SED

Student Experiment Documentation

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Mission: REXUS 11

Team Name:

Experiment Title: **AD**vanced **I**solation **O**n **S**ounding-rockets

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	Dominique Daab	FH Aachen
	Joana Hessel	FH Aachen
	Fabian Baader	FH Aachen
	Tobias Wagner	FH Aachen
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1.11		All	Post PDR Version
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3	2011-09-01	Chapter 3.2.4, 4.2.1.1, 4.4.4, 5.2, 6; Appendix A, B, C; SGRP	IPR
4	2011-11-21	3.2, 3.3, 6.3, 6.5, APPENDIX B, APPENDIX C,	Pre-Campaign
4.4	2012-04-12	4.8	
5	2013-10-07	Results	Final report

CONTENTS

ABSTRACT

ADIOS (ADvanced Isolation On Sounding-rockets) is a development project for a cost-effective μ-gravity platform on sounding rockets. The previous project *VibraDamp* has been successfully tested on REXUS 7. This abstract will discuss the advancement in flight readiness of the platform by a design update.

Due to movements and vibrations induced by other experiments on a sounding rocket, the quality of the μ-gravity is extensively reduced. To decouple an experiment with stringent requirements on the μ-gravity, a group of students of the FH Aachen University of Applied Sciences invented a platform as free flying experiment container. This platform is theoretically able to decrease the influences of the residual forces onto the contained experiment down to five percent. The technical design of the *VibraDamp* project, working on the eddy current principle, achieved a damping of up to 85% for peaks and 65% on average. The major goal of *ADIOS* is to increase the average damping and hence, to increase the quality of the μ-gravity by design improvements of the platform. During the reduced gravity flight phase, the experiment container is uncoupled and free flying. The container is damped by small neodymium magnets. The first eigenfrequency of the container is given by the adjustment of small beam springs. During launch and landing, the container is securely locked to avoid damage onto the experiment. The secondary goal is to decrease the mass of the platform by using carbon fibre reinforced materials. A lower mass of the platform yields in a longer reduced gravity phase due to a higher altitude of the ballistic flight. Additionally, the mass of the contained experiment could be extended. The big advantage of the *ADIOS* platform is the easy adaption to a broad range of different types of experiments with demanding requirements to the quality of μ-gravity. The damping system can be easily adjusted to the
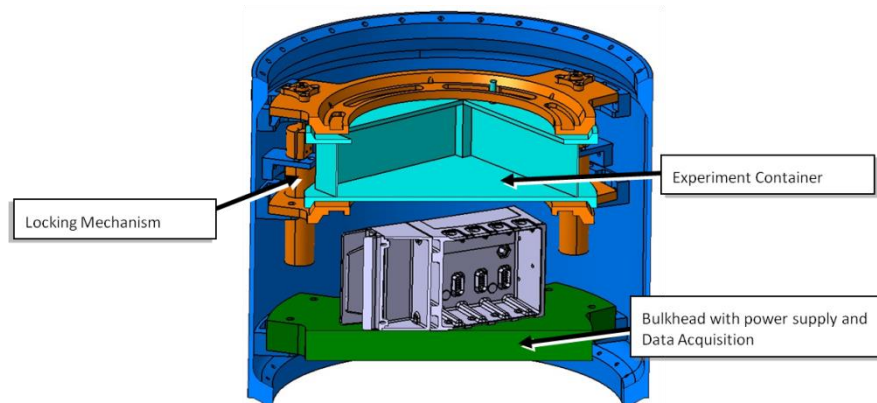
Picture 1: Overview - ADIOS Experiment Platform

size and mass of the contained experiment by the layout of magnets and springs. A single small box of electronics will run the locking mechanism independently from the experiment. In the actual status, the *ADIOS* platform will be tested on the REXUS 11 flight in March 2012 in Kiruna / North Sweden. Acceleration sensors mounted on the free flying experiment container and on the rocket structure will measure the residual acceleration onto the elements of the platform. Calculations with Fourier transformations can determine the difference of accelerations between the container and the rocket structure. To measure the acceleration onto the container, a highly accurate measurement system has to be established. Usually, the noise of the sensors is higher than the measured signal. Therefore a complicated compensation of the signal and processing of the data is compulsory to obtain evaluable data. The applicability of the principle is already proven by the *VibraDamp* project on REXUS 7. If the improvements of the *ADIOS* platform design accomplish the goal of 85-90% damping in average, the platform can be offered to scientific experiments to use cost-effective sounding rockets without a rate control system.

1   INTRODUCTION

1.1   Scientific / Technical Background

In designing a rocket one is faced with the challenge of developing a lightweight structure on the one hand which is able to withstand the high mechanical loads during launch and landing on the other hand. Observing both requirements is hardly achievable without a good knowledge of all acting forces and resulting loads onto the structure during the flight of the rocket. For that, tension shall be measured during launch and landing because those are the critical phases with high mechanical loads. During the reduced gravity phase, there is no tension measurement necessary because the acting forces are very small. But they might be too high for experiments which rely upon a high microgravity quality. For those, a passively damped experiment container will be designed which shall isolate the experiment against external forces using the eddy current principle for damping. Because this experiment container shall be a Free Flying Experiment Device (FFED), it has to be fixed to the outer structure during launch and landing to prevent any movement of the FFED and therefore, any disturbances or even damages caused by the FFED. This will be done using a locking mechanism.

1.2   Experiment Objectives

The ADIOS Experiment is divided in two different experimental parts with different goals. The primary part (EXP1) is the further development of the VibraDamp Project, launched on RX7 in March 2010. The goal is to measure the performance of the developed passive isolation by the comparison of the accelerations on the damped system and the rocket structure.

The secondary part (EXP2) is the practical verification of a numerical analysis of the loads and forces acting onto the rocket structure during the whole flight time. Due to the loads, tensions shall be measured at different interesting points on the structure like motor separation level, nose cone and centre of mass.

1.3   Experiment Overview

The ADIOS experiment is divided in two parts (EXP 1 and EXP 2).

EXP 1 contains following hardware:

- FFED including magnets and springs
- Locking mechanism including three servo motors, clamping rings, and limit switches
- Two tri axial acceleration sensors

EXP 2 contains following hardware:

- 12 strain gauges and amplifiers (8 one-axial, and 4 two-axial strain gauges)
- 6 temperature sensors for temperature compensation of the measured strain

Both experimental parts will fit into a 300 mm REXUS module. The data acquisition (DAQ), the control of the locking mechanism, and the communication with ground are going to be handled by a real-time controller.

1.4 Team Details

1.4.1 Contact Point

The Team ADIOS can be contacted:

REXUS@fh-aachen.de

ADIOS-on-REXUS@gmx.de

Phone: +49 (0)176 61261739

Picture 2: ADIOS-Logo

FH Aachen

Fachbereich 6 / Luft- und Raumfahrttechnik

Studierendenprojekt *ADIOS*

Hohenstaufenallee 6 – Room O2105

52064 Aachen

NRW / Germany

Picture 3: URL Link to ADIOS Website

Name	E-Mail	Phone
Stefan Krämer	Stefan.Kraemer@alumni.fh-aachen.de	+49 176 / 61261739
Brigitte S. Müller	Brigitte.Mueller@alumni.fh-aachen.de	
Dominique-Jonas Daab	Dominique-Jonas.Daab@alumni.fh-aachen.de	
Lysan Pfützenreuter	Lysan.Pfuetzenreuter@alumni.fh-aachen.de	
Vladimir Klassen	Vladimir.Klassen@alumni.fh-aachen.de	
Joana Hessel	Joana.Hessel@alumni.fh-aachen.de	
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Johannes Stahl	Stahl.johannes@alumni.fh-aachen.de	
Andreas Gierse	Andreas.Gierse@dialup.fh-aachen.de	

Table 1: Contact details of the Team members

1.4.2   Team Members

Stefan Krämer (B.-Eng)

Project management, Structure, Science

1st Semester – Astronautical Engineering (M.-Sci)

FH-Aachen - Luft- und Raumfahrttechnik

Apprenticeship: Precision Mechanic - Technician

Brigitte S. Müller

Outreach / PR, Management Assistance

12th semester – Astronautical Engineering (B.–Eng)

FH-Aachen - Luft- und Raumfahrttechnik

Apprenticeship: Precision Mechanic - Technician

Dominique-Jonas (Nick) Daab

Electronics

12th semester – Astronautical Engineering (B.–Eng)

FH-Aachen - Luft- und Raumfahrttechnik

Apprenticeship: Mechatronics - Technician

Lysan Pfützenreuter (M. -Eng)

Science, Programming, Data Acquisitioning

Graduated – Astronautical Engineering

FH-Aachen - Luft- und Raumfahrttechnik

Joana Hessel (B.-Eng)

Structure

1st semester – Astronautical Engineering (M.-Sci)

FH-Aachen - Luft- und Raumfahrttechnik

Fabian Baader (B.-Eng)

Programming / Experiments Controle

1st semester – Astronautical Engineering (M.-Sci)

FH-Aachen - Luft- und Raumfahrttechnik

Tobias Wagner (B.-Eng)

Structure, Electronics

1th semester – Astronautical Engineering (M.-Sci)

FH-Aachen - Luft- und Raumfahrttechnik

Georg Gdalewitsch (B.-Eng)

Data Acquisitioning, Data Analysis S/W

3rd semester – Astronautical Engineering (M.-Sci)

FH-Aachen - Luft- und Raumfahrttechnik

Dipl.- Ing Andreas Gierse

Science, Electronic Development

Graduated

FH-Aachen - Luft- und Raumfahrttechnik

Picture 4: Team ADIOS

1.4.3 Team structure

At the moment the Team consists of ten team members studying at the FH Aachen. Participants of the former project *VibraDamp* are supporting the team with knowledge and the experience regarding the REXUS-Project.
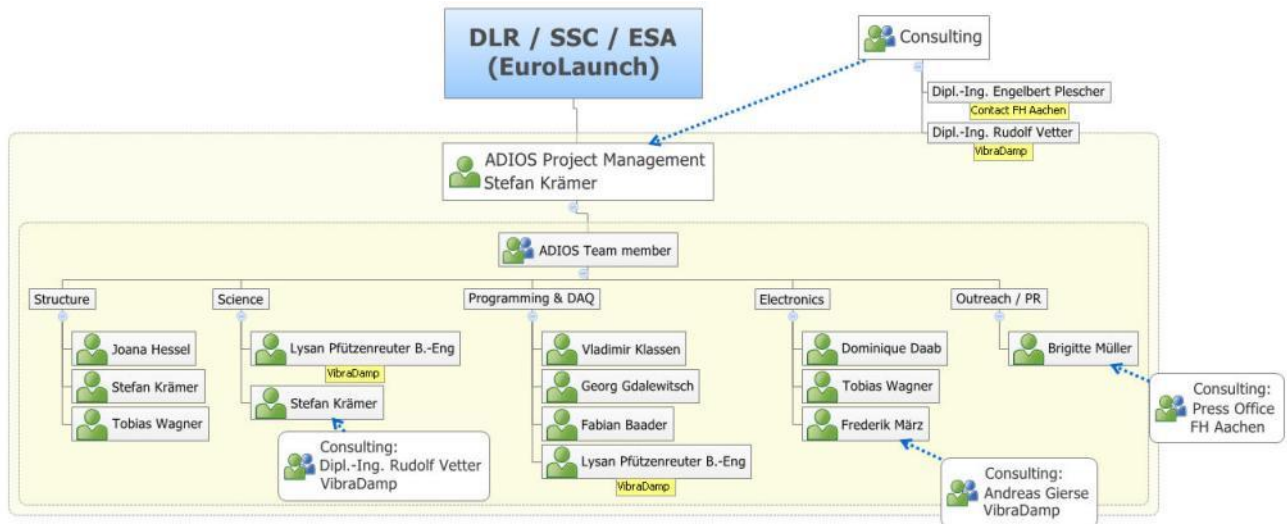

Figure 1: Team structure

The management is the major link between the Team ADIOS and the EUROLAUNCH Consortium, the DLR RY and the DLR Space Agency on the one hand side and the team members on the other hand side. Acquiring sponsors and handling the financial budget and manpower is another aspect of the management.

The structure will be improved by using light weight carbon fibre composites. Due to this change in the construction new calculations and FE-Method simulations have to be made to proof the reliability of the experiment. The responsible team members will do the CAD-Modelling and the structural analysis.

In a close relationship to the structure the science branch is developing the simulations on which the experiments will base. Important is a good knowledge of structural analysis and design. The major part of this workload will be within the framework of at least one master thesis.

The major part of work in the field of programming will cover the development of the S/W for the cRIO with LabVIEW to control the experiment functions as well as the DAQ.

Electronics will be a complex and comprehensive part of the experiment. The power supply and the sensor control needs to be developed and build.

The outreach program and the link for public relations is covered by Brigitte Müller. Due to the parallel work for two other student projects she is in touch with the department of P/R of the FH Aachen and to local media. The administration of the ADIOS website will also be done by Brigitte Müller.

The ADIOS-Logo has been created by Sabina Zits, a Communication Design student of the department of Design of the FH Aachen.

2 EXPERIMENT REQUIREMENTS

2.1 Functional Requirements

The essential requirements to the experiment to achieve reliable data are:

EXP1: *Verification of damped System / FFED*

- F.1: The experiment shall measure the accelerations on the damped FFED during reduced gravity phase using a tri-axial acceleration sensor.

- F.2: The experiment shall measure the accelerations on the undamped structure during reduced gravity phase using a tri-axial acceleration sensor.

- F.3: The damping system shall isolate the FFED from influences due to the rocket

- F.4: The locking mechanism shall prohibit any movements of the FFED during launch and landing

- F.5: For verification the FFED shall be excited by a defined imbalance in a broad bandwidth of frequencies.

EXP2: *Determination of static loads*

- F.6: The mechanical loads onto the structure due to launch and landing shall be determined by a separate tri-axial acceleration sensor.

- F.7: The mechanical loads onto the rocket structure shall be determined by strain gauges mounted in three levels of the module structures during the whole flight.

Infrastructure

- F.8: All acquired data shall be stored on a reliable data storage device.

- F.9: The acquired data shall be sent particularly via telemetry.

- F.10: The control and DAQ shall work autonomously.

2.2 Performance requirements

2.2.1 Acceleration Sensors

EXP1: *Verification of damped System / FFED*

P.1: The two tri-axial sensors need to measure accelerations with an accuracy up to 10^{-6} g

P.2: The measuring range should be ±2 g

P.3: The ACC-Sensor shall be resistant against static loads of launch: 20 g

EXP2: *Determination of static loads*

P.4: The acceleration data shall be acquired with a sample rate of 200 Hz

2.2.2 Strain gauges (EXP2)

P.5: Each strain gauge shall measure the strain with a sample rate of 4000 Hz and should measure with a sample rate of 16000Hz

P.6: The strain gauges shall have a resolution of 100µε

P.7: The strain gauges shall be calibrated for usage onto aluminium

2.2.3 Isolation

P.8: The Isolation setup by magnets and springs shall reach an isolation of min 90 % on the FFED.

2.2.4 Electronics

P.9: The Power consumption shall be in average beneath 1 A

2.2.5 Imbalance generator

P.10: The imbalance generator shall give a defined vibration to the FFED

2.3   Design Requirements

2.3.1   Structure

D.1:   The internal bulkhead should stay as stiff as possible by reduced weight.

D.2:   The Isolation shall work passively.

D.3:   The locking mechanism shall prohibit any movements of the FFED during launch and landing

D.4:   There shall be easy access to electronic boards for maintenance and calibration

D.5:   Electronic access via Ethernet connector at assembled status.

D.6:   The Experiment shall fit into a REXUS 300mm Module

D.7:   To economise weight the locking mechanism shall be build from carbon fibre composites

2.3.2   Electronics, Sensors, Programming

D.8:   The strain gauges should be mounted on the inside of the outer structure.

D.9:   EXP1 and EXP2 shall work independent from each other. If one fails the other one shall not be affected seriously.

D.10:   The electronics shall be as simple as possible

D.11:   The electronic setup should be as light weight as possible

D.12:   The Electronics shall cope with ±28 V

D.13:   Power consumption needs to stay beneath 3 A peak

D.14:   The data volume on the cRIO shall not exceed 0,7 GB for all data

D.15:   The strain shall be measured at three cross-sectional areas, where one is located near the motor adapter, one is located in the Adios-experiment and a third cross-section near the nosecone adapter.

D.16:   The sensors shall be temperature compensated

D.17:   The ACC-Sensors shall be Shock resistant up to 20 g

D.18:   The four strain gauges of one cross-section shall be attached to the structure as shown in Figure 2.
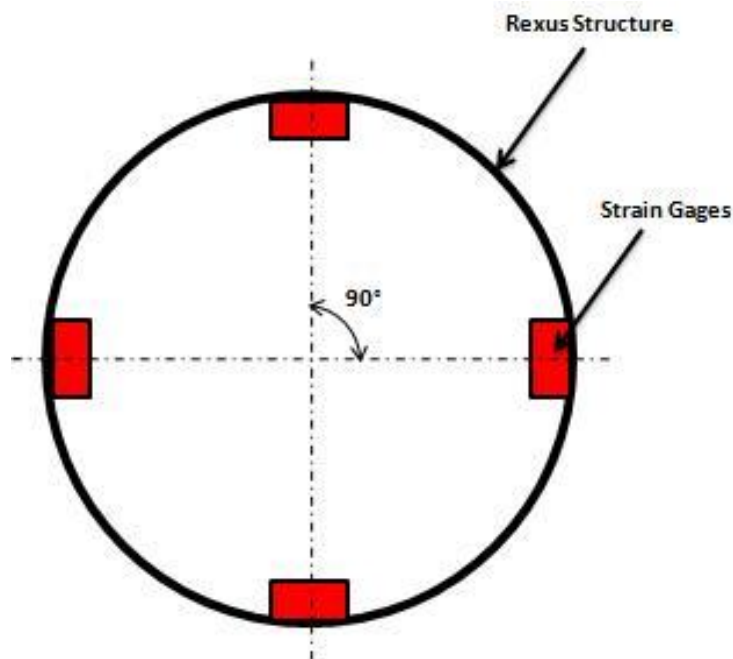
Figure 2: Application of the strain gauges onto the structure

Additional Requirements to the performance of the strain gauges:

1. The strain gauges shall be calibrated for aluminium
2. The strain gauges shall have a minimal sensitivity of 100 µε
3. The sample rate for the strain shall be the same as for the temperature
4. The data volume on the cRIO shall not exceed 0.7 GB measured for all data.
5. Each strain gauge shall measure the strain with a sample rate of 4000 Hz and should measure with a sample rate of 16000Hz

2.4   Operational Requirements

O.1: The temperature of the structure shall not under-run - 20°C.

O.2: The Esrange recovery crew should disarm the experiment with a transport plug.

3 PROJECT PLANNING

3.1 Work Breakdown Structure (WBS)

The following work breakdown structure shows the preliminary work packages for the single subsystems. Regarding the readability, the subsystems are showed in particular in Appendix D.
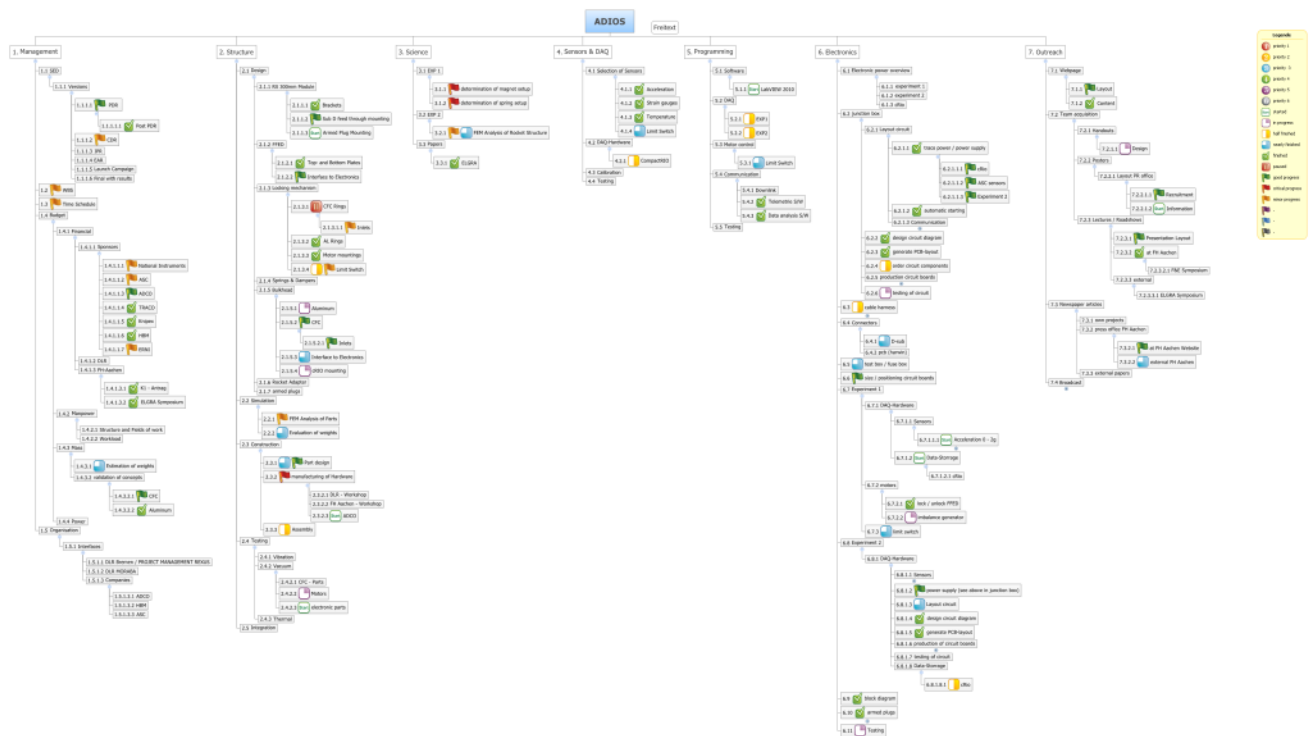

Figure 3: Work breakdown structure of ADIOS, status: 07 October 2013

A frequent update of the status icons shows the progress of the single processes. The caption shows the meaning of the status icons. It is also attached in Appendix D. E.g. red flags show critical processes and green ticks the already finished work packages.

3.2 Resources

3.2.1 Manpower

The actual team size has been enlarged up to ten members.

The team members do their work on the project voluntarily. High motivation and the goal: the launch campaign in sight, is forcing the team to spend an uncountable amount of time to the project. The fields of specialisation of the single members represent their skills and major interests.

Andreas Gierse (Member of the further project VibraDamp) is heavily supporting the team in the field of electronics.

Dipl.-Ing. Rudolf Vetter, Team manager of VibraDamp is consulting the ADIOS management and gives advice in the field of structure dynamics.

Mr. Dipl.-Ing. Engelbert Plescher is the reliable and important link to the university. He provides the team with his experience and expert knowledge in the field of technical aspects as well as project management. Mr. Plescher himself has participated the MAPHEUS 01 – Program of the DLR providing the RAMS experiment. He also was responsible for several parabolic flight experiments.

3.2.2 Workload

The following table shows the possible workload which can be done in a week by each team member.

Team member	Field of work	Estimated workload [h/week]
Stefan Krämer	Management, Structure	15+
Brigitte Müller	Outreach, Website, Management assistance	10+
Dominique Daab	Electronics	10+
Lysan Pfützenreuter	Science, Programming	25h from 1th June 2011
Joana Hessel	Structural design	8
Fabian Baader	Programming cRIO	8+
Tobias Wagner	Electronics, Structural design	8
Georg Gdalewitsch	Programming Data analysis	10
TOTAL		107

Table 2: Possible workload of each team member

3.2.3 Budget

Following an estimation of the budget needed for the successful realization of the ADIOS experiments.

Subsystem	Element		Buy		Phase
Structure	External (RX Module)			On Stock (RX 7 / VibraDamp)	D
	Internal	Carbon fibre composite parts	2000 €	Provided by ADCO	D
		Locking Mechanism	800 €		C
		Magnet holders	200 €		D
Sensors	Acceleration	6x Kistler (2x out of order)		On Stock (RX 7 / VibraDamp)	
		2x ASC (tri axial) 2g	3500 €	(DLR)	C (ordered)
		Strain gauges	691 €	Sponsored by HBM	C
DAQ / Storage	c Rio			NI (RX 7)	
	c Rio Modules		1300 €		C
Electronics	Boards		2000 €		C-D asap
	Amplifiers / Filters		1500 €		C-D asap
Isolation	Magnets / Springs		50 €		D
Tests	Hardware		1000 €		D
Office supplies	Outreach / PR / Print paper / Posters / Stickers		500 €		A-E
Project costs			14.550 €		

Table 3: Budget list of parts

3.2.4 External Support

The TEAM ADIOS is deeply grateful for the support, given by the following companies. A realisation of the ADIOS project would not be possible without their sponsoring. Thank you all!

FH Aachen

The application for the FH Aachen internal commission for education and studies was successful and the team ADIOS will be supported with an amount of 5000 € for the year 2011.

Additionally the FH-Aachen will partially finance the participation fees and travel cost for the ELRGA-Symposium (European Low Gravity Research Association) in Antwerp/Belgium in September 2011 for three students.

FH Aachen – Lehrwerkstatt

Special thanks goes to the Lehrwerkstatt for the fast and uncomplicated cooperation by building structural parts for the ADIOS experiment.

ADCO (Advanced Composites)

The directors of ADCO assured ADIOS to provide the carbon fibre composite parts for the experiment under the condition of practical support by the team. For the sponsor it is important that the team gains experience with the material.

TRACO Electronic

TRACO supports the team ADIOS with two free POWER TRACO´s amounting to 90€ for the power supply unit.

KNIPEX Pliers

The Knipex Company is providing a Four-Mandrel Crimping Plier for turned D-Sub connector pins as a permanent loan. The plier is amounting about 1000€ and can be also used for further and parallel space related student projects. Additionally the Knipex Company has conducted a crimping course to the Team ADIOS.

Picture 5: Four-Mandrel Crimping Plier

HBM *Hottinger Baldwin Messtechnik:*

The HBM sales office in Düsseldorf-Erkrath has sponsored the whole delivery of strain gauges amounting 691€ in total. The delivery included strain gauges, glue, temperature sensors and covering silicone.

ERNI Electronics

The ERNI Company confirmed the sponsoring of D-Sub – connectors for the ADIOS experiment. The sponsored amount connectors is about 70 conectors including all needed accessories. The delivery is amounting about 200 €.

FCT Electronics

The FCT Company has sponsored the Team ADIOS by providing D-Sub connectors and pins as well tools for the assembly.

HARWIN

Harwin has provided the connectors for the acceleration sensors amounting 200 €. The crimping plier will be loan for the time of assembly.

NI – *NATIONAL INSTRUMENTS*

The NI Acadmic Relations Office has sponsored the Team with the required NI-Modules: 2x NI 9205 and 1x NI 9505 including accessories. The delivery is amounting 2147 €

Böllhoff

The Böllhoff Group Germany has Sponsored the required HELICOILS for fhe structural parts including the needed tools for

processing the threads. The delivery is amounting about 300 €.

BCE Special Ceramics

BCE will supply the Team ADIOS with three ACC-Interfaces for the wall mounting of the acceleration sensors.

Erich Frank – Schrauben Metall- und Normteile e.K.

Schrauben Frank has delivered the whole amount of more than 700 screws, nuts and bolds.

E&K Leiterplatten, Heinsberg

The Company E&K Leiterplatten GmbH provides the Flight Hardware- PCB´s for the ADIOS-Experiment.

3.3 Outreach Approach

The outreach plan is an important part of the project. There are several ways of represent the project in the public and media.

FH Aachen:

There was already an interview by the department of PR of the FH Aachen and it was published at the 10th of January on the FH Aachen webpage (Appendix B).

The own homepage is online on the webpage of the FH Aachen Faculty of Aeronautical and Astronautical Engineering and on update status.
http://www.fb6.fh- aachen.de/lur/studienprojekte/rexus-adios/
Posters and Handouts (Flyer) in updated versions are in process.

3.3.1 Public presentations

Research and Development at the FH Aachen

The Team has presented the ADIOS-Project at the Research and Development Symposium of the Faculty of Aeronautical and Astronautical Engineering. The schedule is attached in the Appendix [B].

ELGRA-Symposium:

A delegation of three members of the Team ADIOS is going to participate in the Symposium of the European Low Gravity Research Association (ELGRA) in September 2011 in Antwerp / Belgium. The Team has represented the project during an oral presentation at the student sessions and with a poster at the poster sessions. The poster is attached in APPENDIX B.

The participation fees and travel costs will be partially financed by the FH-Aachen and by the ESA education office.

The Team is applying for the Student Session at the biennial ELGRA Symposium in Rome / Italy in September 2013

Space Utilisation Lecture - SUT / Prof. Dachwald (FH Aachen), Prof. Willnecker (FH Aachen / DLR), Stephan Ulamec (DLR)

In the framework of the SUT lecture, a presentation about REXUS-Requirements and the ADIOS Experiment has been held by Stefan Krämer on the 14th of November 2011.

NI-User Symposium 2011 Aachen

The Team has been represented by Stefan Krämer at the National Instruments User Symposium in Aachen on the 2nd of December 2011 with an 30 minutes presentation about REXUS and ADIOS in combination with NI-Components.

21st ESA Symposium for Rocket and Balloon related Research

The Team ADIOS is going to present the results of the two experiments in the framework of the ESA Symposium by an oral presentation. The symposium takes place in Thun, Switzerland between the 9th and 13th of June 2013.

3.3.2   Publications, Papers and Abstracts

Abstracts for the Abstract-Book of the ELGRA-Symposium 2011 in Antwerp. Publicated at ISBN

Paper for Journal: *Microgravity Science and Technology,* ISSN: 0938-0108, Journal no. 12217, Springer Verlag

Paper for 21st ESA Symposium on Rocket and Balloon Related Research

- **Development and Testing of a System to Damp Vibrations for Micrigravity Experiments on Sounding Rockets** (Stefan Krämer et al. – EXP1)
- **Experimental In-Flight Modal-Analysis of a Sounding Rocket Structure** (Andreas Gierse et al. – EXP2)

3.4   Risk Register

Table 3: Risk Register

ID	Affected Parts	Risk (& consequence if not obvious)	P	S	P x S	Action
TC10	Interfaces	Damage during test	B	2	Very low	Spare parts
TC20	Motors	Damage during test	A	1	Very low	Spare parts already on stock

SF10	Motors	Damage during flight	A	3	Very low	Experiment shut down
TC30	cRIO	Damage during test	A	3	Very low	Spare part already on stock
MS10	cRIO / Software	Programme failure during flight	B	2	Very low	Loss of data
MS20	cRIO	Damage during ascent	B	3	Low	Total loss of all data
VE10	cRIO	Damage during µg-phase (Loss of locking control)	A	4	Very low	Reliable structure cage
MS30	cRIO	Damage during descent	A	2	Very low	Reduced EXP2 Performance
MS40	Sensors EXP1	Damage during launch	D	3	Medium	Loss of data EXP1
MS50	Sensors EXP2	Damage during ascent	A	2	Very low	Loss of data EXP2
TC40	Electronics	Damage during test	C	2	Low	Spare parts
MS60	Electronics	Damage during flight	A	2	Very low	Loss of data
TC50	Imbalance Generator	Damage during test	A	1	Very low	Spare parts
MS70	Imbalance Generator	Damage during flight	A	2	Very low	Reduced EXP1 performance

3.5   Time Schedule
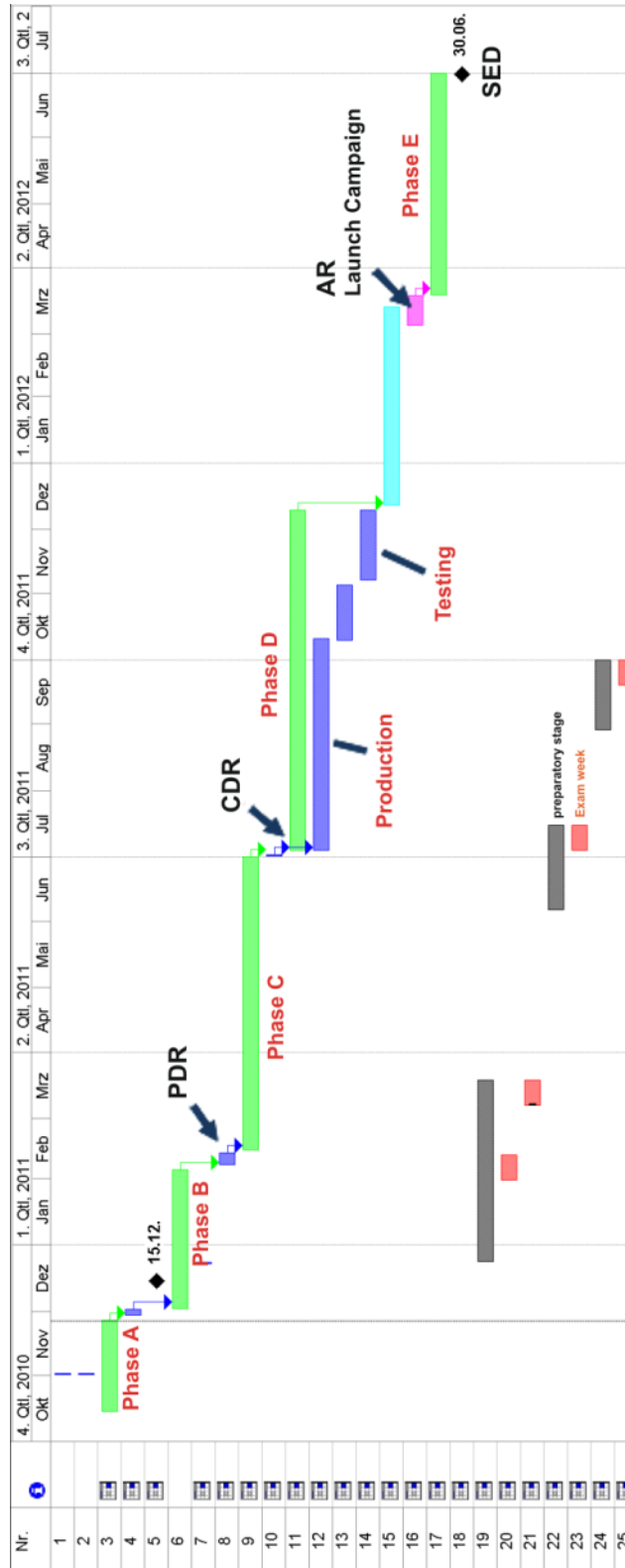
Figure 4: preliminary time schedule

4 EXPERIMENT DESCRIPTION

4.1 Experiment Setup

The experiment ADIOS is divided into two sub experiments. Those experiments will work independently and will not influence each other in case of malfunction of one experiment. The only malfunction which would affect both experiments would be a failure of the cRIO.

4.1.1 EXP1: Verification of the damped System / FFED

The experiment consists of a FFED, locked between two disks during the launch and impact phase.

