SED

Student Experiment Documentation

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Mission: REXUS 10

Team Name: EXPLORE

Experiment Title: EXPeriment for Liquid On-orbit REfueling

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1	2010-01-21	All Chapters	PDR
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2.1	2010-07-16	1.4.2: Stoerk & Nathanson university/study info updated 2.1, 2.2, 2.3, 2.4: Requirements amended and updated 3.1, 3.2: WBS & schedule update 3.3.2: updated budget 3.3.3: added BMWi & ITLR 4.2.1: updated structure design 4.2.2: deleted 24V 4.4: updated mech. design & mass budget 4.5, 4.7, 4.8: updated electrical system and software 4.9: updated ground support 5.1: verification matrix adapted to chapter 2 5.2: added date/status for tests 6.1.3: added temperature constraint for EXPLORE launch 6.2, 6.3, 6.4 & 7.1, 7.2, 7.3, 7.4, 7.5: re-added headings Appendix (A, B, C, D, E, F, G, H)	Post-CDR Update
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Abstract:

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CONTENTS

ABSTRACT

Space exploration missions, in particular human and large cargo flights, will require considerable transportation efforts to future destinations such as Moon and Mars. One option to achieve this payload and crew capabilities is through the refuelling of orbital transportation stages. EXPLORE aims at informing the investigation of technologies and processes for these orbital refuelling activities through a microgravity experiment.

While storable propellants are already transferred in orbit (e.g. at ISS), the handling of more efficient cryogenic propellants pose specific challenges. A fuel tank is typically pressurized by a gas which then remains in the tank after depletion. Refuelling activities then have to ensure best filling of the tank without mixture of the liquid and gaseous phases, while keeping the imposed pressure to avoid propellant boil off. This refuelling process shall be reproduced in the EXPLORE experiment to investigate the influence of the filling flow velocity on the propellant flow and final fill level.

EXPLORE uses six transparent test chambers with connected gas reservoirs that will be filled from two central liquid reservoirs. The fuel transfer process is observed visually by a camera and through the recording of pressure and temperature data. The flow velocity profile will be varied for each chamber to identify optimal conditions for maximum chamber filling.

EXPLORE has been initiated and is implemented throughout the year 2010 by six students of aerospace engineering from the University of Stuttgart, Germany, and one student of electronic and computer engineering from the Offenburg University of Applied Sciences, Germany.

The EXPLORE Team is (left to right): Robert Schelling, Emil Nathanson, Daniel Stoerk, Johannes Weppler, Andreas Fink, Christine Hill, Juergen Schlutz.

1 INTRODUCTION

1.1 Scientific/Technical Background

Space exploration missions, in particular human and large cargo flights, will require considerable transportation efforts to future destinations such as Moon and Mars. One option to achieve these payload and crew capabilities is refuelling on orbit. EXPLORE aims at informing the investigation of technologies and processes for these orbital refuelling activities through a microgravity experiment. While storable propellants are already transferred in orbit (e.g. at ISS), the handling of more efficient cryogenic propellants pose specific challenges. A fuel tank is typically pressurized by a gas, which remains in the tank after the fuel is depleted. Refuelling activities have to ensure best filling of the tank without mixture of the liquid and gaseous phase, while keeping the imposed pressure to avoid propellant boil off.

This refuelling process shall be reproduced in the EXPLORE experiment to investigate the influence of the filling flow rate on the propellant flow and final fill level.

EXPLORE is based on the Fluid Acquisition and Resupply Experiment (FARE) which was flown by NASA in 1992 and 1993.

1.2 Experiment Objectives

- Investigation of the influence of the flow rate on filling process and final fill level.
- Demonstrating liquid fluid transfer between volumes while minimizing mixture of liquid and gas phases without a separating membrane.
- Achieving fill level in test chamber of >90% (TBC).

There are several parameters, which influence the fluid tank filling process, e.g. the tank geometry, the liquid surface tension or the filling flow rate. EXPLORE will use small models of state-of-the-art propellant tanks which will have the same diameter to length ratio. Using six identical test chambers the influence of the flow rate on filling process and final fill level will be investigated.

In order to minimize movable fuel tank hardware there will be no membranes or pistons, which could easily separate fuel and gaseous phases inside the test chambers. Using acrylic test chambers and a video camera EXPLORE will demonstrate that phase-separation during micro-gravity tank filling is difficult but possible.

According to NASA's FARE program which achieved final filling level up to 99% using spherical test chambers EXPLORE aims to reach fill level of >90%.

1.3 Experiment Overview

The key elements of EXPLORE are the video camera and the six test chambers which are made of acrylic glass so that the filling process can be observed and recorded by the camera. A pressurized gas tank provides the experiment with the needed pressure. During each of the three filling procedures the gas pressure pushes the test liquid out of the two liquid reservoirs into two test chambers. Each liquid reservoir is connected through one flow controller to three test chambers. The flow rate is managed by these flow controllers. Each test chamber is also connected to a collection chamber, which ingests the gas from the test chamber during the filling process. The initial gas from the collection chamber is vented through a pressure control valve to keep the counter pressure to a constant value.

All gas and liquid flows are controlled by flow controllers and magnetic valves, which are normally closed. During the experiment temperature and pressure are measured. The module is illuminated by several LEDs. All this is managed by a microcontroller, which also makes the electrical power, which is provided through the REXUS rocket, available for all components. The microcontroller is the only interface between EXPLORE and the rocket.

After the start of the experiment two test chambers are filled at a time. This is done three times until all test chambers are executed. The recorded data are sent to the ground by the telemetry system of the rocket or are stored on-board.

1.4 Team Details

1.4.1 Contact Point

Team contact will be the Project Manager Christine Hill. Contact information is as followed:

Address: EXPLORE Team - Christine Hill
IRS, Universität Stuttgart
Pfaffenwaldring 31
70569 Stuttgart
GERMANY

Telephone: +49 151 23068754

E-Mail: team@explore-rexus.de

1.4.2 Team Members

Christine Hill - Project Management

Christine is responsible for the overall management of the EXPLORE project. She's the main contact person and controls all documentation as well as the project time plan.

Christine is a student of aerospace engineering at the University of Stuttgart in her final year. She specializes in Space Systems and Space Applications.

Andreas Fink - Payload Management

As the payload manager, Andreas oversees the technical design of the EXPLORE experiment. He's also our CAD expert and responsible for all the nice 3D representations.

Andreas is a student of aerospace engineering at the University of Stuttgart in his final year. He specializes in Space Systems and Aircraft Design.

Emil Nathanson - Telemetry, Tracking and Command Management

Besides being the TT&C contact person, Emil is mainly responsible for the EXPLORE test campaign. He will manage the test procedures and facilities to make sure our experiment is ready for flight.

Emil is a student of aerospace engineering at the University of Stuttgart in his fourth year. He specializes in Space Systems and Space Applications.

Juergen Schlutz – PR, Outreach and Sponsorship Management

Juergen ensures that the world knows about our experiment as our PR and outreach contact. He searches sponsors, communicates with the press, manages the EXPLORE website, and initiates local and regional event participation.

Juergen is a PhD student of aerospace engineering at the University of Stuttgart. He specialized in Space Systems and Control Systems and currently works on human space exploration missions.

Johannes Weppler - Earth Ground Support Management

Johannes is the EXPLORE hardware manager. He coordinates the selection and manufacture of all hardware items during the project development as well as the required support equipment for the launch campaign.

Johannes is a student of aerospace engineering at the University of Stuttgart. He specializes in Space Systems and Aircraft Design.

Robert Schelling - Mechanical Design Management

Robert is our fluid dynamics expert and responsible for the theoretical foundations of the EXPLORE experiment. His calculations drive the mechanical design and the experiment process flow.

Robert is a student of aerospace engineering at the University of Stuttgart. He specializes in Fluid Dynamics and Aircraft Propulsion Systems.

Daniel Stoerk - Electrical Design Management

As the only non-aerospace member of the team, Daniel brings in his expertise in electronics and ensures power and control for the experiment at all times. His responsibilities include the power supply, microcontroller, cabling and software design.

Daniel has joined our team in March 2010. He studies electronic and computer engineering at the Offenburg University of Applied Sciences in his third year.

2 EXPERIMENT REQUIREMENTS

This chapter will handle the functional, performance, design and operational requirements, which need to be determined. The appropriate numbering X.Y.Z is as following:

X: E - Electrical

M - Mechanical

Y: F - Functional

P - Performance

D - Design

O - Operational

Z: Consecutive numbering

2.1 Functional Requirements

Table 2-1: EXPLORE Experiment Functional Requirements.

ID	*Description*	*Response to.*
E.F.1	The experiment shall monitor the pressure inside the gas tank during all activated phases.	
E.F.2	The experiment shall measure the temperature of the fluid during all activated phases.	
E.F.3	The electronics subsystem shall ensure operational power distribution to all experiment components. Only the camera is allowed an auxiliary power storage and supply if required.	
E.F.4	The electronics subsystem shall operate all electrical components in a timed sequence during flight.	
E.F.5	The electronics subsystem shall monitor the system status during all activated phases.	
E.F.6	The experiment shall capture video of all test chambers.	
M.F.1	The experiment shall use a single gas pressure tank.	
M.F.2	*Moved to M.P.17*	
M.F.3	*Moved to M.P.18*	

ID	*Description*	*Response to.*
M.F.4	*Moved to M.P.19*	
M.F.5	*Moved to M.P.20*	
M.F.6	The illumination and the camera shall be coordinated to get clear and bright videos.	
M.F.7	The experiment shall use an antifreeze fluid as propellant substitute in order to ensure liquid condition throughout experimental timeline.	*(new v2.1)*
M.F.8	The experiment shall use six test chambers.	*(new v2.1)*
M.F.9	The experiment shall fill all six test chambers consecutively, two at a time, within the microgravity period.	*(new v2.1)*
M.F.10	The experiment shall provide a safe pressurized system.	*(new v2.1)*
M.F.11	The experiment shall include adequate safety measures against fluid leakage.	*(new v2.1)*

2.2 Performance Requirements

Table 2-2: EXPLORE Experiment Performance Requirements.

ID	*Description*	*Response to.*
E.P.1	The gas tank pressure shall be measured between 0 and 10 bar.	E.F.1
E.P.2	The gas tank pressure shall be monitored with an accuracy of 0.1 bar (TBC).	E.F.1
E.P.3	The gas tank pressure shall be monitored at a rate of 2 Hz.	E.F.1
E.P.4	The temperature levels shall be measured between -30 and 60 degrees centigrade.	E.F.2
E.P.5	*deleted*	*E.F.2*
E.P.6	*deleted*	*E.F.2*
E.P.7	The temperature of the fluid shall be measured with an accuracy of 0.1 K (TBC).	E.F.2
E.P.8	The temperature of the fluid shall be measured at a	E.F.2

ID	Description	Response to.
	rate of 5 Hz or more (TBC).	
E.P.9	The experiment power budget shall not exceed 84 W (3A @ 28V, according to REXUS user manual).	E.F.3
E.P.10	The camera field of view shall be at least 10x10 cm^2 in a distance of 5 cm.	E.D.4
E.P.11	*Moved to E.D.5*	
E.P.12	*Moved to E.D.6*	
E.F.7	The fluid and gas valves shall remain normally closed.	
M.P.1	The gas tank shall allow gas pressures up to at least 10 bar (TBC).	M.D.1
M.P.2	The gas tank shall have a volume between 0.5 litres and 1.5 litres.	M.D.1
M.P.3	The pressure relief valve shall be able to hold the pressure of a 1 bar balance.	
M.P.4	The used anti-freezing fluid shall withstand a temperature between -30 and 50 degrees centigrade.	
M.P.5	*Moved to M.D.11*	
M.P.6	The flow control device shall be able to control the flow stageless in a range of 0 to 300 ml/min using an electrical signal from the microcontroller.	
M.P.7	The flow measuring device shall measure volume a flow rate of 0 to 300 ml/min.	
M.P.8	The fluid valves shall provide a flow rate of up to 300 ml/min.	
M.P.9	The fluid and gas valves shall withstand pressure of up to at least 10 bar.	
M.P.10	The pressure relief valve shall withstand pressures up to at least 10 bar.	
M.P.11	The test chamber shall withstand a pressure range of up to at least 10 bar.	
M.P.12	The flow control device shall have an accuracy of 10% or better.	

ID	Description	Response to.
M.P.13	The whole experiment setup shall withstand vibration conditions according to the REXUS manual.	M.D.13
M.P.14	The whole experiment setup shall withstand temperature conditions according to the REXUS manual.	M.D.14
M.P.15	The whole experiment setup shall withstand vacuum conditions according to the REXUS manual.	M.D.15
M.P.16	The fluid and gas valves shall work under vacuum conditions.	
M.P.17 (M.F.2)	The used anti-freezing fluid shall have a reduced viscosity and surface tension compared to water.	M.F.7
M.P.18 (M.F.3)	The used anti-freezing fluid shall be non-toxic and non-hazardous.	M.F.7
M.P.19 (M.F.4)	The used anti-freezing fluid shall be non-corrosive with used materials.	M.F.7
M.P.20 (M.F.5)	The used anti-freezing fluid shall prevent growing of algae.	M.F.7
M.P.21	All pressurized components and integrated systems shall be tested up to a safety level of 2 (TBC, 1.43 requested at CDR) with regard to the maximum nominal expected pressure.	M.F.10 *(new v2.1)*

2.3 Design Requirements

Table 2-3: EXPLORE Experiment Design Requirements.

ID	Description	Response to.
E.D.1	The electronics subsystem shall use a single control box for all components (excluding fluid control and camera).	
E.D.2	The electronics subsystem shall provide power and data connectors according to the REXUS specifications.	
E.D.3	The electronics subsystem shall provide power and	

ID	Description	Response to.
	data connectors for testing prior to launcher integration.	
E.D.4	The experiment shall use at least one camera for video capture.	E.F.6
E.D.5 (E.P.11)	The camera shall allow for video storage on a local device (TBC).	E.F.6, E.D.4
E.D.6 (E.P.12)	The camera shall provide its own power supply and storage (TBC).	E.F.3 E.D.4
M.D.1	The whole EXPLORE experiment shall fit into the REXUS module.	
M.D.2	The gas tank shall be safely mounted in the experiment structure.	M.F.1
M.D.3	The test chambers shall be of cylindrical shape and with hemispherical head covers to resemble real tank shapes.	
M.D.4	The test chambers shall have a length to diameter ratio between 3 and 3.5 to resemble real tank dimensions.	
M.D.5	The test chamber shall be of transparent material allowing the camera to record fluid movements inside the test chambers.	
M.D.6	The collection chambers shall contain a device to prevent any fluid from leaving the system.	
M.D.7	The used batteries shall be qualified for the use on a REXUS rocket (TBC).	E.P.12
M.D.8	The camera batteries shall either be rechargeable or shall have sufficient capacity to run the video recording during flight after pre flight tests and flight preparations.	E.P.12
M.D.9	The whole experiment setup (fluid lines and tanks) shall prevent loss of water.	
M.D.10	The test chambers shall be installed in a way to allow for easy removal (service and refill).	
M.D.11 (M.P.5)	The illumination shall not dazzle the camera.	M.F.6

ID	Description	Response to.
M.D.12	The experiment shall include fluid collection devices (e.g. pampers) to avoid fluid leakage out of the REXUS module.	M.F.11 *(new v2.1)*
M.D.13	The experiment shall be designed to operate in the vibration envelope of the REXUS rocket.	M.P.13 *(new v2.1)*
M.D.14	The experiment shall be designed to operate in the temperature profile of the REXUS rocket.	M.P.14 *(new v2.1)*
M.D.15	The experiment shall be designed to operate in the vacuum (air pressure) envelope of the REXUS rocket.	M.P.15 *(new v2.1)*
M.D.16	The experiment shall be designed to allow for safe handling of all equipment and fluids at all times.	*(new v2.1)*

2.4 Operational Requirements

Table 2-4: EXPLORE Experiment Operational Requirements.

ID	Description	Response to.
E.O.1	The experiment shall be designed in a way to operate fully autonomously during flight.	E.F.4
E.O.2	The experiment shall accept a manual start command from the ground segment.	
E.O.3	The experiment shall accept a manual reset command from the ground segment.	
E.O.4	The experiment shall accept a manual shut-off command from the ground segment.	
E.O.5	Upon shut-off command, the experiment shall switch to a safe dead-payload mode.	
E.O.6	The experiment shall store all measured data onboard during flight.	E.F.5
E.O.7	The experiment shall allow telemetry monitoring of selected measurement and status data.	E.F.5
M.O.1	The experiment shall ensure safe handling of the pressurized system and provide adequate safety	M.D.16 *(new v2.1)*

ID	Description	Response to.
	documentation.	
M.O.2	The experiment shall allow for multiple fill and drain cycles during testing and integration.	M.D.16 *(new v2.1)*
M.O.3	The experiment shall ensure safe handling of the liquid fluid during testing and integration, including adequate filling procedures.	M.D.16 *(new v2.1)*

3 PROJECT PLANNING

3.1 Work Breakdown Structure (WBS)

The work packages for the design, development, assembly, test and operations of the EXPLORE experiment are summarized in the work breakdown structure below. A detailed work breakdown structure can be found in the appendix.

