SED

Student Experiment Documentation

Document ID: RX16_HORACE_SEDv5-0_31Oct14_final.docx

Mission: REXUS 16

Team Name: HORACE

Experiment Title: Horizon Acquisition Experiment

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Version:	Issue Date:	Document Type:	Valid from:
5.0	**31 October 2014**	**Spec**	**31 October 2014**

Issued by:

Thomas Rapp

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Change Record

Version	Date	Changed chapters	Remarks
0	2008-12-18	New Version	Blank Book 2010
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		3, 4, 5, 6, Appendix B, C, D, E, F	Pre-Campaign • 3 update • 4 minor updates & fixed errors • 4.8 added dataflow-diagrams • 5 update, added traceability matrix • 6 update • Appendices update
5		Abstract, 1.5, 3, 4, 5, 7, Appendix B, C & minor changes in other chapters	Final report • Abstract: update to post-flight • 1.5.1 contact address changed!

			• 1.5.2 update • 3 update to post-flight • 4 past tense applied to indicate post-flight, actual flight performance of subsystems indicated or reference to corresponding chapters / documents where appropriate • 4.8 major improvements to document the software design • 5 update to post-flight • 7.1 actual analysis procedures added • 7.2, 7.3, 7.4 new • Appendices update • Minor changes & fixes (language mistakes, outdated technical details, usage of past tense) throughout the complete document

Abstract: This paper contains the complete documentation of the HORACE-project which was launched on May 28 2014 13:30 UTC+2 from Esrange Space Center/Kiruna as payload of REXUS 16. Version 5.0 of the documentation is the final experiment report, including the post-flight evaluation and all results of the experiment.

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

CONTENTS

ABSTRACT

The aim of the Horizon Acquisition Experiment (HORACE) was 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 flight onboard REXUS 16, which was launched May 28 2014 13:30 UTC+2 from Esrange Space Center/Kiruna, both video and calculated data were 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 provided 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.

Unfortunately, due to a malfunction of the payload cameras of HORACE the captured video footage of the flight was severely overexposed, while all other subsystems of the experiment worked perfectly nominal throughout the complete countdown and flight. Hence, with this set of scientific data it was not possible to neither prove nor disprove the general approach and test the image processing algorithms under space-like conditions. Therefore, also the conclusions drawn regarding the qualitative and quantitative evidence were limited or could only indirectly be given. Nevertheless, the approach seems to be accurate (±0.6°), fast and robust enough for attitude determination in emergencies and a future operational system could also be applicable for small satellites. At the current stage of development towards the long term aim, the major limiting factors of the approach in general are the camera and the threshold filter. However, with further autonomy of the threshold filter than tested on HORACE, it is likely that one will overcome this in the future.

HORACE was 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 was developed and implemented from fall 2012 to spring 2014 and launched in May 2014 in the scope of the REXUS programme. With the issue of this final experiment report the project-lifecycle is completed.

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

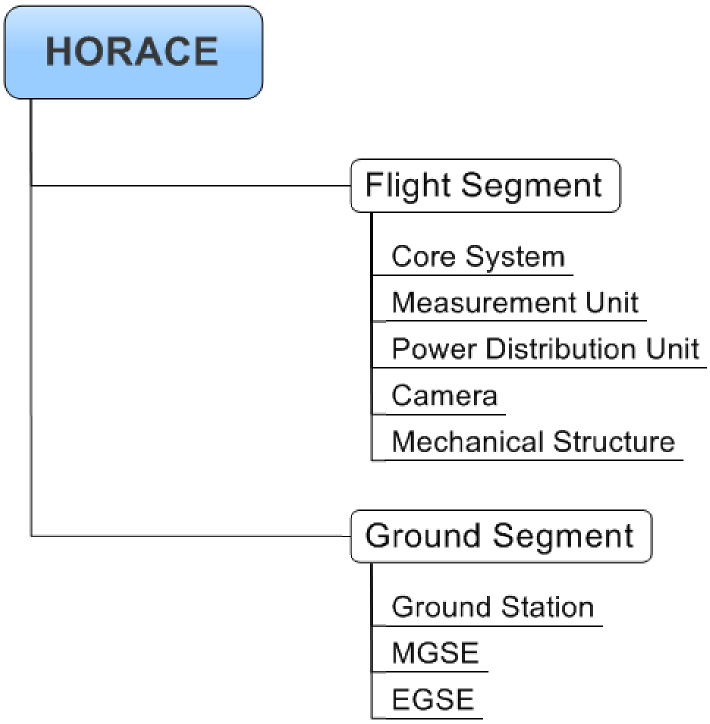


Figure 1-1: Hierarchy of HORACE

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).

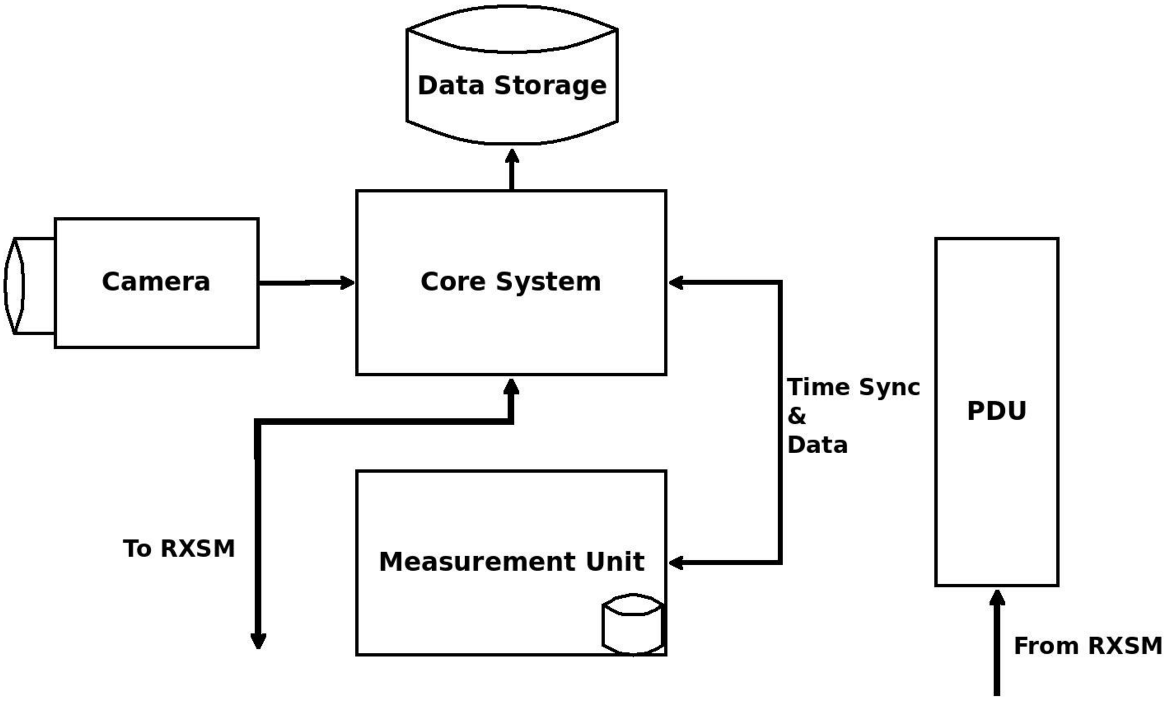


Figure 1-2: Subsystems of Flight Segment

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:

Address: HORACE Team – Thomas Rapp
c/o Prof. Dr. Hakan Kayal
& Dipl.-Inf. Gerhard Fellinger (supervisors)
Lehrstuhl Informatik VIII
Professur für Raumfahrttechnik
Julius-Maximilians-Universität Würzburg
Sanderring 2
97070 Würzburg
GERMANY
Phone: +49 1577/ 1529248
E-Mail: team@horace-rexus.de

1.5.2 Team Members

Thomas Rapp – Project Management

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

He was also part of the software work group and responsible for the Measurement Unit, as well as for the overall experiment evaluation.

Thomas took part in the project from the beginning of his second undergraduate year of his studies of Aerospace Information Technology at University of Würzburg and graduated with the project-related Bachelor Thesis (12ECTS) "Development and Post-Flight-Analysis of HORACE the Horizon Acquisition Experiment" [1] in September 2014.

Jochen Barf – Algorithmic Development

Jochen's main task was 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 also developed the required software components for later data evaluation.

Jochen took part in the project from the beginning of his second undergraduate year of his studies of Aerospace Information Technology at University of Würzburg and graduated with the project-related Bachelor Thesis (12ECTS) “Development and Implementation of a Horizon Sensing Algorithm Based on Image Processing Technologies” [2].

Sven Geiger – Embedded System Development & Porting

It was Sven’s job to make sure that Jochen’s algorithms ran on the embedded system of the HORACE-System.

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

At the initiation of the project Sven was at the beginning of his second undergraduate year of studies of Aerospace Information Technology at University of Würzburg and he will graduate during fall 2014.

Florian Wolz–Electrical & Mechanical Engineering

As electrical engineer, Florian ensured that every component was supplied with power and implemented the electrical interface to the REXUS-Bus.

Together with Matthias he also worked on the mechanical and thermal design and was mainly responsible for device assembly and manufacturing.

Florian is a student of Aerospace Information Technology at University of Würzburg in his third undergraduate year and took part in the project from the beginning of his second undergraduate year.

Matthias Bergmann – Mechanical & Optical Engineering

Matthias joined the team in April 2013 and did the main part of the mechanical and thermal design, including CAD and calculations and assisted Florian with the device assembly.

He was also in charge of all parts concerning the camera and optics of HORACE. Additionally, he programmed the Ground-Station User-Interface.

When he joined Matthias was in his fourth undergraduate semester of studies of Aerospace Information Technology at University of Würzburg and he will graduate during fall 2014.

Arthur Scharf – Simulation Environment & Public Outreach

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

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

Arthur is a student of Aerospace Information Technology at University of Würzburg in his third undergraduate year and took part in the project from the beginning of his second undergraduate year.

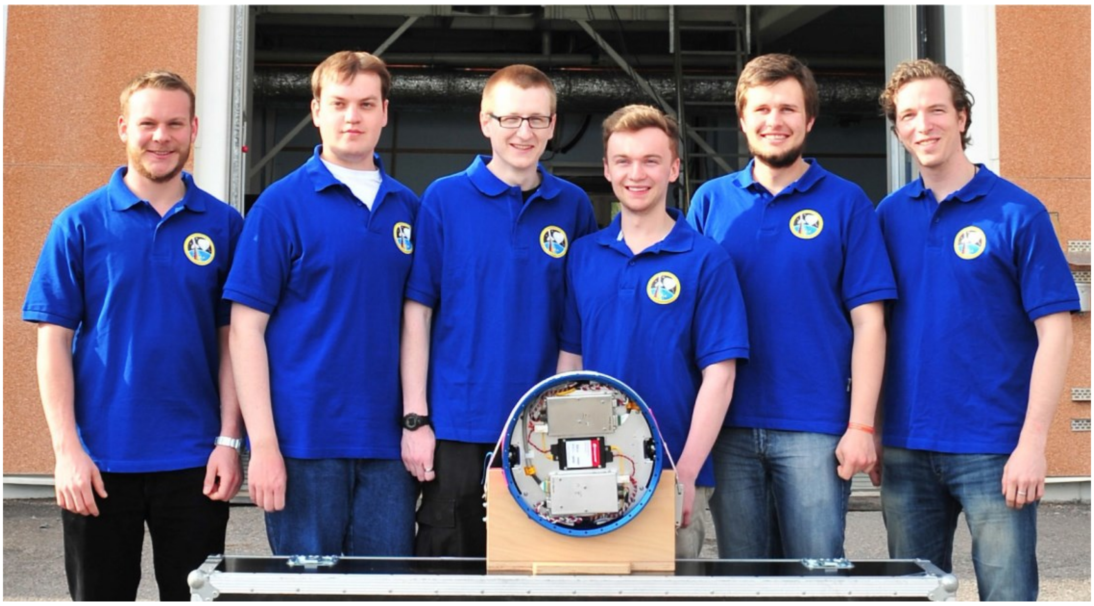


Figure 1-3: The HORACE team with the experiment after the flight (left to right): Jochen Barf, Matthias Bergmann, Florian Wolz, Arthur Scharf, Thomas Rapp, Sven Geiger

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. This applies to all work packages but some sub-packages of “Public Outreach” as the project is completed but the website and social media pages will be maintained continuously and presentations will be held where appropriate.

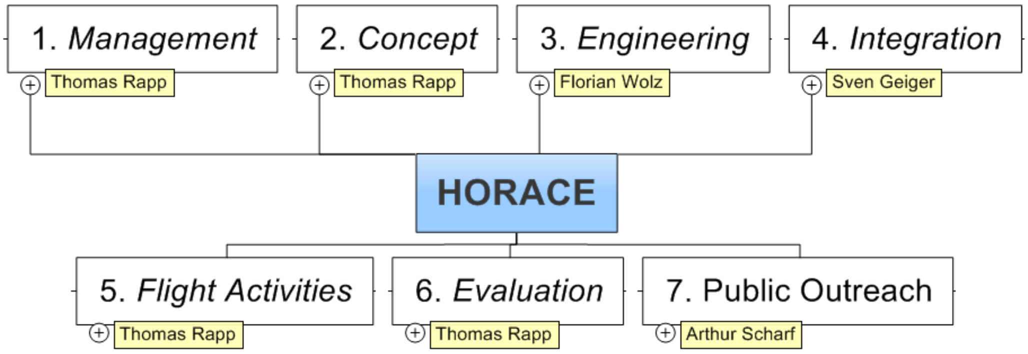


Figure 3-1: WBS overview

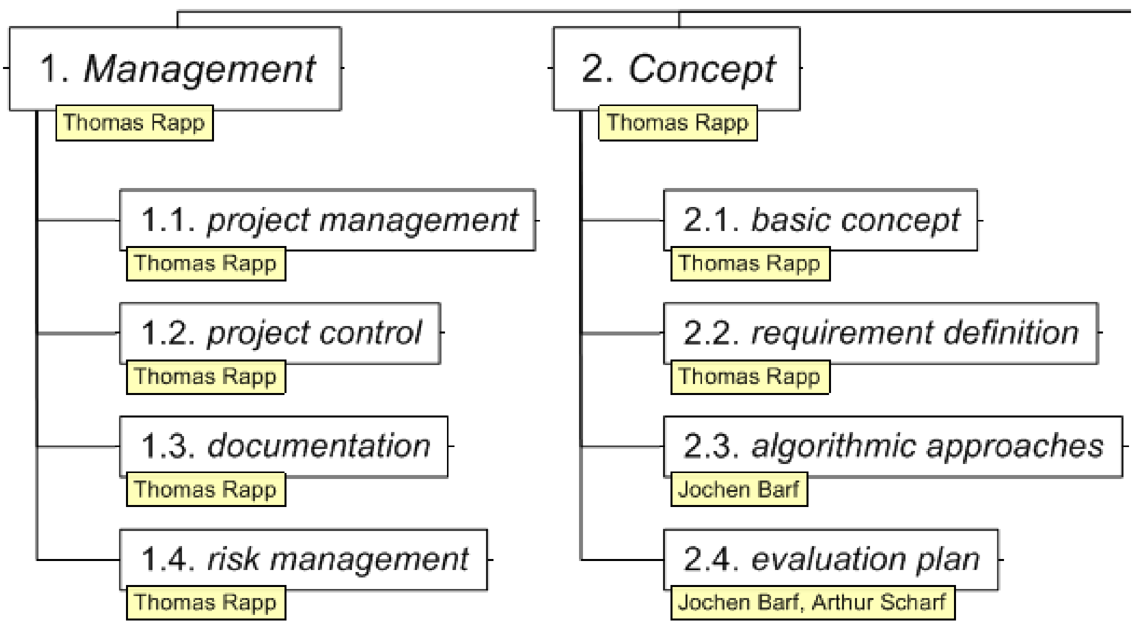


Figure 3-2: detailed WBS Management & Concept

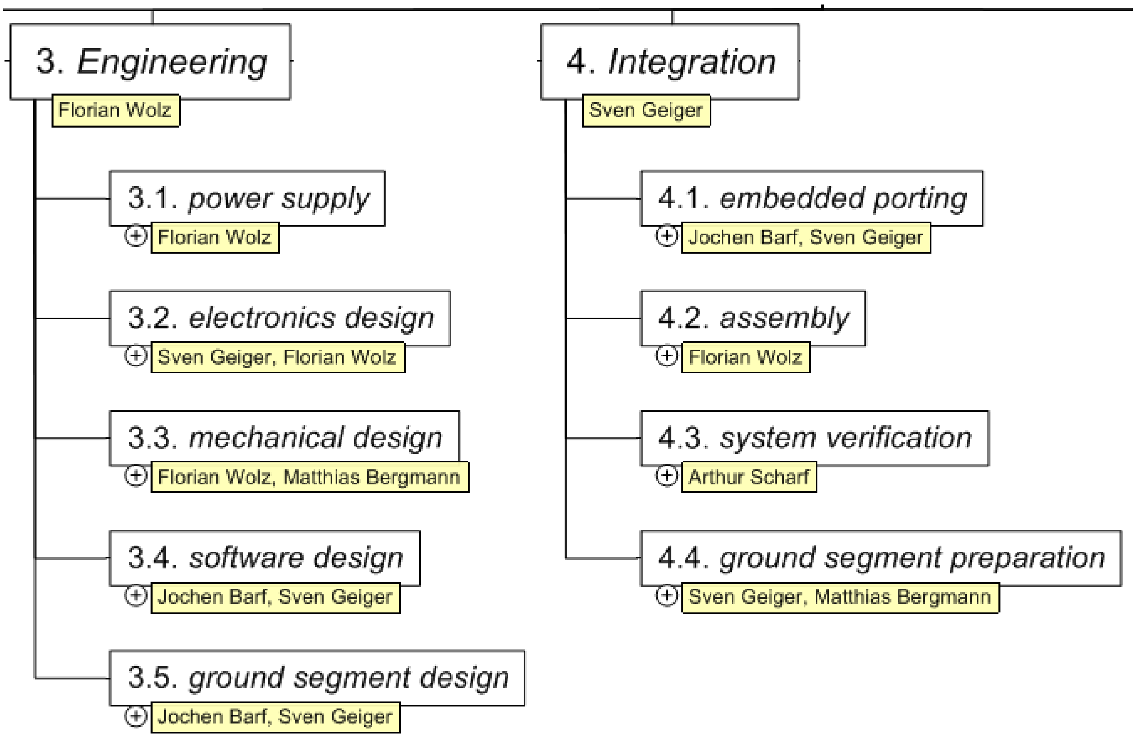


Figure 3-3: detailed WBS Engineering & Integration

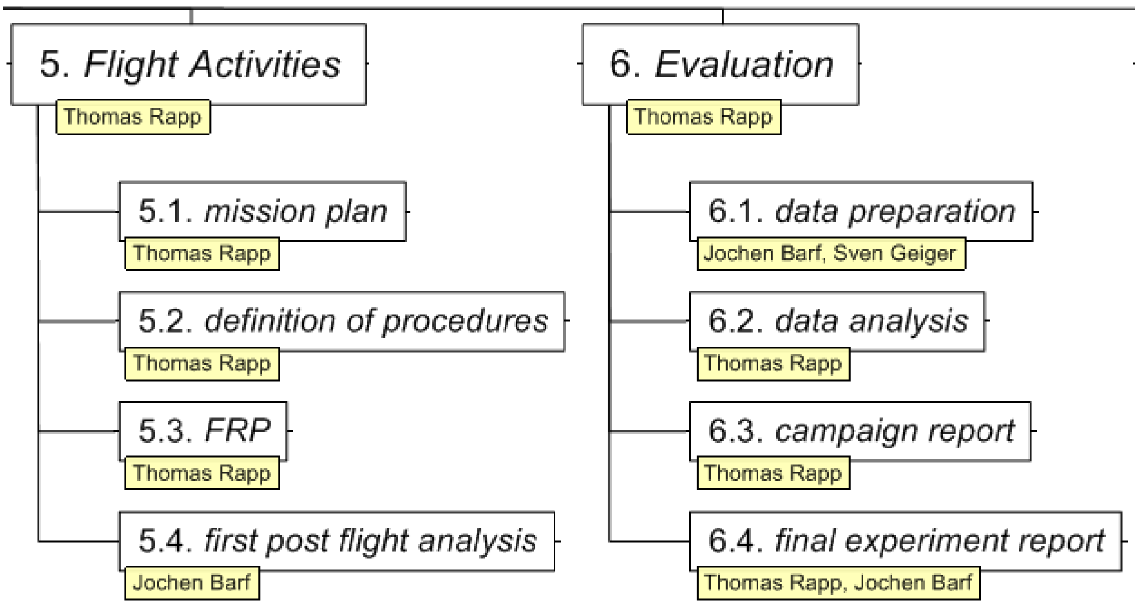


Figure 3-4: detailed WBS Flight Activities & Evaluation

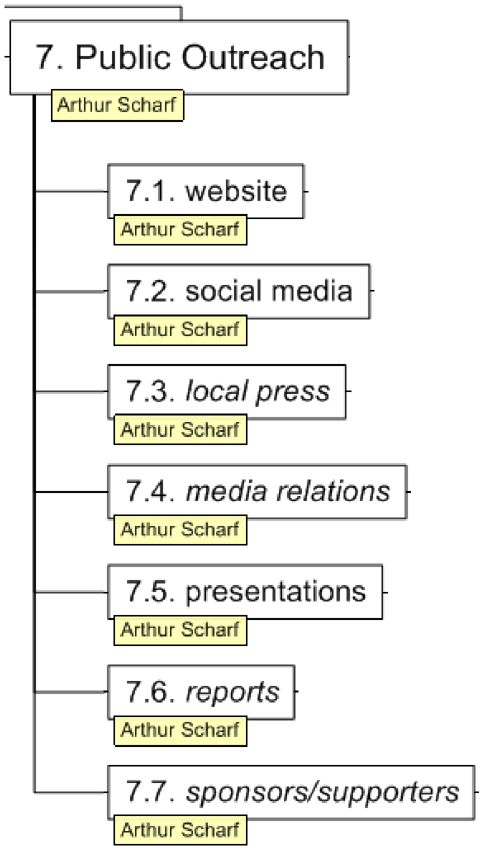


Figure 3-5: detailed WBS Public Outreach

3.2 Schedule

Throughout the complete life-cycle of the project several parts got delayed due to various reasons, but all of them could be caught up thanks to the intense work of the team during the last two years and the relatively late launch date. Therefore, all milestones and deadlines were met perfectly and in time, although some issues were detected just during ITW shortly before the delivery of the experiment to EuroLaunch. But as solutions for those issues could be developed with spare parts, the delivery was not affected and the solutions were applied right in the beginning of the launch campaign, which took place from May 19 2014 to June 01 2014. Thus, also during the campaign no delays were caused.

As also the post-flight evaluation, which was conducted throughout June to September 2014, is finished, the project is completed with the issue of this final report.

The complete conducted schedule with detailed information is available in Appendix C .

3.3 Resources

3.3.1 Manpower

The allocation of specific work packages and tasks to the team members has been completed already in an early stage (cf. 3.1) according to the disposition of fields of work (cf. 1.5.2).

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

The “Engineering” WP and “Integration” WP, as well as the sub-packages concerning the electronics and mechanics of HORACE, were strongly related to each other. Following the focus, which was a bit different and the team members’ fields of work, “Engineering” was assigned to Florian Wolz and “Integration” to Sven Geiger. The sub-package “mechanical design” was completely assigned to Matthias Bergmann, who took miscellaneous tasks and shared workload with other team members on demand, when his main work packages was completed – among them the implementation of the ground station software.

Jochen Barf was responsible for the software design of the flight segment, which was divided to several main work packages.

As it was covered by his Bachelor Thesis, the “Evaluation” WP was allocated to Thomas Rapp.

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

Throughout the complete life-cycle each team member contributed approximately 10-15h/week in average for HORACE and all six team members were active and available during all design, implementation, testing, operational and evaluation phases of the experiment.

3.3.2 Budget

On the next page the budget plan for HORACE is given. The expenses were mainly covered by the funds which are available from the REXUS-programme for the German share and the Chair of Aerospace Information Technology. Although the costs of small parts and consumables were severely underestimated in the first place, they were absorbed by the conservative margin and as many of the components themselves were directly sponsored by the manufacturers or suppliers. As the team failed to raise enough funds for the travel expenses for the 5th and 6th team-member to the campaign, most of them were privately covered by the team.