The FFED is the damped container which easily can be customized for an experiment with a higher requirement on reduced gravity or micro gravity in an excited system like a rocket or a space station. Parts of the container need to be built from a metal to enable the eddy current principle in reaction with the magnets, mounted on the locking mechanism. In the weight of the FFED is not improved to have a similar mass like a real experiment.

To achieve the goal of minimized influences due to the outer structure onto the FFED the knowledge of the effective residual acceleration inside the FFED is essential. This verifies the working principle and improves the TRL of this type of a passive damping system.
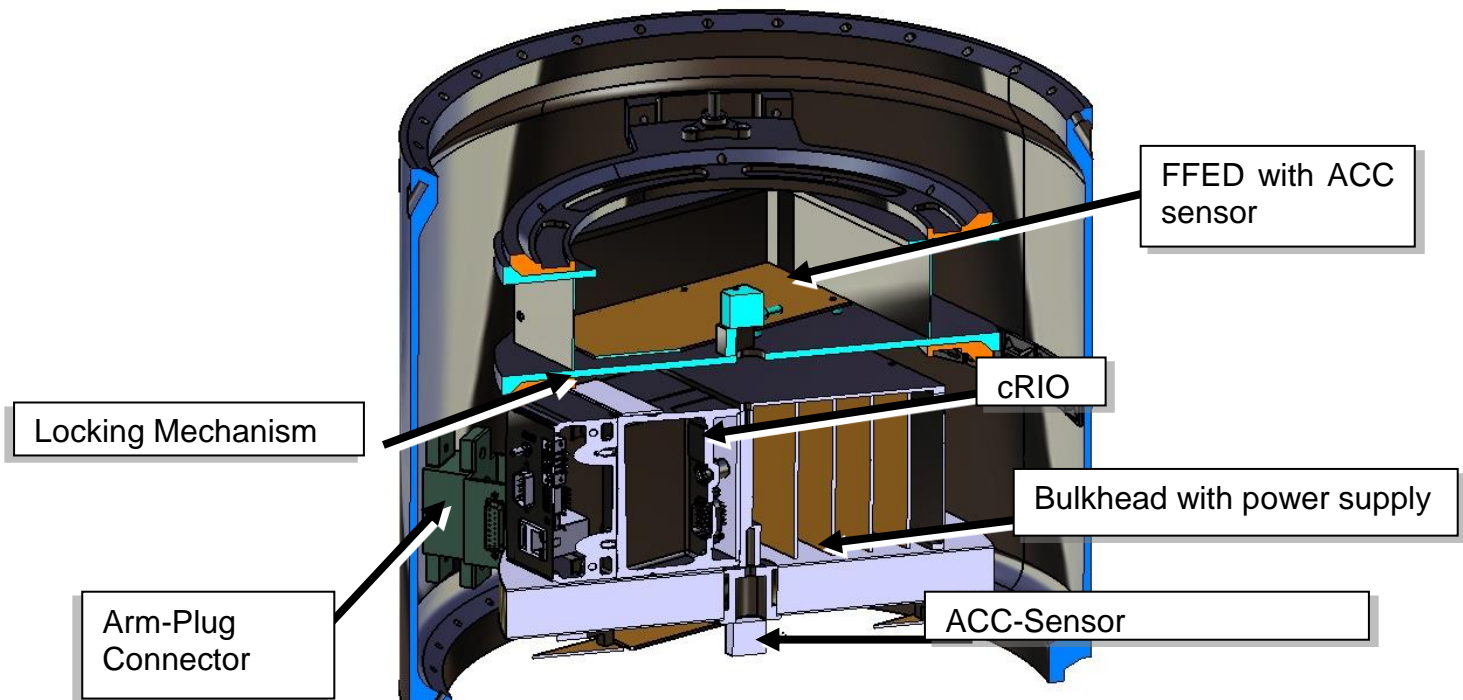
Picture 6: Overview of the Experiment

The residual accelerations onto the FFED are very small. Depending on the sensor setup the noise could be higher than the measured data. To avoid this loss in accuracy the FFED will be excited by an imbalance generator. This generator, probably known from the alarm of mobile phones, gives a defined acceleration in variable frequencies which can be determined and compared. The excitement will act for about 20-30 s and will be hardly measured at the outer structure, neither it would affect other experiments. First estimations showed that a maximum acceleration of 800 µg would suffice to excite the 2kg FFED. This equates an imbalance of $\frac{1}{27} \ cm^3$ with a rotating disk of r ≈ 22 mm.

An accurate calculation can be done after the exact knowledge of masses.

4.1.2   EXP2: Determining of static loads

The mechanical loads acting on the structure during the flight will be measured by strain gauges in critical points. These points need to be determined by structural analysis by building a FE-Model and simulating the acting forces. Presumably several measuring points need to be set in several levels allotted on the inside of the module structures, even at other experiment modules. Due to the setup the strain gauges will be temperature compensated. It need to be confirmed if it is necessary to amplify the signal before transmitting it to the DAQ in the ADIOS Module.

4.2 Experiment Interfaces

4.2.1 Mechanical

4.2.1.1 Cable feed through and D-Sub mountings

The cable mountings will be placed at 180° and a mounting for the D-Sub connectors will be provided in this position. The D-Sub mounting provides space for five connectors (D-Dub 15 Pin). The cable harness is fixed by cable guides (Picture 8: Cable guide) which are glued to the RX-Module wall.
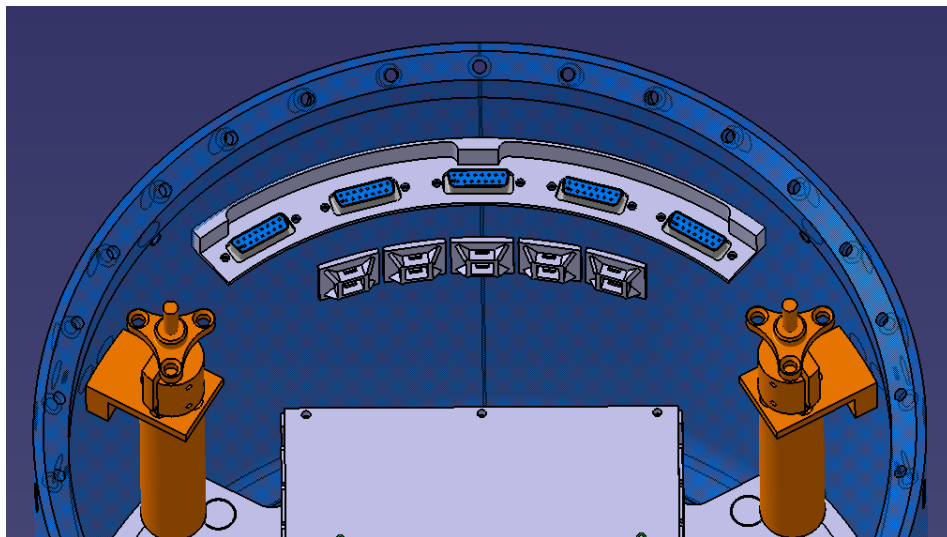
Picture 7: Cable Feed Through at 180°
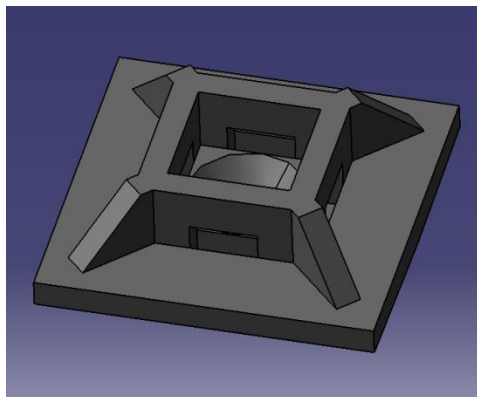
Picture 8: Cable guide

4.2.1.2 Module / Module

The structural connection is given and unchanged by the supplier of the RX-300mm Module. The ADIOS Module will provide the required space for cablings in the connection section between ADIOS and the service module.

4.2.2 Electrical

The interface between the RX service module and the ADIOS experiment is a D-SUB 15 female connector. It will be plugged to a junction box, which distributes the electrical power to several components and includes the power supply for the CompactRIO itself.

- **Signals**

  EXP1:

70s on / 320s off:	start of data acquisition (±2g sensors are switched on)
80s on / (320s) off:	start of experiment (unlock locking mechanism)
	Relocking must be finished at least 10sec. before parachute opens.

  EXP2:

10 seconds before ignition:	start of experiment
1 seconds after impact:	end of experiment

- **Power**

  The ADIOS experiment is completely supplied by the REXUS service module. An application of batteries is not necessary.

- **Up- and downlink**

  An uplink to the ADIOS experiment is not needed.

  The amount of collected data will be too much to transmit it in total to ground. There is no possibility to filter the data in real time to send a preselected data package to ground. The ADIOS experiment data will be stored in total on the build in storage of the cRIO. Status information of the sensors, motors and power supply will be sent and processed in real time on ground to have the actual status of the functions of the experiment during the flight time.

4.3 Experiment Components

The following table shows a rough estimation of the weights and size. In particular the single parts with more accurate information according the weight are shown in APPENDIX D

Experiment mass (in kg):	ca.14 kg
Experiment dimensions (in m):	0,3120
Experiment footprint area (in m^2):	0,0995
Experiment volume (in m^3):	0,0310
Experiment expected COG (centre of gravity) position:	t.b.d. asap

Table 4: Experiment summary table

4.4 Mechanical Design

The mechanical design is based on the design of the VibraDamp experiment. Some aluminium parts will be replaced by CFC-components to reduce mass.

During PDR the team agreed to use a 300mm RX-Standard module to save approximately 0.9 kg on the structure additionally.

The chosen material for the carbon fibre reinforced parts will be a *MD55* carbon fibre laminate with an anodized and vented aluminium honeycomb. This material is space environment tested and certified and will be processed in a qualified workshop.

Part	Laminate	Sandwich
Bulkhead	MD 55 – 8 layer	1" AL honeycomb
(Locking mechanism	MD 55 – 8 layer	1/3" AL honeycomb)

Table 5: Carbon fibre materials

All mountings and threads in the laminate will be reinforced by AL-Inlets with HeliCoils to avoid deformations of the honeycomb. The sponsoring company ADCO is going to support the planning by consulting the structure responsible team members.

The principle of the locking mechanism as well as the mounting on the outer structure will not be changed because it is tested and worked properly on RX7.
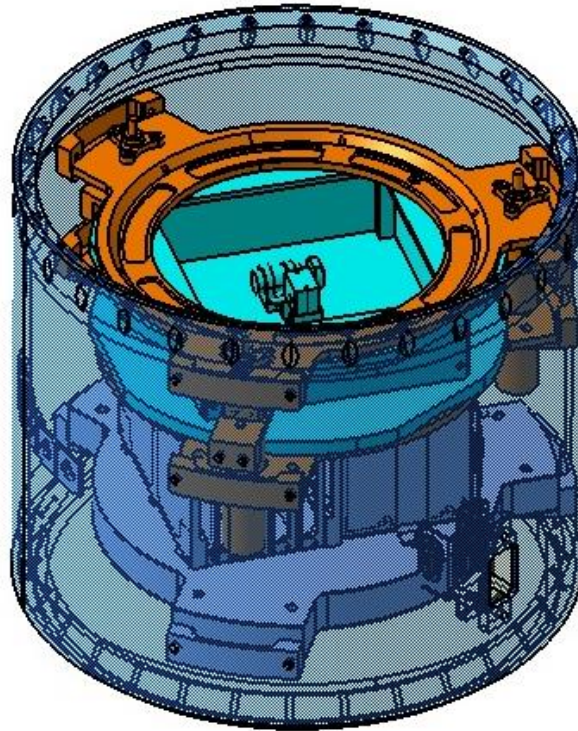
The electronic boxes attached on the FFED are going to be removed and the electronic boards will fit into the FFED. Therefore, the inner volume has been enlarged by changing the position of the walls.

4.4.1   Locking Mechanism

The LM works on the principle of form fitting. Two rings on the upper and lower side of the FFED are holding it during launch and landing. The lower Ring is attached directly to the module walls. During the reduced gravity phase, three geared electric stepped motors are driving the upper ring to enlarge the space in between the LM and the FFED is free flying. Bevelled circles on the upper and lower ring are fitting exactly to the bevels on the FFED. This assures the perfect position during locking. Positioning sticks are mounted on the FFED and are fed through the LM – rings. If the LM has a malfunction during locking after the reduced gravity phase, these positioners avoiding damage to the module and electronics as well as DAQ during landing. Due to this the FFED is not able to move further than a few mm away from the x-axis of the rocket.

![ADIOS logo - advanced isolation on sounding-rockets, no vibrations, good vibrations]

![EuroLaunch logo - A DLR and SSC cooperation]
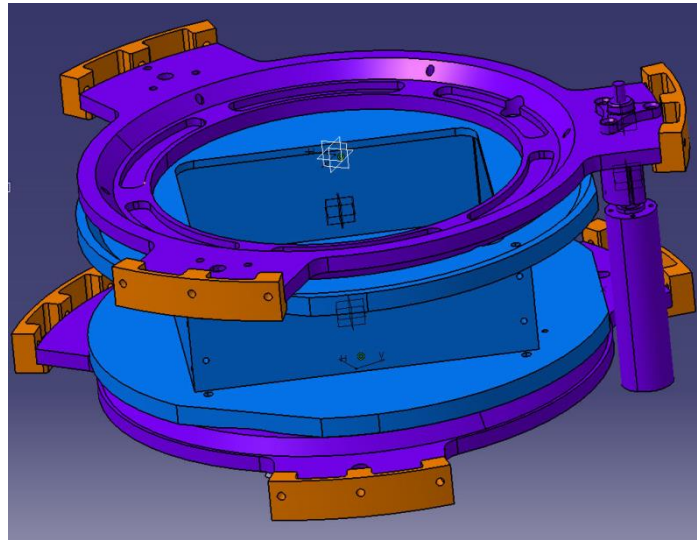
Picture 9: Locking mechanism and FFED

A limit switch will assure the optimised position of the LM and hence a defined distance between the LM-rings. This is necessary to assure the calculated magnetic damping.
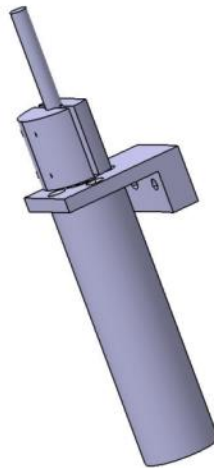
Picture 10: Motor and attachment

4.4.2 FFED (Free flying experiment device)

The FFED is the experiment container, which could be offered to µg-experiments. Later on the volume could be easily adapted to the size of an experiment. In the ADIOS experiment the FFED contains the ACC-Sensor and the amplifying PCB as well as the imbalance generator. The FFED is

secured against damage due to a malfunction of the locking mechanism. Pins on top and on the bottom of the FFED are penetrating the locking mechanism and avoid an undesired movement out of the boundaries of the locking mechanism.
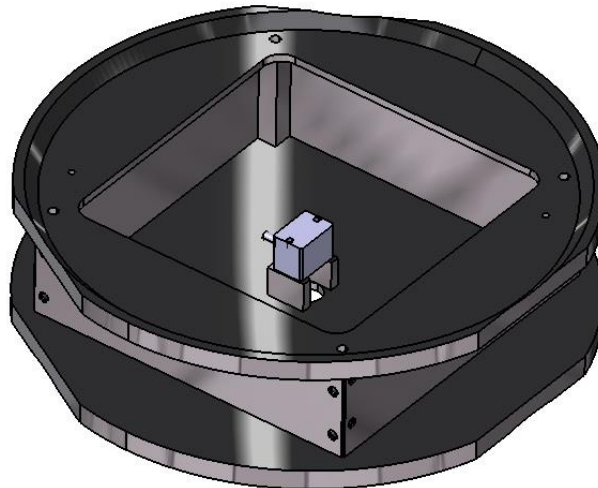
Picture 11: FFED with ACC-Sensor

4.4.3   Bulkhead

The Bulkhead is a complete new design. A Carbon fibre sandwich with an aluminium honeycomb will serve the basic plate. Inlets are employed at the places where forces are acting on the structure. For example, the anchorage of the cRIO as well as the EXP2 PCB Box, are tubes which are glued into the structure of the honeycomb between the CFC plates.
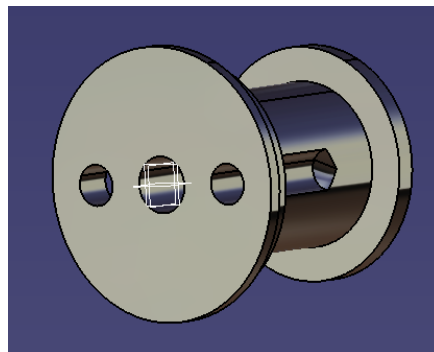
Picture 12: M5 Inlet

To save weight by high stiffness, the amount of used inlets is as low as possible. The screws for the cRIO and the EXP2 PCB-Box are also holding the interfaces for the ACC-PCB and the junction box. The EXP2 PCB-Box contains the four PCB´s for the amplification of the strain and temeperature measurements. The design will assure the easy access to the PCB´s for calibration and test. It is mounted to the bulkhead by six M5 screws.
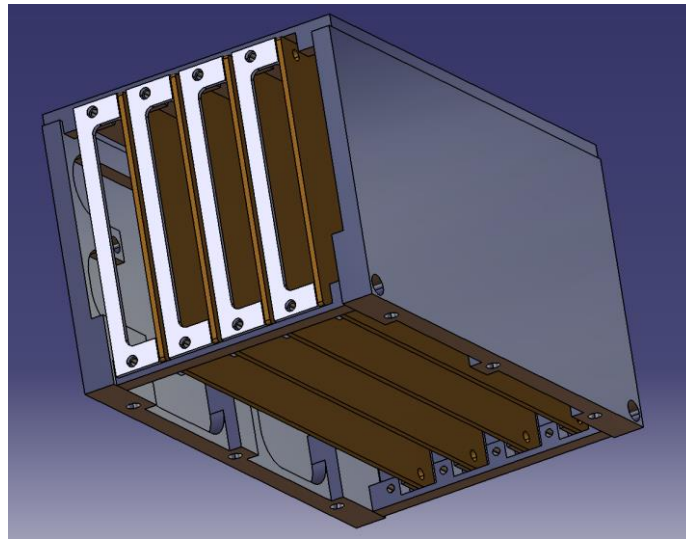
Picture 13: EXP2 PCB-Box
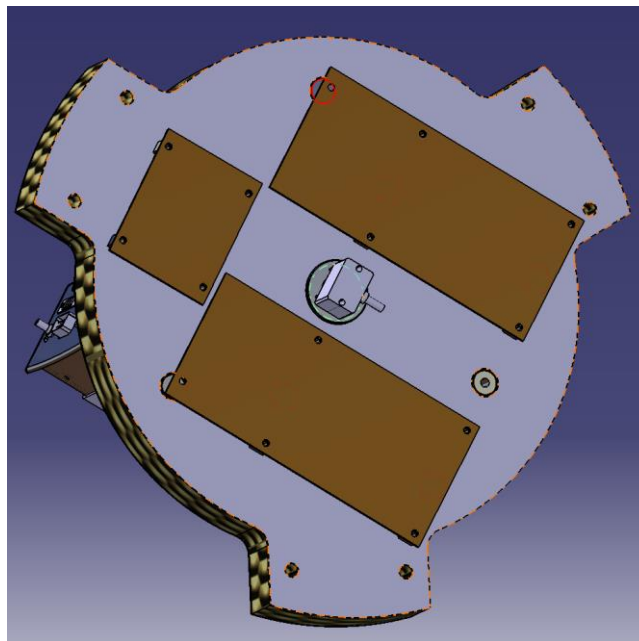
Picture 14: Bottom view of the Bulkhead with PCB-Dummies
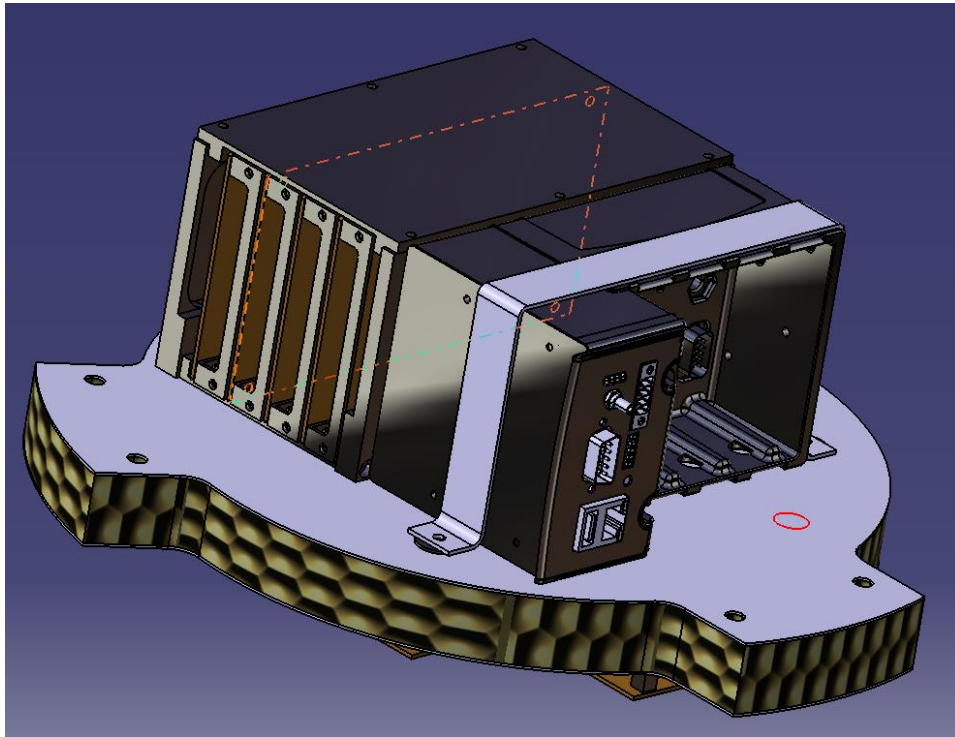
Picture 15: Bulkhead with cRIO and EXP2 PCB-Box

The cRIO is mounted to the EXP2 PCB-Box and reinforced by a aluminium belt which is fixed on the bulkhead. The Belt also avoids a loosening of the NI-Modules of the cRIO.

4.4.4   Arm plugs

For the Arm plugs the RX-Module needs to be processed for a hole of 40 mm x 24 mm. The connector will be mounted from the inside to the wall and closes the hole. A 9 Pin D-Sub will be used as an Arm plug which can easily assembled and disassembled to the experiment.
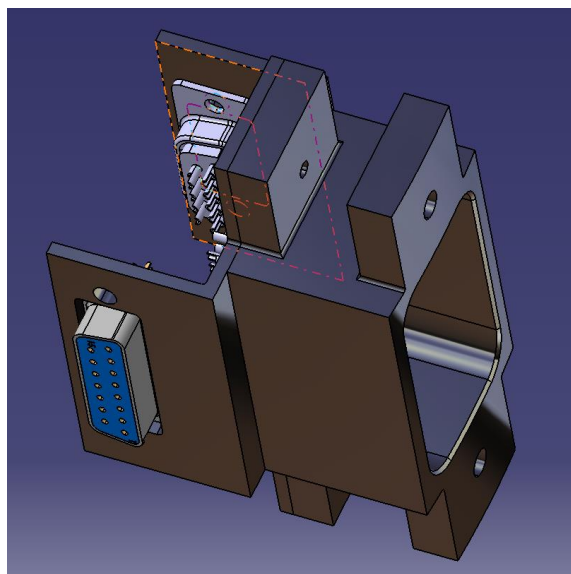
Picture 16: Arm plug interface
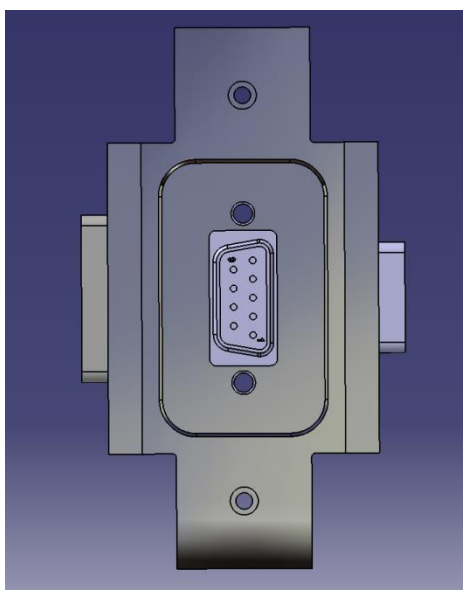
Picture 17: Arm plug interface front view
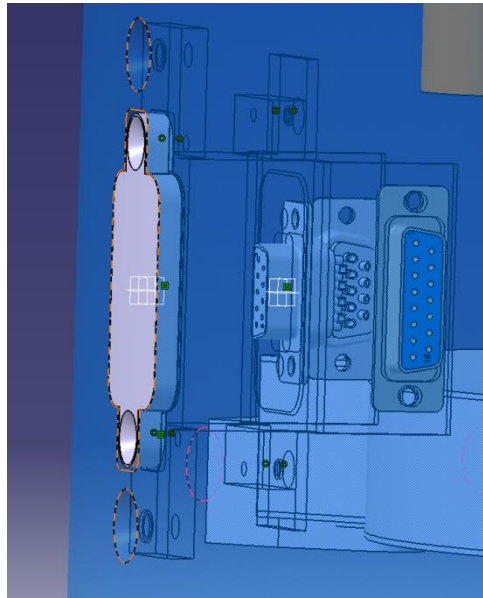
Picture 18: Arm Plug interface with cover

4.4.5 Position of acceleration Sensors

A late change has occurred in changing the position of the verifying acceleration sensor on the bulkhead. Therefore a new position is fixed on the inside of the outer rocket structure. The reasons for the change are the improved comparability of the measured data. There are now no parts with unknown structural behaviour in the way of the vibrations. A structural analysis of the single carbon fibre bulkhead is complicated and would not assure a detailed knowledge of the isolating behaviour of the bulkhead itself.

To keep the sensor in an acceptable temperature range it is necessary to use insulating material for the interface between RX-Module and acceleration sensor. Therefore we need to use ceramic material with a heat transmission factor of 2 W/m^2 like Z700.This interface will be supplied by *BCE Special Ceramics.*

4.4.6 Mass reduction

Forced by the review board during the PDR the mass of the experiment has to be reduced down to 13 kg. The goal will be reached by using light weight CFC including an aluminium honeycomb for the bulkhead. For the LM there are two possible options of mass reduction.

The first option is the milling of cut outs into the existing VibraDamp parts. The second option is the redesign by using CFC .In the table in APPENDIX D the single parts are shown with the actual weight and the estimation for the new parts.

The VibraDamp 400mm RX Module will be replaced by a 300 mm RX Module. Due to this change it is possible to save up to 0.95 kg.

The FFED will be designed smaller and hence lighter. The casing material will be changed from 2 mm to 1mm AL sheet metal. A cut out, also used as access hatch, will save weight as well.
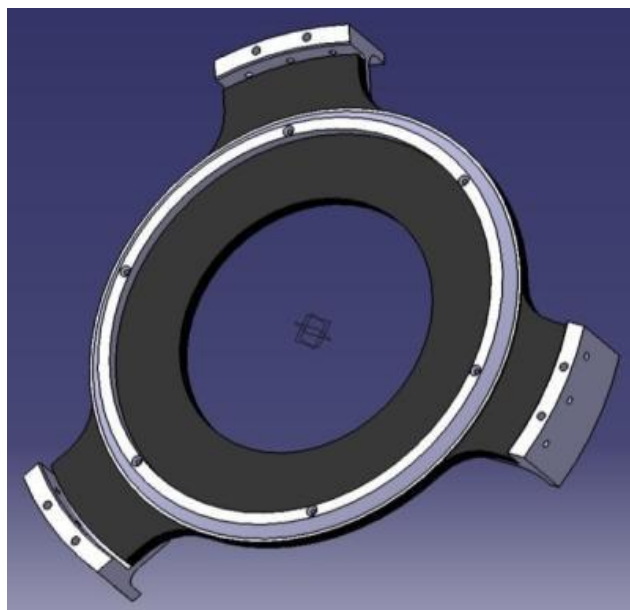
The redesign of the brackets saves up to 50% in weight.

Regarding the financial budget it is compulsory to work with highest cost effectiveness. It is needed to evaluate the price and workload to build the
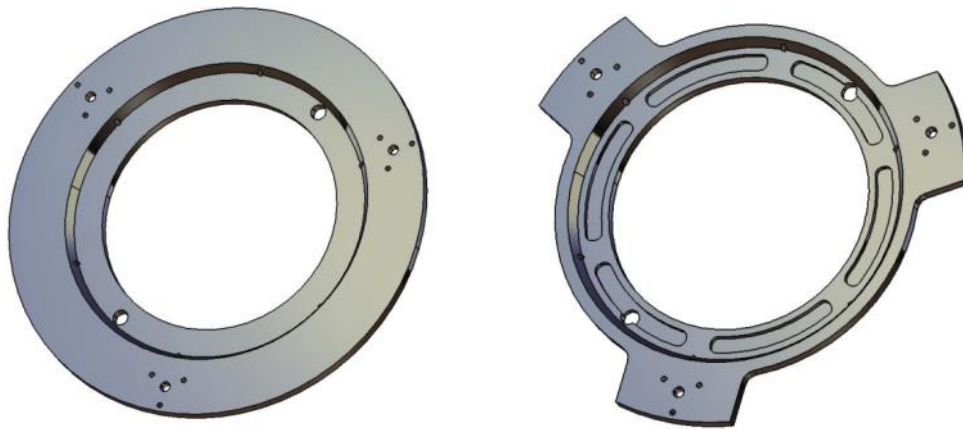
Picture 19: Old and new design of the LM aluminium rings

carbon fibre composites in comparison with the processed VibraDamp parts.

Picture 20: Alternative CFC LM design
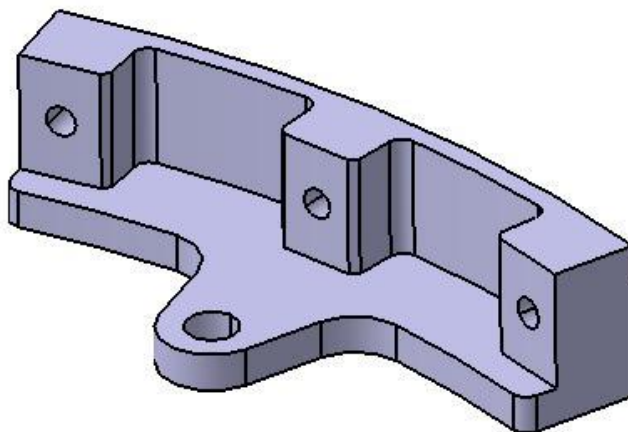
Picture 21: Mounting of locking mechanism
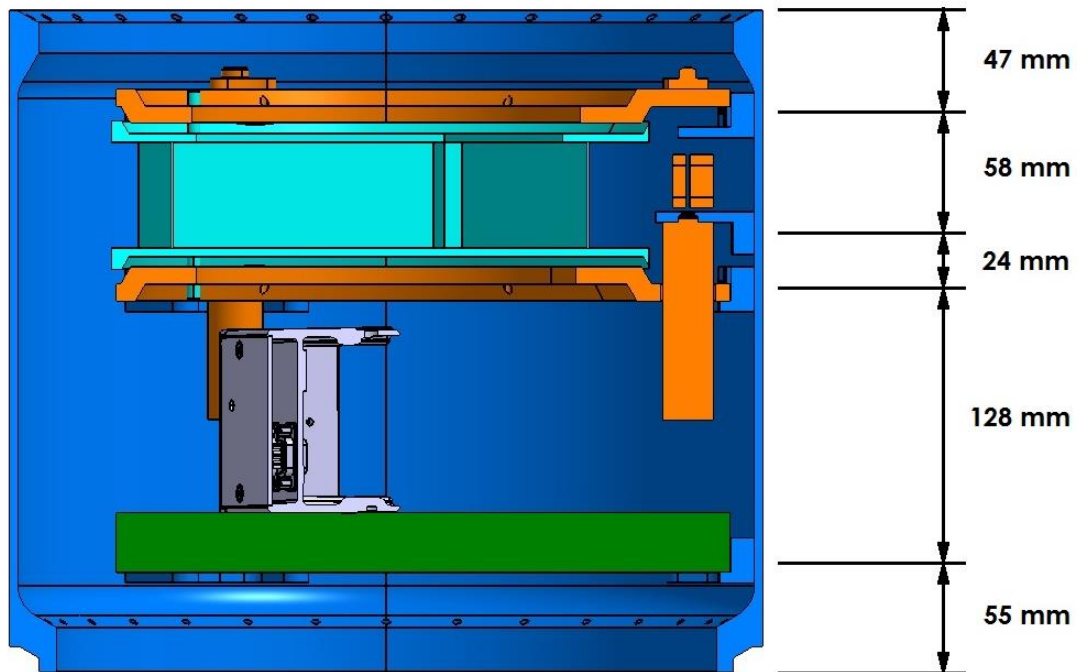
Figure 5: Structural levels

The bulkhead and the locking mechanism are mounted on the structure. The mountings therefore are shown in the following picture.
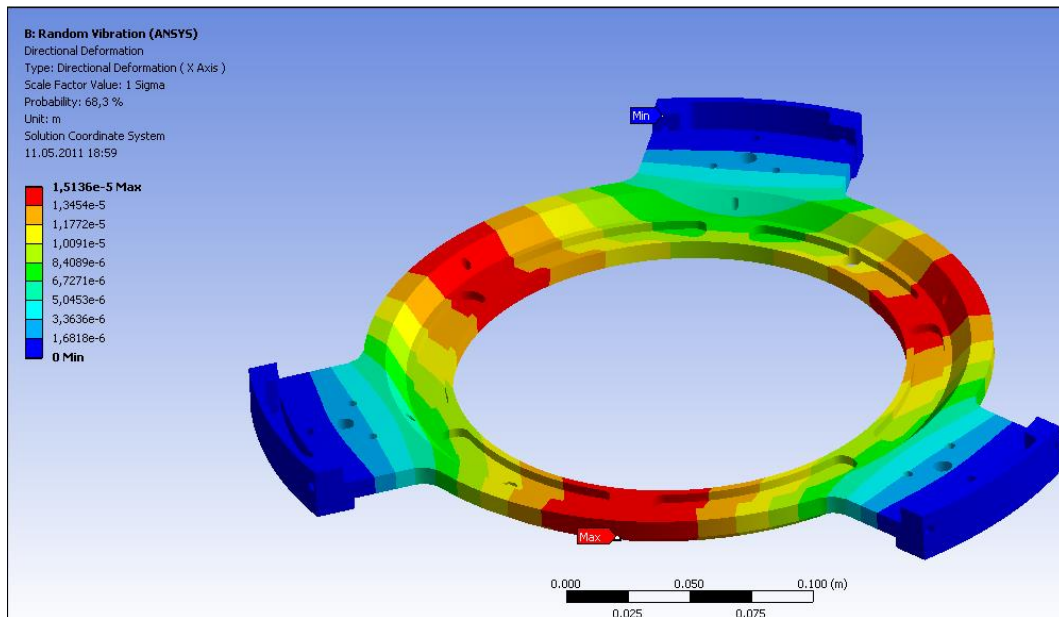
4.4.7 Structural Analysis

