REXUS User Manual

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Abstract: This document has been created to assist experimenters taking part in a REXUS flight as part of the REXUS/BEXUS Programme. It is continually updated and developed in order to serve the experimenters and operators better. It describes important information about flights for experimenters, interface details, design guidelines, and testing.

Keywords: rocket, education, interface, EuroLaunch, space, experiments

This is not an ICD document.

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1 INTRODUCTION

The REXUS/BEXUS programme allows students from universities and higher education colleges across Europe to carry out scientific and technological experiments on research rockets and balloons. Each year, two rockets and two balloons are launched, carrying up to 20 experiments designed and built by student teams.

The REXUS/BEXUS programme is realised under a bilateral Agency Agreement between the German Aerospace Center (DLR) and the Swedish National Space Agency (SNSA). 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).

EuroLaunch, a cooperation between the Esrange Space Center of SSC and the Mobile Rocket Base (MORABA) of DLR, is responsible for the campaign management and operations of the launch vehicles. Experts from DLR, SSC, ZARM and ESA provide technical support to the student teams throughout the project.

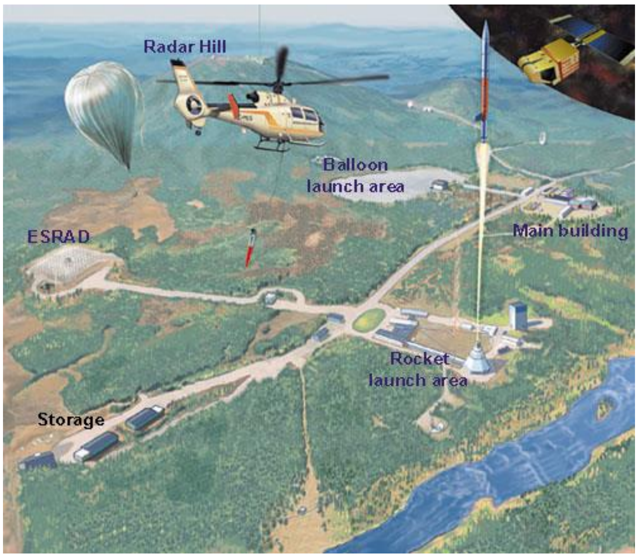

Figure 1-1: SSC, Esrange Space Center

The REXUS launch campaigns are held at the SSC, Esrange Space Center near Kiruna in northern Sweden.

The REXUS payload is modularised to provide simple interfaces, good flexibility and independence between experiment modules. Up to four experiment modules with a 355.6 mm (14 inch) diameter and maximum total length of 800 mm can be accommodated in one payload. All payload service systems necessary for telecommunication, payload control, launch, flight and recovery are included in the system.

This document is a manual for the users of REXUS including the services offered by EuroLaunch. It defines the requirements that apply to the REXUS experiment modules and gives design recommendations. It also includes a description of the technical REXUS components – the REXUS system – as well as the programmatic elements, the pre-flight tests and the campaign schedule and, finally, there is a chapter on quality assurance and safety.

If you require additional information on the REXUS system, please contact the EuroLaunch project manager or the system engineer of the current project.

1.1 Definitions

The REXUS system consists of the following technical components according to the EuroLaunch definition.

REXUS	The complete integrated vehicle to perform the flight.
Ground Support Equipment (GSE)	REXUS supporting systems and equipment on ground.
Electric Ground Support Equipment (EGSE)	Equipment used to control and communicate with various modules during tests and flight.
Rocket Motor	The part of REXUS giving the accelerating force.
Payload	Experiment modules and all EuroLaunch subsystems.
Rocket system	All systems required for flight control, recovery and telemetry.
Scientific Payload	All experiment modules including the experiments
Experiment Module	Experiment equipment and its outer structure.
Launcher	Launch rail of the rocket

Hierarchy:

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REXUS System
        ├Vehicle
        |       ├Payload
        |       |       ├Scientific Payload / Experiment Modules
        |       |       └Payload Service Subsystems
        |       |               ├TM/TC Systems
        |       |               ├Power System
        |       |               ├Sensors
        |       |               ├Radio System
        |       |               └Recovery System
        |       └Rocket Motor
        |
        └Ground Equipment
                ├Esrange Facilities
                ├Experiment Module Ground Support Equipment
                └Service System Ground Support Equipment
```

1.2 References

NOTE: All reference documents can be found on the REXUS/BEXUS Team Site along with the manual. For access to the documents, registration is required.

[1] ECSS, *Space project management / Project planning and implementation*, ECSS-M-ST-10C Rev. 1 (ESA Publications Division, 2009)

[2] ECSS, *Space product assurance / Manual soldering of high-reliability electrical connections*, ECSS-Q-ST-70-08C (ESA Publications Division, 2009)

[3] ECSS, *Space product assurance / Crimping of high-reliability electrical connections*, ECSS-Q-ST-70-26C (ESA Publications Division, 2008)

[4] SSC Esrange, Esrange Safety Manual, SCIENCE-60-4208 ver. 9 (Esrange, 2020), https://sscspace.com/news-activities/rockets-and-balloon-activities/

[5] ECSS, *Space product assurance / Data for selection of space materials and processes*, ECSS-Q-70-71A rev. 2 (ESA Publications Division, 2014)

[6] *SED Template*, (REXUS/BEXUS Organisers, 2020)

[7] *SED Guidelines*, (REXUS/BEXUS Organisers, 2020)

[8] DLR, *REXUS IV ff TMTC-Structure*, (Mobile Raketenbasis, 2009)

[9] Finite Element Modelling Continuous Improvement (FEMCI), Section Validity Checks (2016), http://femci.gsfc.nasa.gov/validitychecks/

[10] RUAG FEM Validation, David Schmid, http://ipek.hsr.ch/fileadmin/user_upload/ipek.hsr.ch/Sub-Menus/VPE-Workshops/2012/Workshop_1/FEM_Validation_Handout.pdf (2012)

[11] Google Earth, https://www.google.de/intl/en/earth/

1.3 Applicable documents

[12] Montenbruck, Oliver & Gill, Eberhard: *Satellite Orbits* (Springer Verlag, 2000)

[13] Vallado, David A.: *Fundamentals of Astrodynamics and Applications* (McGraw-Hill Companies, Inc, 1997)

[14] Sounding Rockets Program Office, *NASA Sounding Rocket Program Handbook*, (Suborbital & Special Orbital Projects Directorate, 2005)

[15] Rossow, C. C., Wolf, K., & Horst, P. (Eds.). (2014). *Handbuch der Luftfahrzeugtechnik*. Carl Hanser Verlag GmbH Co KG.

[16] in DIN eV, N. L. (1990). *LN 9300: Luftfahrtnorm*. Beuth-Verlags GmbH, Köln.

2 ALWAYS READ THIS

There is plenty of useful information in this manual. Make sure that you have found and understood the meaning of the following information.

Experiment safety

If there are hazardous items such as chemicals, pyrotechnics, hot ovens, free-falling objects, lasers, radiation, etc. included in the experiments, there may be a need for further investigation by the Esrange Safety Board. This may take some time and should be done early in the design process.

Durability of your experiment

During the pre-flight tests and the countdown, the experiments will be turned on and off several times over the course of many hours and multiple days. Make sure that there is enough battery, memory, etc. to survive these activities, in addition to that which is required for the flight.

Spin and balance

Before the start of the campaign, the rocket will be balanced (during the Environmental Tests). After this, no changes are permitted which could impact the mass, its distribution in the experiment, inertial moment or balance.

Transceivers

All equipment that emits or receives RF must have permission from Esrange to do so. Compatibility with the REXUS Service Module should be clarified.

Radio Frequency interference test and flight simulation

After the RF test, it is not permitted to make any changes to the experiments before flight. If the RF test during the campaign preparation phase fails, it may be necessary to remove your experiment or fly the rocket with your experiment turned off. If your experiment disturbs any of the flight systems or other experiments, it will not be flown at all.

Weather constraints

Due to weather constraints, it is not possible to guarantee a launch during any specific week.

Planning

It is essential to have checklists for your experiment. Without these, there is a significant risk of failures and delays during the campaign week.

Safety in launch area

No one is allowed to visit the motor preparation hall or the launch-towers without the permission of the Operations Officer.

Radio Silence

During the launch campaign there will be various hazardous operations which are also affecting the payload, especially when it is mounted to the rocket motor. To keep everyone safe, who is executing those operations, there will be a special announcement for certain areas of the range, called "**Radio Silence**".

This means, that it is strictly forbidden to transmit on any radio frequency, no current flow is allowed inside any part of the payload (except for unavoidable leakage current of components) and no battery charging or any switching. This condition must be achieved from every single experiment to have a “Dead Payload”.

Flight Requirements Plan

This is a document that is compiled by the EuroLaunch Project Manager based on input and requests from all experiment teams. If special equipment such as specialized tools or gases are required, this information needs to be communicated well before the campaign.

Our goal is to have a successful and enjoyable campaign with all teams and their experiments. You are always welcome to contact us with any questions.

3 REXUS PROJECT OVERVIEW AND MILESTONES

3.1 Project Organisation

The technical support in the integration and testing phase, as well as the campaign management and operations are provided by EuroLaunch. EuroLaunch is a collaboration of SSC Esrange and the Mobile Rocket Base (MORABA) of the German Aerospace Center (DLR). The DLR project share concerning integration, testing and student support is provided by-ZARM under contract of Germany's Space Agency at DLR.

When EuroLaunch is mentioned in this document, it means that both institutions (SSC, MORABA) may be involved.

The scientific evaluation of the experiment proposals and the financial support of the students are the responsibility of Germany's Space Agency at DLR and the Swedish National Space Agency (SNSA), in the latter case through cooperation with the European Space Agency (ESA).

The following key-positions will be assigned for every flight project:

- Project Manager
- Payload Manager
- Mechanical Design Lead
- Electrical Design Lead
- Telemetry (TM) and Telecommand (TC) Systems Lead
- Electric Ground Support Equipment (EGSE) Lead

One person can have dual assignments.
Additional positions will be assigned during the campaign.

The majority of the communication between EuroLaunch and the experiment teams shall pass through the project managers.

3.2 Flight Ticket

Students from universities and higher education colleges across Europe can apply for a REXUS "flight ticket" which includes the services listed in Figure 3-1.

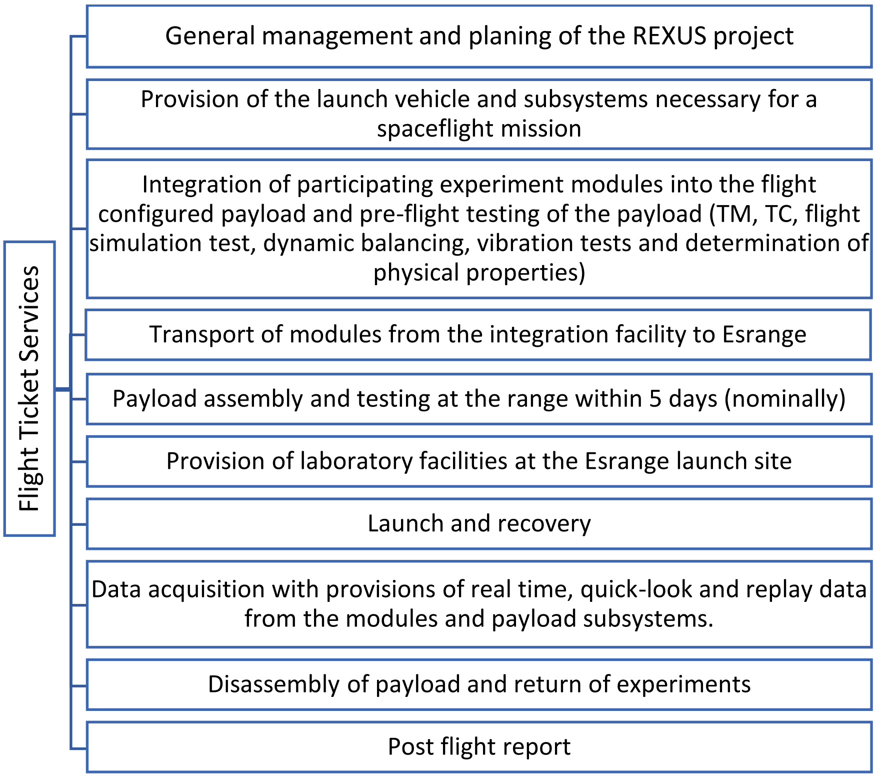

Figure 3-1: Services included as part of the REXUS flight ticket

3.3 Experimenter's Role

Once selected to participate in the REXUS/BEXUS programme, the experiment teams become a part of the mission team. Their primary responsibility is to ensure the timely delivery of their portion of the scientific payload in good order. This responsibility extends to defining the investigation, providing the instrumentation, processing data in a timely manner, and publishing of results. The experimenters must also contribute to establishing and conducting the operational programme through correspondence and fulfilment of the documentation requirements.