ID	Component	Sponsors	Status	No.	Single cost [EUR]	Total Cost [EUR]
Electronics						
1	Camera mvBlueCOUGAR-X102b	1x DLR 2x ZARM	3x delivered,	3	600.00	1'800.00
2	MIO-2260 with Intel Atom N455 1,66GHz	1x DLR, 1x JMU 2x ZARM	3x delivered, 1x damaged in test	4	214.00	856.00
3	SDRAM 2GB DDR3 667MHz SO-DIMM	1x JMU 2x ZARM	3x 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	4x Watterott	4x delivered	4	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	3	99.44	298.32
9	Micro SD 2GB Class 2	2x JMU 2x ZARM	4x delivered 1x damaged in test	5	4.40	22.00
10	CF Card 600x 8GB (TS8GCF600)	3x DLR	3x delivered	3	30.00	90.00
11	LM2596 DC/DC regulator module	9x JMU	9x delivered	9		0.00
12	PDU PCB board	ZARM	3x manufactured	3	0.00	0.00
13	RS-232 TTL Module for Arduino	3x JMU	3x delivered	3	0.00	0.00
14	wiring / connectors	JMU, DLR, ZARM	delivered	1	800.00	800.00
Mechanical						
15	main structure		flight models ready	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, ZARM	delivered	1		0.00
18	protective window & mounting	5x ZARM	5x delivered	5	50.00	250.00
Ground Support						
19	laptop	3x T-Systems	3x delivered	3	0.00	0.00
20	power supply		available at JMU	0	0.00	0.00
21	tools	team, ZARM & JMU	available in team			0.00
22	usb-sticks, card reader etc	ZARM	delivered	0	50.00	50.00
Other						
23	CDR - travel expenses for 6th team member	JMU		1	0.00	0.00
24	Launch campaign - travel expenses for 5th & 6th team member	team		2	1'380.00	2'760.00
	SUM [EUR]					**7'270.88**
	Margin			**20%**		**1'454.18**
	TOTAL BUDGET [EUR]					**8'725.06**

Table 3-1: HORACE budget plan

3.3.3 External Support

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

The team was generously supported by:

- The Chair of Aerospace Information Technology at University of Würzburg. In particular Prof. Dr. Hakan Kayal and Dipl.-Inf. Gerhard Fellinger supported the team with technical and management expertise. Furthermore, the Chair of Aerospace Information Technology provided 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 were used for the Measurement Unit of HORACE.
- Watterott electronic GmbH from Leinefelde handsomely sponsored all temperature and current sensors, which were 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.
- Hermann Zerver GmbH & Co. KG (HAZET), a tool-manufacturer from Remscheid sponsored two torque handles, which were needed for assembly.
- Students of Franz Oberthür Schule Würzburg, an upper vocational school, manufactured heat sinks for the PDU as exercise for school.
- T-Systems International GmbH, the subsidiary IT company of Telekom Deutschland GmbH, generously gave three laptops which had been withdrawn from service, but coming with a native RS-232-port and thus were ideal for the ground station.
- Ströbel GmbH from Langenzenn sponsored some shock-watch devices, which were applied to our transport box, indicating if there were mechanical shocks during transportation (and hopefully made carriers to handle it with care)
- ES&S Solutions GmbH from Viersen handsomely sponsored some meters of ultra-flexible CAT-5-cable, which was used between camera and core system.
- Werner Schartel and Michael Rapp supported the team with donations to cover travel expenses.

3.4 Outreach Approach

Since public outreach was a very important part of the HORACE-project we involved a broad spectrum of news-spreading media. We broadcasted news the old-fashioned way via newspaper, especially the local newspaper "MainPost" in Würzburg. Also, we were and still are highly integrated in digital media like social websites etc. and we held a couple of presentations and lectures at the University of Würzburg, to raise public awareness.

To reach this approach we had to diversify what kind of information we should 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 were issued before and after launch.

Additionally, presentations at University of Würzburg, which already were part of our outreach approach, were 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, 2013 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. Another short presentation in another English class took part on November 29, 2013. Shortly after the EAR, on January 24, 2014 the team also presented their experiment to staff of the Chair of Aerospace Information Technology in an advanced graduate seminar.

At the beginning of October 2013 we presented the experiment during 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. On February 6, 2014 we gave a good example for the practical usage of theoretical teaching contents for freshmen by talking about the horizon acquisition in the lecture "Algorithms and Datastructures".

Additionally we presented HORACE in a lecture to show students the development process of a real space project after the Launch Campaign.

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

3.4.2 Local Publicity

To publicize the experiment regionally we released some information about HORACE at the local newspaper called „MainPost".

Additionally, we printed some informational posters (in german and english) for 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. Since our Mission is almost completed, we are changing the Landing Page of the Website, so that visitors will have a brief overview over the complete project.

The website also features a download section, where the documentation is made available for the public and a sponsor section, where 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 published 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 were uploaded to these pages since they are more likely to be watched than status updates consisting of plain text. Some little serials (e.g. for non-material supporters, like open-source communities) were set up, to have regular posts, even if there were no updates for a while.

Although after the end of HORACE’s lifecycle there will be no more updates regarding the project, both the website and social media pages will stay online to keep the information publicly available and, where appropriate, news which seem to be interesting for our audience (e.g. RX/BX updates, status of follow-up projects, space-related topics in general) will be (re)posted.

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	> protective window
TC-171	remainder of TC-170	A	4	very low	
TC-180	hot gas flow damages lens	B	4	low	> protective window
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

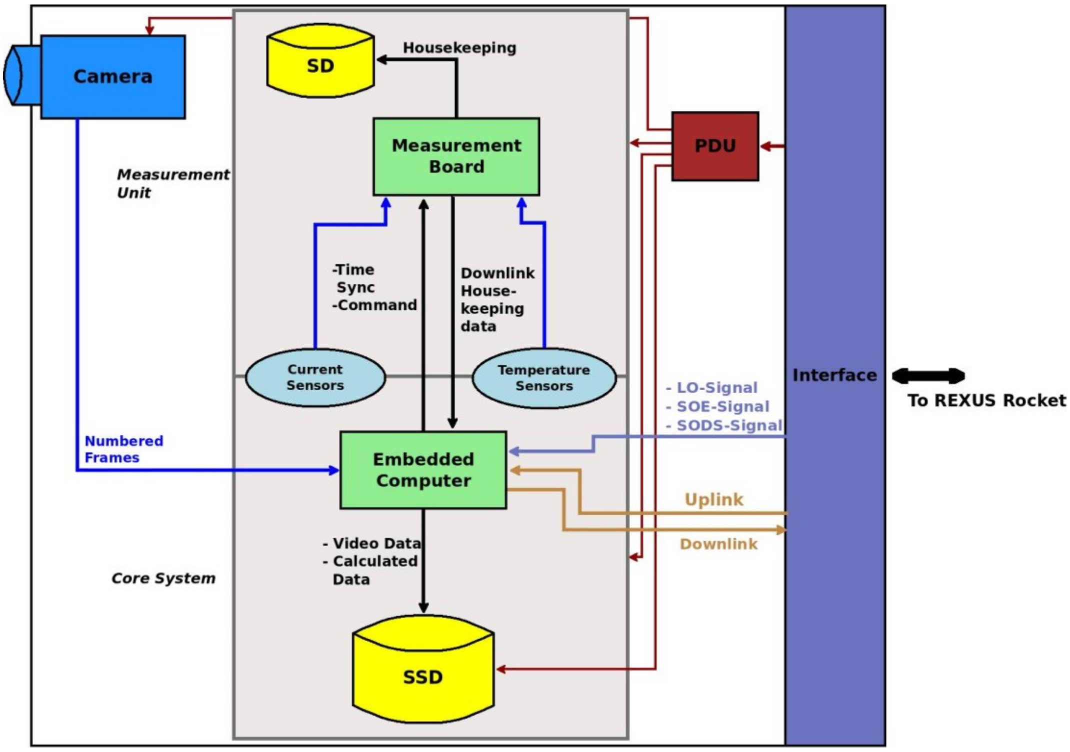


Figure 4-1: Flight Segment – experiment setup

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 camera, 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-signal other signals are not needed for the flight segment, the SOE- and SODS-signals are 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. Thermal tests have shown (cf. 5.3) that a protective window is strongly recommended to protect the optical system from contact with hot gases. Those windows use the mechanical interfaces to the module which originally were designed for other protective measures (fin & adapter).

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.

During IPR it was confirmed by EuroLaunch that HORACE can fly **two identical systems without implementing own auxiliary power units.** Also the implementation of a low power mode for the second system was not necessary.

4.2 Experiment Interfaces

4.2.1 Mechanical

HORACE features 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 99.5mm, the assembly fits into a 120mm long module, disregarding the restrictions for a gap of 20mm to the upper end of the module only at eight small spots (nuts which are 4mm higher than actually allowed), what was confirmed by EuroLaunch.

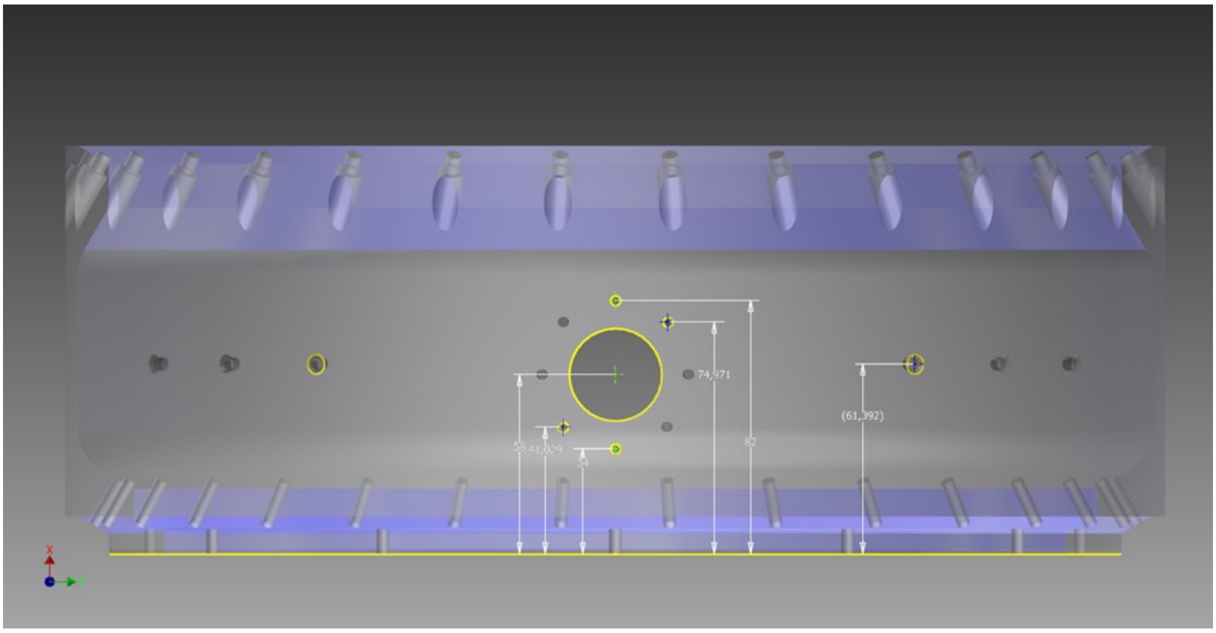


Figure 4-2: required modifications (holes) of the 120mm module

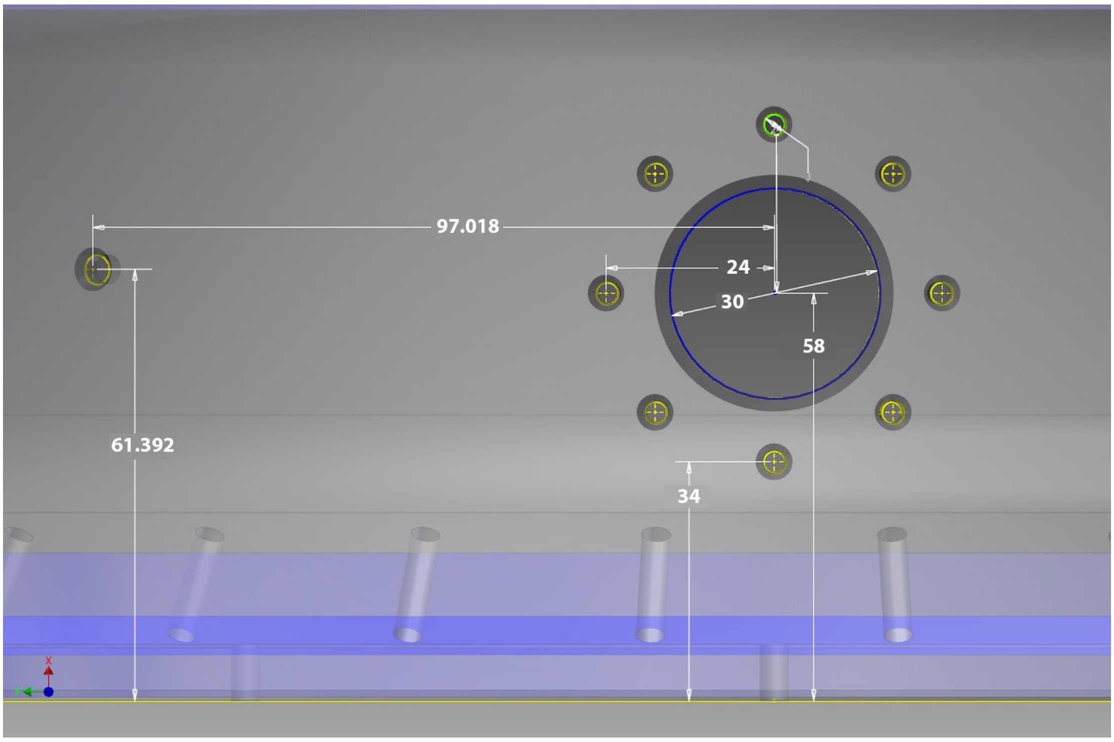


Figure 4-3: detailed view of bores in the module

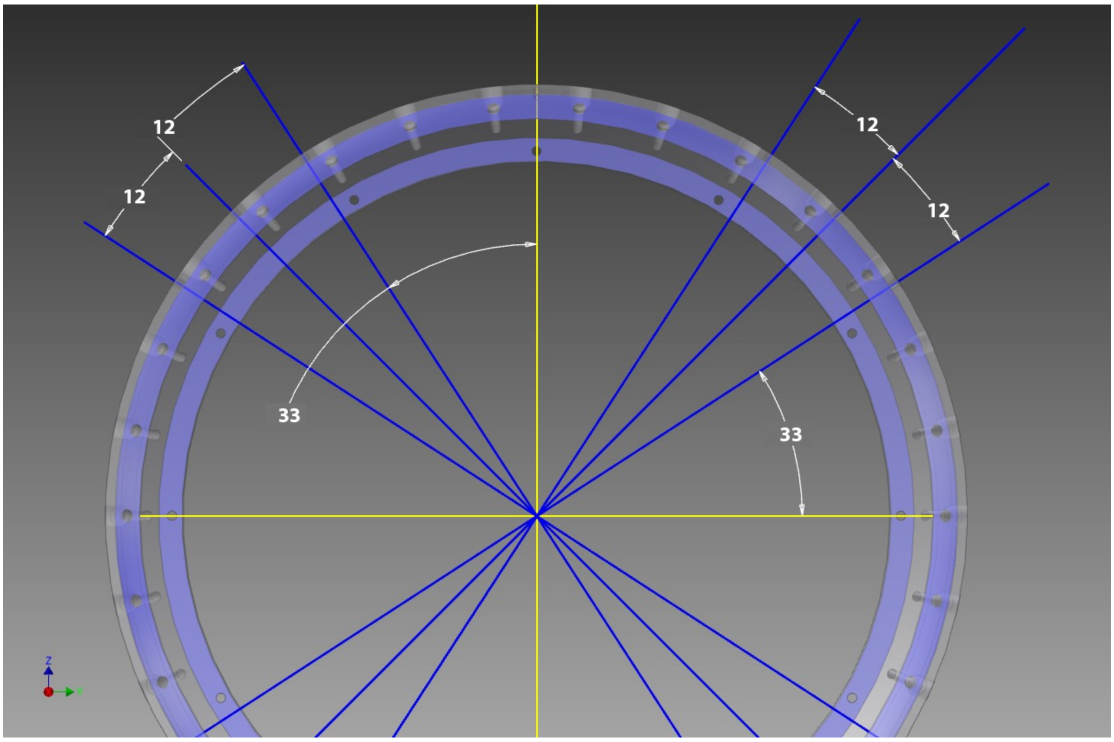


Figure 4-4: top view of the module with angles of bores indicated

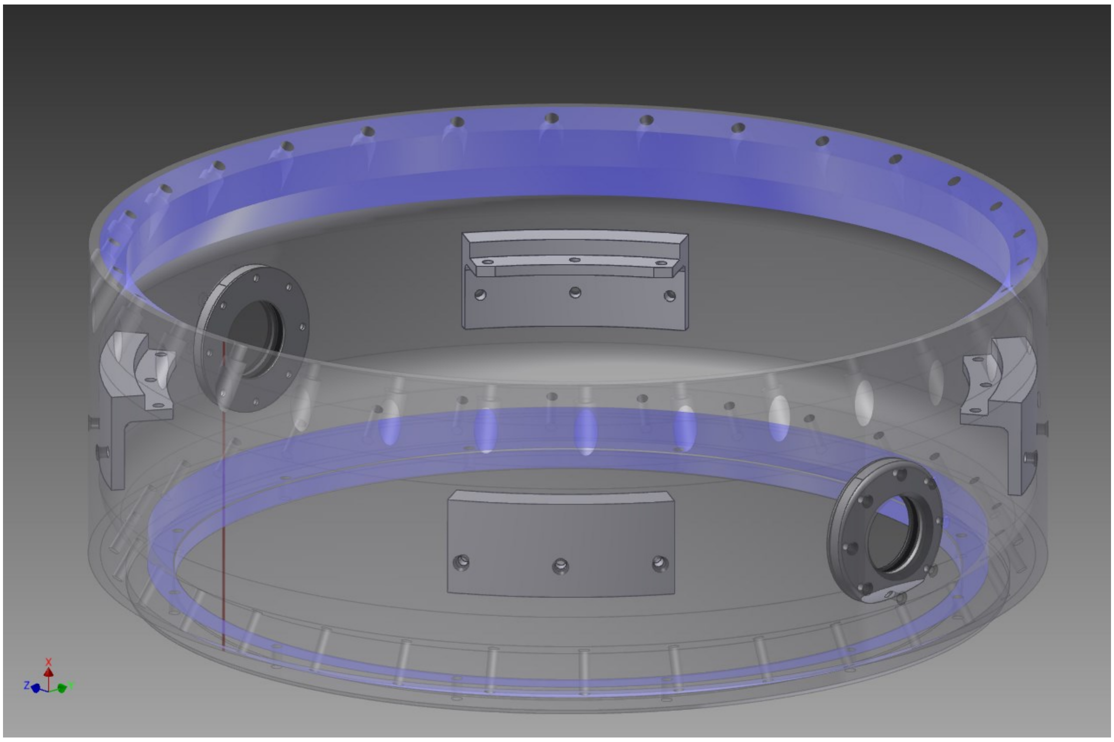


Figure 4-5: module with brackets and protective windows

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 used to mount the protective windows. Thus, this design change did 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 uses 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 consumes about 67W on average for two systems, respectively 35W for one system (both including 50% margin, worst case calculation according to data sheets). The measurements performed during testing (see 6.1.3) fit well the power consumption logged by RXSM of 2.74Wh (Slave) and 2.76Wh (Master) that was actually drawn from RXSM during flight. (cf. [1, pp. 27-28])

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-signal is actually the only needed signal, the SOE- and SODS-signals are 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).

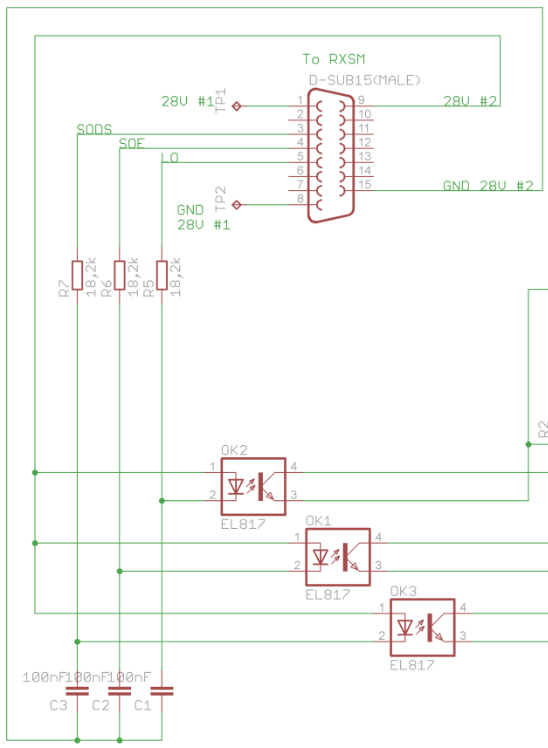


Figure 4-6: signal interface

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.

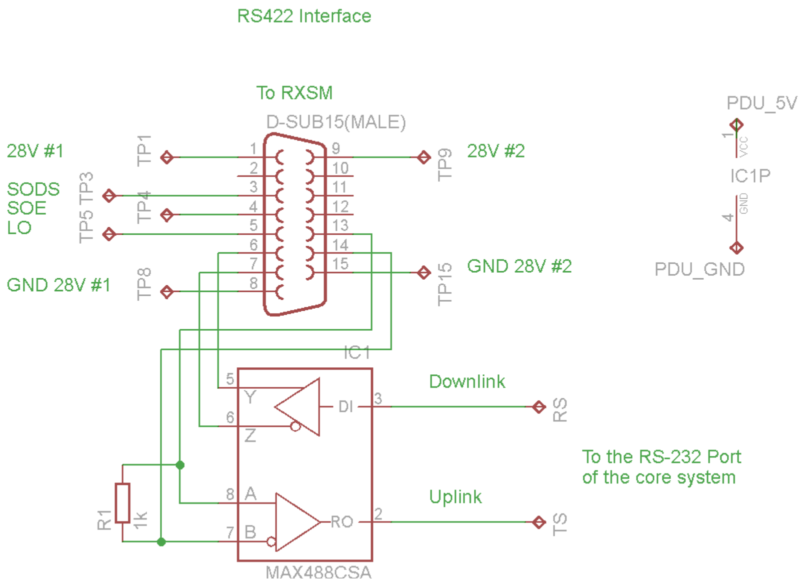


Figure 4-7: electronic schematic TM/TC interface

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 .

Two systems were flown and each of them used an own electrical interface to RXSM.