The “Management” work package is still in progress since this work package is part of the whole project.

The “Engineering” work package is almost finished. All components are defined and already ordered. Components like the test chambers and the structure still have to be manufactured and are already commissioned.

The concept and design of the EXPLORE experiment as a part of the “Integration” work package are finished. First component tests have already been fulfilled. Next test weekends are already in planning.

The “Operation” and “Outreach” work packages are still under progress.

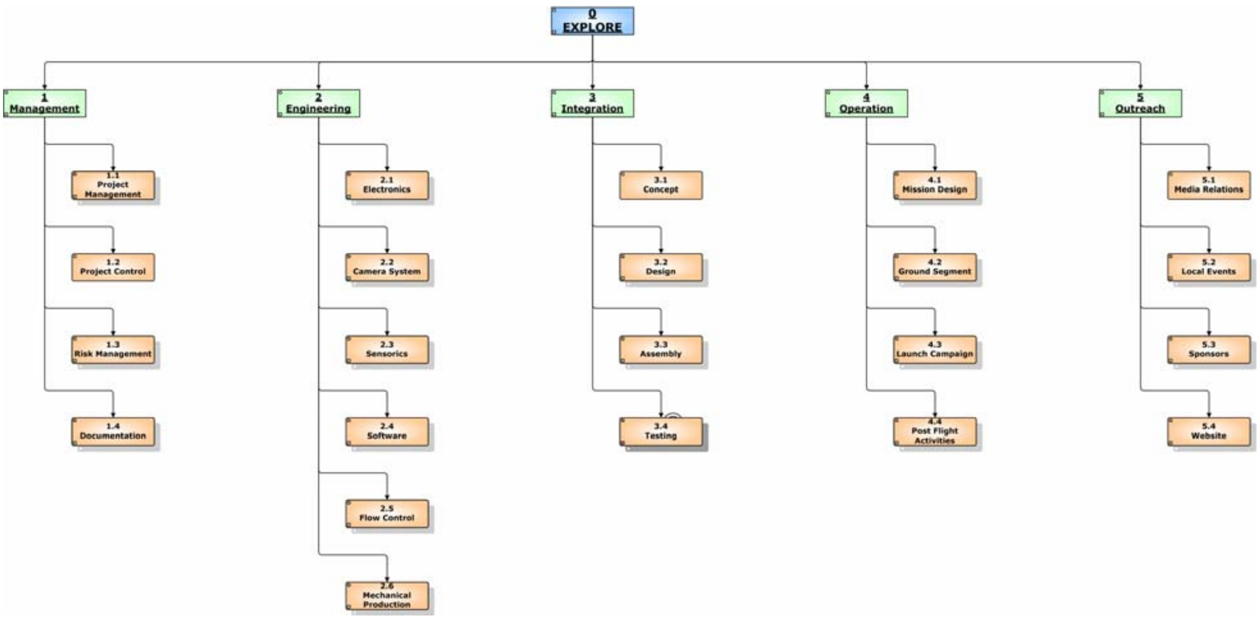


Figure 3-1: EXPLORE Work Breakdown Structure.

3.2 Schedule

A detailed schedule for the whole project can be found in the Appendix. As already mentioned before, the mechanical and electrical concept and design processes have been finished. All chosen components have been ordered.

First component and functional test have been performed (see also chapter 5.2). Outreach activities took place during the “Aerospace Lab”, the “Yuri’s Night” in Stuttgart and the “Tag der Wissenschaft” at the University of Stuttgart (see also chapter 3.4). Last components are already ordered and on their way. All parts that have to be manufactured are already comissioned. The next test weekend is in planning.

3.3 Resources

3.3.1 Manpower

All team members now have been allocated to specific work packages as already mentioned in chapter 1.4.2.

Christine Hill is responsible for the overall project management and therefore is working on the “Management” work package as well as the controlling of all other work packages.

Andreas Fink – as our payload manager – is responsible for the “Engineering” and “Integration” work packages. In particular he is responsible for the overall design of the EXPLORE experiment (includes all CAD drawings).

Emil Nathanson deals with the organization of the testing for the EXPLORE experiment. Additional to that the “Telemetry, Tracking and Command” work package (as part of the “Software” work package) is part of his work.

Juergen Schlutz now manages the “Outreach” work package with all its included work packages: media relations, local events, sponsors and the website.

Johannes Weppler is mainly handling the “Ground Support” work package, including all tasks. Besides this he’s also responsible for several design parts.

Robert Schelling in particular is responsible for the design of the test chambers (includes inner design). The therefore needed flow calculations are also part of his work package.

Since February 2010 a new team member joined the EXPLORE team to support us with electrical know-how. Therefore Daniel Stoerk deals with the design, assembly and testing of the electrical design for the EXPLORE experiment. Besides this he’s programming the onboard software and is therefore also responsible for the “Software” work package.

All EXPLORE members currently are active and available throughout the whole experiment manufacturing, assembling, testing and operations phases.

3.3.2 Budget

As almost all components have been defined you can find a budget calculation for the EXPLORE experiment below. As long as the ground support equipment (additional test items, spares, specific tools) and components are not finally fixed and estimations for the travel costs have to be finalized a margin of about 20% has been added to the calculated budget.

Table 3-1: EXPLORE Experiment Cost Budget.

Mechanical			
Component	No.	Single Cost [EUR]	Total Cost [EUR]
Gas tank (Primus Fuel Bottle, 1l)	1	--	--
Cap (self made, one water connection, one bycicle valve, with o-ring)	1	--	--
Bicycle Valve (as one connector for the gas tank cap)	1	--	--
Pressure reducer	1	--	--
Cap (self made, one water connection, one gas connection, with o-ring)	2	--	--
Fluid tanks (Primus Bottle, 0.35l)	2	--	--
Mass flow Control	2	180.00	360.00
Master safety valve (fluid, item no. KH 143 V PP)	2	88.04	176.08
Test chambers (PLEXIGLAS® XT (allround), tube, transparent 0A070 GT,)	6	13.90	13.90
Test chambers (hollow hemisphere, PLEXIGLAS® XT (allround), tube, transparent 0A070 GT)	12	35.09	35.09
Cap (self made, three water connections, one gas connection, with o-ring)	2	--	--
Collection chambers (Primus Bottle, 0.35l)	2	--	--
Pressure relief valve (Item No: 855811307001)	2	21.00	42.00
Fluid valve	12	72.83	873.96
Tubing	*1*	*87.51*	*87.51*
Main structure	*1*	*34.52*	*34.52*

Electronics			
Component	No.	Single Cost [EUR]	Total Cost [EUR]
Pressure sensor (series 3301, Item No: 351603341125)	1	72.20	72.20

Mass flow sensor	2	288.00	576.00
Electronics	*1*	*201.01*	*201.01*
Camera GoPro Hero	2	309.00	618.00
LED Module (4 x SMD, waterproof, Item No: 025834)	5	3.15	15.75
Temperature sensor (liquid)	2	60.00	120.00

Fluids			
Component	No.	Single Cost [EUR]	Total Cost [EUR]
Test liquid - Glysantin (5l)	1	10.00	10.00

Ground Support Equipment			
Component	No.	Single Cost [EUR]	Total Cost [EUR]
Laptop	1	--	--
Power supply	1		
Electric cabling and connectors		--	--
Tubing and connectors		--	--
Tools		--	--

Others			
Component	No.	Single Cost [EUR]	Total Cost [EUR]
PDR -Travel expenses for two additional team members	2	660.00	1320.00
Launch campaign - Travel expenses for two additional team members	3	970.00	2910.00
Two review meetings for two additional team members	3	150.00	450.00
Website	24	10.00	240.00

SUM [EUR]			**7507.82**
Margin	**10%**		**750.79**
TOTAL BUDGET [EUR]			**8258.61**

3.3.3 External Support

The EXPLORE team is constantly seeking support for the experiment realization, including technical and management expertise, hardware provisions and financial support.

At the current stage, the team is well supported by:

- The Ministry of Economics through the German Aerospace Center (DLR). DLR is maintaining overall REXUS project management and supporting the acquisition of experiment hardware.
- The Institute of Space System (IRS) of the University of Stuttgart. Represented by its director Prof. H.-P. Roeser, the IRS provides access to local expertise and facilities as well as logistics support for EXPLORE.
- Prof. S. Schlechtriem, lecturer at IRS and head of DLR Lampoldshausen, and his research staff provide technical advice in the area of refuelling and propulsion. They also provided initial test material for the fluid system to us, particularly tubing and fittings.
- The Institute of Aerospace Thermodynamics (ITLR) of the University of Stuttgart. The in-house mechanical workshop of the institute manufactures most of the customized EXPLORE parts.
- Development and management of the EXPLORE website is supported by IT-Services Benjamin Ackermann in order to provide a flexible and powerful platform for outreach and communication.
- The new EXPLORE logo has been designed by Leonore Kleinkauf, a design student from Stuttgart Media University.
- Primus AB of Stockholm, Sweden, supports the EXPLORE team with their expertise in fuel handling and provides gas and fluid tanks as well as manufacturing of components (tank caps and connectors) for the fluid system.
- The foundation of the federal state bank of Baden-Wuerttemberg (Landesbank Baden-Württemberg, LBBW) supports EXPLORE financially with a substantial amount to procure components, raw material and test equipment.
- The Evonik business segment Acrylic Polymers is manufacturer of PLEXIGLAS® and offered special discount support for the EXPLORE raw material to build our test chambers.
- The German Ralf Bohle GmbH is market leader for bicycle tires in Europe with its Schwalbe label. Schwalbe valves will also be used to fill and pressurize the EXPLORE gas section.

- B.I.O-TECH e.K. supports EXPLORE as specialist for fluid sensorics. They provide miniature mass flow meters to monitor the exact propellant flow rate during the rocket flight.

3.4 Outreach Approach

Due to its direct link of the experiment to space exploration activities and discussions, there are various opportunities for outreach at public, university and even industry level. We are intending to exploit all three of those.

3.4.1 Website

The EXPLORE web presence is one of the major public outreach tool, enabling us to provide regular updates, materials and images to all followers of the experiment development. It is a constantly growing platform with various features, describing the experiment itself, the REXUS campaign, the development, integration and testing process as well as creating links to other teams and on-orbit refuelling related sites and activities. The website has been set up using the powerful content management system TYPO3 and is maintained by the EXPLORE team. It features regular news and image updates on the experiment development, the launch campaign and the results analysis, while links to Facebook and Twitter enable the contact to a wide and diverse audience, including all interested visitors as well as our sponsors and partners. The whole website becomes more populated once the experiment work progresses.

The website shall also enable interested visitors to get involved with the EXPLORE team and experiment. It provides means of direct contact as well as a forum for discussion. We are providing downloads and continuative links. Furthermore, specific contents increases public awareness of our activities and enables the visitor to become part of the effort himself.

The website is accessible at: http://www.explore-rexus.de and currently features info on (both in German and English):

Table 3-2: Sitemap of the EXPLORE web presence.

Site	***Description / Contents***
1. HOME	Welcome, recent news, a few links … this is the introduction page.
2. ABOUT US	Presentation of the EXPLORE team with images and short info on each member.
3. BLOG/NEWS	Regular news updates on the experiment progress, meetings, etc.

4. THE EXPERIMENT	Discussion of the experiment and its context.
4.1 REXUS/BEXUS	A few words on the rocket and the campaign, with links to DLR.
4.2 BACKGROUND	General intro to the science and technologies behind EXPLORE, some related experiments, links to online discussions and info on orbital refuelling. (TBD)
4.3 CONCEPT	Experiment design, images, etc.
4.4 MILESTONES	Important dates and an overview of the project timeline.
4.5 HARDWARE	Information on the implemented hardware. (TBD)
5. IMAGES	Images of the team, workshops, and experiment.
6. YOUR NAME IN SPACE	One of our outreach efforts to stimulate public participation in EXPLORE.
7. PARTNERS/SPONSORS	Logos and links for sponsors and partners.
8. DOWNLOADS	Download our information brochure as well as related info and press releases.
9. GUESTBOOK	Discussion forum for guests and the team. (TBD)
10. LINKS	Links to relevant pages and organisations.

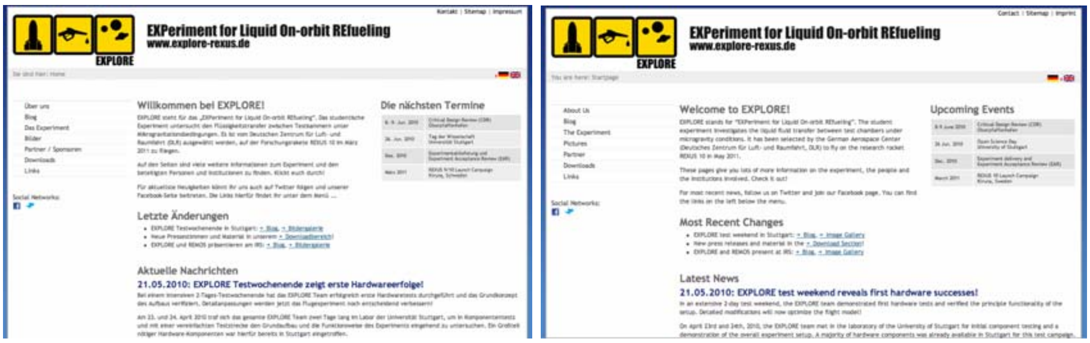


Figure 3-2: Screenshot of the EXPLORE website in German (left) and English (right).

3.4.2 Public

A particular example of a public outreach project is the **"Your Name in Space"** project of EXPLORE. This project was initiated at the REXUS Public

Day (see below) and allows interested individuals and partners to submit their name and contact details. These names will then be included electronically in the EXPLORE experiment and go on the REXUS trip together with the hardware. If time and resources allow, the list of names will be transmitted to the ground station via telemetry at the top part of the parabola trajectory. After successful flight, a certificate of participation will be made available on the website to all participants to proof their support to the EXPLORE project. Furthermore, the participants will receive regular updates on the experiment progress throughout the project through a feature newsletter from the team.

An initial list of more than 50 participants was collected at the REXUS public day. This list is available today on the EXPLORE website for everyone to see their participation, while new interested followers can join in via the homepage as well.

We are also searching directly for interested **media publicity in local and regional newspapers and radio** as well as exhibition of the hardware and concept when available and appropriate at local events. A general information brochure has been drafted and is available online and in print form, together with logo stickers and business cards. We are using this brochure and material to contact media representatives to attract their interest.

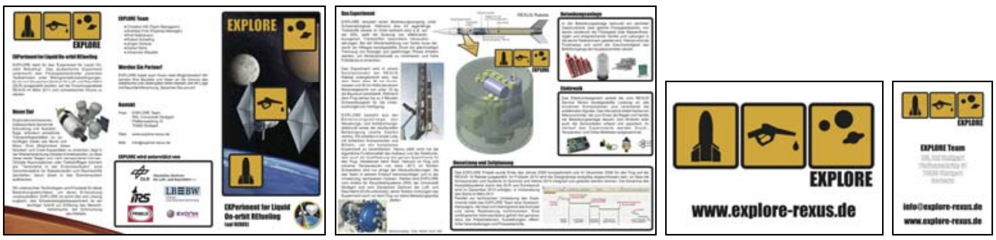


Figure 3-3: EXPLORE outreach material (left to right: flyer front, back, sticker, business cards.)

Outreach events in the Stuttgart area have already been another pillar of our public relations activities and will continue to play a role in the future. Cooperation with the also local REMOS teams enables interesting local and regional events.

The first large event participation was the one in Yuri's Night, the World Space Party on April 11, 2010. Embedded in the larger event format, EXPLORE and REMOS organised the **1st REXUS Public Day**, inviting all other current REXUS 9/10 teams as well as past REXUS 7/8 teams to come to Stuttgart and to showcase their work with posters, presentation, handout material, exhibition hardware, and hands-on activities. A total of four teams (EXPLORE, REMOS from Stuttgart, SQUID from Stockholm, FOCUS from Munich) were present in Stuttgart and contributed to a very successful event with more than 500 visitors and diverse offerings for the mixed audience.

