



# SED

## Student Experiment Documentation

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**Mission: REXUS 09**

**Team Name: EXPLORE**



Experiment Title: EXPeriment for Liquid On-orbit REfueling

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0	2008-12-18	New Version	Blank Book 2010
1	2010-01-21	All Chapters	PDR
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	<p>and software design.</p> <p>5.1, 5.2: Updates on Verification Matrix and Test Plan</p> <p>6.4: Updates on Post Flight Activities</p> <p>7.1, 7.2, 7.3, 7.4, 7.5: Updates on Data Analysis Plan, Implementation of Launch Campaign, Results, Discussion and Conclusions and Lessons Learned Sections</p> <p>Appendix A: Updates on Project Plan</p>	
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## 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 refueling of orbital transportation stages. The “EXPeriment for Liquid On-orbit REfueling” (EXPLORE) aims at informing the investigation of technologies and processes for these orbital refueling 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. Refueling 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 refueling 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 were filled by 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 profiles have been varied for each test chamber to identify optimal conditions for maximum test 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, one student of electronic and computer engineering from the Offenburg University of Applied Sciences, and one student of information technology from the University of Applied Sciences Aalen, Germany.



***The EXPLORE Team is Juergen Schlutz, Robert Schelling, Thorben Heinrichs, Johannes Wepler (back row, left to right), Christine Hill, Emil Nathanson, Daniel Störk, Andreas Fink (front row, left to right).***

**Keywords:** REXUS, BEXUS, SED - Student Experiment Documentation, Refueling

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## 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 refueling on orbit. The “EXPeriment for Liquid On-orbit REFueling” (EXPLORE) aims at informing the investigation of technologies and processes for these orbital refueling 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 refueling 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 velocity on the filling process and final fill level.
- Demonstration of fluid transfer between volumes, while minimizing mixture of liquid and gas phases without a separating membrane.
- Achievement of a fill level in at least one test chamber of >90%.
- Identification of the best flow velocity (as fast as possible) to achieve the objectives above.

There are several parameters, which influence the fluid tank filling process, e.g. gravity, surface tension, geometry, temperature or inflow velocity. EXPLORE used small models of state-of-the-art propellant tanks, which had the same diameter to length ratio. For example the diameter to length ratio of the Space Shuttle Transport System equals 3.51, the ratio of the ARIANE V launcher equals 3.15, while the EXPLORE test chambers used a diameter to length ratio of 3.23 (length 11 cm, diameter 3.4 cm). Herewith the transferability and scalability on bigger launching systems could be ensured.



In addition to that an inner structure was investigated for the test chambers to ensure a smooth and evenly liquid surface inside the test chambers without chaotic movement of the liquid during the microgravity phase.

Using six identical test chambers the influence of the flow rate on filling process and final fill level were investigated.

In order to minimize movable fuel tank hardware there were 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 a final filling level up to 99% using spherical test chambers EXPLORE aims to reach a fill level of >90% in at least one test chamber.

### **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 (water mixed with antifreeze fluid) 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 five LED modules (three LEDs per each LED cluster). 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 and is interacting autonomously.

After the start of the experiment two test chambers are filled at the same time. This is done three times until all test chambers are executed. The recorded housekeeping data (pressure and temperature data, status of valves, sensor and control units, camera status and rocket signals) are sent to the ground by the telemetry system of the rocket.



## 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  
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### 1.4.2 Team Members

#### **Christine Hill** - Project Management

Christine was 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 oversaw the technical design of the EXPLORE experiment. He's also our CAD expert and responsible for all the nice 3D representations. Beside that all FEM calculations as well as the Ground Support Software were made by Andi.

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 was mainly responsible for the EXPLORE test campaign. He managed 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 ensured that the world knows about our experiment as our PR and outreach contact. He searched for sponsors, communicated with the press, managed the EXPLORE website, and initiated local and regional events.

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 was the EXPLORE hardware manager. He coordinated the selection and manufacture of all hardware items during the project development as well as the required support equipment for the launch campaign. He also supported Emil and Robert with the necessary testing.

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 was our fluid dynamics expert and responsible for the theoretical foundations of the EXPLORE experiment. His calculations drove the mechanical design and the experiment process flow. He also supported Emil and Johannes with the necessary testing.

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 a non-aerospace member of the team, Daniel brought in his expertise in electronics and ensured power and control for the experiment at all times. His responsibilities included 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.

#### **Thorben Heinrichs** – Software Design Management

Thorben is the second non-aerospace member of the team (although he has past aerospace experience), he enforced the team with his expertise in software development. His responsibilities included software design for on-board, ground support and post-flight analysis software.

Thorben has joined the team in October 2010. He studies information technology at the University of Applied Sciences Aalen in his second year.

## 2 EXPERIMENT REQUIREMENTS

This chapter will handle the functional, performance, design and operational requirements, which have been 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.*

<b>ID</b>	<b>Description</b>	<b>Response to.</b>
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	<i>Moved to M.P.17</i>	
M.F.3	<i>Moved to M.P.18</i>	
M.F.4	<i>Moved to M.P.19</i>	

<b>ID</b>	<b>Description</b>	<b>Response to.</b>
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.*

<b>ID</b>	<b>Description</b>	<b>Response to.</b>
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.	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	<i>Deleted</i>	E.F.2
E.P.6	<i>Deleted</i>	E.F.2
E.P.7	The temperature of the fluid shall be measured with an accuracy of 1K.	E.F.2
E.P.8	The temperature of the fluid shall be measured at a rate of 5 Hz or more (TBC).	E.F.2
E.P.9	The experiment power budget shall not exceed 84 W (3A @ 28V, according to REXUS user manual).	E.F.3

<b>ID</b>	<b>Description</b>	<b>Response to.</b>
E.P.10	The camera field of view shall be at least 10x10 cm <sup>2</sup> in a distance of 5 cm.	E.D.4
<i>E.P.11</i>	<i>Moved to E.D.5</i>	
<i>E.P.12</i>	<i>Moved to E.D.6</i>	
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 15 bar.	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.	
<i>M.P.5</i>	<i>Moved to M.D.11</i>	
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.	
<i>M.P.7</i>	<i>Deleted</i>	<i>(new v4.1)</i>
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.	
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

<b>ID</b>	<b>Description</b>	<b>Response to.</b>
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 1.43 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.*

<b>ID</b>	<b>Description</b>	<b>Response to.</b>
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 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.	E.F.6, E.D.4
E.D.6	<i>Deleted</i>	E.F.3

<b>ID</b>	<b>Description</b>	<b>Response to.</b>
(E.P.12)		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 tanks.	
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	<i>Deleted</i>	
M.D.8	<i>Deleted</i>	
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
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.	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.*

<b>ID</b>	<b>Description</b>	<b>Response to.</b>
E.O.1	The experiment shall be designed in a way to operate fully autonomously during flight.	E.F.4
<i>E.O.2</i>	<i>Deleted</i>	
<i>E.O.3</i>	<i>Deleted</i>	
<i>E.O.4</i>	<i>Deleted</i>	
<i>E.O.5</i>	<i>Deleted</i>	
<i>E.O.6</i>	<i>Deleted</i>	
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 documentation.	M.D.16 <i>(new v2.1)</i>
M.O.2	The experiment shall allow for multiple fill and drain cycles during testing and integration.	M.D.16 <i>(new v2.1)</i>
M.O.3	The experiment shall ensure safe handling of the liquid fluid during testing and integration, including adequate filling procedures.	M.D.16 <i>(new v2.1)</i>

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## 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.

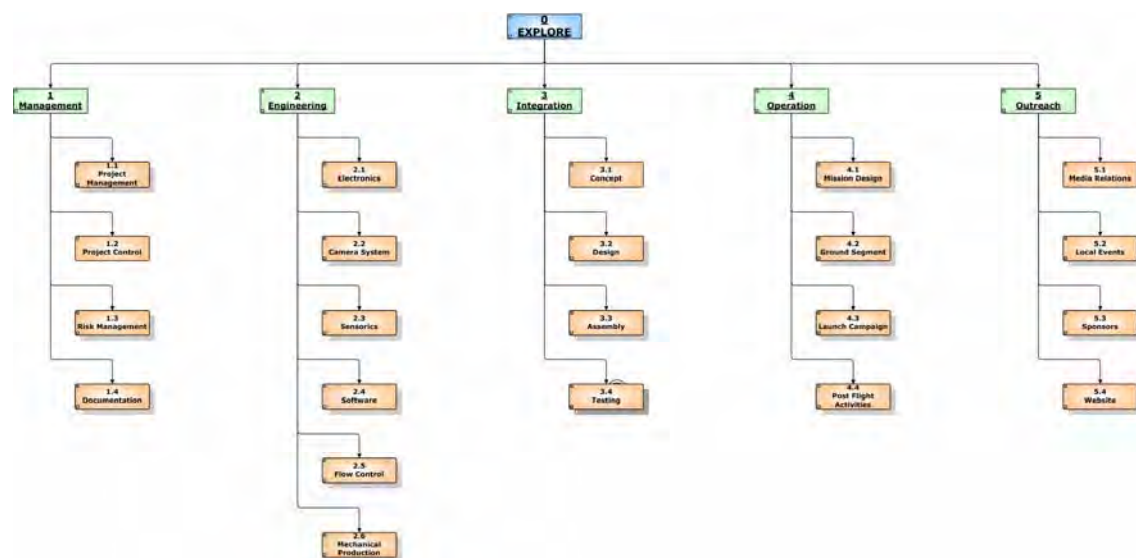
The “Management” work package is still in progress since this work package is part of the whole project. It will end with the submission of the final SED version in mid June 2011, when the EXPLORE project will be finished.

The “Engineering” work package is finished including all defined components. Components like the test chambers and the structure have been manufactured including the inner structure

The concept and design of the EXPLORE experiment as a part of the “Integration” work package are finished. Component tests and a full functionality test with all relevant components (including video and illumination tests) have been fulfilled. A functionality test in combination with the flight electronics was also successfully performed. The thermal-vacuum-, as well as the shaker test have been performed at the IRS and the DLR in Stuttgart. For more details see chapter 5. The final assembly of the EXPLORE experiment took place in the workshops at the University of Stuttgart and is finished.

The “Outreach” work package is still under progress since it is an ongoing process. It will end with the submission of the final SED version in mid June 2011, when the EXPLORE project will be finished. More information about the outreach work that has been performed can be found in chapter 3.4.

The “Operation” work packages are finished since the main operational work took place during the launch campaign in Kiruna, North Sweden from 14 February 2011 till 27 February 2011. The mission design and ground segment were defined and prepared for the launch campaign. The actual flight of the EXPLORE experiment took place on February 22<sup>nd</sup> 2011 onboard the REXUS 9 rocket and was successful. Post flight activities already started with the evaluation and presentation of the experiment results at the 20<sup>th</sup> ESA symposium on European Rocket and Balloon Programs and Related Research in Hyères, France, from 22 May 2011 till 26 May 2011. The experiment results will also be presented at the upcoming European Low Gravity Research Association (ELGRA) symposium in Antwerp, Belgium from 6 September 2011 till 9 September 2011, as well as on the International Astronautical Congress (IAC) in Cape-Town, South Africa from 3 October 2011 till 7 October 2011. The FRP as well as all necessary preparation work can be found in chapter 6.



*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, as well as the manufacturing of all needed components have been finished. In addition the operational processes were performed during and after the launch campaign in February 2011. Therefore the EXPLORE experiment is mostly finished, except for two due papers.

## 3.3 Resources

### 3.3.1 Manpower

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

Christine Hill was 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 – was responsible for the “Engineering” and “Integration” work packages. In particular he was responsible for the overall design of the EXPLORE experiment (including all CAD drawings) All FEM calculations as well as the Ground Support Software were made by him

Emil Nathanson dealt 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) was part of his work.



Juergen Schlutz managed the all outreach activities with all its included work packages: media relations, local events, sponsors and the website.

Johannes Wepler mainly handled the “Ground Support” work package, including all tasks. Besides this he was also responsible for several design and testing parts.

Robert Schelling in particular was responsible for the design of the test chambers (including inner design and filling profiles). The therefore needed flow calculations were also part of his work package.

Daniel Stoerk dealt with the design, assembly and testing of the electrical design for the EXPLORE experiment. Besides this he was programming the onboard software and was therefore also responsible for the “Software” work package.

Since October 2010 a new team member joined the EXPLORE team to support us with software know how. Thorben Heinrichs dealt with the programming of the communications between the REXUS rocket and the Ground Support Software as well as debugging the on board software to perform the experiment.

### **3.3.2 Budget**

As all components have been defined and all sponsoring was received a budget listing for the EXPLORE experiment can be found below. It is divided into three main sections, with the total budget income and outgoings, an income listing, as well as an outgoing listing. Please note: An indication of the sponsored hardware costs could not be realized for all components. Since the income and outgoings for these components are identical, the prize was fixed as 0 € for these components. Please note that not all travel expenses are listed for the EXPLORE experiment. In particular travel costs for several test weekends in Stuttgart and Offenburg are not included in the cost calculation of the EXPLORE experiment.

**Table 3-1: EXPLORE Experiment Cost Budget - Total.**

EXPLORE Status	Assured	Received	Spent
<b>INCOME</b>	14.882,65 €	14.882,65 €	14.181,00 €
<b>OUTGOINGS</b>	-14.181,00 €	-14.181,00 €	-14.181,00 €
<b>SUM</b>	<b>701,65 €</b>	<b>701,65 €</b>	<b>0,00 €</b>

**Table 3-2: EXPLORE Experiment Cost Budget – Income listing.**

Short	Description	Type	Assured	Received	Spent	Available
<b>LBBW</b>	LBBW Sponsoring	Sponsoring	2.500,00 €	2.500,00 €	2.499,96 €	0,04 €
<b>YN10</b>	Yuri's Night Sponsoring / Income	Sponsoring	595,00 €	595,00 €	595,00 €	0,00 €
<b>EBS</b>	Erich-Becker-Stiftung	Sponsoring	2.000,00 €	2.000,00 €	2.242,30 €	-242,30 €
<b>WBS</b>	Walther-Blohm-Stiftung	Sponsoring	3.000,00 €	3.000,00 €	2.825,62 €	174,38 €
<b>DLR</b>	DLR Sponsoring	Sponsoring/Hardware	1.345,77 €	1.345,77 €	1.345,77 €	0,00 €
<b>SWS</b>	Studentenwerk Stuttgart e.V.	Sponsoring	2.890,00 €	2.890,00 €	2.120,48 €	769,53 €
<b>BIotech</b>	BIotech Sponsoring	Hardware	199,75 €	199,75 €	199,75 €	0,00 €
<b>BEST</b>	Swagelok Sponsoring	Hardware	72,29 €	72,29 €	72,29 €	0,00 €
<b>Hydrobar</b>	Hydrobar Sponsoring	Hardware	0,00 €	0,00 €	0,00 €	0,00 €
<b>Pig</b>	New Pig Sponsoring	Hardware	10,00 €	10,00 €	10,00 €	0,00 €
<b>GoPro</b>	GoPro-Shop.com Sponsoring	Hardware	1.059,80 €	1.059,80 €	1.059,80 €	0,00 €
<b>SFS</b>	SFS Fluidsysteme Sponsoring	Hardware	12,00 €	12,00 €	12,00 €	0,00 €
<b>Atmel</b>	Atmel Sponsoring	Hardware	0,00 €	0,00 €	0,00 €	0,00 €
<b>Schwalbe</b>	Schwalbe Sponsoring (Ralf Bohle GmbH)	Hardware	0,00 €	0,00 €	0,00 €	0,00 €
<b>Staiger</b>	Staiger Sponsoring	Hardware	0,00 €	0,00 €	0,00 €	0,00 €
<b>Aalen</b>	FH Aalen Sponsoring	Sponsoring	423,00 €	423,00 €	423,00 €	0,00 €
<b>Thorben</b>	Travel Costs Thorben	Sponsoring	516,04 €	516,04 €	516,04 €	0,00 €
<b>Juergen</b>	Own Outgoings	Sponsoring	259,00 €	259,00 €	259,00 €	0,00 €
<b>SUM</b>			<b>14.882,65 €</b>	<b>14.882,65 €</b>	<b>14.181,00 €</b>	<b>701,65 €</b>

**Table 3-3: EXPLORE Experiment Cost Budget – Outgoings listing.**

No.	Company	Position	RE-No.	Date	Sum	Paid by
1	Gröner	Shirts	RE 41621426	20.01.2010	79,09 €	LBBW
2	Wiesinger Media	T-Shirt-Print	bar	28.01.2010	81,40 €	LBBW
3	SAS, NO, Esrange	Travel costs Kiruna (Jürgen)	verschiedene	08.02.2010	560,17 €	EBS
4	Swiss, HK, NO, Esrange	Travel costs Kiruna (Johannes)	verschiedene	08.02.2010	610,52 €	EBS
5	Electronic Sensor	3 Temp-Sensors	RE 306266	18.03.2010	114,12 €	LBBW
6	Ralf Bohle GmbH	Schalbe valves	Sponsoring	31.03.2010	0,00 €	Schwalbe
7	Pollin	ATmega, Evaluations-Board	RE 05197176	01.04.2010	31,17 €	WBS
8	Evonik	Plexiglas, glue	Sponsoring / DLR	06.04.2010	64,63 €	DLR
9	Gröner	Shirts Stammi, Fitts, Olle	RE 41647474	16.04.2010	34,92 €	LBBW
10	Gröner	Shirt Leonore	RE 41651054	21.04.2010	11,55 €	LBBW
11	Idealux	LEDs (double cluster)	RE 2237	22.04.2010	20,05 €	LBBW
12	Die Speiche	Pressure Sensor	RE 25630	23.04.2010	14,90 €	LBBW
13	Conrad	ATmega	bar	23.04.2010	8,86 €	WBS
14	OBI	Cable strap, pump	bar	23.04.2010	45,83 €	LBBW
15	Gröner	Shirt Daniel	RE 41648930	27.04.2010	11,79 €	LBBW
16	SFS Fluidsysteme	Pressure reducer	Sponsoring	27.04.2010	12,00 €	SFS
17	2M-Security	HD Hero	RE 11784	05.05.2010	309,00 €	LBBW
18	Pankoke & Roll	Glystantin	RE 054542	07.05.2010	11,90 €	LBBW
19	Wiesinger Media	T-Shirt-Print	bar	10.05.2010	73,78 €	WBS
20	Digi-Key	Electronic parts for test board	RE 31470082	19.05.2010	32,03 €	LBBW
21	Hydrobar	Threaded nozzle and clamps	RE HB-44608	21.05.2010	285,00 €	LBBW
22	ba IT-Service	Website Hosting	RE 0042/2010	01.06.2010	142,80 €	LBBW
23	ba IT-Service	Website Design	RE 0043/2010	01.06.2010	595,00 €	YN10
24	Diverse	Travel costs (Daniel, Bar)	bar	08.06.2010	117,79 €	WBS
25	Bauhaus	Wooden model	bar	24.06.2010	23,41 €	LBBW
26	Hydrobar	Tubing, sealing, etc.	RE HB-45177	28.06.2010	177,79 €	LBBW

No.	Company	Position	RE-No.	Date	Sum	Paid by
27	Swagelok	T-connector	Sponsoring	05.07.2010	72,29 €	BEST
28	BIOtech	Flow sensor	Sponsoring	08.07.2010	199,75 €	BIOtech
29	Staiger	15 valves	RE 2102379	09.07.2010	1.104,38 €	LBBW
30	Frischemarkt Roth	Food ITLR workshop	bar	15.07.2010	11,97 €	WBS
31	Eskip	Electronic Board	RE 459	20.07.2010	24,84 €	WBS
32	Bauhaus	Organizer, screws, etc.	bar	21.08.2010	18,49 €	WBS
33	GoPro-Shop	HD Hero cameras	Sponsoring	25.08.2010	619,90 €	GoPro
34	BIOtech	Flow sensor	RE 201009/7629	07.09.2010	199,75 €	WBS
35	Eskip	Electronic Board	RE 524	07.09.2010	28,73 €	WBS
36	Evonik	Plexiglas foil	RE 2014057670	16.09.2010	23,94 €	WBS
37	Digi-Key	Electronic components	RE 32646995 1	15.09.2010	178,87 €	WBS
38	UPS	Sending Daniel	RE 500000024435	16.09.2010	34,11 €	WBS
39	Bauhaus	Tools, etc.	bar	18.09.2010	112,80 €	WBS
40	Acryline	Plexiglas spheres	RE 1002428	29.09.2010	98,50 €	WBS
41	Metall-Service Berli	Aluminum tubing	RE 433505	30.09.2010	140,42 €	WBS
42	Staiger	O-Rings	Sponsoring	06.10.2010	5,00 €	Staiger
43	Deutsche Bahn	Tickets (IPR Tine, Jürgen)	bar	07.10.2010	192,00 €	Juergen
44	Idealux	LEDs (3 cluster)	RE 3312	07.10.2010	20,05 €	WBS
45	Dräger Kabel	Cables	bar	07.10.2010	7,50 €	WBS
46	Bauhaus	Screws	bar	09.10.2010	8,13 €	WBS
47	Price-Guard	Glystantin	8K950616Y1443414M	11.10.2010	11,67 €	WBS
48	Kaufland	Food IPR	bar	12.10.2010	17,49 €	WBS
49	Amazon	External Storage Device	RE D2jK4MqTR	13.10.2010	130,39 €	WBS
50	Reichelt Elektronik	USB-Serial-Adapter	RE I-764857	26.10.2010	23,05 €	WBS
51	Electronic Sensor	2 Temp-Sensors	RE 307107	28.10.2010	79,61 €	WBS
52	Atmel	Programmer, Boards, Microcontroller	Sponsoring	02.11.2010	0,00 €	Atmel
53	Bauhaus	Pads	bar	03.11.2010	18,00 €	WBS
54	Frischemarkt Roth	Condoms	bar	03.11.2010	5,59 €	WBS