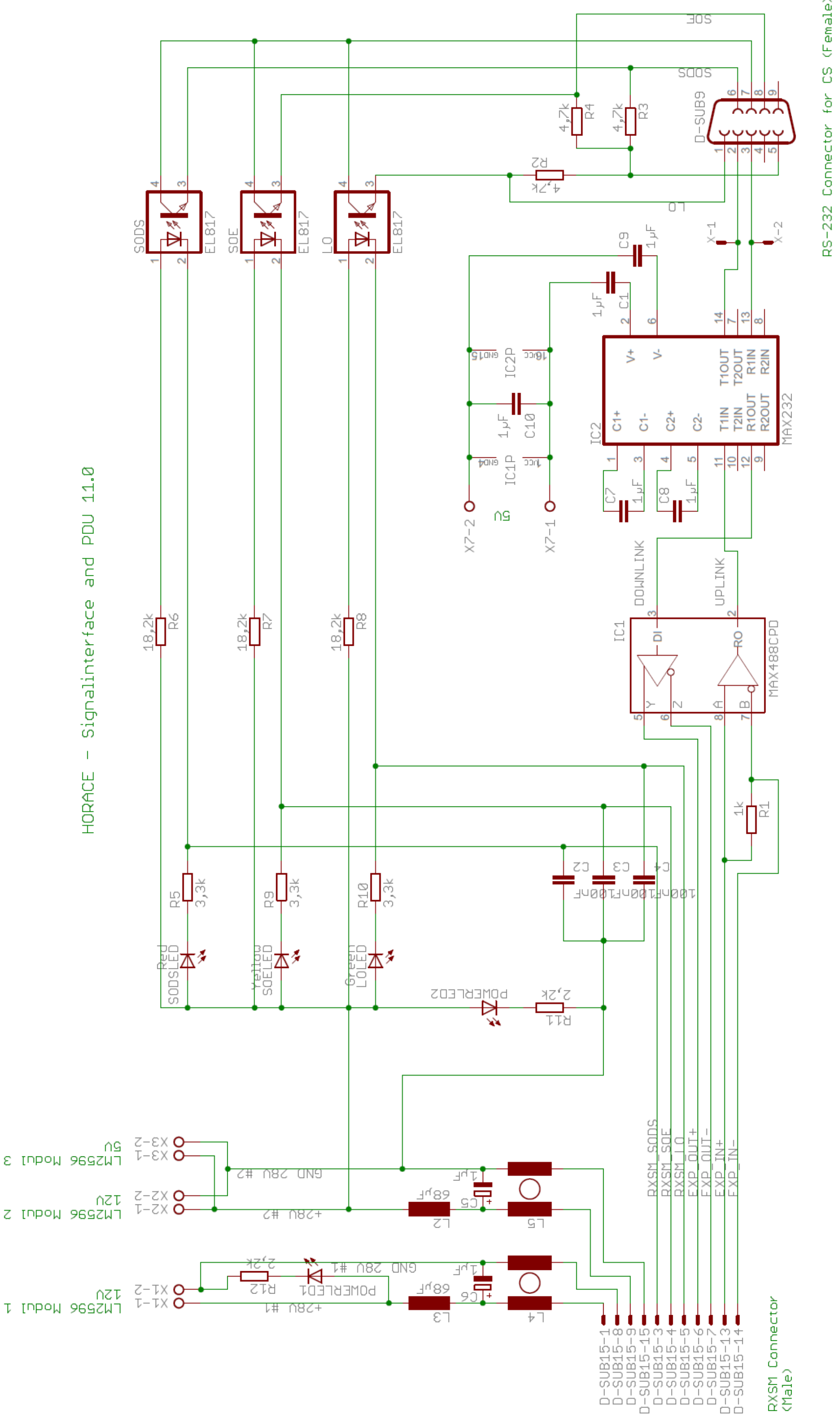


Figure 4-8: electronics schematic for complete PDU-carrier-board (including signal & TM/TC interface)

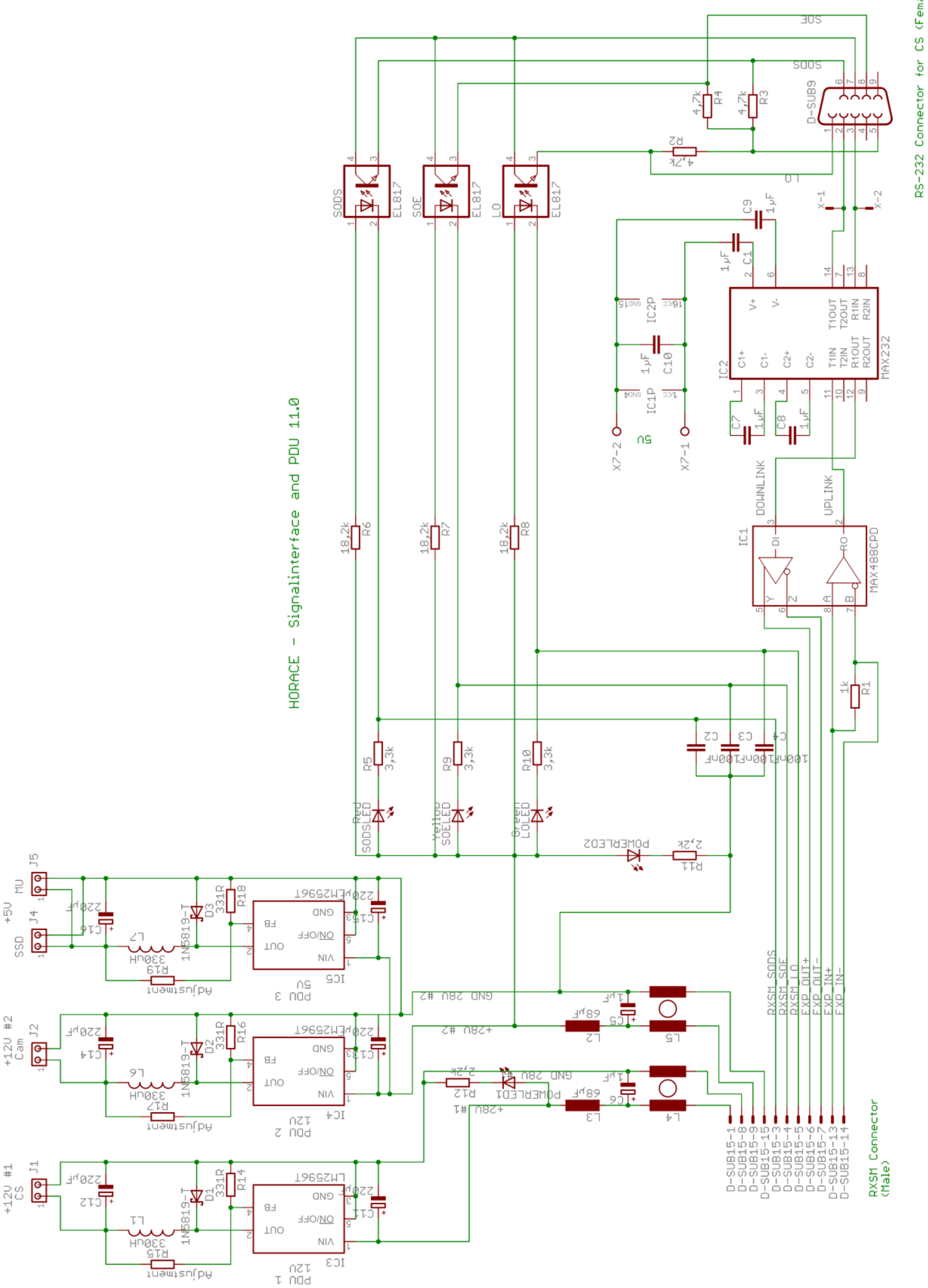


Figure 4-9: full electrical interface incl. DCDC-converter-modules

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 are only 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.

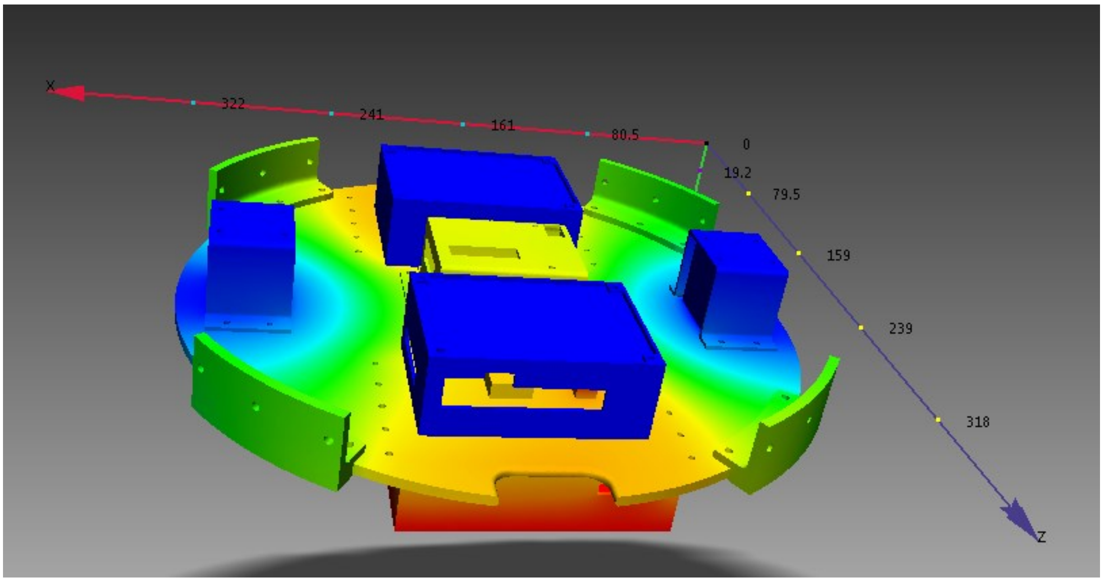


Figure 4-10: heat distribution in the flight segment in vacuum, regarding only internal heat sources; button-up view; blue=35°C, red=60°C

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 are 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 is implemented.

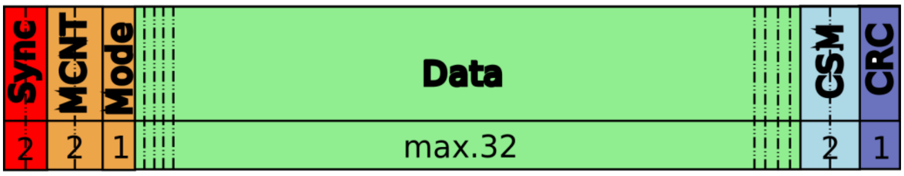


Figure 4-11: protocol frame CS → RXSM

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.
RTS-pin on CS for forwarding LO-signal and sending time pulse.

RX-pin on MU for receiving protocol frames.
CTS-pin on MU for trapping forwarded LO-signal and 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 RTS/CTS-pin is sent when transmitting this protocol frame. This provides an accurate time synchronisation between the core system and the MU.

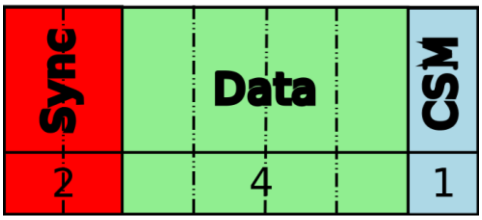


Figure 4-13: protocol frame MasterCS → MU

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.

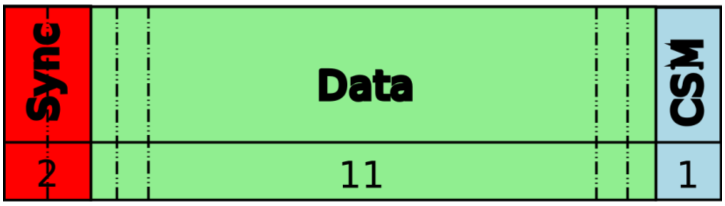


Figure 4-14: protocol frame MU → MasterCS

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.

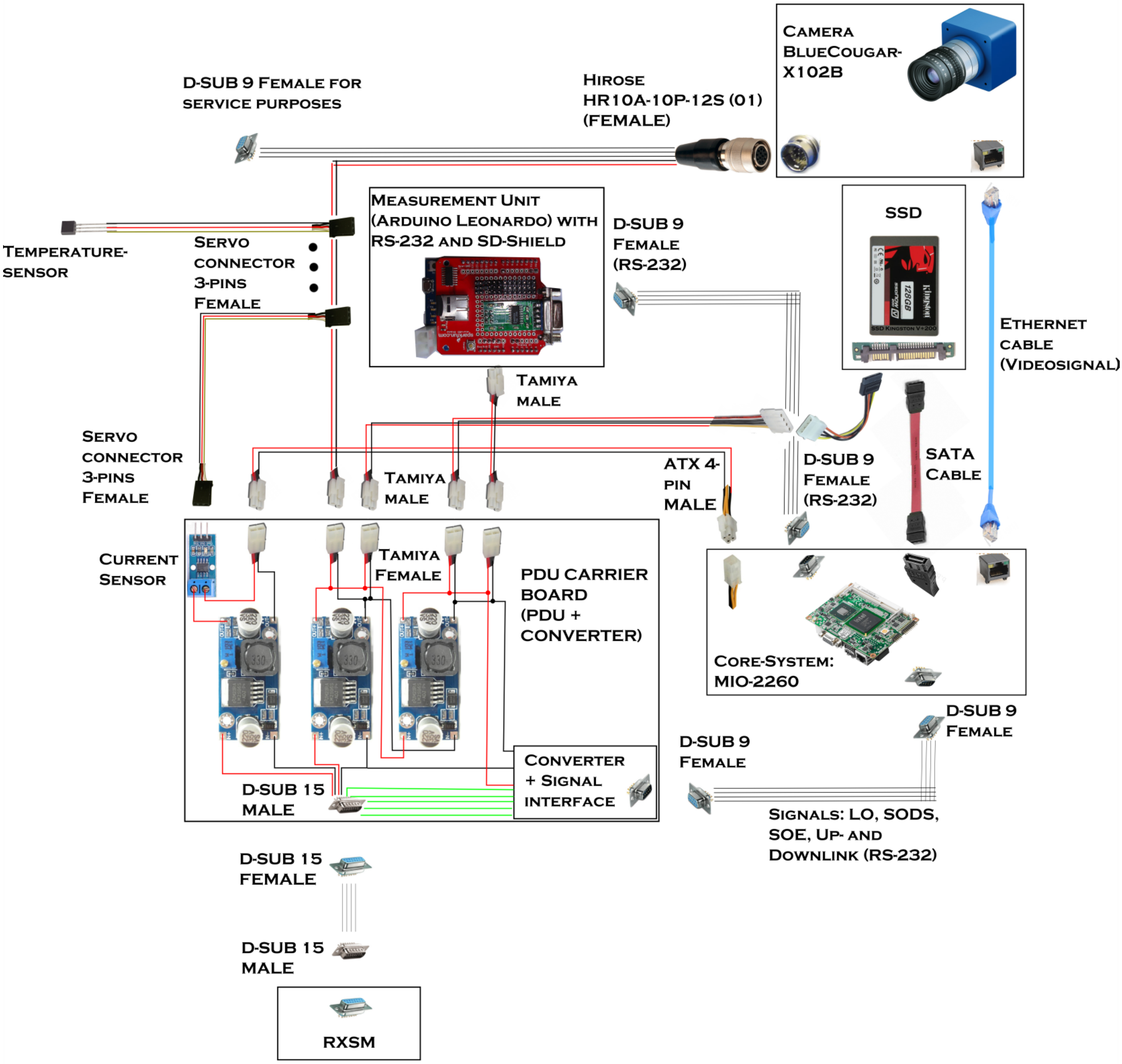


Figure 4-15: overview of electrical & data interfaces, cabling & connectors

4.3 Experiment Components

ID	Component	Manufacturer	Status	Comment
Electronics				
1	Camera mvBlueCOUGAR-X102b	Matrix Vision	3x delivered,	
2	MIO-2260 with Intel Atom N455 1,66GHz	Advantech	3x delivered, 1x damaged in test	
3	SDRAM 2GB DDR3 667MHz SO-DIMM		3x delivered	
4	Arduino Leonardo	Arduino	3x delivered	
5	Arduino SD shield	Arduino	3x delivered	
6	current sensor ACS712	Allegro MicroSystems Inc.	4x 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	4x delivered 1x damaged in test	
10	CF Card 600x 8GB (TS8GCF600)	Transcend	3x delivered	
11	LM2596 DC/DC regulator module	Linear Technology	9x delivered	
12	PDU PCB board	team	3x manufactured	
13	RS-232 TTL Module for Arduino	Maxim Integrated	3x delivered	
14	wiring / connectors	several	delivered	
Mechanical				
15	main structure	team & ZARM	flight models ready	
16	lens + adapter ring		3x delivered	
17	mounting support (screws)	several	delivered	
18	protective window & mounting	Schott & ZARM	5x delivered	
Ground Support				
19	laptop	Dell	3x delivered	serial interface needed; older models suffice
20	power supply	--	available at JMU	
21	tools	--	available in team	
22	usb-sticks, card reader etc		delivered	

Table 4-1: experiment components

Experiment mass (in kg):	7.84kg (for 2 systems, including 10% margin, including module)
Experiment dimensions (in m):	0.348m x 0.318mm x 0.0995m
Experiment footprint area (in m^2):	0.056 m^2
Experiment volume (in m^3):	$1.4*10^{-3}$ 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=66.0mm; ±<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.

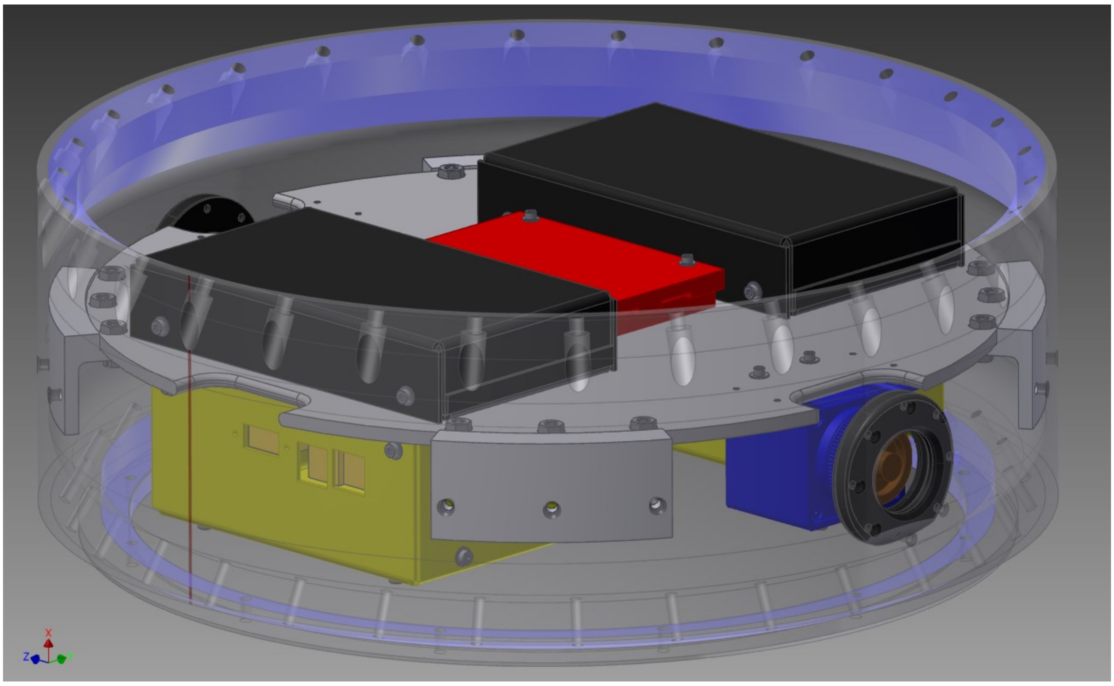


Figure 4-16: 3D-view of flight segment setup

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 SSDs before integration in the module and during disassembly they are not boxed. Wiring within the module is done through the cable feedthroughs of the bulkhead plate. The specific location of each component shown in Figure 4-18 & Figure 4-19 ensures 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 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 4-24). 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 4-25).

The socket uses the mounting points originally designated for the conical adapter and the fins. Thus, this design change did not affect the mechanical interface to the REXUS rocket.

The components are mostly fixed with M3 and M4 screws (brackets). To secure the connections, thread inserts in the boxes and helicoils in the bulkhead are used. Additional locking (e.g. with locknuts or locktite) was not applied due to the good results of the shaker-test (cf. 5.3). The flight justified this decision as not a single screw was loosened.

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

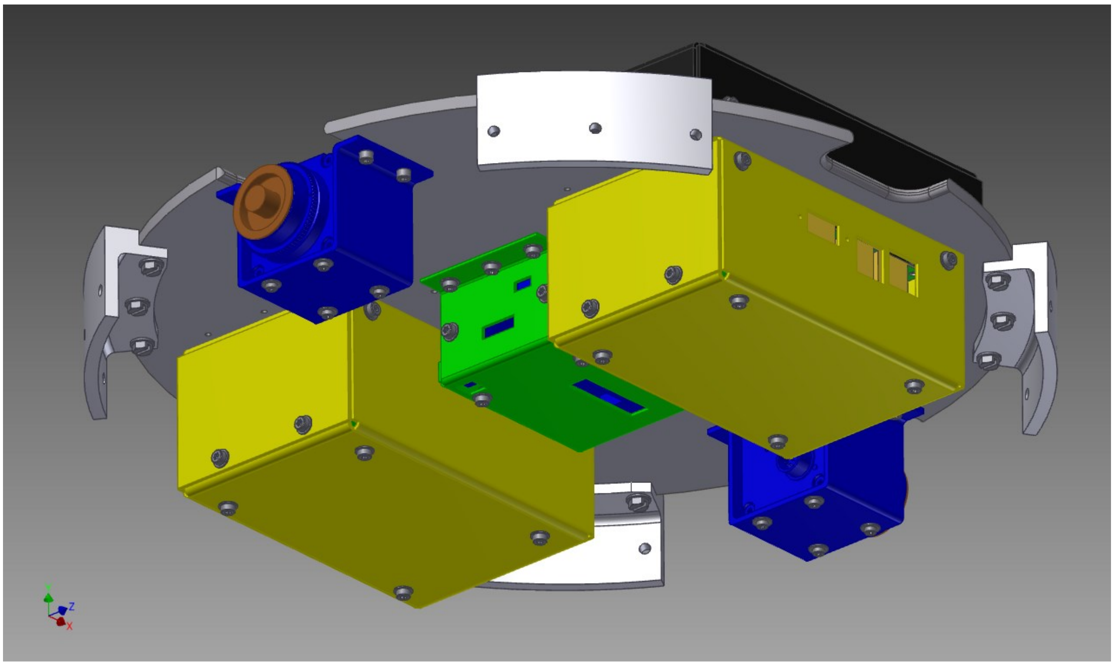


Figure 4-17: 3D-view of flight segment setup without module

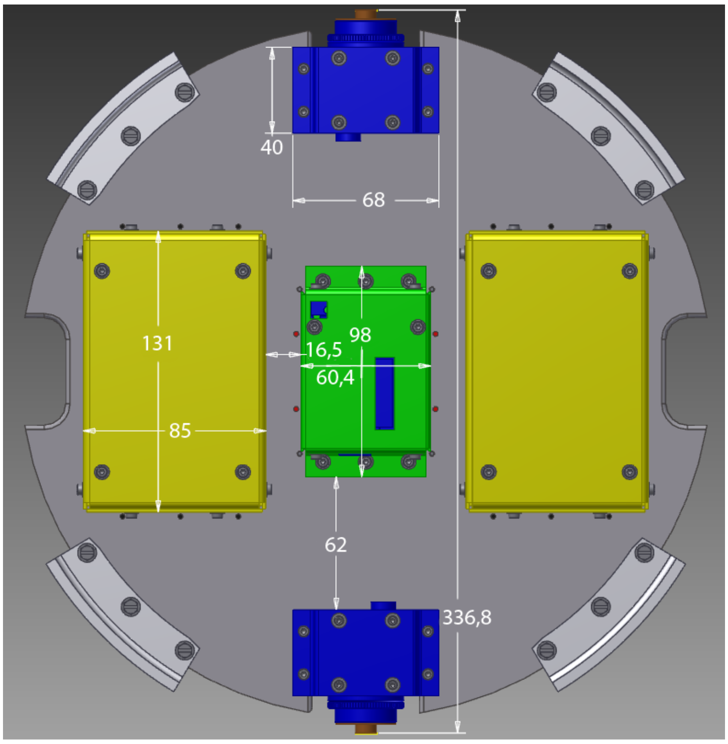


Figure 4-18: bottom-up-view; grey - bulkhead, brackets; blue: cameras with brackets; yellow - core systems; green - measurement unit

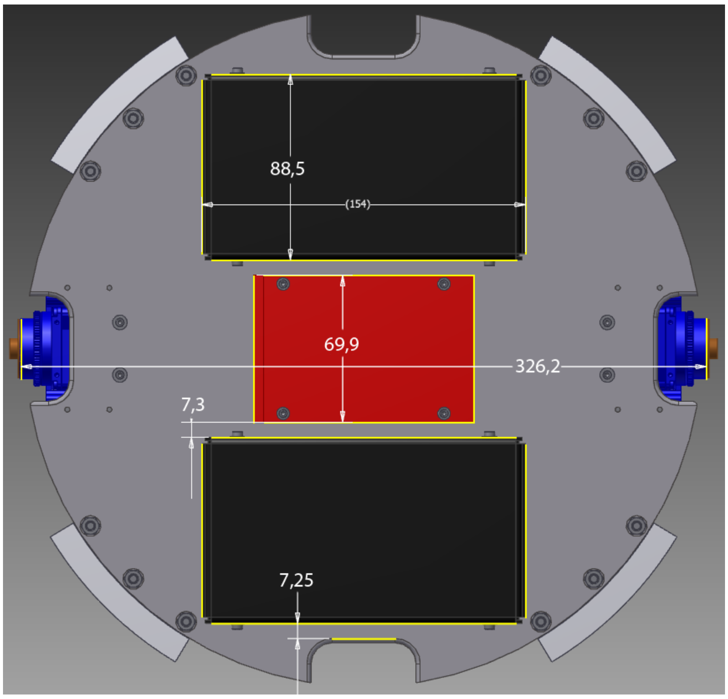


Figure 4-19: top-down view: black - PDUs; red - SSDs

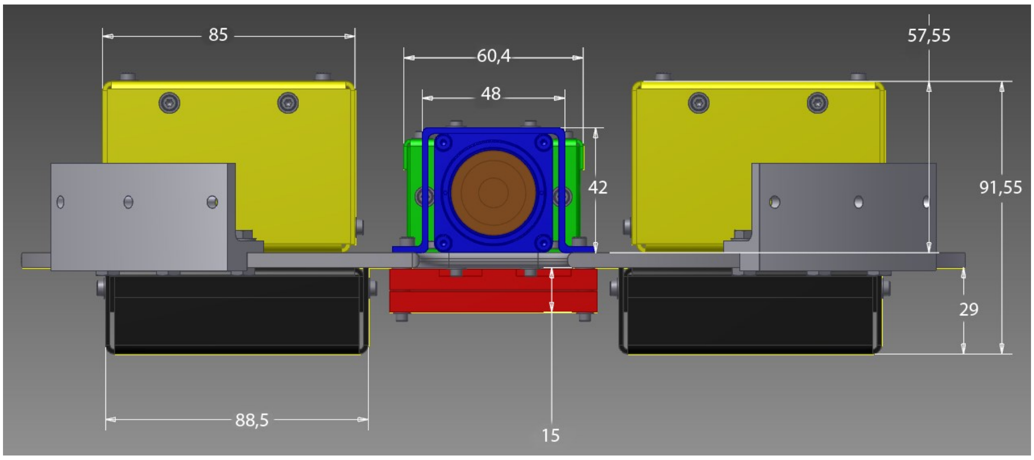


Figure 4-20: side view (upside down)