EXPLORE exhibited a poster together with initial experiment hardware, gave a presentation on the experiment background and concept, and organised a hands-on rocket building and launching workshop for children that was incredibly well received. Local media reported on the event and the student involvement, thus encouraging further efforts. Some images of the event are shown below.

Figure 3-4: EXPLORE outreach material together with experiment hardware at a presentation at the University of Stuttgart, April 2010.

Figure 3-5: EXPLORE at the 1st REXUS Public Day on Yuri's Night Stuttgart 2010.

Targeting school kids fascinated by science and technology, EXPLORE also supports the work of the **Aerospace Lab** in the youth research center in

Herrenberg, where we presented the REXUS opportunities and our experiment in particular. Teachers and students were very interested and EXPLORE initiated the formation of a REXUS student group in Stuttgart to further coordinate the cooperation between the Aerospace Lab, the University of Stuttgart and the DGLR local members. The group is meeting on a monthly basis and we are looking forward to new and compelling projects from there.

The next upcoming events after CDR include:

- 2nd Aerospace Lab meeting in Herrenberg, 11 June 2010
- Open Science Day at University of Stuttgart, 26 June 2010

Another idea has been brought forward to implement a drawing contest or similar with school kids in order to raise awareness of the opportunities and technical challenges of exploration in Germany. The pupils can draw their own ideas about space exploration and orbital refuelling activities, which will then be attached to the experiment setup and flown to the edge of space. More details on this contest will be finalized in the future.

3.4.3 University

We are seeking close interaction with research staff and lecturers at the University of Stuttgart in order to support the on-orbit refuelling debate and technology development within the aerospace engineering curriculum. A meeting with the director of the Institute of Space Systems (IRS), Prof. H.-P. Roeser, has been held in January, where he acknowledged the participation and efforts of the EXPLORE team. IRS is offering support to the team in various ways, including logistics, expertise and potentially credit for the involved students within their studies.

As a return, the EXPLORE team will partner with the other local REXUS team, REMOS, to present their experiments and the campaigns within the lecture series “Raumfahrt aus Leidenschaft” in the winter semester 2010/11 to fellow students, university staff and interested visitors. Furthermore, EXPLORE will be present at the university science day (“Tag der Wissenschaft”) on 26 June 2010. Existing experiment hardware will be presented together with concept and outreach aspects of the project.

In February 2010, upon completion of the PDR, a web news article on the EXPLORE and REMOS teams was published on the IRS homepage to communicate the successful selection and project kick-off of the student experiments within the REXUS/BEXUS campaign. Also, in March 2010, both teams were featured in the faculty newsletter of aerospace engineering. Both articles are available on the EXPLORE website for download.

In April 2010, selected members of the EXPLORE and REMOS teams presented the current status of the experiment development to an audience of professors and research staff at the Institute of Space Systems of the University of Stuttgart.

As already outlined in the Pubic section, EXPLORE also initiated the formation of a local REXUS student group that discusses project ideas and seeks close cooperation with the University, the Aerospace Lab in Herrenberg and the local DGLR group.

3.4.4 Industry

Industry partnership opportunities are potentially available still at different levels. Primarily we are contacting local small to medium enterprises to help us with hardware, manufacturing and expertise towards the realization of EXPLORE. The main interest is to use non-space-qualified hardware to reduce cost. These partners will then be featured in the experiment campaign while gaining "flight-proof" of their hardware. This effort has already paid off through the provision of various hardware components for free or significantly reduced prices, resulting in most of the flight hardware being already available in Stuttgart, particularly:

- Gas and fluid tanks with cap connectors, provided by Primus AB
- Tubing and fittings for testing, provided by DLR Lampoldshausen
- Mass flow sensors, provided by B.I.O.Tech
- Plexiglas material, reduced price by Evonik
- Fluid valves, reduced price by Staiger
- Thermal sensors, reduced price by Electronic Sensor
- Pressure regulator, provided by SFS

We will continue to search for these opportunities to minimize cost of the overall experiment while maximising its visibility to industrial partnes.

Second, we get in touch with larger industry for financial support of the campaign. These can be either space industry with a natural interest in the research proposal, but also related industries such as oil companies or similar that can link their own outreach activities to the refuelling experiment. We are currently drafting the “Future of Refuelling” campaign, aiming at communicating the opportunities of orbital refuelling for future space exploration and utilization to professionals and interested individuals. This campaign shall both create awareness of the concepts and address potential partners and sponsors of the EXPLORE experiment.

Additionally, the experiment team is actively searching for financial support through foundations and similar grants. This support shall enable hardware acquisitions as well as travel of the experiment team to workshops and campaign events throughout the next year. Current successes of these efforts have been:

- o Financial support through the Erich-Becker-Stiftung: 2x500 EUR to support travel of 2 non-sponsored team members to the training week in Kiruna
- o Financial support through the foundation of the Landesbank Baden-Württemberg (LBBW), 2500 EUR for the acquisition of materials and components

Figure 3-6: EXPLORE partners and supporters.

3.5 Risk Register

Due to design changes and first component and functional tests some risks could be minimized. A detailed risk register can be found below:

Table 3-3: EXPLORE Experiment Risk Register.

ID	*Risk*	*P*	*S*	*PxS*	*Action*
TC10	Experiment fails any of the vibration, vacuum or leakage tests.	B	4	Low	Perform tests early and allow for sufficient time to solve problems between test and experiment delivery.
VE10	Experiment may leak.	B	4	Low	Perform leakage tests after assembly, vibration test and integration.
VE20	Parts come loose from the structure/rocket casing.	B	4	Low	Vibration testing.
MS10	Corrosion or algae in fluid blocks valve or test chambers.	A	3	Very low	Add anti-algae fluid to test fluid, make sure materials used are corrosion resistant.
MS20	Fluid might freeze after landing and before recovery. Increased volume could damage experiment.	A	3	Very low	Add anti-freeze to test fluid.
MS30	Pressure valve V-0 fails and remains closed.	A	1	Very low	Valve V-0 removed from setup.
MS40	Software program in microcontroller fails during flight.	C	3	Low	Watchdog checks for crashes and resets if necessary.
MS50	Water leakage causing a short circuit in the electrical system.	A	4	Very low	Protect electrical equipment.
MS60	Malfunction of a valve in one branch.	B	2	Very low	Testing of all valves prior to integration.
MS61	Malfunction of several valves in one branch.	B	3	Low	Testing of all branches.

MS70	Leakage of pressurized tank & loss of needed pressure to commence filling process.	B	4	Low	Testing of several fill and drain cycles of the pressurized tank.
MS80	Failure of Flow Control Device.	C	3	Low	Redundancy with second device.
MS90	Experiment is destroyed during flight.	A	5	Low	No action possible.
MS100	Cable or connector gets loose during flight.	C	3	Low	Implement secure connectors.
TC20	Critical component is destroyed during testing or integration.	C	4	Medium	Order spare parts.
MS110	Test chambers or camera experience reduced visibility due to fogging.	C	3	Low	Thermal tests.

4 EXPERIMENT DESCRIPTION

4.1 Experiment Setup

The experiment is designed to simulate the refueling of small model fluid tanks. To perform this task a variety of subsystems are required which are listed in the block diagram in Figure 4-1. The diagram also shows the interfaces and flows between the subsystems.

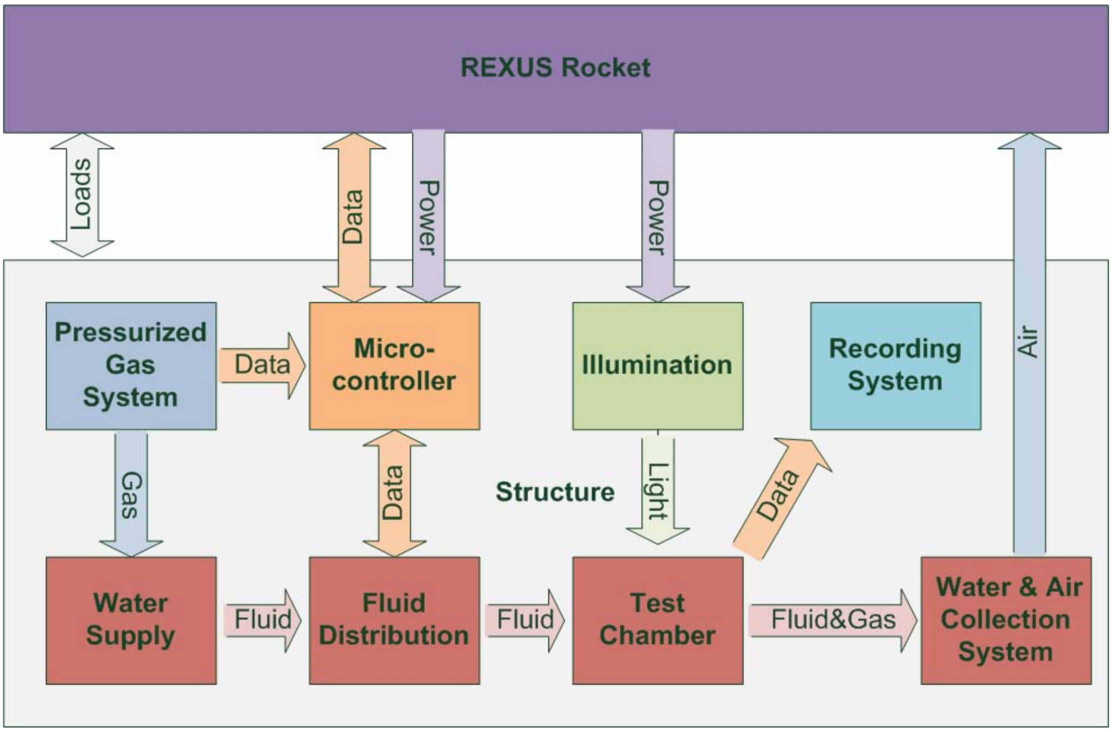


Figure 4-1: Block diagram of EXPLORE experiment and subsystems.

The central part of the experiment setup consists of

- the fluid supply system
- the fluid distribution system
- six fluid tanks reffered to as “test chambers”
- six overflow collection chambers which are reffered to as “collection chambers”
- the pressurized gas system

The fluid supply system and the pressurized gas system simulate the liquid propellant supply system of an on-orbit re-fueling station. The test chambers and the collection chambers simulate the liquid propellant tank and pressure tank of a spacecraft being refueled.

The pressurized gas subsystem provides the pressure needed to drain the water supply tanks and drive the fluid into the test chambers in microgravity. It consists of a pressurized gas supply tank, a gas pressure sensor and a pressure reduction valve. The readings of the gas pressure sensor are used as housekeeping data and stored onboard as well as sent down to the ground station.

The fluid supply system consist of two fluid tanks which hold the fluid used in the experiment before and during launch. The tanks are fully filled before launch in order to prevent any disturbance to the rockets stability due to fluid movement. During the experiment the tanks are drained and the fluid is moved to the test chambers. A membrane provides separation of fluid and pressurized gas.

The fluid distribution system guides the fluid from the fluid supply system to the test chambers once the experiment is started. A series of hoses, electrically controlled magnetic solenoid valves, temperature sensors, flow control devices and flow measurement devices is used in the setup to control the fluid inflow speed into the test chambers and the flowrate. Data is send back and forth between the different flow control devices and the micrcontroller.

The test chambers are designed to resemble miniature propellant tanks. Here the actual experiment takes place when the chambers are being filled. The test chambers are made of transparent material so that the filling process can be monitored and recorded by a recording system (see below).

Excess water and air from the test chambers is stored in the collection chambers. The residual air in the test chamber is released out of the system via a pressure relief valve once the air from the test chambers flows in. A membrane prevents any fluid from leaving the system and spilling into the REXUS rocket.

In addition to the subsystems mentioned before the EXPLORE experiment features a microcontroller which handles ground communication (housekeeping data) via the REXUS internal communication system, controls the fluid distribution system and processes data from the different sensors in the pressurized gas system and the water distribution system.

A camera is used as a recording system which monitors and records the filling of the test chambers during the experiment.

An illumination system consisting of various LEDs provides sufficient light for the recording system. The illumination system is powered by the REXUS onboard 28V DC power supply.

The structure is the central subsystem, which supports the other subsystems and transfers loads between REXUS and the individual EXPLORE components.

In order to provide a more detailed understanding of the experiment setup the flow diagram in Figure 4-2 shows the individual components of the pressurized gas system, of the fluid supply and distribution system and the test chambers as well as the collection chambers.

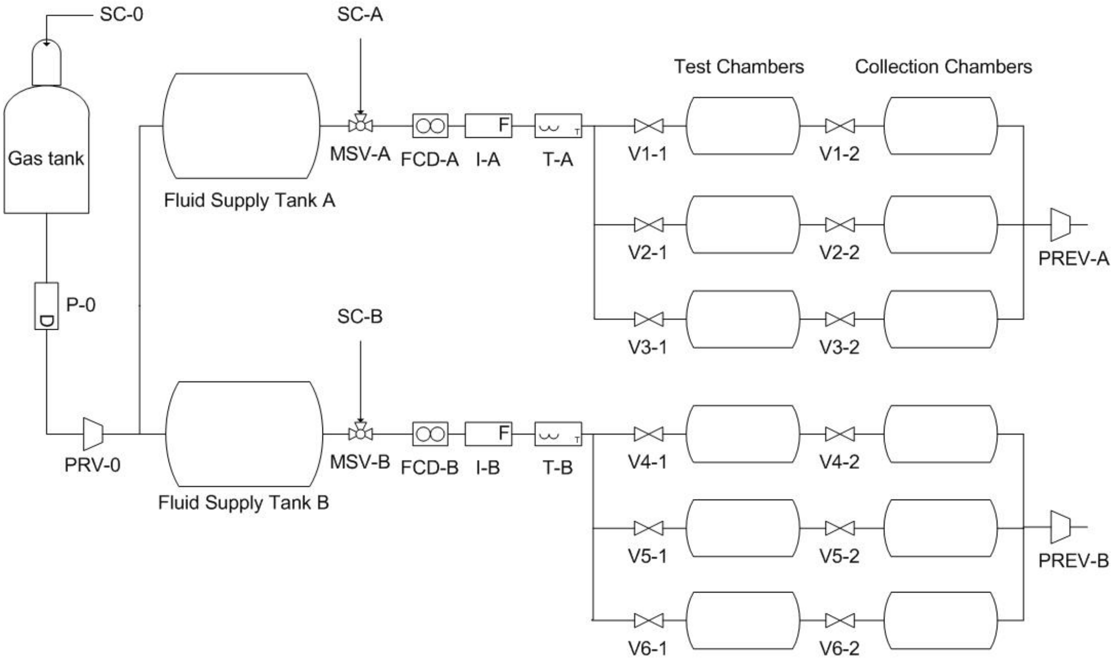


Figure 4-2: Block diagram of EXPLORE experiment.

The gas tank (<6 bar) of the pressurized gas system is connected to both fluid storage tanks. The pressure sensor P-0 monitors tank pressure and reports data back to the microcontroller. This provides housekeeping data for the gas tank and allows for early detection of leakages. A pressure reduction valve (PRV-0) reduces system pressure in the connected fluid storage tanks to 2.5 bar. Once the gas tank is pressurized the fluid supply tanks will be pressurized as well. This means a change in design respective to the first version of this document, where it was intended to use magnetic valves to cut off the fluid supply tanks from the gas tank. These changes were implemented to reduce complexity and weight of the experiment.

The two fluid storage tanks hold the fluid used in the experiment and are connected to the pressurized gas system on one side and to three test chambers each on the other side. Inside each fluid storage tank is a membran which separates the gas of the pressurization system and the fluid used for the experiment (for details see chapter 4.4). A flow control device (FCD-A and

FCD-B) at the outlet of every tank enables a continous control of the fluid inflow speed via the microcontroller. The flow measurement devices I-A and I-B cross-check the settings of the flow control devices and report the data back to the micrcontroller. A manually operated master safety valve (MSV-A and MSV-B) is installed after each tank to prevent fluid from escaping the tank during system tests of the magnetic solenoid valves. The master safety valves are to be opened before launch.

Before and after the test chambers electrically controlled magnetic solenoid valves (V1-1 to V6-2) are installed to control which chamber is being filled and to preserve the condition in the chambers after filling is completed. During launch the fluid storage tank is completely filled and the test chambers and the collection chambers are empty. Once the experiments starts the valves in the system are opened sequentially to fill two test chambers at the same time. One test chamber is filled from fluid supply tank A and the other one from fluid supply tank B. The test chambers being filled are arranged symmetrically around the center line of the REXUS rocket so that no significant CoG shifting occurs during the filling process.