The successful operation of experiments is vital to the overall success of the REXUS/BEXUS missions. EuroLaunch supports the experiment teams in order to obtain valuable scientific returns. Information and expertise will be offered when required for assisting decisions relating to design, component, materials, operation, and any other mission related issues. Final decisions are normally left to the experimenters but if required (by safety or otherwise), EuroLaunch withholds the right to enforce decisions on any issue. Before flight, the experimenters must successfully demonstrate to EuroLaunch through evidence of testing, simulation, and documentation that their experiment is fit and safe for flight.

The experimenters are responsible for developing and providing the scientific payloads and support equipment. EuroLaunch can aid with many of these issues but the team is responsible for ensuring that these are organised in a timely manner. They are also responsible for ensuring that the experiments conform to all required electrical and mechanical interface specifications and meet all safety requirements. EuroLaunch supports the teams in troubleshooting where possible but the experimenters must keep in mind that the solution of issues is their responsibility.

3.4 Project Planning

A detailed project plan and time schedule will be released by EuroLaunch as soon as possible after the selection workshop. These will be updated regularly throughout the project.

A general progress plan for REXUS flight projects is listed below (mo = month). Detailed descriptions of reviews and tests are given in chapter 8.

T-18 mo	Call for experiment proposals
T-16 mo	Proposal submission deadline
T-16 mo	Proposal shortlisting
T-15.5 mo	Selection workshop at ESTEC (ESA) / Bonn (DLR), presentation of proposals
T-15 mo	Final experiment selection
T-13.5 mo	Student Experiment Documentation (SED) v1-0 submitted
T-13 mo	Student Training Week (STW) at SSC, Esrange Space Center or DLR Oberpfaffenhofen. Preliminary Design Review (PDR)
T-9 mo	SED v2-0 submitted
T-8.5 mo	Critical Design Review (CDR) at DLR Oberpfaffenhofen including soldering course
T-7.5 mo	SED v3-0 submitted
T-7 mo	Integration Progress Review (IPR) at experimenters' organisation
T-5 mo	SED v4-0 submitted
T-4.5 mo	Experiment Acceptance Review (EAR) at experimenters' organisation or a ZARM/SSC facility
T-4 mo	Delivery of Experiments to Integration Week (ITW) at ZARM Bremen (experimenters required)
T-2.5 mo	Bench Test at DLR Oberpfaffenhofen (experimenters required)
T-0.5 mo	Spin and Balance Test (experimenters not present)
T+0 mo	Campaign at Esrange
T+0.5 mo	Flight Report Documentation from experimenters submitted
T+1 mo	Distribution of the REXUS post flight report by EuroLaunch
T+3 mo	SED v5-0 submitted including experiment results
T+4 mo	Publication of Final Report/Results Seminar

3.5 Experimenter Documentation Requirements

3.5.1 Student Experiment Documentation (SED)

The SED provides EuroLaunch and other stakeholders from SNSA, ESA, DLR and ZARM with all important information on a particular experiment. During the phases of experiment development, production and flight, the SED will be the main documentation for students to describe their experiment and 5 versions shall be provided. All documentation relating to the requirements of this document can be found at the REXUS/BEXUS Team Site, including the SED guidelines and SED template documents.

3.5.2 Flight Requirements Plan

Any requests for input from EuroLaunch must be fulfilled by the student teams. The Flight Requirements Plan (FRP) is a reference document for the many people who will be involved in the launch of experiments, and care must be taken that information is correct and clear to avoid errors concerning the experiments. These requirements will be made on an individual basis with each of the teams. For the update of the flight timeline and trajectory calculation, the FRP is released at least in three versions, before the Integration Week, before the Bench Test and before the campaign. (see also section 11.3)

3.5.3 Ground Safety Plan Questionnaire (GSP-Q)

A few weeks prior to the campaign, the Esrange Safety Board (ESB) requires detailed inputs for the campaign risk analysis and safety evaluation (see also section 11.2). Therefore, the experimenters are requested to fill out a questionnaire form including all required details. The form will be provided by SSC.

3.5.4 Recovery Sheet

During the campaign, the recovery officer of Esrange requests a maximum of a single A4 sheet containing dedicated experiment recovery instructions. This recovery sheet shall explain the handling after landing in limited text with coloured pictures of the experiment (e.g. how to switch off / disarm the experiment, how to disassemble protruding equipment for transport…).

A recovery instruction shall be:

- Safe (the recovery shall, at first hand, be safe for the recovery team)
- Fast (the recovery time can be limited due to broken payload, bad weather, darkness, snow, trees, water, cold temperature etc.)
- Simple (it is therefore important that the instructions are easy to understand and execute)

3.5.5 Flight Report Documentation

EuroLaunch requires a post-flight report document for inclusion in the Flight Report that must be produced following each launch. The experimenters shall submit only one to two pages regarding performance of their experiment during the flight and preliminary results when possible. This must be submitted two weeks after the launch campaign (each experiment team is expected to present a preliminary performance overview whilst at the campaign following the launch).

4 REXUS SYSTEM

4.1 REXUS Vehicle

The typical REXUS vehicle is a single-stage rocket, consisting of an Improved Orion motor and the payload. This rocket vehicle provides approximately two minutes of weightless conditions. The specific apogee and duration of weightless conditions depends on the payload mass which can be up to ~120 kg, including the service and recovery systems.

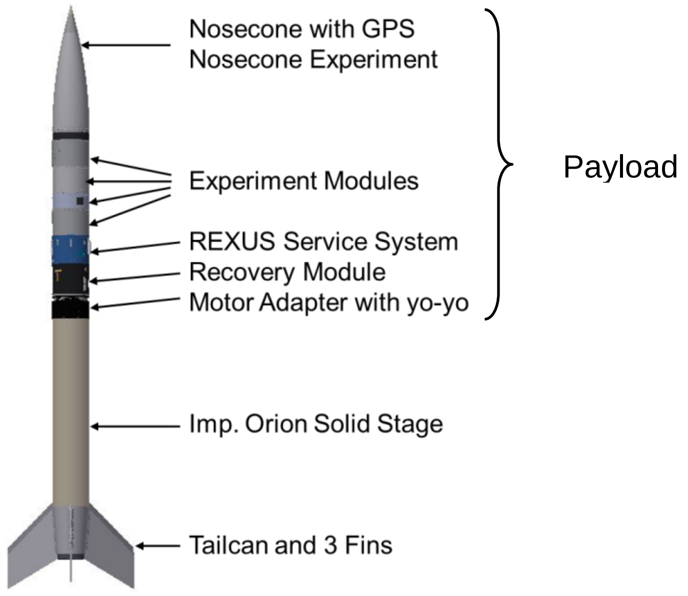

Figure 4-1: REXUS Standard Configuration

A typical configuration is shown in Figure 4-1. Each configuration is adapted to optimise vehicle and experiment characteristics.

4.1.1 Service Module

The objectives of the Service Module are to establish the communication between the ground and the experiments and to control and monitor the experiments. Furthermore, the Service Module monitors the ambient conditions, the flight parameters (acceleration, angular rates) and the housekeeping data. It also delivers power to the experiments.

The Service Module consists of two sections. The first one contains the electronic part of the Service Module (E-Box), while the other contains devices such as RF-parts, GPS, sensors and batteries. These are mounted on the bulkhead of this module.

The Service Module has four main electrical interface types to following systems:

- To the EGSE via umbilical
- To the experiments and recovery module
- To the ignition unit, separation unit and yo-yo system
- To the experiment pyrotechnics

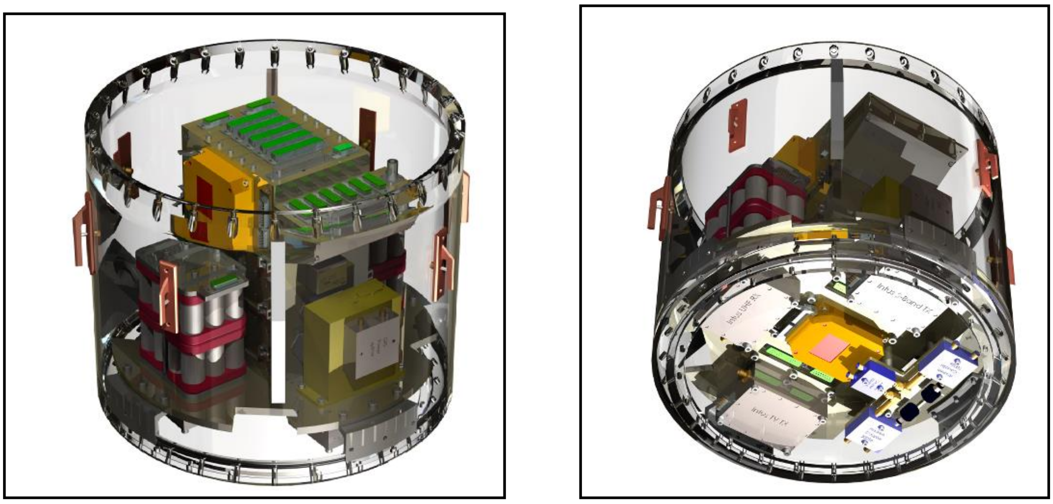

Figure 4-2: REXUS Service Module (RXSM)

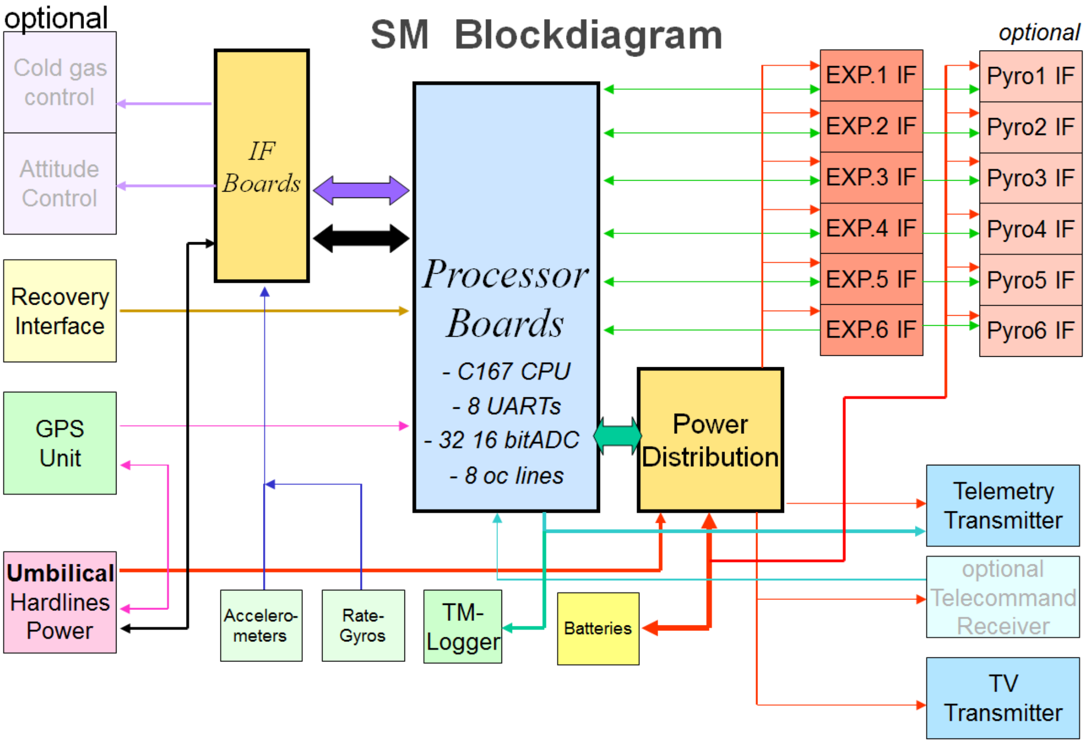

Figure 4-3: REXUS E-Box Block Diagram

The vehicle is equipped with a GPS receiver from which the service module is able to receive time and position information during flight. The GPS position is transmitted via the telemetry stream. Among other things, the GPS position is used by the recovery team for quick and easy location of the payload. The payload is normally brought back to Esrange within a few hours of launch.