No.	Company	Position	RE-No.	Date	Sum	Paid by
55	ELB Eloxalwerk Ludwigsb.	Anodizing	RE 22000-019515	03.11.2010	86,54 €	WBS
56	Digi-Key	Electronic components	RE 33178611 1	05.11.2010	298,24 €	WBS
57	UPS	Sending Daniel	RE 500000043951	07.11.2010	56,92 €	WBS
58	Conrad	Electronic boxes	bar	08.11.2010	21,39 €	WBS
59	Ralf Bohle GmbH	Valve components	Sponsoring	11.11.2010	0,00 €	Schwalbe
60	Conrad	Electronic components	bar	12.11.2010	19,92 €	WBS
61	Bauhaus	Cable straps, Adapter	bar	13.11.2010	22,20 €	WBS
62	Kaufland	Food Test WE, Balloons	bar	13.11.2010	12,18 €	WBS
63	Deutsche Post	Sending Daniel	bar	15.11.2010	11,90 €	WBS
64	Bauhaus	Organizer	bar	17.11.2010	18,90 €	WBS
65	GoPro-Shop	HD Hero 960 cameras	Sponsoring	17.11.2010	439,90 €	GoPro
66	Staiger	5 Valves	RE 2104098	18.11.2010	393,47 €	SWS
67	Hydrobar	Tubing, Sealing	RE HB-47819	19.11.2010	94,12 €	WBS
68	Conrad	Measurement Devices	bar	19.11.2010	97,49 €	WBS
69	Bauhaus	Sending components for EAR	bar	20.11.2010	25,32 €	WBS
70	Diverse	Gas (Daniel, Bar)	bar	22.11.2010	134,55 €	WBS
71	Beta Layout	Electronic board	--	23.11.2010	249,30 €	WBS
72	Reichelt Elektronik	Programmer Atmel	RE 2966463	24.11.2010	58,39 €	WBS
73	Bossert	2-component glue	RE 3011225	26.11.2010	51,86 €	WBS
74	Kopier-Service Eigelsteintor	T-Shirt-Print	bar	17.12.2010	60,00 €	SWS
75	Gröner	Shirts Thorben, Michael, Bernd	RE 41731635	22.12.2010	14,30 €	WBS
76	Reichelt Elektronik	Tools	RE I-968912	11.01.2011	57,41 €	SWS
77	Amazon	Tools	302-3373454-9748352	11.01.2011	22,98 €	SWS
78	Kaufland	Food Kiruna (Johannes, bar)	bar	12.01.2011	113,24 €	WBS
79	Amazon	Tools	302-0718948-2532313	12.01.2011	7,95 €	SWS
80	Conrad	USB-Serial-Adapter	bar	15.01.2011	21,95 €	SWS
81	SAS	Flight Kiruna Jürgen	117-2116635053-54	28.01.2011	458,03 €	SWS

No.	Company	Position	RE-No.	Date	Sum	Paid by
82	SAS	Flight Kiruna Tine	117-2116635051-52	28.01.2011	458,03 €	EBS
83	Staiger	2 Valves	RE 100-00000256	31.01.2011	154,46 €	SWS
84	Schulzeshop	8 T-Shirts for Launch Campaign	20640026	01.02.2011	124,65 €	SWS
85	Dit-un-Dat	T-Shirt-Print	bar	10.02.2011	120,00 €	SWS
86	El Giganten	SD cards 32 GB	bar	16.02.2011	344,07 €	DLR
87	Estrange Space Center	Hotel Launch Campaign (Juergen)	RE 19712	25.02.2011	613,58 €	SWS
88	Estrange Space Center	Hotel Launch Campaign (Tine)	RE 19711	25.02.2011	613,58 €	EBS
89	Estrange Space Center	Hotel Launch Campaign (Thorben)	RE 19713	25.02.2011	516,04 €	Thorben
90	Digi-Key	USB-Serial-Adapter	--	--	13,36 €	WBS
91	BIOTech	Flow sensor	DLR	--	199,75 €	DLR
92	Esska	Safety valves, Pressure sensor	DLR	--	216,58 €	DLR
93	New Pig	Absorption tissue	Sponsoring	--	10,00 €	Pig
94	Swagelok u.a.	Tubing, Fittings, etc.	Sponsoring	--	0,00 €	DLR
95	SAS	Flight Kiruna Thorben	Sponsoring	--	423,00 €	Aalen
96	Statoil	Gas Kiruna (Olles Auto)	bar	19.02.2011	14,60 €	SWS
97	Buchbinder	Rental Car and gas Integration Week	DLR	13.12.2011	520,74 €	DLR
98	ba IT-Service	Website Hosting	RE 0012/2011	23.03.2011	71,40 €	SWS
99	Commundo Tagungshotel	Hotel Stuttgart IPR	RE 550129986	19.11.2010	67,00 €	Juergen
100	PAC Symposium	Registration Fee	--	20.05.2011	500,00 €	DLR
101	Etap Hotel Hyères, France	PAC Symposium	--	27.05.2011	279,00 €	DLR
102	Avis Rental Car	PAC Symposium including gas and fees	--	31.05.2011	1.050,00 €	DLR
	<b>SUM</b>				<b>16.015,00 €</b>	

Travel costs
Other costs

Mechanic Parts/Connectors
Electronic Parts/Connectors

Fluid
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### 3.3.3 External Support

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

At the final stage, the team was supported by:

- The Ministry of Economics (BMWi) through the German Aerospace Center (DLR). DLR was 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 provided 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 provided technical advice in the area of refueling 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 manufactured most of the customized EXPLORE parts.
- Development and management of the EXPLORE website was 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, supported the EXPLORE team with their expertise in fuel handling and provided 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) supported 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 was also used to fill and pressurize the EXPLORE gas section.



- B.I.O-TECH e.K. supported EXPLORE as specialist for fluid sensorics. They provide miniature mass flow meters to monitor the exact propellant flow rate during the rocket flight.
- The Walther-Blohm-Stiftung supported EXPLORE financially for the procurement of experiment hardware and electronics as well as for the covering of general team costs due to outreach activities and travel costs.
- GoPro-Shop.com supported EXPLORE as an official distributor of GoPro HD camera products in Germany. They provided GoPro HD Hero helmet cameras for high quality video coverage of the experiment and flight.
- Staiger fluid systems supported EXPLORE by the provision of special discounts in the procurement of miniature fluid valves and by provision of additional mounting support elements and expertise.
- Hydrobar Hydraulik und Pneumatik GmbH of Boeblingen/Sindelfingen supported the EXPLORE experiment with their extensive fluid system expertise and by providing tubing hardware to the team.
- New Pig of Hazeldonk, the Netherlands, is an expert in absorption products and provided absorption pads to EXPLORE as fluid collection devices.
- The Studentenwerk Stuttgart e.V. is a local organization to support and to enable student projects at the University of Stuttgart and abroad. The Studentenwerk confirmed financial support to the team for hardware procurement and travel expenses.
- The Erich-Becker-Stiftung supported EXPLORE financially for the covering of general team costs due to outreach activities and travel costs.

### **3.4 Outreach Approach**

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

#### **3.4.1 Website**

The EXPLORE web presence was and still 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 refueling 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 became more populated once the experiment work progressed.

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

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

**Table 3-4:** Sitemap of the EXPLORE web presence.

<b>Site</b>	<b>Description / Contents</b>
1. HOME	Welcome, recent news, a few links, a launch counter (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, conferences, etc.
4. LIVE FROM KIRUNA	A launch counter and some information on the launch campaign in Kiruna, as well as a live stream from the labs.
4.1 WEEK 1	Daily news from the first week in Kiruna during the launch campaign.
4.2 LAUNCH VIDEOS	Flight videos from the launch campaign.
5. THE EXPERIMENT	Discussion of the experiment and its context.
5.1 REXUS/BEXUS	A few words on the rocket and the campaign, with links to DLR.
5.2 CONCEPT	Experiment design, images, etc.
5.3 ROCKET	General information on the REXUS 9 rocket.
5.4 FLIGHT PROFILE	General information about the flight profile of the REXUS rocket as well as specific information on the EXPLORE timeline.
5.5 MILESTONES	Important dates and an overview of the project timeline.
6. IMAGES	Images of the team, workshops, and experiment.

Site	Description / Contents
6.1 EXPERIMENT	Images of the experiment.
6.2 EVENTS	Images of all workshops and events.
6.3 TEAM	Images of the team.
7. YOUR NAME IN SPACE	One of our outreach efforts to stimulate public participation in EXPLORE.
8. PARTNERS/SPONSORS	Logos and links for sponsors and partners.
9. DOWNLOADS	Download our information brochure as well as related info and press releases.
10. LINKS	Links to relevant pages and organisations.

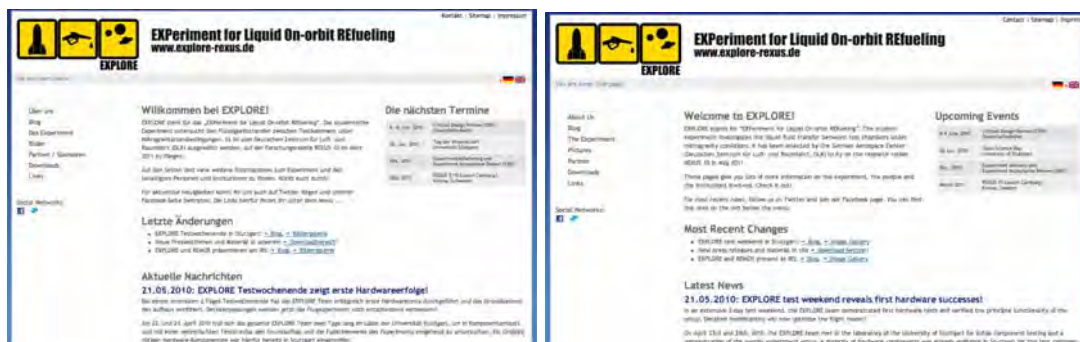


Figure 3-2: Screenshot of the EXPLORE website in German (left) and English (right).

In addition to the EXPLORE website itself, EXPLORE has been and continues to be very visible on the internet in social networks, in particular through active pages at:

- Facebook fanpage: <http://www.facebook.com/pages/EXPLORE/273539127111?ref=search>
- Twitter news updates: [http://twitter.com/EXPLORE\\_REXUS](http://twitter.com/EXPLORE_REXUS)
- YouTube channel: <http://www.youtube.com/ExploreRexus>

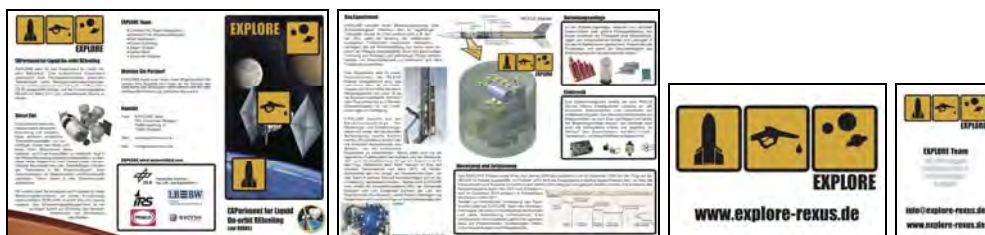
### 3.4.2 Public

A particular example of a public outreach project was the “**Your Name in Space**” project of EXPLORE. This project was initiated at the REXUS Public Day (see below) and allowed interested individuals and partners to submit their name and contact details. These names were then included electronically in the EXPLORE experiment and went on the REXUS trip together with the hardware. After successful flight, a certificate of participation was made available on the website to all participants to proof their support to

the EXPLORE project. Furthermore, the participants received 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. Since June 2010, this list was also available on the EXPLORE website for everyone to see their participation, while new interested followers could join in via the homepage as well. In September 2010, EXPLORE briefly introduced the project at the Space Generation Congress 2010 and the International Astronautical Congress 2010 in Prague, where another number of international participants in the project could be collected.

We were 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 had been drafted and is available online and in print form, together with logo stickers and business cards. We were 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. Cooperation with the also local REMOS team enabled 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 organized the **1<sup>st</sup> 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 organized 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:** EXPLORÉ outreach material together with experiment hardware at a presentation at the University of Stuttgart, April 2010.



**Figure 3-5:** EXPLORÉ at the 1<sup>st</sup> REXUS Public Day on Yuri's Night Stuttgart 2010.

Targeting school kids fascinated by science and technology, EXPLORÉ also supported 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 EXPLORÉ 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.

On 26 June 2010, EXPLORÉ participated in the **Open Science Day** at the University of Stuttgart. While part of the team was actively testing hardware,



public visiting the Institute of Space Systems could talk to the team and our outreach material was openly available to the visitors.

In September 2010, several members of the EXPLORE team participated in the **Space Generation Congress 2010** and the **International Astronautical Congress 2010** in Prague. They introduced both the REXUS program in general and the EXPLORE experiment in particular to students, young professionals and space experts, providing outreach material and collecting participation in the “Your Name in Space”-Project. Amongst others, the team had the privilege to shortly introduce the project to NASA administrator Charles Bolden.

Finally the EXPLORE team got the chance to showcase their flown experiment hardware on the **20<sup>th</sup> ESA symposium on European Rocket and Balloon Programmes and Related Research** exhibition in Hyères, France between May 22<sup>nd</sup> and May 26<sup>th</sup> 2011.

### 3.4.3 University

We were seeking close interaction with research staff and lecturers at the University of Stuttgart in order to support the on-orbit refueling 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 was 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 2011/12 to fellow students, university staff and interested visitors. Furthermore, EXPLORE has been present at the university science day (“Tag der Wissenschaft”) on 26 June 2010. Existing experiment hardware was 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. A second presentation of that sort has been done in October 2010.

### 3.4.4 Industry

Primarily we were contacting local small to medium enterprises to help us with hardware, manufacturing and expertise towards the realization of EXPLORE. The main interest was to use non-space-qualified hardware to reduce cost. These partners were then featured in the experiment campaign while gaining "flight-proof" of their hardware. Hardware was provided by:

- 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
- HD cameras, provided by GoPro-Shop
- Tubes, fittings, seals, etc., provided by Hydrobar
- Absorption mats, provided by New Pig

Additionally, the experiment team was actively searching for financial support through foundations and similar grants. This support enabled hardware acquisitions as well as travel support of the experiment team to workshops and campaign events throughout the REXUS campaign.

- Financial support through the Erich-Becker-Stiftung: 2x500 EUR to support travel of 2 non-sponsored team members to the training week in Kiruna, as well as 1x1000 EUR to support travel to 1 non-sponsored team member to the launch campaign in Kiruna.
- Financial support through the foundation of the Landesbank Baden-Württemberg (LBBW): 2500 EUR for the acquisition of materials and components.
- Financial support through the Walther-Blohm-Stiftung: 3000 EUR for acquisition of hardware and electronics as well as general team expenditures.
- Financial support through the Studentenwerk Stuttgart e.V.: 2850 EUR for hardware procurement and travel expenses



Walther-Blohm Stiftung, Studentenwerk Stuttgart e.V.

Figure 3-6: EXPLORÉ partners and supporters.

### 3.5 Risk Register

The following list is showing the identified risks up to the launch campaign in Kiruna. Fortunately no possible risk could be observed during and after the rocket launch.

Table 3-5: EXPLORÉ Experiment Risk Register.

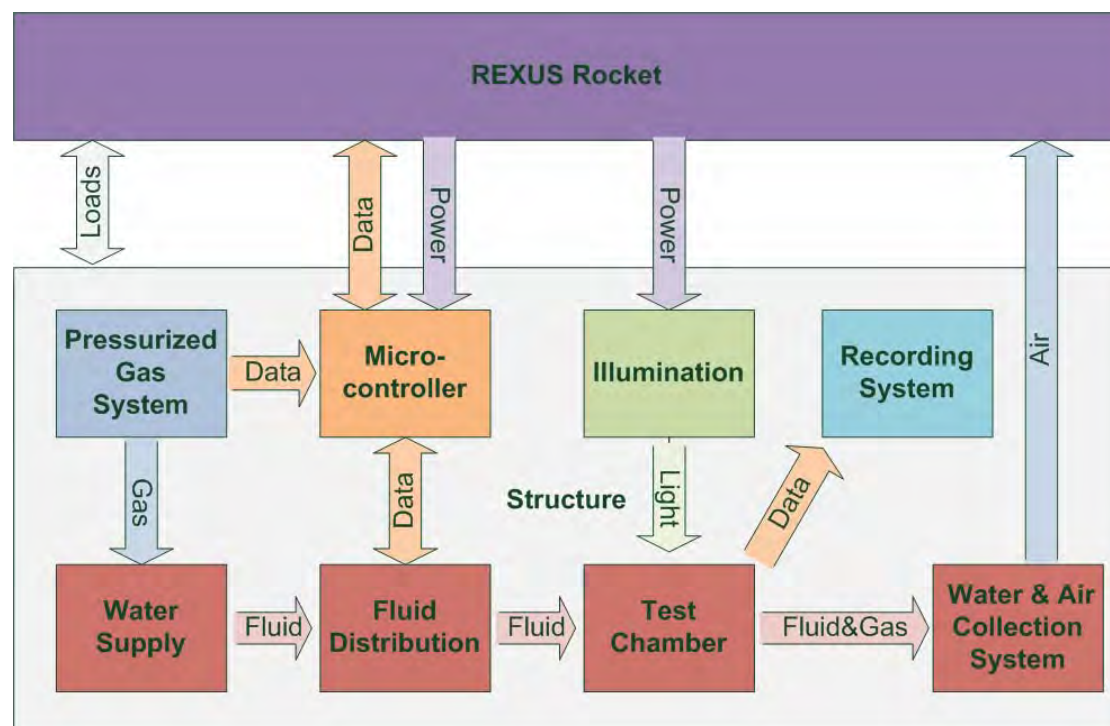
ID	Risk	P	S	PxS	Action
TC10	Experiment fails any of the vibration, vacuum or leakage tests.	B	4	Low	Perform tests early and allow for sufficient time to solve problems between test and experiment delivery.
VE10	Experiment may leak.	A	4	Very Low	Perform leakage tests after assembly, vibration test and integration.
VE20	Parts come loose from the structure/rocket casing.	A	4	Very Low	Vibration testing. Glueing.
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	A	1	Very	Valve V-0 removed from

<b>ID</b>	<b>Risk</b>	<b>P</b>	<b>S</b>	<b>PxS</b>	<b>Action</b>
	and remains closed.			low	setup.
MS40	Software program in microcontroller fails during flight.	B	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	Fluid Collection Device (FCD).
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.	A	4	Very Low	Testing of several fill and drain cycles of the pressurized tank.
MS80	Failure of Flow Control Device.	A	3	Very 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. Glueing.
TC20	Critical component is destroyed during testing or integration.	B	4	Low	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 was designed to simulate the refueling of small model fluid tanks. To perform this task a variety of subsystems were 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 referred to as “test chambers”
- two overflow collection chambers
- the pressurized gas system

The fluid supply system and the pressurized gas system simulated the liquid propellant supply system of an on-orbit refueling station. The test chambers



and the collection chambers simulated the liquid propellant tank and pressure tank of a spacecraft being refueled.

The pressurized gas subsystem provided the pressure needed to drain the water supply tanks and drove the fluid into the test chambers in microgravity. It consisted of a pressurized gas supply tank, a gas pressure sensor and a pressure reduction valve. The readings of the gas pressure sensor were used as housekeeping data and were sent down to the ground station.

The fluid supply system consisted of two fluid tanks which held the fluid used in the experiment before and during launch. The tanks were fully filled before launch in order to prevent any disturbance to the rocket stability due to fluid movement. During the experiment the tanks could be drained and the fluid moved to the test chambers. A membrane provided separation of fluid and pressurized gas in the fluid supply system.

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

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

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

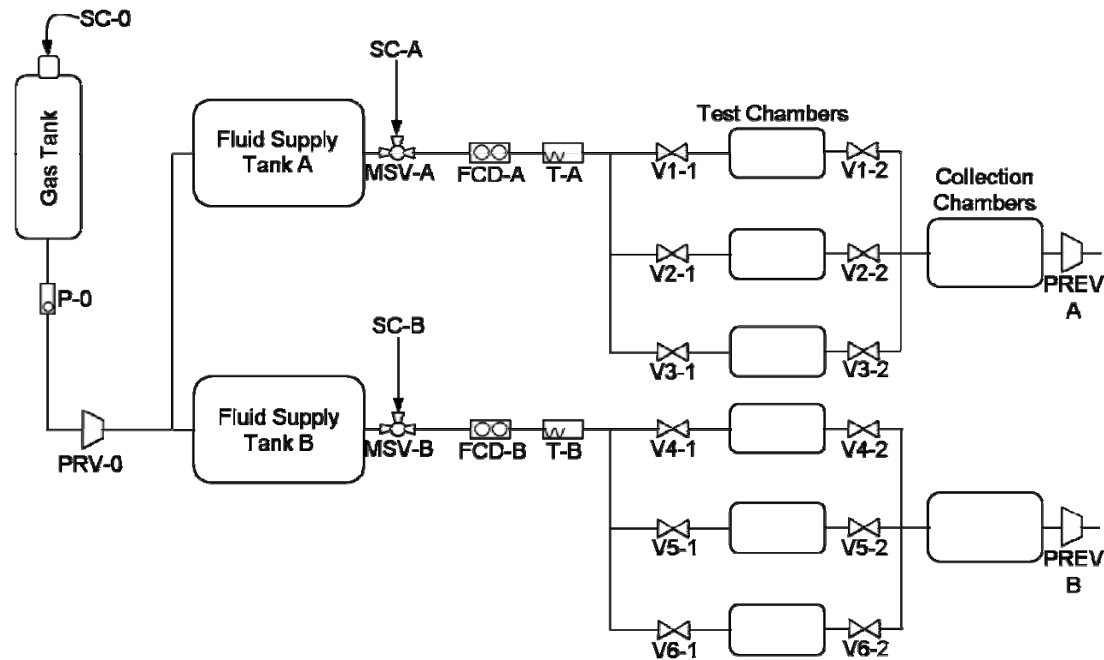
In addition to the subsystems mentioned before the EXPLORE experiment featured a microcontroller which handled ground communication (housekeeping data) via the REXUS internal communication system, controlled the fluid distribution system and processed data from the different sensors in the pressurized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

A camera was used as a recording system which monitored and recorded the filling of the test chambers during the experiment. An additional camera was filming the outside environment during the flight.

An illumination system consisting of various LEDs provided sufficient light for the recording system. The illumination system was powered by the REXUS onboard 12V DC power supply.