The test chambers are finally connected to the collection chambers. The collection chambers feature a membran which works like an inflatable balloon and collects the excess volume (air and fluid) from the test chamber. As the ballon increases in size the residual air in the collection chamber outside the ballon leaves the system through the pressure relief valves PREV-A and PREV-B. This mechanism keeps the system pressure in the collection chambers and the test chambers constantly at 1 bar. At the same time it prevents any fluid from leaving the system and entering the REXUS experiment container. See chapter 4.4 for details.

In order to refill the gas tank and water supply tank after experiment testing, without having to dismantle the entire experiment, three service connectors are added to the tubing system. SC-0 is the connector for repressurization of the gas tank. SC-A and SC-B are used to refill the fluid supply tanks. The fillig process is as follows: First any residual pressure in the gas tank has to be released and the valve of SC-0 has to remain open during the process. Then the required amount of liquid is supplied to the fluid tanks through SC-A and SC-B, while the valves before the test chambers are closed. After SC-A and SC-B are closed, pressurized air can be supplied to the gas tank through SC-0.

In order to drain the test chambers and the collection chambers the connected pipes must be disconnected from the valves and the containers have to be renoved from the structure.

4.2 Experiment Interfaces

The following section describes the interfaces of the EXPLORE Experiment to the REXUS Rocket and the REXUS Service Module.

4.2.1 Mechanical

The EXPLORE experiment structure is made up of three major sub-structures: The module (green), the bulkhead/ base plate (purple) and the support tower (yellow), see Figure 4-3. All experiment components are fixed to these individual sub-structures. The tower is connected to the bulkhead, which in turn is connected to the module through four brackets. The REXUS experiment module is the actual interface to the rest of the REXUS rocket.

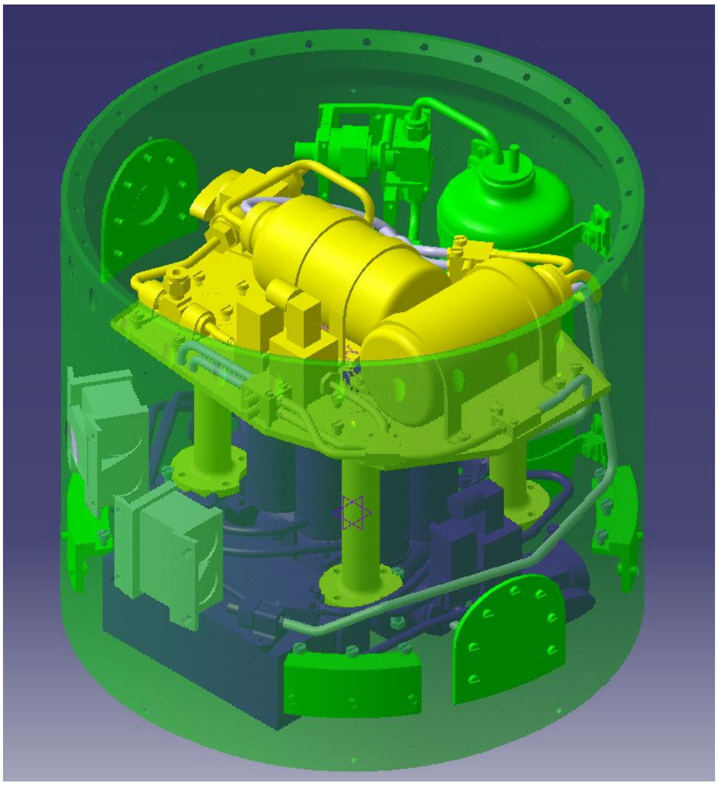


Figure 4-3: EXPLORE experiment structure.

All screw connections are secured with Loctite. All nuts used are self-locking nylon nuts. Additional information on screw size and positions can be found in the structural analysis and the assembly and manufacturing drawings in the appendix. Tubing and electrical cables are fixed by cable straps.

Tower:

The tower structure consists of four support legs (green) and a top plate (yellow, see Figure 4-4). The support legs are fixed to the top plate and (at final integration) to the bulkhead with four screws each (locked with nylon nuts). The components are fixed to the top plate by M4 and M5 screws. Details can be found in chapter **Fehler! Verweisquelle konnte nicht gefunden werden.**. Results of FEM analysis can be found in the Appendix.

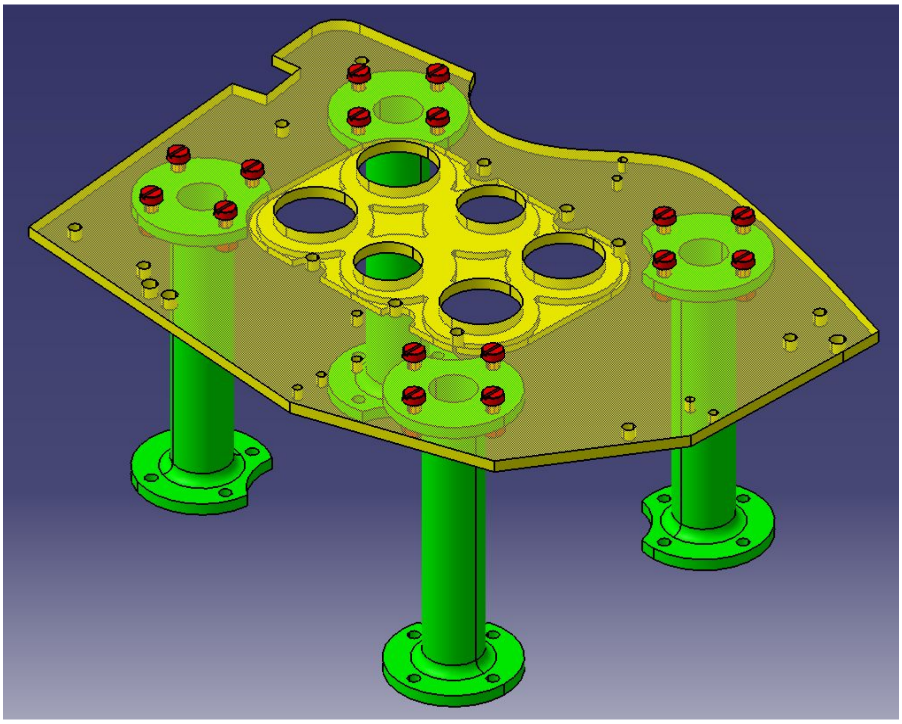


Figure 4-4: Tower structure.

The bulkhead

The bulkhead connects the tower and the module. It also houses some components of the experiment, similar to the tower. Valves, temperature sensors, test chambers etc. (illustrated in yellow in Figure 4-5) are mounted to the top of the bulkhead with the help of M4 and M5 screws. See chapter 4.4 for details.

The fluid tank, collection chamber (both red in Figure 4-6) and the electronics box are mounted to the bottom of the bulkhead. Fluid tank and collection chamber are fixed in place be two clamp bands (orange) each, whereas the electronic box (purple) is hold in place by screws.

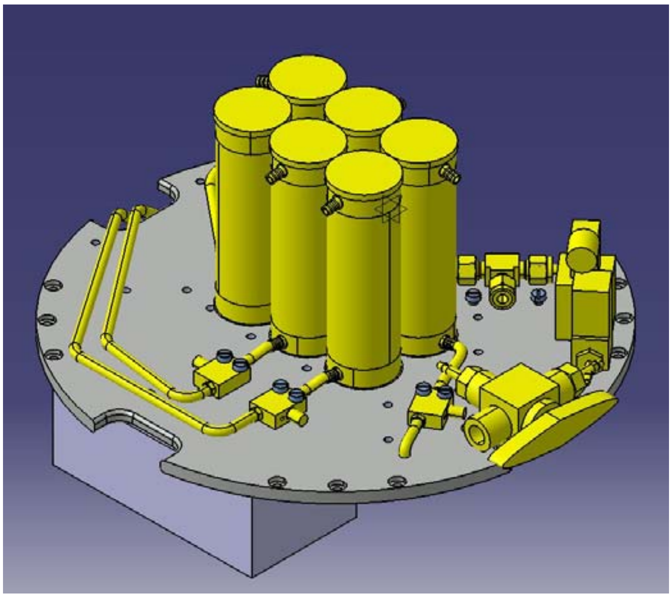


Figure 4-5: Bulkhead (view from top).

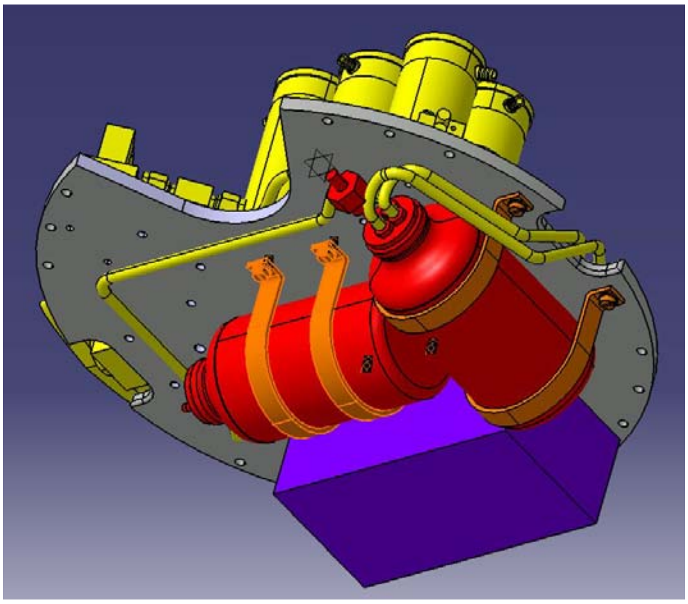


Figure 4-6: Bulkhead (view from bottom).

The Module:

The bulkhead is attached to the module through four brackets, which are shown in red in Figure 4-7 and Figure 4-8. Three M5 screws are used per bracket to firmly attach the bulkhead (and with it the tower) to the module.

Also attached to the module are a number of experiment components, such as the pressurized gas tank (blue in Figure 4-7) of the experiment. Four support structures (green) are connected to the module, using two M5 screws each. Two clamp bands (orange) are mounted on the support structures to attach the pressure tank firmly to the module. An additional 5th support structure (see Figure 4-8) is located below the gas tank to provide additional support during the phase of high acceleration during lift-off. FEM analysis was performed to confirm that the structure is strong enough to cope with flight loads. Details and results of this analysis can be found in the Appendix.

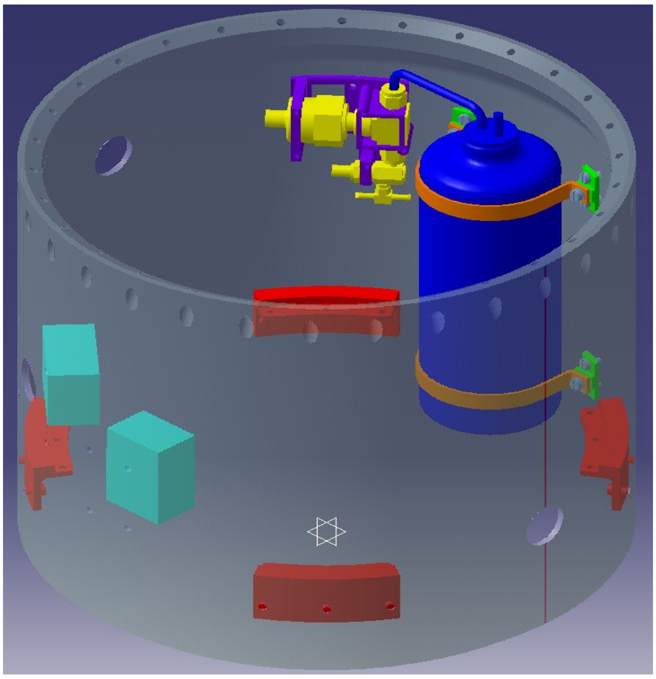


Figure 4-7: REXUS module (3D view).

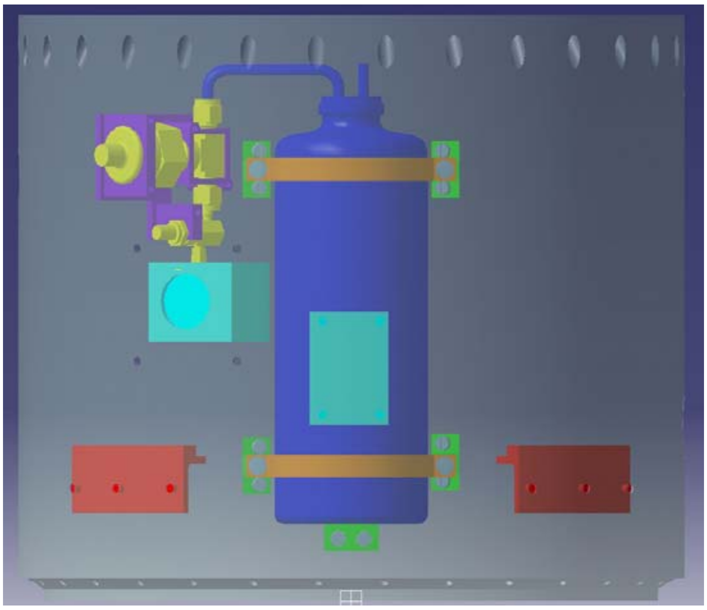


Figure 4-8: REXUS module (front view).

The pressure sensor and pressure reduction valve (yellow) are mounted to the module using a special support structure (purple), which is illustrated in detail in Figure 4-9. The experiments components are fixed to this support structure through three clamps (white) with the help of M3 screws. The support structure is fixed to the module with the help of two M5 screws.

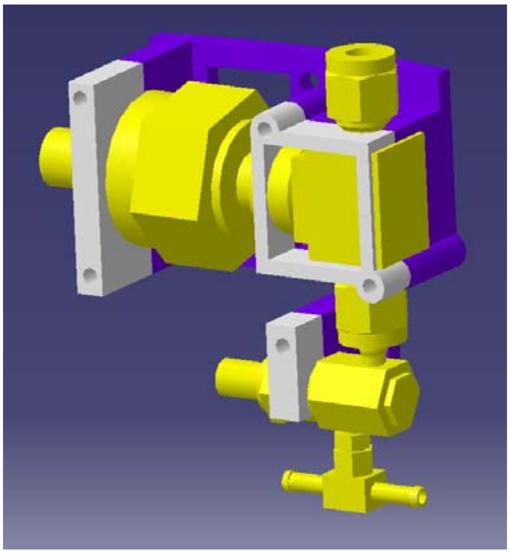


Figure 4-9: Pressure Sensor Support Structure.

Two cameras (turquoise in Figure 4-7) are also mounted to the module. One camera (right in Figure 4-10) is oriented in a way to film the inside of the module and the test chambers, while the second camera (left in Figure 4-10) is oriented to film the environment outside of the rocket. The support structures for both cameras are very similar and will be mounted to the module using four M5 screws per camera. For the "external" camera, a hole (30 mm in diameter) is needed in the experiment module (see Figure 4-11 for details) to allow sufficient outside view for the camera lens. The hole will be covered by a 3 mm thick glas sheet from the inside of the module, which is part of the camera support structure (green in Figure 4-10). This design will prevent hot gases from entering the inside of the module during "re-entry" phase.

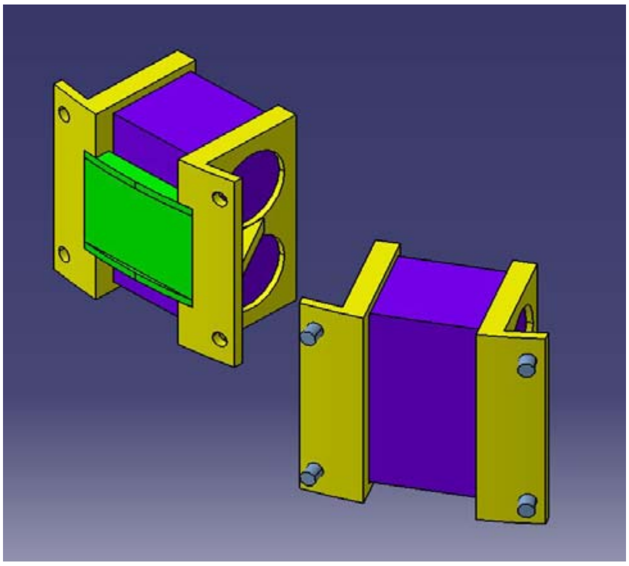


Figure 4-10: EXPLORE Camera (Left: Camera 2 external, Right: camera 1 internal).

In addition to the hole needed for the support screws and the external camera, two holes of 30mm diameter are needed at both sides of the experiment module (see **Figure 4-11**). These double-function as venting holes and late access hatches to manually arm the Master Safety Valves of the experiment shortly before launch. After arming the valves the holes will be covered by sheet metal as described in chapter 5.4 of the REXUS manual. They are shown on the right in Figure 4-11 on the right.