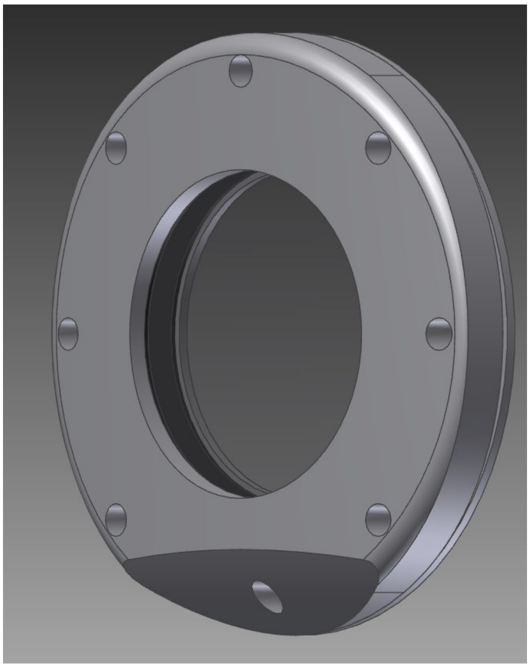


Figure 4-22: detailed view protective window

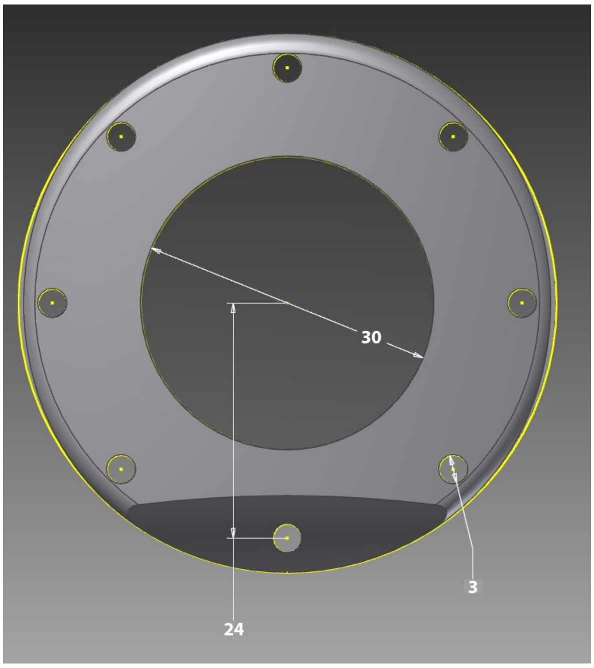


Figure 4-21: front view protective window with measures

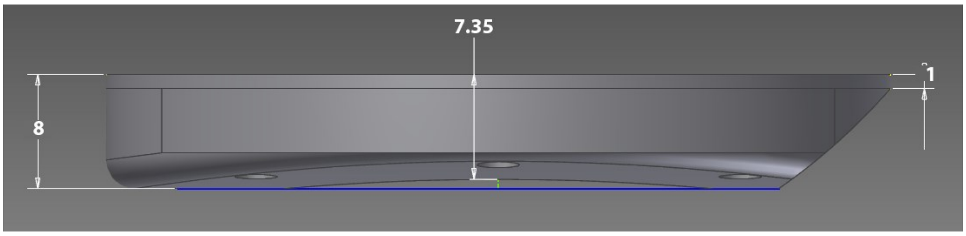


Figure 4-23: side view protective window

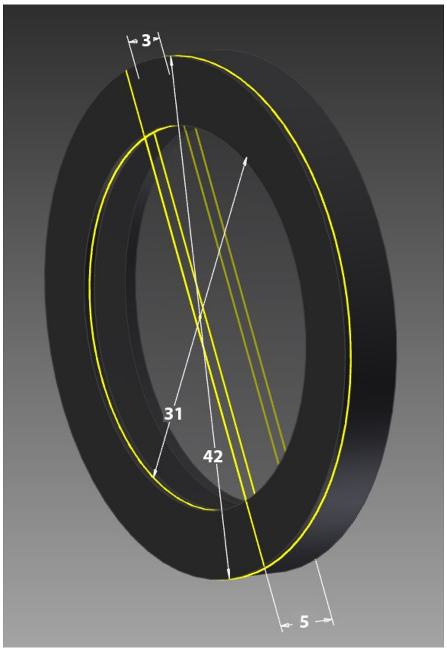


Figure 4-25: glass of protective window with silicon seal

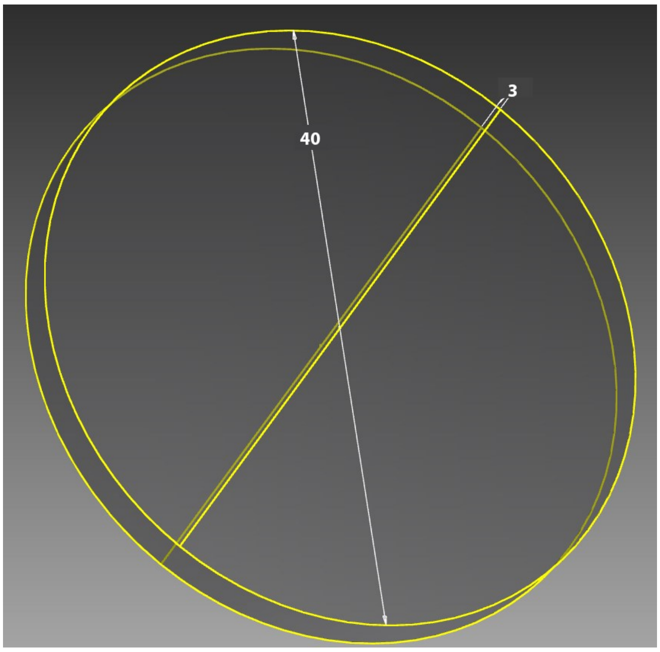


Figure 4-24: pure glass of protective window

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**

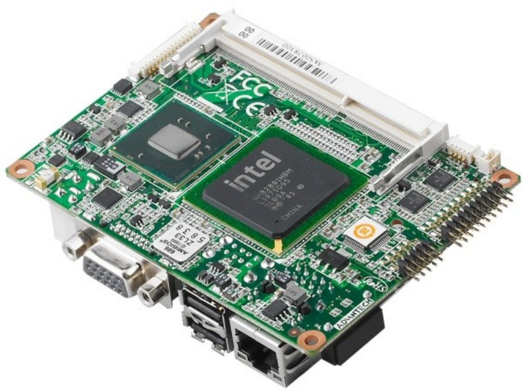
Figure 4-26: components mass & dimensions (estimated values marked red)

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. With the integrated FPGA various settings, like exposure time, resolution and frame rate can be programmed during implementation. With those variable settings it was possible to adjust the frames exactly to the needs of the algorithm even in a later development process. A resolution of 1024px x 768px with a three-coloured (RGB) depth of 8bit was set. 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 documentation, available drivers and utility software, as well as the support of the manufacturer, which was considered to be good in the beginning, lead to the decision of this model. Unfortunately, the documentation and available utility software, turned out to be much worse than expected, what eventually had the consequence that during flight the automatic adjustment of the exposure time was not enabled, thus severely overexposed images were captured during flight (cf. 7.4.1.4).

4.5.2 Core System



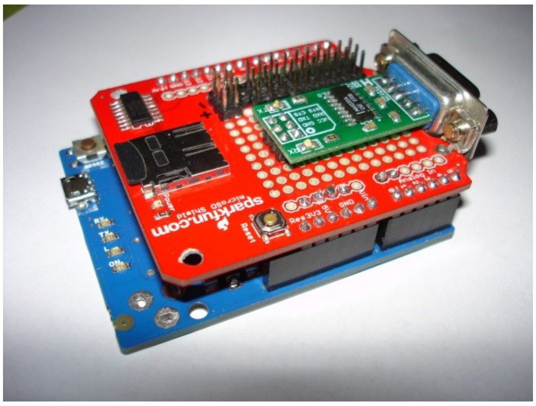
On the core system, which is the embedded computer Pico-ITX MIO-2260 with an Intel Atom CPU, the actual experiment – image processing and horizon detection – is performed (cf. 4.8). Therefore it receives the provided video data via the GigE interface, which is then directly stored to the SSD via SATA-interface. 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.
Only one MU is integrated (cf. 4.5.3), which is linked to only one of the core systems. Thus, only one core system 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) at six points of the experiment (lens, CS, PDU each system) and current of the core systems with the ACS714 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. Although there are two core systems, 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 master 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 are cooled by passive heatsinks which are linked to the bulkhead. Each PDU for one system consists of three regulator modules, which are placed next to the PDU-carrier-board (for complete electronics schematics cf. 4.2.2 and Appendix F).

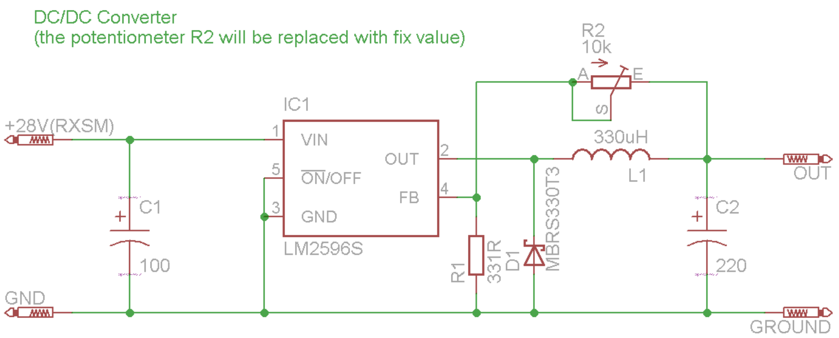


Figure 4-27: electronics schematic for one DC/DC converter module

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.

The feedback ripple caused by the DC/DC converters is minimized with LC-circuits on the PDU carrier board to the levels specified in the REXUS Manual.

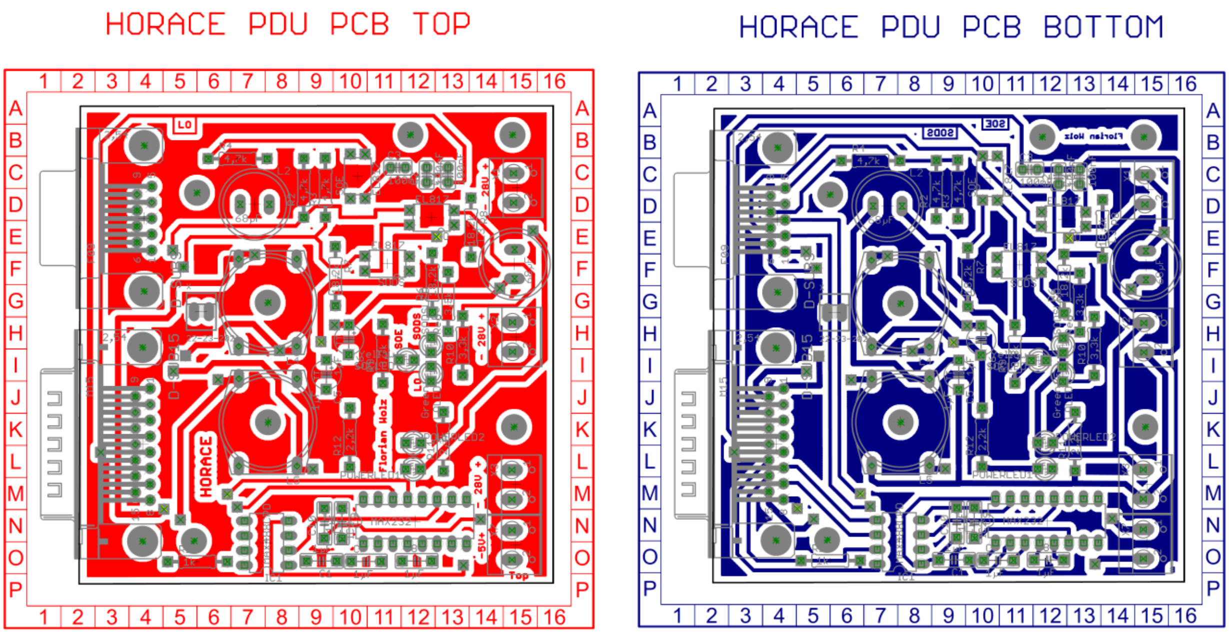


Figure 4-28: PDU carrier board PCB

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
Exp. 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
Real Temp.	+10°C	+20°C	+15°C	+15°C	+15°C to +23°C	+15°C to +23°C	+23°C to +57°C	~+15°C

Table 4-4: Expected temperature ranges inside the module and exposure times (according to flight profile of RX10 and RX11 and REXUS manual) & real temperatures measured during hot CD and flight (cf. [1, pp. 30-31])

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 were 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 countdown 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.

All of the discrepancies listed above, except 3), were successfully tested, and thus the discrepancies proven to be uncritical, in a combined thermal test during which all components were cooled down to -40°C, then switched on and tested for full functionality (cf. 5.3).

Discrepancy 3) was also successfully tested and proven to be uncritical (cf. 5.3).

As the temperature conditions actually were less harsh than expected (cf. Table 4-4), in fact none of the discrepancies occurred.

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).

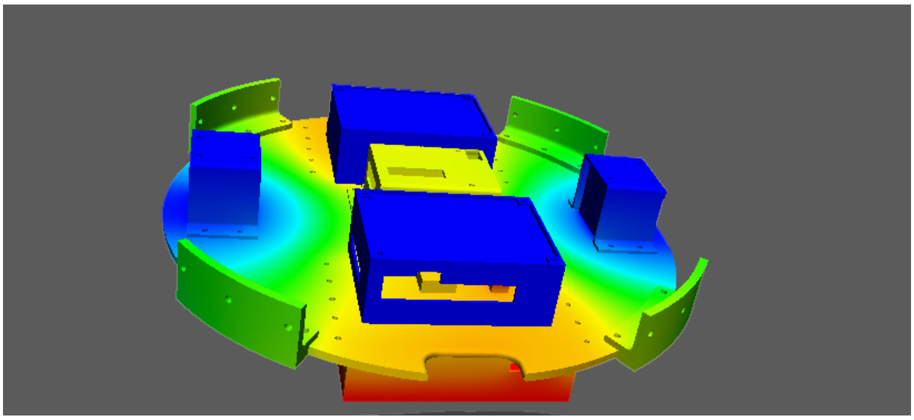


Figure 4-29: result of temperature simulation

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).

The recorded temperature data (cf. Table 4-4) proved also those estimations and the cooling to be sufficient.

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. The calculations below show the worst-case scenario, based on information provided by the manufacturers in the datasheets, for actual measurements see 6.1.3.

The evaluation of the data logged by RXSM showed a total power consumption during flight of 2.74Wh (Slave) and 2.76Wh (Master) fit to the measurements performed during testing (see 6.1.3), which are much lower than the calculations below.

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

This chapter describes the aspects software design relevant to the Flight Segment. For information about the ground station see 4.9.3.

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 or SODS-signal) the mode is switched to the flight-mode. When the internal clock reaches T_S (T+590s) the mode is changed to shutdown. Transitions between the three software modes can also be triggered by TC for testing, but are not nominal for the flight sequence and therefore not shown in Figure 4-30.

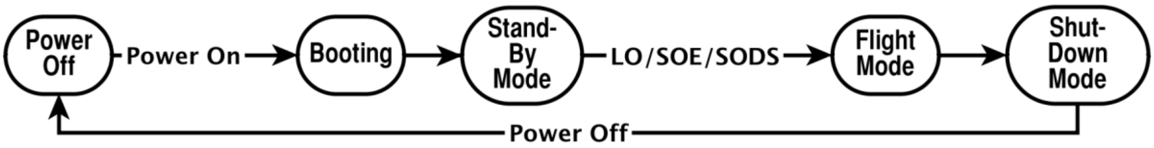


Figure 4-30: software modes

The following subchapters describe the activities performed and the data-flow of the Flight Segment in the different modes with the means of standardized UML-activity diagrams as well as data-flow-graphs.

4.8.1.1 Stand-by

Several activities start simultaneously immediately after all systems are fully booted. As the activities of the CS and the MU are very similar and to improve readability only one activity-diagram (Figure 4-32) is provided – indicating differences between the two subsystems with comments in brackets.

Self-Check

The MU performs two self-check-procedures (read-SD and write-SD) to ensure that the microSD-card is accessible and written data is stored correctly. The CS preforms similar procedures to check the accessibility of the SSD/CF and furthermore checks whether the Camera is ready to send images.

Check for TC, Forward TC, Decode TC, Execute Command

The receiving buffer of the RS232-interface to RXSM is regularly checked if new TC-packages have arrived. Those are then forwarded to the MU and decoded for execution. The two most important commands during a nominal timeline are to clear all data storages and to start the video recording already before lift-off. It is important to clear the data storages manually to prevent accidental loss of data (e.g. automatic procedure erasing the data when system is accidentally powered on again after flight) but to ensure that there is enough free space on the data storage devices. The video recording is started before lift-off manually to ensure that it started correctly, but would be additionally triggered by LO if the command was missed/not sent.

Check for LO, Forward LO

This activity waits for the LO-, the SOE- and SODS-signal, in case of the MU respectively the forwarded signal, and changes to flight-mode after receiving one of them. The CS additionally forwards the signal to the MU.

Collect Housekeeping, Check for new Housekeeping, Send TM

Both CS and MU provide their status and return codes of commands as housekeeping data (signals, checks). Additionally, the MU regularly collects sensor data (temperatures, currents). When available, the MU sends this data to the CS. The CS regularly checks the receiving buffer for TM and forwards the housekeeping data provided by the MU to the ground while own TM of the CS data is directly sent to ground as well.

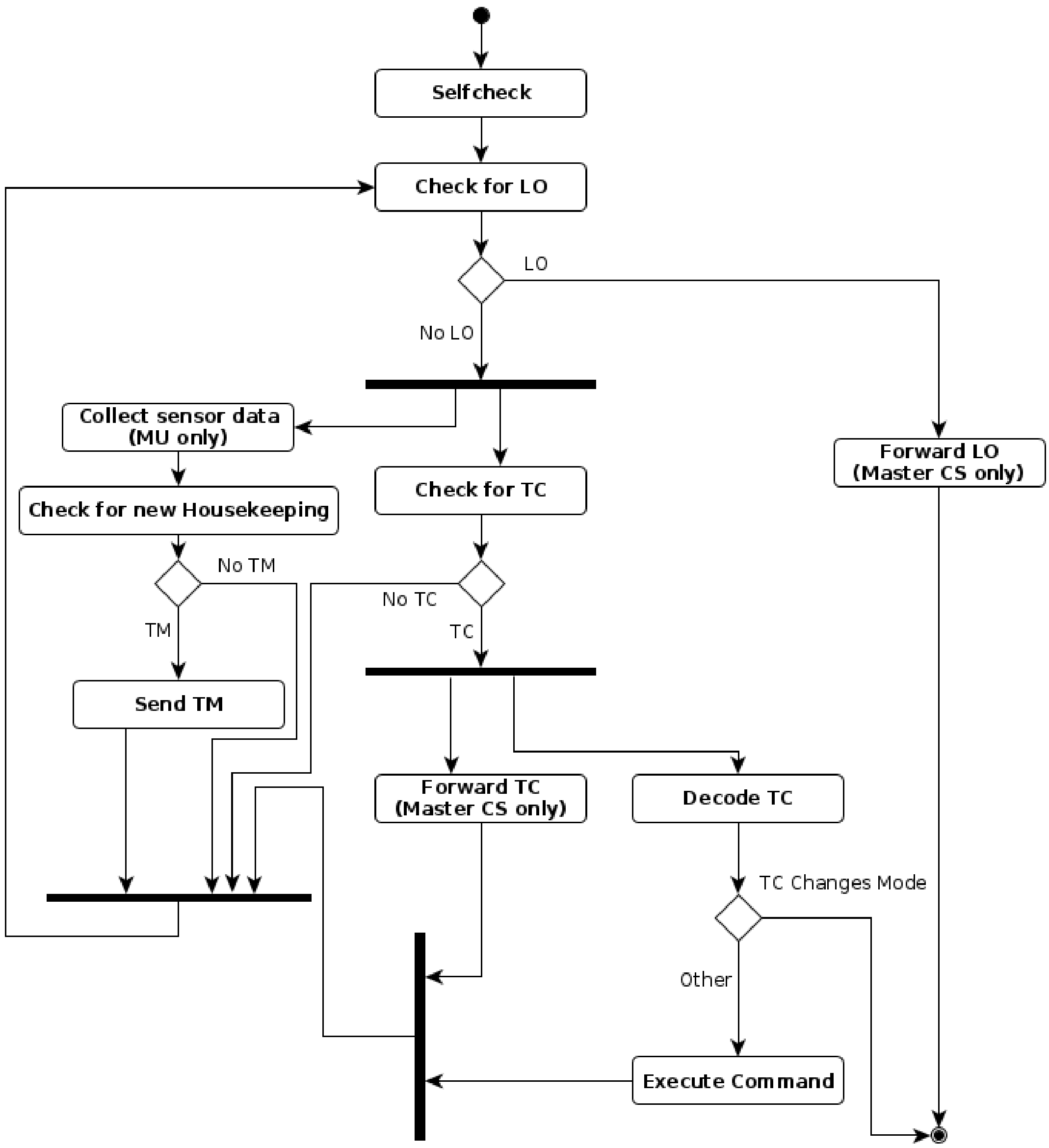


Figure 4-32: combined (CS & MU) activity diagram standby-mode

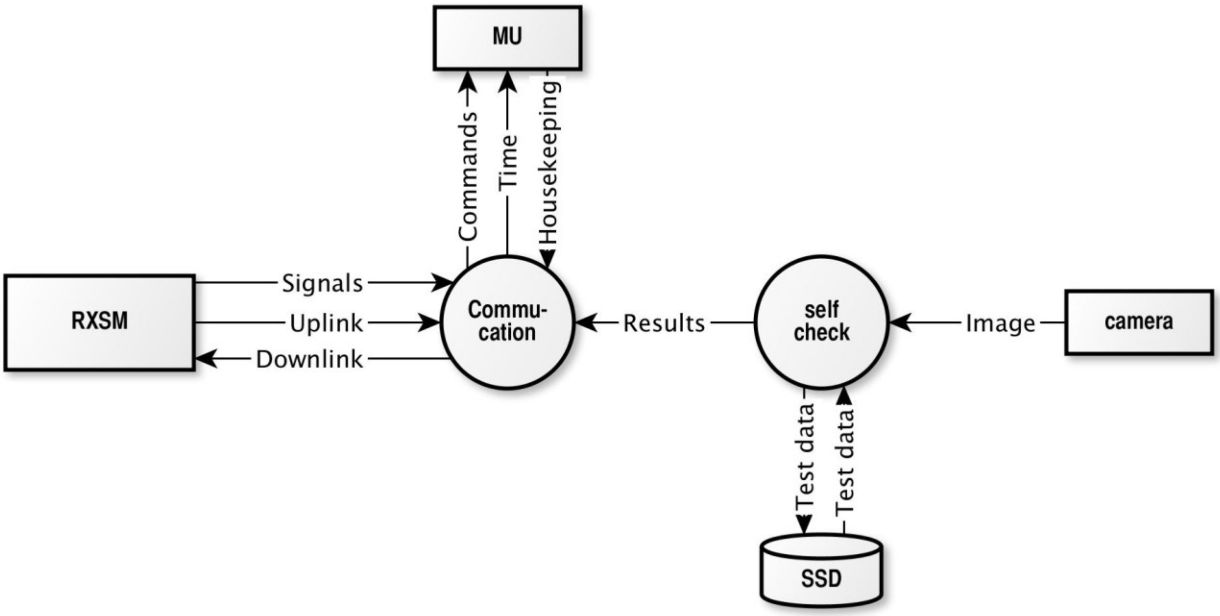


Figure 4-34: dataflow-diagram for Core System in stand-by-mode

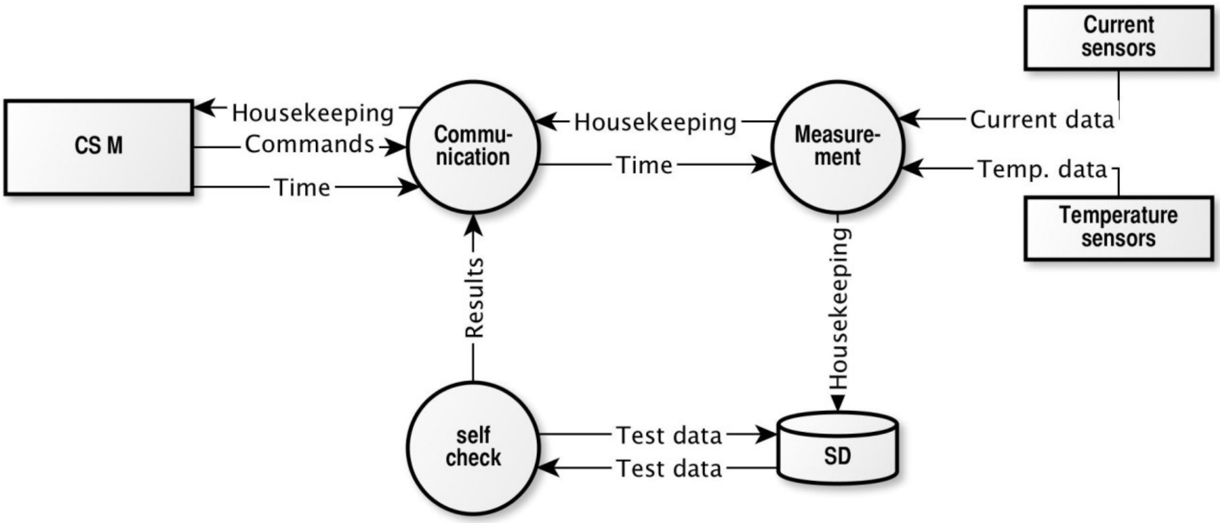


Figure 4-33: dataflow-diagram for MU in stand-by-mode

4.8.1.2 Flight Mode

Several activities start working simultaneously and directly after switching. As the activities performed by the CS and the MU are quite different, two distinct activity-diagrams (CS: Figure 4-37; MU: Figure 4-38) are provided. In the explanations it is indicated which subsystem the activity corresponds to.

CS: Get Image

This activity has the sole function to get video data via the GigE-vision interface from the camera and add an unique frame number.

CS: Save Image
This activity has the sole function to save the received video data to memory.