The structure was the central subsystem, which supported the other subsystems and transfer 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 (pressure < 8 bar) of the pressurized gas system was connected to both fluid storage tanks. The pressure sensor P-0 monitored tank pressure and reported housekeeping data back to the microcontroller. This provided housekeeping data for the gas tank and allowed for early detection of leakages. A pressure reduction valve (PRV-0) reduced system pressure in the connected fluid storage tanks to 2.5 bar.

The two fluid storage tanks held the fluid used in the experiment and were connected to the pressurized gas system on one side and to three test chambers each on the other side. Inside each fluid storage tank was a membran which separated 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 enabled a continuous control of the fluid inflow velocity via the microcontroller. A manually operated master safety valve (MSV-A and MSV-B) was installed after each tank to prevent fluid from escaping the tank during system tests of the magnetic solenoid valves. The master safety valves were opened before launch.

Before and after the test chambers, electrically controlled magnetic solenoid valves (V1-1 to V6-2) were 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 was completely filled and the test chambers and the collection chambers were empty. Once the experiments started the valves in the system were opened sequentially to fill two test chambers at the same time. One test chamber was filled from fluid supply tank A and the other one from fluid supply tank B. The test chambers being filled were arranged symmetrically around the center line of the REXUS rocket so that no significant CoG shifting occurred during the filling process.

The test chambers were finally connected to the collection chambers. The collection chambers featured a membrane which worked like an inflatable balloon and collected the excess volume (air and fluid) from the test chamber. As the balloon increased in size the residual air in the collection chamber outside the balloon left the system through the pressure relief valves PREV-A and PREV-B. This mechanism kept the system pressure in the collection chambers and the test chambers constantly at a pressure level of 1 bar. At the same time it prevented 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 were added to the tubing system. SC-0 was the connector for repressurization of the gas tank. SC-A and SC-B were used to refill the fluid supply tanks. The filling process was as follows: First any residual pressure in the gas tank had to be released and the valve of SC-0 had to remain open during the process. Then the required amount of liquid was supplied to the fluid tanks through SC-A and SC-B, while the valves before the test chambers were closed. After SC-A and SC-B were closed, pressurized air could be supplied to the gas tank through SC-0. In order to drain the test chambers and the collection chambers quick-disconnectors were installed in the pipes before and after each test chamber. By opening these disconnectors the test chambers could be drained without removing them from the experiment.

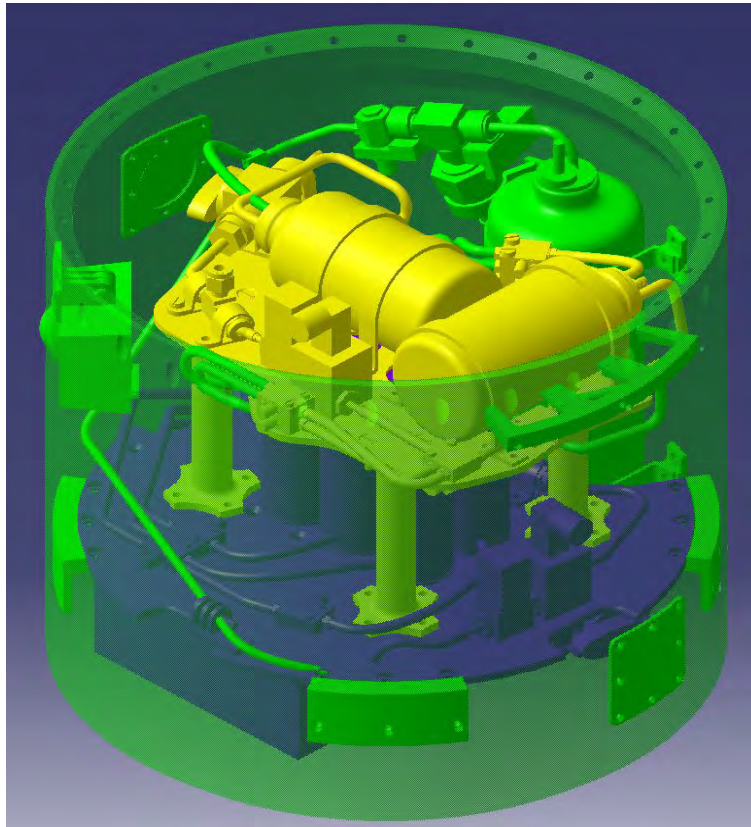
## **4.2 Experiment Interfaces**

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

### **4.2.1 Mechanical**

The experiment structure provided the mechanical interface between the experiment components and the REXUS rocket. The structure was made up of three major sub-structures which are shown in Figure 4-3: The module (green), the bulkhead/ base plate (purple) and the support tower (yellow). All experiment components were fixed to these individual sub-structures. The tower was connected to the bulkhead, which in turn was connected to the

module through four brackets. The REXUS experiment module was the actual interface to the residual REXUS rocket.

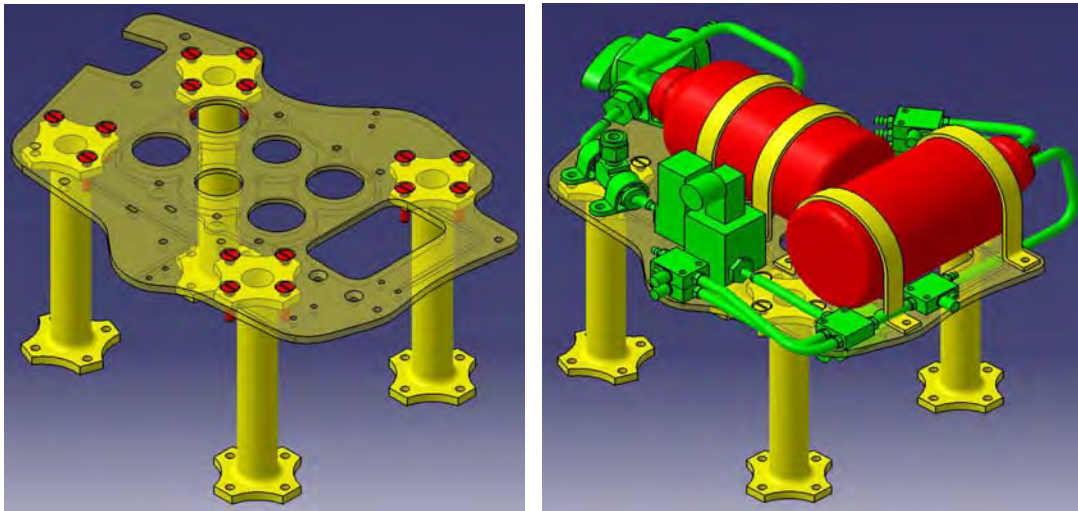


**Figure 4-3:** EXPLORE experiment structure.

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

#### Tower:

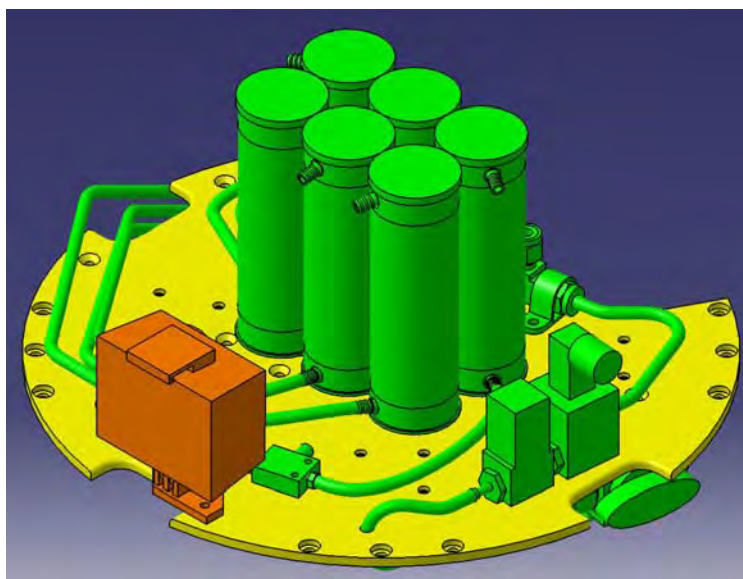
The tower structure consisted of four support legs and a top plate, see Figure 4-4. The support legs were fixed to the top plate and (at final integration) to the bulkhead with four M5 screws each (locked with nylon nuts). The components were fixed to the top plate by M3 - M5 screws. The tower was subject to an FEM analysis to confirm that design is able to withstand the loads. The results can be found in the Appendix.



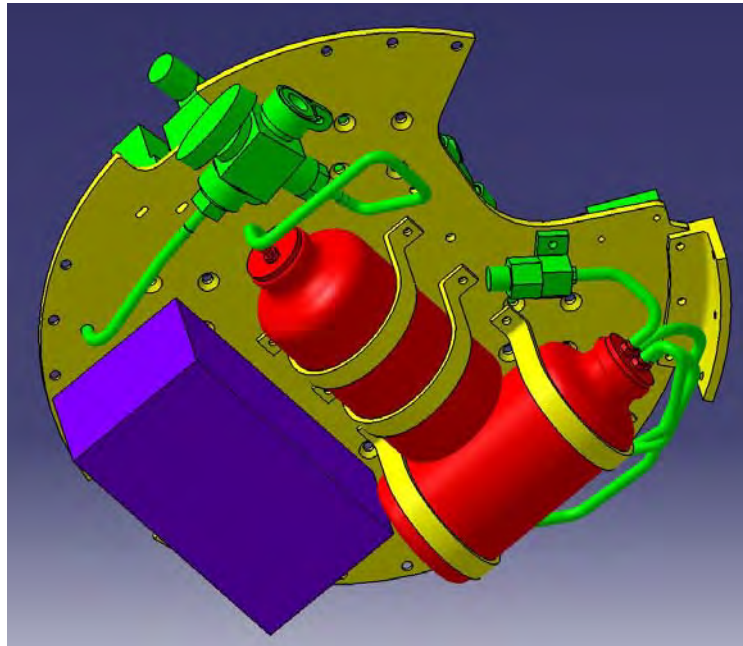
**Figure 4-4:** Tower structure.

### Bulkhead

The bulkhead connected the tower and the module. It also housed some components of the experiment, similar to the tower. Valves, temperature sensors, test chambers etc. (illustrated in green in Figure 4-5) were mounted to the top of the bulkhead with the help of M4 and M5 screws. The fluid tank, collection chambers (both red in Figure 4-6) and the electronics box (purple) were mounted to the bottom of the bulkhead. Fluid tank and collection chamber were fixed in place by two clamp bands (yellow) each, whereas the electronic box was held in place by four M4 screws. Results of the FEM analysis for the bulkhead can be found in the Appendix.



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

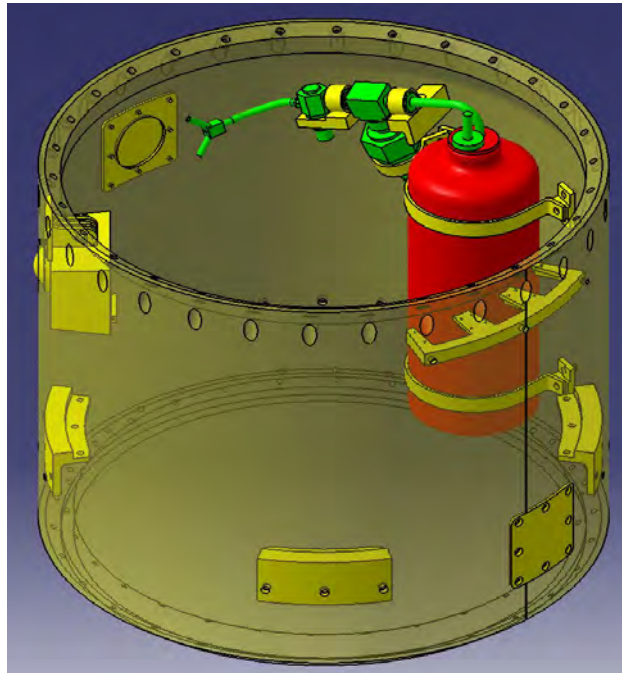


**Figure 4-6:** Bulkhead (view from bottom).

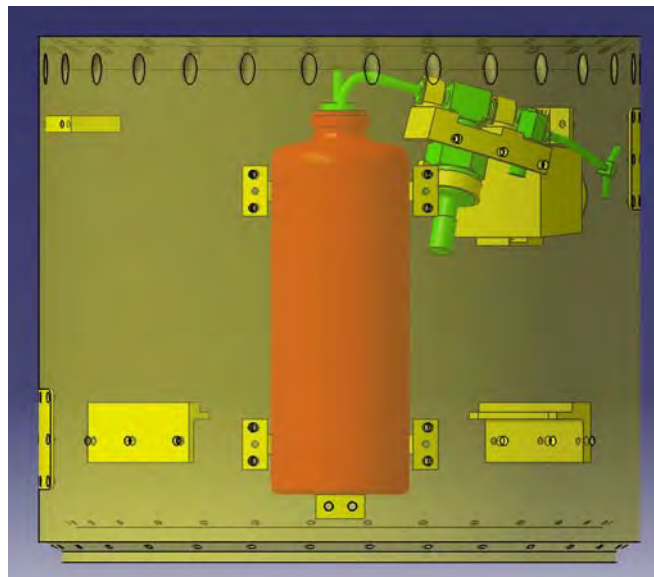
### Module

The bulkhead was attached to the module through four brackets, which are shown in yellow in Figure 4-7 and Figure 4-8. Three M5 screws were used per bracket to firmly attach the bulkhead (and with it the tower) to the module. Brackets were standard parts provided by Euro Launch.

Also attached to the module were a number of experiment components, such as the pressurized gas tank (red in Figure 4-7). Four gas tank support structures were connected to the module, using two M5 screws each. Two clamp bands were mounted on the support structures to attach the pressure tank firmly to the module. An additional 5<sup>th</sup> support structure (see Figure 4-8) was located below the gas tank to provide additional support during the phase of high acceleration during lift-off. An 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.



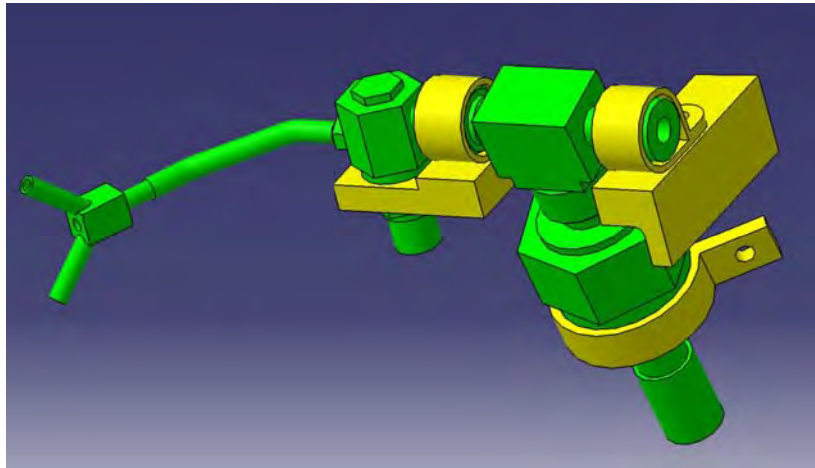
**Figure 4-7:** REXUS module (3D view).



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

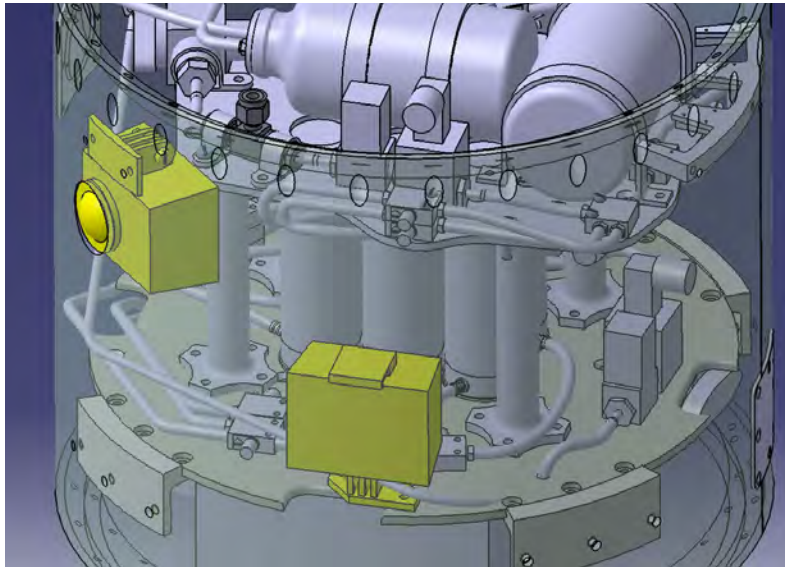
The high pressure system (pressure sensor and pressure reduction valve, green) were mounted to the module using a special support structure (yellow), which is illustrated in detail in Figure 4-9. This support structure was bolted to the module by three M5 countersunk screws from the outside of the module. The pressure sensor was mounted on the T-junction and secured against distortion with a clamping band (yellow in Figure 4-9). As the pressure

reduction valve already features a thread and a nut, these were used to fix the pressure reduction valve to the support structure. Behind the pressure reduction valve a Y-connector divided the flow system to supply both fluid storage tanks.



**Figure 4-9:** Pressure Sensor Support Structure.

Two cameras (yellow in Figure 4-7 and orange in Figure 4-5) were also used for the experiment. One camera (right in Figure 4-10) is oriented in a way to record 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 structure for the “internal” camera was mounted to the bulkhead while the support structure for the “external” camera was mounted to the module using two M4 screws. For the “external” camera, a hole (37.5 mm in diameter) was needed in the experiment module (see Figure 4-11 for details) to allow sufficient outside view for the camera lens. The hole was covered by a 1.5 mm thick acrylic glass sheet from the inside of the module, which was part of the camera support structure. This design was preventing hot gases from entering the inside of the module during “re-entry” phase.



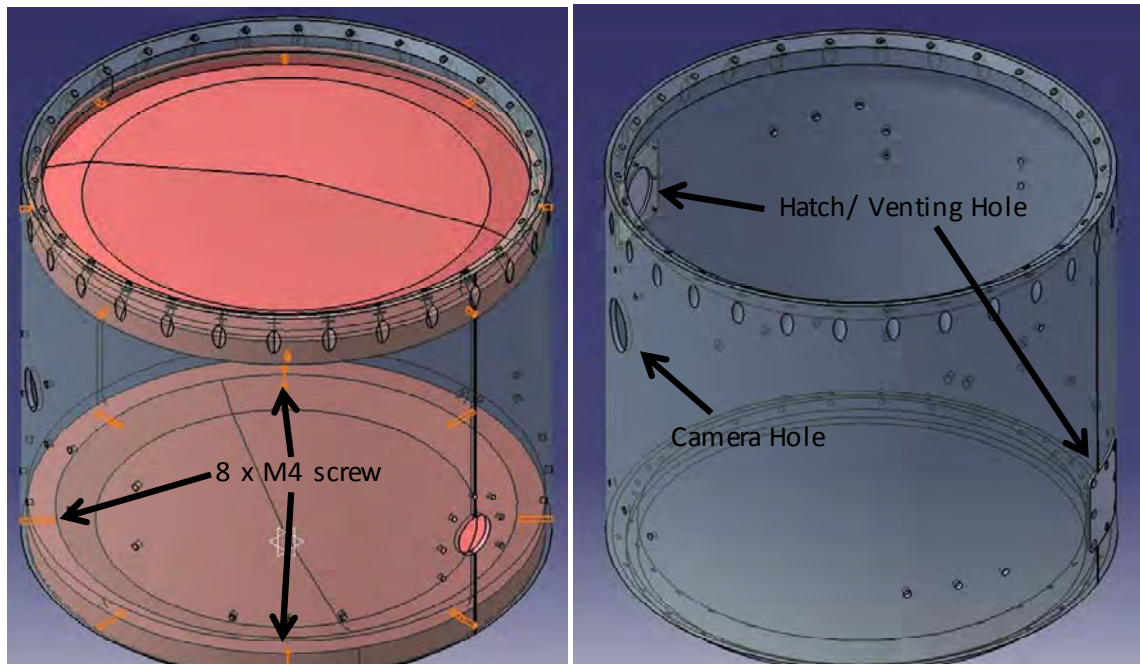
**Figure 4-10:** EXPLORE Camera (left: “external” camera, right: “internal” camera).

In addition to the hole needed for the external camera, two holes of 30 mm diameter were needed at both sides of the experiment module (see Figure 4-11). These functioned as late access hatches to manually arm the Master Safety Valves of the experiment shortly before launch. After arming the valves the holes were covered by sheet metal as described in chapter 5.4 of the REXUS manual. They are shown in Figure 4-11 on the right. Eight M3 countersunk screws fixed the cover plate to the module.

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. The Fluid Collection Device was a backup system which, in case of any leakage in the fluid system, absorbed the fluid and prevented it from leaking into other modules of the rocket. It was mounted to the top and bottom end of the module using four M4 screws and washers per side.

### Cable Feed-through

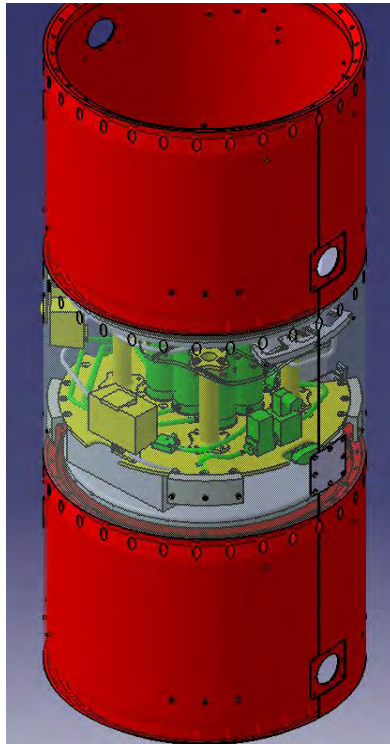
As shown in Figure 4-7, a support bracket for the D-sub connectors of the feed-through cables was installed near the top Fluid Collection Device in order to feed the electrical cables through the Fluid Collection Device into the next module.