4.1.2 Telecommand

A telecommand is a command sent to control a remote experiment. It could be used for systems that need a remote control of measurements.

There are two different scenarios of using a telecommand:

- On ground: It always exists for all experiments via hard line. Since the hard line is disconnected at lift-off, command via hard line is not available during flight.
- During experiment phase: In exceptional cases, it is possible to use telecommand via HF communication. For a request of telecommand, please contact your ZARM/DLR or SSC/ESA supervisor as well as describe your requirement as input to the Flight Requirements Plan (FRP) in chapter 6 of your SED.

No special telecommand design requirements are necessary. But your system has to distinguish between rocket on launch pad and rocket during flight phase. (See also chapter 7.5 and 7.7.3)

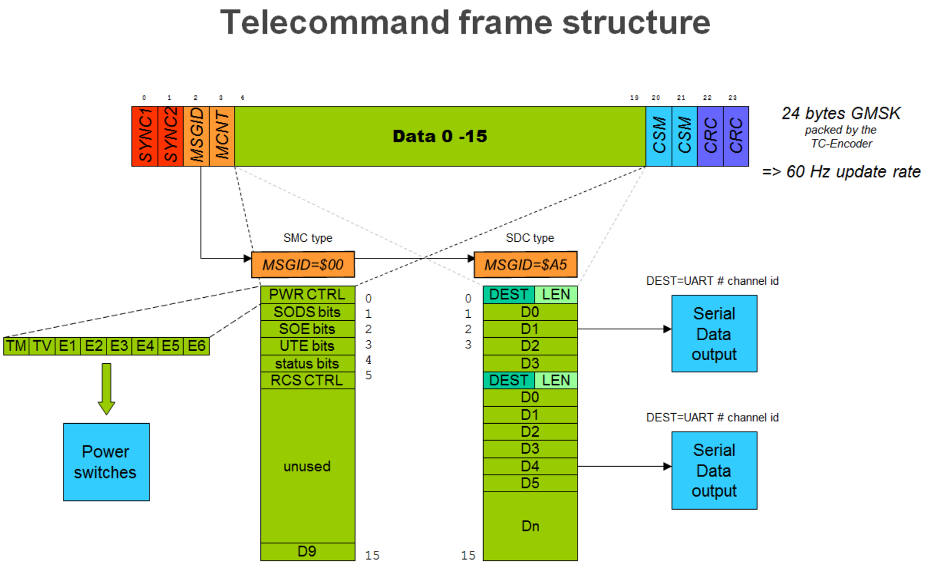

Figure 4-4 REXUS Telecommand Data Structure

4.1.3 TV Channel

Two analogue TV channels are available for simultaneous video transmissions.

The TV signal should be a standard PAL (B/G) with 1 Vss at 75 Ohm. A BNC connector should be used for signal transmission to the Service Module. It is possible to switch between one and another experiment during the flight. You have to request the TV channel in chapter 6 in your SED. For further information, see chapter 7.9.

4.1.4 Recovery Module

For the safe retrieval of the experiments, a recovery system is integrated at the aft end of the payload. It consists of a two-stage parachute system with a first stage drogue parachute for initial stabilization and a second stage main parachute for main deceleration. The drogue parachute has a circular ribbon canopy with a reference drag area of 3.9 m^2 whereas the main parachute has a cross-shaped canopy and a reference drag area of 71.7 m^2.

Figure 4-6: Drogue Parachute

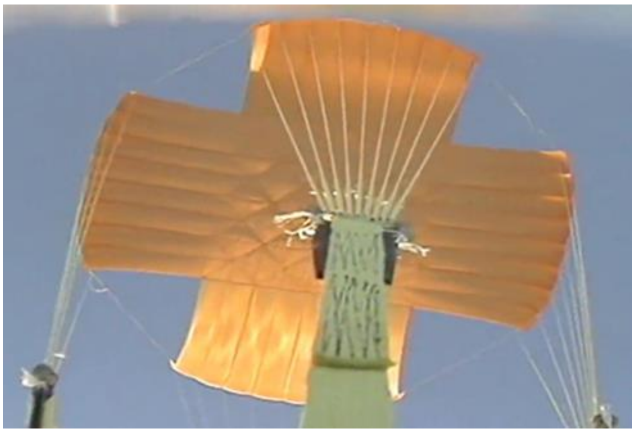

Figure 4-5: Main Parachute

During the payload descent, the parachute system is activated by barometric pressure switches at an altitude of 15.000 ft (4572 m) and decelerates the payload to comfortable landing velocities below 10 m/s. Nominal activation velocities range between 80-100 m/s. The parachute system is designed for payload masses up to 200 kg and activation velocities up to 150 m/s. At re-entry, the parachute system is protected by a heat shield which is mounted to the back side of the recovery module. As the back end of the recovery module represents the separation plane for motor and payload separation, the heat shield is subjected to high thermal loads during re-entry and is therefore silicone-coated.

Figure 4-7: Main Parachute and Payload Recovery after Touchdown

At parachute sequence activation, the heat shield is ejected by two pyrotechnically driven heat shield cannons. The heat shield lid is connected to the drogue parachute which is pulled out of the packing back during ejection. The drogue parachute is deployed in a reefed state for the first 5 seconds, the complete stand time for the drogue parachute phase is 25 seconds until steady state descent conditions are reached. The drogue parachute release harness is then cut by a pyrotechnically driven guillotine and the main parachute is pulled-out of the packing by the separating drogue parachute. The main parachute is reefed for the first 5 seconds after deployment as well, to decrease the loads on the parachute system caused by the deceleration shocks of the payload.

The recovery module has different mechanical interfaces on each side. On the forward side, it is connected to the Service Module via a RADAX joint; on the aft end, it features a manacle interface to enable payload separation from the rocket motor. The manacle flange is replaceable.

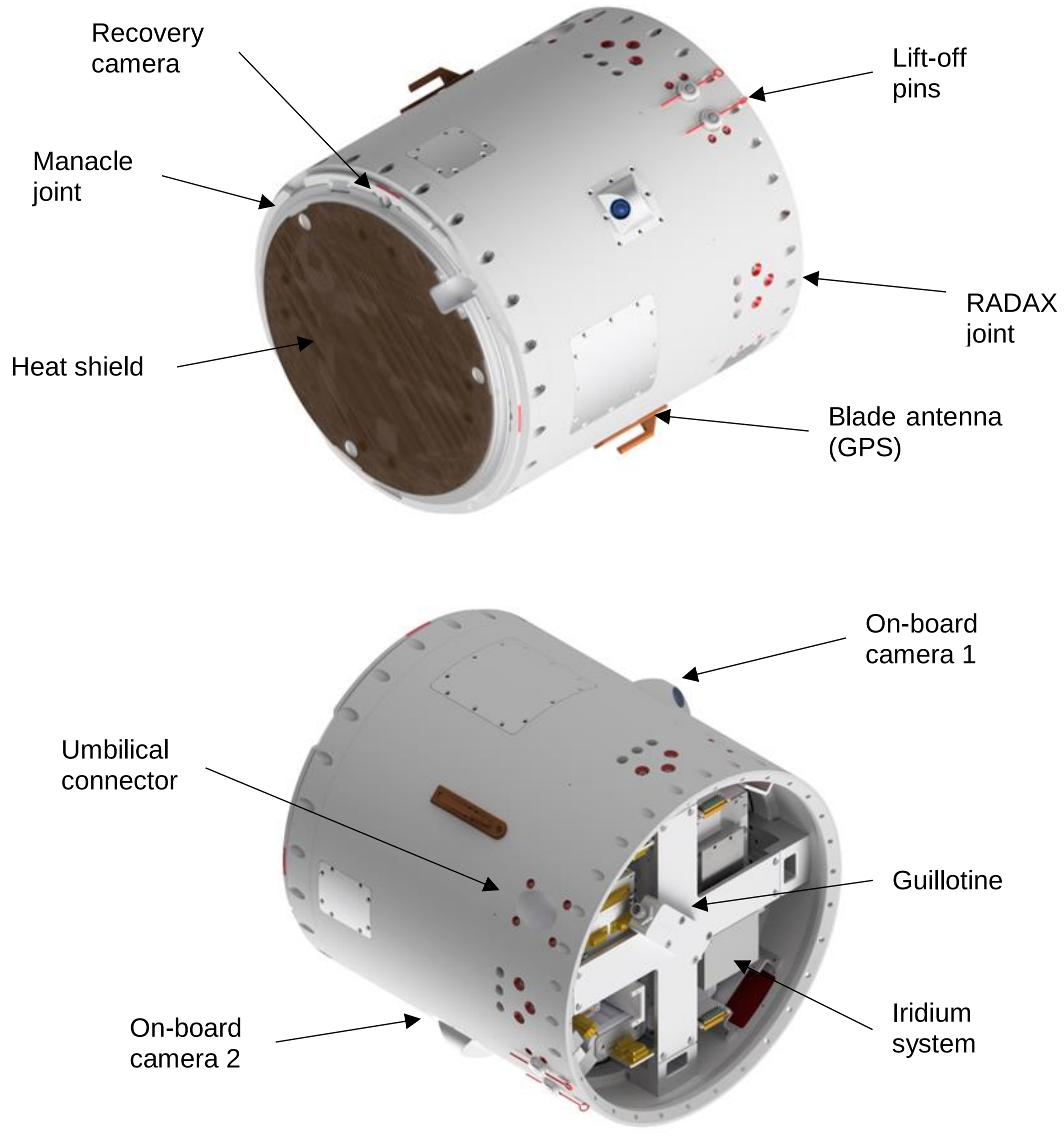

Figure 4-8: Recovery Module

Besides the parachute system, the Recovery Module contains various electrical components such as an autonomous ignition unit, video cameras, battery packs and an Iridium-based GPS tracking system. The ignition unit controls safety critical in-flight pyrotechnical events such as nosecone separation, motor separation, yoyo de-spin, heat shield activation and main parachute release. The integrated ignition unit timer is activated by two redundant lift-off pins which are connected with the launch rail via steel cables and are pulled at lift-off. In addition to the lift-off pins, further safety features are incorporated that avoid unintended activation of pyrotechnics. The safety chain consists of a pair of SAFE and ARM connectors that short-circuit or connect the ignition unit firing lines, a 5.000 ft (1524 m) barometric pressure switch and a “recovery enable” timer event, programmed into the ignition unit that finally arms the pyrotechnic outputs.

Three video cameras are integrated into the system; one of them is placed in the manacle flange and records the payload separation and parachute sequence and the other two are mounted in opposite direction to the outer surface of the module, to observe the payload and motor during the flight. The Iridium tracking system is described in a separate chapter.

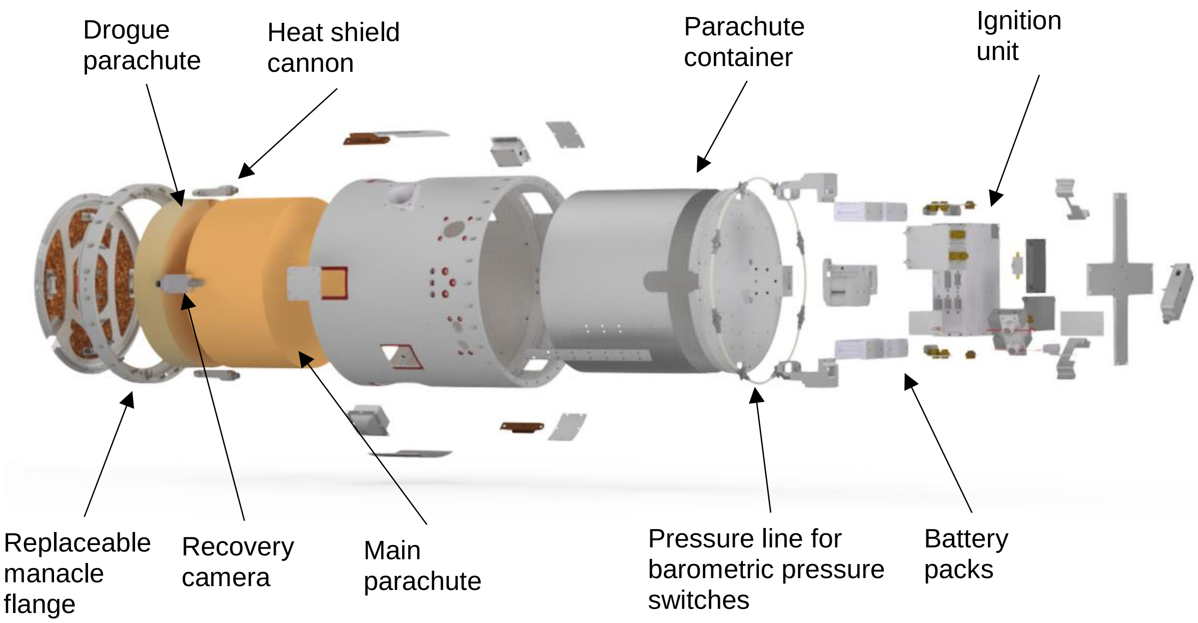

Figure 4-9: Exploded-view Drawing of the Recovery System

The electrical interfaces of the Recovery Module are an umbilical connection for the ignition unit to the EGSE, pyrotechnic lines for nosecone separation, motor separation and yo-yo despin, a serial interface to the Service Module for data transmission and a video interface for the transmission of the cameras’ TV signals.

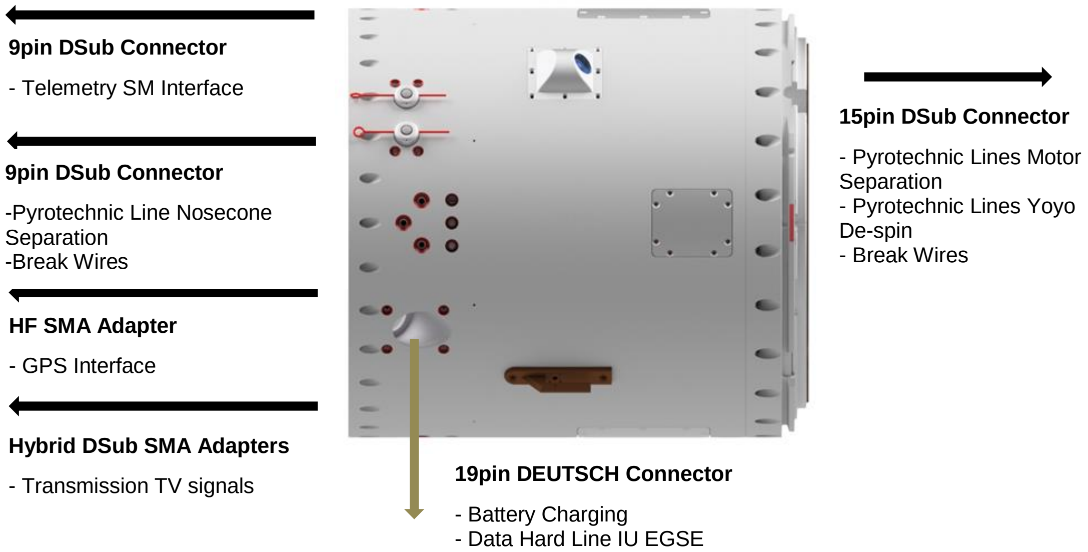

Figure 4-10: Electrical Interfaces Recovery Module

4.1.5 Rate Control

A de-spin system (the Yo-Yo) can be used to reduce the spin after the launch phase. If the experiments require a de-spin of the vehicle, the system will be implemented. Then, the vehicle will be de-spun from a maximum spin rate of 4 Hz to a maximum residual spin rate of 0.08 Hz (30°/s) in a clockwise direction when viewed from the rear.

4.1.6 Motor

The REXUS vehicle is a one-stage rocket, consisting of an Improved Orion motor and the payload. The Improved Orion is a single stage vehicle based on a demilitarized MIM-23 HAWK surface to air military surplus motor. In its simplest configuration, the 14'' diameter rocket motor is fitted with three fins to sufficiently stabilize a payload of the same diameter. The motor and Tailcan section has a mass of 420 kg and measures 2.8 m in length. A three fin Boat Tailcan and retractable launch lugs warrant minimum loss of performance due to drag. Fin incidence is used to impart a final spin rate of up to 4 Hz in the interest of flight path accuracy.

Figure 4-11: Improved Orion launch

4.2 Body Frame Coordinate System

For REXUS, the Body Frame Coordinate System (BF) is used for the orientation of rocket components and experiments. The following figure shows the standardised (LN9300) coordinate system of REXUS [15][16]. Its accurate application is strictly required for the correct application and interpretation of related mathematic relations and phenomena! Drawings of components and experiments should respect this axis definition. Accelerations are measured with the accelerometers referring to this coordinate system. The longitudinal axis is the roll-axis x_{BF}, which along with the pitch-axis y_{BF} and the yaw-axis z_{BF} build a right-hand system.

Angular velocities about the axes are given as right handed positive, i.e. the angular velocity ω_{roll}, commonly called roll-rate, is counted positive if it follows the usual right-hand rule (thumb along the roll axis). The same definition holds for the other axes as well. A REXUS rocket during the ascent spins with a positive roll rate (see Figure 4-13). The origin of the system is located at the interface between the motor adapter and the payload on the longitudinal axis of the REXUS vehicle.