In the following pictures the results of the modal analysis of the critical parts and assemblies are shown. The excitation is simulated by a random vibration with 20 Hz - 20.000 Hz. The pictures show the deformation. The material is aluminium.
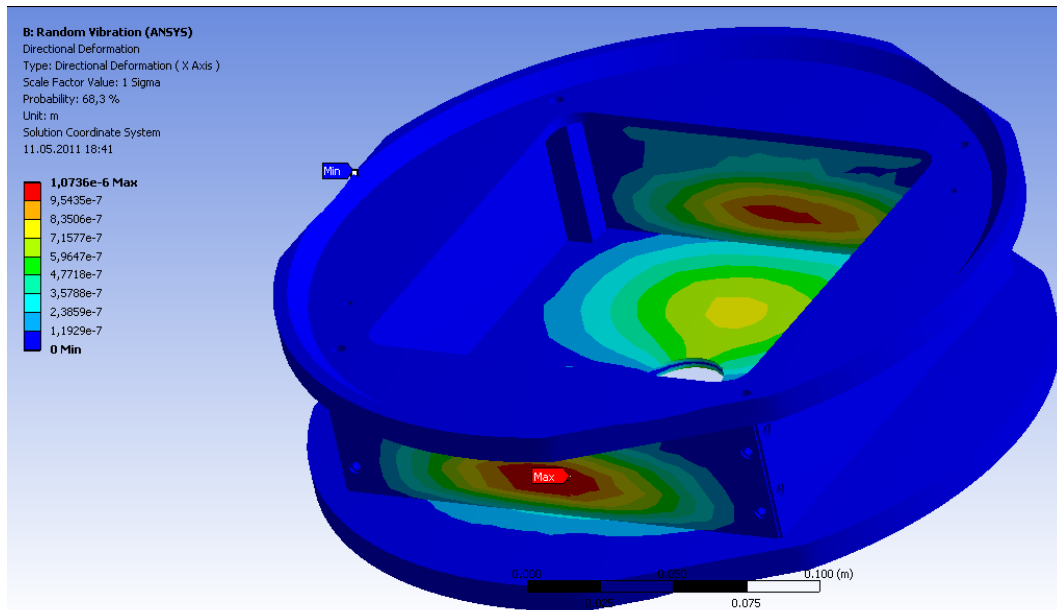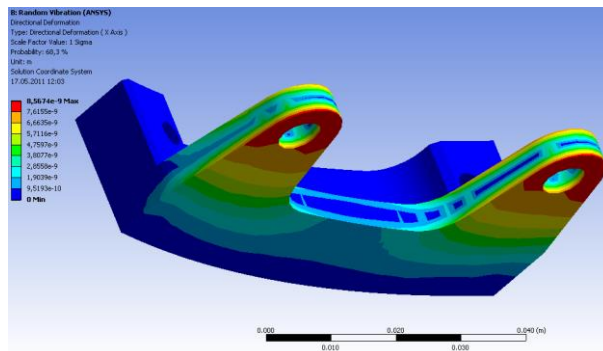

Picture 22: deformations of the FFED
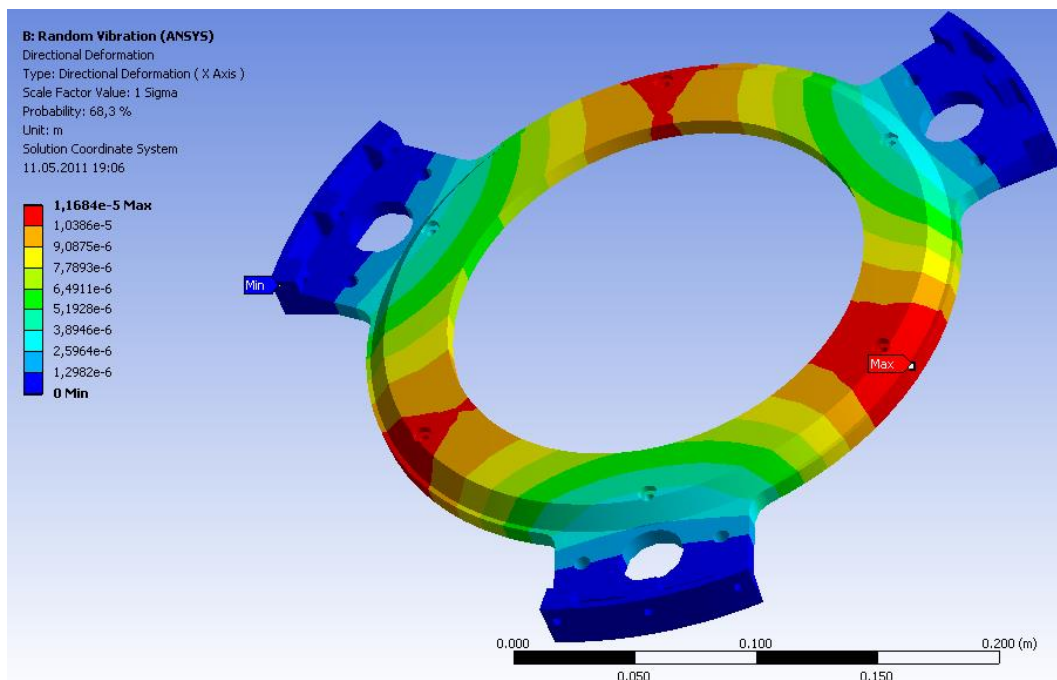
Picture 23: Deformations of the LM bottom plate

Picture 24: Deformations of the LM top plate
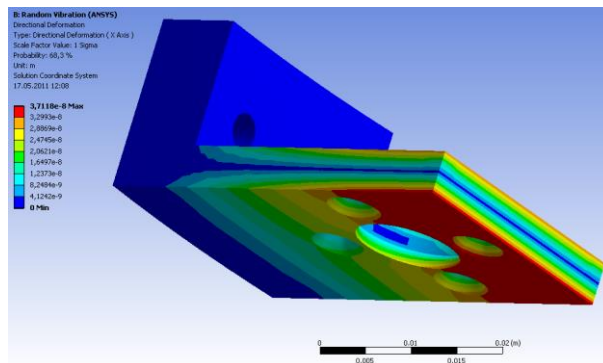
Picture 25: Deformations of the Motor mounting

Picture 26: Deformations of the Brackets

The results show that there will not be any critical deformations of the structural parts.

4.4.8 Drawing Number System

To keep an overview over the CAD parts and drawings a numbering system was invented. The CAD parts and assemblies will be archived in folders of levels of the structure. The single parts will have version numbers to easily identify status of progress and changes. Because of the evaluation of weight the materials of the different parts are named in the system.

4.5   Electronics Design

The ADIOS experiment consists of two different experiments. The first experiment (EXP1) verifies the quality of the damping system. EXP 2 will measure the loads and forces which affect the structure of the rocket during the whole flight.

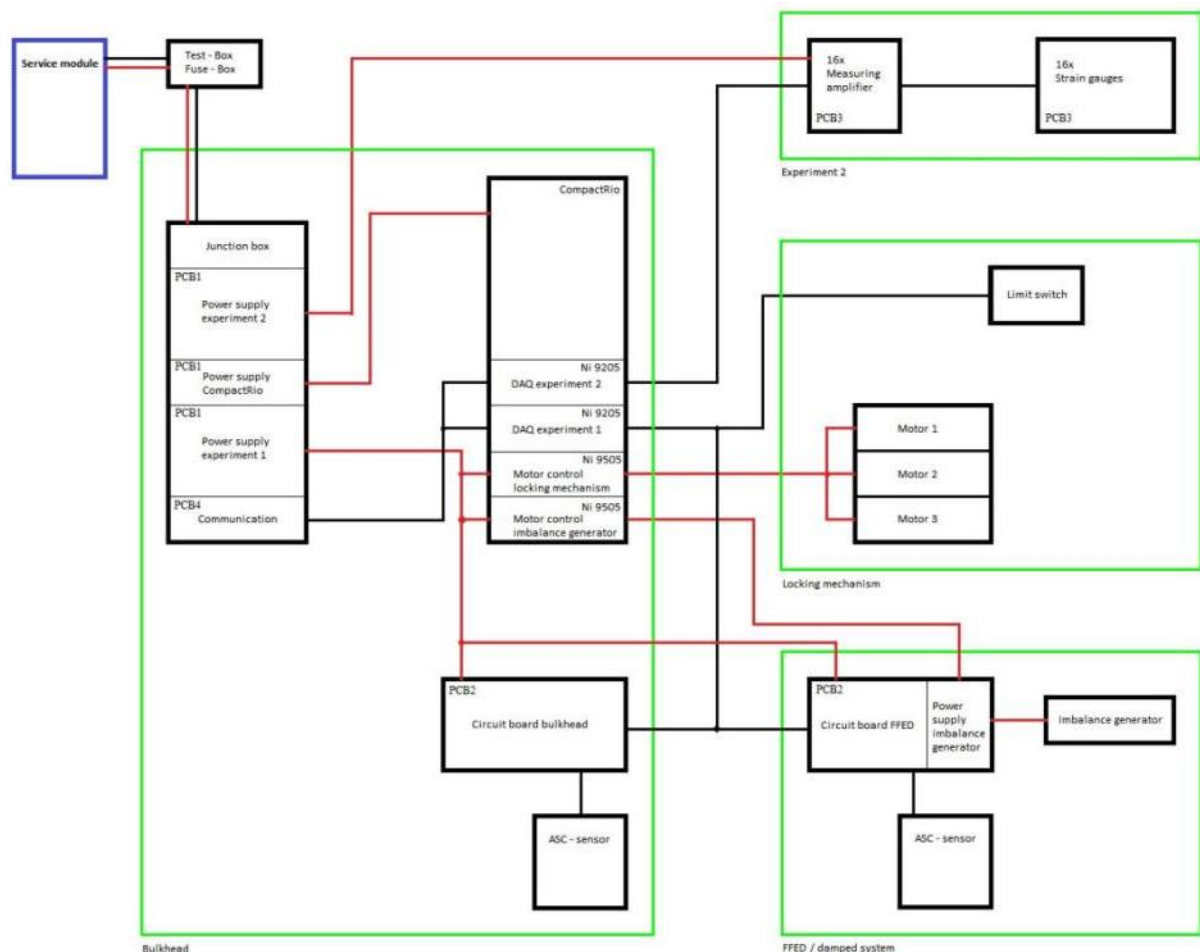### 4.5.1   Block diagram of the ADIOS experiment
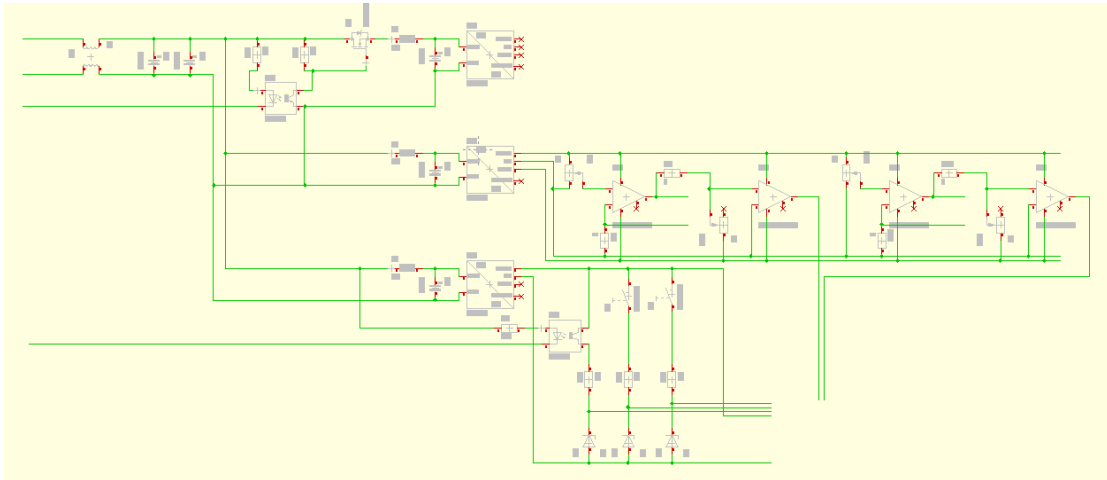
Figure 6: Block diagram ADIOS experiment

Figure 7: Overall schematic ADIOS experiment electronics

4.5.2   EXP1

The accelerations are measured by a tri-axial acceleration sensor on the FFED and by an identical sensor on the structure. The measured data are stored in a CompactRIO module. To drive the locking mechanism three motors are required. An additional motor will be mounted on the FFED to drive a defined imbalance. The motors are driven by the CompactRIO module NI 9505.
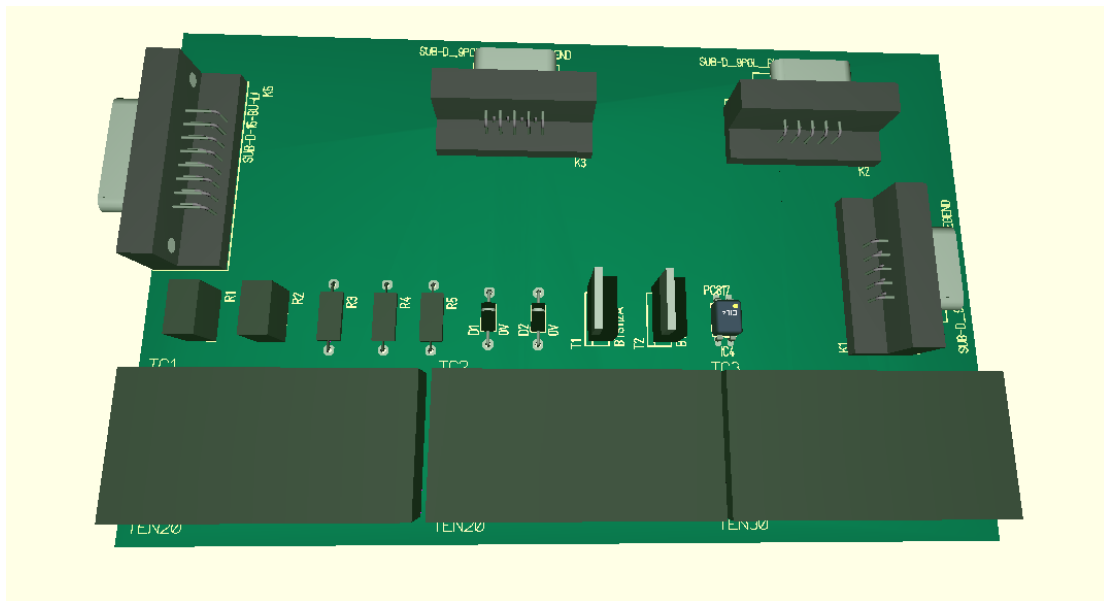
Electrical Components:

Junction box

> The interface between the REXUS service module and the ADIOS experiment is a D-SUB 15 female connector. It will be plugged on a junction box which distributes the several electrical components. The Junction box consists of PCB1 and an RS232. PCB1 is implemented with three Traco power DC-DC converters. Each experiment is supplied by a Traco TEN 20-2423 DC-DC converter with a demand of 20W. It provides a voltage of ±15V at a current of 667mA. The DC-DC converters are enabled by signals of the REXUS service module (SODS/SOE). That is realised by a FET, which distributes the converter with an input voltage of 28V after switching. The third DC-DC converter is used for power supply of the CompactRIO module. The Traco TEN 30-2413 DC-DC converter has a demand of 30W and provides an output voltage of 15V at a current of 2A. That DC-DC converter is directly linked to the input voltage of 28V of the REXUS service module which implies that the CompactRio module is booting before liftoff. On PCB1 an optocoupler is used to convert the liftoff-

signal (LO) of the REXUS service module to a TTL-signal which is linked to the CompactRIO´s serial interface.

Schematic 1: Junction Box (PCB1)

Picture 27 : layout junction box (PCB1)

RS232 converter (PCB4)

A RS232 module is used to provide the communication between the REXUS service module and the CompactRIO´s serial interface. The circuit of the converter was found on http://www.amateurfunkbasteln.de/rs485/rs485.html.
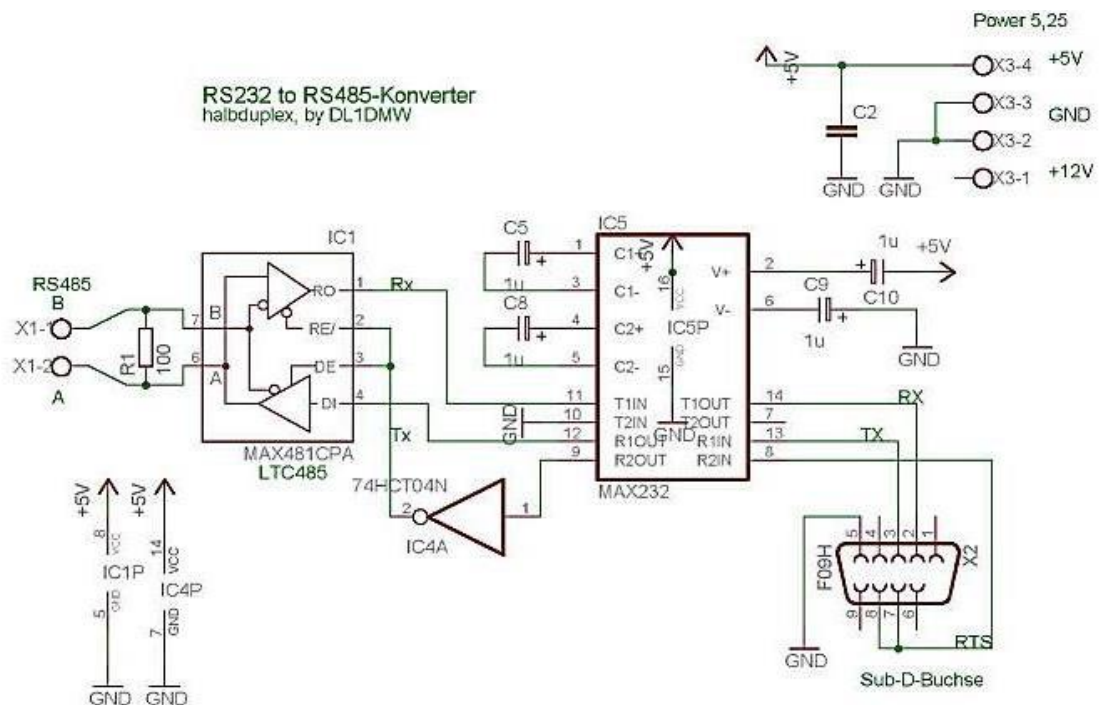
Schematic 2: RS232 converter (PCB4)

CompactRIO

The CompactRIO has several modules:

- Module NI 9505 drives the motors for the locking mechanism.
- A second Module 9505 drives the motor for the imbalance generator.
- The two modules NI 9206 are the interfaces between the CompactRIO and the acceleration sensors as well the strain gauges.

±2g tri-axial sensors

Every sensor needs its own circuit board (PCB2). To provide short ways for the unamplified signals, the circuit board is situated next to the acceleration sensor. The sensor measures in three axes. Every axis has its own data channel. Therefore the circuit board is realised with three measured data amplifiers. The two sensors are powered by one Traco TEN 20-2423 DC-DC converter which is located in the junction box.

Motors

The three motors of the VibraDamp experiment have worked very well that we decided to use this type again. These motors are supplied by one of the 9505 modules of the CompactRIO. The used motors are provided by Maxon Motors. The details are listed below.

- A-max 26 (12V, max 4W) Model 110173
- GP26B Planetary gear Model 144044

An additional motor which is supplied by the second NI 9505 module of the CompactRIO drives the imbalance generator.

Picture 28: Motor FFED

Limit switch

To switch off the motors, which drive the locking mechanism, a limit switch is mounted on the structure. An Omron D2F-01D3 ultra sub miniature basic switch is used. To verify the surviving of the switch during the liftoff, it will be tested on the shaker and in the vacuum chamber. During the liftoff phase the limit switch doesn't have any function. Thus there is no effect on the experiments when it switches while launching of the rocket. This type of switch is recommended for the use in CUBE-SAT´s.

Picture 29: Limit Switch

Circuit board components:

For the VibraDamp experiment, several electronic components were already tested in a vacuum chamber. Those components will be used on the ADIOS experiment as well. Components which are different to the VibraDamp experiment were also tested in the vacuum chamber.

Picture 30: Circuit board components during VibraDamp thermal / vacuum test

Circuit boards / Printed circuit boards (PCB):

The circuits are drawn in TARGET 3001. That program allows also a derivation of the electrical circuit to the layout of the PCB. The PCBs will be produced and drilled Otto Junker GmbH in Simmerath-Lammersdorf. The assembly and the soldering of the PCBs will be at FH-Aachen. Circuit boards will have a 35µm copper layer.

Connectors:

To link the several electronic components D-Sub 9 Pin, 15 Pin, and 25 Pin connectors are used. Turned pins which are crimped with the Knipex Four-Mandrel Crimping Pliers will provide a secure connection. To realise the connection from the acceleration sensors to the belonging PCB Harwin Datamate connectors (Vertical PC Tail Reverse Fix) are used. The connectors are screwed directly on the PCB. The Pin configuration of the connectors is specified at special documents. Each connector has its own document which shows the gender, the location and the function of the pins.

D-Sub 9 Pins

Name	gender	Location
2-3	female (plug)	C-Rio → Junctionbox

Pin Nr.	Name	Remarks
1	DCD	(Data) Carrier Detect
2	RXD	Recieve Data
3	TXD	Transmit Data
4	DTR	Data Terminal Ready
5	GND	Ground
6	DSR	Data Set Ready
7	RTS	Request to Send
8	CTS	Clear to Send
9	RI	Ring Indicator

Table 6: connector pin configuration

Cabling:

At FH-Aachen we have a LI-F12YC11Yö 3x2x0,25mm² cable with a length of several hundred meters. That cable will be split into the single strands which have 6 different colours. The aperture of 0,25mm² equates to the AWG 24 (American Wire Gauge). The cable coating is heat resistant which was tested in the climate camber.

Picture 31: cable

DC-DC converter

Each experiment is supplied by a Traco TEN 20-2423 DC-DC converter with a demand of 20W. It provides a voltage of ±15V at a current of 667mA. A Traco TEN 30-2413 DC-DC converter which has a demand of 30W, provides an output voltage of 15V at a current of 2A. That DC-DC converter supplies the CompactRio module.

Picture 32 : Traco Power DC-DC converter

Optocoupler

On PCB1 an optocoupler is used to convert the liftoff-signal (LO) of the REXUS service module to a TTL-signal which is linked to the CompactRIOs serial interface

Test-box / Fuse-box

The Test-box is used to safeguard the service module of the REXUS rocket. For the first initiation, it is switched between the service module and the ADIOS experiment. The 15 pin D-sub connector 28V wires (pin 1 and pin 9) are conducted to a fast 2,5A fuse. The fuse is mounted on PCB4 which is located in the Test-box / Fuse-box. The housing of the Test-box / Fuse-box has an input- and an output-15 Pin D-sub connector.

Sensors

On the ADIOS experiment two tri-axial ±2g sensors (ASC 5511LN) will be used. For every sensor three single amplifiers will be mounted on one circuit board (PCB2). The two sensors are powered one Traco power DC-DC converters.

Picture 33 : ASC ±2g acceleration sensor

Schematic of EXP1 (PCB2):

The circuit was build and tested on a breadboard. It also will be tested on a pendulum when the test sensor arrives. The principle depends on a simple one stage amplification. To realize a gain factor of about 1000, an analog Device OP177 will be used. The OP177 is offering a cut off frequency of nearly 100Hz at a closed loop gain of 70dB at -20°C.
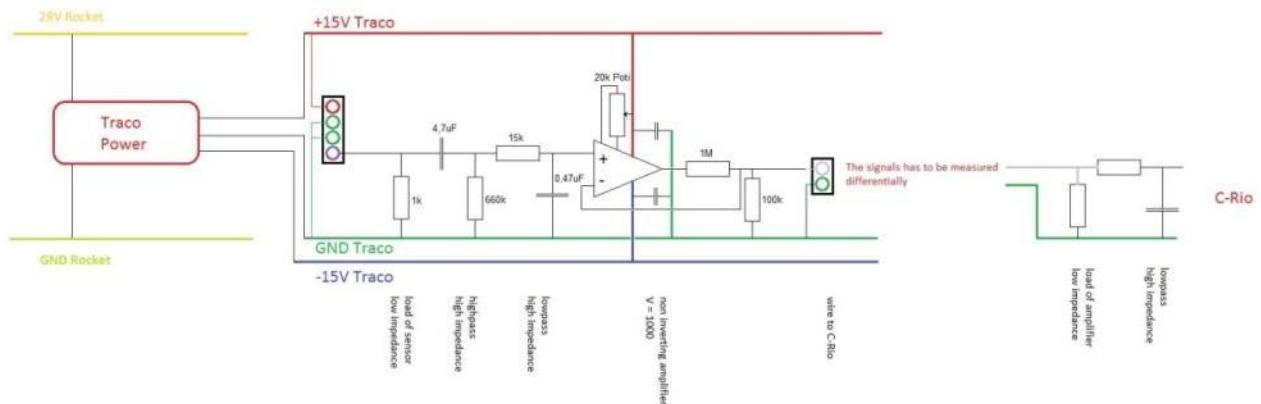
Schematic 3: acceleration amplification (PCB2)

4.5.3   EXP2

Electrical components:

CompactRIO

A second module NI-9205 is used for the DAQ of the strain measurement.

Strain gauges and temperature sensors

There will be 8 one-axial strain gauges attached to two cross-section areas of the REXUS rocket as outlined in Figure 2. They are measuring the strain in flight direction. There will be 4 two-axial strain gauges located inside the ADIOS-experiment.

First rough estimations show that there will be a maximum deformation of 0.6 mm near the motor adapter. Because the orientation of the rocket is not predictable there have to be at least two measurements of the strain at one cross-section which are displaced by 90 ° to each other.

Because one measurement cannot be used to differentiate between bending and longitudinal excitations a second pair of strain gauges has to be used which are symmetrically with respect to the first two strain gauges attached to the structure.

To follow the oscillating deformations a second and third measurement cross-section are required. One will be inside of the ADIOS-experiment and one should be near to the nosecone adapter.

Each strain gauge demands an amplifier.

The data of the strain gauges has to be temperature compensated. Due to the high temperature gradient during launch and landing it is not applicable to use strain gauges in a full-bridge configuration. Hence, the temperature compensation has to be outsourced as post-flight activity. For that the temperature of the structure has to be measured during flight. There will be 2 temperature sensors at each cross section.

The sizes of the train gauges are very small and the required space for the wall application will not exceed 20mm x 20mm for each measuring point. The cables will be assembled to one cable harness which leaves the module.

HBM, manufacturer and sponsor of the strain gauges, provided us a package of 10 x 120 Ω linear strain gauges for testing the application and function of the amplification. These strain gauges will be tested at the VibraDamp REXUS 7 Module.
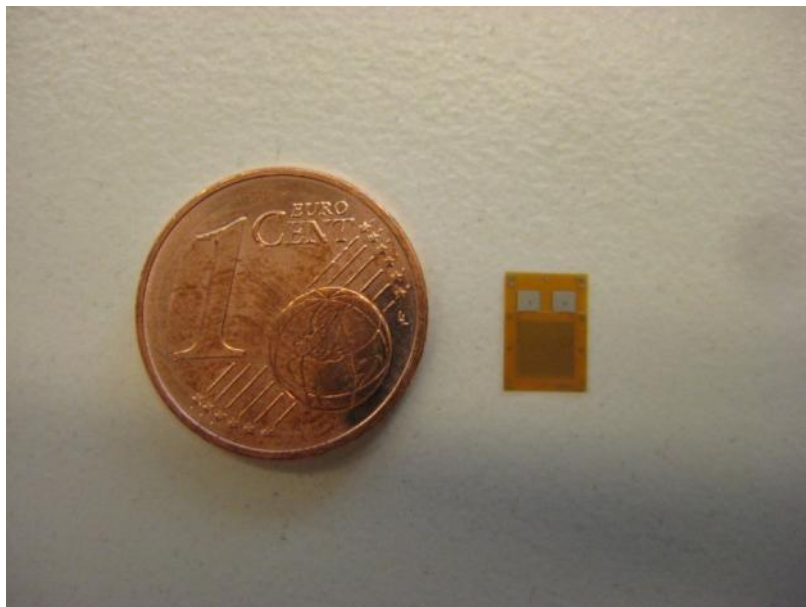
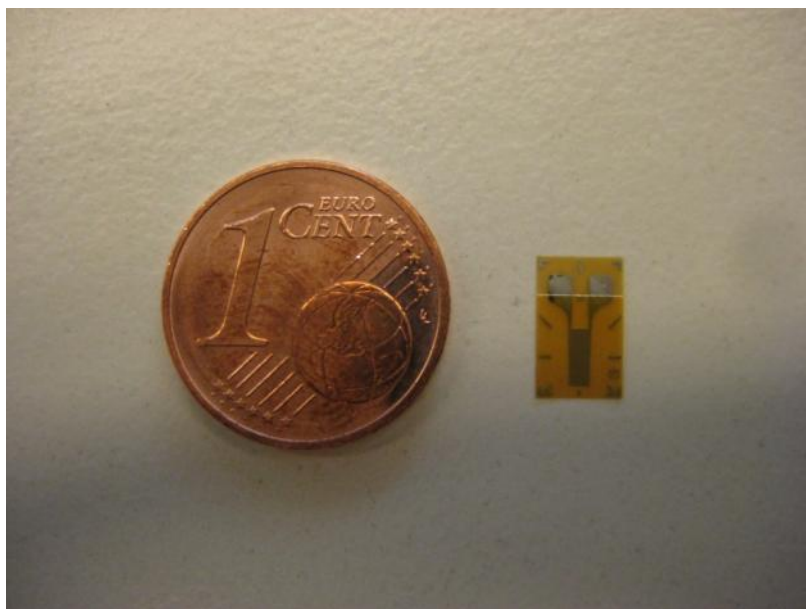The actual size of the strain gauges is shown in the following pictures.
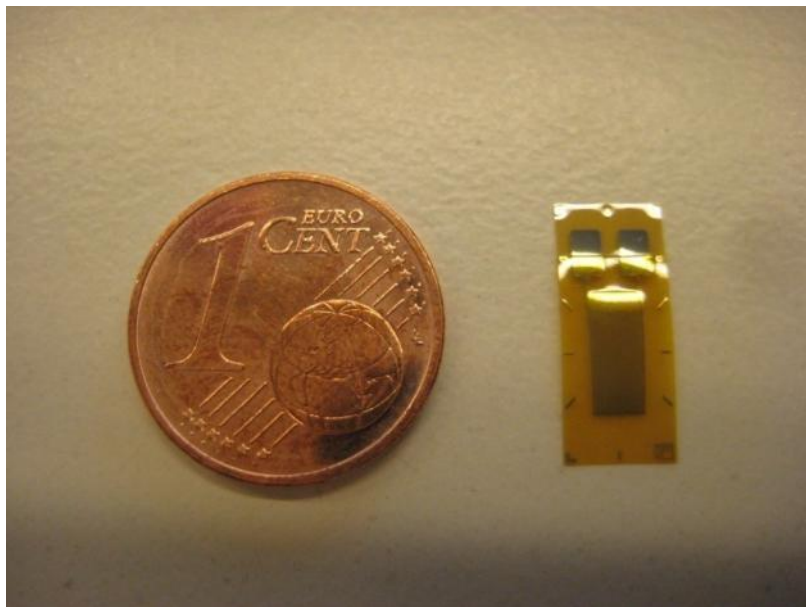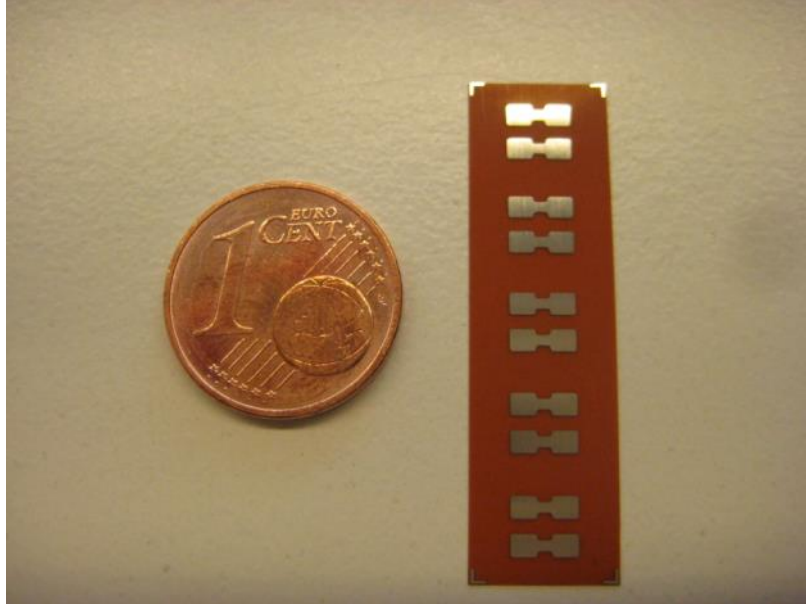
Picture 34: linear strain gauge (350 Ω)
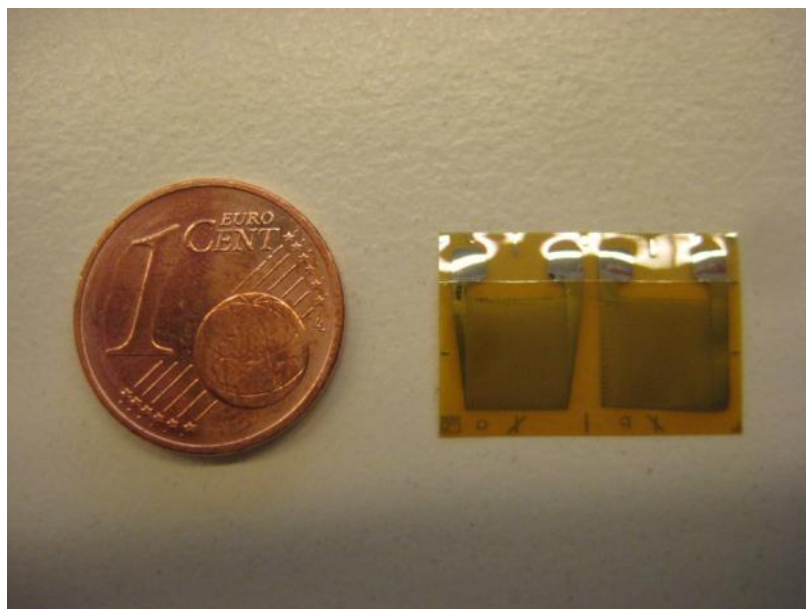
Picture 35: T-rosettes strain gauges (350 Ω)

Picture 36: Temperature sensor (350 Ω)

**Picture 37: linear strain gauge for testing (120 Ω)**

Picture 38: strain relief for cabling

A detailed introduction to the assembly is explicitly shown in APPENDIX C in the document RX11_ADIOS_SGRP_v1.6.pdf [14]

Schematic of EXP2 (PCB3):