Also illustrated in Figure 4-11 on the left is the fluid collection device (red) at the top and bottom end of the experiment module. It is mounted to the top and bottom end of the module using eight M4 screws + washers (orange) per side.

Cable Feed-through

Although not showing in the pictures, feed-through brackets are installed near both Fluid Collection Devices in order to feed the electrical cables through the Fluid Collection Device.

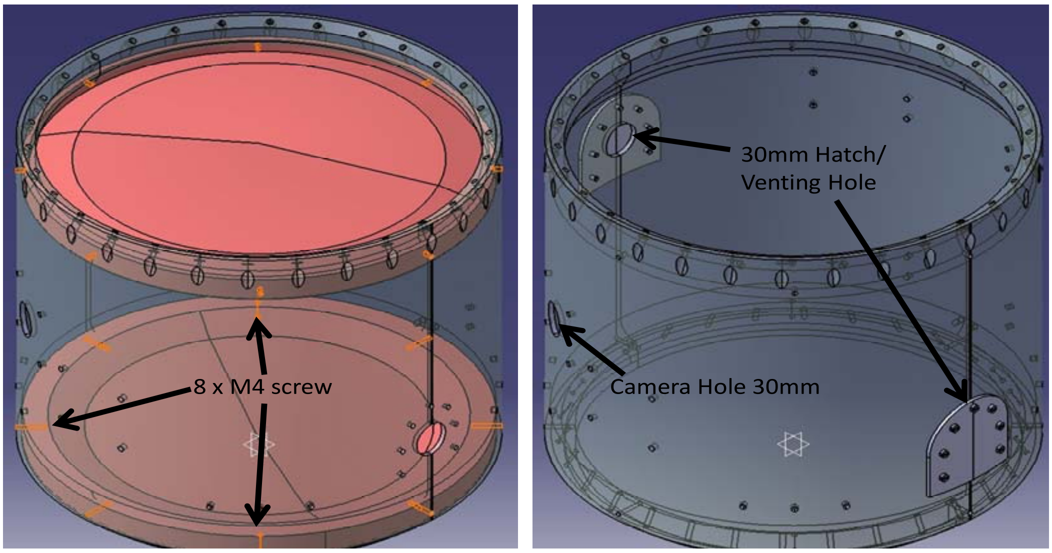


Figure 4-11: Fluid Collection Device Support & Hatch/Venting Hole.

4.2.2 Electrical

The EXPLORE Experiment will use the power provided by the REXUS service module to power its electronics consisting of the microcontroller, SD card, the valves, the flow controllers and sensors and the LED lights during flight. The 28V from the service module will be converted into 3.3V, 5V and 12V by DC/DC converters.

The EXPLORE components will need a total amount of approximately 22 W power during the flight.

Although the microcontroller will trigger the experiment with implemented signals, the time signals such as “lift off”, “start of data storage” and “start of experiment” supplied by the REXUS Service Module will be used as a backup. An uplink to the experiment has minor priority and will probably not be implemented.

During the flight the EXPLORE Experiment will use the REXUS Service Module downlink to send collected tank pressure, fluid flow and temperature data to the ground station.

4.3 Experiment Components

Table 4-1: EXPLORE Experiment Components List.

Mechanical			
Component	Manufacturer	Status	Comments
Gas tank (Primus Fuel Bottle, 1l)	Primus	available from Primus	certified, lightweight
Cap (self made, one water connection, one bycicle valve, with o-ring)	Primus	available from Primus	self-made, aluminum
Bicycle Valve (as one connector for the gas tank cap)	Schwalbe	available from Schwalbe	aluminum, lightweight
Pressure reducer	SFS	available	aluminum
Cap (self made, one water connection, one gas connection, with o-ring)	Primus	available from Primus	self-made, aluminum
Fluid tanks (Primus Bottle, 0.35l)	Primus	available from Primus	certified, lightweight
Mass flow Control	Bürkert	has to be ordered	
Master safety valve (fluid, item no. KH 143 V PP)	Hydrobar	available	lightweight, resistant to a wide temperature range
Test chambers (PLEXIGLAS® XT (allround), tube, transparent 0A070 GT,)	Evonik	are manufactured by ITLR	Have to be adapted to experiment needs
Test chambers (hollow hemisphere, PLEXIGLAS® XT (allround), tube, transparent 0A070 GT)	Evonik	are manufactured by ITLR	
Cap (self made, three water connections, one gas connection, with o-ring)	Primus	available from Primus	self-made, aluminum
Collection chambers (Primus Bottle, 0.35l)	Primus	available from Primus	certified, lightweight
Pressure relief valve (Item No: 855811307001)	Esska	available	
Fluid valve	Staiger	available	Mass flow rate, lightweight
Tubing	--		
Main structure	--		

Electronics			
Component	Manufacturer	Status	Comments
Pressure sensor (series 3301, Item No: 351603341125)	Esska	available	
Mass flow sensor	B.I.O.-TECH	ordered	
Electronics	--	*available*	
Camera GoPro Hero	GoPro	one available, second has to be ordered	
LED Module (4 x SMD, waterproof, Item No: 025834)	Idealux GmbH	available	
Temperature sensor (liquid)	Electronic Sensor	available	

Fluids			
Component	Manufacturer	Status	Comments
Test liquid - Glysantin (5l)	BASF	available	

Ground Support Equipment			
Component	Manufacturer	Status	Comments
Laptop	--	available in team	
Power supply	TBD	to be ordered	
Electric cabling and connectors	--		
Tubing and connectors	--		
Tools	--	available in team and at IRS	

4.4 Mechanical Design

The mechanical design of the EXPLORE experiment and its subsystems, which were introduced in paragraph 4.1, is described in this paragraph. Figure 4-12 displays the mechanical design of the experiment, showing the EXPLORE experiment on the REXUS bulkhead. The following chapter describes the mounting points and the individual components of the EXPLORE experiment in detail.

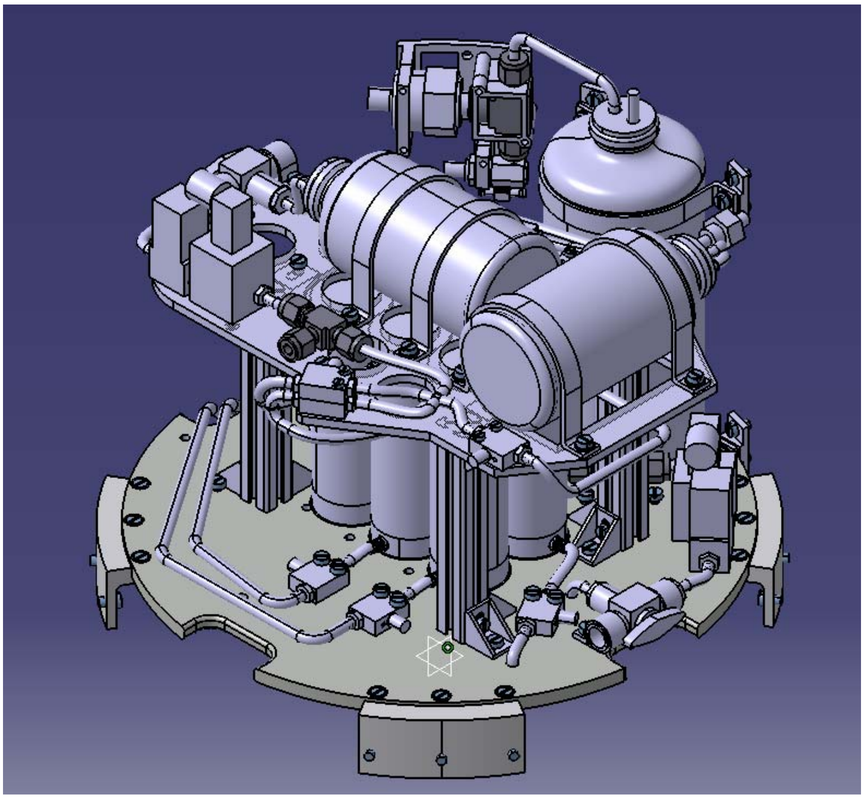


Figure 4-12: Mechanical setup of EXPLORE experiment showing components (Image shows old design, to be updated!)

Tower Structure

Except the components which are mounted to the experiment module as described in detail in chapter 4.2.1, all other components are mounted to either the bulkhead or the tower structure. This tower structure as shown in Figure 4-4 consists of the top plate (marked yellow in Figure 4-4) and four support legs (green). The support legs are stiffened by four screws (red) each. The components are fixed by M5 screws. The experiment components are fixed to the top plate in various ways as described below:

The Master Safety Valve and the temperature sensor are fixed to the top plate with the help of two clamps (green) each. Each clamp is fixed to the top plate by a M5 screw. The valve blocks are attached using two M3.5 screws per block. For details see Figure 4-13.

The mass flow sensor is attached to the top plate using two M4 screws (see Figure 4-15). The screws are mounted from the underside of the top plate. This design is necessary due to the defined fixation points of the mass flow sensor.

The fluid tank and the collection chamber are attached to the support structure with the help of two clamp bands and four M5 screws each, see Figure 4-14.

The tubing parts and electronic wires are fixed to the top plate using cable straps.

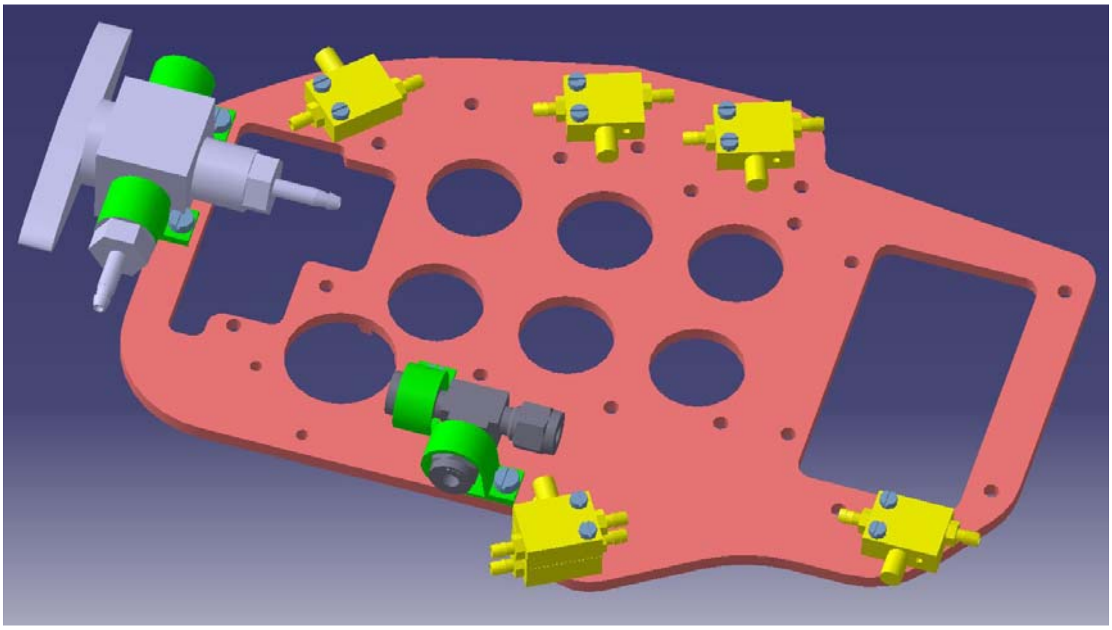


Figure 4-13: Master Safety Valve, Temperature Sensor and Valve fixation (picture has to be updated).

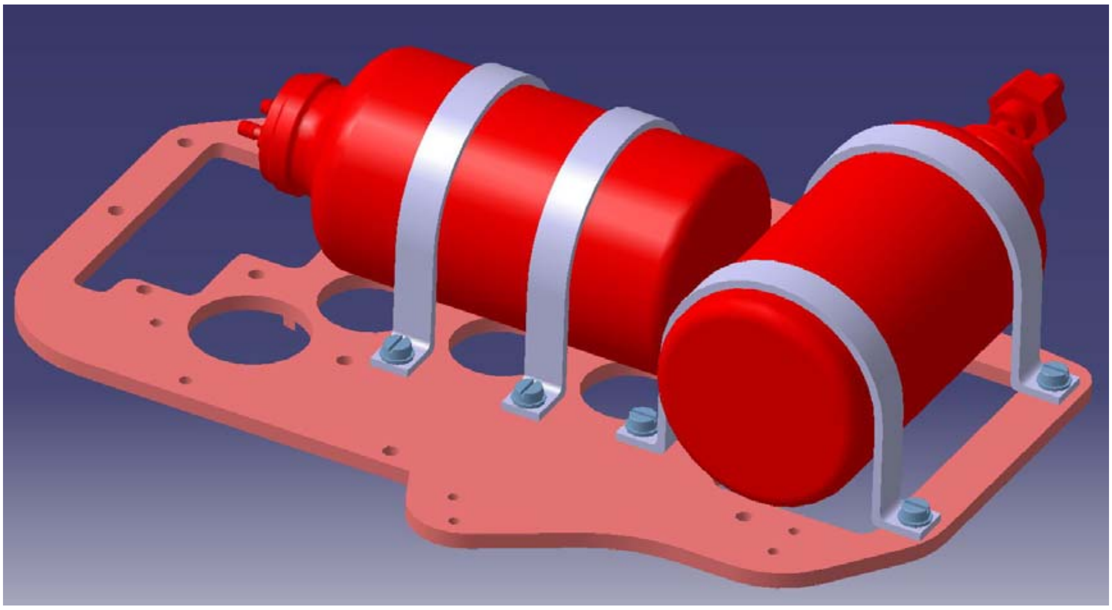


Figure 4-14: Fluid Tank & Collection Chamber fixation (picture has to be updated).

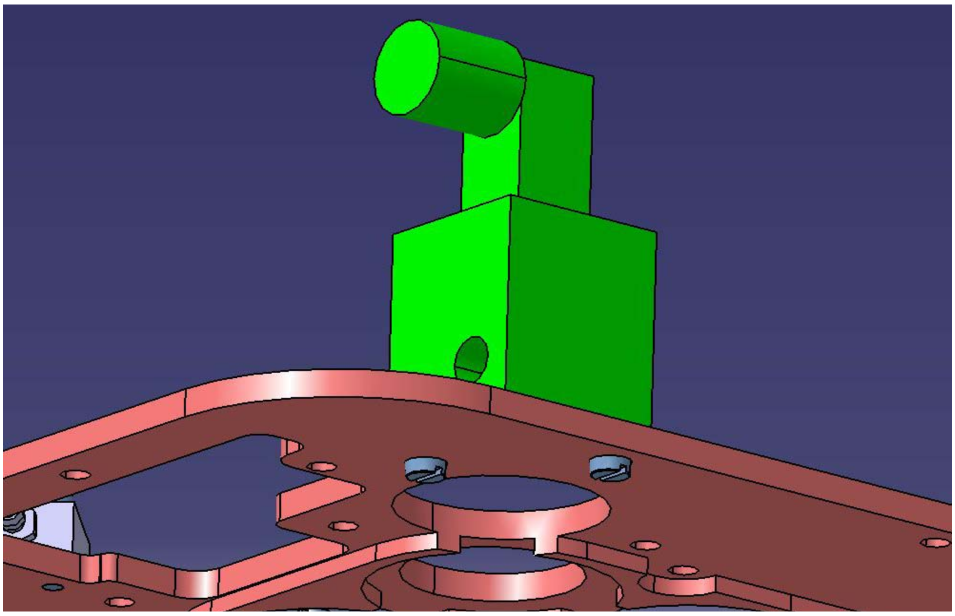


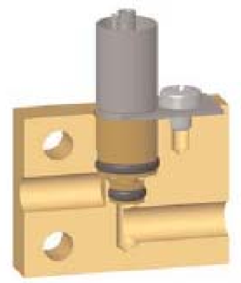
Figure 4-15: Mass Flow Sensor Connection (picture has to be updated).

Gas Tank, Fluid Supply Tanks and Collection Chambers

These components are supplied by Primus and are liquid gas bottles used for camping. They are made of aluminium and had been tested by the manufacturer to hold up to 29 bar of pressure. For the gas tank a bottle with a volume of 1 L was chosen, while the fluid supply tanks and the collection chambers only contain 0.3 L. To seal the tanks custom made caps were designed to host the appropriate connectors. The gas tank cap contains a thread to connect the tube and a Sclaverand bicycle valve, which can be used to vent or refill the tank. On the fluid supply tanks and the collection chambers the cap incorporates 2 and 4 threads for the tube connectors. Inside the fluid supply tanks a membrane separates gas and liquid. And the collection chambers host 3 membranes to collect the spill of three test chambers individually. A pressure relief valve vents the collection chambers.