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

### Experiment design envelope

Exact experiment dimensions can be found in chapter 6. The way the Rexus experiment modules were designed there was a small overlapping section of approximately 12 mm when the modules are stacked on top of each other at rocket integration (see Figure 4-12). Therefore, it was important that the experiment left enough free space either on the top or bottom side of the experiment module. For the EXPLORE experiment a design envelope was defined which stretched from the top of the module down to a plane with a 12 mm offset from the bottom end of the module. In order to provide sufficient space for the experiment module which was mounted underneath the EXPLORE module, all experiment components must not exceed the design envelop.



*Figure 4-12: Module stack at rocket integration, EXPLORE module in the middle*

#### **4.2.2 Electrical**

The EXPLORE Experiment used the power provided by the REXUS service module to power its electronics consisting of one micro controller, two cameras, twelve solenoid valves, two flow controllers, two temperature sensors, one pressure sensor and five LED cluster lights. The 28 V from the service module were converted into 5 V, 12 V and -5 V by commercial of the shelf DC/DC converters. The EXPLORE components needed a total power consumption of approximately 0.08 Wh during the flight. To trigger the EXPLORE experiment time signals, such as “lift off”, “start of data storage” and “start of experiment”, provided by the REXUS Service Module, were used. During the rocket flight the EXPLORE Experiment used the REXUS Service Module downlink to send collected housekeeping data (temperature, pressure, as well as flow control device status) to the ground station.

### 4.3 Experiment Components

**Table 4-1: EXPLORE Experiment Components List.**

<b>Mechanical</b>			
Component	Manufacturer	Status	Comments
Gas tank (Primus Fuel Bottle, 1l)	Primus	available from Primus	certified, lightweight
Cap (self made, one water connection, one bicycle valve, with o-ring)	Primus	available from Primus	self-made, aluminum
Bicycle Valve (as one connector for the gas tank cap)	Schwalbe	available 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	certified, lightweight
Mass flow Control	Bürkert	available	
Master safety valve (fluid, item no. KH 143 V PP)	Hydrobar	available	lightweight, resistant to a high temperature
Test chambers (PLEXIGLAS® XT (allround), tube, transparent 0A070 GT,)	Evonik	available (by ITLR)	Have to be adapted to experiment needs
Test chambers (hollow hemisphere, PLEXIGLAS® XT (allround), tube, transparent 0A070 GT)	Evonik	available (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
<i>Tubing</i>	--	<i>available</i>	
<i>Main structure</i>	--	<i>available</i>	

<b>Electronics</b>			
Component	Manufacturer	Status	Comments
Pressure sensor (series 3301, Item No: 351603341125)	Esska	available	
Mass flow sensor	B.I.O.-TECH	available	
<i>Electronics</i>	--	<i>available</i>	

Component	Manufacturer	Status	Comments
Camera GoPro Hero	GoPro	available	
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	--	Provided by IRS and SSC	
Electric cabling and connectors	--	Provided by IRS and SSC	
Tubing and connectors	--	available	
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 4-3 displayed the mechanical design of the experiment, showing the EXPLORE experiment on the REXUS bulkhead. The following chapter gives a detailed description of the mechanical design and the individual experiment components. Additional information as well as technical drawings of most of the components can be found in the Appendix.

All experiment components were either mounted to the experiment module, the bulkhead or the tower structure. Although the tower structure, bulkhead and module have already been briefly described in section 4.2.1, a closer look is taken at these components again in the first part of this chapter to give a detailed description of how the experiment components were arranged. In the second part of this chapter the individual components are described in more detail. At the end of this chapter the mass budget was calculated and is presented.

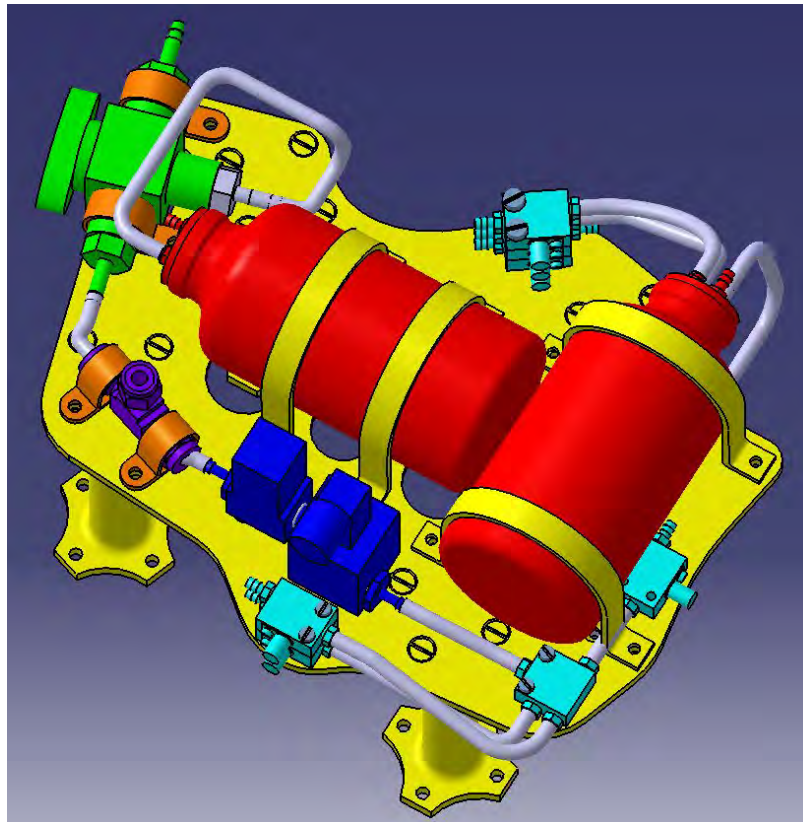
#### 4.4.1 Tower Structure

The tower structure consisted of the top plate (marked yellow) and four support legs. The experiment components were fixed to the top plate in various ways as described below. See Figure 4-13 and Figure 4-14 for details.

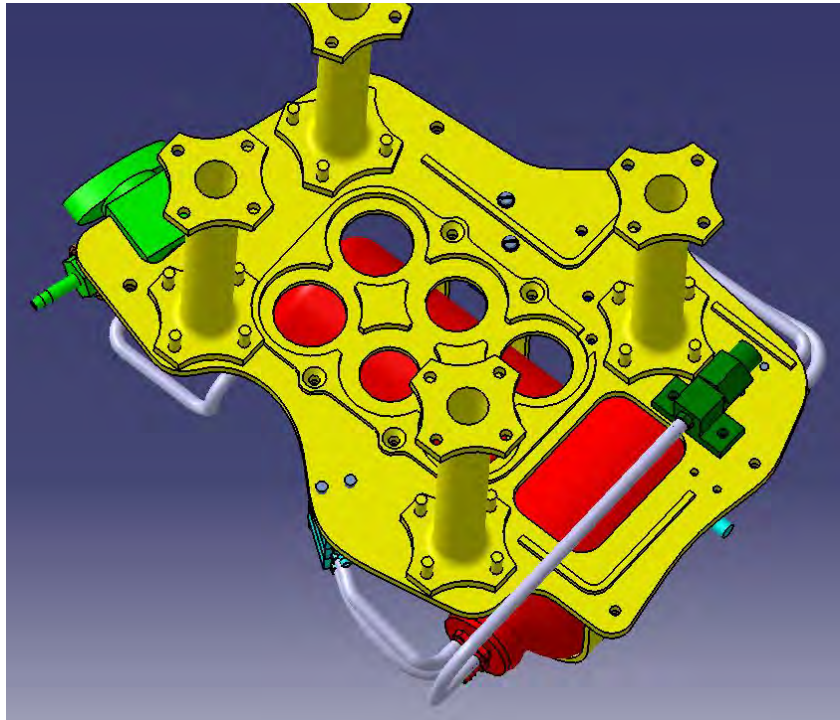
The Master Safety Valve (light green) and the temperature sensor (purple) were fixed to the top plate with the help of two clamps (orange) each. Each clamp was fixed to the top plate by a M 5 screw. The valve blocks and the distributor (light blue) were attached using two M 3.5 screws per block. The flow controller (dark blue) was fixed to the tower plate by M 4 screws (from the downside of the plate). The fluid tank and the collection chamber (red) were attached to the support structure with the help of two clamp bands (yellow) and four M 5 screws each. The pressure relief valve (dark green) was mounted to the downside of the tower plate. Teflon tubes (grey) connected the individual components.

It is important to note that the collection chamber, the pressure relief valve and the three valves stacked in the upper right corner were part of Fluid System B, while the other components were part of Fluid System A.

The electronic wires (not shown in the model) and fluid tubes were fixed to the tower structure using cable straps (not shown).



**Figure 4-13:** Components on tower structure (Top view).



**Figure 4-14:** Components on tower structure (Bottom view).

#### 4.4.2 Bulkhead

The bulkhead (yellow, see Figure 4-15 and Figure 4-16) hosted various experiment components as well as the tower structure (not shown in the pictures in this section).

On the top side of the bulkhead the six test chambers (light brown), the “internal” camera (dark brown), the temperature sensor (purple), the flow control device (dark blue), and the valves and distributor (light blue) were mounted.

The master safety valve (light green), the pressure relief valve (dark green), the fluid tank and the collection chamber (red) were all mounted to the downside of the bulkhead.

The temperature sensor and the master safety valve were fixed to the bulkhead with the help of two clamps (orange) each. Each clamp was fixed to the bulkhead by a M 5 screw. The fluid tank and collection chamber were attached to the bulkhead with the help of two clamp bands (yellow) and four M 5 screws each.

Teflon tubes (grey) were used to connect the individual components.

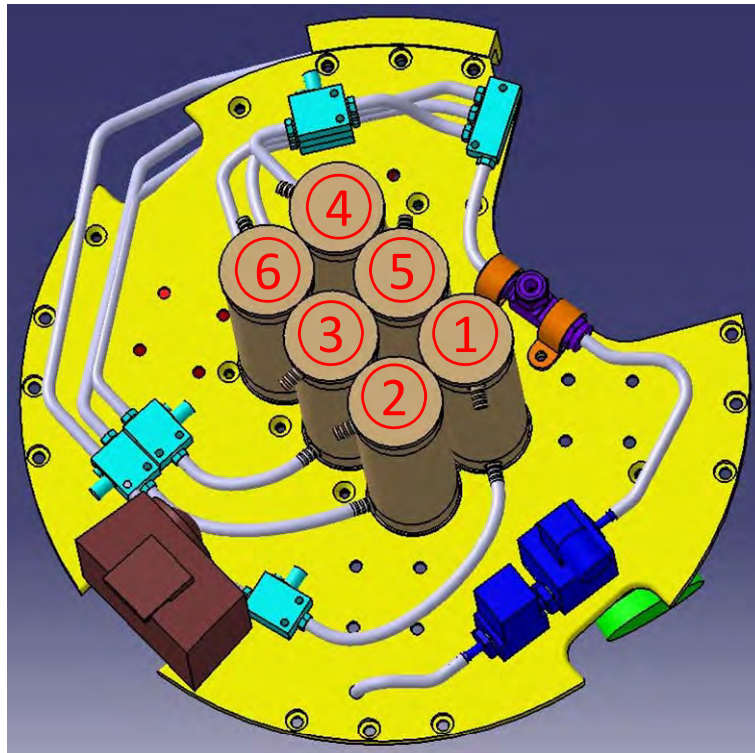
It is important to note that the collection chamber, the pressure relief valve and the three valves in the left half of Figure 4-15 were part of Fluid System A, while the other components were part of Fluid System B. The numbers of the

test chambers are also displayed in the figure. Test chamber 1-3 were part of Fluid System A, whereas test chamber 4-6 were part of Fluid System B.

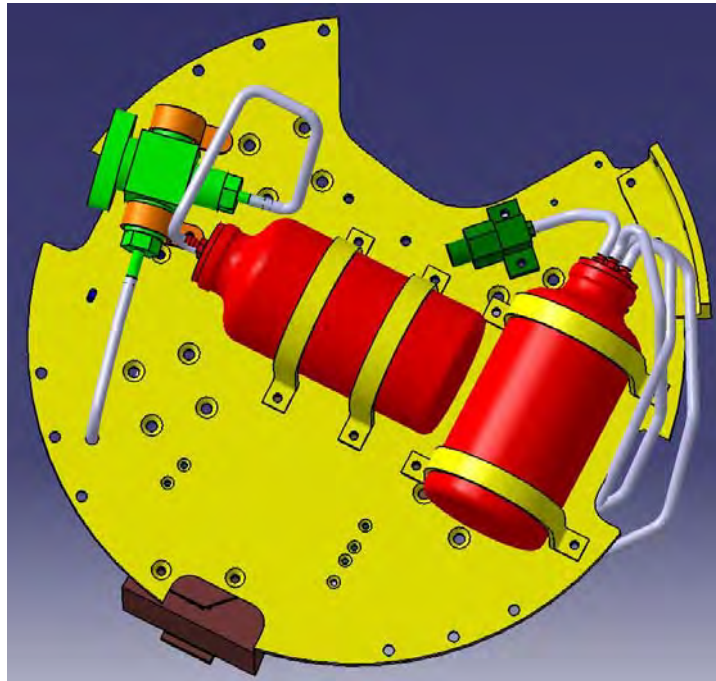
Electronic wires (not shown in the model) and fluid tubes were fixed to the tower structure using cable straps (not shown).

#### 4.4.3 Module

The module is described in sufficient detail in section 4.2.1. Additional details and technical drawings of the module can also be found in the Appendix.



**Figure 4-15:** Components on bulkhead (Top view)



**Figure 4-16** Components on bulkhead (Bottom view)

#### 4.4.4 Individual components

##### Gas Tank, Fluid Supply Tanks and Collection Chambers



These components were supplied by Primus and are liquid gas bottles used for camping. They are made of aluminum 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 Scloverand bicycle valve, which can be used to vent or refill the tank. On the fluid supply tanks and the collection chambers the cap incorporated 2 and 4 threads for the tube connectors. Inside the fluid supply tanks a membrane separated gas and liquid. The collection chambers hosted 3 membranes to collect the spill of three test chambers individually. A pressure relief valve vented the collection chambers.

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

### Solenoid Valves

Because the experiment needed 12 solenoid valves to control the fluid velocity, a small and lightweight solution was of significant importance. The Staiger Spider VA 204-7 valve provided the required functionality and flow characteristics while only weighing around 13 g. This valve came with a support structure made containing threads to connect the tubing and holes to mount the valve. For weight reduction these supports were made of aluminum.

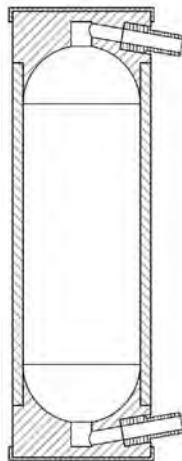


### Flow Control and Flow Measuring



In order to control the volume flow to the test chambers a flow controller needed 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 provided enough margin for various flow profiles as the required flow rate for filling of a test chamber is ca. 180 ml/min.

### Test Chambers



The test chambers were designed to consist of three major parts. There were 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 was acrylic glass, so that the camera system could record the fluid movements. The test chambers were placed between the bulkhead and the upper plate of the structure. Both, the bulkhead and the upper plate of the structure, contained pockets to hold the base of the test chamber. As the structure was bolted together, it held the test chamber in between and the pockets prevented any movement. Rubber spacing between the bulkhead and the test chamber reduced tensions in the acrylic glass due to shocks and thermal expansion.

Inside the test chambers a structure, also made of acrylic glass, was incorporated to aid the fluid flow and the separation of gas and liquid. This structure basically consisted of two plates, which were glued together perpendicular, and a sphere which was glued to the plates on the side facing the inlet into the test chamber. Due to the design of this structure and the test chamber itself, it was not necessary to glue the parts into the test chamber, as it just fitted inside the test chamber when the test chambers were installed.

### Tubing and Connectors

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



The system pressure in the high pressure part was 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 were designed to withstand pressures up to 300 bar and thus were more than sufficient for the EXPLORE experiment's high pressure system. Also these components were very leak tight, so that no gas pressure was lost while the experiment sat on the ground.

As the pressure in the low pressure system did 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 were 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 was easier but the valves and other components could not be supported by the hoses and had to be mounted separately. Hydrobar also supplied the connectors between the hoses and the respective threads of the valves and flow controllers. Only the connectors to the test chambers had 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 was shoved over one end of the connector and held in place by the tension forces and a layer of glue. Additionally a Teflon band was wrapped around the connection to finally secure it.

### Master Safety Valve



The master safety valve was 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 allowed 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 was also supplied by Hydrobar.

### Membrane

In the fluid supply tanks a membrane was used to separate fluid and gas. The component of choice so far was 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. For the collection chambers common condoms were used as membranes to guarantee an adequate filling volume for the residual air and fluid.

### Fluid

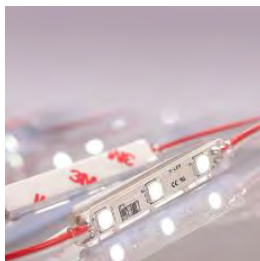
The major concern with the fluid used in the experiment was freezing either during launch preparations or after landing. Therefore Glysantin was added in a 50 % mixture to regular water. This mixture kept the fluid down to  $-40^{\circ}\text{C}$ . A side effect of using Glysantin was that it is of pink color and thus increased the visibility of the fluid in the test chambers and reduced the surface tension of the water/anti-freeze mixture.

### Camera

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



### Illumination



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

### Leakage/Fluid 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 was installed on top and below the experiment. The gauze that absorbs spilled liquids was hold in place between two wire nets installed to the experiment



module by a sectioned metal ring. That way the EXPLORE experiment was not disturbing other experiments due to leakage of fluid.

As the leakage Collection Device sealed the EXPLORE Experiment mechanically, a special arrangement for the feed through of the cables to the other experiments on top of EXPLORE had to be made. A bracket that mounts connectors for the cables to the other experiments was provided by SSC Erange and was installed on the Experiment Module at the top end of the EXPLORE Experiment. The EXPLORE Team routed the cables through the experiment, so that they came out at the bottom end. Experiments on top of EXPLORE could connect their cables to the connector and thus were connected to the REXUS Service Module.

#### 4.4.5 Mass Budget

The budget in the Table below shows the mass calculation as of the CATIA Model of the actual launch campaign model (February 2011). Since the EXPLORE experiment already flew on the REXUS 9 rocket in February the total mass is given without any margins. As you can see later, the mass estimation of the CATIA CAD model o

**Table 4-2: EXPLORE Experiment Mass Budget.**

<b>Structure</b>			
Component	No.	Single Mass [kg]	Total Mass [kg]
Bracket 14in	4	0.067	0.268
Bulkhead	1	0.826	0.826
Clamping Band Primus	2	0.040	0.080
Clamping Band Primus	8	0.048	0.384
Clamping Band Support Block	4	0.006	0.024
D-sub bracket	1	0.025	0.025
Experiment Module	1	5.270	5.267
GoPro HD Hero Structur B	1	0.405	0.405
GoPro HD Hero Structure A	1	0.320	0.320
Hatch Cover	2	0.019	0.038
Pressure Sensor Support Structure	1	0.028	0.028
Screws, Nuts, Bolts	1	0.500	0.500
Support Beam	4	0.073	0.292
Top Plate	1	0.432	0.432

<b>Fluid System</b>			
Component	No.	Single Mass [kg]	Total Mass [kg]
Collection Chamber C	2	0.014	0.028
Collection Chamber M	6	0.002	0.012
Connector CON 6M5	1	0.004	0.004
Connector FT 618 I-A	2	0.014	0.028
Distributor A	1	0.010	0.010
Distributor B	1	0.010	0.010
Fluid	2	0.350	0.700
Fluid Collection Dev	2	0.200	0.400
Fluid Tank Cap	2	0.017	0.034
Fluid Tank Membran	2	0.002	0.004
Gas Tank Cap	1	0.016	0.016
Gas Tank Support Base Structure	1	0.012	0.012
Gas Valve	1	0.007	0.007
Mass Flow Control De	2	0.300	0.600
Mass Flow Sensor A	1	0.080	0.080
Mass Flow Sensor B	1	0.080	0.080
Master Safety Valve	2	0.048	0.096
Pressure Reduction Valve	1	0.045	0.045
Pressure Relief Valve	2	0.033	0.066
Pressure Sensor ESKK	1	0.090	0.090
Primus-0.35l	4	0.056	0.224
Primus-1.0l	1	0.150	0.150
Staiger Valve	12	0.003	0.036
TC Base	12	0.025	0.300
T Connector	12	0.001	0.012
TC Damper	12	0.002	0.024
Temperature Sensor	2	0.014	0.028
Testkammer Rohr	6	0.037	0.222
T-Fitting Swagelok A	2	0.022	0.044
T-Fitting Swagelok S	1	0.101	0.101
Valve Block	12	0.009	0.108

<b>Fluid System</b>			
Component	No.	Single Mass [kg]	Total Mass [kg]
Tubing	1	0.214	0.500

<b>Electronics</b>			
Component	No.	Single Mass [kg]	Total Mass [kg]
E-Box	1	0.400	0.400
GoPro HD Hero	2	0.095	0.190
GoPro HD Hero Case	2	0.095	0.190

<b>TOTAL MASS [kg]</b>			13.740
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The main structure, as part of the mechanical components, included the REXUS experiment module and the REXUS standard bulkhead with brackets.