Four circuit boards are used (PCB3) for EXP2. Every circuit board has four strain gauges amplifiers and two amplifiers for the temperature sensors. The strain gauges and the temperature sensor are operated with a constant current of an (JRC) Dual High Current Operational Amplifier NJM4556AD. The flowing current is compared to a common sensor signal very high (4mA – 20mA) and has a very constant value. Thus the measuring cable is highly resistant against irradiation. That technology is immune to the inductance of the measuring cable which allows cable length up to 100m, too. The housing of the NJM4556AD shelters two operational amplifiers. The first operational amplifier provides the constant current which flows through the sensor. The second operational amplifier is an analogue summer and is able to amplify the output signal. The first operational amplifiers output voltage changes if the resistance of the sensor varies. Now the offset voltage is compensated with the analogue summer. The residual voltage is amplified and the output value is stored in the CompactRio module. To ensure exact measurement the circuit has to be calibrated in Kiruna.
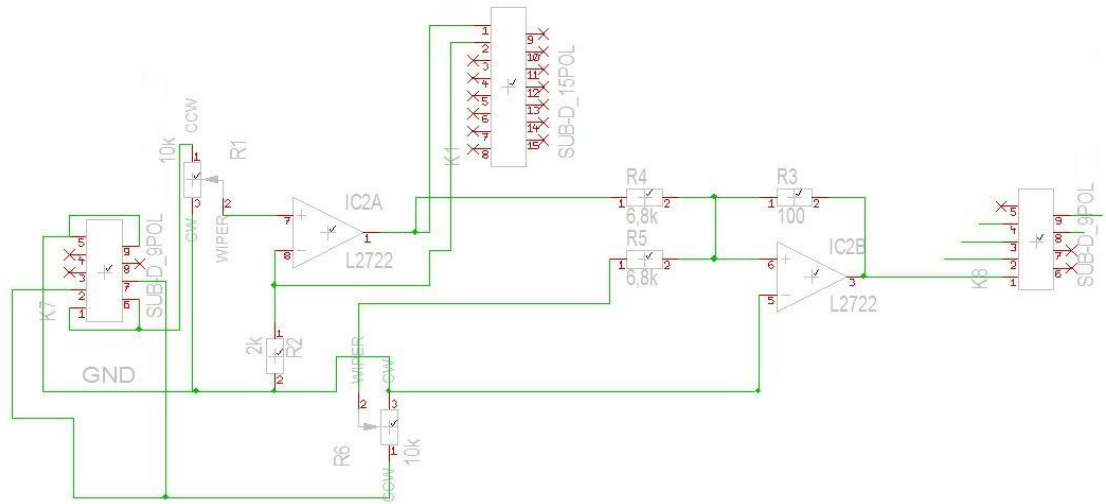
Schematic 4 : circuit EXP2 (PCB3)
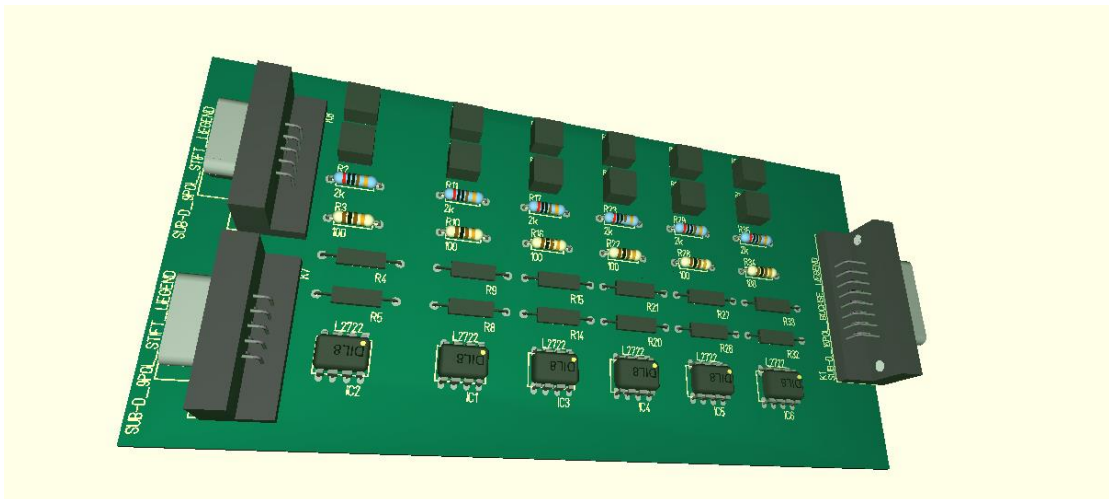
Picture 39 : layout EXP2 (PCB3)

4.5.4   Arm plugs

To ensure a soundly active experimental procedure during flight it is necessary to pass some passive test runs on ground before. It is therefore of crucial importance that the ADIOS experimental module can be placed safely into an armed und disarmed mode. This determination will be implemented by using three different types of arming and disarming plugs:

1. The *flight plug* has to be assembled before flight and closes the power connection to the service module. All dynamic systems are set to active. The defined experimental procedure can be actually performed.
2. The *test plug* is used for ground testing in horizontal condition. All dynamic systems are set to inactive. In this way the free flight experimental device FFED will be still fixed by the closed locking mechanism and take no damage during the bench test in the final assembled status under gravity. The defined experimental procedure will be performed in virtual simulation.
3. The *transport plug* will be used for the transport to Kiruna as well as after landing to open all power lines to the cRIO and to avoid an accidental reboot, which results in a deletion of memory and loss of all data.

The technical implementation is carried out by a manual plug-in mechanism with D-Sub ports. As the rocket during the test phase is fully integrated, the mechanism must be accessible from the outside, i.e. it connects the experimental module located in the rocket with the outer shell of the rocket.

The unit consists of a machined metal housing to which a total of three D-Sub connectors (2 x 9-pin, 1 x 15-pin) to be arranged opposite each other. The front-positioned D-Sub connector is the interface to the outside. The metal hou sing is attached with screws to the outer shell of the rocket.
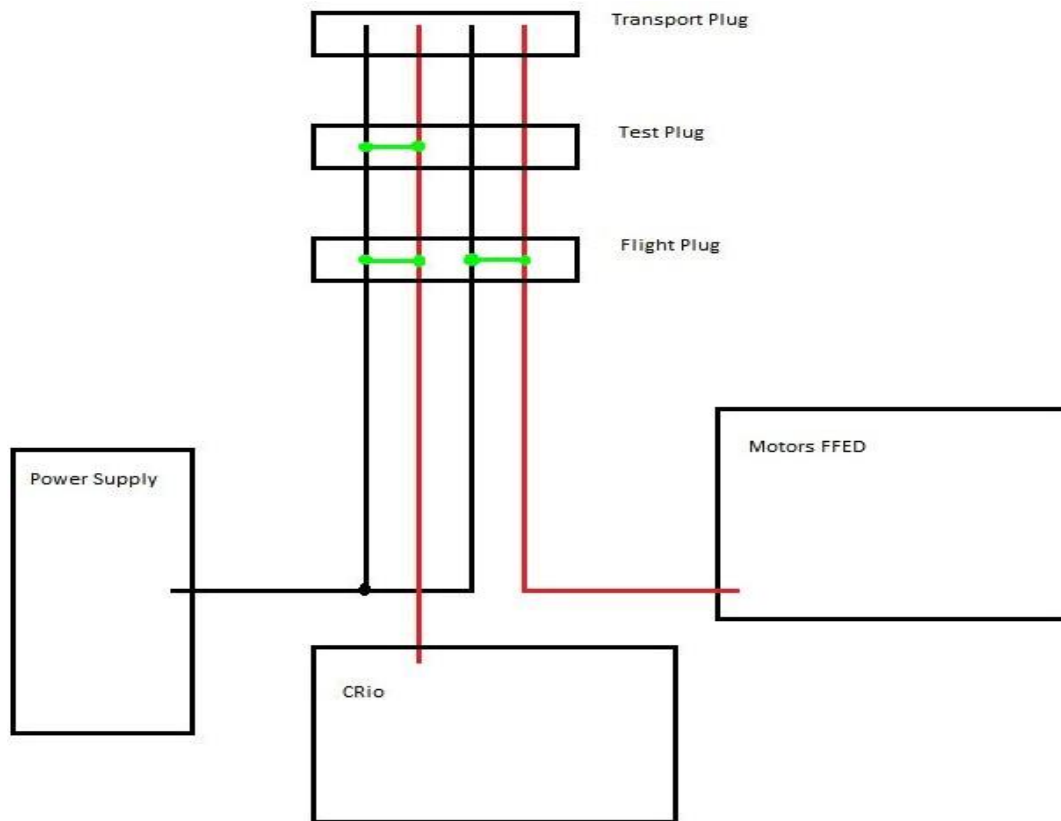
Figure 8: Block diagram Arm plugs

4.6 Thermal Design

The requirements for the thermal design are based on the compensating curves and the internal temperature compensation of the ACC sensors. The sensors shall not reach a temperature of less than - 20 °C. If this could not be screened out we have to use a heating system or a passive thermal insulation for the pre launch phase.

The electronics of the ADIOS experiment will dissipate heat during operation. The major dissipater will be the cRIO. In the former project VibraDamp the experiment had no problems because of heat. But this experience is no more valid for ADIOS because of the higher workload onto the cRIO in the operation mode. It needs to be tested in the vacuum chamber as far the 3rd and 4th NI-Module is delivered. An assembly of a cooling element could solve the problem if the cRIO operation temperature increases above 50 °C.

Furthermore there are the working temperature ranges of the major components as well as the critical temperatures shown in the following table.

Component	Operating range	Critical temperature	Status
cRIO	-40 °C to 70 °C	High temp. due to operation possibly critical.	Needs to be tested
Strain gauges	Up to 200 °C	Higher than 250°C	
Temp. Sensors	-50 °C to +180 °C		
Strain gauges glue	-200 °C to +280 °C		
ACC Sensor	-20 °C to +85 °C	Temp. below -20 °C	Ambient temp. during Flight phase not critical – no contact to hot outer structure /

Table 7: Thermal operating ranges of electrical and structural components

4.7 Power System

All single terms are approximated with a safety factor of minimum 30%.
The average of the power consumption is approximately 23W. The total power consumption is 3,2Wh (130mAh).

Timeline	Part	Single power consuption [mA]	Number of Parts	Power consuption [mA]	Power consumption [W]	Timespan [s]	Power consuption [mAh]
600 sec. Before ignition	CompactRIO	100	1	100	2,8		
(prior to flight)				100	2,8	600	16,67
Ignition / Lift off	CompactRIO	100	1	100	2,8		
(during flight)	Strain gauge	20	16	320	8,96		
	Temp. Sensor	20	6	120	3,36		
				540	15,12	72	10,80
Unlock	CompactRIO	100	1	100	2,8		
	Motor	80	3	240	6,72		
	Strain gauge	20	16	320	8,96		
	Temp. Sensor	20	6	120	3,36		
				780	21,84	10	2,17
Measurement time	CompactRIO	100	1	100	2,8		
	Motor	80	3	240	6,72		
	G-sensor ±2g	70	6	420	11,76		
	Strain gauge	20	16	320	8,96		
	Temp. Sensor	20	6	120	3,36		
	Imbalance gen.	100	1	100	2,8		
				1060	29,68	266	78,32
Relock	CompactRIO	100	1	100	2,8		
	Motor	80	3	240	6,72		
	Strain gauge	20	16	320	8,96		
	Temp. Sensor	20	6	120	3,36		
				780	21,84	10	2,17
landing	CompactRIO	100	1	100	2,8		
	Strain gauge	20	16	320	8,96		
	Temp. Sensor	20	6	120	3,36		
				540	15,12	10	1,50
132 sec after landing	CompactRIO	100	1	100	2,8		
(after flight)	Strain gauge	20	16	320	8,96		
	Temp. Sensor	20	6	120	3,36		
				540	15,12	132	19,80
						500	131,42

Table 8 : Power consumption ADIOS experiment

4.8   Software Design

The software is responsible for DAQ and controlling the locking and unlocking procedures. All tasks will be programmed using LabVIEW 2010. The software design used for ADIOS will be an adjusted version of the running programme used for the VibraDamp-experiment.

For the software on ADIOS we thought about using a modified version of VibraDamp's software, but after some tests we struggled with significant

performance problems. So we were forced to do a bigger modification and had to reprogram the software partially to handle all tasks with the limited power of the cRio's 40 MHz processor. One big point to decrease the load of the central processor was to outsource as much processes as possible to the FPGA.

The programme will be executed in the following way:

1. Booting cRIO 9014, initializing modules and connected hardware
2. Initialize Serial Port for data transfer
3. Start signal monitoring (LO, SOE)
4. Prepare DAQ (Create and open files and folders)
5. Waiting for LO signal
6. Parallel execution of:
   a. Strain Measurement, start sending strain to ground station
   b. Unlocking the FFED and starting acceleration DAQ (signal triggered when SOE "on"), sending acceleration instead of strain
   c. Time-triggered imbalance generator running 3 frequencies
   d. Locking the FFED and stopping acceleration DAQ (signal triggered when SOE switches to "off"), sending strain again
7. Shutdown routine after landing, before power off

During the whole process the cRIO will send status information and measured data to ground via serial port. Because of the low bandwidth it is not possible to send the complete data and because of the very limited processor power it is not possible to build packages. This would be a risk for running the software (storing all the data in flight) safely and was not an option. As a result the transmitted data is not useable for any statement according our measurement results, but during flight it indicates our software is working well. The status information is transmitted properly so the ground station can reproduce the given LO and SOE signals as well as the information of "power on" and "end of program / shut down".

The internal data stream of the cRIO is shown in the following diagram. The cRIO is interacting with the FPGA Chassis linked to the A/D Modules (NI9205) and the motor control units (NI9505).
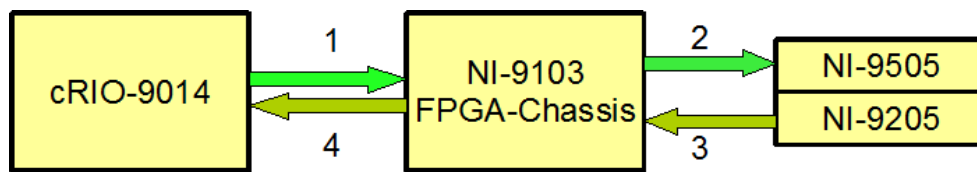
Figure 9: Data interactions

The routine is following shown as a block diagram.
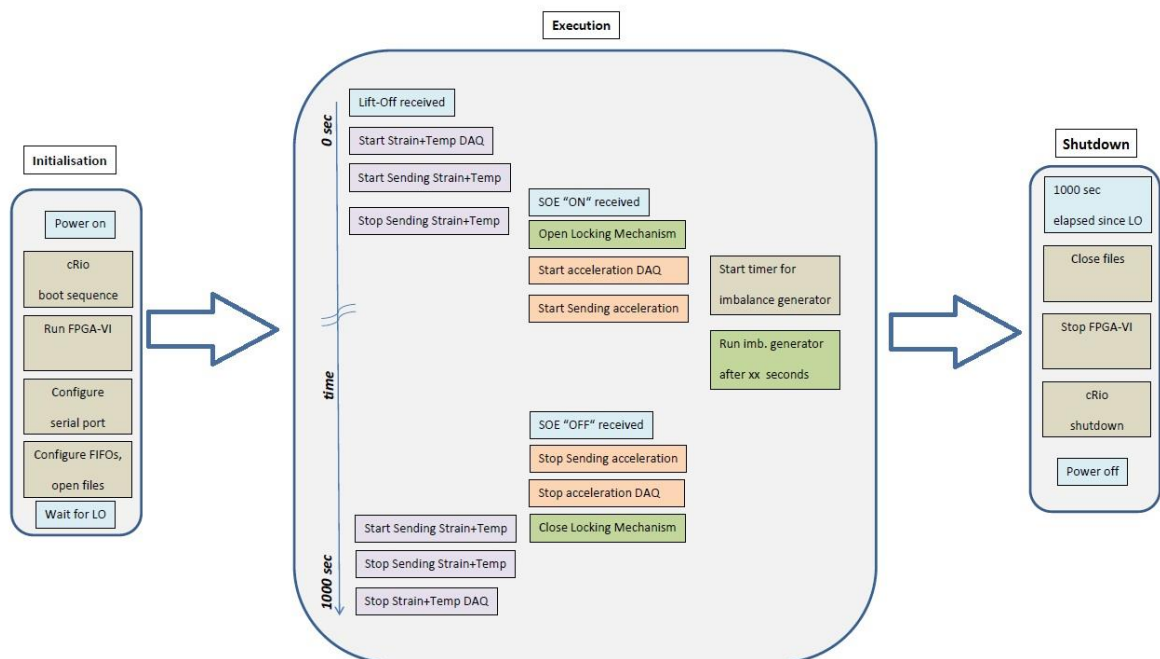
The LO signal is required for starting the Strain+Temp measurement and calibrating the internal clock. Acceleration DAQ starts with SOE ON after unlocking the FFED. When the Test Plug is installed the software will simply skip the "unlock/lock" action, so nothing will get stuck in the final tests in horizontal orientation after assembly.

For a simulation time of 1000 s, the data volume is approximately 0.66 GB (16000 Hz strain measurement, 800 Hz acceleration measurement).

The data volume for the planned experimental setup for 1000 s measurement of strain and temperature and approximately 160s measurement of acceleration will be as follows:

- 16   strain gauges   0.4768   GB
- 6   temperature sensors   0.1788   GB
- 6   acceleration sensors   0.0003   GB

Sum : 0.6559 GB

Since the data volume of the cRIO memory is about 2 GB, it is necessary to replace files during flight. It is not necessary to have manual access to the cRIO the files will be replaced by software.

4.9 Ground Support Equipment

4.9.1 Telemetry Software

To receive, display and safe the data, which is sent during the flight, a telemetry receiving program has been written.

Directly after the lift off strains and temperatures are measured. Because of lack of downstream capacity the transmitted data is only a part of the measured data set. Two strains and two temperatures are sent each with a sample rate of 500Hz. The sample rate fulfills the Nyquist Criterion. The values have a size of 16Bit. Thus 32kBit/s is broadcasted. The ground station receives the data and transmits it via serial port in an ASCII format to the user's laptop. During the weightless phase acceleration data is transmitted instead of strains and temperatures. Acceleration data of six sensors is sent each with a sample rate of 300Hz. With 16Bit per value it makes 28.8kBit/s. The sample rates are higher than the Nyquist frequency. After the weightless phase the strain and temperature data is sent in the same way as at the beginning. The strains, temperatures and accelerations are displayed on graphs in real time. The figures are transmitted in a defined order to allocate them to the right graph. Also status information is sent and displayed to know what the cRIO is doing at that time.

All the received data is saved in a log text file.
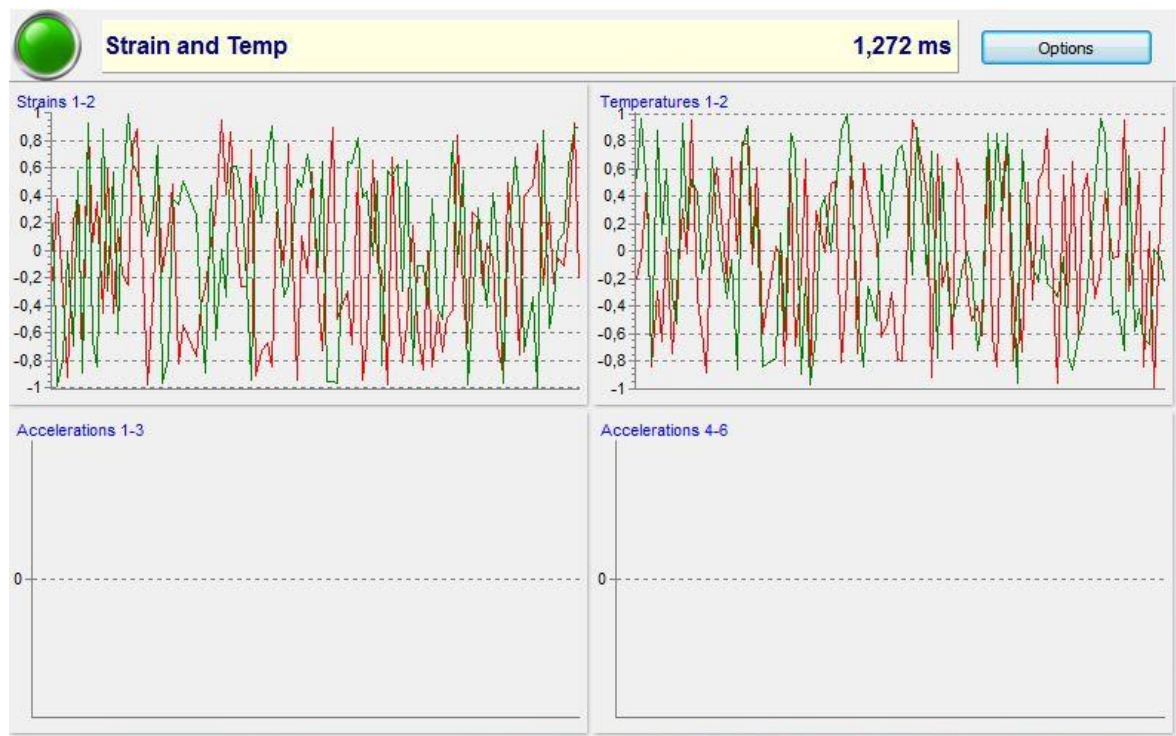
Picture 40: Telemetry Software screenshot

5 EXPERIMENT VERIFICATION AND TESTING

5.1 Verification Matrix

ID	Requirement text	Veri-fication	Status
F.1	EXP1 - The experiment shall measure the accelerations on the damped FFED during reduced gravity phase using a tri-axial acceleration sensor	A T R	Test plan 1;4
F.2	EXP1 - The experiment shall measure the accelerations on the undamped structure during reduced gravity phase using a tri-axial acceleration sensor	A T R	Test plan 1;4
F.3	EXP1 - The damping system shall isolate the FFED from influences due to the rocket	R	
F.4	EXP1 - The locking mechanism shall prohibit any movements of the FFED during launch and landing	T A	Test plan 1
F.5	EXP1 - For verification the FFED shall be excited by a defined imbalance in a broad bandwidth of frequencies	A T R	Test plan 1;5
F.6	EXP2 - The mechanical loads onto the structure due to launch and landing shall be determined by a separate tri-axial acceleration sensor	T	No more needed
F.7	EXP2 - The mechanical loads onto the rocket structure shall be determined by strain gauges mounted in three levels of the module structures during the whole flight	R T	Test plan 1;5
F.8	Infrastructure - All acquired data shall be stored on a reliable data storage device	R T	Test finished
F.9	Infrastructure - The acquired data shall be sent particularly via telemetry	R T	
F.10	Infrastructure - The control and DAQ shall work autonomously	R T	

P.1	EXP1 - The two tri-axial sensors need to measure accelerations with an accuracy up to 10^-6 g	I T	
P.2	EXP1 - P.2: The measuring range should be ±2 g	I T	Datasheed reviewed
P.4	The ACC-Sensor shall be resistant against static loads of launch: 20 g	T R	
P.5	Strain gauges - measure the strain with a sample rate of 4000 Hz	T R	
P.6	The Isolation setup by magnets and springs shall reach an isolation of min 90 % on the FFED	R	Test Plan 5
P.7	The Power consumption shall be in average beneath 1 A	T R	Test Plan 4;5
P.8	The imbalance generator shall give a defined vibration to the FFED	T	

D.1	The internal bulkhead should stay as stiff as possible by reduced weight.	R	
D.2	The Isolation shall work passively.	R	Verified by calculation
D.3	The locking mechanism shall prohibit any movements of the FFED during launch and landing	T R	
D.4	There shall be easy access to electronic boards for maintenance and calibration	R I	reviewed
D.5	Electronic access via Ethernet connector at assembled status	R	No more Umbilical access needed
D.6	The Experiment shall fit into a REXUS 300mm Module	R T	CAD-Model-ling
D.7	To economise weight the locking mechanism shall be build from carbon fibre composites	R	Design change
D.9	The strain gauges should be mounted on the	R	Several

	inside of the outer structure		application tests completed
D.10	The Strain gauge setup shall be temperature compensated	R T	Test Plan 5
D.11	EXP1 and EXP2 shall work independent from each other. If one fails the other one shall not be affected seriously	R T	reviewed
D.12	The Electronics shall be as simple as possible	R	reviewed
D.13	The electronic setup should be as light weight as possible	R	reviewed
D.14	The Electronics shall cope with ±28 V	R T A	Breadboard tests finished
D.15	Power consumption needs to stay beneath 3 A peak	R T	Test Plan 5
D.16	The sensors shall be temperature compensated	R T	Test Plan 3
D.17	The ACC-Sensors shall be Shock resistant up to 20 g	R	

O.1	The temperature of the structure shall not under-run - 20°C		Passive thermal insulation
O.2	The Esrange recovery crew should disarm the experiment with a transport plug		

Table 9: Verification table

5.2 Test Plan

5.2.1 Shaker Test

Test number	1
Test type	**Shaker test**

Test facility	Laboratory for light weight structures / FH Aachen
Tested item	1. RX Module including Bulkhead with Electronics 2. RX Module including Locking Mechanism with FFED
Test level	5 – 2000Hz; random; Sinus; 6 g; 12 g
Test campaign duration	2 day (incl. preparation shaker)

Table 10: Shaker Test

To avoid damage to the ACC-Sensors the first run of the qualification shaker test will be done without the flight hardware sensors. It is important to proof that the Eigen-frequencies will not have impact on the highly accurate ACC-Sensors.

The principle of the locking mechanism is already tested and flight proofed. Nevertheless it is necessary to test the locking mechanism as far it is constructed. The shaker test will verify the clamping behaviour during launch phase.

5.2.2 Vacuum Test

Test number	2
Test type	**Vacuum test**
Test facility	Laboratory for space technology / FH Aachen
Tested item	1. Structural parts: CFC Bulkhead 2. Electronic boards (Strain gauge amplification, Acceleration amplification, Power supply) 3. cRio 4. Motors 5. COTS RS-232 to RS-422
Test level/procedure and duration	Qualification 3×10^{-5} bar 15 min
Test campaign duration	24 h

Table 11: Vacuum Test

The Vacuum test covers two different responsibilities. The first one is the vacuum compatibility of the single parts soldered on the electronic boards. The second one is to proof the function under the changing circumstances from ambient pressure down to vacuum.

5.2.3 Thermal / Environmental Test

Test number	3
Test type	**Thermal test**
Test facility	Laboratory for space technology / FH Aachen
Tested item	1. Electronic boards (Strain gauge amplification, Acceleration amplification, Power supply) 2. cRio 3. Motors 4. COTS RS-232 to RS-422
Test level	Qualification -30°C up to 60°C
Test campaign duration	24 h

Table 12: Thermal / Environmental Test

Regarding the very small expected signals it is very important to know the behaviour of the amplification boards as well the power supply under changing environmental conditions.

5.2.4 Functional Sensor Test

Test number	4
Test type	**Functional test – Acceleration Sensors**
Test facility	Laboratory for fluid dynamics / FH-Aachen
Tested item	Test of ACC sensors on a pendulum for calibrating Filters and Amplifiers
Test level	1 g – 2 g
Test campaign duration	5 h

Table 13: Functional Sensor Test

To test the function of the ACC-Sensors, they will be mounted to a pendulum. The acceleration can be measured in the single axis. The sensors will be calibrated by the manufacturer.

For the calibration and test of the strain gauges, the first test items have been placed on the VibraDamp RX7 Module. The application has already been tested under different conditions. There are to different types of testing.

1. Static test: The RX-Module with the applicated strain gauges will be mounted to a rack and bended by a load.

2. Dynamic test: The RX-Module will be put on the shaker including the strain gauges and an additional mass.

5.2.5   Functional Electronic Test

Test number	5
Test type	**Functional test – Electronics**
Test facility	Laboratory for space technology / FH Aachen
Tested item	Electronic circuits, Bread boards and prototypes,
Test level	
Test campaign duration	5 days

Table 14: Functional Electronic Test

The functional tests have been done parallel to the development of the circuits. Every change in the design has been followed by a test of the circuit on the bread board and later on the prototype.

Every single PCB will be tested completely.

5.2.6   Functional Test – Assembled Mode

Test number	6
Test type	**Functional test – Assembled Mode**
Test facility	Laboratory for space technology / FH Aachen and later at ESRANGE
Tested item	Function of Electronics and Mechanics in combination
Test level	

Test campaign duration	5 days and again 1 day at ESRANGE

Table 15: Functional Test - Assembled Mode

In the final assembled mode, the whole experiment will be tested before the payload integration and the bench test.

5.3 Test Results

The test results will be divided again into the results of the two experiments. The Protocols of the conducted test are stored in a folder on the BSCW-Server. A list of the conducted tests and a protocol example is shown in APPENDIX C.

EXP1:

The ACC-Data will be processed by a data processing s/w which calculates the total damping of the FFED in relation to the frequency. The comparison of the data of the two ACC-sensors is the basic of the calculations.

EXP2:

The data determined by the strain gauges will be processed again in a special data processing s/w. Here the ACC-data of the service module and the strains will be put into relation and finally compared with the ANSYS structural analysis.

6 LAUNCH CAMPAIGN PREPARATION

6.1 Input for the Campaign / Flight Requirement Plans

6.1.1 Dimensions and mass

Experiment mass:	kg	Estimation regarding carbon fibre parts: ca.13 kg
Experiment dimensions:	m	0,3120
Experiment footprint area:	m^2	0,0995
Experiment volume:	m^3	0,0310
Experiment expected COG (centre of gravity) position:		t.b.d. asap

Table 16: Experiment mass and volume

6.1.2 Safety risks

There are no safety risks known for the moment. The experiment will not require liquids, explosive batteries, pyrotechnical devices or poisonous or hazardous parts. The moving parts are not accessible when the experiment is fully assembled.

6.1.3 Electrical interfaces

The ADIOS Experiment will not have any special requirements belonging to the launch site. An Ethernet cable connection to our computer an our own S/M-Simulator for testing are the only necessary electrical I/F before P/L assembly.

The I/F to the service module for assembly, hot test and flight as well as experimental time are shown in the following in 6.2.

6.1.4 Strain gauges

The Strain gauges shall be mounted in three different levels of the rocket. Therefore the chosen RX-Modules shall have four 20 x 20 mm spaces left on the inner side of the structure.

The anodization has to be removed at these areas to provide clean surface and an optimized adhesion of the glue. There is no space for the mounting of the amplifiers necessary. The amplification and data acquisition will take place at the ADIOS Module (EXP2 PCB-Box). Further information about the assembly are given in the document RX11-12_ADIOS_SGRP_v1.x.pdf

6.2   Electrical interfaces applicable to REXUS

REXUS Electrical Interfaces		
Service module interface required? Yes		
	Number of service module interfaces:	1
	TV channel required?	no
Up-/Downlink (RS-422) required? Yes		
	Data rate - downlink:	38.4. Kbit/s
	Data rate – uplink	0 Kbit/s
Power system: Service module power required? Yes		
	Peak power consumption:	30W
	Average power consumption:	23W
	Total power consumption after lift-off (until T+600s)	3,2 Wh
	Power ON	600s before lift-off
	Power OFF	600s after lift-off
	Battery recharging through service module:	No
Experiment signals: Signals from service module required? Yes		
	LO:	Yes
	SOE:	Yes, at 70s after YoYo-Despin
	SODS:	no

Table 17: Electrical interfaces applicable to REXUS

6.3 Campaign Preparation

For the campaign preparation following topics have to be taken in account.

The heavy toolboxes and boxes of spare parts should be delivered to DLR MoRaBa for the Bench Test in January to ship these items in the DLR container to Kiruna.

6.3.1 List of tools

6.3.2 List of spare parts

6.3.3 List of campaign attending team members

For the campaign it is necessary, that every subsystem is covered by a responsible person. In the case of problems and failures, the responsible should be able to find solutions for it.

Management

1. Stefan Krämer

Electronics

1. Dominique Daab

2. Andreas Gierse

Structure

1. Joana Hessel

2. Tobias Wagner

Software

1. Fabian Baader

Outreach

1. Brigitte Müller

6.4   Launch Site Requirements

The Experiment temperature shall not fall below –20°C because of the calibration of the acc-sensors.

6.5 Preparation and Test Activities at Esrange

6.5.1 Assembly of spring setup

The springs of the passive isolation of EXP1 will be assembled to the module on the launch side to avoid damage due to the transport. To assemble the springs, minor parts of the structure and the locking mechanism need to be disassembled. Numbered parts and locations in the structure will prevent accidental interchange while the assembly.

The Springs are prepared for assembly. One screw will mount the spring to the wall of the RX-Module. The second end of the spring has to be glued to the FFED.

6.5.2 cRIO preparation

The cRIO will not be updated unless a failure occurs during testing. An Ethernet-cable is sufficient for connecting the cRIO with the ground support computer. At least two computers will be on the same S/W status to connect to the cRIO to assure connectivity.

6.5.3 Arm plugs

The ADIOS Experiment will use three different types of armed and disarmed plugs.

The *Flight Plug* has to be assembled before flight and closes the power connection to the service module. The *Test Plug* is used for ground testing to avoid the opening if the locking mechanism during the bench tests in the final assembled status.

6.6   Timeline for countdown and flight

Time (Second)	Event
-600 S	POWER ON Service Module – booting of cRIO
0	LO-Signal – EXP2 measurement starts LO
+63 S	Yo-Yo Release
+70 S	Start EXP1: DAQ; Drive LM (unlock) SOE on
+250s	Drive Imbalance Generator via internal Timeline
+320 S	Drive LM (lock); Stop EXP1 DAQ; Start EXP2 DAQ – SOE off
+500 S	Stop of EXP2: DAQ
+530 S	Shutdown cRIO
+600 S	POWER OFF Service Module (or 1 minute after landing)

Table 18: Timeline for countdown and flight

Regarding the RX11 Timeline, the ADIOS Experiment is quiet flexible to handle. The LM needs to unlock after YoYo-Despin and to lock before re-entry. The use of the Imbalance Generator can be pushed to the end of the μg-phase to avoid disturbances to other experiments. A time slot of 45s to 60s for the excitation would be appreciated.

6.7   Post Flight Activities

- The Recovery Crew shall remove the *Flight Plug* before recovery to the Esrange base. The change is not compulsory, if the S/M will not be switched on again before the cRIO has been switched to hardware save mode.

- The FFED needs to be disassembled to access the cRIO before reboot and data backup to avoid a accidently deletion of the memory (hardware safe mode).

- Data backup via Computer access to cRIO.

- Data analysis (e.g. temperature compensation of strain etc.)

7   DATA ANALYSIS PLAN

7.1   Data Analysis Plan

Due to the two experiments the data for each experiment must be processed in particular. Therefore following boundary conditions need to be considered:

- The sampling rate of EXP1 ACC sensors is 800Hz
    - DAQ starts and ends with SOE
- The sampling rate of EXP2 Strain Gauges is 12000Hz
    - DAQ starts with LO until t+1000s
- The official Timeline for flight is included.