As seen in Figure 4-14 one of the fluid supply tanks as well as one collection chamber are mounted on the upper plate of the structure. The other fluid supply tank and collection chamber are mounted underneath the bulkhead in the same way as the bottles on the structure. The bottles are hold in place by clamping bands that are bolted to the experiment module, the bulkhead or the upper plate of the structure. Additional triangular shaped blocks support the bottles.

Solenoid Valves



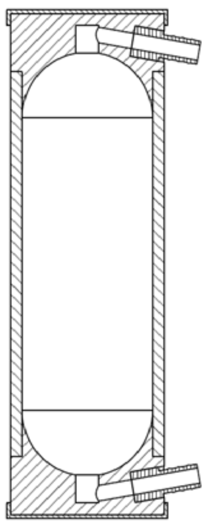
Because the experiment needs 12 solenoid valves to control the fluid flow, a small and lightweight solution is of significant importance. The Staiger Spider VA 204-7 valve provides the required functionality and flow characteristics while only weighing around 13 grams. This valve comes with a support structure containing threads to connect the tubing and holes to mount the valve.

Flow Control and Flow Measuring

In order to control the volume flow to the test chambers a flow controller needs to be installed. This component is a Bürkert Type 2822 direct acting 2/2-way proportional valve with a maximum flow rate of 450 ml/min. This flow rate provides enough margin for various flow profiles as the required flow rate for filling of a test chamber is about 180 ml/min.

A second device monitors the flow rate in the system for control purposes. This device is an oval gear flowmeter supplied by BIO-Tech.

Test Chambers



The test chambers are designed to resemble the geometry of commonly used fuel tanks in space systems. It is of a cylindrical shape with hemispherical caps.

The test chambers are designed to consist of three major parts. There are two identical bases that contain the connection to the fluid supply and a spacing where the tube can be shoved over and glued to the base. The material of the test chambers will be acrylic glass, so that the camera system can record the fluid movements inside the chamber. The test chambers are placed between the bulkhead and the upper plate of the structure. Both, the bulkhead and the upper plate of the structure, contain pockets to hold the base of the test chamber. As the structure is bolted together it will hold the test chamber in between and the pockets prevent any movement. Rubber spacings between the bulkhead and the test chamber reduce tensions in the acrylic glass due to shocks and thermal expansion.

Tubing and Connectors

For the tubing the experiment is split up into two parts, a high pressure system between the gas tank and the pressure reduction valve and a low pressure system that connects all the other components.

The system pressure in the high pressure part is specified to be in the range of 6 to 10 bar and therefore the tubes and connectors in this system were chosen to be stainless steel tubes with 6 mm outer diameter and 1 mm wall thickness and Swagelok connectors. These parts are designed to withstand pressures up to 300 bar and thus are more than sufficient for the Explore experiment's high pressure system. Also these components are very leak tight, so that no gas pressure is lost while the experiment sits on the ground.

As the pressure in the low pressure system does not exceed 2.5 bar, the above described stainless steel components would be way oversized and add a lot of weight to the experiment. So for the low pressure system PTFE hoses and the appropriate fittings were chosen. These parts are supplied by Hydrobar and are designed to withstand pressures of about 10 bar depending on the temperature. Also the PTFE hoses are flexible to a certain degree, which means that assembling is easier but the valves and other components cannot be supported by the hoses and have to be mounted separately. Hydrobar also supplies the connectors between the hoses and the respective threads of the valves and flow controllers. Only the connector to the test chambers have to be custom made because of the angle of the thread.

The connection of the hoses to the individual components is as follows: The hose is shoved over one end of the connector and hold in place by the tension forces and a layer of glue. Additionally a Teflon band is wrapped around the connection to finally secure it.

Master Safety Valve

The master safety valve is used to shut down any fluid movements during valve testing and also as service connector to refill the fluid supply tanks. This component is a 3- way tap, which allows to block every fluid movement or to connect either one of the connectors at the side with the connector at the bottom. The master safety valve also is supplied by Hydrobar.

Membrane

In the fluid supply tanks and in the collection chambers a membrane is used to separate fluid and gas. The component of choice so far is a regular party balloon. Tests conducted to this point showed satisfying results in terms of reliability in filling and emptying as well as durability in cold environments and against the anti- freeze fluid.

Fluid

The major concern with the fluid used in the experiment is freezing either during launch preparations or after landing. Therefore Glysantin is added in a 50% mixture to regular water. This mixture keeps the fluid liquid down to -40°C. A side effect of using Glysantin is that it is of pink colour and thus increases the visibility of the fluid in the test chambers.

Camera

The camera of choice to record the fluid movements is the GoPro Hero HD helmet camera. This camera comes with a waterproof casing and its own SD card to store the video information. It has a framerate of 30 fps in full high definition and a framerate of even 60 fps at a lower resolution. The camera weighs only about 170 grams including the casing. Because it is especially designed for outdoor activities it is very shock resistant. Inside the casing the camera can even be used for underwater filming and thus should withstand the vacuum conditions during the flight. The angle and focus range of this camera are sufficient for direct filming of all test chambers, so a mirror is not necessary.

Illumination

The illumination for camera recording is provided by LED modules that are behind the test chambers from the camera's point of view. These modules provide a high degree of illumination while consuming little energy. The arrangement with two LEDs per module allows a highly flexible setup of the light sources according to the needs of the experiment. Additionally these modules are waterproof. They are supplied by an internet LED shop.

Leakage Collection Device ("Diaper")

In order to prevent any liquid from leaking out of the experiment into other experiments or into the REXUS service module a fluid collection device is installed on top and below the experiment. The gauze that absorpts spilled liquids will be hold in place between two wire net installed to the experiment module by a sectioned metal ring. That way the EXPLORE experiment should not be able to compromise other experiments due to leakage of fluid.

As the leakage Collection Device seals the EXPLORE Experiment mechanically, a special arrangement for the feed through of the cables to the other experiments on top of EXPLORE has to be made. A bracket that mounts connectors for the cables to the other experiments is provided by SSC Esrange and will be installed on the Experiment Module at the top end of the EXPLORE Experiment. The EXPLORE Team the will route the cables through the experiment, so that they come out at the bottom end. Experiments on top of EXPLORE can connect their cables to the connector and thus will be connected to the REXUS Service Module.

Table 4-2: EXPLORE Experiment Mass Budget.

Mechanical			
Component	No.	Single Mass [g]	Total Mass [g]
Gas tank (Primus Fuel Bottle, 1l)	1	150.000	150.000
Cap (self made, one water connection, one bycicle valve, with o-ring)	1	18.960	18.960
Bicycle Valve (as one connector for the gas tank cap)	1	2.300	2.300
Pressure reducer	1	45.000	45.000
Cap (self made, one water connection, one gas connection, with o-ring)	2	18.960	37.920
Fluid tanks (Primus Bottle, 0.35l)	2	56.040	112.080
Mass flow Control	2	300.000	600.000
Master safety valve (fluid, item no. KH 143 V PP)	2	48.000	96.000
Test chambers (PLEXIGLAS® XT (allround), tube, transparent 0A070 GT,)	6	46.007	276.044
Test chambers (hollow hemisphere, PLEXIGLAS® XT (allround), tube, transparent 0A070 GT)	12	15.509	186.109
Cap (self made, three water connections, one gas connection, with o-ring)	2	17.471	34.942
Collection chambers (Primus Bottle, 0.35l)	2	56.040	112.080
Pressure relief valve (Item No: 855811307001)	2	33.000	66.000
Fluid valve	12	3.275	39.300
Tubing	*1*	*526.840*	*526.840*
Main structure	*1*	*9901.186*	*9901.186*

Electronics			
Component	No.	Single Mass [g]	Total Mass [g]
Pressure sensor (series 3301, Item No: 351603341125)	1	90.000	90.000
Mass flow sensor	2	40.000	80.000
Electronics	*1*	*288.700*	*288.700*
Camera GoPro Hero	2	100.000	200.000
LED Module (4 x SMD, waterproof, Item No: 025834)	5	10.000	50.000
Temperature sensor (liquid)	2	10.000	20.000

Fluids			
Component	No.	Single Mass [g]	Total Mass [g]
Test liquid - Glysantin (5l)	1	800.000	800.000

SUM [g]			**13563.460**
Margin	**10%**		**1356.346**
TOTAL MASS [g]			**14919.807**

Table 4-3: EXPLORE mass budget

The main structure as part of the mechanical components includes the REXUS experiment module (5302 g) and the REXUS standard bulkhead (1422 g) with brackets (4 pieces each with 67 g).

4.5 Electronics Design

The electrical subsystem of EXPLORE will include all valves, two cameras, one microcontroller, the pressure and temperature sensors, the mass flow controllers and sensors as well as all additional supporting cabling, connectors and electronic components.

The electronics subsystem will be divided into three segments:

- Control and command segment (incl. microcontroller, REXUS interfaces and all associated electronic components)
- Flow control segment (incl. all electronic valves as well as flow controllers)
- Sensoric segment (incl. pressure, temperature, mass flow sensors and the camera)

A schematic overview of the EXPLORE electronics layout is shown in Figure 4-16. A schematic of the printed circuit board is attached in the appendix.

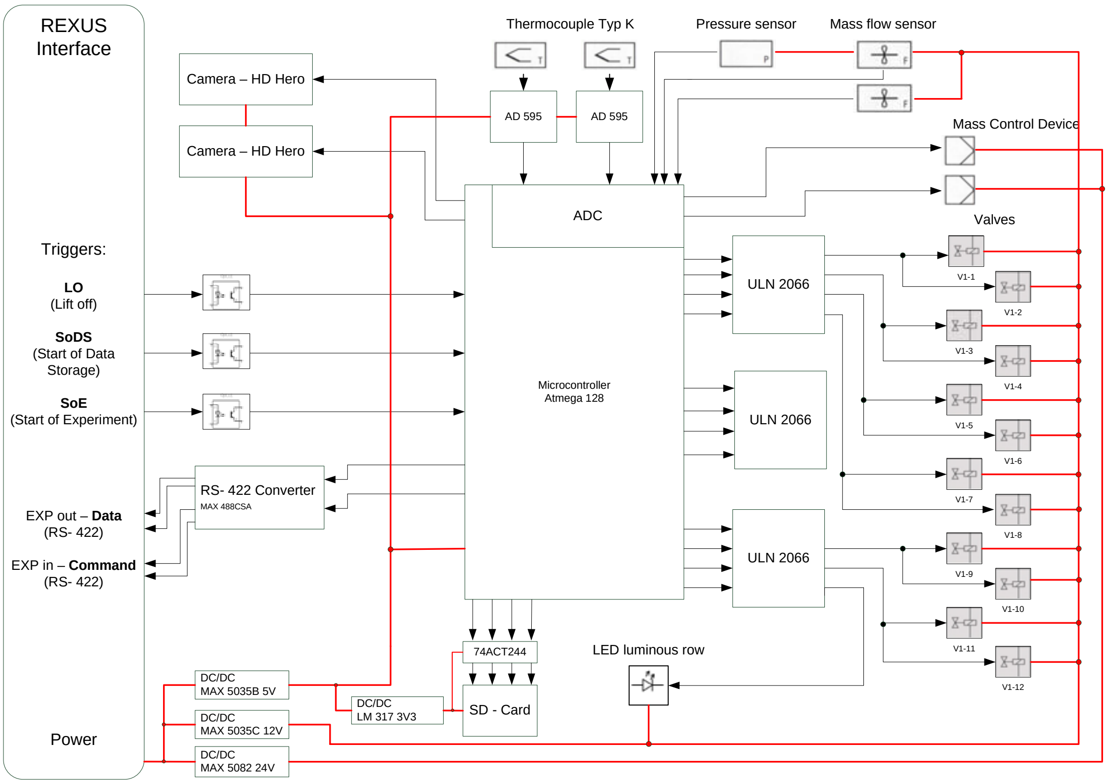


Figure 4-16: EXPLORE electrical setup schematics.

The control and command segment is dominated by the microcontroller, which will be responsible for the overall experiment control as well as the internal management of the data and the data exchange with the REXUS service module. The segment will be mounted into a single water tide electronics box comprising all necessary control logic. The heat produced by the electronics is assumed to be very little and will be absorbed and dissipated by the electronic box.

The selected microcontroller is an ATmega128, built by Atmel. The ATmega128 is a low-power CMOS 8-bit microcontroller. Amongst others it provides the following features: 128KB of In-System Programmable Flash with Read-While-Write capabilities, 4KB EEPROM, 4KB SRAM, 53 general purpose I/O lines, 32 general purpose working registers, Real Time Counter (RTC) and four flexible Timer/Counters. The software will be implemented by AVR Studio 4 using C as the computer language.

In addition to the microcontroller, the control and command segment comprises supporting electronics components like optocouplers, one SD memory card and one RS-422 connector to link to the REXUS service module as well as voltage converters for power management and distribution. The chosen ULN2066 interfaces' design needs no external power connection.

The flow control segment includes all electronic components that are in direct contact with the liquid and gaseous fluids in order to manage and control the fluid flow. These components are the 12 Staiger valves for the test chambers and the two Bürkert flow controllers.

The test chambers will use solenoid, normally-closed magnetic valves to allow for secure power-off mode of the EXPLORE experiment. Each valve simply opens as soon as power is provided to it and closes when no power is applied. Through adequate circuitry, the microcontroller ensures opening of the gas tank valve upon start of experiment and the consecutive opening of four valves at a time to enable filling of two test chambers simultaneously during flight.

The selected Staiger VA 204-7 solenoid valves operate at a voltage of 12V DC and use approximately 0.5W each. The mass flow controllers are provided by Bürkert at a power consumption of 2W each.

The sensorics segment comprises all measurement devices that collect data throughout the EXPLORE experiment. In particular, data acquisition includes video, mass flow rates, pressure and temperature measurements. The sensor systems are controlled by the microcontroller and the provided data is stored onboard the experiment local storage. A selected set of data is transmitted to the ground station via the REXUS service module in order to monitor the experiment status.

Temperature measurements will use standard thermocouples that have a long history in experimental setups. The voltage output of these thermocouples will be amplified by an AD595 chip set.

Pressure of the gas reservoir is monitored through a miniaturized pressure transducer provided by Esska. The device operates on a 12V DC power supply and provides an analogue data signal that is interpreted by the microcontroller.

Two independent flow sensors monitor the real flow rate achieved in each liquid circuit. Similar to the pressure transducers they provide a measurement signal to the microcontroller, while power has to be applied from the service module and the 12V DC/DC power converters.

EXPLORE will use two GoPro Hero HD video cameras to capture the filling process and to take a video of the REXUS rocket flight. The camera taking the video of the rocket flight will of course film the outside of the rocket and hopefully see the separated motor or nosecone. The GoPro Hero is a compact and very tough camera which is often used by people who do extreme sports like parachute jumping, mountain biking or motocross. The camera provides a USB 2.0, HDTV Out and an Audi Out for data transfer. Power will be supplied by two rechargeable Lithium-Ion batteries. If the cameras could be operated without the batteries but with power supply through USB has to be tested.

4.6 Thermal Design

The most critical component for the thermal design of the EXPLORE experiment is the test fluid. Since real propellants have been far too dangerous to be handled in this experiment, the simplest solution has been chosen as the test fluid: water. The harsh environmental conditions at the launch site during February/March can cause freezing of water as the test fluid which will lead to a fatal failure of the experiment. In order to avoid this problem we will add Glysantin ® Alu Protect/G 30 anti-freeze fluid to the water. A 50% mixture will lower the freezing temperature of the test fluid to ca. -38° C (see data sheet in appendix). This will guarantee liquidity of the test fluid during all phases of transport, integration and execution of the experiment.

Also important is the functionality of certain mechanical and electronic components of the experiment (e.g. valves, pressure sensors etc.). All of these components have been chosen to meet the thermal requirements stated in the REXUS Manual (see respective data sheet in appendix). Additional tests in the thermal test chamber of the IRS laboratory will verify the correct functionality of each component within the experiment set-up.

In order to prevent heating of the experiment from external radiation the entire set-up has been designed to have minimal contact with the external shell of the rocket. The space between the experiment and the module exterior will (especially during vacuum) insulate it from the temperature changes occurring during the flight of the rocket, thus averting unintended influences on the experiment and its results.

The main part of the experiment will not generate any heat during its operation. Only the electronics will experience a slight increase in temperature. The electronic components (e.g. DC/DC converters) have been chosen to produce only a minimal amount of heat during regular operation. Furthermore, most of the electronics will be enclosed in a casing to protect it and to prevent excessive heat transmission to other parts of the experiment and the rocket.