CS: Calculate
"When looking at a picture (…) it is easy for the human mind to identify the earth, the sun and even sun flares. We can tell where the center of the earth must be at first glance. That is because our brain can recognize objects and is able to compare them with familiar objects from the memory. But how can a computer manage this? To make it possible for machines to acquire the earth's horizon, this approach, [illustrated in Figure 4-36,] uses the high contrast between the earth (bright) and space (dark). The first step in the preprocessing is to convert the coloured image into a grayscale image. This image is then converted to a black-and-white image also known as binary image. Now bright areas of the picture are represented by pixels holding 1, respectively dark areas by pixels holding 0. The border between a 1 area and a 0 area is called an edge. Since the contrast between earth and space is high, the horizon is an edge in the picture. Unfortunately, it can happen, that the horizon is not the only edge in the picture. Therefore, it is necessary to find the edge that represents the horizon. Having found this edge, the horizon line still is a set of pixels that are part of a circle. To find this circle, represented by its center and the radius, this algorithm finds a circle that fits the best to all data points. Having the center of the circle that represents the earth's horizon it is obvious how to calculate the direction vector from the image frame origin to the center." [2, pp. 17-18]. More detailed information can be found in [2].

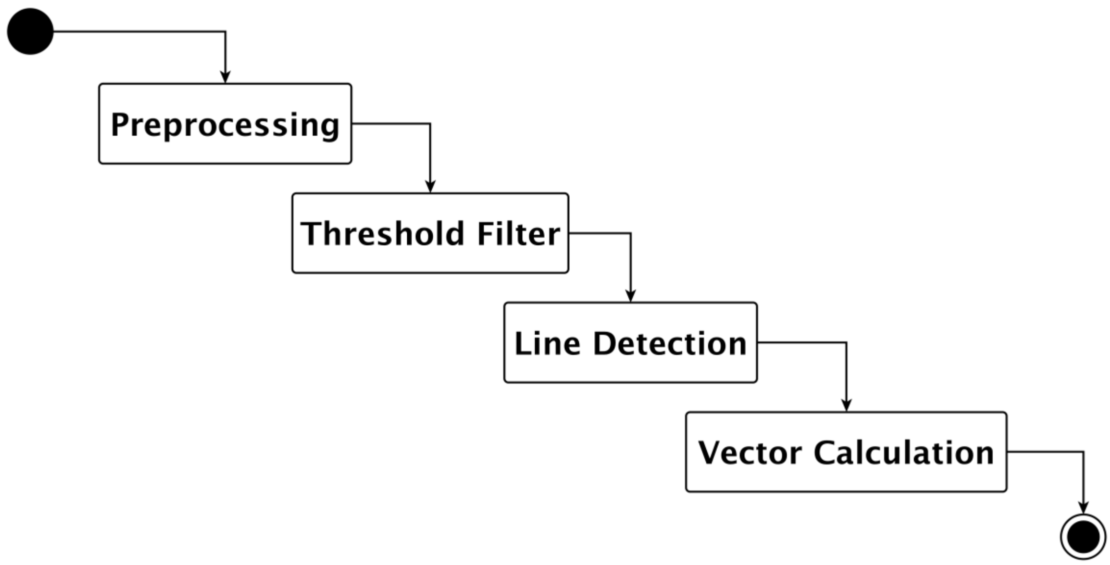


Figure 4-36: activity diagram for algorithm [2, p. 18]

CS: Downlink minimal Data

According to 4.8.2 a minimal subset of the scientific data is downlinked to ensure that a minimal evaluation is also possible in case of data losses within the Flight Segment. Only a subset and not the full set (especially not the video data) can be downlinked due to bandwidth limitations.

CS: Save extended Data

The full set of the results of the calculation activity (see 4.8.2) is saved to memory.

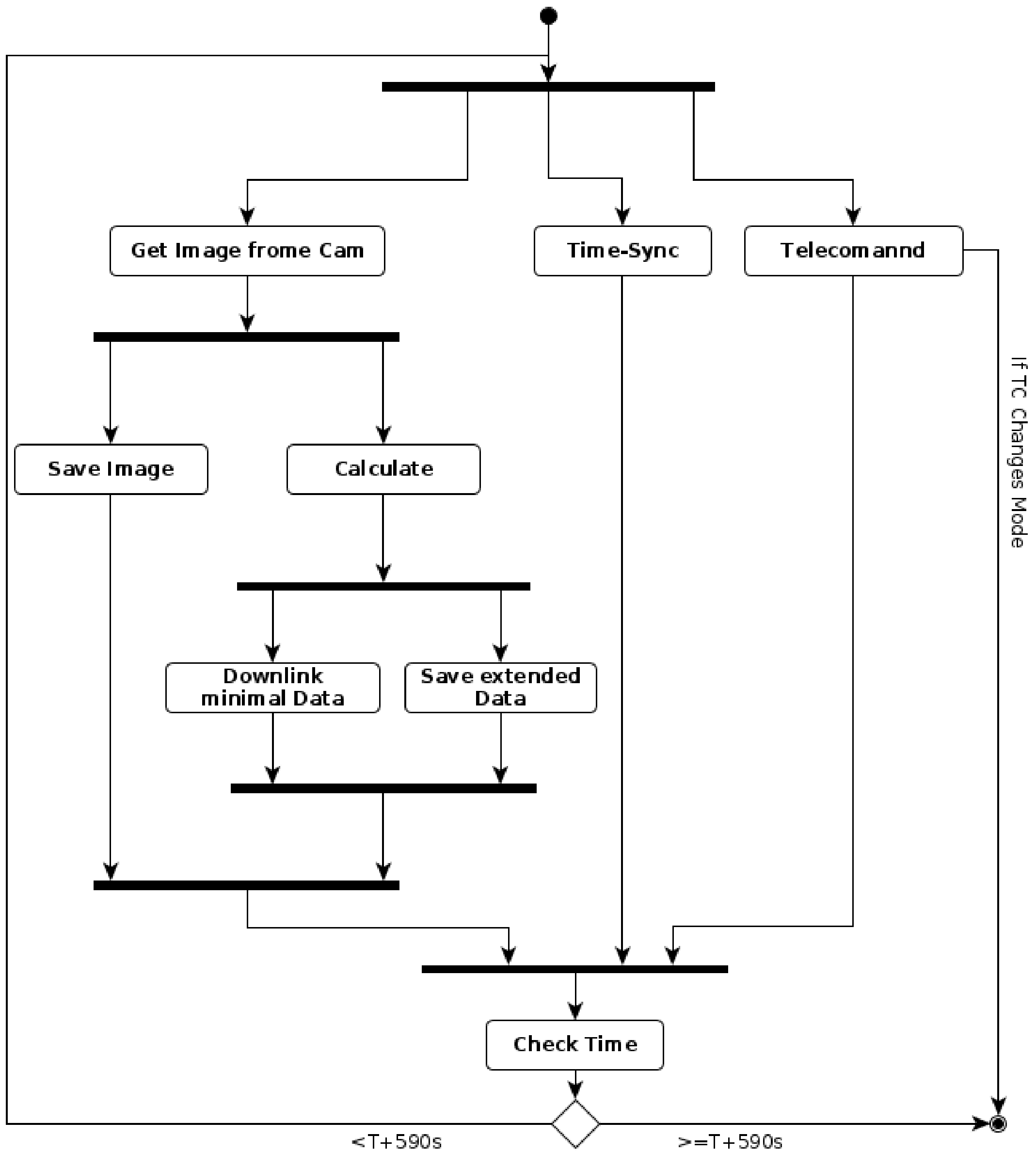


Figure 4-37: activity-diagram for CS during flight-mode

CS & MU: Telecommand

This activity is basically the same as “Check for TC, Forward TC, Decode TC, Execute Command” in 4.8.1.1, but abbreviated as TC is only used for testing and is neither available nor necessary during a nominal flight-sequence.

CS & MU: Time-Sync

The CS regularly sends its system time according to the protocol described in 4.2.4.2 to the MU which synchronizes its internal clock to that time.

CS & MU: Check Time

At T_S (T+590s) the software-mode is switched to “shut-down” autonomously.

MU: Collect sensor data, Save Housekeeping

The MU regularly collects sensor data also during flight. But as the downlink capacities are used for the results of the horizon acquisition, they are only stored with timestamp to the microSD-card.

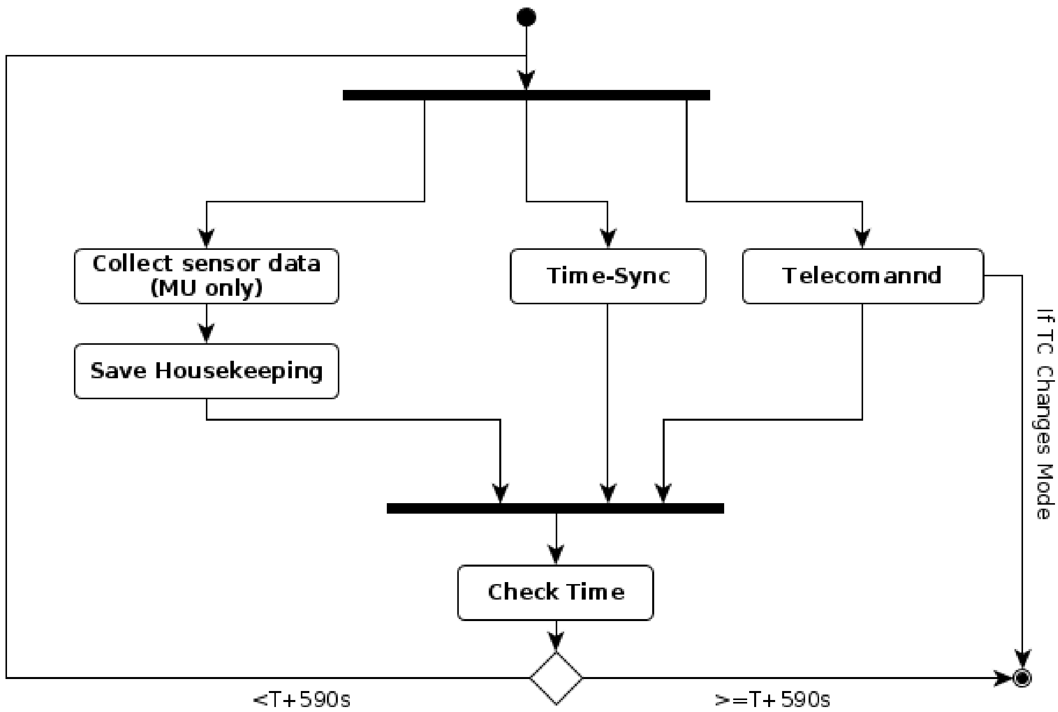


Figure 4-38: activity-diagram for MU during flight-mode

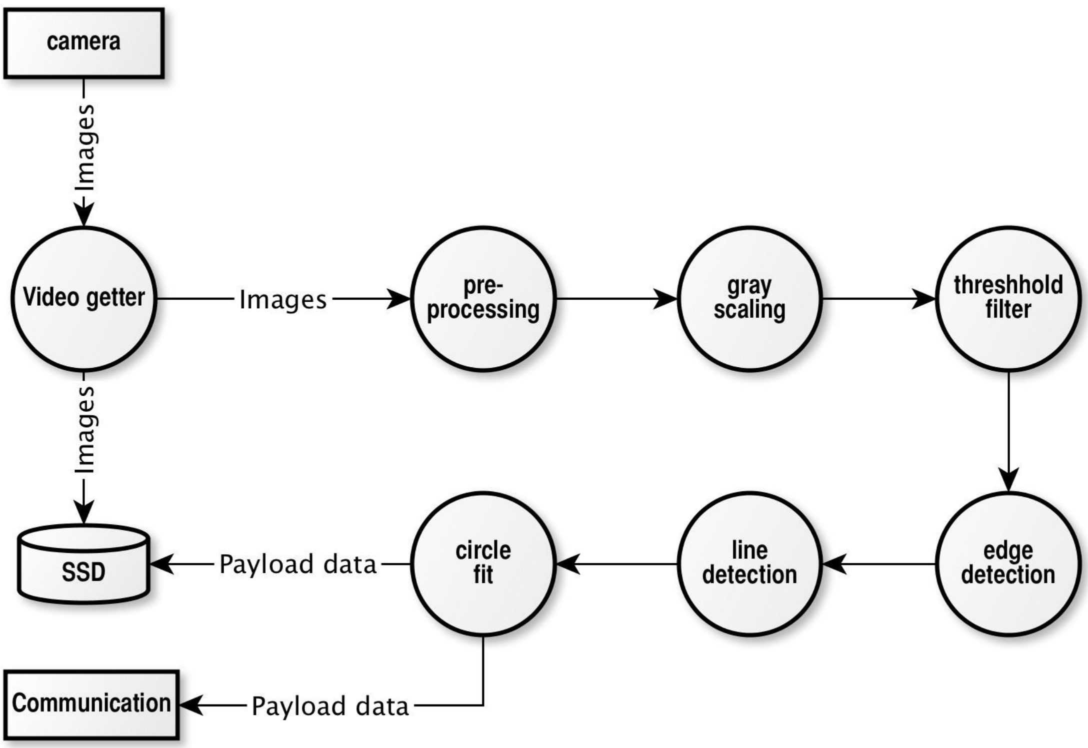


Figure 4-40: dataflow-diagram for algorithm

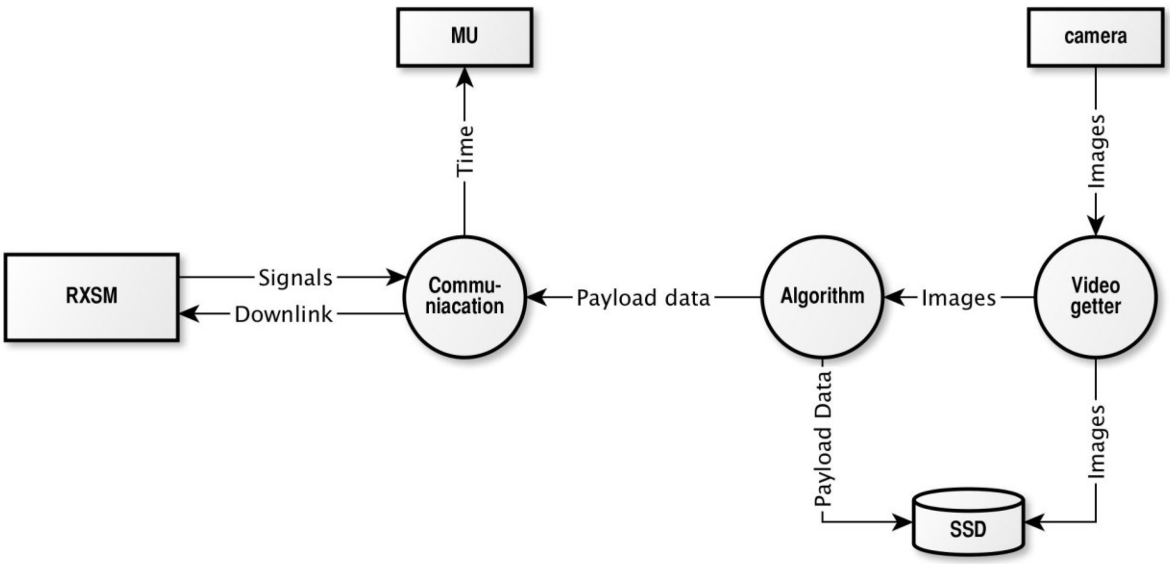


Figure 4-39: dataflow-diagram for CS during flight-mode

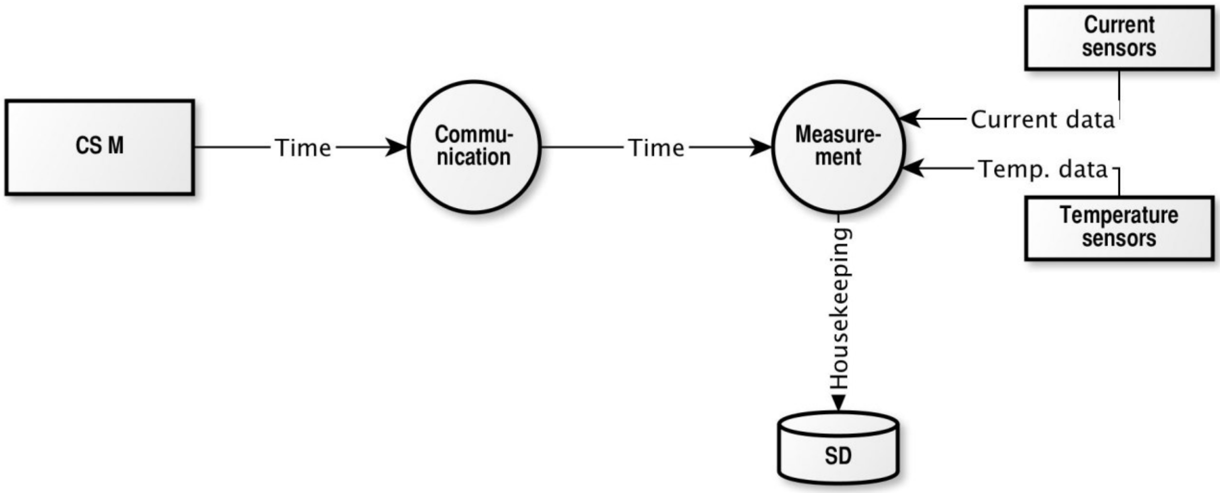


Figure 4-41: dataflow-diagram for MU during flight-mode

4.8.1.3 Shut-Down

Several activities start simultaneously immediately after all systems are fully booted. As the activities of the CS and the MU are very similar and to improve readability only one activity-diagram is provided – indicating differences between the two subsystems with italic comments.

Collect Housekeeping, Check for new Housekeeping, Send TM

Both CS and MU provide their status and return codes of commands as housekeeping data (signals, checks). Additionally, the MU regularly collects sensor data (temperatures, currents). When available, the MU sends this data to the CS. The CS regularly checks the receiving buffer for TM and forwards the housekeeping data provided by the MU to the ground while own TM of the CS data is directly sent to ground as well.

Telecommand

This activity is basically the same as "Check for TC, Forward TC, Decode TC, Execute Command" in 4.8.1.1, but abbreviated as TC is only used for testing and is neither available nor necessary during a nominal flight-sequence.

Power OFF

This mode is nominally only left by cutting off the power for the whole system by RXSM.

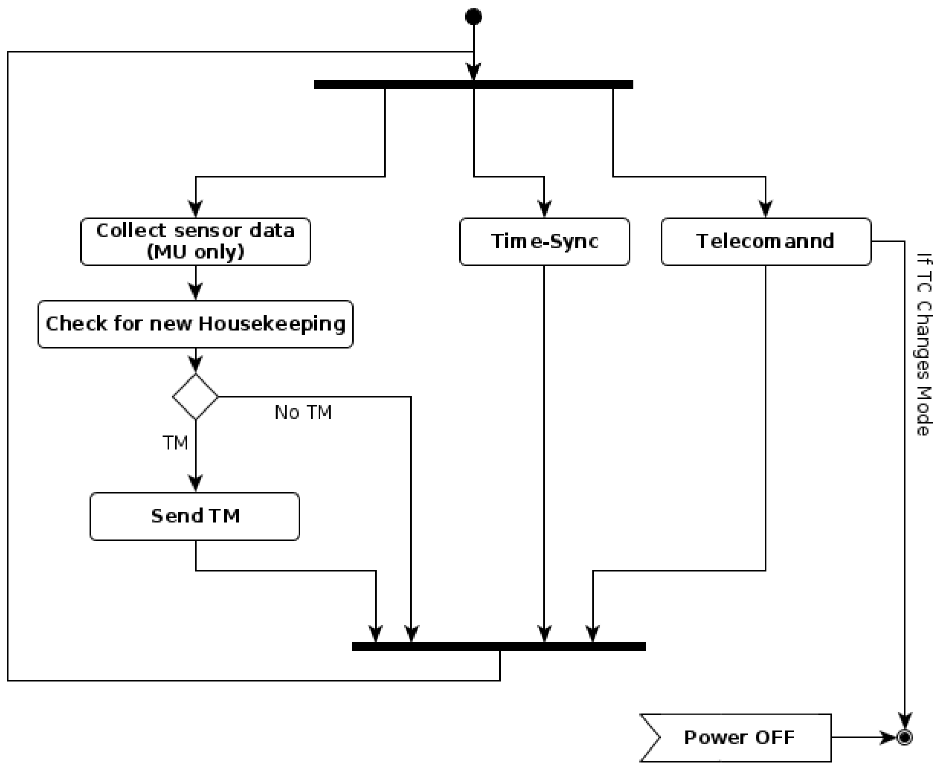


Figure 4-42: combined (CS & MU) activity-diagram for shut-down-mode

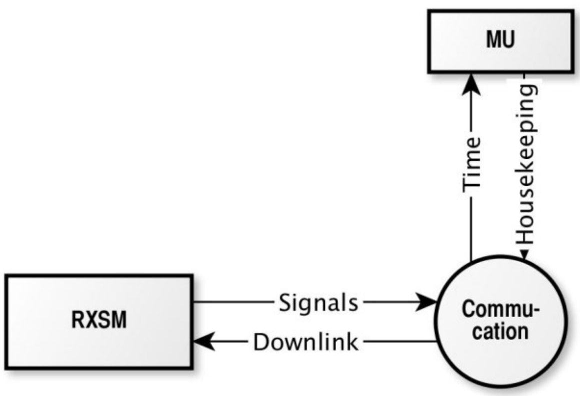


Figure 4-44: dataflow-diagram for CS in shutdown-mode

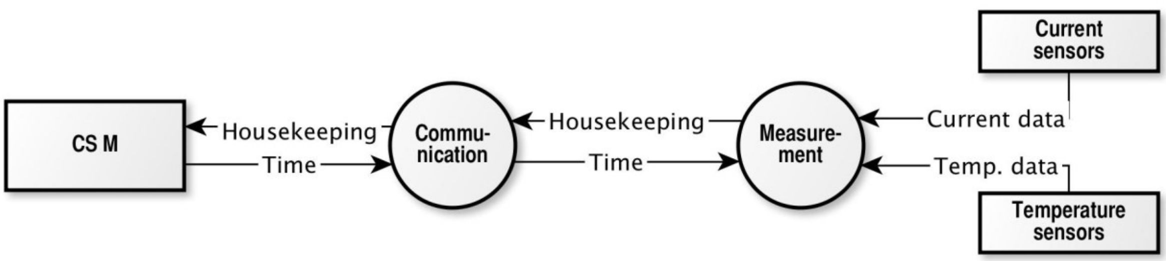


Figure 4-43: dataflow-diagram for MU in shutdown-mode

4.8.2 Data Handling

This subchapter summarizes the data handling already given above in the different states and defines the data packages.

The stream of the raw video data is directly saved to the video memory (Video Data Package) and is then forwarded to the calculation process. All results are stored as Calculation Data Packages to calculation memory, while only a subset of the results is sent to the ground (Flight-Mode Downlink Data Package). All downlink packages received on the ground station are displayed and saved to downlink memory. The measurement data from current and temperature sensors is stored in the measurement memory (Measurement Data Package) and in specific modes forwarded to the CS (MU-To-MasterCS Data Package).

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	Status	Mode	Echo
3	2	2	2	2	2	2	2	2	1	1	1

MasterCS-To-MU Data Package

Command	Time
1	3

Figure 4-45: 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

Ec ho	Sign als	Che cks	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

Ta sks	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 4-46: 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

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/C++ the development environment XCode is chosen.

The rest of the CS-software is also developed in C/C++ for Linux systems, as well as the MU is programmed with the C/C++-derivation for the Arduino-Platform using Atmel Studio as development environment.

The application running on the ground station will also be implemented in C/C++ and is fully specified in 4.9.3.

To standardize the communication processes and interfaces and increase reusability an own C/C++ communication-middleware following the OOP-approach was developed.

All code is shared among the team and backed up via an SVN-server.

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.

4.9.1 EGSE

To test, modify and prepare the experiment there are three notebooks with the needed RS232, USB and Ethernet interfaces, all needed utility software provided by manufacturers of components as well as the ground station software and tools for data evaluation.

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

Another Arduino Leonardo is used to check out the MU.

For debugging the CS an additional VGA-Monitor and USB-Keyboard is used.

During development and implementation an RXSM simulator device is used for testing.

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

Some "common" computer devices, like USB-sticks, Card-Readers (SD-micro and CF), SATA to USB-adapter, external hard disks, are used for fast and safe data transfer between several devices.

For debugging mainly the PDU basic electrical equipment (multimeter, oscilloscope, soldering iron) are used.

For more detailed information see 6.1.4 and Appendix C .2.

4.9.2 MGSE

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

For more detailed information see 6.1.4 and Appendix C .2.

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 was 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).

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.