RX 11 Timeline		v3-0_13Mar12				
#	Time [s]	Altitude [km]	Event		Altitudes from REXUS 11 Traj calculation	
					Key:	
1	T - 600	0.332	**Experiments Power On**		CaRu	
2	T - 600	0,332	TV Channel Caru		GGES	
3	T - 300	0,332	RAIN mission mode activation via uplink		ADIOS	
4	T - 240	0,332	GGES SOE		RAIN	
5	T - 120	0,332	*RXSM switch to internal power*		Tscobe	
6	T + 0	0,332	*Lift off*		Tscobe pyro/hatch	
7	T + 0	0,332	CaRu LO		TV Channel	
8	T + 0	0,332	GGES LO			
9	T + 0	0,332	RAIN LO			
10	T + 0	0,332	ADIOS LO			
11	T + 0	0,332	Tscobe LO			
12	T + 26	21	*Burnout Imp Orion*			
13	T + 65		TV Channel Caru -> Recov			
14	T + 67		RAIN pyro firing **RECOV**			
15	T + 70		*Yo-yo despin*			
16	T + 74		*Motor Separation*			
17	T + 78		TV Channel Recov -> Tscobe			
18	T + 78		Tscobe pyro/hatch power on		safe timing for peak consump - close to motor sep as poss	
19	T + 86		Tscobe Exp SODS		boom deployment - 8 secs later than hatch	
20	T+ 90		ADIOS SOE activation		unlocking - 4 sec after Tscobe deployment for reduction of oscillation	
21	T + 105		TV Channel Tscobe -> Caru			
22	T + 105		ADIOS unlocking complete		15 secs after SOE	
23	T + 117		CaRu SOE		2 secs after ADIOS unlocking complete	
24	T+ 139	81,11	*Apogee*			
25	T + 170		ADIOS imbalance generator on	TBC	40 secs before locking for imbalance generator (min 30 s)	
26	T + 210		ADIOS SOE deactivate		locks FFED must be done with less than 1g	
27	T + 220		TV Channel Caru -> Tscobe			
28	T+ 225		Tscobe Exp SOE		jettison	
29	T + 232		Tscobe hatch closing			
30	T + 240		Tscobe pyro/hatch power off		safely before "reentry"	
31	T + 247		TV Channel Tscobe -> Recov			
32	T + 247 ~	26	Maximum Decelleration			
33	T + 251 ~	16	Start of subsonic flight			
34	T + ~	4.6	Heatshield, stab chute activation & beacon activation			
35	T + ~	3.9	Stab chute dereefing			
36	T + ~	3.0	Main chute activation			
37	T + ~	1.7	Main chute dereefing			
38	T + 600 ~	0.6	**Experiments Power Off (not incl. ADIOS)**			
39	T + 1000 ~	0.6	TM/TV Power Off			
40	T + 1000 ~	0.6	ADIOS power off			

If experiments are powered off without completing launch sequence: RAIN must reset status with uplink

Table 19: RXS 11 Timeline

7.2 Launch Campaign

For the ADIOS Team the Launch Campaign was very successful. For the Launch five students were able to attend the campaign sponsored by DLR and FH Aachen.

The preparations have been fulfilled without any problems. The Experiment has survived the half year waiting period without any influences. The team assumed changes in the calibration of the measuring equipment but these concerns have not come true. The Experiment was ready for launch again in time and conducted all pre-flight test successfully.

First analysis of the data after the RXS 11 flight showed that the conditions of reduced gravity have been very poor although the damping mechanism of EXP 1 obviously has worked. All measurement points of EXP 2 have delivered data until the end of the flight. ADIOS has worked perfectly!

7.3 Results

A detailed presentation and discussion of the results of the experiments 1 and 2 can be found in Chapter 8.3Appendix D and 8.3Appendix E in the framework of the submitted papers for the 21st ESA Symposium on Rocket and Balloon related Research.

7.3.1 Experiment 1

The acceleration data shows clearly the strong disturbance induced by the wobbling effect of the payload after motor separation. The graphs in Figure 10 indicate the acceleration in flight axis of the vehicle in order to the time after driving the LM of the ADIOS Experiment 1.

The red line represents the X-Axis of the undamped wall. It is directly influenced by the vibrations of the outer structure. The green line belongs to the ACC sensor carried by the FFED.

A band filter washed out the deep frequent perturbation by the movement of the vehicle and shows clearly the difference between the undamped (bright blue) and the damped (deep blue) system.

The strong signal at the end of the timeline is erected by the run of the imbalance simulator.
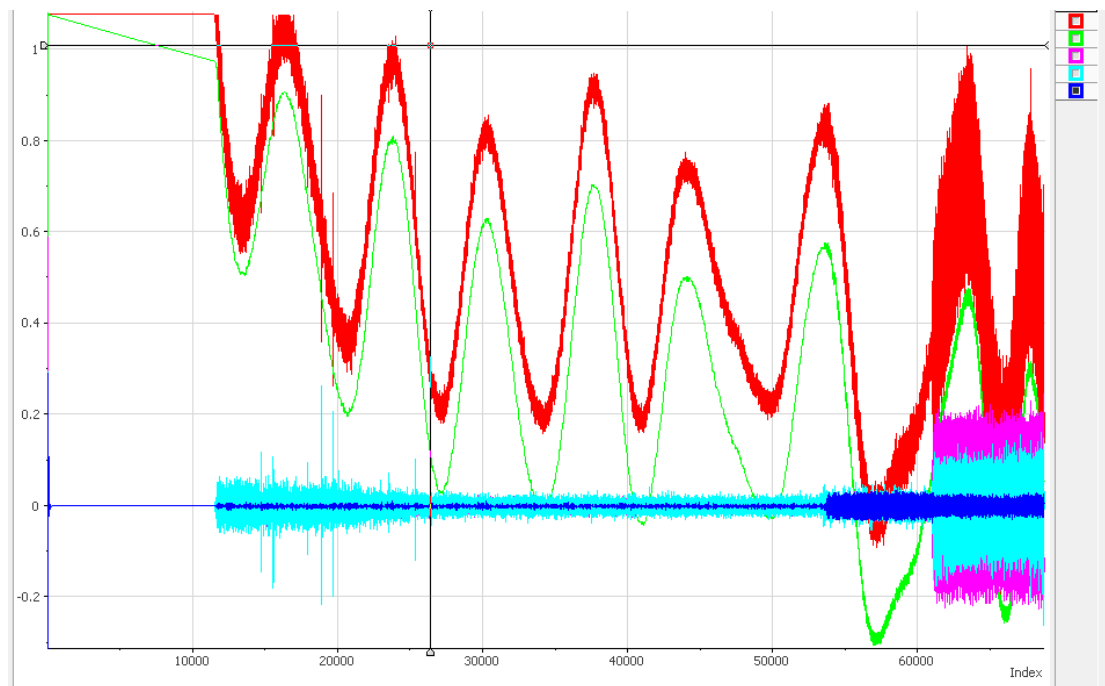
Figure 11: Filtered and unfiltered Signal of the X-Axis ACC
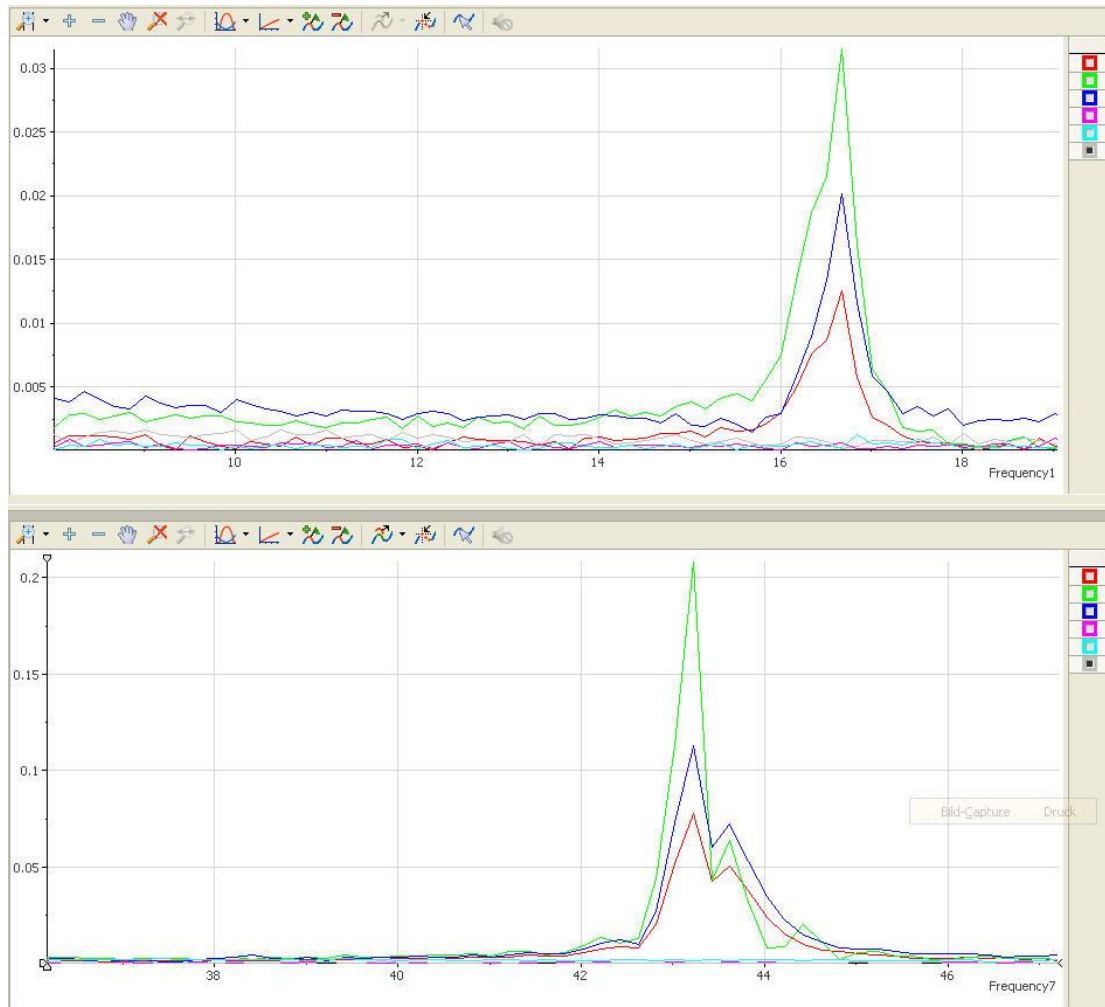
Figure 12: Fourier Transformation of the filtered Signal

7.3.2   Experiment 2

The following data was determined by a numerical simulation to compare it with the measured flight data.

After mode superposition:

- Extrema for deformations caused by longitudinal vibrations:
    - Maximum at L = 3.5 m (inside of service module)
    - Minimum at L = 4.8 m (nosecone)
    - Two other extrema inside of rocket motor
- Extrema for deformations caused by bending vibrations
    - Maximum at L = 3.2 m (recovery module)
    - Minimum at L= 4.4 m (Romulus)
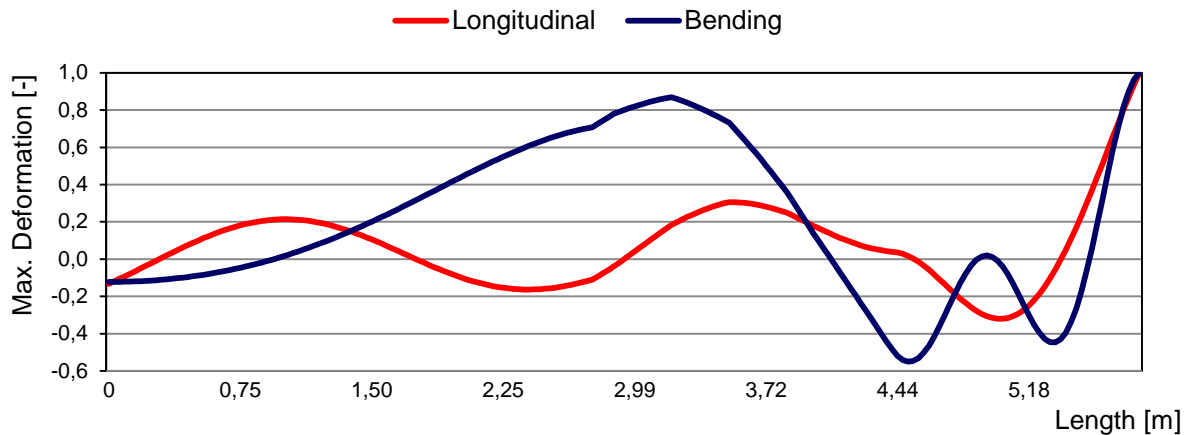
Figure 13: Mode superposition for REXUS 11 - Maximum deformations over length of the rocket

Based on the data given in the REXUS/BEXUS technical overview and the SEDs of the single student teams, first estimations about the structural behaviour of the REXUS rocket during the whole flight were made using ANSYS 13 Mechanical APDL. Since, the rocket is losing weight during flight because of burning propellant and following motor separation several phases of flight has to be considered to specify where, how, and how many strain gauges has to be applied to the rocket structure. Figure 1 shows the estimated resulting strain shortly after Lift-Off. Figure 2 shows the estimated resulting strain during the landing phase. As shown in those figure, the location of maximum strain (coloured in red) is moving from bottom of the recovery module to upper part of the nosecone during flight.

Figure 14: Estimated resulting strain in flight direction during launch phase
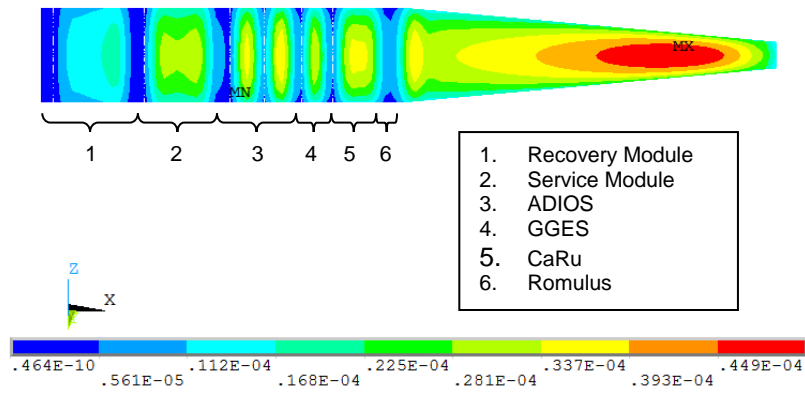
Figure 15: Estimated resulting strain in flight-direction during landing phase

8 ABBREVIATIONS AND REFERENCES

8.1 Abbreviations

This section contains a list of all abbreviations used in the document.
Add abbreviations to the list below, as appropriate.
In version 5 of the SED (final version), delete unused abbreviations.

ADIOS	ADvanced Isolation On Sounding-rockets
AIT	Assembly, Integration and Test
asap	as soon as possible
A/D	Analogue / Digital transformation
BO	Bonn, DLR, German Space Agency
BR	Bremen, DLR Institute of Space Systems
CAD	Computer Aided Design
CDR	Critical Design Review
CFC	Carbon Fibre Composites
COG	Centre of gravity
cRIO	compactRio (NI)
CRP	Campaign Requirement Plan
DAQ	Data Acquisition System
DLR	Deutsches Zentrum für Luft- und Raumfahrt
EAT	Experiment Acceptance Test
EAR	Experiment Acceptance Review
ECTS	European Credit Transfer System
EIT	Electrical Interface Test
EPM	Esrange Project Manager
ESA	European Space Agency
Esrange	Esrange Space Center
ESTEC	European Space Research and Technology Centre, ESA (NL)
ESW	Experiment Selection Workshop
EXP1	Experiment part 1 (Isolation of FFED)
EXP2	Experiment part 2 (measuring mechanical loads)
FAR	Flight Acceptance Review
FFED	Free-Flying Experiment Device
FH Aachen	Aachen University of Applied Sciences
FST	Flight Simulation Test
FRP	Flight Requirement Plan

FRR	Flight Readiness Review
GSE	Ground Support Equipment
HK	House Keeping
H/W	Hardware
ICD	Interface Control Document
I/F	Interface
IPR	Interim Progress Review
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)
NI	National Instruments
OP	Oberpfaffenhofen, DLR Center
PCB	Printed Circuit Board (electronic card)
PDR	Preliminary Design Review
PST	Payload System Test
SED	Student Experiment Documentation
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
TRL	Technology Readiness Level
WBS	Work Breakdown Structure

8.2   References

[1]   EuroLaunch: **REXUS User Manual** (2010).

[2]   European Cooperation for Space Standardization ECSS: Space Project Management, **Project Planning and Implementation**, ECSS-M-ST-10C Rev.1, 6 March 2009.

[3]   SSC Esrange: **Esrange Safety Manual**, EU A00-E538 , 20 March 2006.

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[5]   European Cooperation for Space Standardization ECSS, Space Project Management, **Risk Management**, ECSS-M-ST-80C, 31 July 2008.

[6]   European Cooperation for Space Standardization ECSS: Space Engineering, **Verification**, ECSS-E-ST-10-02C, 6 March 2009.

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[9]   FH-Aachen News Page; Bedbur, Ruth: **Zu den Sternen,** http://www.fh-aachen.de/newsarchiveinzel.html?&tx_ttnews[pS]=1293836400&tx_ttnews[pL]=2678399&tx_ttnews[arc]=1&tx_ttnews[pointer]=2&tx_ttnews[tt_news]=2916&tx_ttnews[backPid]=231&cHash=5f2e7b5e37 (accessed 23th March 2011),

[10]   Diploma Thesis, UAS Aachen – Aerospace Department: **Entwicklungen einer Prüfstruktur mit einem Schwingungs-isolationssystem, mit magnetsicher Dämpfung und Test beim Parabelflug einer REXUS Rakete**, Rudolf Vetter, 2010.

[11]   Diploma Thesis, UAS Aachen – Aerospace Department: **Entwicklungen einer berührungslosen Dämpfung zur Verminderung von Resonanzüberhöhungen eines Systems zur Schwingungsisolation eines Schmelzofens in der Raumfahrt (ADVANCED TITUS)**, Manuela Franke, Nov. 2001.

[12] Bachelor Thesis, UAS Aachen – Aerospace Department: **Autonome Experimentsteuerung mittels LabVIEW für ein Raketenexperiment**, Lysan Pfützenreuter, 2010

[13] RX_PDR_minutes v1_ADIOS_03Mar11.doc ,

[14] **ADIOS Strain Gauge Requirement Proposal**, Stefan Krämer, Lysan Pfützenreuter, FH Aachen, 2011, RX11_ADIOS_SGRP_v1.6.pdf,

[15] **RX_CDR_minutes_ADIOS** DLR/ESA/SSC-Review Board - **Experiment Critical Design Review** , Mark Fittock, 2011

8.3   List of tables and pictures

APPENDIX A – EXPERIMENT REVIEWS

PDR – Minutes [13]

Flight: **REXUS-11**

Payload Manager: Mark Fittock

Experiment: ADIOS

Location: DLR Oberpfaffenhofen, Germany   **Date: 9/02/2011**

---

1. Review Board members

Mark Fittock [MoM] (DLR RY), Markus Pinzer (DLR MORABA), Macus Hoerschgen (DLR MORABA), John Richardson (DLR RY), Martin Siegl [MoM] (DLR RY), Helen Page (ESA ESTEC), Andreas Stamminger [Chairman] (DLR MORABA), Olle Persson (SSC), Mark Uitendaal (SSC), Koen DeBeule (ESA ESTEC)

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2. Experiment Team members

Stephan Kraemer, Lysan Pfuetzenreuter, Brigitte Mueller, Dominique-Jonas Daab

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3. General Comments

- Presentation
    - easy and understandable, but requires prior knowledge from Vibradamp;
    - a lot of detail still missing, also from version 1.8;
    - communicate your work to us; SED a little bit light regarding EXP2;
    - diagrams and graphics adequate;
    - there is a flow chart for the software, but it is outdated; whole document is in English, but flowchart is in German, please correct that.

- SED
    - slides are good; don't say "this is my part of the presentation"; big improvement over SED in terms of content;
    - resubmission will be required

---

4. Panel Comments and Recommendations

- Requirements and constraints
    - expand on requirements, number them, full sentences, expand on operational requirements;
    - there are many misclassifications;

- Mechanics
    - difficult to judge, there is not much description;
    - show the components in the pictures; Single components should also be depicted. Also a picture of the complete payload has to go into the SED.
    - detail how many boxes there will be in the E-box and what are you going to place where. Describe position and size of strain gauges;
    - hard to understand where the measurements shall be taken. Suggest position for the strain gauges, how big are they, what are the electrical interfaces;
    - what do you expect to see on the strain gauges? - Simulations required.
    - what is the movement of the box? – 2 cm in radial direction.
    - feed through other experiment cables next to your module: implement it already now;
    - bring your mass down: not just say, but act; set a level for mass and make sure it will be below this level. Provide a mass budget.
    - lots of good points where weight could be reduced: holes in plates, for example;
    - **proposal of EXP2 sensor locations must be given to your project manager together with the SED resubmission**
    - consider possibility of using a 300 mm module

- Electronics and data management
    - main part is compact rio: overview diagram for power and data handling missing;
    - more detail in block diagrams required;
    - Power distribution to different experiments not clear
    - operational amplifier: frequency to be adapted to reasonable value;
    - use optocouplers to avoid noise on the signal lines;
    - power consumption much higher than Vibradamp, please check. What will the peak consumption be?
    - nomenclature: describe what compact rio modules are, what their names are; "module of modules" is hard to understand;
    - expected data rate needs to be defined; team would like to sample with 40khz per sensor; requires on-board storage solution;
    - clarify timeline with regard to measuring the landing; put it in the timeline;

- Thermal
    - EXP2: temperature compensation for the sensor – how will this be conducted? Thermal needs to be considered better for that, thermal range for each component.
    - maybe use wheatstone bridge to compensate the sensor?

- Software
    - running program from Vibradamp will be adjusted.
    - when do measurements start, for how long?
    - why are measurements starting again after stop of the experiments?
    - clarify the timeline wrt to software, call the signals SOE / SODS (don't give them any other names)
    - what has worked on the previous, may not run on this one; perform tests.
    - can you fall back from C if you do not get on with Labview?
    - use the signal lines from the service module wisely;
    - make sure you are able to clear the memory by command;

- o team requests an Ethernet umbilical -> use an access hatch instead

- ▪ Verification and testing
  - o **locking mechanism has to be tested;**
  - o verify that the structure is strong enough once the mass has been reduced
  - o verification matrix missing in SED;
  - o perform a thermal test;

- ▪ Safety and risk analysis
  - o mission risk: how much mass is uncontained if the locking mechanism fails?
  - o if locking mechanism opens before launch, the balance of the rocket can be ruined
  - o Risk MS40: D is a bit high; manufacturer cannot guarantee that they will survive take-off;

- ▪ Launch and operations
  - o no problems;

- ▪ Organisation, project planning & outreach
  - o a lot to discuss about project planning and organization;
  - o **project management must be discussed with your project manager and a proper solution must be found**

- ▪ Others
  - o movie team at Esrange: possible, but needs to be pre-organized
  - o funding for acceleration sensors
  - o one board per sensor ok?
  - o project management is a concern again;
  - o CDR will be a critical step for the project

5. Final remarks

- ▪ Summary of main actions for the experiment team
  - o **Design must be developed further (or better described) before a full pass is given**
  - o **Resubmission of SED at the end of March including preliminary CDR content**
  - o **proposal of EXP2 sensor locations must be given to your project manager together with the SED resubmission**
  - o **locking mechanism has to be tested;**
  - o **project management must be discussed with your project manager and a proper solution must be found**

- ▪ PDR Result: conditional pass
Pass is given upon the condition that an SED is resubmitted including all PDR information required, taking into account the PDR comments and developing a proper project plan

- ▪ Next SED version due 30 March 2011

Source 1: PDR Minutes by the Review Board

REXUS / BEXUS
Experiment Critical Design Review

Flight: REXUS-11
Payload Manager: Mark Fittock
Experiment: ADIOS
Location: DLR Oberpfaffenhofen, Germany **Date:** 10.06.2011

1. Review Board members
Adam Lambert (ESA), Paul Stevens (ESA), Marcus Hoerschgen (DLR), Markus Pinzer (DLR), Frank
Hassenpflug (DLR), Frank Scheurpflug (DLR), Andreas Stamminger [Chair] (DLR), Tobias Ruhe (DLR), Mark Uitendaal (SSC), Nils Hoeger (DLR), Mark Fittock [MoM] (DLR)

2. Experiment Team members
Dominique Daab, Vladimir Klassen, Stefan Kraemer

3. General Comments
SED:
o Filename and mission should refer to RX 11, Change Record should be updated
o When referring to EuroLaunch: this is only DLR and SSC
o DLR Space Agency has changed name to DLR Space Administration
o **Need to include overall schematic in the appendices, just include all schematics**
o Need to be very careful in the documentation that you can clarify which details are for which experiment
Presentation:
o Generally good, clarify the difference between the two experiments, larger size of text
o Amount of data downlink was there but not clear in the SED

4. Panel Comments and Recommendations
· Requirements and constraints
o Missing compliance to the vehicle
o Operations requirements need to be reviewed
· Mechanics
o EXP1: looks fine now, clearly depicted in general, well described for the changes
o EXP2: not as good, strain gauges mentioned but clear positioning is not there, need to describe clearly the connections and cabling
o Need a better definition and to clearly identify the integration possibility
o Can't see from this document how the assembly looks and the connections
o Should have some simulations of what you expect to measure, identify what the team is focussing on
o Describe complete vehicle and complete payload and where you would place them
o Need to look at the different options, is it possible just from the ADIOS module, are there

minimum requirements
o It is very important for the payload integration that we have a clear indication of how this would occur, number of connectors, where the cables are routed
o Should have done some basic analysis for determination of location of strain gauges
o *Team wants to use only a single cable for the strain gauges*
o Need to ask other teams whether you can pass your line through their modules
o Couldn't find scientific justification for a second cross-section of measurements, looks like it could be done from one, justification needs to be given
o This experiment would also be very valuable if done with one cross-section

- o **Require a significant report on justification of other cross-sections and a proposal solution**
- o Is bulkhead electrically conductive? Experiment needs to have a good ground, can have a simple thin (0.2/0.3 mm) aluminium plate
- o **Cable feed-through must be at 180o**
- o Have to consider how to secure the cables, especially in the case with late cables
- o Arm plug should be an arm plug, use a hatch to cover the plug, leave this at 240 if possible
- o Good structural analysis
- o Need to make significant assumptions to cover simulations before sci P/L week

- · Electronics and data management
- o If you turn arm plug 90o this will make it much easier for the mounting of connectors
- o For the interfaces, there is no overall schematic so it is not possible to see all the connections, this is not so good as can't help the team by checking the design
- o Have to change the power supply as they can't operate directly off our signals, use an optocoupler
- o Need to introduce some filtering
- o **Resubmission of electronics schematics for review**
- o How can you be sure that the strain gauges are temperature compensated? *Are measuring next to the strain gauge* Need to calibrate the sensors with regard to temperature
- o Investigate shielding of the cable
- o Is it really sampled at 500 MHz? *Is most likely a mistake*
- o For telemetry: are the baudrates the required telemetry baudrate? *No, is regarding the sensors*
- o Can use a COTS RS-232 to RS-422 converter but need to test it carefully
- o Have requested multiple signals from RXSM, change this as the signals come from the CRio

- · Thermal
- o Component approach is fine
- o Need to be careful of temperature sensitivity of sensors
- o Can use the temperature data of REXUS-8 that is found on the teamsite

- · Software
- o Is it possible to send commands to the CRio? *Not planned*
- o Data storage is a problem, need to be careful with the arm plug and the data

- · Verification and testing
- o Verification matrix is ok but not all are done
- o Need to expand on the testing, consider components, calibration, vibration etc.
- o The calibration of the strain gauges, is it being done on the module itself? Must use a test with similar setup and loads
- o **Must submit a new test plan for CDR to Delivery**
- o Push you thermal tests

- · Safety and risk analysis
- o Risk register is not updated and is limited, **review the risk register and expand**
- o Need to know that FFU does not move inside the payload
- o **Add analysis of this situation to the ADIOS SED and clarify that it is safe for launch and re-entry**

- Launch and operations
- o Need to clarify your mass estimate
- o **Need to work on the arm plug solution with your payload manager**

- Organisation, project planning & outreach
- o Found a good solution for the organization for EXP 1, EXP 2 needs lots of work
- o Good progress on the budget
- o Access to the teamsite is very useful
- o Outreach approach is great

- Others
- o Need to have a helicoil and hole to add shielding, is it possible to do this in the other sections? Yes, but needs to have a very good proposal for EXP 2
- o Is there a curing oven available for the assembly of the strain gauges? Can find one for this in Bremen

5. Final remarks
A clear proposal for experiment 2 must be submitted so that the inclusion of the sensors in other modules is possible (6th of July 2011)
The sensors for experiment 2 can be included in other experiment modules but shall not be included in MORABA system modules or the nosecone
All comments in bold must be acted upon for an SED resubmission
SED to be resubmitted on 18th of July 2011 including experiment 2 proposal
CDR conditional pass (SED resubmission)

Source 2: CDR Minutes by Review Board

APPENDIX B – OUTREACH AND MEDIA COVERAGE

Source 3: Press release 10th January 2011 [9]

Picture 41: First and second recruitment poster

Source 4: ADIOS Homepage at the FH Aachen website

Link: http://www.fb6.fh-aachen.de/lur/studienprojekte/rexus-adios/

Picture 42:
Presentation / F&E/ Research & Development Conference / FH Aachen - Fachbereich Luft- und Raumfahrttechnik

Picture 43: Presentation/ F&E/ Research & Development Conference/ FH Aachen – No Vibrations – Good Vibrations, S. Krämer

Studium & Lehre | Rexus-Projekt

Studierende experimentieren
mit Raketen unter Raumfahrt-bedingungen

Die Rexus-7 beim Start in Schweden

PeopleMover

Magazin der Sektion Luft- und Raumfahrttechnik im alfha.net
und des Fachbereiches 6 der FH Aachen

alfha.net

Ausgabe 2011

Alumni	Veranstaltungen	Studium & Lehre	Forschung	Intern
Die erfolgreichen Absolventen des Fachbereichs ▶ 09	Einblicke in die Praxis beim Absolventen-kongress ▶ 13	Compass-Projekt Der unverwüstliche Pico ▶ 23	Navigieren unter Wasser leicht gemacht ▶ 42	Neues Kompetenz-zentrum Mobilität ▶ 48

Stefan Krämer, Lysan Pfützenreuter, Nick Daab und Brigitte Müller, Studierende der Luft- und Raumfahrttechnik an der FH Aachen, nehmen an einem Praxisprojekt der besonderen Art teil: REXUS (Raketen-Experimente für Universitäts-Studenten) ist ein deutsch-schwedisches Studierendenprogramm, das von der European Space Agency (ESA) und dem Deutschen Zentrum für Luft- und Raumfahrt (DLR) ermöglicht wird. Es bietet Studierenden die einmalige Chance, wissenschaftliche und technische Experimente auf suborbitalen Raketenflügen unter kurzzeitigen Weltraumbedingungen durchzuführen.

Das junge Team um den studentischen Projektmanager Stefan Krämer und Betreuer Dipl.-Ing. (FH) Engelbert Plescher führt ein Experiment fort, das bereits im März 2010 mit dem Raketentreibsatz REXUS-7 in Schweden gestartet wurde. Ziel war die Entwicklung einer Experimentiereinheit, die materialwissenschaftliche und biologische Experimente in der weitgehend störungsfreien Umgebung im Weltraum ermöglicht. Mit magnetischer Dämpfung und Federn fanden die Studierenden damals außerdem eine Lösung, um die Einheit vor den Erschütterungen des Raketenflugs zu schützen – und konnten dabei eine Isolationswirkung von bis zu 80 Prozent erzielen.

Stefan Krämer und sein Team wollen diese Isolationswirkung nun optimieren und durch eine Neuanordnung der Magnete und Änderungen bei der Datenübertragung Schwingungen und aerodynamische Störungen, die die Schwerelosigkeitsphase beeinflussen, weitestmöglich eindämmen. Im März 2012 soll die nächste REXUS-Generation an den Start gehen. | PRESSESTELLE, RUTH BEDBUR/DV

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Source 5: PeopleMover 2011

ADIOS
advanced isolation on sounding-rockets
no vibrations, good vibrations

EuroLaunch
A DLR and SSC cooperation

Dimensionen 01 | 2011
Magazin der FH Aachen
University of Applied Sciences

STUDIUM
Ein echter Volltreffer
Studierende des Fachbereichs
Gestaltung entwerfen Plakat
für Frauen-Fußball-WM ▶ 26

INTERNATIONAL
Graswurzelarbeit in Äthiopien
Hilfe, die ankommt:
Prof. Dr. Michael Frings baut
Jura-Studiengänge an der
Adama University auf ▶ 38

FORSCHUNG
Vollständig vernetzt
Prof. Dr. Thomas Ritz
über die Bedeutung mobiler
Informationssysteme ▶ 48

Der Traum vom Fliegen

Ob Luftfahrt oder Raumfahrt: FH-Studierende
sammeln in praxisnahen Projekten
wertvolle Erfahrungen für den Berufseinstieg ▶ 06

FH AACHEN DIMENSIONEN 01/11 — TITELTHEMA | STUDIUM | INTERNATIONAL

Zu den Sternen

Raumfahrtprojekte sorgen an der FH für einen hohen Praxisbezug in Studium und Forschung

Ob Spaceshuttle, Rakete oder Satellit:
Für Forscher und Studierende ist die
Raumfahrt ein reizvolles Aufgabengebiet

Auf der Suche nach neuen wissenschaftlichen Erkenntnissen arbeiten Planetologen, Astrophysiker, Kosmologen und Raumfahrtingenieure intensiv daran, in die Tiefen des Weltraums vorzudringen. Auch die FH Aachen beteiligt sich an zahlreichen Programmen, die Lehrenden wie Studierenden ermöglichen, unter Raumfahrtbedingungen zu arbeiten und Schritt für Schritt den Kosmos und seine Planeten mit Raketen, Satelliten, Sonnensegeln und sogar einer Einschmelzsonde zu entdecken. Vor allem wegen ihres hohen Praxisbezugs in Lehre und Forschung gehört die FH Aachen im Bereich der Luft- und Raumfahrttechnik zu den führenden deutschen Hochschulen.

„Jede Mücke wäre im Weltall ein Elefant"
„Nur ein Augenzwinkern, nicht länger als drei Sekunden, schon war die Rakete fast vollständig von der Bildfläche verschwunden", erinnert sich Rudolf Vetter, der live beim Raketenstart der REXUS-8 im Raumfahrtzentrum Esrange bei Kiruna in Nordschweden dabei war. Der junge FH-Student hat gemeinsam mit seinen Kommilitonen Lysan Prützenreuter, Michael Laumschat und Andreas Gierse vom Fachbereich Luft- und Raumfahrttechnik am Programm REXUS teilgenommen, das Studierenden ermöglicht, wissenschaftliche und technische Experimente auf suborbitalen Raketenflügen kurzzeitig unter Weltraumbedingungen durchzuführen. REXUS (Raketen-Experimente für Universitäts-Studenten) ist ein deutsch-schwedisches Studierendenprogramm der European Space Agency (ESA) und des Deutschen Zentrums für Luft- und Raumfahrt (DLR).