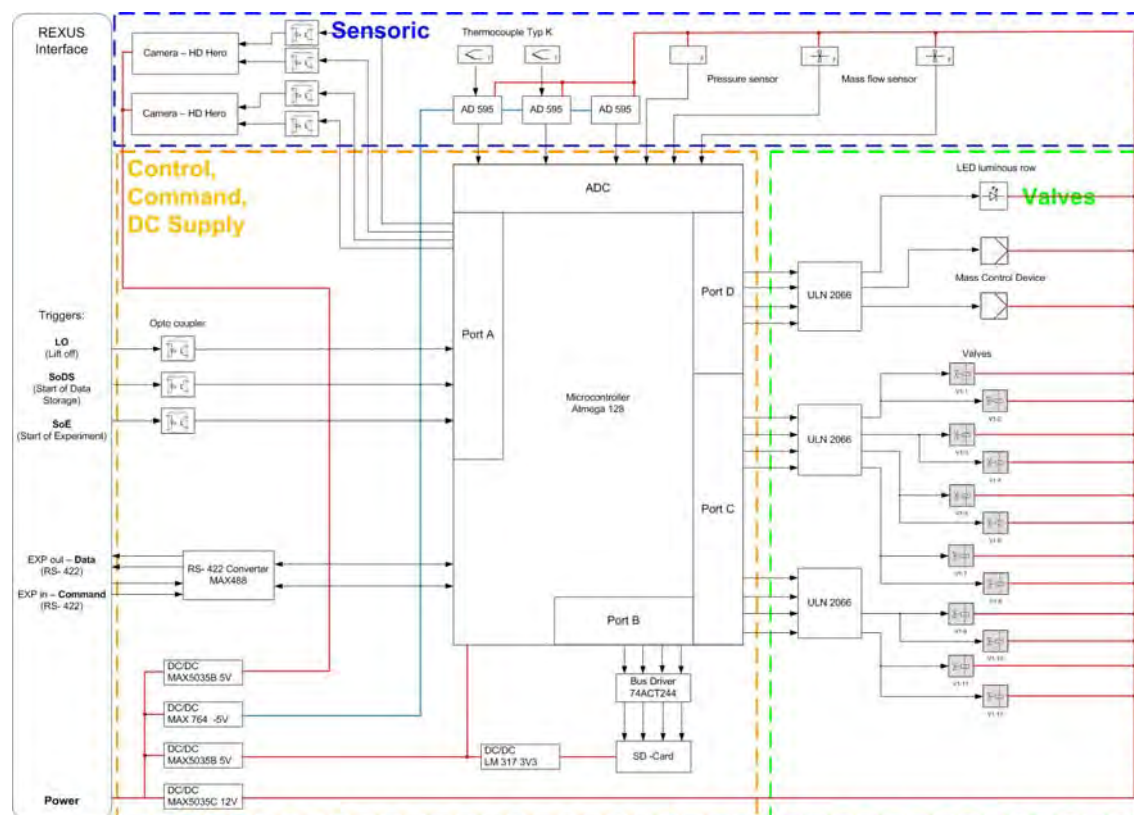
After final assembly the total weight of the EXPLORE experiment was measured by 13.25 kg including all cables, the fluid collection device, the electronic-box and cables inside the experiment and fluids and mounted in the module.

## 4.5 Electronics Design

The electronics subsystem was divided into three main segments:

- Control and command segment (including microcontroller, REXUS interfaces and all associated electronic components).
- Flow control segment (including all electronic valves as well as flow control devices).
- Sensorics segment (including pressure and temperature sensors and two cameras).

A schematic overview of the EXPLORE electronics layout is shown in Figure 4-17. A schematic of the printed circuit board is attached to the Appendix.



**Figure 4-17:** EXPLORE electrical setup schematics

The control and command segment is dominated by the microcontroller, which is 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 is mounted into a single electronics box comprising all necessary control logic. The heat produced by the electronics is very low and is absorbed and dissipated by the electronic box. The selected microcontroller (ATMega128) and all used electronic components are commercial of the shelf parts and were partly sponsored by Atmel. The ATMega128 is a low- power CMOS 8-bit microcontroller and is programmed via the AVR Studio 4. 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 inflow velocity. It includes twelve solenoid valves for the test chambers, sponsored by Staiger and two flow control devices, sponsored by Buerkert.

The used solenoid valves equal normally closed magnetic valves to allow a secure power-off mode of the EXPLORE experiment. Each valve simply opens as soon as power is provided and closes when no power is applied. The valves operate at a voltage of 12 V DC and need a power consumption of about 0.5 W each, while the flow control devices need a power consumption of about 2 W each. The sensorics segment comprises all measurement devices that collect data throughout the EXPLORE experiment. In particular,



data acquisition includes video, status of flow control devices, pressure and temperature measurements. 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. A miniaturized pressure sensor monitors the pressure of the gas reservoir. The device operates on a 12V DC power supply and provides an analogue data signal that is interpreted and transmitted by the microcontroller. To record the EXPLORE experiment two Go Pro Hero HD video cameras are used to capture first the filling process and second the actual rocket flight. The camera provides a USB 2.0, HDTV Out and an Audi Out connection for data transfer. Power will be supplied by one of the 5 V DC/DC converters and will be connected by USB.

#### **4.6 Thermal Design**

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

Also important was 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 verified 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 had been designed to have minimal contact with the external shell of the rocket. The space between the experiment and the module exterior (especially during vacuum) insulated 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 was not generating any heat during its operation. Only the electronics experienced a slight increase in temperature. The electronic components (e.g. DC/DC converters) had been chosen to produce only a minimal amount of heat during regular operation. Furthermore, most of the electronics were 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 was expected as shown below.

**Table 4-3: EXPLORE Experiment Power Budget.**

<b>Component</b>	<b>Voltage [V]</b>	<b>Current [A]</b>	<b>Amount</b>	<b>max. Power [W]</b>
SD-card	3.00	0.11	1	0.33
74ACT244	3.30	0.01	1	0.03
4066 Analog Switch	5.00	0.01	2	0.10
LVR 3V3	5.00	0.11	1	0.55
microcontroller	5.00	0.04	1	0.20
AD595	5.00	0.00	3	0.02
temperature sensor	5.00	0.03	2	0.30
LED illumination	12.00	0.25	1	3.00
Staiger fluid valves	12.00	0.04	12	6.00
pressure sensor	12.00	0.03	1	0.30
flow sensor	12.00	0.01	2	0.30
flow controller	12.00	0.08	2	2.00
Camera	5.00	0.50	2	5.00
DC/DC -5V	28.00	0.03	1	0.84
DC/DC 5V	28.00	0.18	2	10.00
DC/DC 12V	28.00	0.11	1	3.10
<b>TOTAL POWER [W]</b>				<b>32.07</b>

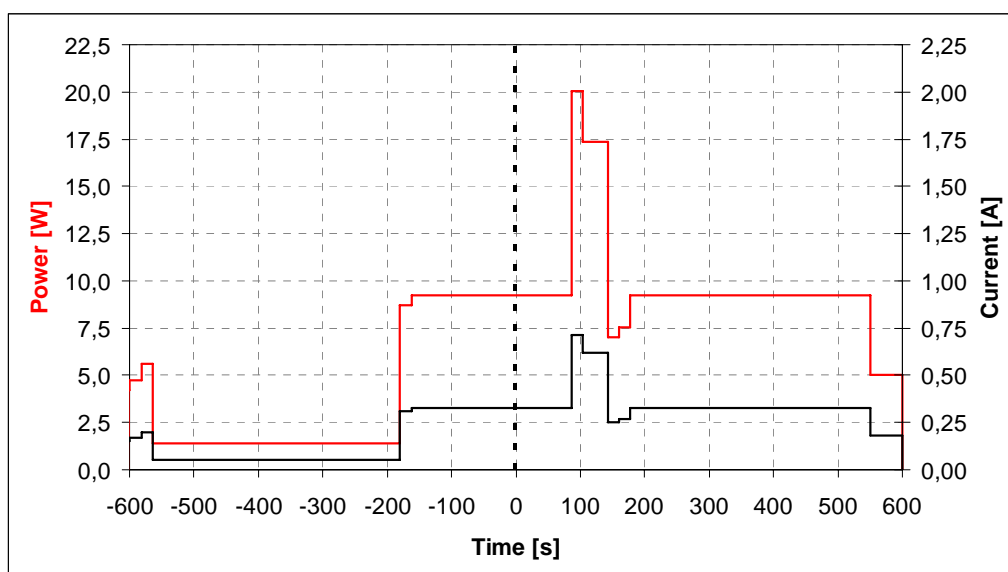
The power budget of the experiment was measured during the Integration Week at the DLR in Bremen and is shown in Table 4-4.

**Table 4-4: EXPLORE experiment measured Power Budget.**

<b>Signal</b>	<b>Action</b>	<b>Current [A]</b>	<b>Duration [s]</b>	<b>Power [W]*</b>	<b>Power Consumption [Ws]</b>
	OFF	0.000	0.00	0.00	0.00
	Power on	0.150	2.00	4.20	0.30
	Cameras on	0.170	19.00	4.76	3.23
	Cameras record	0.200	17.00	5.60	3.40
	Cameras off	0.050	379.00	1.40	18.95
<b>WAIT SODS</b>					
	Cameras / LED on	0.310	19.00	8.68	5.89
	Cameras record.	0.330	248.00	9.24	81.84
<b>WAIT SOE</b>					

Signal	Action	Current [A]	Duration [s]	Power [W]*	Power Consumption [Ws]
	Filling testchambers 1&4	0.715	17.00	20.02	12.16
	Filling testchambers 2&5	0.620	18.00	17.36	11.16
	Filling testchambers 3&6	0.620	23.00	17.36	14.26
	Camera 0 off. camera 1 record	0.250	17.00	7.00	4.25
	Camera 0 on. camera 1 record	0.270	17.00	7.56	4.59
	Camera 0 record. camera 1 record	0.330	373.00	9.24	123.09
<b>WAIT SODS</b>					
	Cameras off	0.180	50.00	5.04	9.00
			<b>1199.00</b>		<b>292.12</b>
<b>Power Peak [W]</b>					<b>20.02</b>
<b>Average Power Consumption [W]</b>					<b>0.24</b>
<b>Total Power Consumption [Wh]</b>					<b>0.08</b>

A maximum power consumption of 20.2 W was reached during the first filling of the test chambers 1 and 4 for a few seconds. The chronological sequence of the power and current consumption over the time can be found in the following Figure.

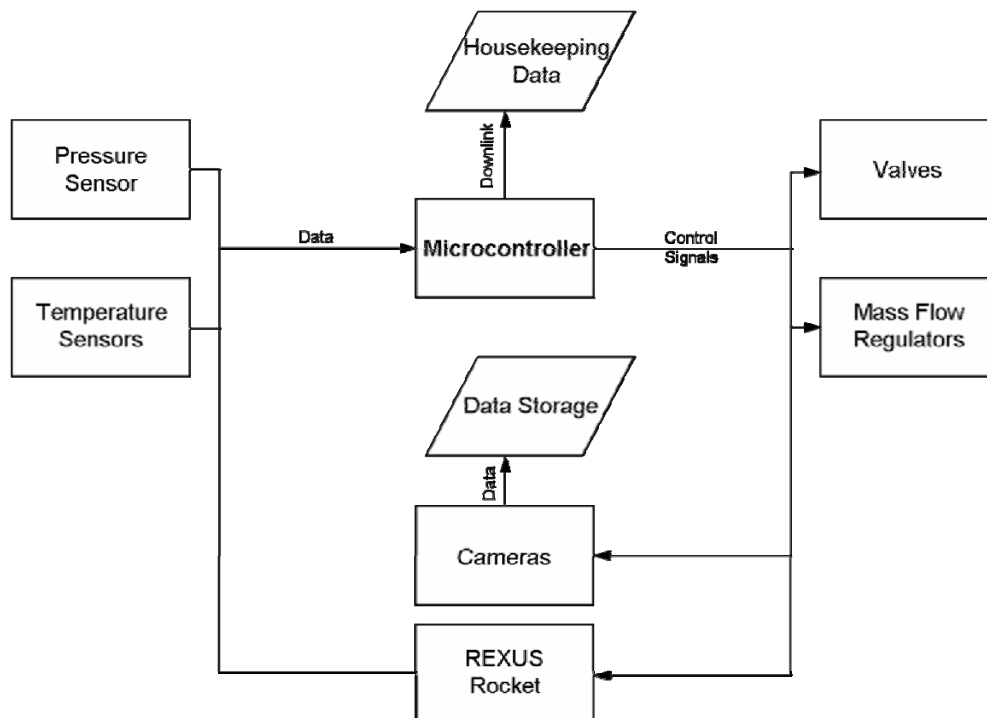


**Figure 4-18:** Chronological sequence of the power and current consumption.

During the flight of the REXUS 9 rocket the total power consumption of the EXPLORE experiment was not measured explicitly. It can be expected that the power consumption during the rocket flight equaled the measured power consumption during the Integration Week in Bremen.

#### 4.8 Software Design

The software of the EXPLORE experiment ran on the microcontroller and thus controls the experiment and its components. The following diagram (Figure 4-19) gives an overview of the command and data flow of the EXPLORE experiment.



**Figure 4-19:** EXPLORE command and data flow.

As it can be seen in Figure 4-19 the microcontroller handled the control signal for the valves and the mass flow control devices and also managed the data recorded by the temperature and pressure sensors as well as status reports. The recorded data was sent to the REXUS Service Module and was down linked to a ground support station. The two cameras were using their own memory cards.

The program started to send data after power on. When it received the “start of data storage (SODS)” signal, the cameras began their record. In the microgravity phase of the rocket flight the experiment started when the program received the “start of experiment (SOE)” signal from the REXUS Service Module.

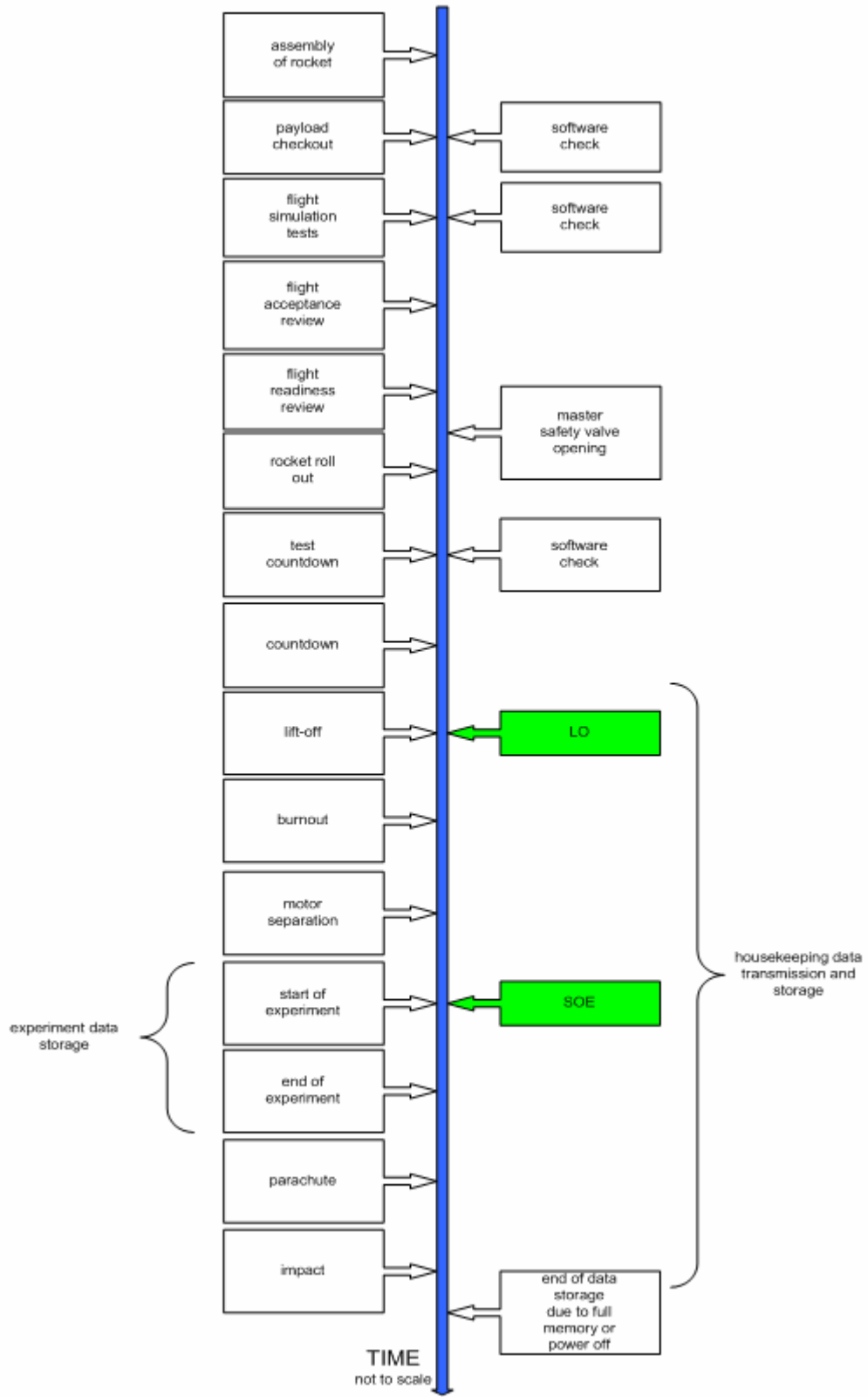
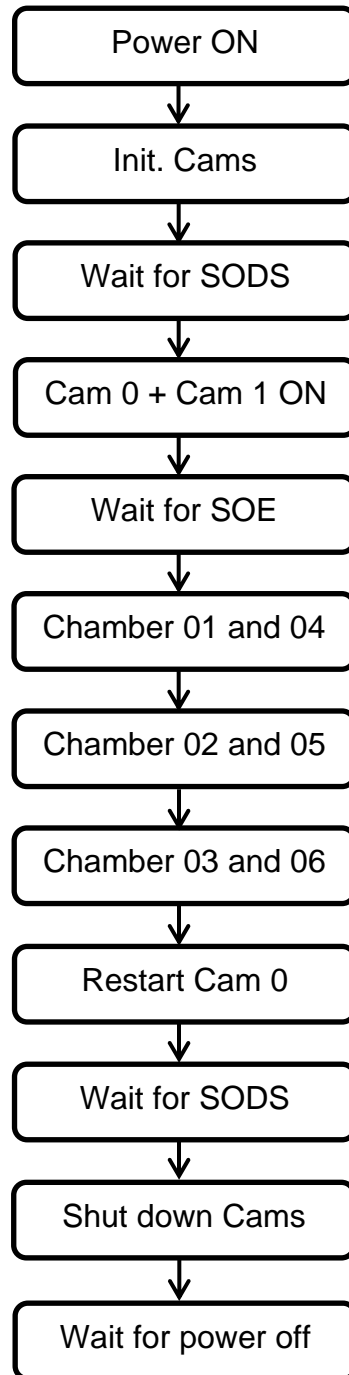


Figure 4-20: Software Timeline.



After receiving the “lift off” signal, the REXUS Service Module had to transmit the SODS signal. In order to monitor the experiment the microcontroller will send housekeeping data to the ground station via the REXUS Service Module downlink. Additionally it has to be stated that the experiment was performing autonomously, so that no active controlling was possible during the complete rocket flight. During various tests with the REXUS Service Module the EXPLORE experiment expected a loss of data of less than 2%. In addition to the onboard software ground support software was developed to evaluate the recorded housekeeping data like the reading of temperature and pressure sensors. Using this program an on site evaluation and discussion of the results could be obtained.



**Figure 4-21: EXPLORE software flowchart.**

The EXPLORE program started with an initializing sequence. This was important, because the cameras might switch in an “error-mode” when power is turned off while it is recording. This can happen during the test with the REXUS rocket before the hot countdown. The initializing reset the mode of the



cameras to ensure an accurate starting of the camera during real flight. During the complete power on time, housekeeping data like pressure or temperature was sent to the ground station.

## 4.9 Ground Support Equipment

The EXPLORE ground support equipment provided all necessary technical and organizational 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 had been identified:

- A laptop computer served as communication interface to the EXPLORE experiment during the testing phase as well as provided ground station support through receiving and interpreting the experiment telemetry during flight. Specific software packages or extensions had been developed to display the telemetry data in an adequate form and to quickly identify and react to possible noticeable errors. A detailed description concerning the functionality of the Ground Support Software can be found in the Appendix.
- Gas tank pressurization was achieved through an air pump in combination with the required tubing and connectors. Necessary tools had been identified already during the integration and test campaign.
- Liquid tank filling also required an adequate reservoir of the fluid and appropriate tubing and connector elements that have been identified.
- Tools for assembly and disassembly of the experiment as well as maintenance tasks had been manufactured.
- Camera for documentation of the launch campaign and another laptop computer with Internet access for news coverage and outreach activities (blog, website maintenance, sponsor contacts, etc.).
- A 28V DC power supply unit was used for powering the experiment during testing and flight integration as required. This needed to be complemented by adequate cabling and connectors.
- Critical spare parts for experiment components were taken along in case of element problems during launcher integration.
- A rod with a grabber at the end which was used to operate the mechanical safety valve using the access hole in the Experiment Module was manufactured.