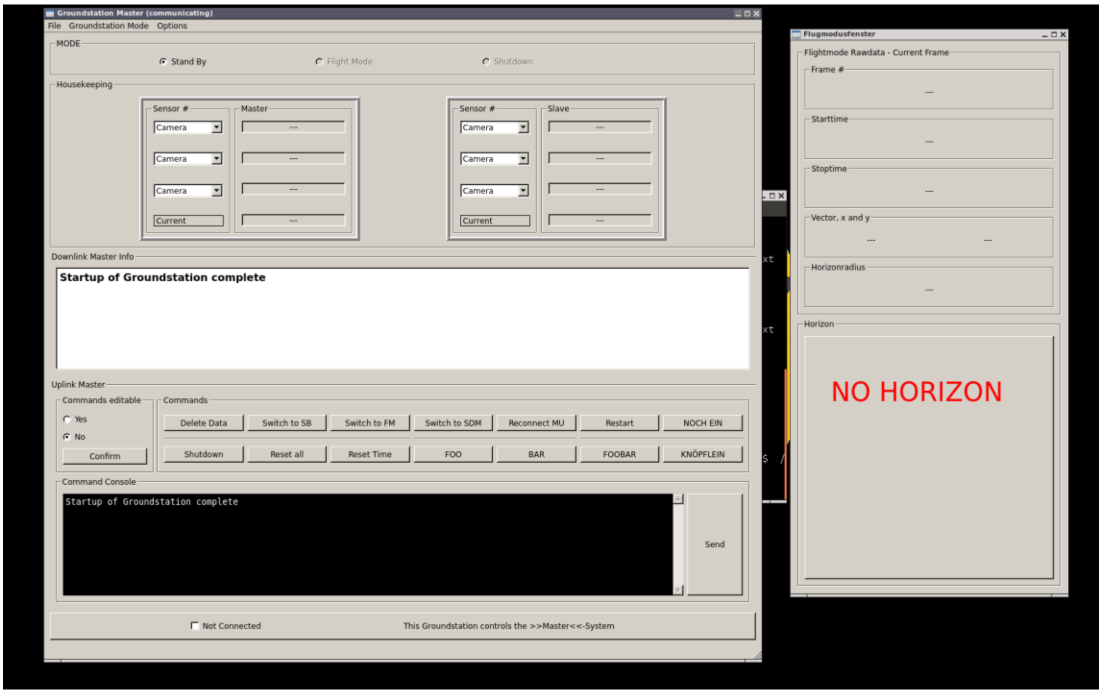


Figure 4-47: screenshot of the GUI for flight-mode view

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 environment of the REXUS rocket	R, I	✓
F-E-02	*moved to D-E-06*	-/-	
F-E-03	The FS shall distribute power to all subsystems	R, T	✓
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	✓
F-M-01	The mounting of the optical sensor should ensure visibility of the horizon	R	✓
F-S-01	The FS shall detect and calculate the line of horizon	R,T	✓
F-S-02	The FS shall calculate the 2D vector to the 2D projection of the earth center	R, T	✓
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	✓
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	✓
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	✓

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	✓
P-M-03	The horizon should be visible in 50% of the operational time	A	✓
P-M-04	The horizon shall be visible in 30% of the operational time	A	✓
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	✓
P-E-09	The optical sensor shall provide an image resolution of 1024px x 768px	R	✓
P-E-10	The exposure time of the optical sensor shall be adjustable in a range from 10µsec to 1sec	R	✓
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	✓
P-E-13	The MU shall measure temperatures with an accuracy of +/- 0,5°C	R	(✓)^1
P-E-14	The MU shall measure temperatures in a range from -55°C to +125°C	R	✓
P-E-15	The MU shall measure temperatures with a sample rate of 1Hz	R	✓
P-E-16	The MU shall measure currents with an accuracy of +/- 100mA	R	✓
P-E-17	The MU shall measure currents in a range of 0A to 3A	R	✓
P-E-18	The MU shall measure currents with a sample rate of 100Hz	R	✓

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	✓
P-E-20	The data storage of the MU shall provide a write speed of 2 kbyte/sec	T	✓
P-E-21	The data storage for the optical raw data shall have a memory size of 45 Gbyte	R, T	✓
P-E-22	The data storage for the optical raw data shall provide a write speed of 71 Mbyte/sec	T	✓
P-E-23	The data storage for the calculated data shall have a memory size of 77 Mbyte	R, T	✓
P-E-24	The data storage for the calculated data shall provide a write speed of 130 kbyte/sec	T	✓
P-S-01	The 2D vector to the earth center should be calculated with 2 digits	R	✓
P-S-02	The system shall calculate the 2D vector to the earth for every successful horizon detection	R, T	✓
P-S-03	The system shall process 30fps for horizon detection	R	✓
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^3
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^3
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^3
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^3

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 disturbances¹ the results of horizon acquisition should be successful² in 70% of those cases.	T	TBD^3
P-S-09	When the rocket is spinning with high rates (> 1.0Hz) AND if there are many image disturbances¹ the results of horizon acquisition should be successful² in 30% of those cases.	T	TBD^3
P-S-10	The amount of false negative horizon acquisitions should be less than 10%.	T	TBD^3
	¹ Image disturbances are phenomena like: sun in the image, lens flares, 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	✓
D-E-02	HORACE shall not electrically interfere with other experiments	R	✓
D-E-03	HORACE shall be compatible to the REXUS electrical interface according to REXUS manual	R	✓
D-E-04	The FS shall use camera(s) as optical sensor(s)	I	✓
D-E-05	The FS may use 2 cameras	I	✓
D-E-06	The FS shall provide a global timestamp, synchronized to LO *(formerly F-E-02)*	R	✓
D-E-07	The FS shall measure the power consumption of selected subsystems *(formerly F-E-04)*	R	✓

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, nowmore detailed)*	R	✓
D-E-09	The optical sensor shall provide the image data as raw data *(formerly P-E-11)*	R	✓
D-E-10	The PDU shall provide 5V and 12V. *(formerly P-E-01)*	R, T	✓
D-E-11	The PDU shall provide currents between 0A and 2.5A *(formerly P-E-02)*	R, T	✓
D-E-12	The PDU shall provide voltages with an accuracy of ±5% *(formerly P-E-03)*	R	✓
D-E-13	The PDU shall provide currents with an accuracy of ±200mA *(formerly P-E-04)*	R	(✓)^2
D-E-14	The PDU shall handle a range of input voltage between 24V and 36V *(formerly P-E-05)*	R, T	✓
D-E-15	The PDU shall handle a range of input current between 0A and 3A *(formerly P-E-06)*	R, T	✓
D-E-16	A new timestamp shall be provided with the frequency 10 kHz *(formerly P-E-07)*	R	✓
D-M-01	HORACE shall not mechanically harm neither the REXUS rocket nor launcher	R	✓
D-M-02	HORACE shall not mechanically interfere with other experiments	R	✓
D-M-03	HORACE shall be compatible to the REXUS mechanical interface according to REXUS manual	R	✓
D-M-04	The core system shall withstand temperature conditions inside the module according to REXUS manual	T	✓
D-M-05	The cameras shall withstand temperature conditions at the module's skin according to REXUS manual	T	✓

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

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

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

5.1.1 Traceability Matrix

The table underneath provides a traceability matrix between Requirements, Verification-Objectives and the current status of verification.

The table features following items:

- ***RQ ID*** = Requirement ID
- ***T*** = Test
- ***A*** = Analysis
- ***R*** = Review-of-Design
- ***I*** = Inspection
- ***VR ID*** = Verification Requirement ID
- ***ST*** = Status

RQ ID	T	A	R	I	VR ID	Status
F-E-01			✓	✓	VR-FE01-A	✓
F-E-03	✓(TR5.4)		✓		VR-FE03-A	✓
F-E-06			✓		VR-FE06-A	✓
F-M-01			✓		VR-FM01-A	✓
F-S-01	✓(TR4.4)		✓		VR-FS01-A	✓
F-S-02	✓(TR4.4)		✓		VR-FS02-A	✓
F-S-03	✓(TR3.1)		✓		VR-FS03-A	✓
F-S-10			✓		VR-FS10-A	✓
F-S-16			✓		VR-FS16-A	✓
P-M-02		✓			VR-PM02-A	✓
P-M-03		✓			VR-PM03-A	✓
P-M-04		✓			VR-PM04-A	✓
P-E-08			✓		VR-PE08-A	✓
P-E-09			✓		VR-PE09-A	✓
P-E-10			✓		VR-PE10-A	✓
P-E-12	✓(TR4.3)				VR-PE12-A	✓
P-E-13			(✓)		VR-PE13-A	(✓)[1]
P-E-14			✓		VR-PE14-A	✓
P-E-15			✓		VR-PE15-A	✓
P-E-16			✓		VR-PE16-A	✓
P-E-17			✓		VR-PE17-A	✓
P-E-18			✓		VR-PE18-A	✓
P-E-19	✓(TR4.1)		✓		VR-PE19-A	✓
P-E-20	✓(TR4.1)				VR-PE20-A	✓
P-E-21	✓(TR4.1)		✓		VR-PE21-A	✓
P-E-22	✓(TR4.1)				VR-PE22-A	✓
P-E-23	✓(TR4.1)		✓		VR-PE23-A	✓
P-E-24	✓(TR4.1)				VR-PE24-A	✓

Table 5-8: Traceability Matrix (1/3)

RQ ID	T	A	R	I	VR ID	Status
P-S-01			✓		VR-PS01-A	✓
P-S-02			✓		VR-PS02-A	✓
P-S-03			✓		VR-PS03-A	✓
P-S-04	X				VR-PS04-A	→ Eval[3]
P-S-05	X				VR-PS05-A	→ Eval[3]
P-S-06	X				VR-PS06-A	→ Eval[3]
P-S-07	X				VR-PS07-A	→ Eval[3]
P-S-08	X				VR-PS08-A	→ Eval[3]
P-S-09	X				VR-PS09-A	→ Eval[3]
P-S-10	X				VR-PS10-A	→ Eval[3]
D-E-01			✓		VR-DE01-A	✓
D-E-02			✓		VR-DE02-A	✓
D-E-03			✓		VR-DE03-A	✓
D-E-04				✓	VR-DE04-A	✓
D-E-05				✓	VR-DE05-A	✓
D-E-06			✓		VR-DE06-A	✓
D-E-07			✓		VR-DE07-A	✓
D-E-08			✓		VR-DE08-A	✓
D-E-09			✓		VR-DE09-A	✓
D-E-10	✓(TR4.2)		✓		VR-PE01-A	✓
D-E-11	✓(TR4.2)		✓		VR-PE02-A	✓
D-E-12			✓		VR-PE03-A	✓
D-E-13			✓[2]		VR-PE04-A	✓[2]
D-E-14	✓(TR4.2)		✓		VR-PE05-A	✓
D-E-15	✓(TR4.2)		✓		VR-PE06-A	✓
D-E-16			✓		VR-PE07-A	✓
D-M-01			✓		VR-DM01-A	✓
D-M-02			✓		VR-DM02-A	✓
D-M-03			✓		VR-DM03-A	✓
D-M-04	✓(TR1.2/2.5)				VR-DM04-A	✓
D-M-05	✓(TR2.2/2.3)				VR-DM05-A	✓
D-M-06	✓(TR5.5)				VR-DM06-A	✓
D-M-07					VR-DM07-Q	Q not needed
D-M-07	✓(TR6.2)	✓			VR-DM07-A	✓
D-M-08			✓	✓	VR-DM08-A	✓
D-M-09			✓	✓	VR-DM09-A	✓
D-M-10			✓	✓	VR-DM10-A	✓

Table 5-9: Traceability Matrix (2/3)

RQ ID	T	A	R	I	VR ID	Status
D-S-01	(✓)(TR3.2)		✓		VR-DS01-A	✓
D-S-02	(✓)(TR3.2)		✓		VR-DS02-A	✓
D-S-03	(✓)(TR3.2)		✓		VR-DS03-A	✓
D-S-04			✓		VR-DS04-A	✓
D-S-05			✓		VR-DS05-A	✓
D-S-06			✓		VR-DS06-A	✓
D-S-07			✓		VR-DS07-A	✓
D-S-08			✓		VR-DS08-A	✓
D-S-09			✓		VR-DS09-A	✓
D-S-10			✓		VR-DS10-A	✓
D-S-11			✓		VR-DS11-A	✓
D-S-12			✓		VR-DS12-A	✓
D-S-13	✓(TR3.4)		✓		VR-DS13-A	✓
D-S-14	✓(TR3.4)		✓		VR-DS14-A	✓
D-S-15	✓(TR3.4)		✓		VR-DS15-A	✓
O-01	✓(TR5.4)				VR-O01-A	✓
O-02			✓		VR-O02-A	✓
O-03	✓(TR3.2)				VR-O03-A	✓
O-04	✓(TR3.4)		✓		VR-O04-A	✓
O-05			✓		VR-O05-A	✓
O-06	✓(TR3.2)				VR-O06-A	✓
O-07	✓(TR3.2)		✓		VR-O07-A	✓
O-08	✓(TR3.2)				VR-O08-A	✓
O-09	✓(TR3.2)		✓		VR-O09-A	✓
O-10			✓		VR-O10-A	✓
O-11	✓		✓		VR-O11-A	✓

Table 5-10: Traceability Matrix (3/3)

[1] See Review-Of-Design Report in 8.3Appendix C Appendix C at P-E-13 for further information.

[2] See Review-Of-Design Report in Appendix C at D-E-13 for further information.

[3] Testing to verify this Requirement is not done before flight, since HORACE is a technology demonstrating mission. Evaluation of the flight data will show if these requirements are missed or met. For approximate values of recognised horizon lines expressed as a percentage, assuming the algorithm is working perfectly with undisturbed image frames, see Analysis Report in Appendix C.

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
Test facility	University of Wuerzburg
Tested item	Core System
Test level/ procedure and duration	The Core System will be tested under low pressure conditions (< 0.5 mbar) according to the REXUS manual chapter 9.1 to verify that the core system is able to run even when there is no convective cooling
Test campaign duration	approx. 1 day
Status	Done, 22Oct13

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/ procedure and duration	The Lens 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.
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	Will not be done!

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	Done, 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	Done, 11Feb14

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	Done, 16 & 17 January 2014

Test Number	3.3
Test type	Functionality Test
Status	Combined with Test Number 4.4

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 (simulating LO,SOE,SODS and Downlink)
Test campaign duration	approx. 1 day
Status	Done, 16 & 17January 2014

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, 31Aug13

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 appropriate Voltage and Current according to Requirements D-E-10, D-E-11, D-E-14 and D-E-15
Test campaign duration	approx. 1 day
Status	Done, 19Sep13

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	Done, 29Oct13

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	Done, 16/17 and 30Jan14

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 shall be tested under flight conditions according to REXUS manual Chapter 9.1 and 9.2.
Test campaign duration	approx. 2 days
Status	Done, 16 & 17 January 2014

Test Number	5.5
Test type	Thermal vacuum
Test facility	University of Wuerzburg
Tested item	System Level Test

Test level/ procedure and duration	One System (consisting of PDU, MU, CS and Camera System) shall be tested under “Worst Case” flight conditions according to REXUS manual Chapter 9.1 and 9.2. to test the systems’ ability to cope with high temperatures under vacuum (45°C at < 0.5mbar, for 10minutes)
Test campaign duration	approx. 2 days
Status	Done, 08 January 2014

Test Number	6.1 – not needed!
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	approx 1.day
Status	Done during Integration Week in Bremen

Test Number	7.1 - not necessary
Test type	Performance Test
Test facility	University of Wuerzburg
Tested item	System Level Test

Test level/ procedure and duration	The whole system shall be disassembled and assembled according to the “Integration and assembly procedure” to verify the assembly procedure is simple and without fault.
Status	Assembling and Disassembling was done multiple Times during the Development of the Mechanical Procedures and during Integration Week, to ensure the procedures are fine. So this test was considered not to be necessary any more.

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	„Done“ during shipping the Experiment to the Integration Week at ZARM in Bremen. A Test Report was considered not to be necessary for this item, since HORACE does not have moving parts in its setup, and the Flight System was transported multiple times during the Integration from the University to the workshop.

5.3 Test Results

The test results can be found separately in a zip-file in Appendix C .3, which contains following items:

Index	Filename	Description
1	RX16_HORACE_TR1.1_v1.0_21Jun13.zip	Test Report for Test #1.1
2	RX16_HORACE_TR1.2_v1.0_24Oct13.zip	Test Report for Test #1.2
3	RX16_HORACE_TR2.2_v1.0_30Jul13.zip	Test Report for Test #2.2
4	RX16_HORACE_TR2.3_v1.0_07Aug13.zip	Test Report for Test #2.3
5	RX16_HORACE_TR2.5_v1.0_07Sep13.zip	Test Report for Test #2.5
6	RX16_HORACE_TR3.1_v1.0_11Feb14.zip	Test Report for Test #3.1

7	RX16_HORACE_TR3.2_v1.0_16-17Jan14.zip	Test Report for Test #3.2
8	RX16_HORACE_TR3.4_v1.0_16-17Jan14.zip	Test Report for Test #3.4
9	RX16_HORACE_TR4.1_v1.0_02Sep13.zip	Test Report for Test #4.1
10	RX16_HORACE_TR4.2_v1.0_19Sep13.zip	Test Report for Test #4.2
11	RX16_HORACE_TR4.2_v1.0_29Oct13.zip	Test Report for Test #4.3
12	RX16_HORACE_TR4.4_v1.0_31.Jan14.zip	Test Report for Test #4.4
13	RX16_HORACE_TR5.4_v1.0_16-17Jan14.zip	Test Report for Test #5.4
14	RX16_HORACE_TR5.5_v1.0_08Jan14.zip	Test Report for Test #5.5
15	RX16_HORACE_TR6.2_140211_ZARM-FAB_REXUS-16_HORACE_ATR01.zip	Test Report for Test #6.2

6 LAUNCH CAMPAIGN PREPARATION

6.1 Input for the Campaign / Flight Requirement Plans

6.1.1 Dimensions and mass

Experiment mass (in kg):	7.84kg (for 2 systems, including 10% margin, including module)
Experiment dimensions (in m):	0.348m x 0.318mm x 0.0995m
Experiment footprint area (in m^2):	0.056 m²
Experiment volume (in m^3):	$1.4*10^{-3}$ m³
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=66.0mm; ±<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 6.9Kbit/s **)
	Data rate – uplink	2x <1Kbit/s
Power system: Service module power required? Yes		
	Peak power consumption:	26.5W *); 51.2W**) (measured values,

		+50% margin)
	Average power consumption:	25.8W*); 49.1W **) (measured values +50% margin)
	Total power consumption after lift-off(until T+600s)	4.3Wh *); 8.2Wh **) (measured values, +50% margin)
	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
- VGA-Monitor (preferably flat-screen)
- USB-keyboard
- 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.

For more detailed information (procedures and schedules) see Appendix C .

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 tests 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.

NOTE: As at T-60s the video recording is started, it will be stopped if a hold of CD occurs between T-60s and LO to prevent data storage overflows. The data storages shall be cleared and the video recording restarted when CD proceeds. Thus, we demand a **reset of CD to T-90s after every hold between T-90s and T-0s.**

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
-580	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 triggered by TC)
-60	GS-TC	command start video record
	FS-CS	start video record (manually 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)
+3	RXSM	SODS (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.

For more detailed information (procedures and schedules) see Appendix C .

7 DATA ANALYSIS PLAN & EXPERIMENT REPORTS

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 (1)
- Calculate deviation of calculated earth vector compared with vector calculated with RXSM-data (1) (2)
- Determine limits of spinning rates for successful horizon acquisition (3)
- Calculate ratio of correctly processed frames per second (4)
- Did false positives occur? Detect reasons. (1)
- Did false negatives occur? Detect reasons. (1)
- Calculate ratio of successful horizon detections to frames on which horizon is indeed visible (1)
- Evaluate correlations between power consumption and algorithmic activities and spinning rates (5)
- Evaluate power consumption as important parameter for later operational use (5)

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.

The data analysis could not be performed exactly as planned above already in a very early stage mainly due to the overexposure of the cameras (see also 7.4.1.4 and [1, pp. 20-25]). Consequently, the evaluation of each question had to be adjusted as indicated above with numbers and explained below:

(1) Because of the overexposure of the cameras no horizon was visible in the video data and thus could not be detected by the algorithm. Hence, also all analysis regarding the actual flight video data was obsolete. To evaluate the algorithmic performance simulation data was analyzed regarding those questions. The advantage of the simulation was that the real earth vectors were known thus a manual evaluation frame by frame was not necessary. The main disadvantage was that the

simulation could not completely model the reality and thus provides less realistic video data.

(2) The data provided by RXSM is not accurate enough to calculate the rocket's attitude and position during flight. Therefore, this question was skipped.

(3) Because of the overexposure no appropriate flight data was available and additionally also the simulation could not model the impact of the image data by high spinning rates. Thus, this question had to be skipped.

(4) Could be evaluated using the flight data. But as no horizon was visible the algorithm skipped all video frames after preprocessing. Hence, the results of this analysis are not representative for the actual operational scenario.

(5) Could be evaluated using the flight data.

7.2 Launch Campaign

7.2.1 Pre-Flight Experiment Preparation

The experiment and all equipment either arrived earlier at ESRANGE than the team or in case of some spare-parts were directly brought by the team. So right after unpacking visual inspections, component tests and finally full-system tests were performed, to ensure that the experiment arrived in good shape and in the same state as handed over after Bench Test.

As the experiment assembly and integration was already complete before the campaign and no consumables, which might to have be replaced, were used besides intense testing only few actions had to be performed.

With some measurements one tried to locate the origin of the shifted electrical ground – a problem which was only detected during Bench Test and caused random software crashes of the MasterCS (see also 7.4.1.2 and [1, pp. 16-18]). But as the causing component could not be identified and furthermore the replacement of the MasterCS with a spare component and the application of software workarounds both for the core systems and the MU reduced the impact of the remaining shifted ground so that it would not harm the overall performance of the experiment, further tinkering was omitted.

The placement of easy to remove and clearly visible RBF-covers to keep the protective windows of the cameras as clean as possible was also conducted as scheduled.

As one of the last scheduled actions before handing over the experiment for final integration to the payload stack the CF-cards of the core systems were glued to their sockets to prevent them from getting loose due to vibrations. Locking other screws or connections (e.g. with locktite) was omitted because of the excellent performance of shaker tests and to simplify late access, which would be time-critical if necessary.

In the spare time as many timeline tests were conducted as possible to train the procedures and detect possible remaining bugs – either using own simulator equipment or the RXSM-simulator provided by EuroLaunch. But none of the tests were performed outdoors in direct sunlight and – as it was a time-consuming procedure – the recorded (video) data was never downloaded and inspected – a “negligence” which turned out to be fatal. During the final testing two unexpected issues concerning HORACE occurred which had to be faced before flight.

As it had not been tested properly before, during the Hot Flight Simulation it turned out that HORACE somehow jammed the GPS-signal received by RXSM. Although some measures, like placing ferrite cores around cables of the HORACE flight segment, were taken by EuroLaunch staff, the problem could not be solved and hence no GPS-information was available for RXSM from T-600s (HORACE power on) to T+600s (HORACE power off) during flight (see also 7.4.1.3 and [1, pp. 19-20)].

During the following test, the Cold Flight Simulation, three days later, HORACE experienced a loss of the microSD-card of the MU as the appropriate selfchecks indicated that the MU could not access the microSD-card (neither reading nor writing; see also 7.4.1.1 and [1, pp. 14-16]). It was assumed that the card’s file system got corrupted during the troubleshooting of the GPS-problem, which was not supervised by the team. As the chances were good to solve the problem by replacing the card and the team had a precise and not too time-consuming procedure prepared for this action, it was approved by the Payload Manager although it would mean to break up the payload stack again and therefore the Cold Flight Simulation had to be repeated – thus delaying the overall schedule for some hours. As the repetition of the Cold Flight Simulation (with the replaced microSD-card) went well for all teams early in the next day’s morning, one could directly go on with the motor mating and roll-out, finally meeting the originally scheduled launch-window despite of the delay caused by HORACE.

7.2.2 Flight Performance

HORACE was launched on May 28 13:30 UTC+2 as part of the payload of REXUS 16 from Esrange Space Center, Kiruna/Sweden after a perfectly nominal hot countdown. Also the flight seemed to be nominal for HORACE in the beginning. All subsystems switched to the flight mode and valid downlink frames were received on the ground stations from both systems. That no horizons could be detected was expected for the ascending phase of the flight, but as none were detected even after the despin of the rocket and the footage of a camera onboard RXSM, which was streamed to the Science Center live, showed that the horizon was clearly visible and should therefore be detected, it was clear that something went other than expected. As HORACE could not acquire a single horizon during flight, but the timeline was conducted correctly (switching to shut-down-mode at T+590s) and from technical point of view the video data was correctly processed by the algorithm (i.e. not causing errors or crashes), an issue with the cameras was presumed already at the end of operations.

7.2.3 Post-Flight Activities

The Flight Segment was returned after recovery to the team in excellent shape. Everything was in its place and even the screws (not being locked) were all still tightened. Only a smoky smell – presumably due to Low Gravity's issue – and some pieces of glue from another experiment were detected.

All data was downloaded from all experiment devices (SSDs, microSD, internal disks of ground stations) and backed up to two external hard drives as well as uploaded to a server of the University according to the procedures without any incident.

Only after that had been finished, the raw data was converted for a first quick evaluation whose results were presented during the Post-Flight Meeting.

Finally, the experiment and all equipment was packed and prepared for shipment.

7.3 Results

This chapter summarizes the results of the experiment divided into technical operational and management aspects and the outcome and conclusions regarding the scientific questions according to [1] and an overall evaluation is drawn in a third subchapter (as well according to [1]). For the full evaluation and results please refer to that cited document.

7.3.1 Technical, Operational and Management Achievements

As – at least from the technical point of view – only few and minor issues were encountered (cf. 7.2 and 7.4.1) throughout the implementation, flight preparation, flight and post-flight activities and as all milestones were perfectly met in time the mission was a great success regarding technical, operational and management aspects. During the 18 months of development and preparation a profound platform to answer the scientific questions was created which also performed mostly excellent during flight.