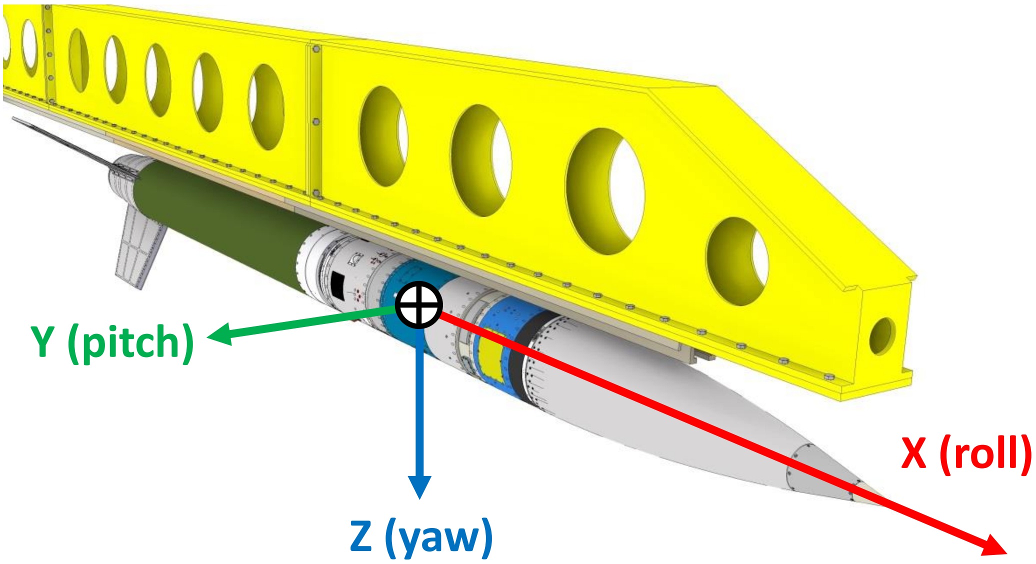

Figure 4-12: Definition of the REXUS BF-System

Figure 4-13 shows the top view on the rocket vehicle with the definition of the payload (PL) body frame coordinate system. The MRL Launcher rail is at PL position 0°.

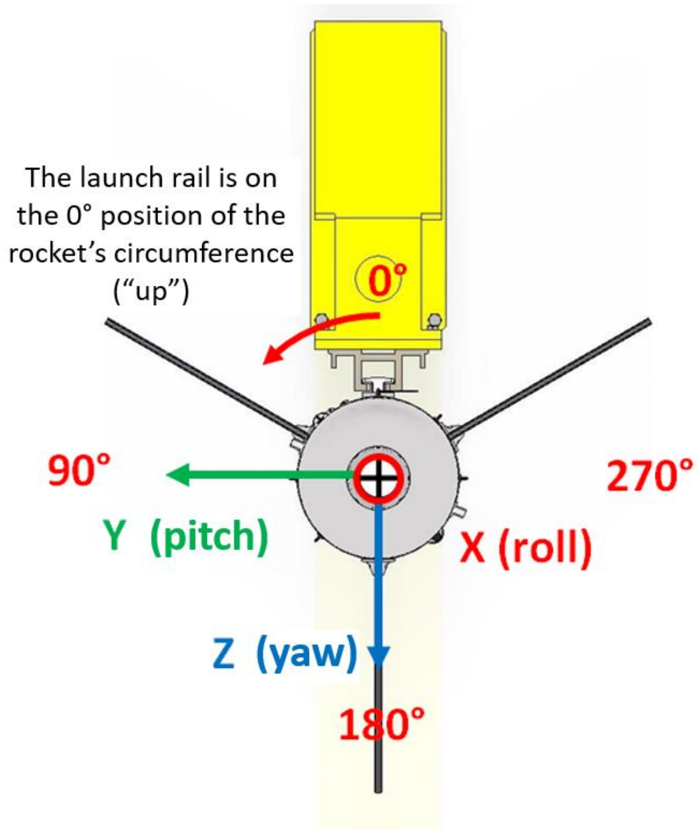

Figure 4-13: REXUS PL Coordinate System (positive x-Axis is in flight direction)

4.3 Performance and Flight Sequence

In the following, the trajectory properties and flight events of typical REXUS flights are described.

4.3.1 Nominal trajectory

The nominal REXUS flight trajectory is dependent on payload mass and configuration as well as latest motor data. Please read the pre-flight version of the Flight Requirement Plan for valid flight events and nominal trajectory data.

The motor offers a 26 s duration burn time structured in a high thrust boost phase with typical maximum accelerations in excess of 20 g and a subsequent low thrust sustainer phase. The motor performance is shown in Figure 4-14.

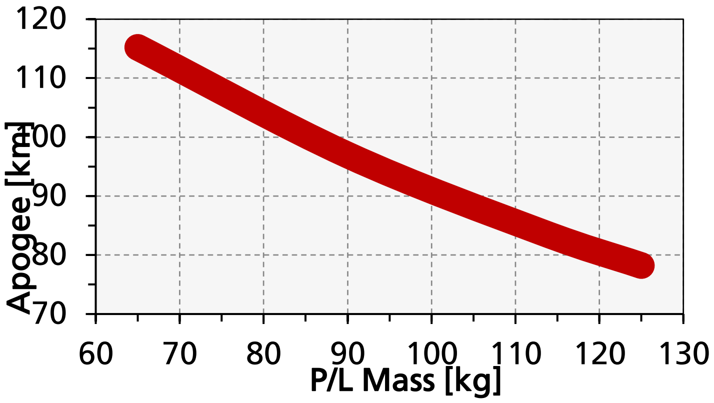

Figure 4-14: Improved Orion Performance (based on 3-Fin 14" payload configuration and 85° launch elevation). "P/L Mass" refers to all mass ahead of the motor forward flange.

The following table gives an overview of the flight events during the REXUS-10 mission. It is typical of any REXUS mission, with minor adaptions.

EVENT	Time (s)	Altitude (km)	Range (km)
Lift-off	0.00	0.332	0.00
Burn-Out	26.00	20.38	2.83
Nose Cone Ejection	61.00	52.73	8.89
Possible Yo-Yo Release	65.00	55.68	9.58
Motor Separation	66.00	56.39	9.76
Apogee	140.00	82.45	22.42
Parachute Opening	~380	4.60	~40
Payload Impact	~800	0.6	42.77

Table 4-1: REXUS-10 Approximate Flight Events

4.3.2 Graphs of typical trajectory

Graphs based on GPS data for the flight of REXUS-10 are shown in Figure 4-15 - Figure 4-25. Graphs of the trajectory prediction of every mission are included in the Flight Requirement Plan.

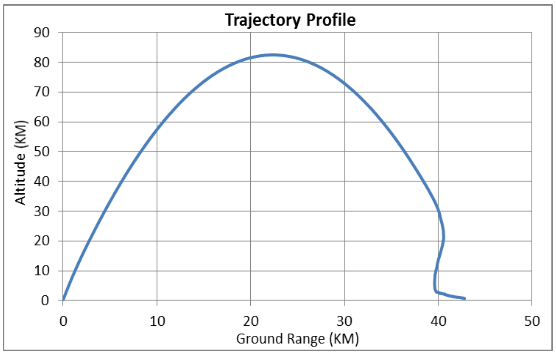

Figure 4-15: RX 10 Trajectory profile

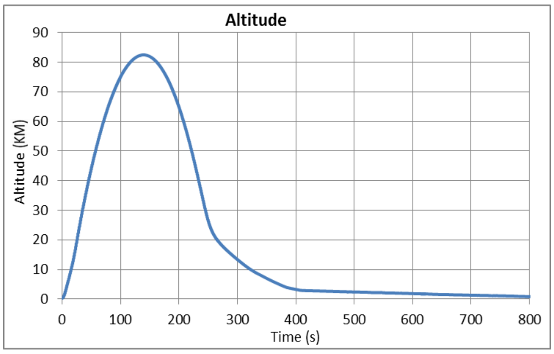

Figure 4-16: Altitude of RX 10

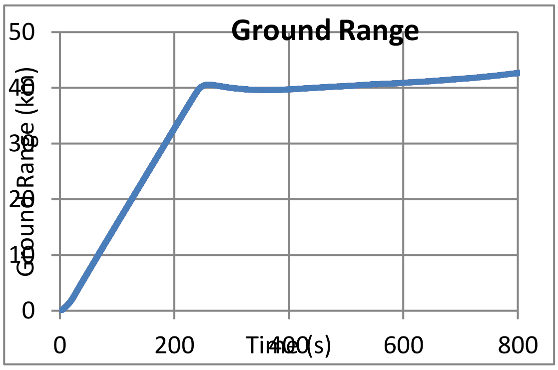

Figure 4-17: Ground Range of RX 10

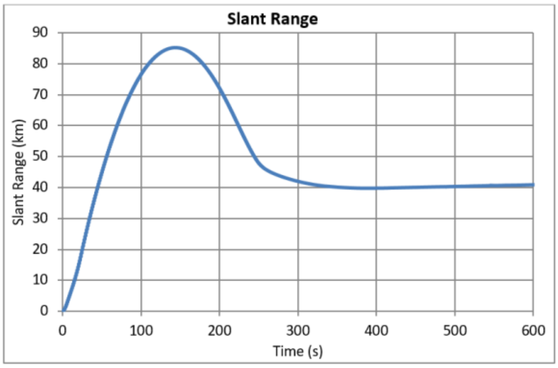

Figure 4-18: Slant Range of RX 10

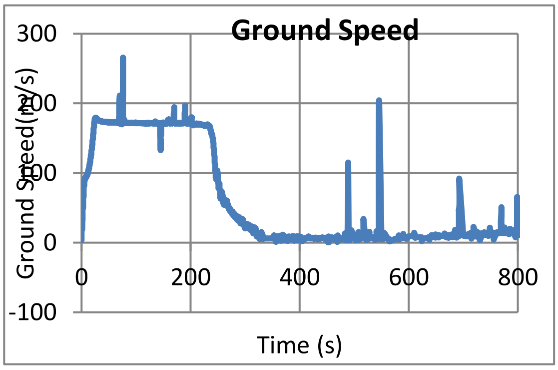

Figure 4-19: Ground Speed of RX 10

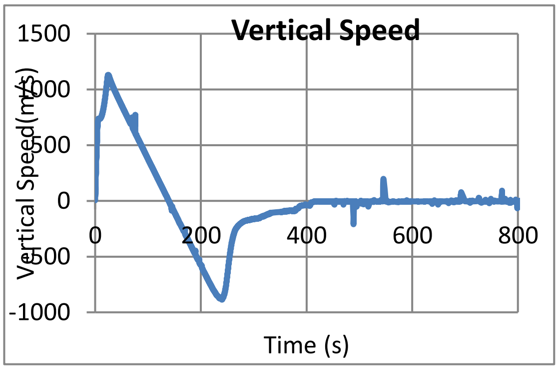

Figure 4-20: Vertical Speed of RX 10

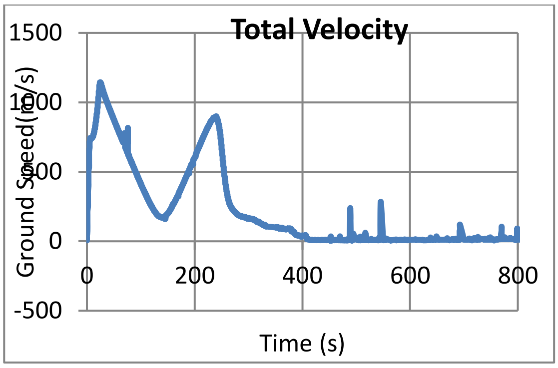

Figure 4-21: Total Velocity of RX 10

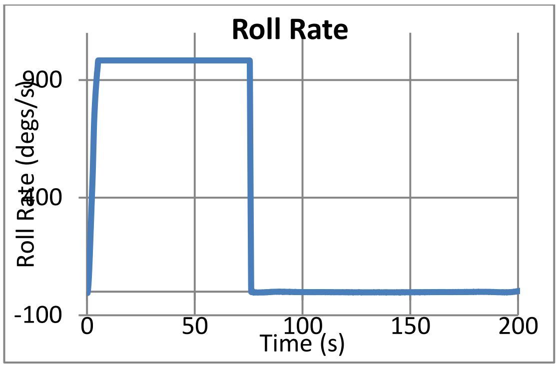

Figure 4-22: Roll Rate of RX 10. The Roll Rate gyro goes into saturation at a rate of 983 deg/s.

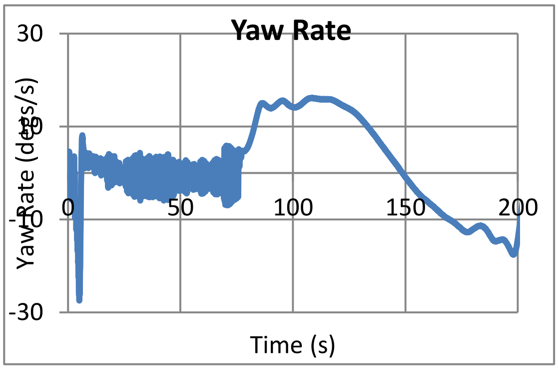

Figure 4-23: Yaw Rate of RX 10

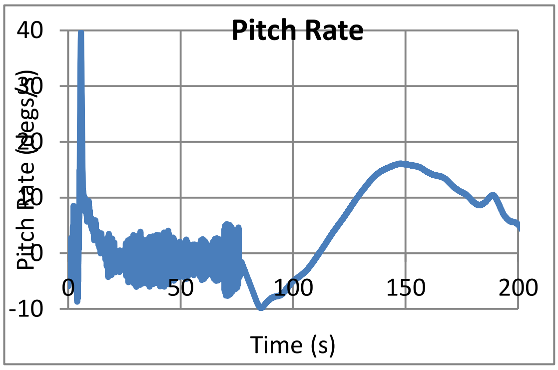

Figure 4-24: Pitch Rate of RX 10

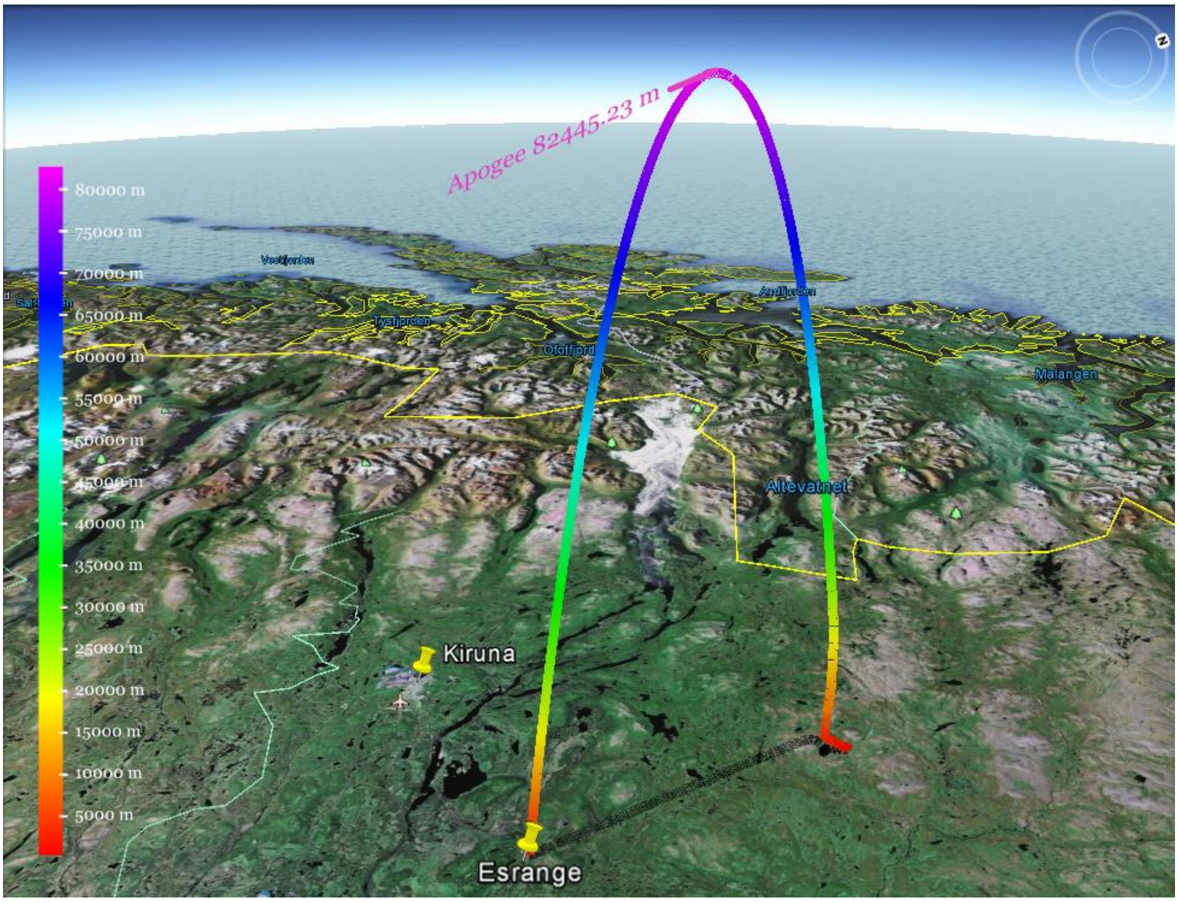

Figure 4-25: nominal REXUS trajectory [11]

Figure 4-26 shows the altitudes vs. flight time of previous REXUS missions. The apogee is strongly dependant on the payload mass as can be seen from the altitude curves of the two missions with lowest (95.1 kg) and highest (120.5 kg) payload mass. The red curve refers to REXUS 22 which reached an apogee of 84348 m at t = 140 s. The payload mass of REXUS 22 was 114 kg.

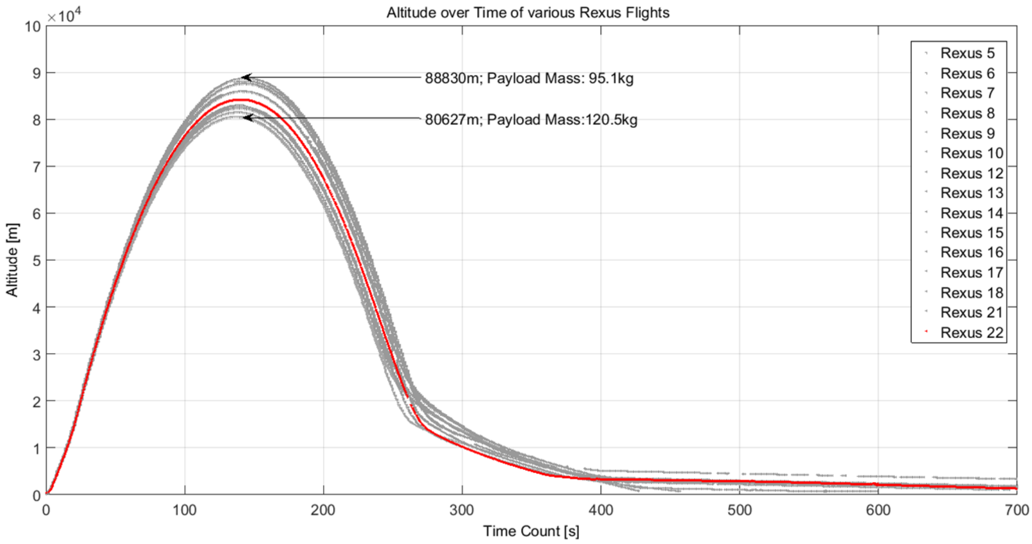

Figure 4-26: Altitude vs. Flight Time for previous REXUS Missions. Note: dashed lines refer to predicted rather than recorded data, where data is missing or corrupt.

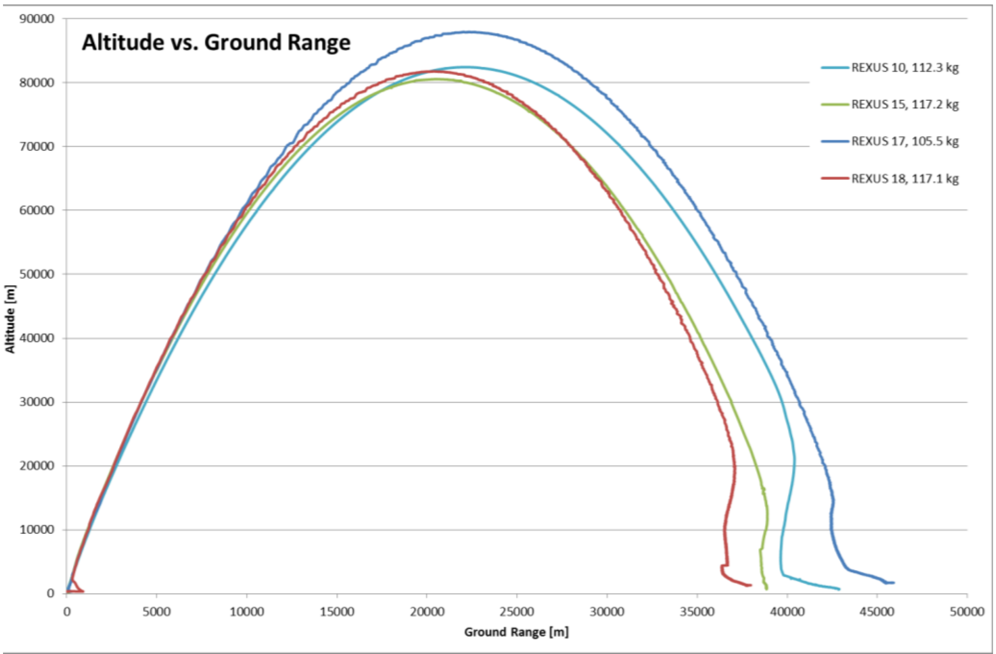

Figure 4-27: Altitude vs. ground range

5 MECHANICAL DESIGN OF EXPERIMENTS

A typical configuration of an experiment module is shown in Figure 5-1 and Figure 5-2. Different types of mechanical interfaces between the experiment deck and the outer structure are possible. EuroLaunch will assist teams to define suitable mounting positions, joints and screws.

It is a requirement that the experiment modules are either made gas tight or equipped with venting holes.

Hatches are used for experiments which require late access. Late access integration has to be finished prior to vehicle arming, which starts at T-40 minutes.

External cooling liquid/gas may be supplied by an umbilical up until launch.

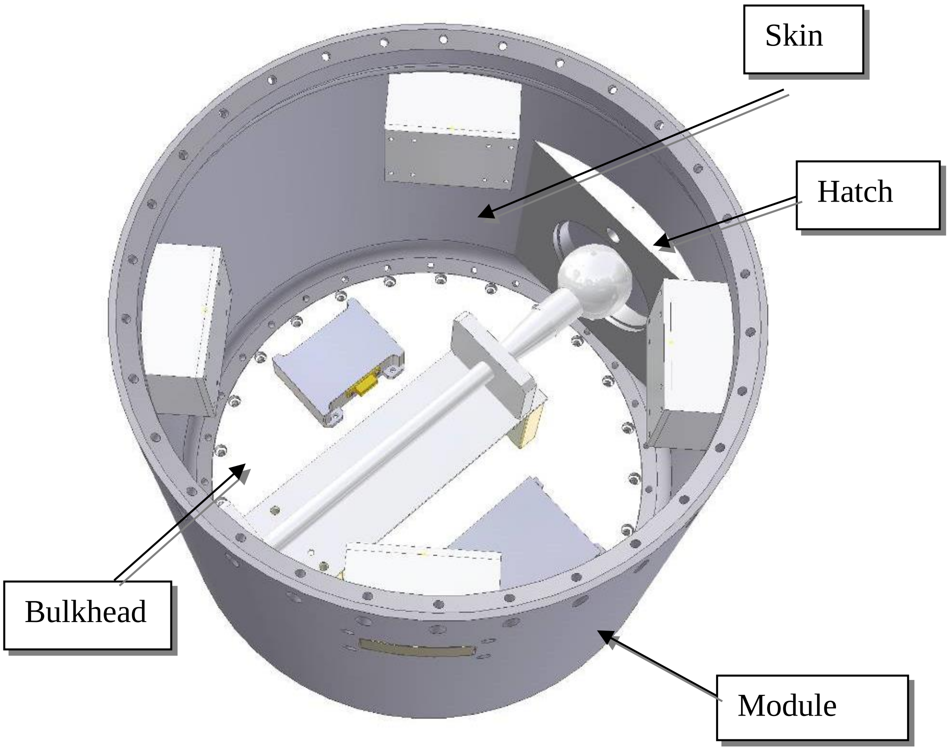

Figure 5-1: Experiment Module

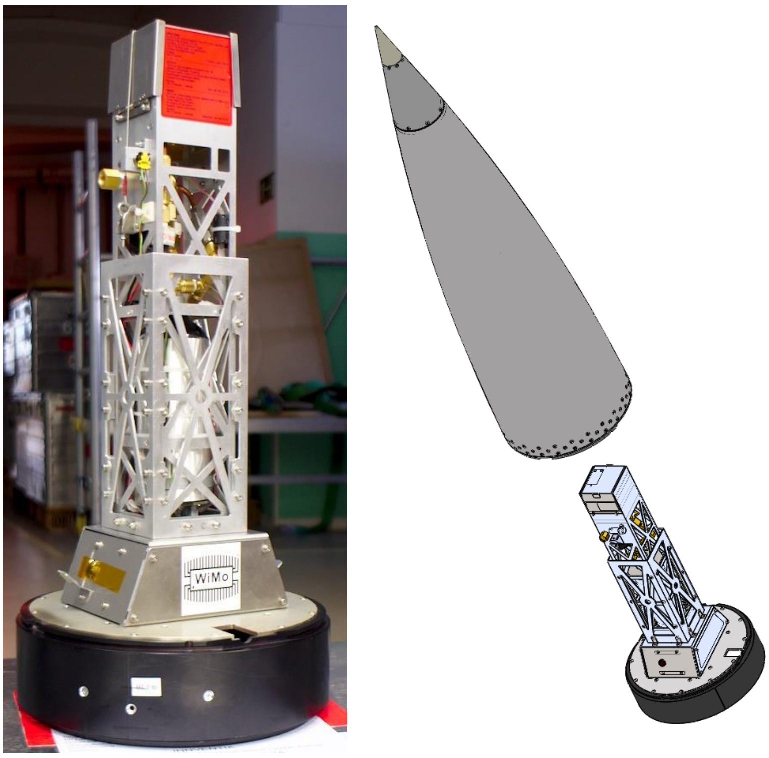

Figure 5-2: REXUS Nosecone Experiment (RX 21 DIANE)

5.1 Outer Structure

The baseline for the mechanical design is that the outer structure is made of 14” diameter (355.6 mm), 4 mm thick, 120, 220 or 300 mm long aluminium cylinder modules (EN AW 7020-T6, blue anodisation). The mass of the modules varies depending on the exact configuration required. These modules are normally supplied by ZARM and SSC. The nosecone features a 4:1 Ogive. Some of its interior space is taken by the nosecone separation system. Any deviations from the baseline must be approved by EuroLaunch.

Note that due to the flange interface, it is generally not possible to use the full length of the module for the experiment. The experiment volume allowance begins 20 mm below the top of the module and ends 10 mm below the bottom surface. This ensures that there is no mechanical interference between experiments. When designing experiments, take care that no connectors protrude into this space, so that assembly can be performed without any problems. For a definition of the PL coordinate system, see section 4.2.

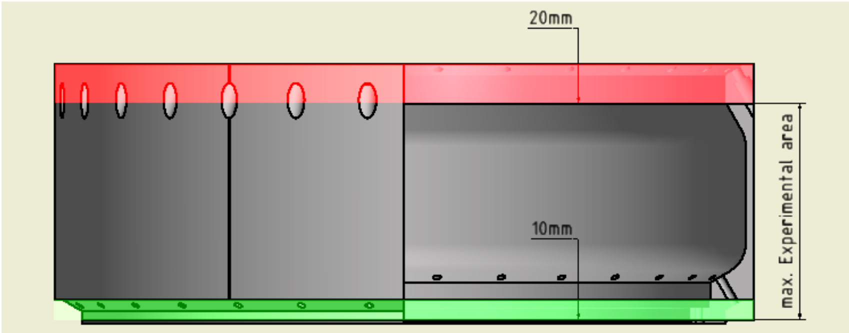

Figure 5-3: Experiment Module

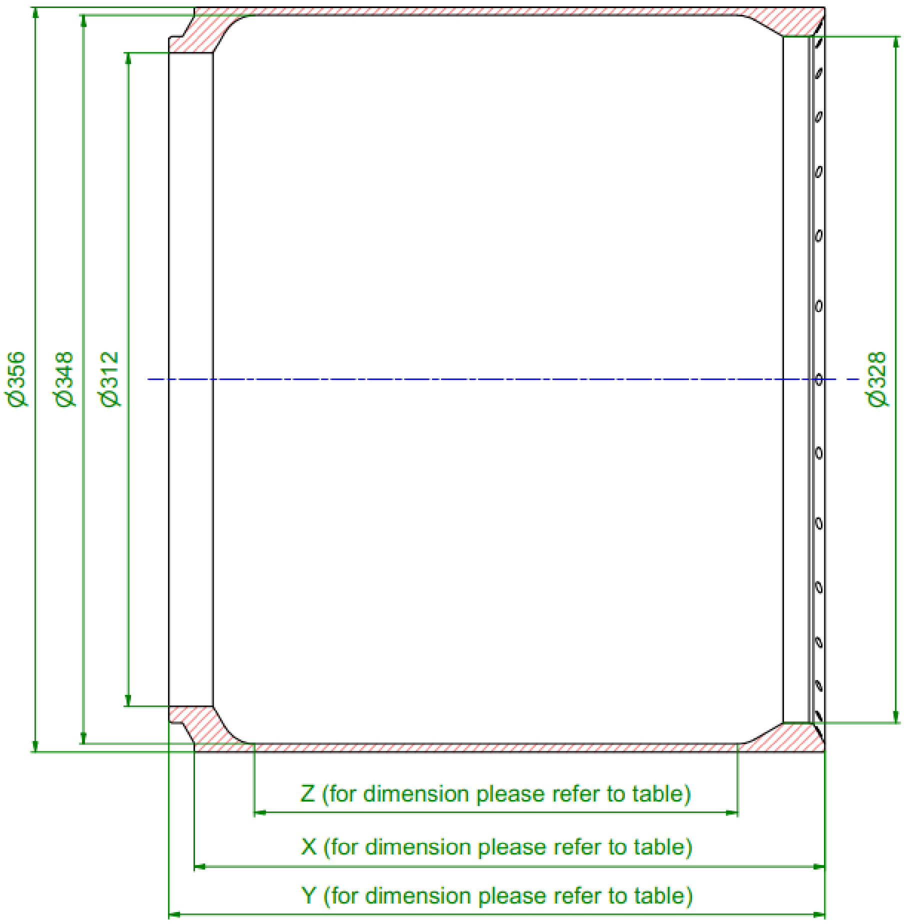

table				
		X	Y	Z
Module length 120 mm		120 mm	132 mm	63,287 mm
Module length 170 mm		170 mm	182 mm	113,287 mm
Module length 220 mm		220 mm	232 mm	163,287 mm
Module length 300 mm		300 mm	312 mm	243,287 mm
Module length 400 mm		400 mm	412 mm	343,287 mm

Figure 5-4: 14” Module geometry (contact DLR MORABA for details)

Figure 5-4 shows the standard layout for a 14” module. Two modules are connected by the so called RADAX joint. RADAX is an abbreviation for Radial-Axial, meaning that the mating surfaces are two – one radial and one axial. The conical surface is NOT the mating surface. There must be a gap between the two conical surfaces when assembled. Helicoil thread inserts are used in the aluminium modules. The following screws are used:

- Hexagon socket head cap screw (ISO 4762, DIN 912), M5 x 16 mm, Material: Steel 8.8 galvanized
- The tightening torque for the M5 screws is 7 Nm.

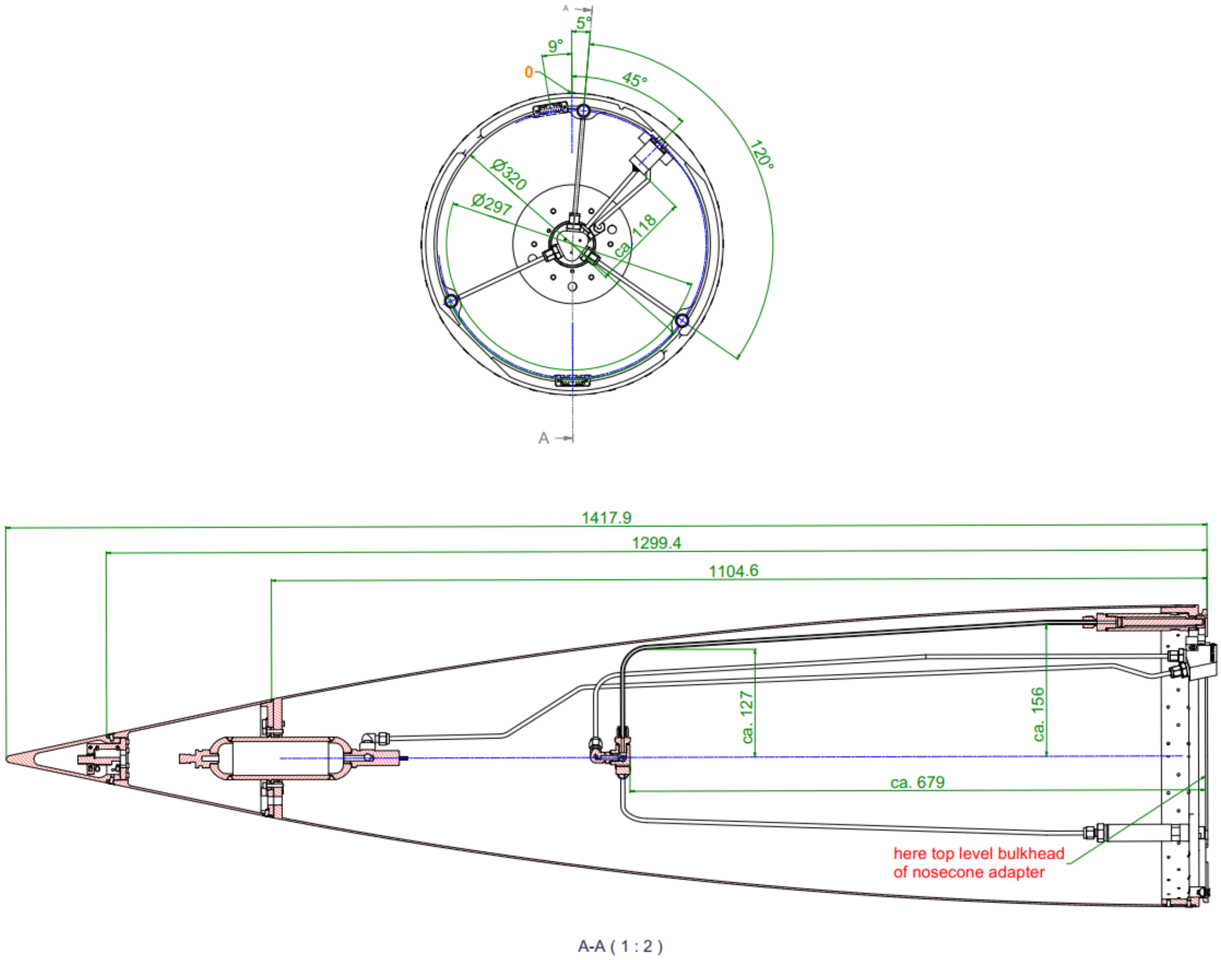

Figure 5-5: REXUS Nosecone geometry

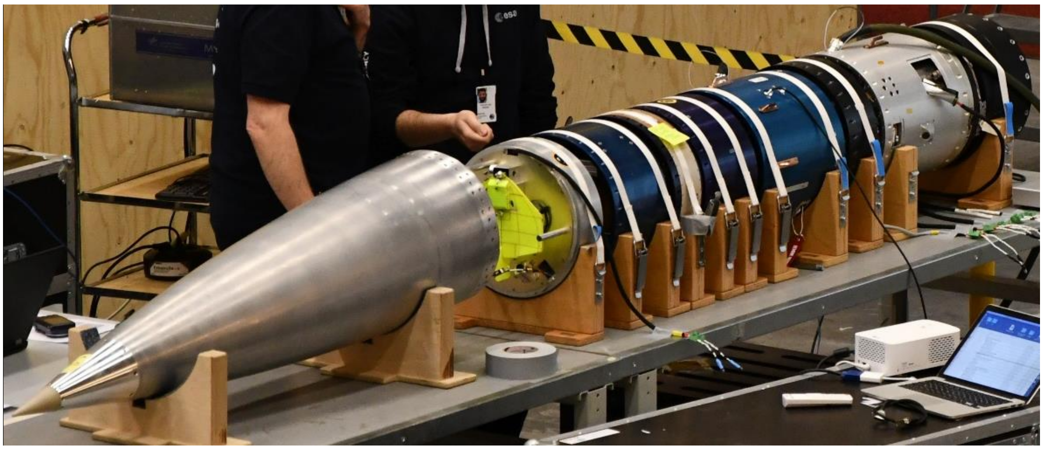

Figure 5-6: Experiment Modules (RX25)

5.2 D-SUB Brackets

For the assembly of scientific payloads, a standard EuroLaunch D-SUB Bracket should be mounted in each experiment. (see also Figure 5-7)

It is to be located at 180 degrees in the module (this is opposite the groove cut in the module for the zero degree line which is represented in the CAD files found on the teamsite). It should sit 20 mm below the bottom of the RADAX flange at the top of the module. Above and below, the space should be left clear so that cables can be easily passed through and mounted to the walls.

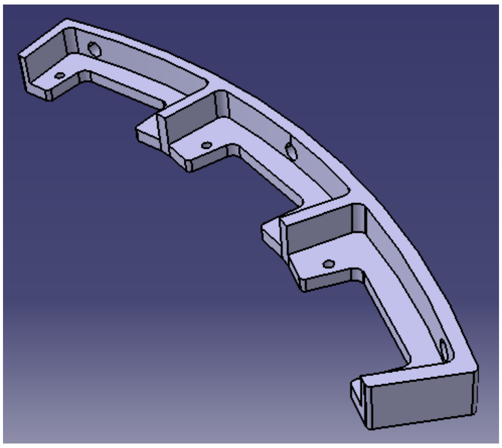

Figure 5-7: Standard EuroLaunch REXUS D-SUB Bracket

In addition, a section of the bulkhead should be left open to accommodate the feed through of up to 4 D-SUB 15 connectors. An example is shown in Figure 5-8.

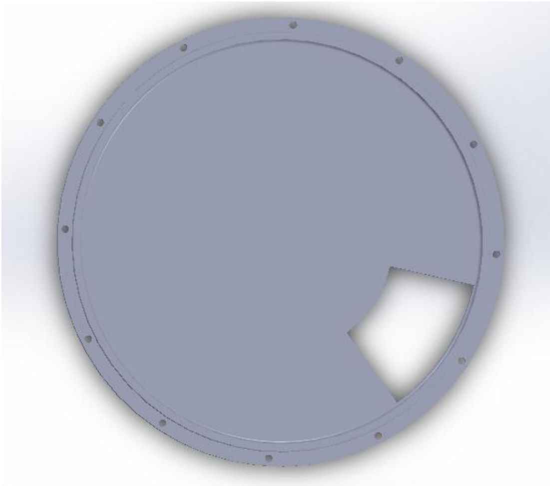

Figure 5-8: REXUS Bulkhead

5.3 Hatches

5.3.1 Late Access Hatches

Hatches for late access shall be oriented so that they are accessible when the payload is on the launcher (i.e. well away from the zero-degree line). Hatches must be mounted before launch. Figure 5-9 shows the recommended hatch/frame design. All late access hatches shall follow the same design rule as inflight actuated hatches.