Vor dem Hintergrund, dass manche materialwissenschaftlichen und biologischen Experimente nur in einer weitgehend störungsfreien Umgebung im Weltraum durchgeführt werden können, bauten die Studierenden eine Experimentiereinheit, die – entkoppelt von der Raketenstruktur – Tests in Schwerelosigkeit erlaubt. Das System reduziert die Erschütterungen der Rakete durch Schwingungen und aerodynamische Strömungen beim Flug mithilfe von magnetischer Dämpfung und Federn. „Jede Mücke wäre da oben ein

Elefant", bringt Vetter die Sensibilit[...] auf den Punkt. Die Studierenden hat[...] Sie konnten in ihrem Experiment eine 60- bis 80-prozentige Isolationswirkung erzielen.

Auch beim nächsten Raketenstart Anfang 2012 ist die FH Aachen wieder mit einer Experimentiereinheit an Bord. Das Team um den neuen studentischen Projektleiter Stefan Krämer konnte sich in einem Wettbewerb gegen sieben deutsche Teams und zahlreiche weitere ESA-Teilnehmer durchsetzen. „Wir möchten die beim letzten Raketenstart erzielte Isolationswirkung optimieren", erklärt Krämer. „Dafür werden wir die Magnete neu anordnen und eine andere Datenübertragung wählen." Koordinator des Projekts ist Diplom-Ingenieur Engelbert Plescher vom Fachbereich Luft- und Raumfahrttechnik. Er betreut die Studierenden und hat selbst schon – gemeinsam mit dem DLR – eine Messplattform entwickelt und auf einem Raketenflug verifiziert.

Huckepack ins Weltall
Neben den suborbitalen Raketenflügen werden an der FH Aachen auch wissenschaftliche Experimente unmittelbar im Weltraum durchgeführt. Am 28. April 2008 schickte ein Team von Studierenden, unterstützt von Professoren und Mitarbeitern des Fachbereichs, den selbst gebauten Pico-Satelliten COMPASS-1 ins All. Seitdem sendet er erfolgreich und viel länger als erwartet technische Daten aus dem Orbit zur Erde. Das Studierendenprojekt ist Testfeld für verschiedene neue Technikkomponenten, deren Haltbarkeit und Leistungsfähigkeit im Orbit untersucht werden.

Nach dem erfolgreichen Anlauf des Studierendenprojekts bekommt der kleine Satellit nun bald Gesellschaft: Das Team plant und baut derzeit – unter studentischer Projektleitung von Matias Bestard Jaume, der im März Felix König ablöste – den Nachfolger COMPASS-2. Dieser soll deutlich größer als sein Vorgänger werden, „um Industrie und Forschung noch mehr Platz für ihre wissenschaftlichen Experimente zur Verfügung stellen zu können", erklärt Jaume. ▶

Source 6: Dimensionen 2011

RX11_ADIOS_SEDv5.3_07October2013_Final.docx

Schon jetzt hätten zahlreiche Firmen und Institute ihr Interesse bekundet. Auch die Technologie des Nachfolgers soll komplexer werden: Die Lageregelung wird erneuert, das Kommunikationssystem verbessert und die Datenübertragungsrate erhöht. „Wir sind gespannt, ob sich COMPASS-2 dort oben genauso gut schlagen wird wie sein Vorgänger", sagt der studentische Projektleiter. „Doch zunächst müssen wir eine Trägerrakete finden, die unseren Satelliten Huckepack ins Weltall befördert."

Grüne Technologie fürs All

Normalerweise sind die Ziele im All durch die Treibstoffmenge begrenzt. Raumfahrzeuge, die mithilfe von Sonnensegeln die kostenlose Sonnenstrahlung als Antriebsquelle nutzen, haben hingegen immer einen vollen Tank. Dadurch ist es sogar möglich, unser Sonnensystem zu verlassen. „In der Antriebstechnik des Sonnensegels steckt ein enormes Anwendungspotenzial", schwärmt Prof. Dr. Bernd Dachwald. Schon bald soll die in Deutschland entwickelte Technologie einem Praxistest unterzogen werden: Danach planen das DLR und die ESA eine gemeinsame Weltraummission, bei der unter anderem die Pole der Sonne mithilfe eines Sonnensegels überflogen werden sollen, um unseren Stern aus einer neuen Perspektive zu untersuchen. „Die Hitze macht dem Sonnensegel nichts aus", erklärt der FH-Professor, der die Mission in einer Arbeitsgruppe der ESA begleiten wird. Es sei vergleichbar mit Backofenpapier, aber wesentlich leichter und feiner. Vorstellbar wäre auch der Einsatz von Sonnensegeln zur Abwehr von Asteroiden. „Ein Sonnensegel könnte Asteroiden finden, die sich so nahe an der Sonne befinden, dass man sie von herkömmlichen Raumfahrzeugen oder von der Erde aus nicht entdecken kann", sagt Prof. Dachwald. Dass es sie gibt, sagen Computermodelle des Sonnensystems voraus. Für diese wäre die Entdeckung solcher Körper ein wichtiger Test. Eine weitere Gefahr seien Sonnenstürme: Sie stoßen regelmäßig Milliarden von Tonnen hochenergetischer Teilchen aus, die nicht nur Astronauten und Satelliten im Umfeld der Erde in Gefahr bringen, sondern auch zu Stromausfällen auf der Erde führen können. Die Weltraummission soll zeigen, ob Sonnensegel dabei helfen können, frühzeitiger als bisher vor diesen „Teilchenschauern" zu warnen. Gefährdete Kraftwerke könnten dann abgeschaltet, Satelliten in Sicherheit gebracht werden.

Gemeinsam mit Fachleuten aus aller Welt möchte Prof. Dachwald die Antriebstechnologie des Sonnensegels vorantreiben. 2009 rief er dazu das „International Symposium on Solar Sailing" ins Leben, bei dem alle drei Jahre über den Stand der Sonnensegeltechnologie diskutiert wird. Das nächste Symposium soll im Juni 2013 in Glasgow, Schottland, stattfinden.

Auf der Spur von außerirdischem Leben

Noch kosmische Zukunftsmusik ist die Mission „IceMole": Die kleine Einschmelzsonde soll sich irgendwann durch den dicken Eispanzer des Mars oder des Jupitermonds Europa schmelzen und dort nach außerirdischem Leben suchen. Im letzten Jahr wurde der Prototyp erfolgreich unter Leitung von Prof. Dachwald auf dem Morteratsch-Gletscher im Schweizer Oberengadin getestet. Derzeit erarbeitet und baut das studentische Projektteam eine zweite, verbesserte Generation des IceMole. Dieser soll sich 2012 erneut in eine dicke Eisschicht graben und auf Herz und Nieren geprüft werden: „Dieses Mal möchten wir ein ‚U' mit dem Eismaulwurf schmelzen und damit die Rückführbarkeit nachweisen", erklärt der studentische Projektmanager Clemens Espe, der im März Chang-sheng Xu ablöste. „Damit wir zeigen können, dass die teuren Messinstrumente, die wir für Wissenschaftler und Unternehmen mitnehmen, auch wieder an die Oberfläche kommen." Zudem laufen derzeit verschiedene Forschungsanträge: Angedacht sind unter anderem Untersuchungen zum Nachweis sogenannter Neutrinos. Da die neutralen Elementarteilchen nicht zu sehen, sondern nur zu hören sind, könnten mithilfe des IceMole akustische Sensoren tief im Eis versenkt werden. Eine weitere Mission könnte in der Arktis stattfinden: Staubkorngroße Mikrometeoriten regnen permanent auf die Erde. Die Untersuchung dieses kosmischen Staubs gibt wertvolle Einblicke in die Entstehung unseres Sonnensystems. Da das arktische Eis sehr sauber ist, eignet es sich besonders gut, um mithilfe des IceMole diese Teilchen zu sammeln, um sie später zu untersuchen.

Die FH Aachen hat es mit ihrer anwendungsorientierten Forschung und ihren zahlreichen Studierendenprojekten geschafft, immer weiter in die Tiefen des Kosmos vorzudringen. Ein großer Wunsch steht jedoch noch aus: „Der Bau einer eigenen Rakete", sagt Stefan Krämer, studentischer Projektleiter im Projekt REXUS. Ein Traum, der schon bald in Erfüllung gehen könnte, denn das DLR bietet dies in seinem neuen Programm „STERN" (Studentische Experimental-Raketen) als Fördermöglichkeit für Hochschulen an, die im Bereich von Trägersystemen ausbilden. „Wir werden uns auf jeden Fall bewerben", sagt Engelbert Plescher. „Und wer weiß, vielleicht heben wir dann in drei Jahren – so lange wird es dauern, bis die Rakete entwickelt und einsatzbereit ist – sogar mit einer eigenen FH-Rakete ab." | **RB**

FH Aachen participates in various programmes that make it possible for teachers as well as students to work in astronautical conditions. Some students perform scientific experiments on suborbital rocket flights through the REXUS programme. FH Aachen's COMPASS-2 satellite transports new technical components into space. Prof. Dr. Bernd Dachwald explores the technology of solar sail propulsion, the use of which will be tested during a space mission. The "IceMole" mission is still a dream of the future, but one day the melting probe will dig into the thick ice layer of Mars or Jupiter's moon Europa to search for extraterrestrial life.

FH AACHEN DIMENSIONEN 01/11   TITELTHEMA | STUDIUM | INTERNATIONAL | FORSCHUNG | PERSONEN | SERVICE   17

An der FH Aachen werden verschiedene Raumfahrtprojekte umgesetzt: Sonnensegel, REXUS-Rakete, Einschmelzsonde IceMole, COMPASS-Satellit

Source 7: ELGRA Symposium Poster Session

ADIOS
advanced isolation on sounding-rockets
no vibrations, good vibrations

EuroLaunch
A DLR and SSC cooperation

FH
Hochschule Aachen

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> **News-Archiv**

Mittwoch, 02. November 2011 17:26

ADIOS!
Von: Ruth Bedbur

Rubrik: News

FH schickt Experimente auf Raketenflug in den Suborbit

Im März nächsten Jahres startet im Raumfahrtzentrum Esrange bei Kiruna in Nordschweden die REXUS-11-Rakete. Mit an Bord sind zwei Experimente, die FH-Studierende am Fachbereich Luft- und Raumfahrttechnik entwickelt haben. Sie nehmen am REXUS-Programm (Raketen-Experimente für Universitäts-Studenten) des Deutschen Zentrums für Luft- und Raumfahrt (DLR), der Swedish Space Cooperation (SSC) sowie der European Space Agency (ESA) teil, das Studierenden ermöglicht, wissenschaftliche und technische Experimente auf suborbitalen Raketenflügen kurzzeitig unter Weltraumbedingungen durch-zuführen.

ADIOS (ADvanced Isolation On Sounding-rockets) heißt das Experiment, das den Versuch auf der REXUS-7 aus dem Jahr 2010 fortsetzt. Vor dem Hintergrund, dass manche materialwissenschaftlichen und biologischen Experimente nur in einer weitgehend störungsfreien Umgebung im Weltraum durchgeführt werden können, bauen die Studierenden eine Experimentiereinheit, die - entkoppelt von der Raketenstruktur - aussagekräftige Tests in Schwerelosigkeit erlaubt. Während der Schwerelosigkeits-Phase dämpft das System die Störungen, die sich aus dem Raketenantrieb und aerodynamischen Strömungseinflüssen ergeben. Diese Schwingungen werden mithilfe von magnetischen Dämpfern und Federn größtenteils eliminiert. Die Studierenden hatten schon 2010 mit dem Vorgänger "VibraDamp" Erfolg: Sie konnten in ihrem Experiment eine 60- bis 80-prozentige Isolationswirkung erzielen. "Diese wollen wir beim nächsten Versuch optimieren", erklärt der studentische Projektleiter Stefan Krämer. "Dafür werden wir die Magnete neu anordnen und ein anderes Dämpfersetup ausprobieren."

Zusätzlich wird parallel ein zweites Experiment durchgeführt: Die Studierenden wollen testen, welche Lasten auf die Raketenstruktur wirken und wo gegebenenfalls Material und somit Gewicht eingespart werden kann. "Wenn die Rakete leichter gebaut werden kann, könnte sie höher steigen oder weitere Experimente mit an Bord nehmen", so Krämer. "Allein die Einsparung von zwei Kilogramm pro Raketenmodul hätte enorme Vorteile." Die Ergebnisse dieses Experiments fließen in die Optimierung des Designs von zukünftigen Höhenforschungsraketen und deren Modulen ein.

Die Experimentiereinheit der Studierenden befindet sich momentan in der Fertigungsphase. Mitte Dezember nimmt das Team von derzeit zehn Studierenden an der "Payload Integration Week" teil. Alle studentischen Projektteams treffen sich beim DLR, um die einzelnen Experimentiermodule zusammen zu setzen und sie gemeinsam mit dem Bordcomputer der Rakete zu testen. Später, wenn die Rakete fertig montiert ist, folgen dann noch Tests, um eine stabile Flugbahn zu gewährleisten. "Die Rakete wird im Prinzip gewuchtet", sagt der FH-Student, "wie beim Autoreifen". Danach kann die Höhenforschungs-rakete dann endlich nach Kiruna und in den Nordhimmel abheben.

Der Start der REXUS-7 im Jahr 2010
© DLR / Torbjörn Sundberg

<- Zurück zu: News-Archiv

Druckversion dieser Seite | Impressum | Letzte Aktualisierung: 06. May 2008

Source 8: Press-Release by Bedbur, Ruth / FH Aachen Press Office 02.11.2011

STUDIENANGEBOT   FACHBEREICHE   DIE HOCHSCHULE   FORSCHUNG

Startseite
Presse
Pressemitteilungen
Aktuelles
Kontakt und Team
Kurzprofil der Hochschule
Publikationen
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Corporate Design

...3-2-1-Zero – Studierende begleiten Raketenstart in Nordschweden

<- Zurück zu: Aktuelles
8.03.12 | Von: Ruth Bedbur

Seit Menschengedenken fasziniert der Weltraum die Menschen. Auf der Suche nach neuen wissenschaftlichen Erkenntnissen arbeiten Planetologen, Astrophysiker, Kosmologen und Raumfahrtingenieure intensiv daran, in die Tiefen des Weltraums vorzudringen. Auch Studierende vom Fachbereich Luft- und Raumfahrttechnik der FH Aachen beteiligen sich: Am Sonntag machen sie sich auf den Weg zum Raumfahrtzentrum Esrange bei Kiruna in Nordschweden, um dort den Raketenstart der REXUS-11 zu begleiten.

Das Studierendenteam: Joana Hessel, Fabian Baader, Dominique Daab, Stefan Krämer, Andreas Gierse, Tobias Wagner und Brigitte Müller (v.l.)
Foto: FH Aachen/Ruth Bedbur

Mit an Bord der Rakete sind zwei Experimente, die von den Studierenden entwickelt wurden. Vor dem Hintergrund, dass manche materialwissenschaftlichen und biologischen Experimente nur in einer weitgehend störungsfreien Umgebung im Weltraum durchgeführt werden können, bauten sie zum einen eine Experimentplattform, die – entkoppelt von der Raketenstruktur – Tests in Schwerelosigkeit erlaubt. Das System reduziert die während der Schwerelosigkeitsphase auf die Experimente einwirkenden Erschütterungen der Rakete mithilfe von magnetischer Dämpfung und Federn. „Je besser diese Störungen abgefangen werden, desto genauer sind die späteren Experimente", sagt Stefan Krämer, studentischer Leiter des Projekts. Zum anderen wird das Team die mechanischen und dynamischen Lasten, die auf die Raketenstruktur wirken, mithilfe von Sensoren untersuchen. Mit den Ergebnissen soll die Raketenstruktur hinsichtlich Gewicht und Material optimiert und damit das Design von Höhenforschungsraketen verbessert werden.

Insgesamt zwei Wochen wird das siebenköpfige Team im Raumfahrtzentrum Esrange verbringen. Dort treffen sie auf die anderen sieben Studierenden-Teams, um gemeinsam ihre Experimente flugtauglich zu machen und sie dann in der zweiten Woche auf insgesamt zwei REXUS-Raketen zu testen. „Es ist toll, Studierende aus anderen Ländern zu treffen, die dasselbe studieren wie wir", sagt Student Dominique Daab. „Und wer kann schon behaupten, mal bei einem echten Raketenstart dabei gewesen zu sein?" Für die FH-Studierenden ist der Besuch des Raumfahrtzentrums das Highlight ihres Projekts. „Der verdiente Lohn nach eineinhalb Jahren Arbeit", so Krämer. „Wir freuen uns sehr darüber, dass die FH Aachen es ermöglicht, dass das gesamte Team fahren kann. Jetzt muss nur noch alles so klappen, wie wir uns das vorstellen."

REXUS (Raketen-Experimente für Universitäts-Studenten) ist ein deutsch-schwedisches Studierendenprogramm der European Space Agency (ESA) und des Deutschen Zentrums für Luft- und Raumfahrt (DLR), das Studierenden ermöglicht, wissenschaftliche und technische Experimente auf suborbitalen Raketenflügen kurzzeitig unter Weltraumbedingungen durchzuführen. Die FH Aachen beteiligt sich an zahlreichen Programmen und gehört vor allem wegen ihres hohen Praxisbezugs im Bereich der Luft- und Raumfahrttechnik zu den führenden deutschen Hochschulen.

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www.fb6.FH-aachen.de/lur/studienprojekte/rexus-adios/

Der Start der REXUS-Raketen kann auf der Webcam des Esrange Space Centers mitverfolgt werden.

Source 9: Press-Release by Bedbur, Ruth / FH Aachen Press Office 08.03.2012

http://www.fh-aachen.de/topnavi/presse/pressepressemitteilungen/pm-details/?no_cache=1&tx_ttnews%5Btt_news%5D=325&cHash=f5a98b19b24ed8997ec9184ea02f8247

Weltraumeinsatz zum Teil erheblich unterscheiden.

Als wesentliches Ergebnis des Workshops hat DLR beschlossen, zunächst kurzfristig ein Instrument für einen ballistischen Flug zu entwickeln, welches bereits einzelne Experimente ermöglicht als auch als Entwicklungsmodell für die orbitale Version dienen soll. Die verbleibende Studienaktivitäten sollen sich nun auf dieses Ziel konzentrieren.

Rainer Treichel
19.3.2012 - [19.03.2012]

TO5 Praktikant supports experiment on REXUS-11

Tobias Wagner, one of out TO5 praktikants, is supporting a Sounding Rocket experiment on REXUS 11. Tobias is studying at the University of Applied Research in Aachen.

Tobis sent us the following status report from Esrange:

"... unsere Software hat zwar anfangs gestreikt, konnte aber mittlerweile debuggt werden. Am Donnerstag haben wir erfolgreich unser Modul zum ersten Mal testweise mit dem Servicemodul verbunden. Am Freitag hat der finale Bench Test stattgefunden. Der Hot Countdown für unsere Rexus 11 ist am kommenden Donnerstag (22. March 2012) angesetzt. Heute um 15 Uhr wird bereits Rexus 12 starten, sofern das Wetter mitspielt."

Mit freundlichen Grüßen aus Esrange
Tobias

The REXUS/BEXUS programme is realised under a bilateral Agency Agreement between the German Aerospace Center (DLR) and the Swedish National Space Board (SNSB). The Swedish share of the payload has been made available to students from other European countries through a collaboration with the European Space Agency (ESA).

Peter Kern
- [19.03.2012]

New Fluid Physics Chemical Lab handed over to Fases Project

On Tuesday Feb 28th the setup of the new Fluid Physics Chemical Lab was completed and the lab was handed over to start operations for the FSL EC Fases Sample Filling activities.

The utilization of the new lab immediately started for the Fases projects with the cleaning, assembly and filling process re-qualifications.

During summer this year filling of 44 EM sample cells as ground reference samples is planned. It is foreseen to complete the Fases sample cell activities in 1st quarter 2013 with the final filling of 44 FM samples.

Gerold Picker - [02.03.2012]

Overview Presentation of Fluid Physics Chemical Lab

Photo and Packaging Table

In Halle 11 the photo and packaging table is now operational. A new camera and a pc for the transfer of the images to a flash memory is installed.

Any ideas for improvment are welcome.

Source 10: Note / ASTRIUM Intranet by Peter Kern (ASTRIUM Friedrichshafen) and Tobias Wagner (ADIOS Team) 19.03.2012

Source 11: Press-Release by Bedbur, Ruth / FH Aachen Press Office 23.03.2012

http://www.fh-aachen.de/topnavi/presse/presseaktuelles/aktuelles-details/?tx_ttnews%5Btt_news%5D=354&cHash=9201c875b5a47fd1a278713 7e0ec3364

ADIOS Outreach List

Team Name	Author(s)	Title	Publication / Activity / Conference	Link	Date
ADIOS	B. Müller	Recruitment - No.1	Poster+Handouts+Exhibit VibraDamp / 23.Raumfahrtkolloquium/ FH Aachen Fachbereich Luft- und Raumfahrttechnik + DGLR + DLR	http://www.fh-aachen.de/232.html?&no_cache=1&tx_ttnews%5Btt_news%5D=2781&cHash=84b9039bee	18.11.2010
ADIOS	B. Müller	Recruitment - No.1	Poster / FH Aachen		25.11.2010
ADIOS	B. Müller	Recruitment - No.1 update	Poster + Handouts(Bookmark) / FH Aachen		06.12.2010
ADIOS	Ruth Bedbur (press office FH Aachen)	Zu den Sternen	Article - News / FH Aachen Homepage	http://www.fh-aachen.de/232.html?&no_cache=1&tx_ttnews[pointer]=3&tx_ttnews[tt_news]=2916&tx_ttnews[backPid]=22&cHash=0de3a0c11f	10.01.2011
ADIOS	B. Müller	Das REXUS/ADIOS Studierendenprojekt	Homepage / FH Aachen - Fachbereich Luft- und Raumfahrttechnik page	http://www.fb6.fh-aachen.de/lur/studienprojekte/rexusadios/	01.02.2011
ADIOS	B.Müller + S.Krämer	HIT FH Aachen (Hochschul-Informationstag)	Laboratory Presentation + Talk / FH Aachen	http://www.fh-aachen.de/angebote.html	05.02.2011
ADIOS	B. Müller	Recruitment - No.2	Poster + Handouts / FH Aachen		18.02.2011
ADIOS	B. Müller		update Homepage / FH Aachen - Fachbereich Luft- und Raumfahrttechnik page	http://www.fb6.fh-aachen.de/lur/studienprojekte/rexusadios/	08.04.2011
ADIOS	B.Müller + S.Krämer	Girl's Day	Laboratory Presentation / FH Aachen	http://www.fh-aachen.de/girls.html	14.04.2011
ADIOS	S.Krämer	no vibration, good vibration Entwicklung einer passive Schwingungs-platform für (micro)g-Experimente auf Höhenforschungsraketen	Presentation/ F&E/ Research & Development Conference/ FH Aachen - Fachbereich Luft- und Raumfahrttechnik		09.05.2011
ADIOS	Ruth Bedbur (press office FH Aachen)	Studierende experimentieren mit Raketen unter Raumfahrtbedingungen	People Mover 2011 / Magazin der Sektion Luft- und Raumfahrttechnik im alfha.net und des Fachbereiches 6 der FH Aachen	Articel page 35 - http://www.fb6.fh-aachen.de/alumni/service/peoplemover/	09.06.2011
ADIOS	S.Krämer + Andreas Gierse + Joana Hessel	ADIOS - No Vibration good Vibrations	Presentation + Poster/ ELGRA- European Low Gravity Research Assiociation/ Symposium/Antwerpen	http://www.elgra.org/Frames.htm	6.-9.09.2011
ADIOS	Team	Laborführung für die Studenten des 1.Semesters (Laboratory guided tour for the freshman student)	Laboratory and Project Presentation (8x) / FH Aachen	--	06.10.2011
ADIOS	S.Krämer + B.Müller + A.Gierse	ADIOS Poster (Allg.)	Poster in print		10.10.2011
ADIOS	Ruth Bedbur (press office FH Aachen)	FH schickt Experimente auf Raketenflug in den Suborbit	Article - News / FH Aachen Homepage	http://www.fh-aachen.de/newsarchiveinzel.html?&tx_ttnews[pS]=1320102000&tx_ttnews[pL]=2591998&tx_ttnews[arc]=1&tx_ttnews[pointer]=2&tx_ttnews[tt_news]=3335&tx_ttnews[backPid]=231&cHash=3473ff5e73	02.11.2011
ADIOS	S.Krämer	SUT Introduction Workshop DLR-Köln	Presentation		14.11.2011
ADIOS	B.Müller + S.Krämer		Poster+Handouts+Exhibit VibraDamp / 23.Raumfahrtkolloquium/ FH Aachen Fachbereich Luft- und Raumfahrttechnik + DGLR + DLR	http://www.dglr.fh-aachen.de	17.11.2011
ADIOS	S.Krämer	National Instrument - Anwendertreffen	FH Aachen + RWTH Aachen		02.12.2011
ADIOS	B.Müller + S.Krämer	HIT FH Aachen (Hochschul-Informationstag)	Laboratory Presentation + Talk / FH Aachen	http://www.fh-aachen.de	04.02.2012
ADIOS	Ruth Bedbur (press office FH Aachen)	...3-2-1-Zero - Studierende begleiten Raketenstart in Nordschweden	Article - News / FH Aachen Homepage	http://www.fh-aachen.de/topnavi/presse/pressepressemittelungen/pm-details/?no_cache=1&tx_ttnews%5Btt_news%5D=325&cHash=f5a98b119b24ed8997ec9184ea0218247	08.03.2012
ADIOS	Peter Kern (ASTRIUM) Tobias Wagner (ADIOS)	TO5 Praktikant supports experiment on REXUS-11	Article - Note / ASTRIUM Intranet		19.03.2012
ADIOS	Ruth Bedbur (press office FH Aachen)	REXUS-11 geht nicht an den Start	Article - News / FH Aachen Homepage	http://www.fh-aachen.de/topnavi/presse/presseaktuelles/aktuelles-details/?tx_ttnews%5Btt_news%5D=354&cHash=9201c875b5a47fd1a2787137e0ec3364	23.03.2012
ADIOS	*Team + press office*	*ADIOS Flyer*	*Infoflyer in progress*		

Source 12: Outreach list:

APPENDIX C - PAPERS AND PUBLICATIONS

ADvanced Isolation On Sounding rockets

(ADIOS)

No Vibrations – Good Vibrations

A. Gierse, S. Krämer, Dipl.-Ing. (FH) R. Vetter

FH Aachen University of Applied Science

Department of Aerospace Engineering

Hohenstauffenallee 6, 52064 Aachen, Deutschland

1. Introduction

Nowadays nearly all kind of experiments can be operated on a great variety of microgravity providing systems like rockets, drop-towers, parabolic flights, satellites as well as space stations. Duration and quality of the µg-environment depends on the chosen platform.

On board of the ISS and other piloted missions, many experiments are affected by perturbations due to vibrations, caused by astronauts, running aggregates and other experiments. Same problems may occur on every mechanical system which deals with non disturbance tolerant experiments.

Using the term „micro-gravity" presumes small amplitudes of acceleration in all axis. To decrease these residual forces, acting onto the experiment, a reliable decoupling mechanism is necessary.

The *DLR (German Aerospace Centre)* and the *FH Aachen University of Applied Science* developed a mechanical decoupling system for the *TITUS II* experiment for usage on the *ISS (International Space Station)*. The system worked with three-dimensional springs and eddy current dampers.

Today's goal is to improve this decoupling mechanism and make it capable for other µg-platforms.

In the **VibraDamp** Student Experiment, launched with *REXUS 7 (Rocket Experiments for University Students)*, a decoupling mechanism for sounding rockets, based on eddy current dampers including a highly reliable locking-device, has been tested successfully.

The **ADIOS** (*ADvanced Isolation On Sounding-rockets*) Student Experiment will be launched on *REXUS 11* in March 2012 and will verify an improved, partly active damping mechanism and locking device.

Basing on the results of **ADIOS,** a standardised decoupling-System for sounding Rockets can be developed. The accumulated stock of knowledge can also be used to develop decoupling mechanisms for other µg-Platforms.

2. Mechanical decoupling

A mechanical decoupling system, which is the same as a flexible machine bearing, naturally consists of springs and dampers. Both, springs and dampers, can be engineered in various designs for different applications.

Here the decoupled experiment, which can be an experiment of any kind, itself is considered to be a single mass without own eigenfrequencies.

The eigenfrequencies of a real experiment set-up are usually of much higher frequency than the eigenfrequencies of the decoupling mechanism what makes it possible to separate these two cases. The decoupling mechanism restrains the energy from the outer structure to affect the experiment. If the experiment itself includes sources of

mechanical vibrations these sources or the most sensitive parts of the experiment have to be decoupled separately.
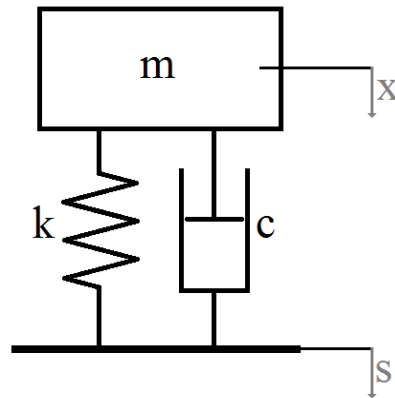
Figure 16: Single mass system incl. spring and damper

Figure 1 shows a one dimensional decoupling mechanism (one degree of freedom „x") consisting of a one dimensional spring, a one dimensional damper and the experiment as a single mass. The movements of the outer structure ("s") are the excitation of the spring and the damper.
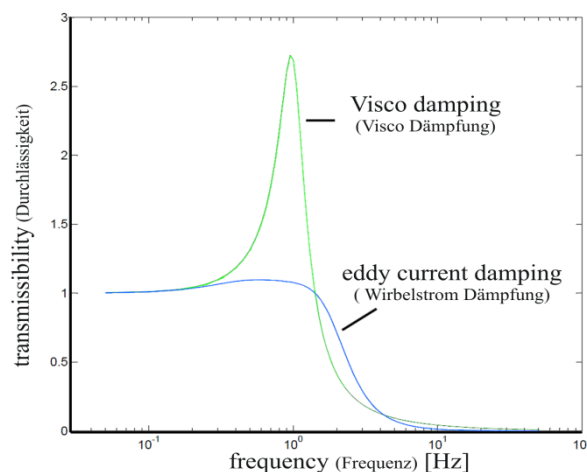
Figure 17: Estimated damping behaviour

Figure 2 compares the dynamic mechanical behaviour of this system using viscous dampers (green) and active eddy current dampers (blue).

A System with one degree of freedom has one eigenfrequency. This eigenfrequency is characterized by a high magnification factor.

At frequencies higher than the eigenfrequency the amplitude of the Experiment decreases and finally is much smaller than the excitation amplitude. This phenomenon is called decoupling.

Obviously the active eddy current damper allows an increased damping close to the eigenfrequency. This results in a smaller magnification factor.

Even more important is the result, that at higher frequencies a very good decoupling is achieved.

2.1 Decoupling all axis

To improve the existing µg-environment, all axes have to be mechanically decoupled. Therefore three-dimensional springs and dampers are necessary.

The dimensioning eigenfrequency should be as low as possible to achieve a decoupling even at low frequencies.
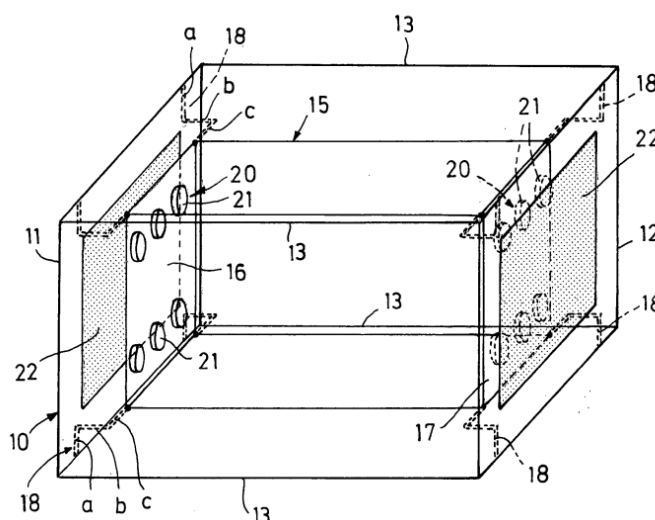
Figure 18: Schematic of Eddy current damping system [1]

Figure 3 (obtained from[1]) shows the patented decoupling mechanism of the *TITUS II* experiment. The three-dimensional springs are realised as bending and torsional beams while magnets are damping the experiment using the eddy current effect.

Working with eddy current dampers the damping depends on the oscillations amplitude, frequency and the distance between the magnets and the corresponding aluminium board.

A full description provides [2].

3. VibraDamp

3.1 Experiment Setup
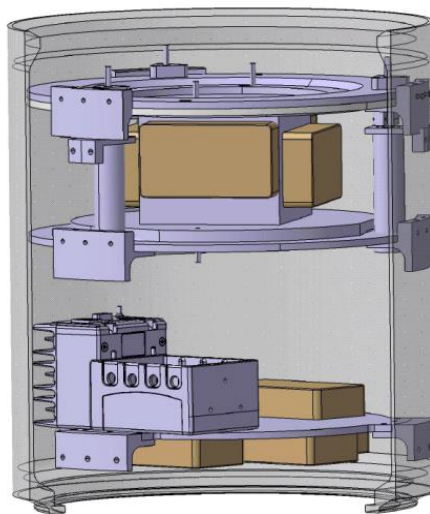
Figure 19: VibraDamp Setup

Figure 4 shows the mechanical design of the ***VibraDamp*** experiment [3],[4].

Located at the top of the module are the decoupling-System and the free flying experiment. Below, the measuring and data acquisition system as well as the power supply, were placed.

Three geared motors, controlled by a *National Instruments* Computer, actuated the decoupling-System.

Six *Kistler* acceleration sensors measured the residual accelerations at the rockets structure and the inside of the free flying experiment.

3.2 Experiment Results
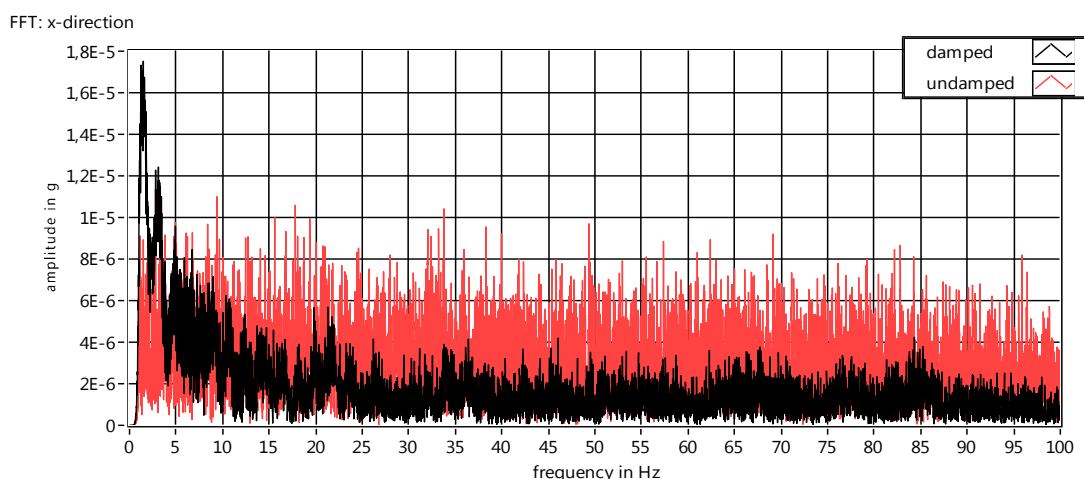
Figure 20: Fast Fourier Transformation of VibraDamp Data – x-axis up to 100 Hz

Figure 5 shows the achieved reduction of acceleration amplitudes for frequencies up to 100 Hz.