4.7 Power System

The power budget of the experiment is expected as shown below. The exact power consumption has to be defined through testing.

Table 4-4: EXPLORE Experiment Power Budget.

Component	Voltage [V]	Current [A]	Amount	max. Power [W]
SD-card	3.00	0.11	1	0.33
74ACT244	3.30	0.01	1	0.03
DC/DC 3V3	5.00	0.11	1	0.55
microcontroller	5.00	0.04	1	0.20
AD595	5.00	0.00	2	0.01
temperature sensor	5.00	0.03	2	0.30
LED	12.00	0.25	1	3.00
Staiger fluid valves	12.00	0.04	4	2.00
pressure sensor	12.00	0.03	1	0.30
flow sensor	12.00	0.01	2	0.30
flow controller	24.00	0.08	2	4.00
DC/DC 3V7	28.00	0.21	1	5.88
DC/DC 5V	28.00	0.18	1	5.00
DC/DC 12V	28.00	0.11	1	3.10
DC/DC 24V	28.00	0.11	1	3.08
		TOTAL POWER [W]		**28.08**

4.8 Software Design

The software runs on the microcontroller and thus controls the experiment and its components. The following diagram (Figure 4-17) gives and overview of the command and data flow of the EXPLORE experiment.

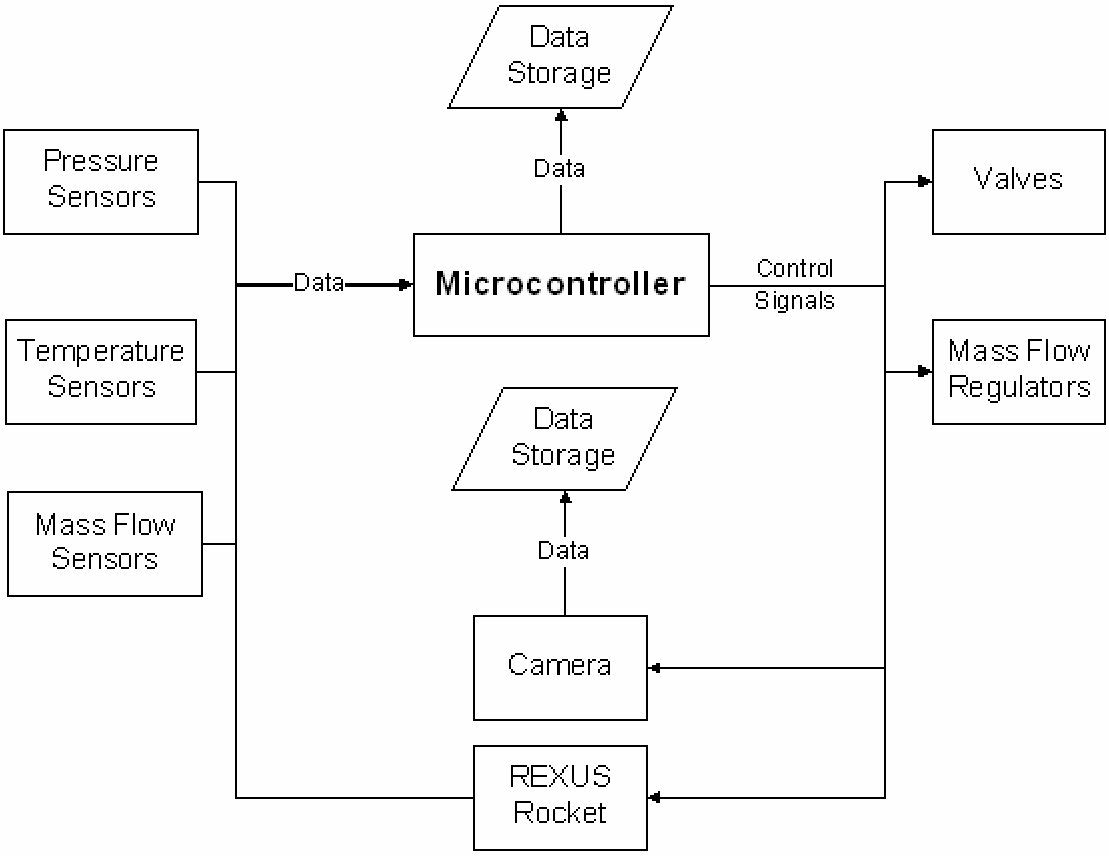


Figure 4-17: EXPLORE command and data flow.

As it can be seen in Figure 4-17 the microcontroller handles the control signal for the valves and the mass flow controllers and also manages the data recorded by the temperature, pressure and mass flow sensors. The recorded data is stored on a SD memory card. The two cameras will use their own memory cards.

Although the software of the microcontroller will include an own time plan of the experiment and a clock to be able to start the experiment when entering the micro gravity phase of the flight, it will use the signals “lift off (LO)” and “start of experiment (SOE)” of the REXUS Service Module as a backup.

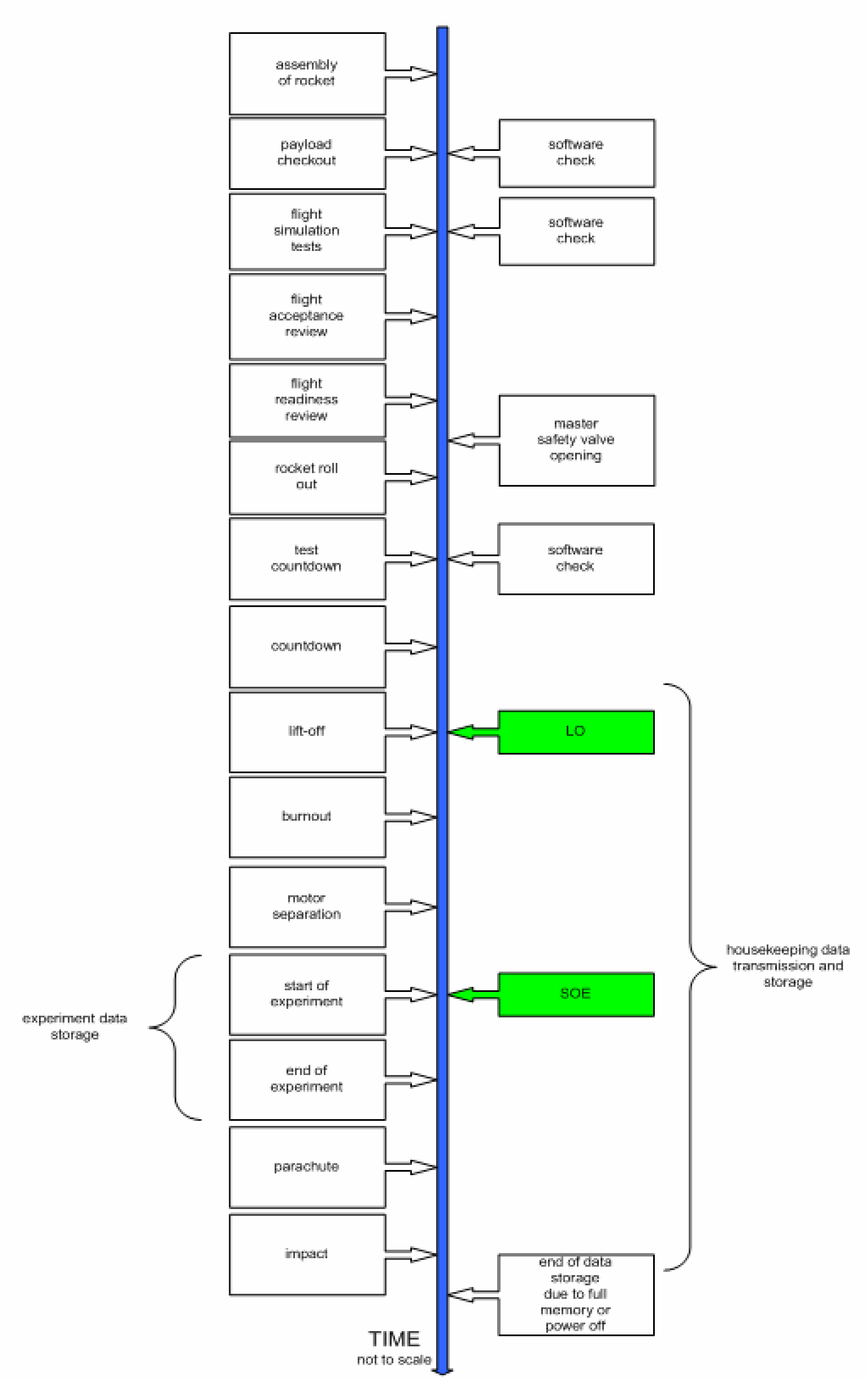


Figure 4-18: Software Timeline.

The camera taking the video of the REXUS rocket flight will be enabled by the LO signal. After the motor separation the Service Module has to transmit the SODS signal. In order to monitor the experiment the microcontroller will send some data of the sensors to the ground station via the REXUS Service Module downlink. While the housekeeping data will be recorded and transmitted once a minute the data collection frequencies will increase to about 5-30 Hz after the SODS signal.

The amount of data gathered during the experiment highly depends on the resolution and recording frequency of the camera and is still to be defined. The amount of housekeeping data sent to the ground station via the REXUS downlink will not exceed 38.4 Kbit/s.

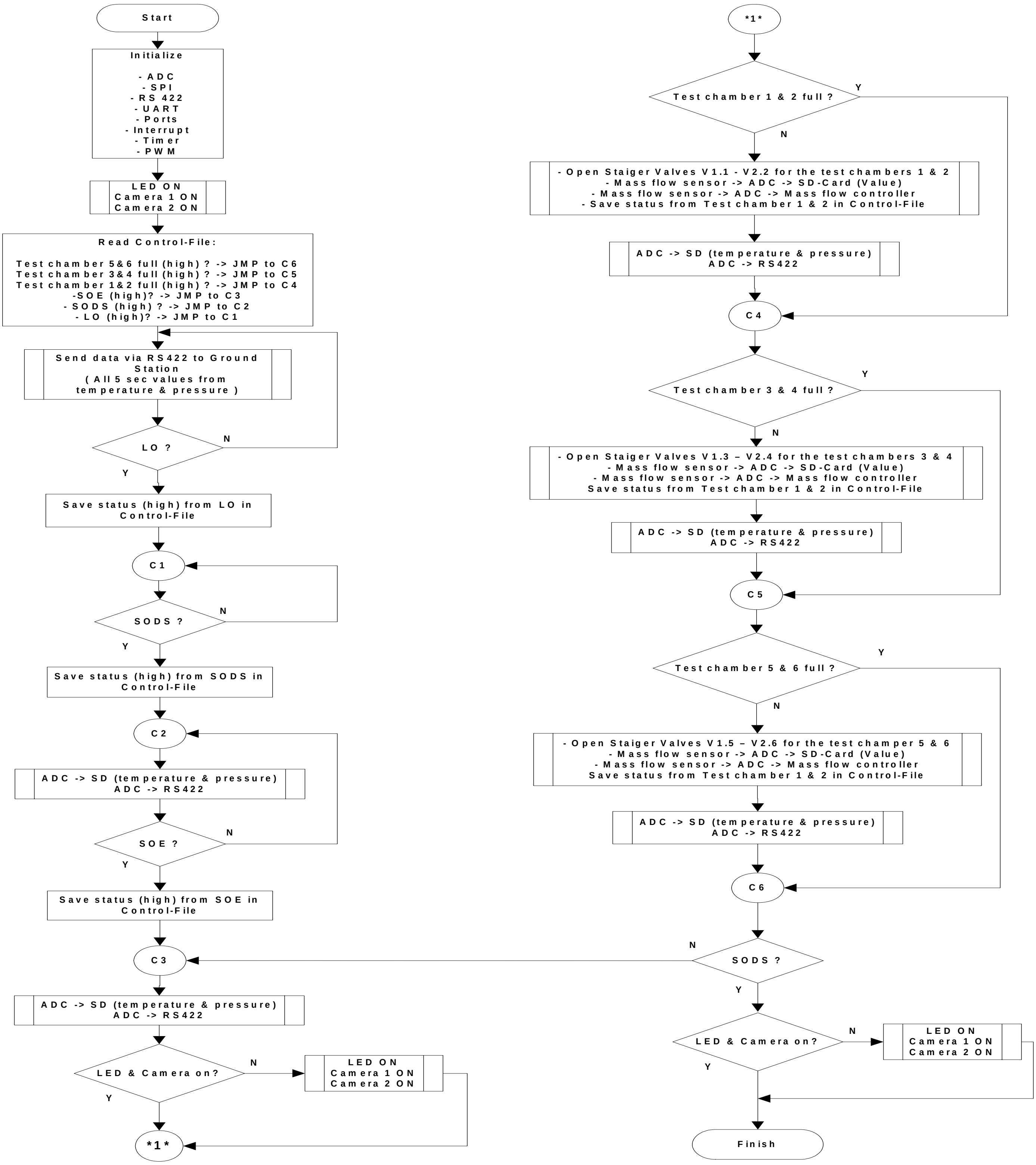


Figure 4-19: EXPLORE software flowchart.

As shown in Figure 4-19 the EXPLORE program starts with an initializing sequence. After the LED and the cameras are switched on the control file is checked. The control file is an important part of the software design. It serves as a backup file in case of a microcontroller reset after a power blackout.

The first loop waits for the LO signal. Meanwhile housekeeping data like pressure or temperature is send to the ground station. After LO and the recording of the new status into the control file the system reaches checkpoint C1. Checkpoint C2 is reached after the SODS signal and C3 after the SOE signal. The status of the LED and the cameras is again checked before test chamber filling procedure is initialized. After the first two test chambers are filled C4 is reached. The filling process is repeated until the “stop of data storage” signal. In the end the status of the LED and the cameras is again checked.

4.9 Ground Support Equipment

The EXPLORE ground support equipment shall provide all necessary technical and organisational tools for the team to prepare and conduct the launch campaign as well as to monitor and potentially command the experiment during flight. For this purpose, the following minimal support items have been identified so far:

- A laptop computer will serve as communication interface to the EXPLORE experiment during the testing phase as well as providing ground station support through receiving and interpreting the experiment telemetry during flight. Specific software packages or extensions will be developed to display the telemetry data in an adequate form and to quickly identify and react to possible noticeable problems.
- Gas tank pressurization will be achieved through an air pump in combination with the required tubing and connectors. Necessary tools have to be identified already during the integration and test campaign.
- Liquid tank filling also requires an adequate reservoir of the used fluid as well as appropriate tubing and connector elements.
- Tools for assembly and disassembly of the experiment as well as maintenance tasks.
- Camera for documentation of the launch campaign as well as another laptop computer with Internet access for news coverage and outreach activities (blog, website maintenance, sponsor contacts, etc.) throughout the campaign.
- A 28V DC power supply unit will be taken for power to the experiment during testing and flight integration as required. This needs to be complemented by adequate cabling and connectors.

- Critical spare parts for experiment components will be taken along in case of element problems during launcher integration.
- A rod with a grabber at the end which will be used to operate the mechanical safety valve using the access hole in the Experiment Module shell.

This preliminary list will be further developed in order to account for all eventualities and nominal issues throughout the launch campaign.

Details of the ground support software will be defined when telemetry data issues are fixed.

5 EXPERIMENT VERIFICATION AND TESTING

5.1 Verification Matrix

Four established verification methods (for details see: ECSS-E-ST-10-02C):

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

The following table lists all requirements and specifies their respective verification method(s).