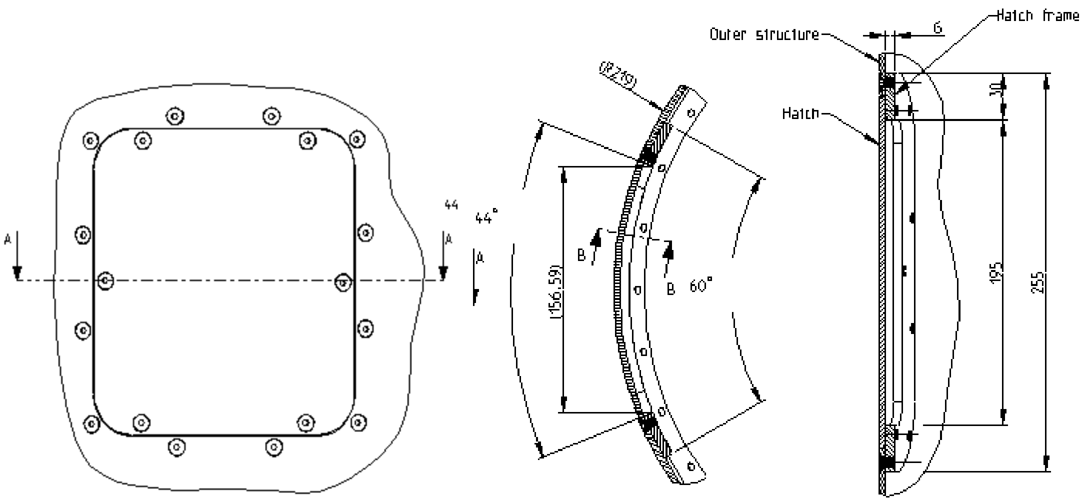

Figure 5-9: Hatch Example

5.3.2 Inflight Actuated Hatches

Inflight actuated hatches are beyond the standard scope of REXUS. Therefore, special design rules are applied here. Any deviation from these rules has to be handled by a

Request for Waiver (RFW) and has to be approved by DLR, ZARM and SSC. Contact your ZARM/DLR or SSC/ESA supervisor for this document.

Generally: The following design requirements are based on the thickness of the wall of a REXUS standard module, which is 4 mm. Furthermore, they are based on the properties of the raw material, used for manufacturing of a REXUS module, which is seamless hot rolled Aluminium artificially aged to the T6 condition: EN-AW 7020 –T6.

Hatch and frame rules:

- The hatch shall be flush with the module skin, follow the shape of the module and shall not protrude outside of the module into the air flow. The hatch may be offset by a maximum of 0.5 mm inwards only.
- The maximum hatch cut-out shall be 156 mm (horizontal) x 156 mm (vertical). **Larger cut-outs require a waiver and always require more than one retention cable and appropriate fixation points on the hatch.**
- The hatch shall have the same thickness as the module wall minus the tolerance to make it flush (standard 4 mm)
- The hatch shall have a surrounding supporting frame to provide sufficient area of contact, to prevent gaps and for centering the hatch. The frame shall be at least of the same thickness as the module (standard 4 mm). The gap between the module’s cut-out and the hatch should be 0.1 to max. 0.5 mm.
- For frame attachment, rivets shall be used (recommended distance 4 times the diameter). The rivets used for frame attachment shall be a pop rivet with a diameter of 4 mm or 5 mm. **A Frame fixation with screws requires a waiver.**
- The overlap frame to module shall be 2.5 times the thickness of the frame. The overlap between hatch and frame shall be:
  - For *Inflight actuated hatches*: 1.25 times the thickness of the frame (as shown in Figure 5-10)
  - For *late access hatches*: 2.5 times the thickness of the frame (as shown in Figure 5-11)
- Module and frame shall be made out of aluminium with similar material properties regarding stiffness.
- Upper and lower RADAX joint designs are not allowed to be changed (untouchable).

Hatch retention systems rules:

- If the Free Falling Unit (FFU) mass exceeds 300 g: The hatch retention/ejection systems shall be decoupled from the retention/ejection systems of the FFU
- The retention systems shall be fully inside the experiment module.
- The retention systems shall be verifiable for correct retention before payload assembly (i.e. verifying tension force of retention cables) which means the tension force of retention cables must be measured during hatch assembly. The attachment points of the steel cable must be designed with a safety margin of 3 when compared to the expected loads.

- Except for steel cable movement, no further movement of parts and components are allowed (no loose hooks etc.).
- Hatch assembly systems with a hatch size over 156 mm x 156 mm shall have two retention mechanisms.

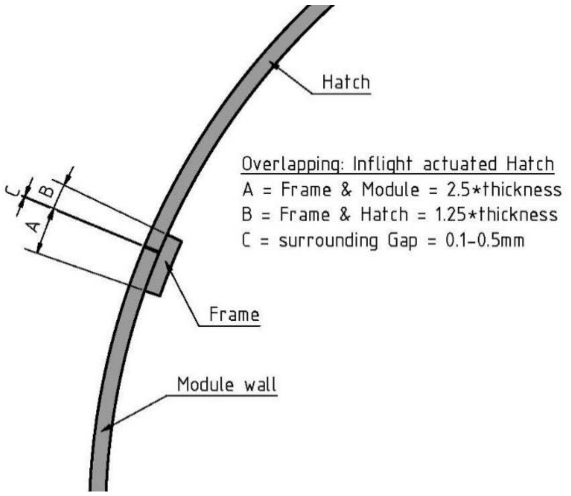

Figure 5-10: Overlapping inflight actuated (ejected) hatch

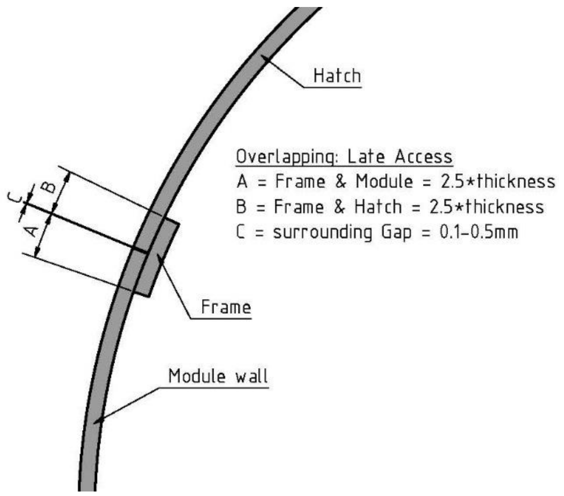

Figure 5-11: Overlapping late access hatch

Steel cable rules:

- In case of cable ends, either eyelets, thread terminals or professional rope locks shall be used. Bicycle brake bowden cables may also be used. A data sheet including material properties is required. The standard MORABA solution is recommended. Contact DLR for more information. (See also chapter 8.8).
- If cables are to be routed around corners, then these corners must be rounded off and shall be made of aluminium or steel. Minimum bending radii of cables are not allowed to be undercut.
- The crimping of the cable shall be carried out by a professional company.

Verification process rules:

- A sine and random vibration test to qualification levels of the hatch flight configuration is required for new builds. For flight-proven system, it has to be discussed which of the vibration tests is required. The accelerometer must be mounted on the hatch. No sensor overloading is allowed. No significant (e.g. associated with rattling of overly compliant mechanism) movement of the hatch is allowed during the vibration test. For more information about required test levels, see section 10.3.2.
- A long duration pretention test (minimum 24 hours) is required to show that there is no significant (max. 10%) reduction of cable pretension forces.
- A strength/stiffness/stability test of the complete retention/ejection system is required.

- From each batch, a minimum of three retention cables shall be tested until break and the breaking loads recorded.
- Provide at least one static load calculation (dead mass, centrifugal forces, acceleration, spring forces etc.) → The result shall be the corresponding static safety factor.
- Optionally, a modal analysis can be performed.

Actuation system preparation rules (see also chapter 8.8):

- No material may hang out from the module.
- No unconstrained debris or material inside the payload is allowed.

Operational rules:

- The team shall describe a procedure for inserting the FFU and hatch as well as the final tensioning of the cable. For CDR we will expect a rough outline and for IPR, we will expect a complete description. The team must provide a calculation of the cable forces and describe how these forces are to be generated and verified.
- Each setup will be reviewed and judged individually by MORABA, SSC and ZARM.

5.4 Gas Outlets

Reaction forces from gas outlets shall be minimised by using at least two openings located symmetrically on the module.

5.5 Venting Holes

To avoid pressure build-up within the payload and to avoid gas-flow between modules, it is sometimes necessary to have venting holes in experiment modules.

One hole of 10 mm in diameter is recommended for each 15 dm^3 of evacuated air volume. A small cap such as the one shown in Figure 5-12 shall cover the holes.

During re-entry, hot air might enter the module through the venting holes and it is recommended to protect heat sensitive equipment or avoid placing it near these holes.

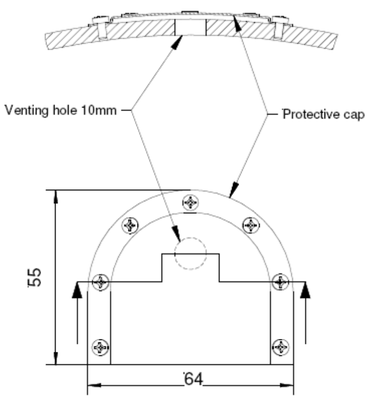

Figure 5-12: Venting Hole with Cap

5.6 Ejectables and Free Falling Units

It is possible to eject items from the modules but this requires an RFW as it is beyond the standard scope of REXUS. ***Contact your ZARM/DLR or SSC/ESA supervisor for this document.***

See also section 5.11.1 regarding ejectables / Free Falling Units and effects on flight dynamics.

The design of any hatch and release mechanism will be closely followed by EuroLaunch and ZARM (see also chapter 5.3 and 8.8).

5.7 External Skin Mounts

It is possible to mount items on the exterior of the modules but this requires an RFW as it is beyond the standard scope of REXUS. ***Contact your ZARM/DLR or SSC/ESA supervisor for this document.***

Great care must be taken with the design of externally mounted objects due to the possibility of influencing flight dynamics. The size should be kept to a minimum and it should be designed to have a very small aerodynamic effect on the payload. External skin mounts must also be designed to ensure that the parachute lines can't get entangled.

5.8 Use of Fluids within Modules

Use of fluids within REXUS modules is allowed but considerable care must be taken to ensure that the fluids stay within the module. All experiments with fluids (greater than 2 ml) in their module must use an absorbent material at the top and bottom of the module so that the possibility of fluid being transferred to other modules is eliminated. This material should have the capacity to absorb twenty times the quantity of the fluid used.