The design of electronics and electrical interfaces, whose main function was to distribute power throughout the whole Flight Segment and provide suitable hardware for the horizon acquisition as well as communication infrastructure, was solid and most of the requirements were met. Furthermore, the principle to keep the electronic design simple because of a significant lack of expertise in the team paid off. The final design and setup with an overall power consumption of 2.74Wh (Slave) and 2.76Wh (Master; cf. Figure 7-1) was perfectly compatible to the capabilities of RXSM for power supply although there had been doubts in early design stages. Only the interference with GPS (cf. 7.4.1.3) and the shifted ground (cf. 7.4.1.2) caused some requirements not to be met, but actually that did not reduce the experiment's performance and did not harm other experiments. Therefore, a profound electrical platform was created. (see also [1, pp. 26-29])

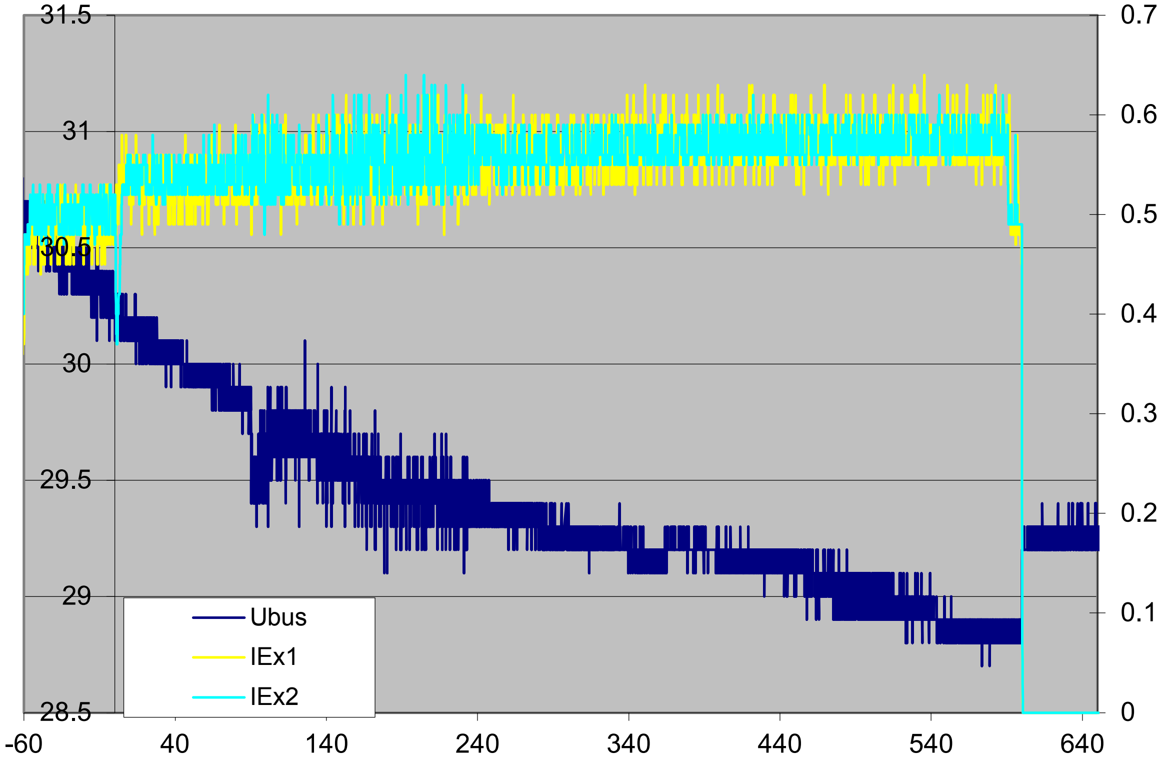


Figure 7-1: HORACE total power consumption recorded by RXSM; Ubus - voltage of the provided power supply [V], IEx1 – current Master [A], IEx2 – current Slave [A]; [1, p. 27]

The thermal design, which should only prevent damage of the experiment due to the harsh thermal environment, turned out to be perfectly dimensioned. Early tests had shown, that low temperatures during countdown were not critical for the experiment and the actual temperatures the experiments was exposed to were even less harsh (+15°C instead of expected -40°C, cf. 4.6). Also higher temperatures during the flight's vacuum condition were exactly as expected, hence leading to no problems and proving the size of the heatsinks for CS and PDU reasonable dimensioned (cf. Figure 7-2; for further discussion of the temperature profiles and the thermal design see [1, pp. 29-31]).

The performance of the mechanics was excellent as well. With the only functionality to ensure the visibility of the horizon and protect the electronic components from the mechanical stress, the mechanical design was quite basic as well and the flight proved it to be perfectly suitable for that. The Flight Segment was returned to the team in excellent shape – not a single component broken or screw loosened (see also [1, pp. 31-33]).

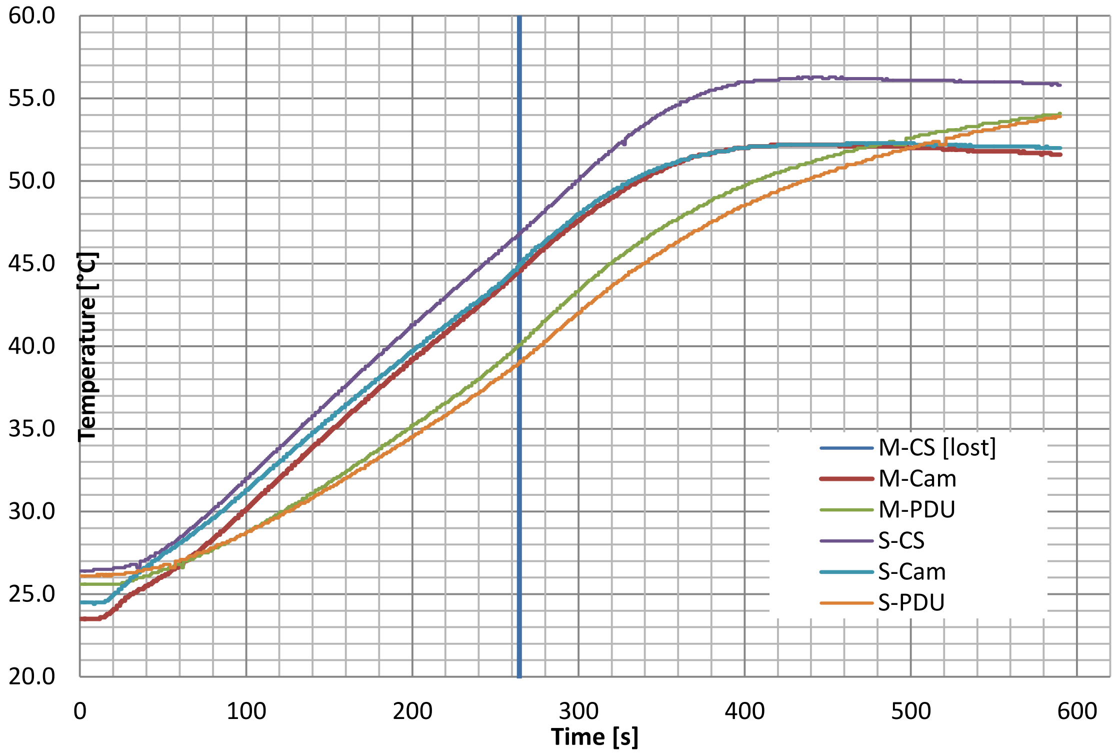


Figure 7-2: MU-data: temperature vs time [1, p. 31]

The OBDH-software of the core systems, which implemented several mostly independent functionalities (cf. 4.8), ran perfectly stable during countdown and flight despite of formerly experienced crashes due to the shifted ground (cf. 7.4.1.2). However, the usage of a Linux operating system and accumulation of functionalities the overall speed, especially regarding the horizon acquisition, was severely affected (cf. 7.3.2). But as reliable (although slow) software was preferred compared to a fast but unstable one and all functional requirements were perfectly met, the OBDH-software of the core systems can be rated as quite good (see also [1, pp. 33-35]).

Furthermore, the communication middleware, which actually was not directly required but implemented to bundle the functionalities of the quite complex communication infrastructure (cf. 4.2.4 & 4.8.2), was a great success as well. This concept following an object-oriented approach not only saved a lot of development effort and time (e.g. for the ground station, cf. 4.9.3) and increased modularity, but also led to a really stable and reliable communication infrastructure (package error rate only around 0.005 presumably due to bad radio link). Hence, the decision to bundle the functionalities regarding data transfer and data storage to that middleware totally paid off and contributed to the fulfillment of the corresponding requirements on data transfer and storage (see also [1, pp. 40-43]).

The Measurement Unit was supposed to collect health- and housekeeping data and downlink or store them according to the software mode (cf. 4.8.1) thus making it possible to check out the experiment during countdown and answer some questions posed in the Mission Objectives (cf. 1.3). As the issue of the corrupted file system of the microSD-card could be solved (cf. 7.4.1.1) the whole timeline was conducted nominally, thus fulfilling all functional requirements. Whereas one had to lower one's sights regarding some performance requirements, because one temperature sensor was lost, the noise on the measurements of one current sensor exceeded the desired value and the necessity of trade-offs regarding the sample rate. Nevertheless, the general performance of the MU is considered to be excellent (see also [1, pp. 43-45]).

Last but not least reliable ground station software, which saves and displays the received data in an appropriate way as well as provides the possibility to send telecommands, was required as the Flight Segment shall downlink some information both for operational and scientific reasons and had to be checked out manually during countdown. The software, whose data and functional layer could nearly entirely be adapted from the communication middleware and whose GUI was designed mostly from direct user feedback, ran absolutely stable throughout the whole campaign (including all tests, as well as the hot countdown and flight) and thus met all requirements and contributed to save scientific data and check out the experiment as intended (see also [1, pp. 45-46]).

7.3.2 Scientific Results

Due to the overexposure of the cameras (cf. 7.4.1.4) the quality of the gathered scientific data regarding the Mission Statement (cf. 1.2) and Experiment Objectives (cf. 1.3) was severely affected although the rest of the image procession including the algorithm for horizon acquisition worked perfectly nominal. Unfortunately, the algorithm could not acquire a single horizon in images with that bad quality. Hence, statements about the accuracy based on real flight data were not possible. Nevertheless, the results of a simulation, which made the comparison of the algorithm's calculation with known reference data possible, show that the algorithm works very accurate not only regarding the direction (±0.6° offset of mean + standard derivation, see Figure 7-3) but also the length of the vector (although a conversion from the reference data to the algorithm calculations was not possible a correlation is obvious, see Figure 7-4). Also the rates of false positives (horizon detected where is none, simulation: 0.00%, required: n.a.) and false negatives (simulation: 10.29%, required: <10%) were nearly excellent (see also [1, pp. 37-40]).

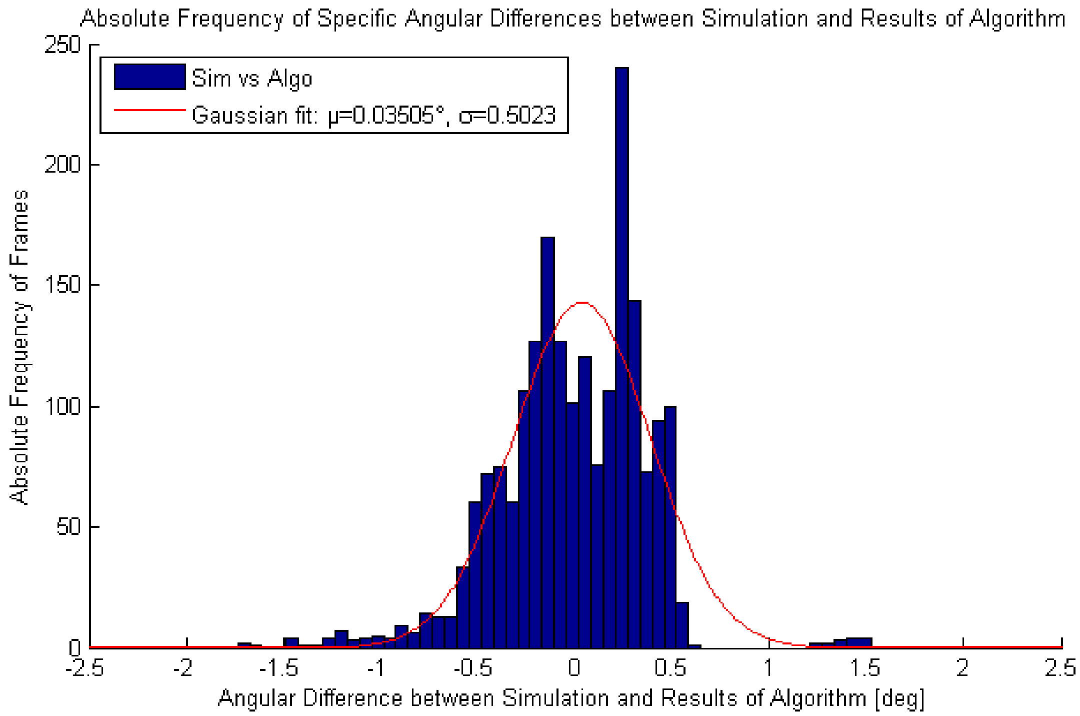


Figure 7-3: histogram of angular difference for simulation; outliers due to dynamic threshold filter; [1, p. 39]

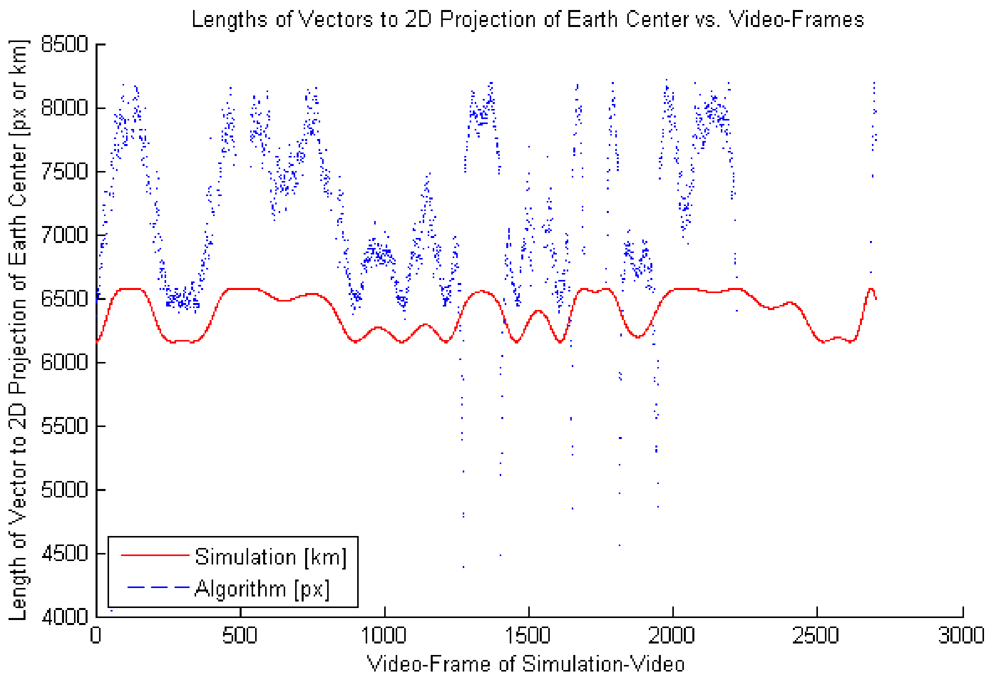


Figure 7-4: comparison of vector-lengths between algorithm results & simulation; [1, p. 39]

The evaluation of the calculation times the algorithm consumed to process an image showed that the algorithm exactly worked as supposed and skipped the bad raw data directly after really fast (50ms–70ms, equivalent to 14fps–17fps, see Figure 7-5) preprocessing. Those rates are of course not representative for the average calculation time as most images were prematurely skipped. Nevertheless, they are clearly contrary to the total number of processed image frames during flight (Master: 1719 = 2.9fps; Slave 1656 = 2.0fps). Regarding the IDs of the processed frames unveiled, that obviously the algorithm only processed every 4th or 5th recorded image frame. This was probably caused by the accumulation of functionalities in the OBDH-software for the core systems and the usage of Linux (cf. 7.3.1). Thus, the operating system probably suspended the algorithm very often and very long (sometimes even during the procession of one frame, causing the outliers in the calculation times) and therefore leading to overall frame rate which was only about 10% of the required one (see also [1, pp. 36-37]).

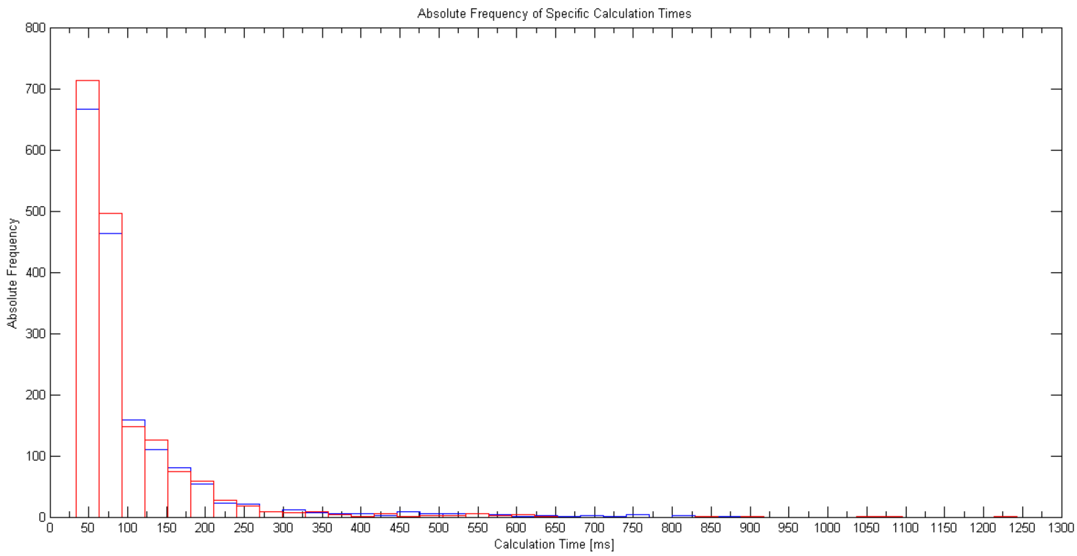


Figure 7-5: histogram of calculation times; red - Master; blue - Slave; [1, p. 37]

The massive overhead to be executed on the core systems is also the reason why no correlation between the algorithmic workload and the power consumption could be shown (cf. Figure 7-6). Furthermore, one can answer the question, if a later operational sensor system would be also applicable for satellites regarding the power consumption (cf. 1.3, 2nd primary objective), only indirectly: The actually consumed power (cf. 7.3.1 & Figure 7-1) clearly exceeds a satellite's power budget. But HORACE was firstly not optimized regarding power consumption and secondly the functional overhead of course further increased it. Taking those factors into account, the actual power consumption is not too high and the chances are good that a later operational system would also be applicable for satellites (see also [1, p. 28]).

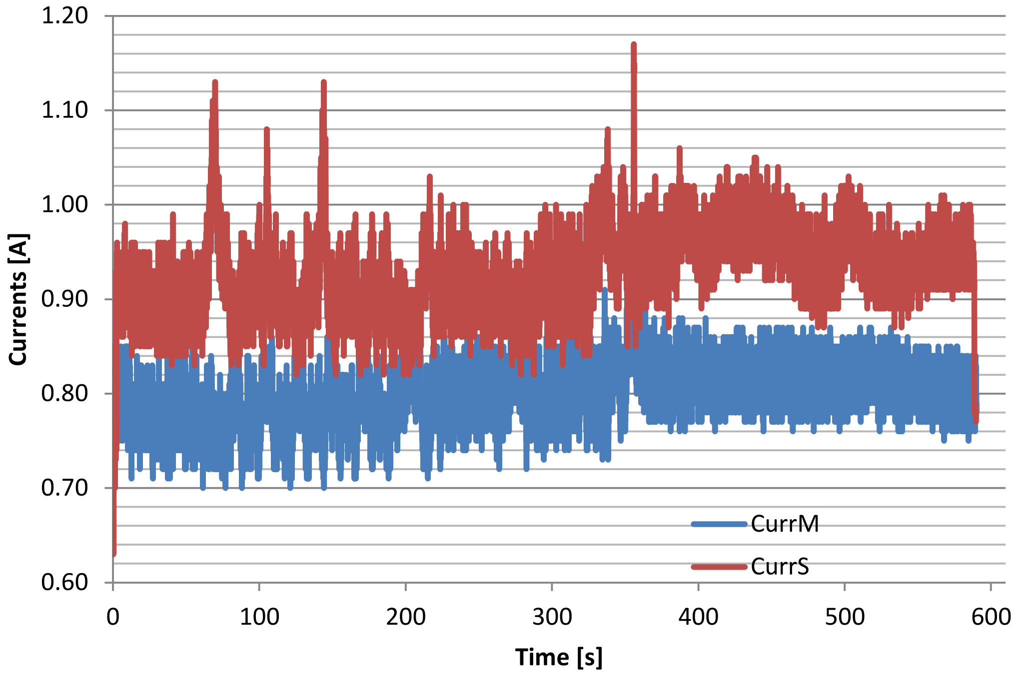


Figure 7-6: power consumption core systems; CurrM - Master, CurrS - Slave; [1, p. 28]

7.3.3 Overall Evaluation

“With the given scientific data gathered during flight, which is deficient due to the overexposure of the cameras of both systems (cf. 7.4.1.4), it is neither possible to ‘prove [n]or disprove the general technical feasibility’ (cf. 1.2) of horizon acquisition with ordinary cameras and powerful image processing algorithms for attitude determination. However, the simulation showed that the algorithm itself with an accuracy of ±0.6° (cf. 7.3.2) is likely to be sufficient for attitude determination (cf. 1.3 – 1st primary objective) – especially in emergency cases during which also only roughly determined attitude information would be better than none – although that could not be proven under ‘realistic, space-like conditions’ (cf. 1.2).

The actually achieved time resolution of approximately 2fps of processed image-frames (cf. 7.3.2) is much lower than required and is not considered to be ‘reasonable’ (cf. 1.3 – 2nd primary objective). But the further evaluation showed that this was mainly due to the massive overhead to be executed by the core systems. So, the time resolution of particularly the algorithm was much higher (about 20fps, cf. 7.3.2) and was close to the required value. Therefore, the time resolution is considered to be ‘reasonable’ in terms of the Experiment Objective despite of the low actual value. The same applies to the overall power-con¬sump-tion: Of course, the power consumption of both the core systems and the total Flight Segment (cf. 7.3.2 with Figure 7-6 & 7.3.1 with Figure 7-1) exceed a satellite’s power budget (especially in emergency cases). But regarding again the functional overhead, which also increased the power-consumption, and furthermore the fact that the experiment was not optimized towards low-power-consumption, the achieved performance seems to be ‘reasonable’ in terms of the Experiment Objective.

Regarding the secondary objectives (cf. 1.3) as systematical limits, the camera and the threshold filter could be identified. Both the quality of the provided images and the parameters of the threshold filter severely affect the quality of the results (cf. 7.3.2). Whereas for the camera simply a better component could be selected if necessary (respectively the issue fixed), the parameters for the threshold filter must either be carefully experimentally determined or dynamically set by a higher autonomous logical unit. The applicability of a future complete sensor system for small satellites can be answered only indirectly, as HORACE was not optimized towards that. Several other projects (like STELLA, [3]) have proven that image processing applications can be run on hardware which is applicable for small satellites. As during the development of HORACE no severe increase of complexity of the image processing software compared to the existing applications was experienced, it can be expected that a full sensor system would also be applicable for small satellites in the future.

Due to the deficient scientific data gathered during flight and the design itself, as pointed out, several of the questions posed in the Mission Statement and Experiment Objectives could only be partially or indirectly answered. That of course decreases also the overall mission success.

On the other hand, the experiment development, which explicitly is defined as ‘part of the mission’ (cf. 1.3), has been nearly perfectly successful. During the project lifecycle all challenging milestones were excellently and always in time reached. The overall design and implementation of the experiment in general was profound (cf. 7.3.1), meeting most requirements and leaving only few issues open, which despite of their severe impact on the experiment performance are from the technical point of view only minor issues. Thus, the experiment could be delivered in time to EuroLaunch and it was successfully launched and fully operational throughout the whole flight (cf. 7.2 & 7.3.1).

Regarding all those factors, all remaining issues but also all achievements, which were obtained, the whole mission ‘HORACE on REXUS 16’ is considered to be an 80% partial success.” [1, pp. 47-48]

7.4 Lessons Learned

7.4.1 Faced Technical Issues

In this section the technical issues, which were experienced during the campaign – some for the very first time in the context of REXUS – and already mentioned shortly in 7.2, are described more detailed and the findings of the analysis performed in the scope of [1] are summarized, to provide guidance both for future student experimentalists and EuroLaunch. **The latter is explicitly encouraged to adapt parts of this subchapter for updates of the REXUS User Manual** [4] **where applicable**. For the full analysis, discussion and all outlined solutions refer to [1].

7.4.1.1 Corruption of File-System of the Measurement Unit

Obviously during the troubleshooting for 7.4.1.3 during which several power cycles of the experiments were performed without the team's supervision the file system (FAT32) of the MU's microSD-card was corrupted. Hence, the MU could neither read nor write files of the microSD-card. The corruption of the file system on the used Arduino platform is a known issue when the SD-card is removed (respectively the power cut off) when the program has file handles open. This was presumably either the case if the power was cut off during the self-check procedures (cf. 4.8.1.1) or when the MU was in flight-mode (cf. 4.8.1.2) and was not taken into account by EuroLaunch staff performing the troubleshooting without the team's supervision of HORACE.