Table 5-1: Verification Matrix

ID	*Description*	*Verification*
E.F.1	The experiment shall monitor the pressure inside the gas tank during all activated phases.	R, T
E.F.2	The experiment shall measure the temperature of the fluid during all activated phases.	R, T
E.F.3	The electronics subsystem shall ensure operational power distribution to all experiment components. Only the camera is allowed an auxiliary power storage and supply if required.	R, T
E.F.4	The electronics subsystem shall operate all electrical components in a timed sequence during flight.	R, A, T
E.F.5	The electronics subsystem shall monitor the system status during all activated phases.	R
E.F.6	The experiment shall capture video of all test chambers.	R, T
M.F.1	The experiment shall use a single gas pressure tank.	R
M.F.2	*Moved to M.P.17*	
M.F.3	*Moved to M.P.18*	
M.F.4	*Moved to M.P.19*	
M.F.5	*Moved to M.P.20*	
M.F.6	The illumination and the camera shall be coordinated to get clear and bright videos.	R, T

ID	Description	Verification
M.F.7	The experiment shall use an antifreeze fluid as propellant substitute in order to ensure liquid condition throughout experimental timeline.	I
M.F.8	The experiment shall use six test chambers.	R, I
M.F.9	The experiment shall fill all six test chambers consecutively, two at a time, within the microgravity period.	T
M.F.10	The experiment shall provide a safe pressurized system.	R
M.F.11	The experiment shall include adequate safety measures against fluid leakage.	R, I

ID	Description	Verification
E.P.1	The gas tank pressure shall be measured between 0 and 10 bar.	A
E.P.2	The gas tank pressure shall be monitored with an accuracy of 0.1 bar (TBC).	A, T
E.P.3	The gas tank pressure shall be monitored at a rate of 2 Hz.	A, T
E.P.4	The temperature levels shall be measured between -30 and 60 degrees centigrade.	A
E.P.5	*deleted*	
E.P.6	*deleted*	
E.P.7	The temperature of the fluid shall be measured with an accuracy of 0.1 K (TBC).	A, T
E.P.8	The temperature of the fluid shall be measured at a rate of 5 Hz or more (TBC).	A, T
E.P.9	The experiment power budget shall not exceed 84 W (3A @ 28V, according to REXUS user manual).	A
E.P.10	The camera field of view shall be at least 10x10 cm^2 in a distance of 5 cm.	I, T
E.P.11	*Moved to E.D.5*	
E.P.12	*Moved to E.D.6*	
E.F.7	The fluid and gas valves shall remain normally closed.	I, T

ID	Description	Verification
M.P.1	The gas tank shall allow gas pressures up to at least 10 bar (TBC).	I, T
M.P.2	The gas tank shall have a volume between 0.5 litres and 1.5 litres.	I
M.P.3	The pressure relief valve shall be able to hold the pressure of a 1 bar balance.	R, T
M.P.4	The used anti-freezing fluid shall withstand a temperature between -30 and 50 degrees centigrade.	I, T
M.P.5	*Moved to M.D.11*	
M.P.6	The flow control device shall be able to control the flow stageless in a range of 0 to 300 ml/min using an electrical signal from the microcontroller.	R, T
M.P.7	The flow measuring device shall measure volume a flow rate of 0 to 300 ml/min.	R, T
M.P.8	The fluid valves shall provide a flow rate of up to 300 ml/min.	A, T
M.P.9	The fluid and gas valves shall withstand pressure of up to at least 10 bar.	I, T
M.P.10	The pressure relief valve shall withstand pressures up to at least 10 bar.	I, T
M.P.11	The test chamber shall withstand a pressure range of up to at least 10 bar.	T
M.P.12	The flow control device shall have an accuracy of 10% or better.	R, T
M.P.13	The whole experiment setup shall withstand vibration conditions according to the REXUS manual.	A, T
M.P.14	The whole experiment setup shall withstand temperature conditions according to the REXUS manual.	A, T
M.P.15	The whole experiment setup shall withstand vacuum conditions according to the REXUS manual.	A, T
M.P.16	The fluid and gas valves shall work under vacuum conditions.	T
M.P.17 (M.F.2)	The used anti-freezing fluid shall have a reduced viscosity and surface tension compared to water.	A, I
M.P.18	The used anti-freezing fluid shall be non-toxic and	I

ID	Description	Verification
(M.F.3)	non-hazardous.	
M.P.19 (M.F.4)	The used anti-freezing fluid shall be non-corrosive with used materials.	T
M.P.20 (M.F.5)	The used anti-freezing fluid shall prevent growing of algae.	I, T
M.P.21	All pressurized components and integrated systems shall be tested up to a safety level of 2 (TBC, 1.43 requested at CDR) with regard to the maximum nominal expected pressure.	T

ID	Description	Verification
E.D.1	The electronics subsystem shall use a single control box for all components (excluding fluid control and camera).	R
E.D.2	The electronics subsystem shall provide power and data connectors according to the REXUS specifications.	R
E.D.3	The electronics subsystem shall provide power and data connectors for testing prior to launcher integration.	R
E.D.4	The experiment shall use at least one camera for video capture.	R
E.D.5 (E.P.11)	The camera shall allow for video storage on a local device (TBC).	R, T
E.D.6 (E.P.12)	The camera shall provide its own power supply and storage (TBC).	R
M.D.1	The whole EXPLORE experiment shall fit into the REXUS module.	R, A
M.D.2	The gas tank shall be safely mounted in the experiment structure.	A, T
M.D.3	The test chambers shall be of cylindrical shape and with hemispherical head covers to resemble real tank shapes.	I
M.D.4	The test chambers shall have a length to diameter ratio between 3 and 3.5 to resemble real tank	I

ID	Description	Verification
	dimensions.	
M.D.5	The test chamber shall be of transparent material allowing the camera to record fluid movements inside the test chambers.	I
M.D.6	The collection chambers shall contain a device to prevent any fluid from leaving the system.	I, T
M.D.7	The used batteries shall be qualified for the use on a REXUS rocket (TBC).	R
M.D.8	The camera batteries shall either be rechargeable or shall have sufficient capacity to run the video recording during flight after pre flight tests and flight preparations.	R, T
M.D.9	The whole experiment setup (fluid lines and tanks) shall prevent loss of fluid.	R, T
M.D.10	The test chambers shall be installed in a way to allow for easy removal (service and refill).	R, T
M.D.11 (M.P.5)	The illumination shall not dazzle the camera.	T
M.D.12	The experiment shall include fluid collection devices (e.g. pampers) to avoid fluid leakage out of the REXUS module.	R, I
M.D.13	The experiment shall be designed to operate in the vibration envelope of the REXUS rocket.	A, T
M.D.14	The experiment shall be designed to operate in the temperature profile of the REXUS rocket.	A, T
M.D.15	The experiment shall be designed to operate in the vacuum (air pressure) envelope of the REXUS rocket.	A, T
M.D.16	The experiment shall be designed to allow for safe handling of all equipment and fluids at all times.	R

ID	Description	Verification
E.O.1	The experiment shall be designed in a way to operate fully autonomously during flight.	R, T
E.O.2	The experiment shall accept a manual start command from the ground segment.	T

ID	Description	Verification
E.O.3	The experiment shall accept a manual reset command from the ground segment.	T
E.O.4	The experiment shall accept a manual shut-off command from the ground segment.	T
E.O.5	Upon shut-off command, the experiment shall switch to a safe dead-payload mode.	R, T
E.O.6	The experiment shall store all measured data onboard during flight.	T
E.O.7	The experiment shall allow telemetry monitoring of selected measurement and status data.	R
M.O.1	The experiment shall ensure safe handling of the pressurized system and provide adequate safety documentation.	R, I
M.O.2	The experiment shall allow for multiple fill and drain cycles during testing and integration.	R, T
M.O.3	The experiment shall ensure safe handling of the liquid fluid during testing and integration, including adequate filling procedures.	R, T

5.2 Test Plan

Test number	0.1
Test type	Inspection and functionality tests
Test facility	IRS laboratory
Tested item	Membrane
Test level/procedure	Testing of membrane functionality and durability (see test report TR-002)
Test duration	1 day
Date / status	21 May 2010 / **completed**

Test number	0.2
Test type	Inspection and functionality tests

Test facility	IRS laboratory
Tested item	Staiger fluid valve
Test level/procedure	Testing of achievable flow rates under a constant pressurization (see test report TR-001)
Test duration	2 days
Date / status	23 - 24 April 2010 / **completed**

Test number	0.3
Test type	Inspection and functionality tests
Test facility	IRS laboratory
Tested item	Staiger fluid valve
Test level/procedure	Testing of achievable flow rates under different pressurizations (see test report TR-003)
Test duration	1 day
Date / status	21 May 2010 / **completed**

Test number	0.4
Test type	Pressure test
Test facility	IRS laboratory
Tested item	Test chambers
Test level/procedure	Testing for air tightness up to 5 bar (includes margin of 20%)
Test duration	1 day
Date / status	Planned for calendar weeks 28, 29 / open

Test number	0.5
Test type	High Pressure Test
Test facility	IRS laboratory
Tested item	Gas tanks
Test level/procedure	Testing of the Gas Tank in terms of filling with high pressure. A safety factor of 2 should be used. Acceptance level: Undamaged pressurization of 13 bar.

Test duration	1 day
Date / status	26 June 2010 / **completed**

Test number	0.5.1
Test type	Functionality test
Test facility	IRS laboratory
Tested item	Fluid & Gas tanks, collection chambers
Test level/procedure	Testing for air tightness up to 5 bar (includes margin of 20%)
Test duration	1 day
Date / status	Planned between calendar weeks 30 and 35 / open

Test number	0.6
Test type	Functionality test
Test facility	IRS laboratory
Tested item	Camera and illumination system
Test level/procedure	Should work in a way to get clear and bright videos without dazzling the camera (see test report TR-004)
Test duration	1 day
Date / status	Planned between calendar weeks 30 and 35 / open

Test number	0.7
Test type	Functionality tests
Test facility	IRS laboratory
Tested item	Microcontroller.
Test level/procedure	TBD
Test duration	TBD
Date / status	Planned for 23 and 24 July / open

Test number	0.8
Test type	Simulation

Test facility	Laptop
Tested item	Ground Support Software shall be able to reset or shut-off the experiment if an error occurs.
Test level/procedure	TBD
Test duration	TBD
Date / Status	Planned for October/November / open

Test number	1.0
Test type	Functionality tests
Test facility	IRS laboratory
Tested item	The whole experiment setup: should operate fully autonomously.
Test level/procedure	TBD
Test duration	TBD
Date / Status	Planned for September / open

Test number	2.0
Test type	Thermal tests
Test facility	IRS laboratory
Tested item	The whole experiment setup.
Test level/procedure	Low temperature: o -10°C (when stabilized: functional test / flight sequence) High temperature: o +45°C (when stabilized: functional test / flight sequence) → during transition from low to high temperature the experiment shall be operating and recording data
Test duration	TBD
Date / Status	Planned for September / open

Test number	3.0
Test type	Vacuum tests
Test facility	IRS laboratory
Tested item	The whole experiment setup.
Test level/procedure	Vacuum conditions: below 0.5 mbar → experiment should operate during lowering the pressure → experiment data should be supervised and recorded during the test → functionality test / flight sequence when reaching 0.5 mbar → keep experiment operating at 0.5 mbar for additional 15 min to detect any leakages and overheating
Test duration	TBD
Date / Status	Planned for September / open

Test number	4.0
Test type	Thermal vacuum tests
Test facility	IRS laboratory
Tested item	The whole experiment setup.
Test level/procedure	TBD
Test duration	TBD
Date / Status	Planned for September / open

Test number	5.0
Test type	Vibration tests
Test facility	DLR Bremen
Tested item	The whole experiment setup.
Test level/procedure	Qualification level: o 10-50 Hz: 0.124 m/s, 4 octaves/min o 50-2000 Hz: 4.0 g, 4 octaves/min → each: X, Y, and Z axis Acceptance level:

	o Longitudinal: 20-2000 Hz, 6.0 g_{RMS}, 0.018 g^2/Hz o Lateral: 20-2000 Hz, 6.0 g_{RMS}, 0.018 g^2/Hz → for 20 sec → EuroLaunch recommends: 60 sec, 12.7 g_{RMS}
Test duration	TBD
Date / Status	Planned for October/November in Bremen / open

Test number	6.0
Test type	Shock tests
Test facility	ISD laboratory
Tested item	The whole experiment setup.
Test level/procedure	TBD
Test duration	TBD
Date / Status	TBD / open

Table 5-2: Test plans

All test reports are available as separate documents on the EXPLORE teamsite.

6 LAUNCH CAMPAIGN PREPARATION

6.1 Input for the Flight Requirement Plan (FRP)

6.1.1 Dimensions and Mass

Experiment mass (in kg):	14.92 kg (includes 10% margin; includes: bulkhead, module, brackets)
Experiment dimensions (in m):	0,25 x 0,335 x 0,29
Experiment footprint area (in m^2):	0,0603
Experiment volume (in m^3):	0,007
Experiment expected COG (centre of gravity) position:	X = 143.3mm, Y = -2.3mm, Z = -0.68mm Coordinate system: Axis aligned parallel to REXUS coordinate frame according to manual, reference point located at bottom center of experiment module

Table 6-1: Experiment mass and volume

6.1.2 Electrical Interfaces

REXUS Electrical Interfaces		
Service module interface required? Yes		
	Number of service module interfaces:	1
	TV cannel required?	no
Up-/Downlink (RS-422) required? Yes		
	Data rate - downlink:	19.2 Kbit/s (TBC)
	Data rate - uplink	0
Power system: Service module power required? Yes		

	Peak power consumption:	28W
	Average power consumption:	22W
	Total power consumption after lift-off (until T+800s)	5Wh
	Power ON/OFF control	2s after lift-off
	Battery recharging through service module:	No
Experiment signals: Signals from service module required? Yes		
	LO:	YES
	SOE:	2s after motor separation
	SODS:	0s

Table 6-2: Electrical interfaces applicable to REXUS

6.1.3 Launch Site Requirements

The entire experiment is designed to ensure a maximum degree of autarchy; nevertheless some minor maintenance procedures will be required before the final assembly of the REXUS rocket and its delivery to the launch pad.

The EXPLORE Team will provide all necessary tools and equipment for these procedures; therefore no specific Launch Site Requirements are needed.

To ensure liquidity of our test fluid an anti-freeze agent is added to the water. This will prevent freezing down to a temperature of -38°C. If temperatures are below this limit (-38°C) our experiment cannot be launched as a correct operation of the experiment cannot be guaranteed.

6.2 Preparation and Test Activities at Esrange

At CDR level not necessary.

6.3 Timeline for Countdown and Flight

At CDR level not necessary.

6.4 Post Flight Activities

At CDR level not necessary.

7 DATA ANALYSIS PLAN AND EXPERIMENT REPORTS

At CDR level not necessary.

7.1 Data Analysis Plan

At CDR level not necessary.

7.2 Launch Campaign

At CDR level not necessary.

7.3 Results

At CDR level not necessary.

7.4 Discussion and Conclusions

At CDR level not necessary.

7.5 Lessons Learned

At CDR level not necessary.

8 ABBREVIATIONS AND REFERENCES

8.1 Abbreviations

AIT	Assembly, Integration and Test
asap	as soon as possible
BO	Bonn, DLR, German Space Agency
BR	Bremen, DLR Institute of Space Systems
CC	Collection Chamber
CDR	Critical Design Review
COG	Centre of gravity
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	European Sounding Rocket Launching Range
ESTEC	European Space Research and Technology Centre, ESA (NL)
ESW	Experiment Selection Workshop
EXPLORE	Experiment for On-orbit Refueling
FAR	Flight Acceptance Review
FCD	Flow Control Device
FER	Final Experiment Report
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
IRS	Institute of Space Systems
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)
MSV	Master Safety Valve
OP	Oberpfaffenhofen, DLR Center
PCB	Printed Circuit Board (electronic card)
PDR	Preliminary Design Review
PRV	Pressure Reduction Valve
PREV	Pressure Relief Valve
PST	Payload System Test
SC	Service Connector
SED	Student Experiment Documentation
SER	Short Experiment Report
SNSB	Swedish National Space Board
SODS	Start Of Data Storage
SOE	Start Of Experiment
SSC	Swedish Space Corporation (EuroLaunch)
STW	Student Training Week
S/W	Software
T	Time before and after launch noted with + or –
TBC	To be confirmed
TBD	To be determined
TC	Test Chamber
WBS	Work Breakdown Structure

8.2 References

[1] Dr. J. Chung, K. Yuan: Two Phase Flow Characteristics and Boiling Heat Transfer Rates During Cryogenic Chilldown and Transport in Reduced Gravity, 2008.

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[3] F. Collins et al: The subscale orbital fluid transfer experiment.

[4] D. Chato: Technologies for Refueling Spacecraft On-Orbit, 2000.

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[13] Itikka Website, REXUS5, http://itikka.servu.org/itikka/overview/.

[14] H. Hellmann, M. Fittock: SED Guidelines, Issue 2.5, 2009.

APPENDIX A – PROJECT MANAGEMENT

The appendix can be found separately on the REXUS Teamsite.

APPENDIX B – DATASHEETS

The appendix can be found separately on the REXUS Teamsite.

APPENDIX C – ELECTRICAL SCHEMATICS

The appendix can be found separately on the REXUS Teamsite.

APPENDIX D – TEST REPORTS

The appendix can be found separately on the REXUS Teamsite.

APPENDIX E – FEM ANALYSIS

The appendix can be found separately on the REXUS Teamsite.

APPENDIX F – CAD DRAWINGS

The appendix can be found separately on the REXUS Teamsite.

APPENDIX G – SAFETY HANDBOOKS

The appendix can be found separately on the REXUS Teamsite.

APPENDIX H – REVIEW REMARKS

The appendix can be found separately on the REXUS Teamsite.