See section 5.11.1 regarding partially filled cavities and effects on flight dynamics.

5.9 Pressure Vessels

All ground support pressure systems must meet Swedish law and regulations (AFS 1999:6) and be approved by the Esrange Safety Board before use.

The pressure systems require a 2:1 safety factor for flight systems and approved procedures for controlled depressurization.

Any deviation from these requirements implies the request for a waiver from the experimenters.

5.10 Dimensioning Loads during Launch, Flight and Recovery

The experiments should be dimensioned to withstand the loads for the complete flight profile.

5.10.1 Acceleration

The typical longitudinal acceleration history (for an Improved Orion rocket motor) has a peak acceleration of 20 g.

Centrifugal forces will also act on the experiments, since the rocket spins at 3-4 Hz.

5.10.2 Re-Entry Loads

The typical deceleration during re-entry is 20 g and can occur in all axes.

5.10.3 Landing Velocity

The landing velocity is approximately 8 m/s. The shock at impact depends on the nature of the ground surface. Nominally, the landing is fairly gentle with no damage to the experiment modules.

5.11 Mechanical Retroaction Forces from Experiments on the Payload

An estimation or measurement of the induced acceleration or vibration levels of each experiment shall be presented to EuroLaunch at least four months before launch.

5.11.1 Vehicle Characteristics

Momentum wheels, cavities filled partially with liquids, ejectables / Free Falling Units, etc. will only be accepted after a successful analysis of the impact on the flight characteristics of the vehicle as well as on other experiments.

5.11.2 Movements

Any movements of components or samples in the module can disturb the payload conditions.

These disturbances shall be kept to a minimum, for instance through counteracting mechanical devices or symmetrical gas exhaust openings.

5.11.3 Vibrations

Vibrations induced by movement of components in the payload will also cause disturbances to the flight conditions.

The vibration levels generated in the module shall be kept as low as possible. As a rule of thumb, the module-produced vibration levels should be lower than $5x10^{-5}$ g_{rms} (0-25 Hz). This level changes from flight to flight and depends on the experiment modules’ sensitivity to vibrations.

5.12 Mass Balance and Mass Properties

The centre of gravity of each module shall be as close as possible to the longitudinal axis. It is not necessary to carry out mass balancing of each module, or to add ballast weights, since the total payload will be mass-balanced to reduce total ballast weight. This work is performed by EuroLaunch during the spin and balance.

The accuracy of the measurements should be as follows:

Total mass		± 0.5 kg
Moment of inertia	I_x	± 0.1 kg·m^2
	I_y	± 0.1 kg·m^2
	I_z	± 0.1 kg·m^2
Centre of gravity	X	± 20 mm
	Y	± 20 mm

The mass of the modules should be kept to a minimum to ensure the best possible performance of the rocket.

6 THERMAL DESIGN OF EXPERIMENTS

6.1 The REXUS Thermal Environment

6.1.1 Pre-Launch Phase

The integration of the modules and payload is done at normal room temperature 20 ± 5 °C. After integration, the payload is mounted to the motor before being transported to the launcher. The ambient temperature during transport can be low (-30 °C or lower), depending on the outside temperature, but the exposure time is short (20-30 minutes). The ambient temperature is highly dependent upon the time of year for launch for some examples. Before spin & balance and the launch campaign, the payload is shipped fully integrated from the Bench Test at DLR Oberpfaffenhofen to Esrange by unheated road transport. During this phase, the temperature may be as low as -30 °C.

6.1.2 Countdown Phase

Experience shows that during countdown, the experiment modules tend to see an increase in temperature over time, especially if long holds are required. Some actions can be taken in the launch tower to improve the situation. However, it is recommended that temperature regulation is included in the design of heat sensitive experiment modules.

The thermal environment in the launcher housing will be controlled before launch. Normally, the vehicle will be in the housing with an air temperature of 17 ± 7 °C. Prior to launch, the housing is removed and the launcher is elevated for launch. This is the phase during which the rocket will see the coldest temperatures. This time period is nominally 20 minutes. However, in the case of a hold between T-20 minutes and launch, this period can be extended to much longer time scales. Experimenters must be fully aware of the impact of low temperature conditions on their experiments. During other phases, the thermal environment can be controlled when required.

6.1.3 Flight Phase

The temperature of the outer structure on the Improved Orion motor flight can reach 110 ºC at 50 seconds after lift-off. Peak skin temperatures in excess of 200 °C are expected during the re-entry phase. This will of course be transferred to internal parts, especially to items mounted onto the skin. For more detailed temperature information, please see previous flight temperature profiles.

6.1.4 Post-Flight Phase

After the impact, the payload will be subjected to snow and cold air in the impact area for a period of typically one to two hours. Depending on recovery conditions, this time can be extended significantly. The temperature during the season when REXUS is launched is normally between -30 °C and 0 °C. Experiments must be able to withstand these post flight conditions, especially if they are sensitive to low temperatures after the flight.

6.1.5 REXUS Thermal Requirements

In all phases (pre-flight, flight and post-flight) the following limits shall apply:

6.1.5.1 Heating of the Outer Structure

The modules' internal thermal dissipation must not heat up the outer structure more than 10° C above the ambient temperature. The tolerance is ± 5 °C.

6.1.5.2 Temperature at the Feed-Through Cable

The modules' internal thermal dissipation must not heat up the parts close to or in contact with the feed-through cable to more than +70 °C.

6.1.5.3 Heat Radiation in the Module Interfaces

The module's internal thermal dissipation must not heat up parts facing other modules to more than +50° C.

6.1.5.4 Convection between Connecting Modules

The heat transport by convection must be limited in such a way that the air temperature at the module interfaces does not exceed the ambient temperature by more than 10 °C.

An insulation deck, in both ends of the module, could be required to comply with these requirements.

7 ELECTRICAL DESIGN OF EXPERIMENTS

7.1 System Overview

As mentioned in chapter 4.1.1, the RXSM works as a data interface between the on-board systems/experiments and the ground control.

There are six identical interface ports available for experiments, five of which are available for payload connection with each port providing TM/TC, control wires and power. Two TV transmitters offer two live video transmissions. Each TV transmitter has the option to switch between two TV cameras with a time control (see also chapter 4.1.3).

The feed-through harness (i.e. the cabling that connects your experiment to the service system) will be designed and provided by ZARM.

7.2 Radio Frequency Constraints

In general, for every transmitter that will be used at Esrange Space Center during a campaign, information must be given to Esrange well in advance in order to receive permission for the operation of the RF transmitter.

At Esrange, the reception of weak satellite signals might be affected by local, stronger transmitters and therefore, special care must be taken regarding the timing and usage of frequencies of any RF transmission.