## 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.*

<b>ID</b>	<b>Description</b>	<b>Verification</b>
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	<i>Moved to M.P.17</i>	
M.F.3	<i>Moved to M.P.18</i>	
M.F.4	<i>Moved to M.P.19</i>	
M.F.5	<i>Moved to M.P.20</i>	
M.F.6	The illumination and the camera shall be coordinated to get clear and bright videos.	R, T
M.F.7	The experiment shall use an antifreeze fluid as propellant substitute in order to ensure liquid condition	I

<b>ID</b>	<b>Description</b>	<b>Verification</b>
	throughout experimental timeline.	
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

<b>ID</b>	<b>Description</b>	<b>Verification</b>
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
<i>E.P.5</i>	<i>Deleted</i>	
<i>E.P.6</i>	<i>Deleted</i>	
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 <sup>2</sup> in a distance of 5 cm.	I, T
<i>E.P.11</i>	<i>Moved to E.D.5</i>	
<i>E.P.12</i>	<i>Moved to E.D.6</i>	
E.F.7	The fluid and gas valves shall remain normally closed.	I, T
M.P.1	The gas tank shall allow gas pressures up to at least 10 bar (TBC).	I, T

<b>ID</b>	<b>Description</b>	<b>Verification</b>
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
<i>M.P.5</i>	<i>Moved to M.D.11</i>	
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
<i>M.P.7</i>	<i>Deleted</i>	
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 (M.F.3)	The used anti-freezing fluid shall be non-toxic and non-hazardous.	I
M.P.19	The used anti-freezing fluid shall be non-corrosive	T

<b>ID</b>	<b>Description</b>	<b>Verification</b>
(M.F.4)	with used materials.	
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

<b>ID</b>	<b>Description</b>	<b>Verification</b>
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)	<i>Deleted</i>	
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 dimensions.	I
M.D.5	The test chamber shall be of transparent material allowing the camera to record fluid movements	I

<b>ID</b>	<b>Description</b>	<b>Verification</b>
	inside the test chambers.	
M.D.6	The collection chambers shall contain a device to prevent any fluid from leaving the system.	I, T
<i>M.D.7</i>	<i>Deleted</i>	
<i>M.D.8</i>	<i>Deleted</i>	
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

<b>ID</b>	<b>Description</b>	<b>Verification</b>
E.O.1	The experiment shall be designed in a way to operate fully autonomously during flight.	R, T
<i>E.O.2</i>	<i>Deleted</i>	
<i>E.O.3</i>	<i>Deleted</i>	
<i>E.O.4</i>	<i>Deleted</i>	
<i>E.O.5</i>	<i>Deleted</i>	
<i>E.O.6</i>	<i>Deleted</i>	
E.O.7	The experiment shall allow telemetry monitoring of selected measurement and status data.	R

<b>ID</b>	<b>Description</b>	<b>Verification</b>
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

**Table 5-2:** Test plans.

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

<b>Test number</b>	0.1.1
<b>Test type</b>	Inspection and compatibility test
<b>Test facility</b>	IRS laboratory
<b>Tested item</b>	All used materials (including plastics and metal)
<b>Test level/procedure</b>	Testing of material compatibility with the used anti freeze fluid Glysantin (see test report TR-008)
<b>Test duration</b>	20 day
<b>Date / status</b>	September 6 <sup>th</sup> 2010 / <b>completed</b>

<b>Test number</b>	0.2.1
<b>Test type</b>	Inspection and functionality tests
<b>Test facility</b>	IRS laboratory
<b>Tested item</b>	Staiger fluid valve
<b>Test level/procedure</b>	Testing of achievable flow rates under a constant pressurization (see test report TR-001)
<b>Test duration</b>	2 days
<b>Date / status</b>	April 23 <sup>rd</sup> to 24 <sup>th</sup> 2010 / <b>completed</b>

<b>Test number</b>	0.2.2
<b>Test type</b>	Inspection and functionality tests
<b>Test facility</b>	IRS laboratory
<b>Tested item</b>	Staiger fluid valve
<b>Test level/procedure</b>	Testing of achievable flow rates under different pressurizations (see test report TR-003)
<b>Test duration</b>	1 day
<b>Date / status</b>	May 21 <sup>st</sup> 2010 / <b>completed</b>

<b>Test number</b>	0.3
<b>Test type</b>	Inspection and design review
<b>Test facility</b>	IRS laboratory
<b>Tested item</b>	Whole experiment with all components
<b>Test level/procedure</b>	Review of design and CAD model to see if all components fit to the spatial constraints. Wooden models of structure components will be used for verification (see test report TR-010).
<b>Test duration</b>	3 days
<b>Date / status</b>	September 17 <sup>th</sup> to 19 <sup>th</sup> 2010 / <b>completed</b>



<b>Test number</b>	0.4
<b>Test type</b>	Pressure test
<b>Test facility</b>	IRS laboratory
<b>Tested item</b>	Test chambers
<b>Test level/procedure</b>	Testing for air tightness up to 5 bar (includes margin of 20%)
<b>Test duration</b>	1 day
<b>Date / status</b>	<b>Cancelled</b>

<b>Test number</b>	0.5
<b>Test type</b>	High Pressure Test
<b>Test facility</b>	IRS laboratory
<b>Tested item</b>	Gas tanks
<b>Test level/procedure</b>	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 (see test report TR-005).
<b>Test duration</b>	1 day
<b>Date / status</b>	June 26 <sup>th</sup> 2010 / <b>completed</b>

<b>Test number</b>	0.5.1
<b>Test type</b>	Functionality test
<b>Test facility</b>	IRS laboratory
<b>Tested item</b>	Pressure sensor
<b>Test level/procedure</b>	Testing of the functionality and readability of the used pressure sensor (see test report TR-006).
<b>Test duration</b>	1 day
<b>Date / status</b>	July 25 <sup>th</sup> 2010 / <b>completed</b>

<b>Test number</b>	0.5.2
<b>Test type</b>	Functionality test
<b>Test facility</b>	IRS laboratory
<b>Tested item</b>	Flow Sensor
<b>Test level/procedure</b>	Testing of the functionality and readability of the used pressure sensor (see test report TR-009).
<b>Test duration</b>	2 day
<b>Date / status</b>	July 23 <sup>rd</sup> to 24 <sup>th</sup> 2010 / <b>completed</b>

<b>Test number</b>	0.5.1
<b>Test type</b>	Functionality test
<b>Test facility</b>	IRS laboratory
<b>Tested item</b>	Fluid & Gas tanks, collection chambers
<b>Test level/procedure</b>	Testing for air tightness up to 5 bar (includes margin of 20% - see test report TR-011)
<b>Test duration</b>	1 day
<b>Date / status</b>	September 18 <sup>th</sup> 2010 / <b>completed</b>

<b>Test number</b>	0.5.2
<b>Test type</b>	Functionality test
<b>Test facility</b>	IRS laboratory
<b>Tested item</b>	Fluid & Gas tanks, test chambers, flow control device, flowmeter
<b>Test level/procedure</b>	Testing of filling cycle with 1 and 3 test chambers supplied by 1 gas and 1 fluid tank. Testing of functionality of flow control device and flowmeter (see test report TR-011).
<b>Test duration</b>	2 day
<b>Date / status</b>	September 18 <sup>th</sup> to 19 <sup>th</sup> 2010 / <b>completed</b>



<b>Test number</b>	0.6
<b>Test type</b>	Functionality test
<b>Test facility</b>	IRS laboratory
<b>Tested item</b>	Camera and illumination system
<b>Test level/procedure</b>	Should work in a way to get clear and bright videos without dazzling the camera (see test report TR-004)
<b>Test duration</b>	1 day
<b>Date / status</b>	September 18 <sup>th</sup> 2010 / <b>completed</b>

<b>Test number</b>	0.7
<b>Test type</b>	Functionality tests
<b>Test facility</b>	DLR Oberpfaffenhofen
<b>Tested item</b>	Microcontroller.
<b>Test level/procedure</b>	Simulation test with signals SODS, SOE and LO using the REXUS service simulator. See test report TR-014
<b>Test duration</b>	1 day
<b>Date / status</b>	November 22 <sup>nd</sup> 2010 / <b>completed</b>

<b>Test number</b>	0.7.1
<b>Test type</b>	Functionality tests
<b>Test facility</b>	IRS laboratory
<b>Tested item</b>	AD595 Amplifier test
<b>Test level/procedure</b>	Test of functionality including wiring, sensor reading and calibration (see test report TR-007)
<b>Test duration</b>	1 day
<b>Date / status</b>	July 24 <sup>th</sup> 2010 / <b>completed</b>



<b>Test number</b>	0.8
<b>Test type</b>	Simulation
<b>Test facility</b>	Workshop Offenburg
<b>Tested item</b>	Ground Support Software.
<b>Test level/procedure</b>	Ground Support Software shall receive data sent by the EXPLORE experiment.
<b>Test duration</b>	2 days
<b>Date / Status</b>	November 4 <sup>th</sup> to 5 <sup>th</sup> 2010 / <b>completed</b>

<b>Test number</b>	1.0
<b>Test type</b>	Functionality tests
<b>Test facility</b>	Workshop Offenburg
<b>Tested item</b>	The whole experiment setup.
<b>Test level/procedure</b>	The whole experiment setup of EXPLORE should operate fully autonomously including module. See test report TR-011
<b>Test duration</b>	1 day
<b>Date / Status</b>	November 4 <sup>th</sup> to 5 <sup>th</sup> 2010 / <b>completed</b>

<b>Test number</b>	2.0
<b>Test type</b>	Thermal tests
<b>Test facility</b>	IRS laboratory
<b>Tested item</b>	The whole experiment setup.
<b>Test level/procedure</b>	<p>Low temperature:</p> <ul style="list-style-type: none"> <li>○ -10°C (when stabilized: functional test)</li> </ul> <p>High temperature:</p> <ul style="list-style-type: none"> <li>○ +45°C (when stabilized: functional test / flight sequence)</li> </ul> <p>→ during transition from low to high temperature the experiment shall be operating and recording data</p> <p>See test report TR- 012</p>
<b>Test duration</b>	1 day
<b>Date / Status</b>	October 14 <sup>th</sup> 2010 / <b>completed</b>

<b>Test number</b>	3.0
<b>Test type</b>	Vacuum tests
<b>Test facility</b>	IRS laboratory
<b>Tested item</b>	The whole experiment setup.
<b>Test level/procedure</b>	<p>Vacuum conditions: below 0.5 mbar</p> <p>→ experiment should operate during lowering the pressure</p> <p>→ experiment data should be supervised and recorded during the test</p> <p>→ functionality test / flight sequence when reaching 0.5 mbar</p> <p>→ keep experiment operating at 0.5 mbar for additional 15 min to detect any leakages and overheating</p> <p>See test report TR-012</p>
<b>Test duration</b>	1 day
<b>Date / Status</b>	October 14th 2010 / completed

<b>Test number</b>	4.0
<b>Test type</b>	Thermal vacuum tests
<b>Test facility</b>	IRS laboratory
<b>Tested item</b>	The whole experiment setup.
<b>Test level/procedure</b>	See test number 3.0 and 2.0, which will be performed in combination. See test report TR-012.
<b>Test duration</b>	1 day
<b>Date / Status</b>	October 14 <sup>th</sup> 2010 / <b>completed</b>



<b>Test number</b>	5.0
<b>Test type</b>	Vibration tests
<b>Test facility</b>	DLR Stuttgart and DLR Bremen
<b>Tested item</b>	The whole experiment setup.
<b>Test level/procedure</b>	<p>Qualification level:</p> <ul style="list-style-type: none"> <li>○ 10-50 Hz: 0.124 m/s, 4 octaves/min</li> <li>○ 50-2000 Hz: 4.0 g, 4 octaves/min</li> </ul> <p>→ each: X, Y, and Z axis</p> <p>Acceptance level:</p> <ul style="list-style-type: none"> <li>○ Longitudinal: 20-2000 Hz, 6.0 g<sub>RMS</sub>, 0.018 g<sup>2</sup>/Hz</li> <li>○ Lateral: 20-2000 Hz, 6.0 g<sub>RMS</sub>, 0.018 g<sup>2</sup>/Hz</li> </ul> <p>→ for 20 sec</p> <p>→ EuroLaunch recommends: 60 sec, 12.7 g<sub>RMS</sub></p> <p>See test report TR-013.</p>
<b>Test duration</b>	2 days
<b>Date / Status</b>	October 29 <sup>th</sup> in Stuttgart and December 7 <sup>th</sup> in Bremen / <b>completed</b>

<b>Test number</b>	6.0
<b>Test type</b>	Shock tests
<b>Test facility</b>	ISD laboratory
<b>Tested item</b>	The whole experiment setup.
<b>Test level/procedure</b>	
<b>Test duration</b>	
<b>Date / Status</b>	<b>Cancelled</b>

All test reports are available as separate documents on the EXPLORE teamsite and also in the Appendix.

## 6 LAUNCH CAMPAIGN PREPARATION

### 6.1 Input for the Flight Requirement Plan (FRP)

#### 6.1.1 Dimensions and Mass

**Table 6-1:** Experiment mass and volume.

Experiment mass* (in kg):	13.25 kg (includes: bulkhead, module, brackets, FCD, service module cables and fluid)
Experiment dimensions (in m):	0.26 x 0.335 x 0.295
Experiment footprint area (in m <sup>2</sup> ):	0.0619
Experiment volume (in m <sup>3</sup> ):	0.006
Experiment expected COG** (centre of gravity) position:	X = 152.9 mm, Y = 0.1 mm, Z = 77.3 mm Coordinate system: Axis aligned parallel to REXUS coordinate frame according to manual, reference point located at bottom center of experiment module

\*Actual mass as weighted after integration of all components

\*\* Values from CAD model. Wires, screws, electronic box mass and integrated circuit boards are not modeled in CAD, therefore the calculated value listed here might differ from the actual value

#### 6.1.2 Electrical Interfaces

**Table 6-2:** Electrical interfaces applicable to REXUS.

<b>REXUS Electrical Interfaces</b>		
Service module interface required? Yes		
	Number of service module interfaces:	1
	TV channel required?	No
Up-/Downlink (RS-422) required? Yes		
	Data rate - downlink:	36.4 Kbit/s
	Data rate - uplink	0
Power system: Service module power required? Yes		
	Peak power consumption:	20.2 W (at 0.715mA)

<b>REXUS Electrical Interfaces</b>		
	Average power consumption:	0.24 W (over 1199 s)
	Total power consumption after lift-off (from T-10 min to T+550 s)	0.05 Wh (292.12 Ws)
	Power ON/OFF control	Experiment power on, when rocket power on. No power off.
	Battery recharging through service module:	No
Experiment signals: Signals from service module required? Yes		
	LO: once	T+0s
	SOE: once	T+87s
	SODS: twice	T-180s and T+550s

### 6.1.3 Launch Site Requirements

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

The EXPLORE Team provided all necessary tools and equipment for these procedures; therefore no specific Launch Site Requirements are needed. However, an air compressor for up to 10 bar was useful to ease the experiment pressurization and final checkout.

To ensure liquidity of our test fluid an anti-freeze agent was added to the water, as already described in earlier chapters. This prevented freezing down to a temperature of -38°C. If temperatures would have been below this limit (-38°C) our experiment could not be launched as a correct operation of the experiment could not be guaranteed.

## 6.2 Preparation and Test Activities at Esrange

While the EXPLORE experiment was designed for maximum autonomy during flight, some preparatory and verification activities had been performed at Esrange prior to integration and launch.

The complete experiment arrived at Esrange fully integrated but empty (i.e. no pressure and no liquid filling). Upon arrival and in order to prepare for launch, the following activities needed to be carried out:

1. Visual inspection



The experiment module shall be unpacked and all experiment parts shall be inspected, looking for:

- Loosened screws or bolts
- Tubing defects or loosened tubes
- Damaged or moved seals

## 2. Functional inspection

- Connect the experiment SUB-D and the ground support umbilical.
- Connect the ground support umbilical to the ground support computer and a 28V DC power supply.
- Turn on ground support computer and ground support software.
- Power-on the power supply. The onboard-computer should automatically boot. Check for nominal sensor data from temperature sensors and the pressure sensor.
- Run experiment timeline (LO, SODS, SOE) according to flight plan. Check for camera recording lights and for valve switching sounds.

## 3. Full leakage check

- Fill water tanks (2): Connect fill tubing to master safety valves and fill 320ml per tank. Check for increasing resistance that might indicate problems with the water membranes. Check tank caps and connected tubing for leakage.
- Pressurize gas tank (1): Open gas fill valve (Sclaverand bike valve), connect gas pump (or compressor if available), fill up to maximum 10 bar, close gas fill valve. Check gas pressure system for gas leakage. Check pressure level continuously throughout the following steps.
- Pressurize system (open master safety valves) and check fluid lines prior to flow control devices for leakage.
- Use ground control computer and software to open flow control devices. Check for leakage in fluid lines prior to fluid valves. Check flow sensor signal (should be 0).
- Open test chamber valves pairwise for the consecutive test chambers and check for leakage around the test chambers and collection chambers. Close valves after complete filling.
- Drain system completely. Particularly drain test chambers.
- Remove cameras, remove SD cards, download movie material, format SD cards, reinstall SD cards and cameras.



#### 4. Prepare experiment for flight

- Fill water tanks (2): Connect fill tubing to master safety valves and fill 320ml per tank. Check for increasing resistance that might indicate problems with the water membranes. Check tank caps and connected tubing for leakage.
- Pressurize gas tank (1): Open gas fill valve (Sclaverand bike valve), connect gas pump (or compressor if available), fill up to a maximum of 10 bar, close gas fill valve. Check gas pressure system for gas leakage.
- Connect ground support umbilical, power supply and ground support computer. Check for nominal sensor readings in software.
- Install leakage collection devices.
- Deliver experiment module for installation on REXUS.

### 6.3 Timeline for Countdown and Flight

The EXPLORE experiment worked fully autonomously, i.e. telecommand was not necessary. Only the experiment signals from the service module triggered the event timelines. The following section describes the experiment activities at each time step and describes the handling requirements.

**Please note: The minimum time after each activity or signal must be regarded!**

The minimum time (see table below) describes the time of the experiment activity after a signal is received. During this time, the experiment can and will NOT acknowledge and react to another signal or activity. This means, that e.g. a minimum time of 21 seconds had to be waited after giving the SODS signal before any other signal could be given. These requirements come from electrical system initialization routines within the software (e.g. camera activation). They needed to be observed in order to guarantee correct functioning and correct saving of the data files.

**Please note: Random power cut offs should be avoided!**

Safe power OFF of the EXPLORE experiment had to be done only when cameras are not recording, i.e. before SODS signal or after experiment execution. While other power cut offs generally had to be handled by the system and electronics, they had to be avoided where possible.

**Please note: Avoid giving SODS during test countdown on launch pad! Maximum recording time of 4 hours must be regarded!**

When the rocket modules were assembled, test countdowns had to be avoided or strictly limited the use of the SODS signal for the EXPLORE experiment. The reason was that the SODS signal will start camera

recordings. These recordings are then saved on an internal SD storage device, one in each camera. The storage space limited the maximum recording time to about 8 hours. Therefore, the accumulated recording time of the EXPLORE cameras had to be strictly observed during tests. Once this accumulated recording time exceeded 7 hours, the experiment cameras had to be accessed in order to safely extract the video files and to re-format the SD storage devices.

### **What happened in EXPLORE after which signal?**

<b>Activity/Signal</b>	<b>Experiment</b>	<b>Min. Time</b>
Power ON	<ul style="list-style-type: none"> <li>• Initialization of the experiment electronics</li> <li>• Initialization of cameras, i.e. cameras ON, start recording, cameras OFF in order to reset cameras</li> <li>• Continuous reading of sensor data (Temperature 0, A, B; Pressure; Mass flow)</li> <li>• Continuous TM of sensor data (Temperature 0, A, B; Pressure; Mass flow)</li> </ul>	45 seconds
SODS HIGH (before LO)	<ul style="list-style-type: none"> <li>• TM of SODS to GSE</li> <li>• Power ON for module lighting (TM to GSE)</li> <li>• Power ON for cameras</li> <li>• Start camera recordings (TM to GSE)</li> <li>• Continuous TM of sensor data (Temperature 0, A, B; Pressure; Mass flow)</li> </ul> <p>Note: This is the first SODS signal <u>before</u> LO or SOE. The SODS signal should be avoided when the experiment is not accessible (e.g. during test countdown on launch pad) since it will trigger camera recordings!</p>	21 seconds
SOE HIGH	<ul style="list-style-type: none"> <li>• Filling of test chambers 1 &amp; 4               <ul style="list-style-type: none"> <li>○ 4 valves opening</li> <li>○ flow control device command</li> </ul> </li> </ul>	150 seconds

<b>Activity/Signal</b>	<b>Experiment</b>	<b>Min. Time</b>
	<ul style="list-style-type: none"> <li>○ 4 valves closing</li> <li>● Filling of test chambers 2 &amp; 5               <ul style="list-style-type: none"> <li>○ 4 valves opening</li> <li>○ flow control device command</li> <li>○ 4 valves closing</li> </ul> </li> <li>● Filling of test chambers 3 &amp; 6               <ul style="list-style-type: none"> <li>○ 4 valves opening</li> <li>○ flow control device command</li> <li>○ 4 valves closing</li> </ul> </li> <li>● Stop of camera recordings</li> <li>● Start of camera recordings</li> <li>● Continuous TM of sensor data (Temperature 0, A, B; Pressure; Mass flow)</li> </ul> <p>Note: SOE HIGH will only be acknowledged, when SODS is HIGH. Otherwise, SOE HIGH will have no effect.</p>	
SOE LOW	No effect	
LO HIGH	<ul style="list-style-type: none"> <li>● No visible effect other than TM of status to ground support software.</li> </ul> <p>Note: LO HIGH will only be acknowledged, when SODS is HIGH. Otherwise, LO HIGH will have no effect.</p>	
LO LOW	No effect	
SODS HIGH (after SOE)	<ul style="list-style-type: none"> <li>● Stop camera recordings (TM to GSE)</li> <li>● Power OFF for cameras</li> <li>● Power OFF for module lighting (TM to GSE)</li> <li>● Continuous TM of sensor data (Temperature 0, A, B; Pressure; Mass flow)</li> </ul> <p>Note: This is the second SODS signal <u>after</u> SOE and experiment execution. After this SODS, Power OFF is required</p>	30 seconds



<b>Activity/Signal</b>	<b>Experiment</b>	<b>Min. Time</b>
	to reset the experiment!!	
Power OFF	<ul style="list-style-type: none"> <li>• Stop of all electronics systems.</li> </ul> <p>Note: Power OFF should not be done after the first SODS signal and before the second SODS signal is given. Otherwise, physical experiment access might be required to ensure full functioning of the system!</p>	

### **Nominal Countdown Activities:**

<b>Time</b>	<b>Action</b>	<b>Duration [sec]</b>
T-600	Power ON	0
T-600	Inits and Generates	0
T-598	Cam 0 ON	2
T-596	Cam 1 ON	2
T-596	send_and_wait()	15
T-581	Cam 0 REC	1
T-580	Cam 1 REC	1
T-579	send_and_wait()	15
T-564	Cam 0 OFF	2
T-562	Cam 1 OFF	2
T-560	send_and_wait()	5
T-555	Wait for SODS and send	370 (depends on SODS inc.)
T-180	LED ON	0
T-180	Cam 0 ON	2
T-178	Cam 1 ON	2
T-176	send_and_wait()	15
T-161	Cam 0 REC	1
T-160	Cam 1 REC	1
T-159	Wait for SOE and send	159
T-0	LO	0
T-0	Wait for SOE and send	87 (depends on SOE inc.)