Frequencies below 1Hz are reproduced faultily because of a used high-pass filter. This filter was necessary, because sounding rockets, without a rate control system, revolve and overturn slowly during the µg-phase.

4. Adios

The Team **ADIOS** has been assembled to develop an improved layout of the successful **VibraDamp**-concept.

The new system allows increasing or decreasing of the damping rate by active positioning of the damping magnets while the system is decoupled. The optimal position of the damping magnets is calculated as a function of the actual acceleration amplitude. This active regulation of the damping rate leads to the following approximated mechanical behaviour as function of different experiment masses.
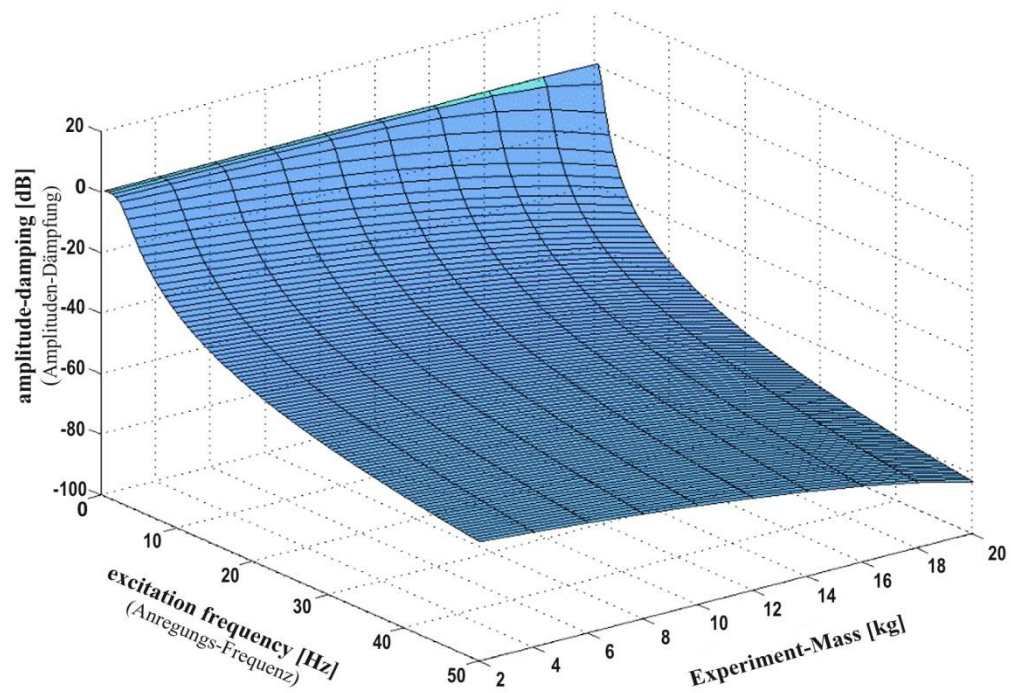
Figure 21: Decoupling as function of experimental mass
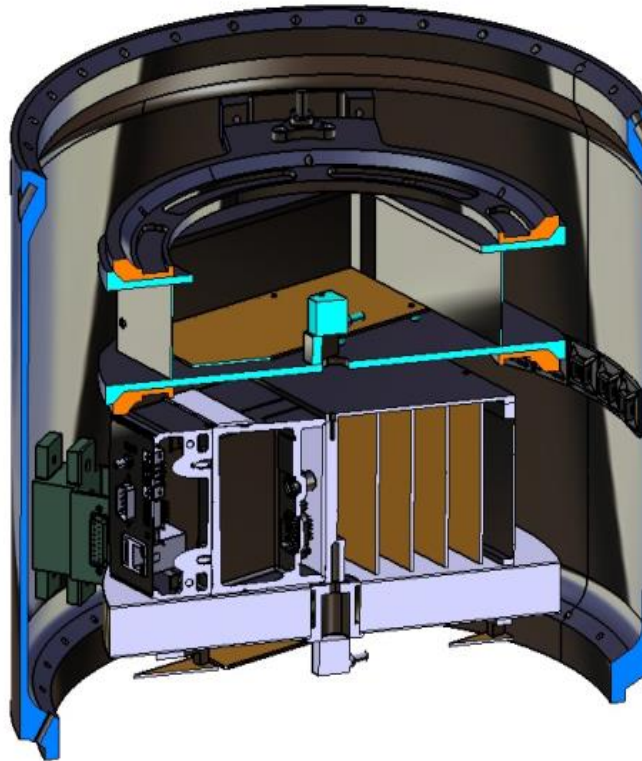
Figure 22: ADIOS Setup

Figure 7 shows the improved mechanical design of the **ADIOS** experiment.

5. Conclusion

The results of the **VibraDamp** experiment show, that the µg-conditions have been improved significantly. The **ADIOS** experiment will show the potential of an actively controlled damping.

A future project will be the additional detection and damping of high frequency (> 10Hz) vibrations produced inside the decoupled experiment using the decoupling eddy current dampers.

Cheap passive decoupling mechanism and more advanced active decoupling mechanism can both play a decisive role in future µg-research.

The FH Aachen would be pleased if research groups which are working on experiment using µg-Conditions make contact with us.

References:

Patent

[1]   Patent DE 10227968 B4. Lagerungssystem in einem Raumfahrzeug   (application: 06/22/2002, published:03/02/2006). Applicant: German   Space Center Cologne. Inventors: Nähle, R., Dipl.-Ing., Troisdorf, DE;   Wahle,   M.,   Prof.Dr.-Ing., Geilenkirchen, DE; Röstel, R., Dr.rer.nat., Berlin,   DE.

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[2]   Franke, M. (2001). Diploma Thesis „Entwicklung einer berührungslosen Dämpfung   zur   Verminderung   von Resonanzüberhöhungen eines Systems   zur   Schwingungsisolation eines Schmelzofens in der Raumfahrt   (ADVANCED   TITUS)" Aachen University of Applied Science and German   Aerospace Center Cologne

[3]   Vetter, R. (2010). Diploma Thesis „Entwicklung einer Prüfstruktur mit   einem   Schwingungsisolationssystem,   mit magnetischer Dämpfung und Test beim Para- belflug einer Rexus Rakete". Aachen University of Applied   Science

[4]   Rudolf Vetter, Andreas Gierse, Michael Lauruschkat. (2009). Student   Experiment Documentation for VibraDamp on Rexus 7.

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APPENDIX D – RESULTS EXP 1

Paper on Experiment 1 – 21st ESA Symposium on Rocket and Balloon Related Research

DEVELOPMENT AND FLIGHT-TESTING OF A SYSTEM TO ISOLATE VIBRATIONS FOR MICROGRAVITY EXPERIMENTS ON SOUNDING ROCKETS

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ABSTRACT

LOW FREQUENCY VIBRATIONS are a limiting factor for many experiments in microgravity environment. Accelerations due to excited structure parts of the experiments can cause strong influences on the quality of the experiments. Especially on sounding rocket flights the time of reduced gravity is very valuable and shall be used efficiently. Constraints due to the interferences between different disturbing experiment events often force to apportion the experimenting time. By the mechanical decoupling of an experiment, the induced perturbations can be minimized in both directions. Protecting the experiment from the influences by the vehicle and shielding all other experiments from the self induced disturbances is the goal of the ADIOS platform.

Key words: Vibration Isolation, Damping, Sounding Rockets, REXUS.

1. INTRODUCTION

The ADIOS platform is a passive and contactless isolation system, based on magnetical damping, which has been designed for experiments on sounding rockets. Driven by the motivation to increase the quality of μ-gravity for experiments on sounding rockets in a easy and cost effective way, in 2008 a student team at the FH Aachen, University of Applied Science, started to develop a system in the framework of the REXUS programme (Rocket borne EXperiments for University Students) of DLR, SNSB / SSC and ESA. Already the second design study of the system, called *VibraDamp* [1], has been tested successfully on the REXUS 7 flight in March 2010. The new developed system was completely passive despite of the locking mechanism for launch and landing. This system makes it possible to decouple an experiment from the rocket structure above frequencies of about 0.5 Hz.

Basing on the results and lessons learned of *VibraDamp* a third student team formed in 2010 which set the goal to increase the performance by a redesign of the system. A much more lightweight construction saves valuable payload mass. The theoretical threshold frequency is lowered down to 0.28Hz for a decoupling above this frequency and the measurement setup has been adapted for the verification purpose.

The new *ADIOS - Advanced Isolation on Sounding Rockets* system[1] verifies the technical setup developed for *VibraDamp*. The function of the improved system was demonstrated during the REXUS 11 flight in November 2012.

In addition to the ADIOS system verification an in-flight modal analysis of the REXUS vehicle has been conducted in the context of a second experiment by the FH Aachen student team.

2. MOTIVATION

Experiments with high requirements on the quality of μ-gravity are often guests on sounding rockets. But reaching high altitudes above the aerodynamic influences of the lower atmosphere is not a surety of low disturbances. Structural vibrations can cause unexpected errors on μ-gravity experiments. The sources of the disturbances can be found e.g. in high frequency resonances of parts, induced by the random excitation of the rocket motor. Weakly damped structures can store vibrational energy like a bell. Additionally the high frequency excitations are usually superimposed with low frequency structural oscillations and vehicle

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[1]Presented at the 21st ESA Symposium on Rocket and Balloon Programmes and Related Research, 9-13th of June 2013, Thun / Switzerland

movements. For most experiments the low frequency excitations are often a limiting factor. High amplitude low frequency movements even can completely disable the function of e.g. physical science experiments. For some cases interferences between the experiments must not be neglected. Due to the short experimenting time sometimes several experiments have to run in parallel. Currently, if one experiment disturbs the performance of another one, the time needs to be apportioned.

A practical solution for this problem is to decouple the sensitive or the disturbing experiment from the rocket structure. Limited power and the need of high reliability leads to a passive, lightweight and straightforward solution.

3. STATE OF TECHNOLOGY

Vibration damping for microgravity experiments can be realized with active or passive isolation systems. Active isolation systems require a high level of technology, sensors, actuators and complex software solutions. Passive systems are usually more cost effective and less complex. Both solutions have advantages which are depending on the environment and on the damping requirements.

Most systems are designed for the International Space Station (ISS). The vibrations and accelerations on the ISS are categorized into three frequency ranges. Low frequencies (below 0.001 Hz) which are caused by gravity gradients and atmospheric drag (less than 10^{-5} g). The frequencies in the range of 0.001 Hz to 1 Hz are for example caused by motion of the astronauts and attitude control maneuvers. Higher frequencies (above 1Hz) can be generated by electric motors, pumps, compressors, fans and also astronaut actions.

Currently passive vibration isolation systems are only used for the damping of high frequencies above 10 Hz and for payloads which are not sensitive to low frequencies. A practical application for even low frequencies is not far developed yet. Active damping solutions are often more convenient to low frequency attenuation and are grouped into active rack isolation and active payload isolation systems.

3.1. Active Vibration Isolation Systems

Active systems provide a vibration isolated environment by utilising actuators which are controlled by a feedback control in combination with sensors. The overall advantage is the wide application bandwidth. Even low frequencies can be isolated typically. Active systems often require much space and power.

3.1.1. Active Rack Isolation

Rack isolation systems can provide an nearly undisturbed environment for a whole experiment rack. This leads to a voluminous design on the one hand and gives the opportunity to change the experiments and further use of the isolation system on the other hand.

The *Active Rack Isolation System* (ARIS) developed by the Boeing Corporation was already tested on the ISS. "These ARIS racks are dynamically controlled by closed feedback loops around inertial sensors and voice coil rotary actuator/pushrods, which connect the rack and the space station structure"[2]. The motions of the ISS and of the rack are measured by accelerometers. That data is used for the ARIS control algorithms.

3.1.2. Active Payload Isolation

Payload isolation systems increase the μ-g level for a single experiment hence the system have fixed optimised design parameters.

- The *Suppression of Transient Accelerations By Levitation* (STABLE) developed jointly by NASA Marshall Space Flight Center (MSFC) and McDonnell Douglas Aerospace Corporation (MDAC), now the Boeing Corporation. The system consists of three actuator assemblies, nine acceleration sensors, three position sensors and the associated electronics and control boards. Control algorithms are used to operate the system.

- The *Microgravity vibration Isolation Mount* (MIM) developed by the Canadian Space Agency. The control of the isolated platform is based on six degree-of-freedom magnetic levitation utilizing eight wide gap Lorentz force actuators.

- The *Modular Wideband Active Vibration Absorber* (MWAVA) developed by NASA's Goddard Space Flight Center and University of Massachusetts Lowell. The isolation is realized via a two stage mechanical connector. One stage is connected to the other structure and the second stage which is free of vibration is connected to the device or experiment.

- The *GLovebox Integrated Microgravity Isolation Technology* (g-LIMIT) developed by NASA Marshall Space Flight Center (MSFC). The g-LIMIT system is similar to the MIM solution.

The mentioned systems were all tested and operated on the International Space Station or on Space Shuttle missions. Hence the damping of vibrations on sounding rockets is relatively new. The active *Vibration Isolation Platform* (VIP) by Controlled Dynamics Inc. has been recently presented at the Next-Generation Suborbital Researchers Conference 2013, Broomfield, Colorado. This system is designed for different applications and even usable on sounding rockets.

The realization of an active isolation system on these

rockets result in a very complex, heavy and costly solution. Especially the highly sensitive acceleration sensors and the required complex software solutions are an uneconomic factor. Also the weights of the payload and of the payload supply systems are limited. Hence a passive, lightweight and simple vibration isolation system for sounding rockets, which is also damping low frequencies, would be eligible.

3.2. Passive Vibration Isolation Systems

Passive systems often use the mass of an experiment platform as the key element for the isolation of higher frequencies. Elements made of rubber or viscous materials are often used for damping purpose. In view of a passive isolation system, the advantages are obvious, high reliability with no power consumption and usually less complexity. Nevertheless the status after Whorton [3] and Grodinsky [2] assumes a high system mass and no possibility of decoupling lower frequencies and high amplitudes without the problem of meeting the natural frequencies of the damping system. Additionally it is assumed, that the decoupling by a passive system only works in one direction: from the excited structure to the experiment. The ADIOS platform mitigates all these constraints. It works in both ways: it decouples an experiment from an excited structure and it can also save the structure and other experiments from the influences by a vibrating system.

A practical solution of a passive vibration reduction system has been developed for the *Advanced X-Ray Astrophysics Facility* (AXAF) [4]. The goal was to decrease the influence by g-jitter, induced by the reaction wheels of the space craft.

4. TECHNICAL REALISATION

In order to achieve the goals of a high sensitive decoupling without the use of active devices which consume energy during action, the principle of the eddy current damping was first developed to damp the TITUS II Experiment on the MIR space station. The working principle has been patented by the DLR in 2002 [5].

4.1. Fundamentals of Mechanical Decoupling

A mechanical decoupling system, which is the same as a flexible machine bearing, consists naturally of springs and dampers. Both, springs and dampers, can be engineered in various designs for different applications. Here the decoupled experiment, which can be an experiment of any kind, itself is considered to be a single mass without own eigenfrequencies. The eigenfrequencies of a real experiment setup are usually of much higher frequency than the eigenfrequencies of the decoupling mechanism, which makes it possible to separate these two
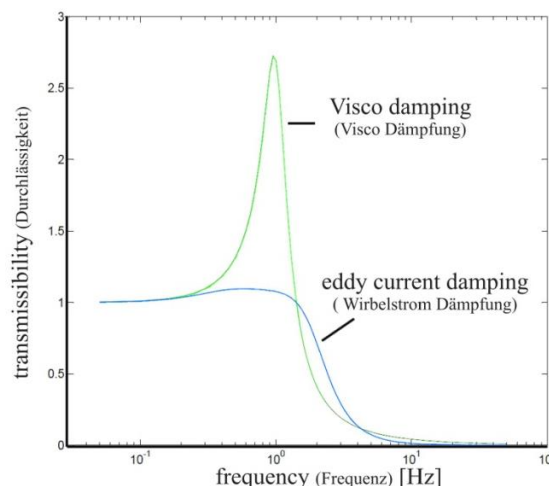
Figure 1. The magnification curve of the eddy current damping in comparison to visco damping
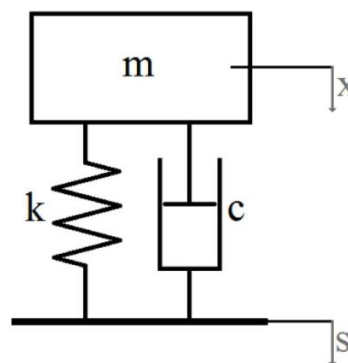
Figure 2. Single mass with spring and damper

cases. The decoupling mechanism restrains the energy from the outer structure to affect the experiment. If the experiment itself includes sources of mechanical vibrations, these sources or at least the most sensitive parts of the experiment should be decoupled separately. Figure 2 shows a one dimensional decoupling mechanism (one DOF (degree of freedom) x) consisting of a one dimensional spring, a one dimensional damper and the experiment as a single mass. The movements of the outer structure (s) are the excitation of the spring and the damper.

Figure 1 compares the dynamic mechanical behaviour of this system using viscous dampers (green) and passive eddy current dampers (blue) with the same isolation quality at higher frequencies. A System with one degree of freedom has one eigenfrequency. This eigenfrequency is characterized by a high magnification factor. At frequencies higher than the eigenfrequency the amplitude of the experiment motion decreases and is finally much smaller than the excitation amplitude. This phenomenon is called "decoupling". Obviously the active eddy current damper

![ADIOS logo - advanced isolation on sounding-rockets, no vibrations, good vibrations](logo)
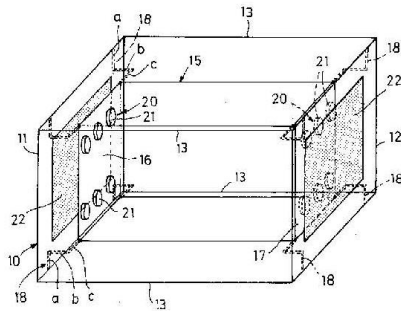
Figure 3. The magnet setup of Eddy current damping (taken from [5])

Figure 4. Magnetic field strength in dependence of the distance to the magnet

allows an increased damping close to the eigenfrequency. This results in a smaller magnification factor. Even more important is the result, that at higher frequencies a very good decoupling is achieved.

4.2. The Working Principle

In order to improve the existing μ-gravity environment, all DOF have to be mechanically decoupled. Therefore six three-dimensional springs and dampers are necessary. The dimensioning eigenfrequency should be as low as possible to achieve a decoupling even at low frequencies. Figure 3 (obtained from [5]) shows the patented decoupling mechanism of the TITUS II experiment. The three-dimensional springs are realised as bending and torsional beams, while magnets are damping the experiment using the eddy current effect. Working with eddy current dampers the damping depends on the oscillation amplitudes, frequency and the distance between the magnets and the corresponding aluminium board.

4.2.1. The Isolation Concept

The key elements for the isolation of vibrations in the mechanical decoupling due to the *free flying experiment device* (FFED). This principle is not new, but it gives the unique base for a nearly disturbance free environment. The technical design can be adapted by optimising the space for the FFED, in which it can and needs to move without contacting the outer structure. Hence the highest amplitude of motion / vibration has to be estimated in advance.

4.2.2. The Damping Principle

Figure 4 indicates the dimensions and influence of the magnetic fields due to the permanent magnets, attached to the locking mechanism. The blue and the red graphs represent the magnetic field strength of the magnets on the

upper as well on the lower side of the locking mechanism in relation to the distance. Due to this certain position of the magnets above and below the FFED, the non magnetic counter plate of the FFED has its initial distance at 8 mm for the current design. The yellow graph shows the superposition of the magnetic fields. If the FFED travels towards one direction away from the initial position, the influence by the magnetic field become immediately stronger. In concern of the eddy current principle, the velocity (hence the frequency) of the movement is a driver of the resulting damping. As higher the frequency, as stronger the damping takes affect.

4.3. Design Parameter

This section deals with a brief explanation of the physical background to determine the design parameters of the presented isolation platform. The framework of this paper is not sufficient to include all considerations for the calculation. It can only give an overview of the basic approach.

4.3.1. Dimensioning of Springs

We regard in the first step the dimensioning of the springs. An effective stiffness of a spring is approximated by implicating the bending and torsion of the spring wire. A spring design shown in figure 5, gives a similar stiffness in all directions of freedom. Using the stiffness calculated as follows:

$$k = \frac{\Delta F}{\sum \Delta x} \tag{1}$$

leads to the overall spring constant.

The single Δx are calculated with the parameters I_B as moment of inertia in bending direction and I_P as moment of inertia in torsion direction. E and G represent
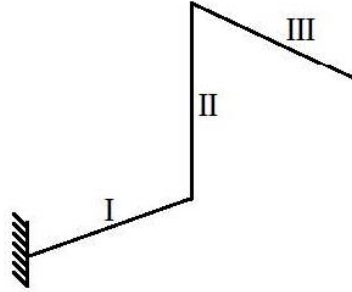
Figure 5. Three dimensional spring design

the Young´s modulus as well as the modulus of shear deformation.

$$\sum \Delta x = 2 \cdot \Delta x_{bending} + 1 \cdot \Delta x_{torsion} \qquad (2)$$

$$\Delta x_{bending} = \frac{\Delta F \cdot L^3}{3 \cdot E \cdot I_B} \qquad (3)$$

and for small angles:

$$\Delta x_{torsion} = \frac{\Delta F \cdot L^3}{G \cdot I_P} \qquad (4)$$

Assuming a force acting in the direction of leg III, the leg II reacts as a bending beam and leg I as a torsion spring. Leg III is assumed to be rigid in force direction. If the spring length is determined this way, a practical length must be chosen. The effective spring constant k_{eff} is calculated with the set length.

$$k_{eff} = \frac{1}{\frac{2 \cdot L^3}{3 \cdot E \cdot I_B} + \frac{L^3}{G \cdot I_B}} \qquad (5)$$

With the reduced mass of the FFED the natural frequency of the damping platform can be determined.

$$f_e = \frac{\omega_e}{2 \cdot \pi} = \frac{\sqrt{\frac{k_{eff}}{m}}}{2 \cdot \pi} \qquad (6)$$

4.3.2. Dimensioning of magnets

First the Lehr´s damping coefficient need to be determined with:

$$\xi = \frac{1}{2 \cdot V} \qquad (7)$$

using the maximal assumed magnification factor V.

To dimension the magnets the required effective damping c_{eff} has to be determined in advance. The effective field strength B_{eff} is a function of the material thickness d, the effective damping c_{eff}, the magnetic material constant of the counter material κ and k.

$$B_{eff} = \sqrt{\frac{c_{eff}}{k \cdot \kappa \cdot d}} \qquad (8)$$

In order to avoid magnetic disturbances to the experiments, the field strength of the chosen permanent magnets stays below the level of the earth magnetic field already in a distance of a few millimetres.

4.4. The ADIOS Experiment Setup

The ADIOS platform uses a free-flyer, containing the sensitive experiment, which is hold in position by six tiny three dimensional beam springs shown in figure 5. This leads to a six degree of freedom mounting of the FFED. The spring wires are bent by 90° to all three axis of motion resulting in beam like displacements, which are easy to calculate. The length of the spring legs (I, II and III in figure 5) are design parameters for the natural frequency of the system. It accords to the deepest frequency which can be isolated by the ADIOS system. The springs are mounted to the rocket structure on the one hand side while they are fixated to the FFED on the other hand side in a 120° interval. After unlocking the system the springs pull the FFED out of the storage position.

The permanent magnets for the eddy current damper function are mounted in flight direction directly to the aluminium rings of the locking mechanism. The magnetic field strength decreases quadratically with the distance and a contained experiment will not feel stronger magnetic forces than the earth magnetic field strength. The optimal damping is reached by a multilevel arrangement of the magnets, which is shown in figure 6. By using different field strength in different levels, a progressive damping behaviour is realised.

In order to validate the spring and damper performance as a result of the formerly explained theoretical dimensioning, the ADIOS damping platform is equipped with measuring electronics. One three axial accelerometer is mounted to the centre of the FFED, a second one is attached to the rocket module as a reference sensor. Close to the reference accelerometer an imbalance generator is mounted to the rocket wall. During the μ-gravity phase the imbalance generator is driven in three different excitation frequencies (see table 1) to generate a valid signal in far distance to the electric noise of the measuring system. The excitation frequencies $f_{excitation}$ give the opportunity to proof the transmissibility for the higher frequencies.
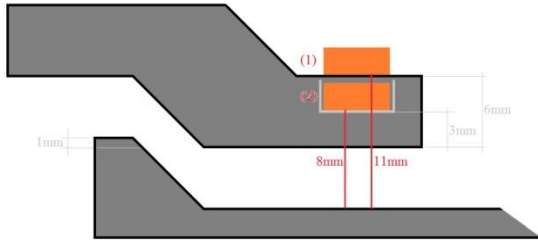
Figure 6. Multilevel magnet setup in a cross section of the locking mechanism and the counter plate of the FFED

Table 1. Excitation Frequencies of Imbalance Generator

Phase	Frequency
$f_{excitationI}$	13 Hz
$f_{excitationII}$	34 Hz
$f_{excitationIII}$	56 Hz

The ADIOS platform only works during free flight phase. Despite the time of μ-gravity the FFED need to be locked to avoid shocks to the experiment. These motors open up the space for the FFED to ensure movements of the structure relative to the locking mechanism during the μ-gravity flight phase. To cope with this a reliable locking mechanism has been developed. Two solid aluminium rings, driven by three strong geared electric motors, clamp FFED in the initial position. Before the payload enters the dens atmosphere, the FFED is locked savely again. The motors are dimensioned to re-lock the FFED after the experimenting time even when it moves out of the centre.

The ADIOS platform is currently designed to fit into a 14" standard rocket module. The structure is mounted to the wall by six aluminium brackets. The platform configuration shown in figure 7 still contains the measurement setup for the ADIOS performance evaluation. The size of the FFED can easily adapted to the given volume of a possible experiment. The current setup is fail save. If the locking mechanism does not open during the μ-g phase, the experiments container "feels" the reduced gravity of the initial platform. Would the locking mechanism fail during re-locking, the FFED had no possibility to escape and can only move in between the few millimetres of opening space

4.5. The ADIOS Technical Level

Concerning to the classification [6] of the *Technology Readiness Levels* (TRL) for the current design of the ADIOS platform adapted to the application on sounding
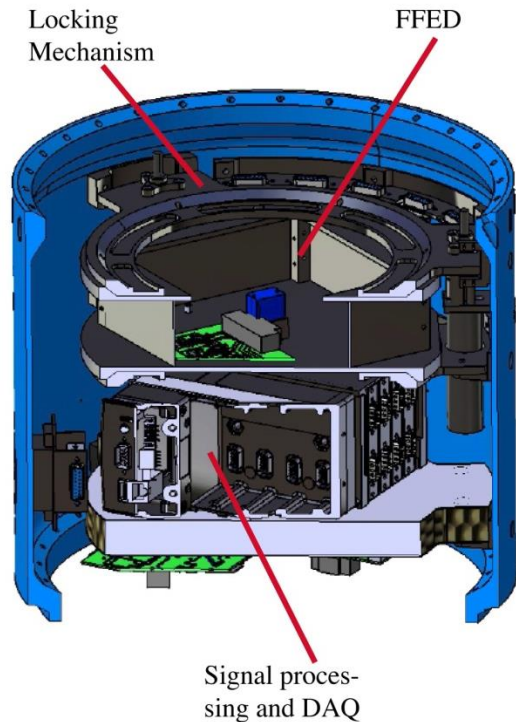
Figure 7. CAD cross section model of the ADIOS experiment setup with FFED, locking mechanism and data acquisition unit

rockets a TRL 7 is reached. This level implements the system prototype demonstration in an operational environment. For the application on other types of reduced gravity platforms like space stations and satellites, the TRL 4 (proven principle) can be assumed. Even short term experiment applications at drop tower facilities or parabolic flight aircrafts can be considered.

5. RESULTS

The in-flight test on REXUS 11 provided good processable data. Although the conditions of the REXUS 11 flight was not as good as usually, the ADIOS system could show its performance for this case. Even the very low frequent tumbling at $\frac{1}{18}$ Hz of the rocket payload was smoothed for the free flying experiment container. The presented graphs in figures 8 and 9 are the measured data of the flight axis of the vehicle. Both other directions (y and z) show very similar results and are mitigated in this discussion.

Regarding the unprocessed data of figure 8, the red graph represent the excited rocket structure, while the green graph show the accelerations inside the FFED. The first 20 seconds of experimenting time are superposed by the capacitor influence of the amplification board and are neglected here. Nevertheless, it is obvious, that the red graph reveals the slow movements ($\frac{1}{18}$ Hz) of the rocket

Figure 9. Fourier transformed signal of the accelerations in flight axis showing the excitation frequencies by the imbalance generator. RED - undamped rocket structure, GREEN - decoupled experiment containment

Figure 8. Unfiltered acceleration signals of the flight axis as a result of REXUS 11 test flight. RED - undamped rocket structure, GREEN - decoupled experiment containment

payload during the phase of reduced gravity. This has been triggered due to the motor separation and the absence of a rate control system. The higher amplitude of the high frequency vibration at the end of the graph indicates the run of the second stage ($f_{excitationII} = 34$ Hz) of the imbalance generator. The first and third stage are just recognisable after Fourier transformation of the data. In the time after about 60 s the movements of the rocket payload section became stronger and the FFED followed the higher amplitude of low frequent agitation. At these amplitudes a contact between the FFED and the structure of the locking mechanism could not be ruled out.

Figure 9 exhibit the processed data by Fourier transformation which point out, that the forced excitations by the imbalance generator of the ADIOS experiment setup have been almost completely isolated. While the peaks of the red graph clearly represent the three excitation frequencies of the imbalance generator, the green graph does not show any transmissio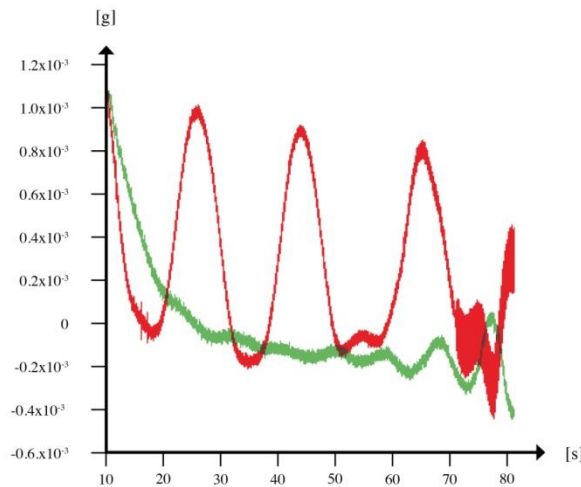n of these vibrations in the outlined frequency band from 1 Hz to 100 Hz. The bandwidth between 0 Hz and 10 Hz is strongly superposed by so called "pink noise" due to the measuring and amplification system. In this data set the natural frequency of the damping system is not recognisable. Therefore the disturbance by low frequent movements was too high.

6. CONCLUSION

The ADIOS platform offers an enhanced reduced gravity in six degrees of freedom by one order of magnitude. In view of the application on sounding rockets an effective decoupling of the experiment from the rocket structure is already reached above 0.5 Hz. The passive system comes with a reliable locking mechanism for launch and landing
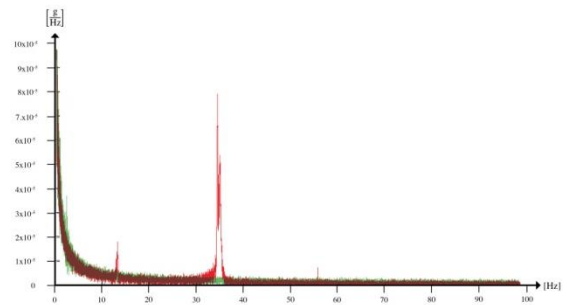
as well as for storage. Designed and demonstrated for sounding rockets the principle can be used for different type of μ-gravity platforms.

Usually very low frequency movements are covered by the rate control system of the sounding rocket system. A combination with the ADIOS platform can reach μ-g levels up to 10^{-5} g. Transient events (shocks) are damped in the range of amplitude in which the FFED does not hit the surrounding locking structure.

7. OUTLOOK

The principle has been proofed and a practical application would show the real worthiness of this system. Nevertheless the ADIOS system works well even for lower frequencies. Now technologies of combined systems are in work to further improve the quality of μ-gravity for any kind of system.

ACKNOWLEDGMENT

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APPENDIX E – RESULTS EXP 2

Paper on Experiment 2 – 21st ESA Symposium on Rocket and Balloon Related Research

EXPERIMENTAL IN-FLIGHT MODAL-ANALYSIS OF A SOUNDING ROCKET STRUCTURE

Andreas Gierse [1], Stefan Krämer[2], Dominique J. Daab[2], Joana Hessel[2], Fabian Baader[2], Brigitte S. Müller[2], Tobias Wagner[2], Georg Gdalewitsch[2], Engelbert Plescher[2] and Lysan Pfützenreuter[3]

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ABSTRACT

Knowledge of the dynamic mechanical characteristics of a microgravity platform together with data of the dynamic loads while flight, enables its further development. Benefits are the possible weight reduction of the platform structure and an improved μ-g quality due to vibration control and purposeful decoupling.

Within the framework of the Adios student experiment a new type of measurement system for in-flight modal analysis was developed and tested. Aim of this setup was the in-flight validation of the system and the validation of a FEM Model of the REXUS 11 rocket.

The achieved Signal-to-Noise-Ratio was sufficient for data analysis. Beside the determined resonance frequencies of the rocket structure several events like motor separation and pyro firings of other experiments were measured. Furthermore the resolution of the measured, low frequency, mechanical stress was higher than anticipated.

Based on these results a further development of the measurement system seems worth the effort.

1. INTRODUCTION

In 2008 students of the FH Aachen, University of Applied Science, formed a team called »VibraDamp« to develop a passive mechanical decoupling system for experiments on sounding rockets in the framework of the REXUS 5 campaign. While this experiment was not finalized in time the project was redesigned to »VibraDampII« and successfully tested on REXUS 7 in 2010. »VibraDampII« contained a »free flying experiment device« (FFED) which was de- and recoupled while ascent and descent using three geared motors. The FFED was hold in the center of the rocket while μ-g phase using six steel springs and it was damped using the eddy-current effect. Two three-axis-accelerometers were used to analyse the mechanical behavior of the decoupled system and the effectiveness of the decoupling from the rocket structure. Results were presented in [1].

