description
1	RX16_HORACE_SED_v3.0_APPENDIX_D_DS_1_camera.pdf	Camera technical manual
2	RX16_HORACE_SED_v3.0_APPENDIX_D_DS_2_embedded_board.pdf	Embedded Board MIO-2260
3	RX16_HORACE_SED_v3.0_APPENDIX_D_DS_3_DCDC-regulator.pdf	LM2596 DC/DC regulator
4	RX16_HORACE_SED_v3.0_APPENDIX_D_DS_4_SSD.pdf	SSD datasheet
5	RX16_HORACE_SED_v3.0_APPENDIX_D_DS_5_Arduino_Leonardo.pdf	Arduino Leonardo Datasheet
6	RX16_HORACE_SED_v3.0_APPENDIX_D_DS_6_Temperature_Sensor.pdf	Temperature Sensor
7	RX16_HORACE_SED_v3.0_APPENDIX_D_DS_7_Current_Sensor.pdf	Current Sensor
8	RX16_HORACE_SED_v3.0_APPENDIX_D_DS_8_CF_Card.pdf	CF Card
9	RX16_HORACE_SED_v3.0_APPENDIX_D_DS_9_MAX488.pdf	MAX488 Transceiver
10	RX16_HORACE_SED_v3.0_APPENDIX_D_DS_10_RS232_TTL_Module.pdf	RS232 TTL Module
11	RX16_HORACE_SED_v3.0_APPENDIX_D_DS_11_Optocoupler_EL817.pdf	Optocoupler EL817

APPENDIX E – DETAILED MECHANICS

This appendix contains more detailed information about the experiment's mechanics – like CAD-drawings, FEM analysis, thermal analysis etc.– and can be found separately on the Teamsite as zip-file with the following contents:

E.1 Engineering Drawings

Index	Drawing-Filename	Description
1	RX16_HORACE_SED_v3.0_APPENDIX_C_DRAW_1_3D-View-Full.png	HORACE with REXUS module, 3D-View
2	RX16_HORACE_SED_v3.0_APPENDIX_C_DRAW_2_3D-View.png	HORACE without REXUS module, 3D-View
3	RX16_HORACE_SED_v3.0_APPENDIX_C_DRAW_3_Front-View-Full.png	HORACE with REXUS module, front view
4	RX16_HORACE_SED_v3.0_APPENDIX_C_DRAW_4_HORACE-Top.png	HORACE, view from above
5	RX16_HORACE_SED_v3.0_APPENDIX_C_DRAW_5_HORACE-bottom.png	HORACE, bottom view
6	RX16_HORACE_SED_v3.0_APPENDIX_C_DRAW_6_HORACE-Side.png	HORACE, side view
7	RX16_HORACE_SED_v3.0_APPENDIX_C_DRAW_7_HORACE-Front.png	HORACE, front view
8	RX16_HORACE_SED_v3.0_APPENDIX_C_DRAW_8_CoreSystem-closed.png	Core-System-Box, closed, 3D-View
9	RX16_HORACE_SED_v3.0_APPENDIX_C_DRAW_9_CoreSystem-open.png	Core-System-Box, open, 3D-View
10	RX16_HORACE_SED_v3.0_APPENDIX_C_DRAW_10_MeasurementUnit-closed.png	Measurement-Unit-Box, closed, 3D-View
11	RX16_HORACE_SED_v3.0_APPENDIX_C_DRAW_11_MeasurementUnit-open.png	Measurement-Unit-Box, open, 3D-View
12	RX16_HORACE_SED_v3.0_APPENDIX_E_DRAW_12_complete_CAD.dwg	HORACE complete CAD File

E.2 Reports

Index	Report-Filename	Description
1	RX16_HORACE_SED_v3.0_APPENDIX_E_REP_1_Mech-Load-Test.pdf	Mechanical Load Test
2	RX16_HORACE_SED_v3.0_APPENDIX_E_REP_2_Temp-Analysis.pdf	Thermal Analysis Report

APPENDIX F – DETAILED ELECTRONICS

This appendix contains more detailed information about the experiment's electronics – like electronic schematics, PCB-layouts etc. – and can be found separately as a zip-file on the Teamsite with the content given below:

F.1 PCB Layouts

Index	Filename	Description
1	RX16_HORACE_SED_v3.0_APPENDIX_F_PCB_1_PDUCarrierTop.pdf	PDU Carrier Board Layout – Top Layer
2	RX16_HORACE_SED_v3.0_APPENDIX_F_PCB_2_PDUCarrierBottom.pdf	PDU Carrier Board Layout – Bottom Layer

F.2 Electronic Schematics

Index	Schematics-Filename	Description
1	RX16_HORACE_SED_v3.0_APPENDIX_F_SCH_1_DCDC-Converter.pdf	DC/DC Converter Module
2	RX16_HORACE_SED_v3.0_APPENDIX_F_SCH_2_PDU-Carrier.pdf	PDU carrier board
3	RX16_HORACE_SED_v3.0_APPENDIX_F_SCH_3_Arduino.pdf	Arduino Leonardo
4	RX16_HORACE_SED_v3.0_APPENDIX_F_SCH_4_microSD-Module.pdf	microSD module for Arduino
5	RX16_HORACE_SED_v3.0_APPENDIX_F_SCH_5_RS232-TTL-Converter.pdf	RS232 -> TTL converter