<b>Time</b>	<b>Action</b>	<b>Duration [sec]</b>
T+87	Fill Test Chamber 1	15
T+87	Fill Test Chamber 4	16
T+103	Delay	0.5
T+103.5	Fill Test Chamber 2	17
T+103.5	Fill Test Chamber 5	17
T+120.5	Delay	0.5
T+121	Fill Test Chamber 3	20
T+121	Fill Test Chamber 6	22
T+143	Delay	0.5
T+143.5	Cam 0 OFF	2
T+145.5	send_and_wait()	15
T+160.5	Cam 0 ON	2
T+162.5	send_and_wait()	15
T+177.5	Cam 0 REC	1
T+178.5	send_and_wait()	5
T+183.5	Wait for SODS and send	366.5 (depends on SODS inc.)
T+550	Cam 0 OFF	2
T+552	Cam 1 OFF	2
T+554	Send	46
T+600	Power OFF	0

### **Arming EXPLORE experiment**

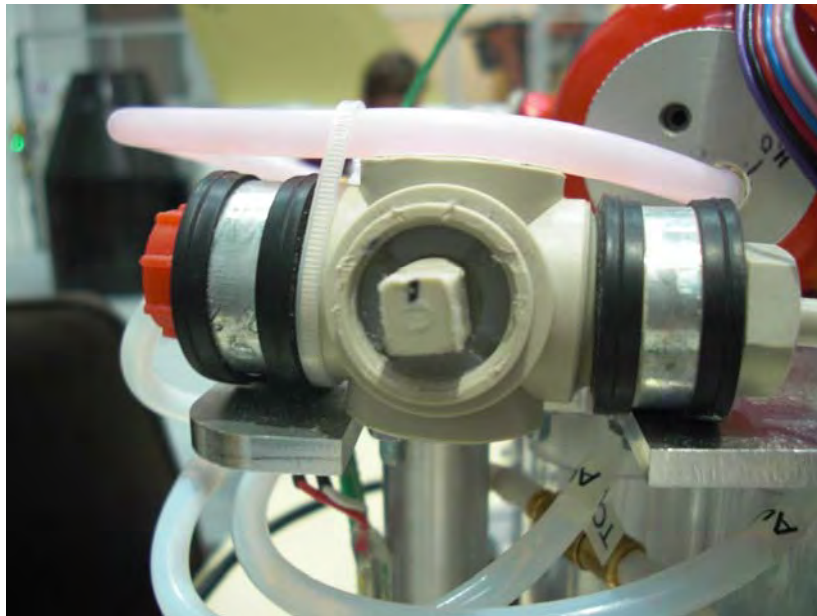
The EXPLORE experiment fluid system was secured through 2 manual master safety valves (MSV). These avoided fluid flow during tests of the electronics systems.

Before launch, these two MSVs needed to be opened. This was currently foreseen during countdown at -1H00 (-3600 sec).

To arm the experiment, follow these steps:

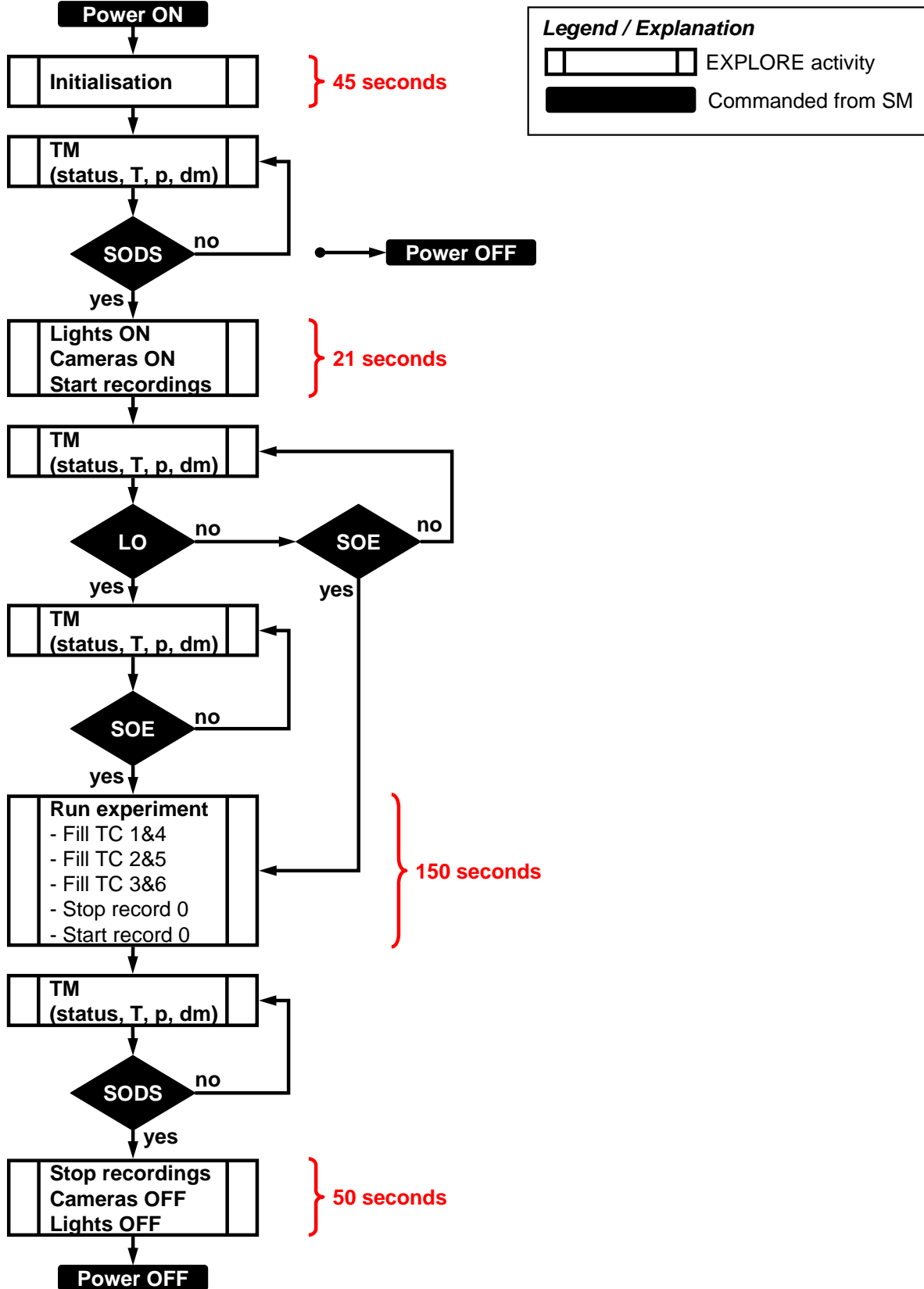
1. Open hatch A (top)
2. Check if black mark is in top position. If not, use the arming tool to turn it to that position.

3. Fit arming tool on the MSV adapter, blue handle facing upwards. Turn 90 degrees counter-clockwise.
4. Close hatch A (top)
5. Open hatch B (bottom)
6. Check if black mark is in top position. If not, use the arming tool to turn it to that position.
7. Fit arming tool on the MSV adapter, blue handle facing upwards. Turn 90 degrees clockwise.
8. Close hatch B (bottom)



**Figure 6-1:** Closed position of MSV.

**Visual representation of EXPLORE event timeline with signals**





## 6.4 Post Flight Activities

The following activities had to be carried out at recovery of the module:

- Disarm experiment (close both MSV)

### Disarming EXPLORE experiment

After flight the two MSV needed to be closed. To arm the experiment, follow these steps:

1. Open hatch A
2. Fit arming tool on the MSV adapter, blue handle facing upwards. Turn 90 degrees counter-clockwise.
3. Close hatch A
4. Open hatch B
5. Fit arming tool on the MSV adapter, blue handle facing upwards. Turn 90 degrees counter-clockwise.
6. Close hatch B

After recovery of the module and disintegration from the rocket, the following activities had to be carried out:

- Place module on a table.
- Dismount fluid collection device on top. Check for any wet areas (leakage) inside the module.
- De-pressurize system: unscrew gas valve and press to release residual gas until no further gas flow is observed.
- Turn module upside down.
- Dismount fluid collection device on top. Check for any wet areas (leakage) inside the module.
- Disconnect camera cables.
- Turn module to correct orientation.
- Dismount outside camera from module wall. Open camera casing and release camera. Take out SD mass storage and store safely!
- Dismount inside camera from bulkhead. Open camera casing and release camera. Take out SD mass storage and store safely!

In case of problems with accessing the second camera mounted on the bulkhead, the following steps could be taken to ease the dismounting:



- 
- Turn module upside down.
  - Dismount electronics box: unscrew 4 corner screws. While removing box from the module, disconnect 25 pole connector.
  - Unscrew pressure tube (PR to FT-B) from fluid tank B. Carefully check for leakage inside the fluid tank. Remove fluid tank if necessary by unscrewing hold-down straps and other tube.
  - Turn module to correct orientation.
  - Unscrew pressure tube (PR to FT-A) from fluid tank A. Carefully check for leakage inside the fluid tank. Remove fluid tank if necessary by unscrewing hold-down straps and other tube.
  - Remove screws between bulkhead and brackets for brackets 1, 2, 3.
  - Remove screws between bracket 4 and module from outside.
  - Carefully remove experiment with bulkhead and tower structure from module.
  - Dismount inside camera from bulkhead. Open camera casing and release camera. Take out SD mass storage and store safely!

## 7 DATA ANALYSIS PLAN AND EXPERIMENT REPORTS

### 7.1 Data Analysis Plan

In space projects, a successful flight is not the end of the story. It is also of utmost importance to analyze and use the data gathered during the flight as well as to draw conclusions about the success of the experiment and think about “Lessons Learned”.

In this section, it will be described how to produce scientific results as well as how to use and analyze the data. It will be indicated what kind of activities are planned and what kind of facilities, instruments, etc. are intended to be used.

The EXPLORE experiment generated the following data:

- High definition video of the filling processes as well as of the outside of the rocket during flight
- Fluid temperature
- Gas tank pressure
- Status reports of the used components and interfaces during flight

The most important data is the high definition video of the filling processes. The pressure data as well as the video of the outside of the rocket during flight are not intended to have any scientific value. The video of the outside of the rocket is part of the outreach program.

The experiment’s data was upgraded by data of the service module, which includes e.g. flight altitude and acceleration.

To analyze the data the EXPLORE team was again supported by the Institute of Space Systems of the University of Stuttgart, which provided computers as well as software like excel or computational fluid dynamics (CFD) tools.

To analyze the data it had first of all to be formatted and diagrams had to be plotted. The major task was to compare the observed fluid behavior during the filling processes compared to the CFD simulations. As flight data is available the simulation constraints can be adapted to the observed conditions.

The objective was to understand the influence of the surface tension and inflow velocity to the fluid behavior in order to generate a fluid dynamic model which can be used to find optimal tank geometries and optimal fluid mass flow rates. It is therefore crucial to know the exact mixture rate of the water and the antifreeze fluid.

Everything that was observed, calculated, estimated and analyzed was documented in the final student experiment document (v5.0) and will be presented at several conferences like:



- The 20<sup>th</sup> ESA Symposium on European Rocket & Balloon Programmes and Related Research 2011 in Hyères, France (22<sup>nd</sup> May till 26<sup>th</sup> May 2011).
  - Exhibition of the EXPLORE experiment
  - Poster presentation
  - Two oral presentations on the results and lessons learned of the EXPLORE experiment
- DGLR Raumfahrtkonferenz in Stuttgart, Germany (30<sup>th</sup> May 2011).
  - Exhibition of the EXPLORE experiment
  - Poster presentation
- The European Low Gravity Research Association (ELGRA) Symposium in Antwerp, Belgium (6<sup>th</sup> September till 9<sup>th</sup> September 2011).
  - One oral presentation on the results of the EXPLORE experiment
- The International Astronautical Conference (IAC) 2011 in Cape Town, South Africa (3<sup>rd</sup> October till 7<sup>th</sup> October 2011).
  - One oral presentation on the results of the EXPLORE experiment

## 7.2 Launch Campaign

The flight preparation activities of the EXPLORE experiment during the launch campaign were as expected. Before starting with the preparation for flight the EXPLORE experiment first was unpacked and examined to possible transport damages. Fortunately the transport to Kiruna, North Sweden went perfectly, so that the preparations for the rocket launch could be started in time.

To guarantee a smooth performance of the experiment, the EXPLORE hardware was again tested several times on site, both with and without fluid by using the REXUS service module. It has to be stated that during the first dry tests there were some strange anomalies observed, which could be detected as electro magnetic compatibility. Therefore it is mandatory to ground the personnel before interacting with the experiment hardware.

All planned tests, both on EXPLORE and also SSC/EuroLaunch side could be performed without any problems. Therefore the integration of the EXPLORE experiment with the other experiments went pretty smooth.

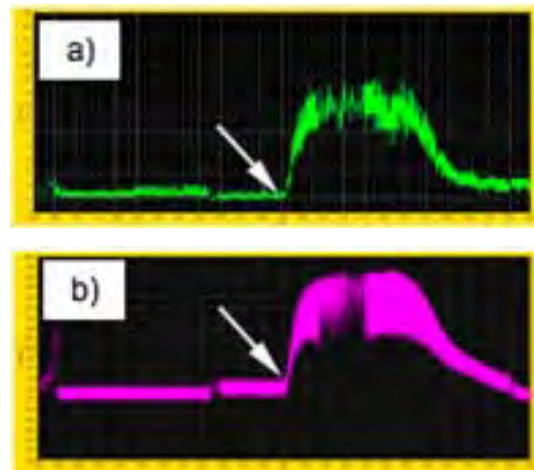
During the cold countdown the communication between the REXUS 9 rocket and the ground support software, which was connected at the Science Center of ESRANGE, went perfectly. All status reports of the used components, as well as signals of the rocket could be seen on the ground support software. During the initialization phase some data was lost, which is not serious and mandatory for the EXPLORE experiment.

Except for a holding of the countdown on ESRANGE side, the hot countdown went very smooth for the EXPLORE experiment. As expected all

housekeeping data (including temperature and pressure values), as well as status reports of the used components and signals could be received. A small amount of 2% data loss occurred during the rocket flight.

Recovery of the EXPLORE experiment went without any problems. The REXUS 9 payload could be found within 3 hours and was handed out to the students on the same day.

It could be seen that using the fluid collection devices in the EXPLORE experiment, it was completely dry inside the module. No obvious damages could be observed after recovery of the experiment. This means, that the EXPLORE experiment, as it is now; can also be used for further measurements. The SD cards of both cameras could be analyzed shortly after the recovery and showed excellent video material.



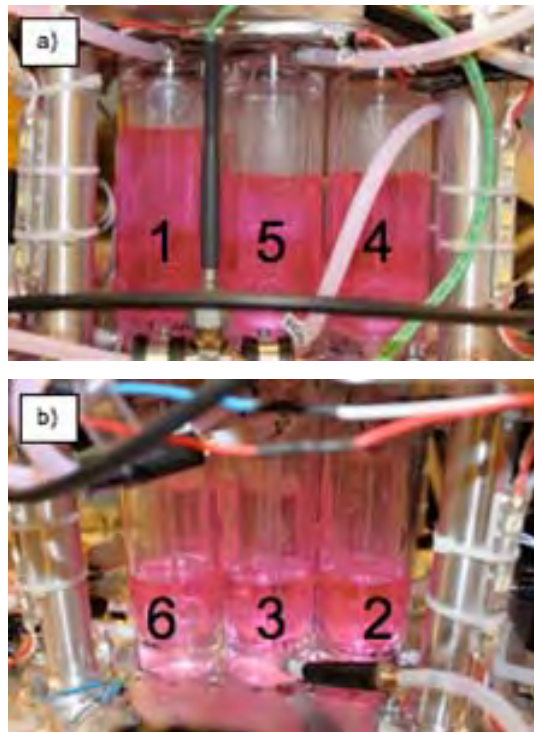
**Figure 7-1:** Temperature (a) and pressure (b) anomalies during the EXPLORE flight.

A first evaluation of the temperature and pressure data on site showed some sensor distribution anomalies. Both the temperature and the pressure showed the same behavior as shown in Figure 7-1. With the lift-off of the REXUS rocket (white arrow) the received data went straight up and decreased again slowly to the original values. It is also obvious that the data showed great variations during the microgravity phase, which still have to be explained. One reason could be that the pressure as well as temperature sensors are not usable in vacuum conditions or have to be calibrated. Both the pressure and temperature sensors were not calibrated against vacuum conditions at the launch campaign, which still has to be evaluated.

The most important goal of the EXPLORE experiment was to achieve a fill level of more than 90 percent in at least one test chamber. After evaluation of the experiment on site and the video material the filling levels of the test chambers were measured as follows:

**Table 7-1:** Measured filling levels of each test chamber after the rocket flight.

<b>Test Chamber</b>	<b>Filling Level</b>
1	80 %
2	30 %
3	30 %
4	60 %
5	60 %
6	30 %



**Figure 7-2:** Filling levels of each test chamber after the rocket flight.

The fill levels of each test chamber can also be seen in Figure 7-2. The evaluation of the video material also showed a clear separation of the gaseous and liquid phase inside the test chambers. There was no turbulent mixture of gas and liquid observed. The structure inside the test chambers showed very good first results to separate gas and liquid. Power consumption was not actively measured during flight and can be expected to be around 20.2 W as measured during the Integration Week at the DLR in Bremen in December 2010. Since the electronic box was separated from the rest of the experiment by a rubber material the thermal issues are not subject of the evaluation. It can be stated that after the evaluation on site the EXPLORE flight was a success.

The EXPLORE experiment was already exposed during the 20<sup>th</sup> ESA Symposium on European Rocket & Balloon Programmes and Related Research 2011 in Hyères, France from 22<sup>nd</sup> May till 26<sup>th</sup> May 2011. It was present on the exhibition area, with posters and two oral presentations on the results and lessons learned. All experts who visited the exhibition and oral presentations were impressed by the work that the EXPLORE team had done during the last year.

The EXPLORE experiment was also exhibited on the DGLR Raumfahrtkonferenz in Stuttgart, Germany on 30<sup>th</sup> May 2011, where it was also well visited.

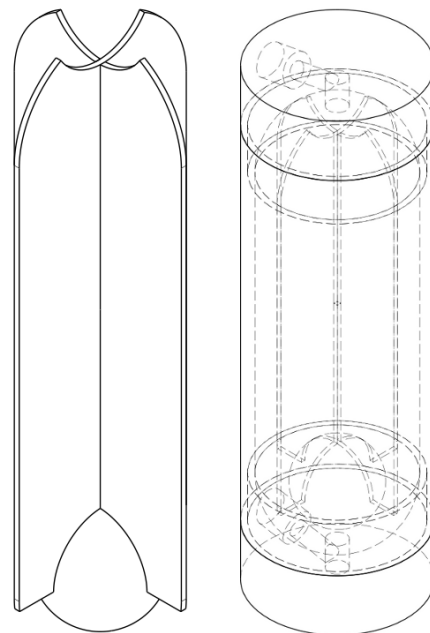
As already mentioned before the EXPLORE experiment will show their final results on several conferences and meetings in the next months.

### 7.3 Results

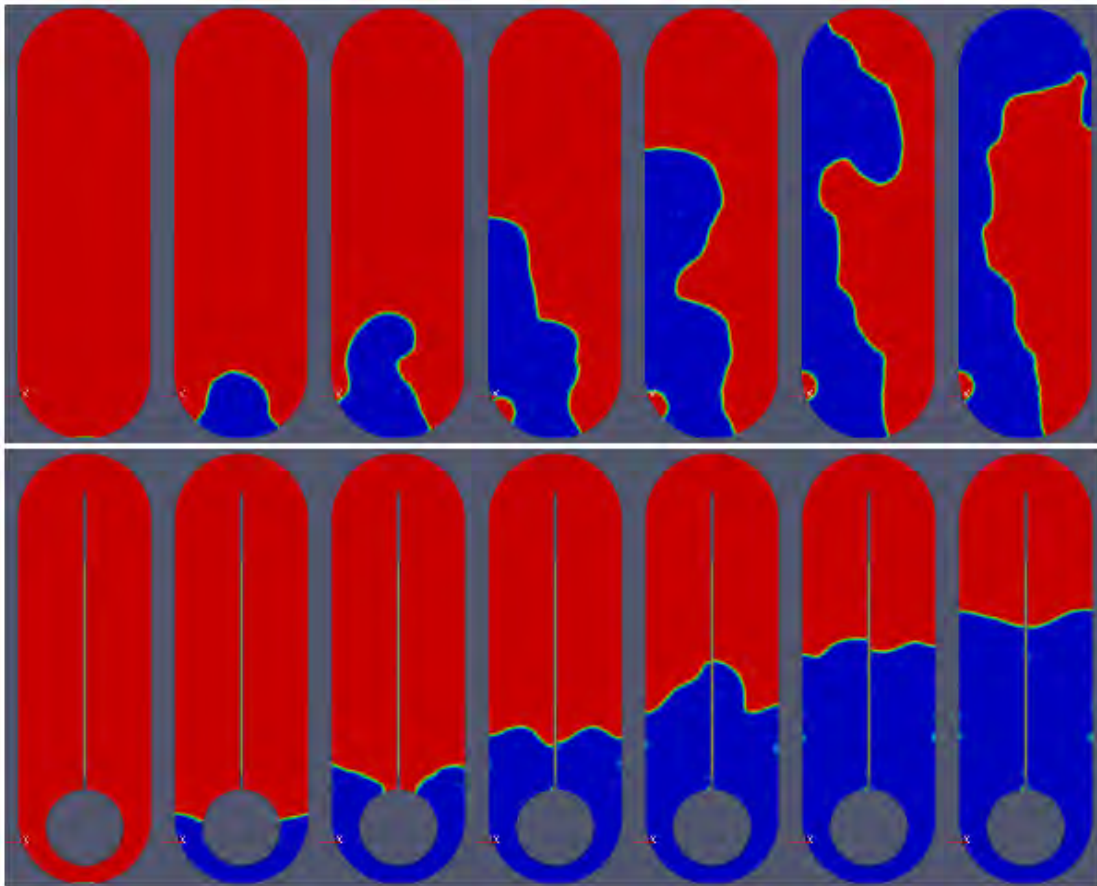
As stated earlier the main objective of the EXPLORE Experiment was to investigate the abilities to separate gas and liquid phases in a tank without the use of a membrane or other moving devices with variable inlet velocities. Thus a fixed structure as seen in Figure 7-3 has been implemented into the test chambers.

Prior to the Experiment simulations have been conducted to evaluate the design of said inner structure and the effects of the inlet velocities of the liquid phase. Those simulations have shown that the inner structure as shown in Figure 7-3 with a sphere and two walls with one being vertical to the other. The sphere slows down the inlet flow by increasing the flow area and also forces the flow to attach to the outer wall of the test chamber. The vertical inner walls hold the sphere and increase the surface area inside the test chamber to improve the phase separation by surface tension.