In 2011 based on VibraDampII a new student team »Adios« (ADvanced Isolation On Sounding rockets) formed with the objective to further develop the VibraDampII system to TRL 7 status. A big effort was spend on lightweight constructions and a highly reliable de- and relocking mechanism. Also the damping system was further developed to a two stage damping.

The object of research was enhenced to the field of vibrations and disturbances of the rocket structure. Therefore a modal analysis measurement system was developed. The development of this system and the results are presented in this paper.

2. MOTIVATION AND AIMS

While ascent and descent the rocket structure is excited by aerodynamic loads. Forces and the frequencies of this disturbances depend directly on speed, air density, spin rate and the angle of attack of the rocket and therewith vary in a wide range. Due to the fact that this effects have an influence on the flight safety, many calculations were done while a sufficient measurement system was not available.

2

Due to the low material damping of a typical rocket structure the energy of the aerodynamic exitations remains in the structure during μ-g phase and lowers the quality of the microgravity conditions. For the purposeful further development of the ADIOS FFED system the movements and disturbances of the rocket structure have to be well known.

Weight reduction of the rocket and payload structures is only possible if the loads are well known. This would by advantageous as it could increase the possible payloads mass at invariant apogee and μ-g time.

3. STATE OF TECHNOLOGY

3.1 Modal analysis

Modal analysis of rocket motors and payloads are nowadays commonly used to avoid dynamic interactions during flight. Numerical analysis of complex, nonlinear structures are prone of errors and hence only used for development. At acceptance- and qualification- tests, shakers are used to analyse the structures. This experimental tests are also not free of errors. The main systematic error is the connection of the analysed structure to the excited part of the shaker (mechanical impedance). The sum of the shaker mass and the mass of the tested device acts different than the device on its own or while it is fixed to the other parts of the rocket. Also all ground based tests can not consider external loads like vibrations of the rocket motor or aerodynamic loads.

An in-flight modal analysis system needs many sensors all over the rocket structure. Such a system has to consider quantitatively unknown boundary conditions. The most important conditions are the fast change of the rocket skin temperature (up to $10\frac{K}{s}$) and the electro magnetic pollution from other experiments due to the necessity of long signal cables.

3.2 Sensors

Acceleration sensors are very expensive and have a high transvers sensitivity if accelerated perpendicular to the measuring axis.

Strain gauges are cheap and small and used succesfully for modal analysis in many applications. A disadvantage of strain gauges is the high sensitivity to temperature changes. Due to the very small size a big advantage of strain gauges is the possibility to applique them to the outer structure of the rocket motor.

4. TECHNICAL REALISATION

The development process included several simulations and preliminary design circuits. Here this process is given chronologically.

4.1. Modal and aerodynamic simulations

4.1.1 Master Thesis by Lysan Pfützenreuter
»FEM CALCULATIONS ON THE REXUS 11 ROCKET« [3]

The aim of these simulations were the estimation of Eigenforms and Eigenfrequencies of the REXUS 11 rocket. Therefore several models of the rocket were designed and calculated using ANSYS. One model considered the launch configuration of the rocket another model considered the configuration during μ-g phase and so forth. The different Eigenforms were calculated to find the ideal positions for strain gauges in the payload where Eigenforms of all configurations could be verified. The main focus was on the Eigenforms while μ-g phase.

Based on this calculations, three levels in three different payload modules were defined. Each level should contain four strain gauges 90° apart of each other at the circumference of the modul.
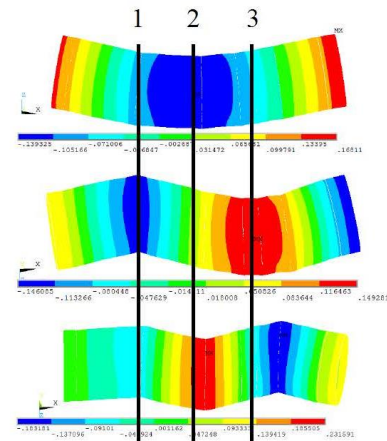
Figure 1; shows the calculated first three bending Eigenforms of the REXUS 11 payload in μ-g condition and the located ideal levels (1,2,3) for the strain gauges

The verification of Eigenforms is based on different strain-amplitude-ratios between the levels at different Eigenforms. As can be seen in Figure 1 at the first Eigenform the strain amplitude is very similar in all levels (free free bending). At the second Eigenform the strain

amplitudes at level 1 and 3 are similar but the strain amplitude in level 2 is considerably lower. Therewith it is possible to accomplish the measured Eigenfrequencies to the calculated Eigenforms.

This thesis was finished in November 2011. All assumptions were actual at that date. The positions of the strain gauges were defined as shown and those appliqued in the modules.

After spin- and balancetest the REXUS 11 payload had to be reconfigurated with the result of new, unideal positions of the strain gauges and therewith to a loss of information in the data (see section 5. RESULTS).

4.1.2 Bachelor Thesis by Stefan Krämer »EVALUATION OF ROCKET FLIGHT LOAD DETERMINATION METHODS« [2]

NASA and DLR developed several software tools during the 1960´s to determine aerodynamic loads on rocket structures.

This evaluation compared the results of the most suitable programms on the special case of the REXUS 11 rocket.

The variation range of the results was unexpectedly huge.
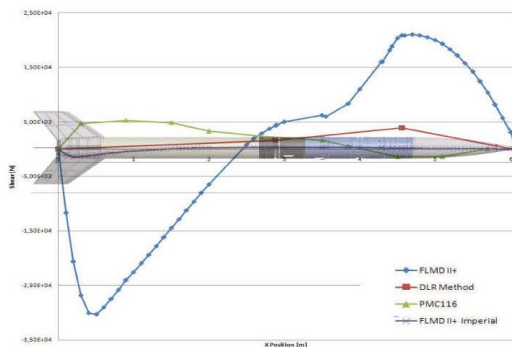
Figure 2; shows the calculated shear forces using different software tools on the REXUS 11 rocket at an angle of attack of 4°

Based on this calculations no special expectations concerning excitations or Eigenfrequencies were formulated.

However these imprecise results showed the necessity of a reliable measurement system. Therefore it was decided to collect data also while ascent and descent.

4.2 Preliminary design on shakertest

For the first tests in a REXUS modul it was decided to test strain gauges in a constant current design due to the advantages of

- small size of sensors and PCBs

- insensitivity against electromagnetic pollution and long cables

- cheap prize

The tests showed that already the warming up of the modul structure due to vibrational energy was sufficient to drift the sensors signals out of the chosen measurement range within 10 seconds. The design was extended by a DC-decoupling and temperatur sensors in all three levels and therewith tested sucessfully.
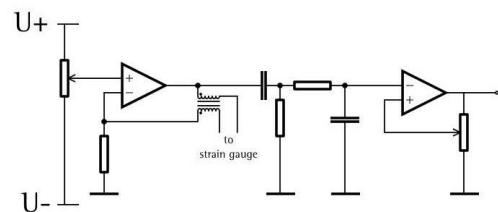
Figure 3; shows the circuits principle of a constant current source, filtering and amplification

4.3 Flight hardware

All electrical parts were manually assembled. The measurement system consisted of 20 channels on four PCBs and a NI cRIO computer system. For wiring shielded twisted pair signal cables were used which were grounded on both ends of the cable to the rocket structure.

Figure 4; shows one PCB containing five measuring channels

4

*Figure 7; shows the final configuration of the RE-
XUS 11 payload and the first two bending Eigenforms of
the new configuration and the new positions of the three
strain gauge levels*

In the new configuration the second level is close to
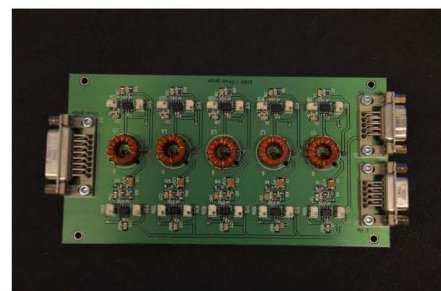the third level. Therewith the strain-amplitude-ratio is
at all bending Eigenforms close to 1. It was clear before
flight that with this configuration the verification of the
Eigenforms was going to be very difficult if possible at
all.

*Figure 5; shows the bulkhead of the ADIOS experi-
ment with cRIO computer and all PCBs of the modal
analysis measurement system*

*Figure 6; shows strain gauges and a temperature sen-
sor (to the right) appliqued to a modul. Also the electrical
grounding of the cable shield can be seen.*

4.4 FEM recalculation of new flight configura-
tion

After spin- and balancetest of the REXUS 11 rocket
it was decided that some experiment modules of the
REXUS 11 and 12 had to be switched.

This reconfiguration changed the positions of the
strain gauges. Even more important was the effect on
the Eigenforms. Those changed mainly due to the recon-
figuration that the nosecone was not ejected. Again the
bending and longitudinal Eigenforms were calculated.

bending	longitudinal
176 Hz	494 Hz
364 Hz	956 Hz
578 Hz	
791 Hz	
980 Hz	

Table 1; shows the calculated Eigenfrequencies

5. RESULTS

The system worked during the hole flight and recorded
about $75 \cdot 10^6$ datapoints.

Short after the end of microgravity time the cRIO
system changed channels for no known reason. Still all
data was relatable.

5.1 Events

Several events like motor separation and deployments
of payload parts were measured qualitatively by the
strain gauges.
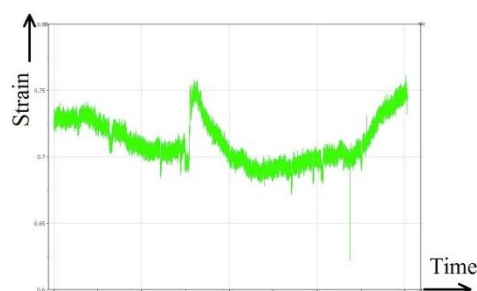
*Figure 8; shows motor separation seen as strain by a
strain gauge*

In Figure 8 also the signal to noise ratio and low fre-
quent shifts can be seen very well.

5

5.2 Excitations and Eigenfrequencies

The measured spectra are fragmented to the three phases ascent, μ-g phase and descent.

In all spectra at low frequencies the pink noise of the measurement system and the low frequent shifts due to temperature changes get visible.

5.2.1 Ascent

Figure 9; shows the spectrum of vibrations while ascent of REXUS 11

Compared to the spectrum at μ-g phase more energy at low frequencies is noticeable. At this time only few experiments were active. The electro magnetic pollution and therewith the noise can be considered lower than while μ-g phase. This low frequent energy seems to be related to temperature shifts while ascent.
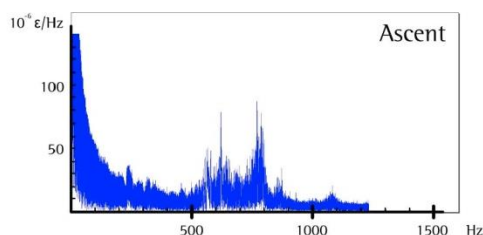
At higher frequencies two major responses (around 600Hz and around 780Hz) can be seen. Those are similar in kind to the resonances measured during μ-g phase what leads to the assumtions of structural resonances.

Many narrow banded peaks are superposing the spectrum between 500Hz and 1000Hz. These may be strains caused by aerodynamic loads.

As the simulation results did not allow any expectations all this events can not be related to a theory.

5.2.2 μ-g phase
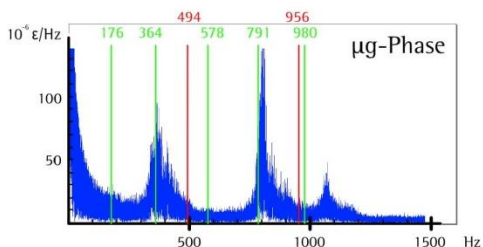
Figure 10; shows the spectrum of vibrations while μ-g phase

The vibrational energy seen in Fig. 10 is partly stored from excitations while ascent and partly caused by payloads.

The frequency ranges in which more energy is measured can be considered to be structural resonances for which are characterized by low damping and energy storing effects.

These measured frequencies are well related to the second and fourth calculated Eigenfrequencies. As assumed before, after reconfiguration the data was not sufficient to verify the different Eigenforms.

The final result therewith is that several resonances were measured which can not be definitly related to specific Eigenforms.

5.2.3 Descent
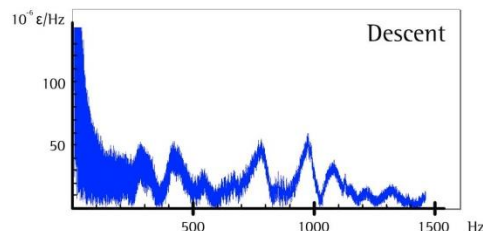
Figure 11; shows the spectrum of vibrations while descent of REXUS 11

During descent much energy in a wide frequency range was measured. Like at ascent much energy was measured at low frequencies which also should be related to temperature shifts due to aerodynamic drag.

At higher frequencies several discrete events were measured which can relate to structural resonances, tumbling movements of the whole payload and also to aerodynamic effects.

6. CONCLUSION AND OUTLOOK

- It can be summarized that the measurement principle worked out very well at all phases.

- The level of pink noise was lower than anticipated.

- Eigenforms were not identified in this case study.

- In the future the measurement range of this system could be extended down to static strain if the system was extended by Chopper Amplifiers.

6

7. ACKNOWLEDGEMENT

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1   L. Pfützenreuter, M. Lauruschkat, A. Gierse and R. Vetter. »VIBRADAMP«. *FH Aachen, Tech Rep., 2010*

2   S. Krämer. »EVALUATION OF ROCKET FLIGHT LOAD DETERMINATION METHODS«. *Bachelor Thesis, 2012, DLR MORABA*

3   L. Pfützenreuter. »FEM CALCULATIONS ON THE REXUS 11 ROCKET«. *Master Thesis, 2011, FH Aachen*

APPENDIX F – STRAIN GAUGE REQUIREMENT PROPOSAL

1. SGRP – Strain gauge requirement proposal
   (document name: RX11_ADIOS_SGRP_v1.6.docx)

ADIOS Strain Gauge Requirement Proposal

Based on the data given in the REXUS/BEXUS technical overview and the SEDs of the single student teams, first estimations about the structural behaviour of the REXUS rocket during the whole flight were made using ANSYS 13 Mechanical APDL. Since, the rocket is losing weight during flight because of burning propellant and following motor separation several phases of flight has to be considered to specify where, how, and how many strain gauges has to be applied to the rocket structure. Figure 1 shows the estimated resulting strain shortly after Lift-Off. Figure 2 shows the estimated resulting strain during the landing phase. As shown in those figure, the location of maximum strain (coloured in red) is moving from bottom of the recovery module to upper part of the nosecone during flight.
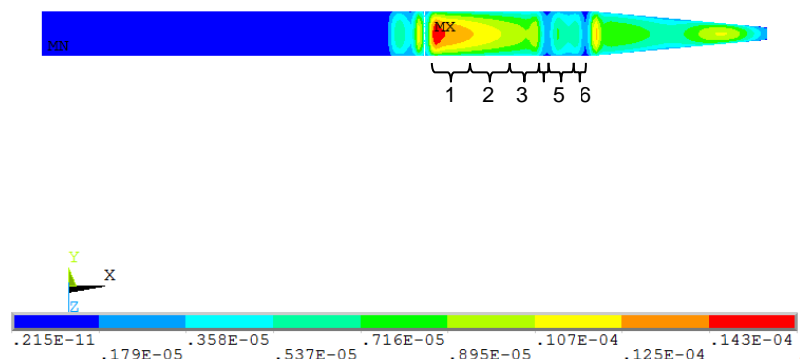

Figure 23: Estimated resulting strain in flight direction during launch phase

7. Recovery Module
8. Service Module
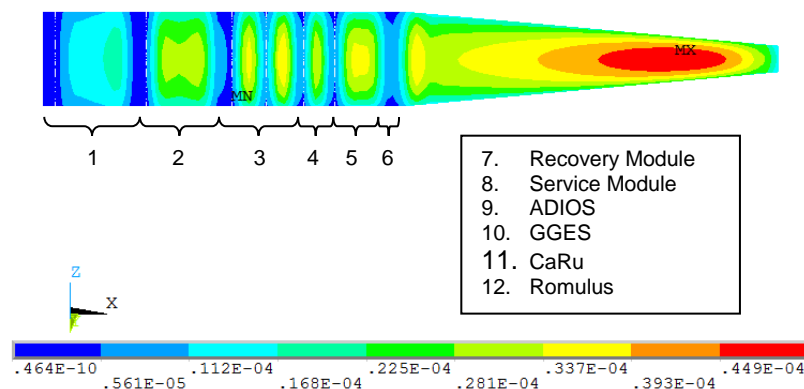9. ADIOS
10. GGES
11. CaRu
12. Romulus

Figure 2: Estimated resulting strain in flight-direction during landing phase

To consider moving maxima, strain gauges have to be applied on several stages of the rocket. Best stages to cover all flight phases are:

1. Recovery module and service module during launch

2. ADIOS and CaRu during landing phase (NC is neglected)

For that, the largest strain at each stage is expected to be in the middle between two "perturbations" of structure. Perturbations are connections between the modules, mountings, and bore holes in the structure. Hence, first stage is located ≈ 92 mm from bottom inside the ADIOS module. The second stage shall be located at ≈120 mm from bottom inside the CaRu module. It would have been good to have a third stage located at ≈200 mm from bottom of the recovery module.

Next, the number of strain gauges in each cross-section has to be termed. For that, the different kind of structural loads have to be considered. During flight, there are longitudinal and bending vibrations. Physically, a longitudinal vibration on a symmetric structure causes equal strain (magnitude and algebraic sign) on opposite sides of the structure. A bending vibration leads to strain with equal magnitude but different algebraic sign. To decide which kind of vibration is acting on the rocket and to measure its magnitude, two strain gauges has to be applied to the structure positioned on opposite sides of the rocket structure (that means displaced by 180°). As Figures 1 and 2 show, the strain maxima in a stage will be displaced by 180° followed by strain minima displaced by 90° to the maxima. Previous to flight, it is not possible to say where those maxima and minima are located. To consider the different behaviour in different positions in one stage, there shall be four strain gages applied equally distributed and displaced by 90° onto the structure.

In addition to the location of each measurement stage, the position of the strain gauges in comparison to the zero degree mark has to be termed. This will be based on the assembly of the ADIOS module. Since, mountings and bore holes in the structure falsifies strain measurement the strain gauges shall not be positioned at 0°, 120°, and 240°. There are the mountings of the bulkhead, the free flying experiment device (FFED), and the motors. Since, the strain gauges are displaced by 90°, the positions of 40°, 80°, 160°, 200°, 280°, and 320° are no possible application position, too. To have the lowest possible perturbations, the strain gauges shall be positioned at 20°, 110°, 200°, and 290°. Figure 3 shows the positioning of the strain gauges in one stage schematically.

Since, strain measurement is always depending on the temperature of structure, either the strain gauges has to be temperature compensated or the temperature has to be measured during flight, to compensate the strain data afterwards. It is not possible to compensate the strain gauges itself with the planned ICP measurement setup. Hence, the temperature at each stage has to be measured. For that, temperature sensors are applied to the structure next to the strain gauges as shown in Figure 3. Since, the rocket is always

rotating a circumferential temperature gradient is not expected. Hence, one temperature sensor for each stage would be enough. To have redundancy, there shall be two of them at each stage.

Using four strain gages and two temperature sensors at each stage, six harnessed cables are going from the CaRu module to the ADIOS module. They shall be guided through the modules together with the other cables coming from the service module at the cable feed-through at 180°.
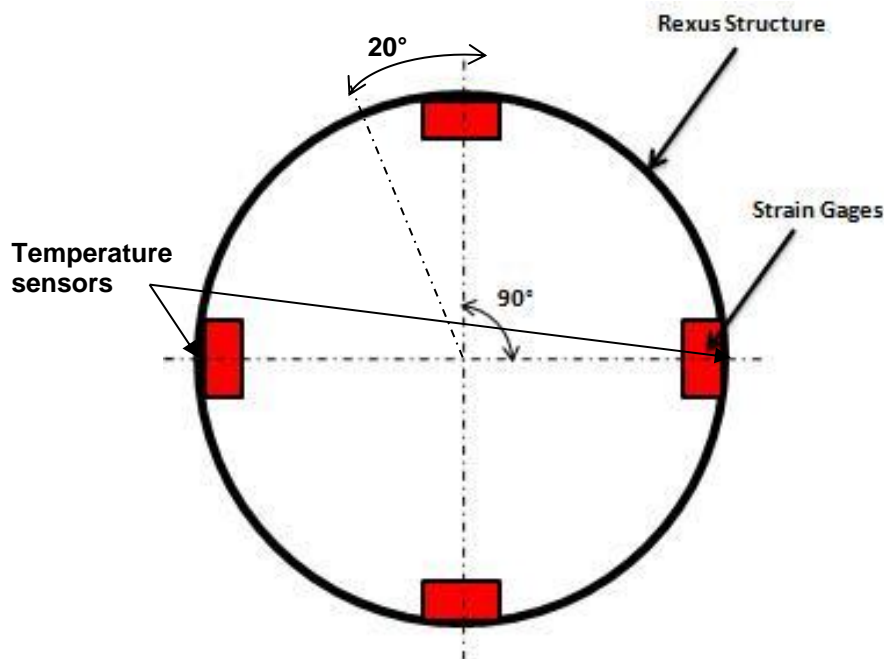
Figure 3: Strain gauge positioning in one stage

Due to the planned measurement setup, the strain gauges will provide only very small voltages. The disturbances and the noise caused by cut cables can be much higher than those signals. Therefore, the cables shall not be cut and equipped with connectors.

To get an idea, how much space one strain gauge and one temperature sensor will need, Figure 4 shows an example of the application of both sensors onto the structure of the VibraDamp module (400 mm height). Figure 5 shows an enlarged picture of the application.
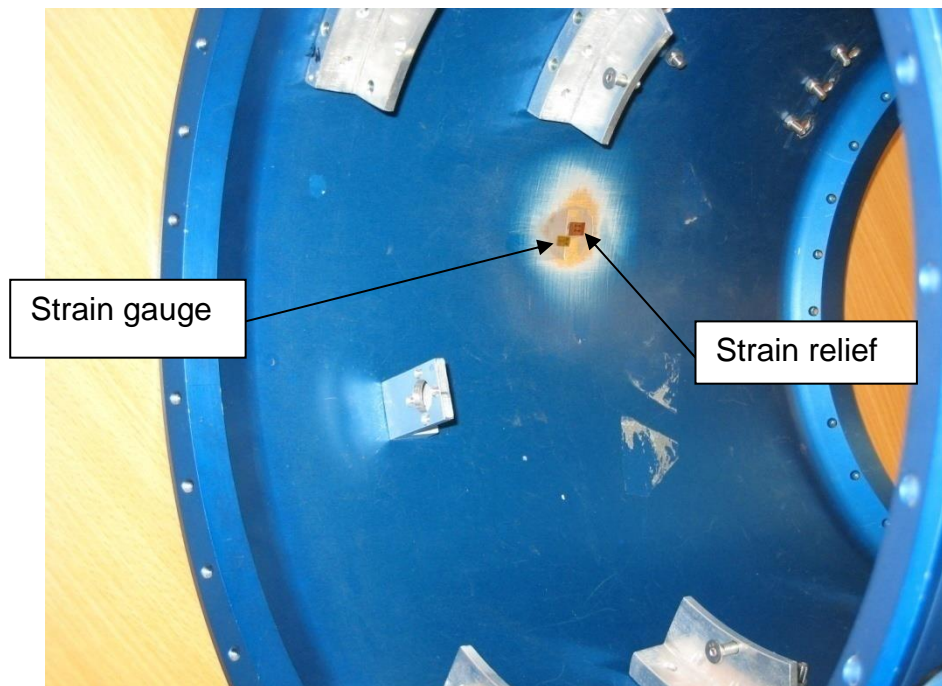
Picture 1: Example of strain gage application
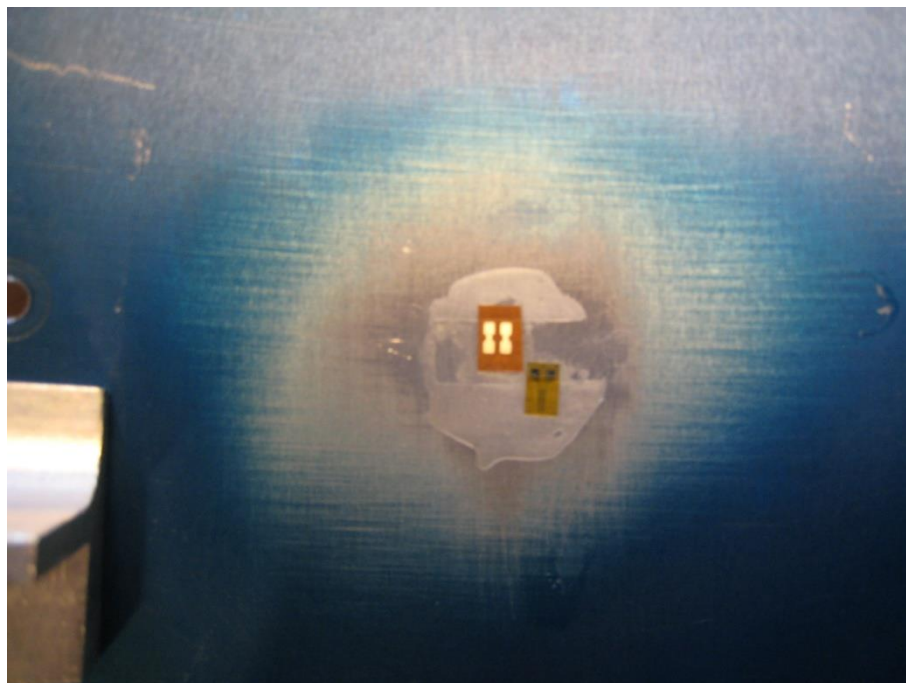
Picture 2: Enlarged picture of the applicated sensors

For the EXP2 of the ADIOS experiment, following requirements are defined:

1. The strain shall be measured at 3 cross sections, each with 4 strain gauges.

2. The first measurement cross section should be near the motor separation adapter (recovery module, at 200 mm).

3. The second measurement stage shall be inside the CaRu module located 120 mm from bottom of this module.

4. The third measurement cross section shall be inside the ADIOS module (92 mm from bottom).

5. The strain gauges at sections 1 and 2 shall be one-axial, to measure the strain in flight direction.

6. The strain gauges in the 3rd section shall be T-Rosettes to measure the strain in flight and lateral direction.

7. Each cross section shall be equipped with 2 temperature sensors.

8. The strain gauges and temperature sensors shall be positioned in one cross section as shown in Figure 3.

9. The required space inside the external modules shall not exceed 20mm x 20mm.

10. The cable harness shall not being cut at the separation planes of the rocket.

11. The cable feed-through shall be at 180°.

Additional Requirements to the performance of the strain gauges:

6. The strain gauges shall be calibrated for aluminium

7. The strain gauges shall have a minimal sensitivity of 100 με

8. The sample rate for the strain shall be the same as for the temperature

9. The data volume on the cRIO shall not exceed 0.7 GB measured for all data.

10. Each strain gauge shall measure the strain with a sample rate of 4000 Hz and should measure with a sample rate of 16000Hz

Strain gauge design

The sizes of the train gauges are very small and the required space for the wall application will not exceed 20mm x 20mm for each measuring point. The cables will be assembled to one cable harness which leaves the module.

Picture 5: Temperature sensor (350 Ω)

Picture 6: Linear strain gauge for testing (120 Ω)

Picture 7: strain relief for cabling

Procedure of application

1. Cleaning of the module surface.

2. Removing anodization in the area around the placement with 80 with abrasive paper. Keep it dry and clean. Use clean gloves!

3. Use provided clean paper tissues for cleaning the surface VERY accurately with chemically pure acetone (very important!!! – do not use technically clean acetone).

4. Do not touch the clean surface again!!!

5. Using transparent adhesive tape to pick up the strain gauge and place on the structure

6. Lifting up the adhesive tape until the matt-finished backside of the strain gauge is visible

7. Apply special glue (read instructions of manufacturer!) on the strain gauge

8. Press the strain gauge on the structure for several minutes (see instructions of manufacturer)

9. Use rubber between tool and strain gauge! Fixate the rubber with adhesive tape.

10. Use tool to build up pressure onto the positioned measuring point.

11. Heat the structure from the outside of the module at least in the area around the strain gauges to a temperature up to 80°C.

12. Wait for at least 5 hours – then remove the tool carefully.

13. Remove adhesive tape

14. Same procedure for strain reliefs

15. Soldering of small cables between strain reliefs and strain gauge

16. Soldering of cable harness to strain relief

17. Cover the whole deanodized area including strain gauges and cable connection with covering agent.

18. Merge the cables of all strain gauges of the cross section at the wall to one cable harness to leave the module at 180°.

19. Connecting the cables to amplifier in ADIOS module

The instructions of the manufacturer HBM can be found on the BSCW Server -> 300 Sensors & DAQ -> Sensorik

APPENDIX G – ADDITIONAL TECHNICAL INFORMATION

Substructure of WBS,

ADIOS
advanced isolation on sounding-rockets
no vibrations, good vibrations

EUROLAUNCH
A DLR and SSC cooperation

1. Management

- 1.1 SED
  - 1.1.1 Versions
    - 1.1.1.1 PDR
      - 1.1.1.1.1 Post PDR
    - 1.1.1.2 CDR
    - 1.1.1.3 IPR
    - 1.1.1.4 EAR
    - 1.1.1.5 Launch Campaign
    - 1.1.1.6 Final with results
- 1.2 WBS
- 1.3 Time Schedule
- 1.4 Budget
  - 1.4.1 Financial
    - 1.4.1.1 Sponsors
      - 1.4.1.1.1 National Instruments
      - 1.4.1.1.2 ASC
      - 1.4.1.1.3 ADCO
      - 1.4.1.1.4 TRACO
      - 1.4.1.1.5 Knipex
      - 1.4.1.1.6 HBM
      - 1.4.1.1.7 ERNI
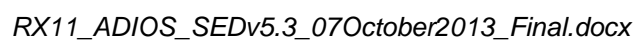   - 1.4.1.2 DLR
    - 1.4.1.3 FH-Aachen
      - 1.4.1.3.1 K1 - Antrag
      - 1.4.1.3.2 ELGRA Symposium
  - 1.4.2 Manpower
    - 1.4.2.1 Structure and Fields of work
    - 1.4.2.2 Workload
  - 1.4.3 Mass
    - 1.4.3.1 Estimation of weights
    - 1.4.3.2 validation of concepts
      - 1.4.3.2.1 CFC
      - 1.4.3.2.2 Aluminum
  - 1.4.4 Power
- 1.5 Organisation
  - 1.5.1 Interfaces
    - 1.5.1.1 DLR Bremen / PROJECT MANAGEMENT REXUS
    - 1.5.1.2 DLR MORABA
    - 1.5.1.3 Companies
      - 1.5.1.3.1 ADCO
      - 1.5.1.3.2 HBM
      - 1.5.1.3.3 ASC

2. Structure

- 2.1 Design
  - 2.1.1 RX 300mm Module
    - 2.1.1.1 Brackets
    - 2.1.1.2 Sub D feed through mounting
    - 2.1.1.3 Armed Plug Mounting
  - 2.1.2 FFED
    - 2.1.2.1 Top- and Bottom Plates
    - 2.1.2.2 Interface to Electronics
  - 2.1.3 Locking mechanism
    - 2.1.3.1 CFC Rings
      - 2.1.3.1.1 Inlets
    - 2.1.3.2 AL Rings
    - 2.1.3.3 Motor mountings
    - 2.1.3.4 Limit Switch
  - 2.1.4 Springs & Dampers
  - 2.1.5 Bulkhead
    - 2.1.5.1 Aluminum
    - 2.1.5.2 CFC
      - 2.1.5.2.1 Inlets
    - 2.1.5.3 Interface to Electronics
    - 2.1.5.4 cRIO mounting
  - 2.1.6 Rocket Adapter
  - 2.1.7 armed plugs
- 2.2 Simulation
  - 2.2.1 FEM Analysis of Parts
  - 2.2.2 Evaluation of weights
- 2.3 Construction
  - 2.3.1 Part design
  - 2.3.2 manufacturing of Hardware
    - 2.3.2.1 DLR - Workshop
    - 2.3.2.2 FH Aachen - Workshop
    - 2.3.2.3 ADCO
  - 2.3.3 Assembly
- 2.4 Testing
  - 2.4.1 Vibration
  - 2.4.2 Vacuum
    - 2.4.2.1 CFC - Parts
    - 2.4.2.2 Motors
    - 2.4.2.3 electronic parts
  - 2.4.3 Thermal
- 2.5 Integration

Legende

- priority 1
- priority 2
- priority 3
- priority 4
- priority 5
- priority 6
- started
- in progress
- half finished
- nearly finished
- finished
- paused
- good progress
- critical progress
- minor progress
- -
- -
- -

Mass reduction list

Mass reduction

Name	VibraDamp pieces	Weight VibraDamp	ADIOS pieces	estimated Weight ADIOS	Part number	Comment	mass loss with AL LM	mass loss with CFC LM
Locking Mechanism Ring top	1	1030	1	400	ADIOS 01-2-01-002 (LM Ring top CFC)	CFC + 8mm Honeycomb		630
	1	1030	1	760	ADIOS 01-2-01-002 (LM Ring top AL-CO)	Aluminum with cut-outs	270	
Locking Mechanism Ring bottom	1	1030	1	400	ADIOS 01-2-01-003 (LM Ring bottom CFC)	CFC + 8mm Honeycomb		630
	1	1030	1	740	ADIOS 01-2-01-00X (LM Ring bottom AL-CO)	Aluminum with cut-outs	290	
Bulkhead	1	1380	1	700	ADIOS 01-1-01-001 (Bulkhead CFC)	CFC + 23mm Honeycomb	680	680
Spacer Ring	1	390	0	0		not needed	390	390
cRio w/o cooling ribs	1	870	1	870	ADIOS 01-4-01-002 (NI cRIO 4Slots)		0	0
Sensor Cube triaxial	2	140	0	0		not needed	280	280
LM Brackets	6	90	3	43	ADIOS 01-2-00-001 (1H Wall Mounting Bracket New)		411	411
BH Brackets	3	66	3	44	ADIOS 01-0-00-001 (2H Wall Mounting Bracket New)		66	66
Motor	3	217	3	217	ADIOS 01-2-02-002 (Motor)		0	0
Motor mounting	3	30	3	30	ADIOS 01-2-02-001 (Motor Wall Mounting)		0	0
cRio Module (A/D)	1	140	2	140			-140	-140
cRio Module (Motor controle)	1	155	2	155			-155	-155
RX Module	1	6326	1	5341	ADIOS 01-0-00-001 (300mm Module)	smaller Module	985	985
Electronic Box FFED	4	160	0	0		not needed	640	640
Electronic Box Bulkhead	6	160	1	300			660	660
Sub D 15	4	60	0	0			240	240
Sub D 9	2	50	0	0			100	100
FFED	1	1600	1	1200	ADIOS 01-3	smaller FFED	400	400
Sum							5117	5817
		17800					12683	11983

Table 20: Mass reduction list