While the replacement of the microSD-card with a spare part (respectively reformatting the original one with EGSE-laptops) solved the issue – and is also after further investigation still considered to be the easiest, fastest and safest solution – it could have been prevented in the first place if the experiment had been monitored (and commanded) by the team during the troubleshooting procedures. Therefore, it is strongly recommended to do so, especially in such late stages shortly before the launch opportunity and with fully mounted payload, although the procedures for the troubleshooting would consume more time and manpower. (see also [1, pp. 14-16])

7.4.1.2 Shifted Electrical Ground

Although the experiment was designed according to the grounding concept of REXUS (cf. [4, p. 52]), the core systems caused a shift of the electrical ground of the Flight Segment. Grounding the structure to the "startpoint" presumably caused then stray currents which led to random software crashes of the core systems. This issue was experienced only very late (during ITW), and the grounding unveiled as the crucial factor even later as during testing the Flight Segment was not properly grounded. The exact source of the offset potential is still not found and the effects leading to software crashes not fully understood, with a proper test setup it would have been unveiled much earlier and it would have been possible to face the issue properly (e.g. by insulating and separately grounding the core system). Therefore, it is recommended that experimentalists test their experiment always grounded via the structure and EuroLaunch staff shall ensure that also for "official" tests – especially bench tests and interference tests during IPR, EAR, ITW and Bench Test Week when equipment like RXSM-Simulator or RXSM is used the student teams are not familiar with. (see also [1, pp. 16-18])

7.4.1.3 Interference with the GPS-System of RXSM

As only unveiled during the Hot Flight Simulation, HORACE severely jammed the GPS signal which was received by RXSM. The direct measures – ferrite cores around cables – had no effect thus REXUS 16 flew without GPS information between T-600s and T+600s (cf. 7.2.1.). Post-flight investigation showed that the SATA-II connection between the core systems and the SSDs was the culprit. None of the involved components could be identified as the source of the interference with certainty but complete shielding of all components canceled the interference. (see also [1, pp. 19-20])

The actions which were performed to identify the problem were very basic and could have been performed during the campaign if there had been enough time. This was not the case, as the exact setup – with the GPS antenna mounted inside the mounted nosecone and the cable harness fed through the experiments – was tested for the very first time during the Hot Flight Simulation. On the other hand, the measures which had to be taken to face the problem (complete shielding) only hardly would have been possible during campaign even further localization of the issue during campaign would have been too late.

Thus it is strongly recommended to test the complete setup (including GPS and the mounting of the nosecone) latest during the Bench Test Week.

Furthermore, experimentalists who plan to use the SATA-II interface within their experiment should be aware of possible interferences and should be reminded of that either directly during reviews by EuroLaunch staff or by the manual already at a very early stage of the design (latest PDR).

7.4.1.4 Overexposure of the Payload-Cameras

The overexposure of the payload cameras was the issue which affected the scientific performance most. The multi-layered problem was difficult to identify and was not foreseen by the team for various reasons (insufficient testing, bad documentation of camera utility software and interfaces, buggy camera utility software, no possibility to check image quality on launch pad), whereas the most appropriate solution is quite simple (setting the auto-exposure-function by the flight software).

As general advice future experimentalists using cameras should not only test their experiment regarding image quality thoroughly always on system level (even if the cameras were sufficiently tested on components level) and implement an easy possibility (e.g. by downlinking single snap-shots during countdown) to check the image quality also at late stages of the flight preparations. (see also [1, pp. 20-25])

7.4.2 General Lessons Learned

This section gives the results (sorted by different aspects of the whole project) of a brainstorming session and team-discussion about experiences drawn from the HORACE project by the team.

7.4.2.1 Experiment Requirements & Design

- As there are numerous dependencies regarding all factors of the project, important design decisions shall be made profoundly but as early as possible. Furthermore, it is important to stick to those decisions.
- The overall complexity of the HORACE-project, regarding objectives, requirements and design, turned out to be reasonable within the scope

of the REXUS-programme and the given team-structure (relatively small team of only undergraduate students).
- The final design is not necessarily the last design.
- Printouts of the CAD-design do help imagining the dimensions of the experiment and its components.

7.4.2.2 Mechanical

- Your components should be firmly fixated but not to the disadvantage of access or time for (dis-) assembling.
- A modularized structure can be beneficial, if components happen to be damaged in tests.

7.4.2.3 Electrical & Mechanical

- There shall be at least two team members who are at least somehow experienced in mechanical and electrical engineering (both regarding design and manufacturing).
- First design the PCBs and then design the mechanics. Don't underestimate the room for your components!
- Design electronics and mechanics so yourself or an already known distributor can manufacture them easily.
- Socialise early with distributors and manufactures and have alternatives ready.

7.4.2.4 Electrical

- Using existing platforms for data-handling (µITX embedded PC for CS, Arduino for MU) saves a lot of development and fabrication time for the electrical engineering.
- Test your off-the-shelf components concerning correct grounding and interference with other systems, like GPS.

7.4.2.5 Software

- No matter how matured the experiment's design is, start coding as soon as possible. During implementation occur several problems will occur that may lead to delays later. Additionally, the earlier implementation is done, the earlier it is possible to test the code which is very important.
- Software development on different operating systems was imagined to be tough, but turned out to be uncritical since in the end it was compiled on UNIX-systems. Also the work of different developers was easily combined via SVN-repository.
- When developing C++ remember: using the key word "new" means you have to use the keyword "delete" somewhere and never ever write "return new …".
- When coding in a group, make the code easy to read and understandable by following common coding directives and using comments.

- Segmentation faults are annoying.
- If there’s a function which blocks the whole program, try firstly to find a “NON_BLOCK” setting for this function, as it might save a day or two of work. Also because that function might be showing blocking behavior on one system, doesn’t necessarily mean it blocks on other systems.
- Linux has its advantages but there were also some problems, due to choosing it. On the one hand it was really easy to develop algorithms, flight-software and ground station software. On the other hand it was necessary to deal with problems concerning the whole OS. Developing on an embedded board makes software more deterministic and straightforward than dealing with all needs of a “real” OS.
- Using a communication framework made it easy to design the TM/TC model. Once implemented, it was possible to easily import it for the CS, ground station and also with little adaptions on the MU. Choosing the object orientated programming language C++ supported this way of programming.

7.4.2.6 Verification & Testing

- A last end-to-end test during campaign is necessary to check all subsystems, although all subsystems are tested and an end-to-end test was performed at home.
- Don't overrate the vacuum specific tests - they are only important due to the fact that you don't have thermal convection (no need for material tests!)
- Don’t “over-test” items in vacuum/thermal tests, if an item is working under specified conditions you don’t have to test it again. Consider this in the test-plan development!
- Do (more) software testing! Or (in case you have really good requirements) consider test-driven software development.
- Start testing or at least test plan development as soon as possible, since testing may have impact on your design!
- Think about verification (or verification possibilities for each requirement) already during designing the requirements.
- Try to avoid excessive “critical” testing (e.g. vacuum, thermal or vibration) after CDR. Replacing and fixing broken components is a time-consuming task.
- Test what you fly, fly what you test.
- Document your tests. If something is broken afterwards, you really want to know exactly what you did during the test.
- Stick to your test procedures.
- Make a brainstorming what could go wrong concerning all systems and how you could test, identify and possible avoid problems. For this you don't have problems one day before launch because e.g. your experiment won’t interfere with the GPS-Antenna
- Test the experiment and the setup outside. In the sun. Before launch.

7.4.2.7 Workshops, Events (STW, Reviews, ITW, Bench Test, Campaign)

- Prepare your presentations for reviews well in advance. This reduces nervousness and improves the quality of your presentation in general.
- Try to make it possible that all team members can attend the reviews and campaign, if your team is relatively small, and preferably four for the official tests (ITW and Bench Test). Thus, all expertise is directly available during the reviews and campaign and during the official tests the workload can be divided to reasonable amounts even if unexpected problems occur.
- Unforeseen problems which occur late or seem to be a big issue tend to draw all attention only to their solution and away from other important tasks and consume a lot of time. In case of HORACE, as a result, no proper end-to-end tests, including the inspection of recorded data, were conducted during campaign, which lead to the fatal overexposure of the payload cameras. Therefore, one shall define those important tasks much in advance (before the actual detailed campaign preparation) and make sure that they are actually scheduled and conducted while enough time is reserved for unexpected problems as well.

7.4.2.8 Project Management

- A small and stable team-structure (less than 10 team-members, everyone available during the whole life-cycle) enormously simplifies the project management regarding all aspects.
- The usage of advanced tools for the overall scheduling (Gantt-Charts, WBS, etc.) may be reduced for smaller teams, if (and only if!) not only the project manager but also the whole team is continuously aware of the status of all subsystems, tasks and the next milestones/deadlines (e.g. thanks to intense weekly meetings & efficient communication even in between).
- It is worth a lot to freely work on the project and making own decisions while only hardly being restricted or influenced by the supervisors from your university. On the other hand, dedicated supervisors, who are actually willing to invest much of their resources and do not only give some advice, are required to perfectly support the team. Finding the best balance between those concurrent factors might be challenging for the supervisors.
- Conducting good outreach is time-consuming and needs to be well coordinated. Therefore, assign the main parts of it on one team member. Nevertheless, this team member shall be involved in the experiment design, but try not to overload him/her with too many other tasks. To reduce the workload for this team member, sub-tasks (like writing blog-posts) may also be distributed among others, whereas the overall coordination shall be centralized at this one team member.
- It shall be clarified early and in detail which infrastructure is available at your university (and which conditions apply), as well as the needed

infrastructure shall be defined early and in detail. Thus, discrepancies can be solved early before they cause delays.
- Team-forming events like parties and other private events help to improve the atmosphere within the team and thus increase the teamwork.
- Even though it seems at first glance, that writing protocols are annoying and no one ever seems to be looking into them, they are important, and enough people need them and look at them afterwards.
- Establish a crowdfunding when participate in REXUS/BEXUS programme to generate enough money (not only for parts and tools but also for travelling, flights, overnight stays etc.).
- Use task management software for team collaboration. It’s handy for assigning specific tasks to team members and for getting an overview about the current project status and/or deadlines. And you get annoying „reminder“-emails every morning.

7.4.2.9 Miscellaneous

- Do not overrate the experts’ feedback during reviews. Of course, thanks to their experience, they provide valuable advice. But on the other hand, they only know a glimpse about your experiment, thus some of the advice may not perfectly fit and blindly following (especially during early stages) it might later turn out to be crucial.
- Both the distribution of knowledge and experience within the HORACE-team, especially regarding mechanical and electrical engineering, and the availability of supervisors from JMUW for those fields were suboptimal. This was mainly due to the fact that the team was hardly properly “interdisciplinary” and neither more experienced team members could be recruited nor more interdisciplinary supervision provided because of the lack of engineering faculties and staff at JMUW.
- Although at least smaller projects of the German share are relatively well funded by the REXUS-programme (both for components & travel expenses), one shall seek for additional funding/sponsors continuously from the beginning on. As it is easier to find sponsors for specific devices/components among the manufacturers/suppliers than to raise actually money, this is important especially regarding travel and miscellaneous expenses.
- Also the experts from all participating institutions put their trousers on one leg at a time and despite of their advance of experience sometimes have to fight the very same problems and face murphy’s law like the student-teams.
- Procedures are annoying when they have to be created but have a huge value when it comes to the situation that you need them. Not only have you already made up your mind about the situation but also is it very helpful for the experts to understand what you are going to do.
- Keep in mind, that outreach can be very time consuming.

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] T. Rapp, Development and Post-Flight Analysis of HORACE the Horizon Acquisition Experiment, Würzburg, 2014.

[2] J. Barf, Development and Implementation of an Horizon Sensing Algorithm Based on Image Processing Technologies, Würzburg, 2014.

[3] O. Balagurin, H. Wojtkowiak and H. Kayal, "STELLA - A New Small Star Tracker for Pico and Nano Satellites," in *8th IAA Symposium On Small Satellites for Earth Observation, IAA-B8-1201*, Berlin, 2011.

[4] S. Mawn, U. Kaczmarczik and A. Schmidt, "REXUS User Manual," 08 01 2014. [Online]. Available: http://www.rexusbexus.net/images/rx_usermanual_v7-11_08jan14.pdf. [Accessed 22 07 2014].

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.

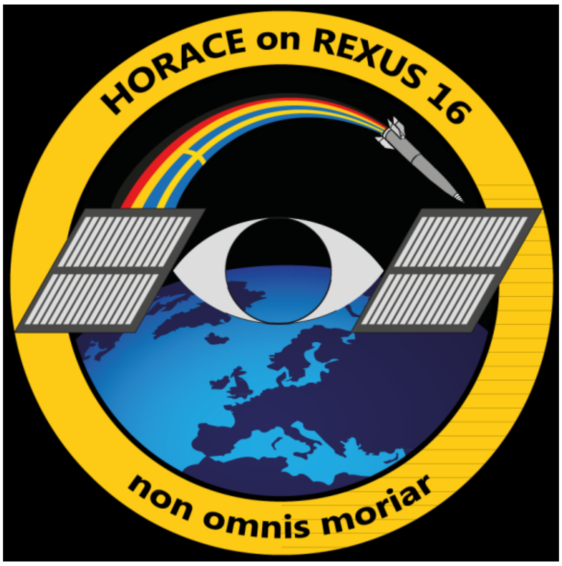
APPENDIX B – OUTREACH AND MEDIA COVERAGE

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
12	http://www.presse.uni-wuerzburg.de/einblick/single/artikel/lift-off-a/
13	http://www.charivari.fm/index.php?id=lokalnachrichten_news_wuerzburg&singleID=37396
14	http://www.wuerzburgerleben.de/2014/05/23/studentisches-experiment-tritt-reise-den-weltraum/
15	http://www.radiogong.com/news/regionalnews-aus-mainfranken.html?content=esrange-space-center-sensor&singleID=37504
16	http://www.spaceboard.eu/news2/spaceboard/2014/05/horace-on-spaceboard/

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 posters, which support our presentations, e.g. on information stands, and is hung up at the floors of the Chair of Aerospace Information Technology. They can be found on a separate zip-file on the Teamsite.

Ref. #	**Name**
1	RX16_HORACE_SED_v5.0_APPENDIX_B_Poster_A1_english.pdf
2	RX16_HORACE_SED_v5.0_APPENDIX_B_Poster_A1_german.pdf

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
Oct. 13	Presentation at “Schnupperwoche” (info day for school-leavers)

	at University of Würzburg
29.11.13	Presentation in the context of English course “English for the Natural Sciences” (students of all fields of science attending) at University of Würzburg
24.01.14	Presentation for staff of the Chair of Aerospace Information Technology in an advanced graduate seminar
17. 06.14	Presentation for second semester undergraduate students, covering the whole development process of our project. The purpose was to encourage them to take part in REXUS/BEXUS or similar projects.

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:

C.1 Basic Project Management

Index	Filename	Description
1	RX16_HORACE_SED_v5.0_APPENDIX_C1_1_full_WBS_02Sep14.pdf	Full WBS (interactive PDF)
2	RX16_HORACE_SED_v5.0_APPENDIX_C1_2_schedule_02Sep14.mpp	Complete Schedule (MS Project 2010)
3	RX16_HORACE_SED_v5.0_APPENDIX_C1_3_Verification_Objectives_24Jan14	Verification Objectives

C.2 Procedures

Index	Filename	Description
G#01	RX16_HORACE_PRO_G_01_writing_procedures_v1-0_23Jan14.docx	How to write good procedures
G#02	RX16_HORACE_PRO_G_02_using_procedures_v1-0_23Jan14.docx	How to use procedures
CD#01	RX16_HORACE_PRO_CD_01_Cheatsheet_v1.0_14Mar14.xlsx	"Cheat-Sheet" with all TC-words/TM-returns, their byte-codes, textual representation and description
CD#04	RX16_HORACE_PRO_CD_04_Tminus4h_v1-0_15May14.docx	Hot CD T-4h to T-600s
CD#05	RX16_HORACE_PRO_CD_05_Tminus600_v1-1_18Feb14.docx	T-600s to T+600s
CD#06	RX16_HORACE_PRO_CD_06_postflight_v1-0_15May14.docx	Postflight Actions
M#01	RX16_HORACE_PRO_M_01_focus_camera_v1-0_13Mar14.docx	Focus camera
M#02	RX16_HORACE_PRO_M_02_demount_bulkhead_v1-0_10May14.docx	Demount bulkhead
M#03	RX16_HORACE_PRO_M_03_mount_bulkhead_v1-0_10May14.docx	Mount bulkhead

M#04	RX16_HORACE_PRO_M_04_replace_coresystem_v1-0_10May14.docx	Replace core system
M#05	RX16_HORACE_PRO_M_05_replace_camera_v1-0_10May14.docx	Replace camera
M#06	RX16_HORACE_PRO_M_06_replace_ssd_v1-0_10May14.docx	Replace SSD
M#07	RX16_HORACE_PRO_M_07_replace_pdu_v1-0_10May14.docx	Replace PDU
M#08	RX16_HORACE_PRO_M_08_replace_mu_v1-0_13May14.docx	Replace MU
M#09	RX16_HORACE_PRO_M_09_replace_window_v1-0_10May14.docx	Replace window
M#10	RX16_HORACE_PRO_M_10_mu_storage_access_v1-0_13May14.docx	MU storage access
S#01	RX16_HORACE_PRO_S_01_update_CS_Software_1-0_12Mar14.docx	Update CS Software
S#02	RX16_HORACE_PRO_S_02_get_specific_SVN_CS_v0.1-0_18Feb14.docx	Get specific SVN revision of CS software
S#03	RX16_HORACE_PRO_S_03_commit_svn_revision_CS_v0.1-0_10Feb14.docx	Commit SVN Revision CS
S#04	RX16_HORACE_PRO_S_04_reload_OS_image_v1-0_5Mai14.docx	Reload CS-OS Image
S#10	RX16_HORACE_PRO_S_10_backup_SSD_data_v1-0_12Mar14.docx	Backup data from SSD
S#20	RX16_HORACE_PRO_S_20_flash_MU_v1-1_18Feb14.docx	Flash MU
S#21	RX16_HORACE_PRO_S_21_MU_get_specific_svn_revision_v1-0_09Feb14.docx	Get specific SVN revision of MU software
S#22	RX16_HORACE_PRO_S_22_debug_MU_v1-1_18Feb14.docx	MU debug
S#23	RX16_HORACE_PRO_S_23_dump_MU_v1-0_18Feb14.docx	MU dump
S#24	RX16_HORACE_PRO_S_24_MU_commit_svn_v1-0_09Feb14.docx	MU Commit to SVN
S#25	RX16_HORACE_PRO_S_25_MU_change_temp_sensor_software_v1-0_14Apr14.docx	Change temp sensor in MU Software

S#30	RX16_HORACE_PRO_S_30_backup_MU_flight_data_v1-0_02May14.docx	backup measurement flight data
S#40	RX16_HORACE_PRO_S_40_start_and_use_groundstation_v1-1_18Feb14.docx	Start & Use Groundstation Software
S#41	RX16_HORACE_PRO_S_41_change_GS_settings_v1-0_04Feb14.docx	Change Groundstation Settings
S#45	RX16_HORACE_PRO_S_45_backup_groundstation_data.docx	Backup Groundstation Data
S#50	RX16_HORACE_PRO_S_50_boot_and_use_EGSE_in_Linux_v1-0_09Feb14.docx	Boot Groudstation in Ubuntu
S#55	RX16_HORACE_PRO_S_55_saving_settings_to_camera_v1-0_13Mar14.docx	saving camera settings

C.3 Analysis, Inspection and Review-of-Design Report

Index	Filename	Description
1	RX16_HORACE_AR_v1.3_25Jan14.zip	Analysis Report
2	RX16_HORACE_RoDR_v1.2_07Aug14.pdf	Review-of-Design Report
3	RX16_HORACE_IR_v1.2_25Jan14.zip	Inspection Report
4	RX16_HORACE_Test-Reports.zip	See 5.3

C.4 Schedules & Packing Lists for Integration Week, Bench Test Week and Launch Campaign

Index	Filename	Description
1	RX16_HORACE_BEN_packing-list_13Mar14.docx	Packing List To/From Bench Test at DLR MORABA
2	RX16_HORACE_BEN_schedule_14Mar14.xlsx	Schedule (specific tasks allocated to attending team members) for Bench Test at DLR MORABA
3	RX16_HORACE_CAM_packing-list_12May14.docx	Packing List To/From Campaign at Esrange Space Center
4	RX16_HORACE_CAM_schedule_15May14.xlsx	Schedule (specific tasks allocated to attending team members) for Campaign at Esrange Space Center

5	RX16_HORACE_INT_packing-list_05Feb14.docx	Packing List To/From ITW at ZARM Bremen
6	RX16_HORACE_INT_schedule_07Feb14.xlsx	Schedule (specific tasks allocated to attending team members) for ITW at ZARM Bremen

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_v5.0_APPENDIX_D_DS_1_camera.pdf	Camera technical manual
2	RX16_HORACE_SED_v5.0_APPENDIX_D_DS_2_embedded_board.pdf	Embedded Board MIO-2260
3	RX16_HORACE_SED_v5.0_APPENDIX_D_DS_3_DCDC-regulator.pdf	LM2596 DC/DC regulator
4	RX16_HORACE_SED_v5.0_APPENDIX_D_DS_4_SSD.pdf	SSD datasheet
5	RX16_HORACE_SED_v5.0_APPENDIX_D_DS_5_Arduino_Leonardo.pdf	Arduino Leonardo Datasheet
6	RX16_HORACE_SED_v5.0_APPENDIX_D_DS_6_Temperature_Sensor.pdf	Temperature Sensor
7	RX16_HORACE_SED_v5.0_APPENDIX_D_DS_7_Current_Sensor.pdf	Current Sensor
8	RX16_HORACE_SED_v5.0_APPENDIX_D_DS_8_CF_Card.pdf	CF Card
9	RX16_HORACE_SED_v5.0_APPENDIX_D_DS_9_MAX488.pdf	MAX488 Transceiver
10	RX16_HORACE_SED_v5.0_APPENDIX_D_DS_10_RS232_TTL_Module.pdf	RS232 TTL Module
11	RX16_HORACE_SED_v5.0_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_v5.0_APPENDIX_E_DRAW_1_3D-View-Full.png	HORACE with REXUS module, 3D-View
2	RX16_HORACE_SED_v5.0_APPENDIX_E_DRAW_2_3D-View.png	HORACE without REXUS module, 3D-View
3	RX16_HORACE_SED_v5.0_APPENDIX_E_DRAW_3_Front-View-Full.png	HORACE with REXUS module, front view
4	RX16_HORACE_SED_v5.0_APPENDIX_E_DRAW_4_HORACE-Top.png	HORACE, view from above
5	RX16_HORACE_SED_v5.0_APPENDIX_E_DRAW_5_HORACE-bottom.png	HORACE, bottom view
6	RX16_HORACE_SED_v5.0_APPENDIX_E_DRAW_6_HORACE-Side.png	HORACE, side view
7	RX16_HORACE_SED_v5.0_APPENDIX_E_DRAW_7_HORACE-Front.png	HORACE, front view
8	RX16_HORACE_SED_v5.0_APPENDIX_E_DRAW_8_CoreSystem-closed.png	Core-System-Box, closed, 3D-View
9	RX16_HORACE_SED_v5.0_APPENDIX_E_DRAW_9_CoreSystem-open.png	Core-System-Box, open, 3D-View
10	RX16_HORACE_SED_v5.0_APPENDIX_E_DRAW_10_MeasurementUnit-closed.png	Measurement-Unit-Box, closed, 3D-View
11	RX16_HORACE_SED_v5.0_APPENDIX_E_DRAW_11_MeasurementUnit-open.png	Measurement-Unit-Box, open, 3D-View
12	RX16_HORACE_SED_v5.0_APPENDIX_E_DRAW_12_complete_CAD.dwg	HORACE complete CAD File

E.2 Reports

Index	Report-Filename	Description
1	RX16_HORACE_SED_v5.0_APPENDIX_E_REP_1_Mech-Load-Test.pdf	Mechanical Load Test

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_v5.0_APPENDIX_F_PCB_1_PDUCarrierTop.pdf	PDU Carrier Board Layout – Top Layer
2	RX16_HORACE_SED_v5.0_APPENDIX_F_PCB_2_PDUCarrierBottom.pdf	PDU Carrier Board Layout – Bottom Layer

F.2 Electronic Schematics

Index	Schematics-Filename	Description
1	RX16_HORACE_SED_v5.0_APPENDIX_F_SCH_1_DCDC-Converter.pdf	DC/DC Converter Module
2	RX16_HORACE_SED_v5.0_APPENDIX_F_SCH_2_PDU-Carrier.pdf	PDU carrier board
3	RX16_HORACE_SED_v5.0_APPENDIX_F_SCH_3_Arduino.pdf	Arduino Leonardo
4	RX16_HORACE_SED_v5.0_APPENDIX_F_SCH_4_microSD-Module.pdf	microSD module for Arduino
5	RX16_HORACE_SED_v5.0_APPENDIX_F_SCH_5_RS232-TTL-Converter.pdf	RS232 -> TTL converter