Figure 7-4 shows the effects of the inner structure on the fluid flow inside the test chamber. In the beginning the test chamber is filled with the gas entirely (shown in red) and the liquid phase (shown in blue) enters the test chamber with constant velocity, which is equal for both cases. The time difference between the individual pictures of the series is not equal throughout the picture series.



**Figure 7-3:** Inner Structure and Test Chamber Design.



**Figure 7-4:** Comparison of flow inside test chamber without and with inner structure.

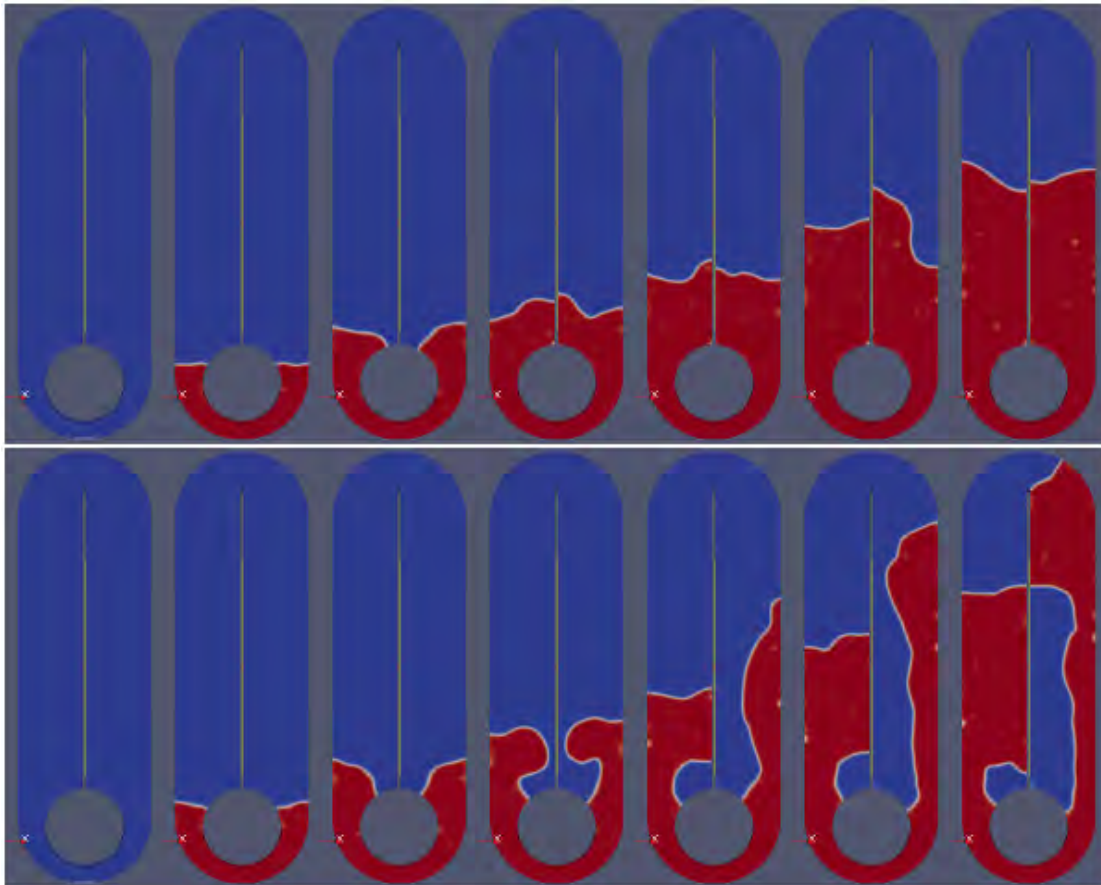
It is obvious that the liquid does not attach to the wall on both sides of the inlet and the surface tension forces the flow to follow this wall to the outlet at the top of the test chamber, where liquid leaves the test chamber. The maximum filling level is reached in the last picture; from this point forward the amount of liquid entering and leaving the test chamber is equal.

The second case with the structure inside the test chamber shows another situation. With the sphere dividing the flow and reducing the flow velocity the liquid attaches to both outside walls in the test chamber. This results in an equal and nice filling of the test chamber. The filling process is not finished in the last picture and the fluid level rises with time until the test chamber is completely filled up. So the structure implemented into the test chamber successfully improves the filling process significantly.

Other structures have been tested the same way, but none of them showed results nearly as good as the sphere and the vertical walls.

The second factor that influences the filling process besides the geometry of the structure is the flow velocity at the inlet. Of course it is desirable to set the inlet velocity as high as possible to decrease the time required for the complete filling of the tank. But simulations with variable inlet velocities have shown that there is a limit to this velocity.

The picture series in Figure 7-5 shows the results of simulations with inlet velocities just below and above the critical value. In the upper picture series the inlet velocity is small enough to allow the flow to follow the geometry completely around the sphere. This way there are not gas bubbles locked in the fluid at the connection of sphere and the vertical wall. In the picture series on the bottom of Figure 7-5 the flow separates from the sphere at about 60% to 75% of the way around due to the higher flow velocity. This results in a relatively small gas bubble on the left side and a significantly bigger one on the right side.

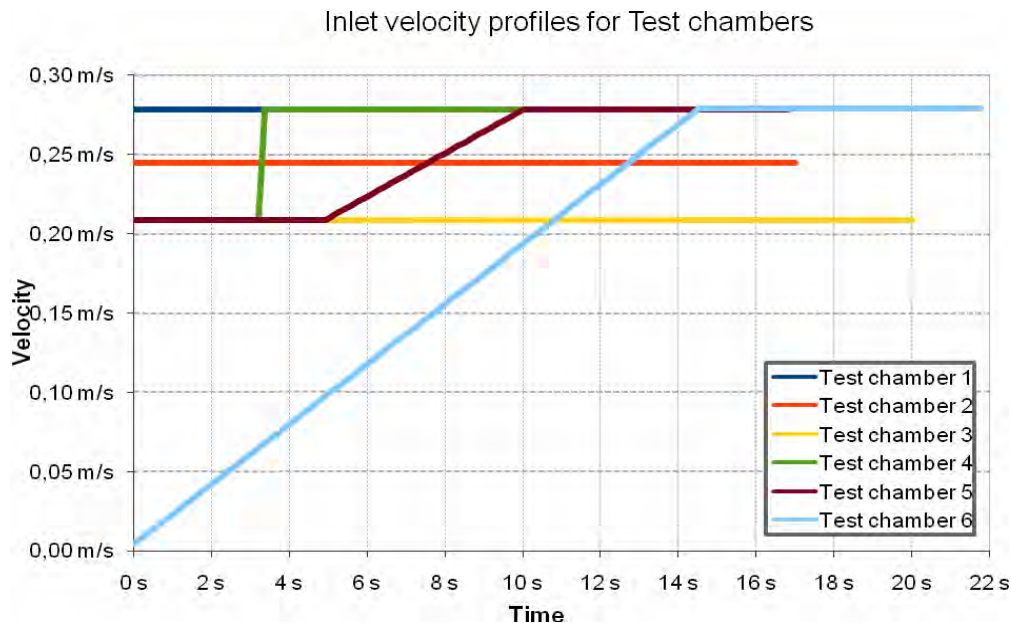


**Figure 7-5:** Comparison of inlet velocities below and above critical velocity.

The formation of such gas bubbles certainly reduces the capacity of the tank itself and thus should be avoided. Based on those simulations the critical inlet velocity was determined to be in the range between 0.275 m/s and 0.29 m/s and the EXPLORE experiment was designed to investigate the flow characteristics in this specific range of inlet velocities.

As the EXPLORE Experiment incorporates six test chambers, six different flow profiles have been developed to first validate the maximum inlet velocity with good filling conditions and secondly to investigate, if variations of the inlet velocity during the filling process have any influence on the flow

characteristics inside the test chambers. These flow profiles are shown in Figure 7-6.



**Figure 7-6:** Inlet velocity profiles for test chambers.

Test chambers 1 to 3 are filled with a constant inlet velocity, which is slightly higher or lower than the critical velocity with flow separation from the sphere. This is to validate the simulations. The velocity profile of the fourth test chamber is lower than the critical velocity and then jumps to a higher value as soon as the liquid has passed the sphere and thus the critical point for flow separation. The same with the velocity profile of test chamber 5 with the difference that the increase in velocity is not abrupt but rather continuous. In test chamber 6 the flow velocity increases continuously from a relatively low number to the maximum.

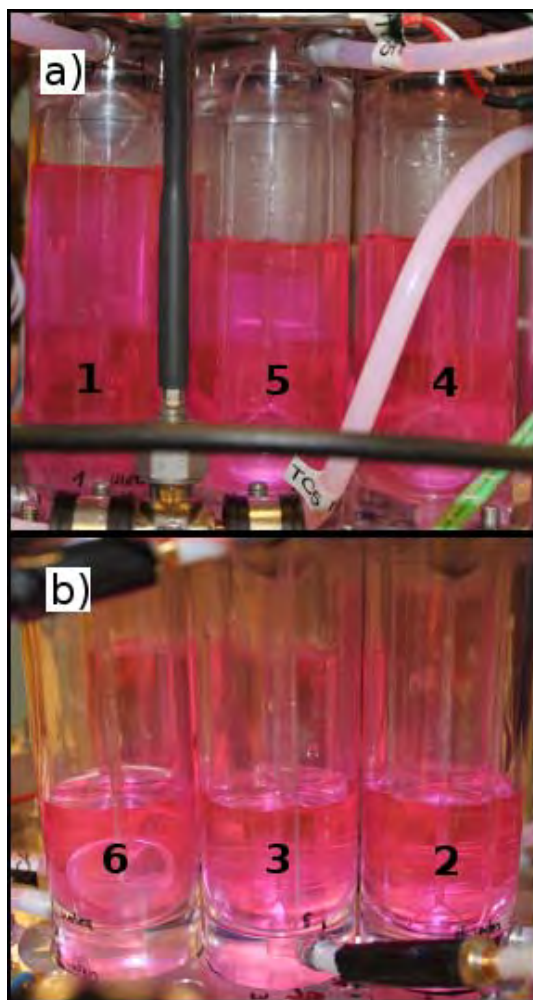
During the flight of the rocket a problem occurred in the fluid system of the experiment causing the mass flow towards the test chambers to decrease. The cause of this problem could not be determined. There are several possibilities, but closer analysis showed that none of them alone could have caused the observed filling levels of the test chambers. The following lists the possible causes and an evaluation of each one.

- *Blockage in the fluid supply tanks due to the membrane*  
Unlikely because the mass flow was reduced in both fluid systems. Also the filling level is different for each test chamber and it would be equal, if the exit of the fluid supply tank was blocked in any way.
- *Blockage in the collection chambers*  
Another possibility is, that the inlet into the membranes in the collection chambers was blocked in some way. This could explain the different filling level of the test chambers, because the inlet could have been

blocked in a different way for each test chamber. But in all prior tests the membranes in the collection chambers never have been a problem.

- *Blockage of the tube to the pressure relief valve*

Right after the disassembly and inspection of the experiment some ice in one of the tubes between collection chamber and the pressure relief valve could be noticed. This ice probably came from some water that was left in the collection chamber from prior tests. But with this ice causing the pressure in the fluid system to rise with ongoing filling of the test chambers, the filling level of the test chambers would not have been almost equal for the test chambers of one fluid system.



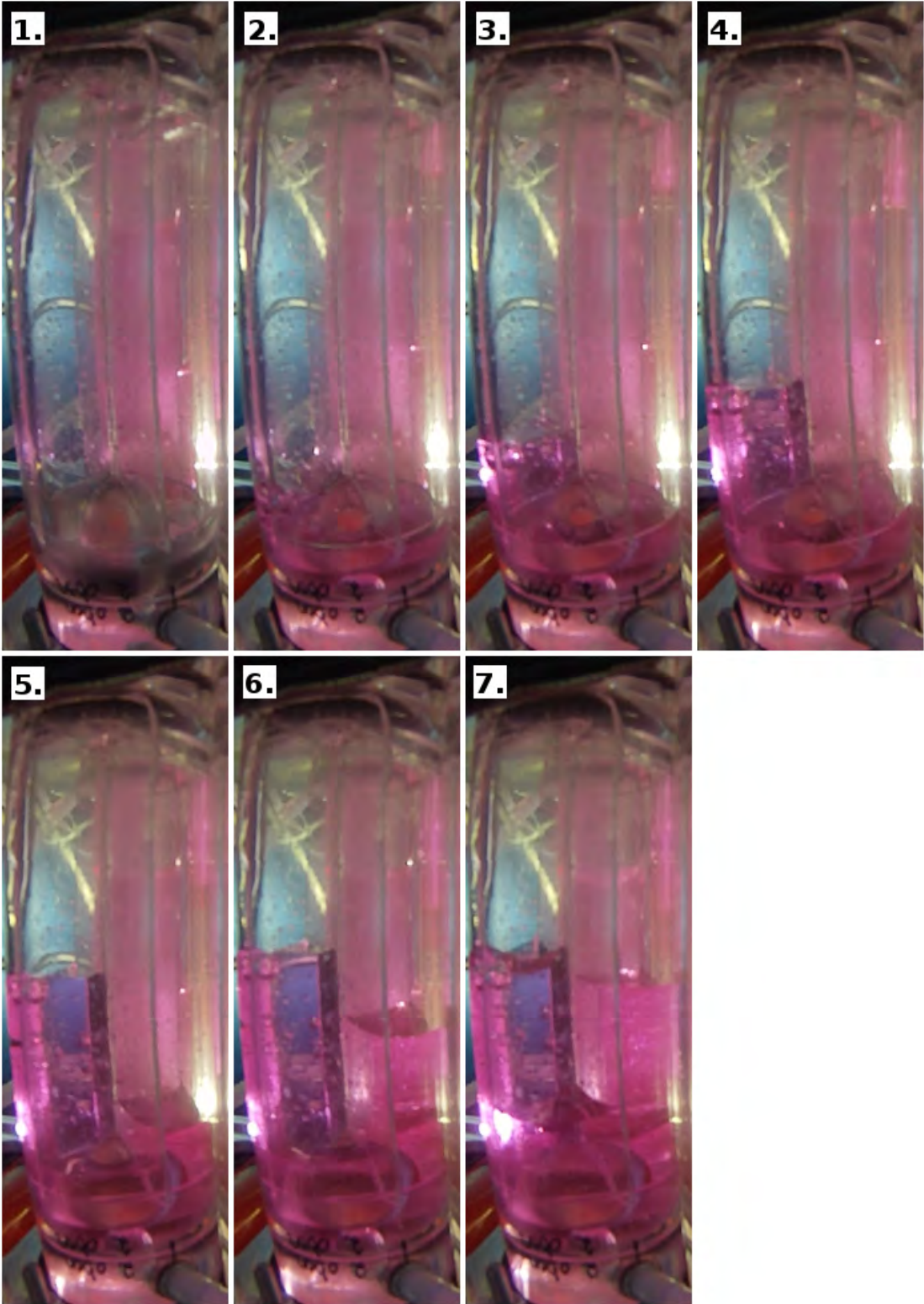
**Figure 7-7:** Filling levels of test chambers after the flight.

Most likely a combination of these reasons caused the decrease of mass flow in the fluid system and the observed filling levels of the test chambers.

With the fluid mass flow reduced and the open loop controlled flow controllers the micro-controller closed the valves before the filling of the test chambers was completed. Also a reduced mass flow results in decreased inlet velocities into the test chambers and the desired flow velocities could not be reached for any of the test chambers.

However the flow into the test chambers was recorded on the camera and the analysis of the video data showed, that the basic principle of liquid and gas separation successfully worked. The picture series in Figure 7-8 is taken from the video of the test chambers during the rocket flight and shows the flow inside test chamber 2. As it can be seen clearly from the pictures the liquid and the gaseous phases are separated successfully without the use of a membrane or other device.

Only the surface tension forces the fluid to migrate along the walls of the test chamber.



Another effect that can be observed in the video data is the unequal filling of the test chamber's four separate parts. The vertical walls inside the test chamber divide the cylindrical shape into those four almost triangular parts. Reasons for the unequal filling can be imperfect centring of the sphere and the vertical walls and special flow characteristics based on the highly three dimensional flow. Residual rotation of the rocket is small enough to be neglected as an influencing factor to the fluid flow.

To summarize the results of the EXPLORE Experiment it can be said that the principle of implementing a specially designed structure into a tank and using the surface tension of the fluid successfully separated liquid and gaseous phases in the tank. However problems occurred during the rocket flight in the fluid system of the experiment resulting in a decreased mass flow and inlet velocity. So the limits of the principle could not be tested.

## **7.4 Discussion and Conclusions**

The “EXPeriment for Liquid On-orbit REfueling” was a complex experiment in the REXUS program of DLR and SNSB. It's main objective was to investigate the separation of liquid and gaseous phase during the refueling process of a tank in micro-gravity conditions. Such a refueling process becomes necessary for further space exploration when space ships will be assembled a fuel or refueled in space and with cryogenic rocket fuels which exceed the capabilities of membranes to separate gas and liquid due to the very low temperatures of such fluids.

EXPLORE was the first to design, implement and test an inner structure inside a cylindrical tank with spherical ends on a sounding rocket. Video data of the test chambers and the view outside the rocket was recorded as well as housekeeping data such as temperatures and pressures during the entire rocket flight. The video data of the test chambers validated the design of the test chambers to be able to separate gas and liquid only by using the surface tension of the fluid. However problems in the fluid system limited the inlet velocities to values below the desired critical value that would have shown the limitations of the principle at higher inlet velocities. So the EXPLORE Experiment can be considered as a start in the field of surface tension based phase-separation but there still is a lot of research to be done before such a principle could be implemented in real spacecrafts.

Nevertheless did the project provide important and valuable skills and experiences to the team and is considered a great success by the team. Now said team would like to conclude with a picture shot by the outboard camera during the REXUS 9 flight from Esrange Space Station on February 22<sup>nd</sup> 2011.

## 7.5 Lessons Learned

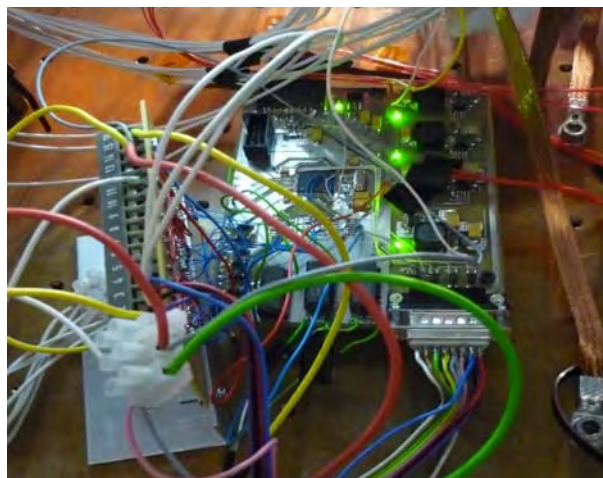
This chapter delivers an insight into some important experiences the students gained while working on the project. Students could avoid a lot of lost time and work if keeping these lessons learned in mind.

The majority of problems are based on a lack of communication and information as well as misunderstandings. Thus it is absolutely crucial to very precisely minute and document everything. Not only changes in the design, but also the reasons which lead to the changes have to be documented.

There is an infinite amount of solutions for any problem but brainstorming has to come to an end at some point. Now one of the solutions has to be chosen and put into action. In the following one has to keep in mind that the chosen solutions may turn out to be unfeasible. This leads to unforeseen changes which usually infect the overall design. In order to minimize these risks one should consult experts or better have them as team members.

The majority of work begins where theoretical knowledge learned at university ends, after the preliminary design is done. When it comes to providing components, it is most important to keep in mind that the delivery time can reach up to months. When it turns out that a delivered component is damaged or it does not meet the requirement at all, it has to be replaced. Thus all components have to be tested quickly after they have been delivered. In addition spare parts have to be scheduled.

The amount of work concerning the electronics and the software was underestimated. These tasks should be processed as soon as possible. The design of a circuit board as well as programming a microcontroller is not easily done without precognition. Figure 7-9 gives an impression of the complexity of the EXPLORE circuit board. The team should include an expert who can concentrate on this task.



**Figure 7-9:** EXPLORE circuit board, a problem child.



Besides this it is desirable to have a teammate who concentrates on the software. The teammates working on electronics and software have to communicate well and they have to know all the important interfaces between electronics and software. When handling the electronics one has to be extremely careful in order to avoid short circuits or electrostatic discharges. Experts from EuroLaunch are telling this several times during the training week and during the launch campaign. One should always remember the warnings and work on electronics calm and concentrated.

Debugging a circuit board which suffered several electrostatic discharges is almost impossible, but also debugging a program written in a higher computer language is time-killing work. A stable and good working program which meets all requirements should not be changed or upgraded. Never change a running system.



## 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
ELGRA	European Low Gravity Research Association
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
IAC	International Astronautical Congress
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.
- [2] D. Chato: Thermodynamic Modeling of the No-Vent Fill Methodology for Transferring Cryogenics in Low Gravity, 1988.
- [3] F. Collins et al: The subscale orbital fluid transfer experiment.
- [4] D. Chato: Technologies for Refueling Spacecraft On-Orbit, 2000.
- [5] S. Dominick, J. Tegart: Low-G Propellant Transfer Using Capillary Devices, 1981.
- [6] S. Dominick, S. Driscoll: Fluid Acquisition and Resupply Experiment (FARE I) Flight Results, 1993.
- [7] S. Dominick, J. Tegart: Orbital Test Results of a Vaned Liquid Acquisition Device, 1994.
- [8] J. Tegart, Z. Kirkland: On-Orbit Propellant Resupply Demonstration - Flight Results, 1985.
- [9] D. Chato, T. Martin: VENTED TANK RESUPPLY EXPERIMENT - FLIGHT TEST RESULTS, 1997.
- [10] D. Chato: LOW GRAVITY ISSUES OF DEEP SPACE REFUELING, 2005.
- [11] K. Benell et al: reel.SMRT SED Issue 0-2, BEXUS8/9, 2009.
- [12] D. Chato: Cryogenic Fluid Transfer For Exploration, 2008.
- [13] Itikka Website, REXUS5, <http://itikka.servu.org/itikka/overview/>.
- [14] H. Hellmann, M. Fittock: SED Guidelines, Issue 2.5, 2009.