The following frequencies are used by the REXUS Service Module:

240.80 MHz and 244.05 MHz	Beacon
2200 MHz till 2400 MHz	S-Band
1625 MHz	Iridium
448 MHz till 450 MHz	Telecommand
2025 MHz till 2125 MHz	Telecommand
1574 MHz till 1576 MHZ	GPS

Table 7-1: Frequencies of the REXUS Service Module

It is also necessary to apply for frequency permission at the Swedish Post and Telecom agency (PTS). SSC applies on behalf of the experiment teams. Parameters such as transmitting frequency, radiated power, bandwidth of signal, antenna and antenna pattern, and modulation type are required information to have in advance.

The frequencies listed in Table 7-2 could be used for the experiments. However, as stated above, SSC is the point of contact for the permission of any RF transmission. Therefore, any frequency has to be confirmed first by SSC.

173 MHz	Beacon
433 MHz	ISM band (communication)
868 MHz	ISM band (communication)
2400 MHz – 2480 MHz	ISM band, WLAN (communication)
5600 MHz	ISM band, WLAN (communication)

Table 7-2: Allowed frequencies

7.3 Durability

After integrating the payload, the whole rocket is mounted on the launcher. In this late phase before lift-off, experimenters do not have regular access to the payload anymore.

During this phase there will be more tests of the whole system which means that the experiments are turned on and off several times. Finally, there will be one (or more) test countdown(s). Experiment teams should make sure that their experiments have enough battery, memory, chemicals, etc. to cope with this, in addition to the complete flight. During the test countdowns the testing signals (LO, SOE, SODS) may be given at any time in any order. Experimenters should be sure that they can cope with these signals, and if necessary, implement a testing state (software or hardware) to avoid the premature activation of once-in-flight items which would result in the need to access their experiment.

7.4 Telemetry System

The REXUS telemetry system consists of the TM master-board, located in the E-Box of the RXSM, and data sources distributed in the experiment part of the payload. All the data streams are multiplexed to a PCM data stream. The PCM/Biphase output from the main encoder modulates an S-band transmitter providing the ground link. The overall data rate of this PCM downlink is 500 kbit/s.

The interface between the TM master and each user in the TM system is implemented using an asynchronous serial link connection. The whole packed PCM downlink is equipped with a forward error correction (FEC) which minimises data loss.

Data losses are expected during the launch and the re-entry phase. During the rest of the flight, the bit error rate is usually $< 10^{-6}$ bit. If a bit error hits a frame's sync information, it could lose the whole frame which means that the serial data (up to 32 byte per data channel) contained in this frame is lost.

From past experiment experience, both short drops and long drops in the telemetry connection should be considered in the software. *Experimenters must consider that drops will occur and design their software to be fault accordingly.* Testing with the Service System Simulator can be conducted using simulated dropouts to verify that the experiment system can cope with potential telemetry situations. For details, please refer to previous flights data.

7.5 Telecommand System

The REXUS telecommand (TC) system consists of the TC master, located in the RXSM, and TC users distributed in the experiment part of the payload. Each experiment module can be individually addressed by ground commands. The telecommand receiver operates in the L-band. Experiment data uplink, i.e. TC, during flight is not part of the standard scope of REXUS and requires an RFW. ***Contact your ZARM/DLR or SSC/ESA supervisor for this document.***

Experiment data uplink is possible before launch through the umbilical.

The telecommands and their characteristics must be specified and submitted in advance to EuroLaunch.

The interface between the TC master and each user in the TC system is implemented using an asynchronous serial link connection.

There is also a possibility to connect directly to an Ethernet Port (FTP-Protocol) to transmit commands and receive downlinked data from the Experiment. For protocol details please contact the payload engineer. In this configuration, the connection is established via the REXUS ground network and not via a serial port.

The overall data rate of this uplink is 19.2 kbit/s. This Gaussian Minimum Shift Keying (GMSK) uplink uses Cyclic Redundancy Check (CRC) and Checksum (CSM) mechanisms to avoid executing corrupt commands.

The telecommand is also possible during the experiment phase via RF (see section 4.1.2)

Please note that both telemetry and telecommand will introduce a small delay of up to 50 ms. This delay will also fragment the messages.

Take precautions on ground (downlink) as well as on experiment side (uplink) to handle those delays.

7.6 Beacon

Beacons are tracking transmitters which facilitate the detection and location of the rocket payload. A transmitter which could be considered for use is following 174 MHz Beacon transmitter:

- Beacon transmitter: TX1-173.250-10 ($32.95)

Please contact your ZARM/DLR or SSC/ESA supervisor for further information.

7.7 REXUS Experiment Interface Description

Each experiment will be allocated its own standardised RXSM interface connector. On this connector, all communication, control, and power lines are implemented. A D-SUB 15 female connector is used as electrical interface on the RXSM side.

Up to 5 interface connectors are available to deliver power, to control the experiments and to exchange data in both directions for the entire payload.

There is a 6th interface connector available, but only with downlink capability (no uplink).

7.7.1 Experiment Interface Connector

The experiment interface connector should be a D-SUB 15 male type. This is the connector which is connected to the Service Module socket. The pin assignment of the experiment interface connector is given in Table 7-3.

Pin Nr	Name	Remarks
1	+28 V	Battery Power (24-36 V unregulated, I_{peak} < 3 A)
2	Charging (28 V/1 A)	
3	SODS	Start/Stop of data storage (open collector to GND or high impedance)
4	SOE	Start/Stop of experiment (open collector to GND or high impedance)
5	LO	Lift off (open collector to GND or high impedance)
6	EXP out+	Non inverted experiment data to Service Module (RS-422)
7	EXP out-	Inverted experiment data to Service Module (RS-422)
8	28 V Ground	Power Ground
9	+28 V	Battery Power (24-36 V unregulated, I_{peak} < 3 A)
10	n.c	
11	n.c	
12	Charging Return	
13	EXP in +	Non inverted Control data (commands) to Experiment (RS-422)
14	EXP in -	Inverted Control data (commands) to Experiment (RS-422)
15	28 V Ground	Power Ground

Table 7-3: Standardised REXUS Experiment Interface

7.7.2 Telemetry Interface

This section describes the ONBOARD data interface.

An RS-422 interface is responsible for the transfer of the experiment data to the RXSM. The baud rate must not exceed 80% (30 kbit/s) of the maximum data throughput. The experiment teams are responsible for the formatting, failure recognition and data correction.

Baud rate: 38.4 kbit/s standard

Format: 8 bits, 1 start and stop bit, no parity

Although this asynchronous downlink is fully transparent, the experiment teams should implement a data protocol as shown in Figure 7-1.

Figure 7-1: Downlink Protocol Example

To avoid channel bandwidth overload, do not send more than 30 kbit/s (in total) through a 38.4 k baud interface.

It is recommended to build packets with a maximum of 64 bytes in order to prevent buffer overflows in the RXSM-TM system.

For further TM/TC Information, please see the PCM Telemetry System document [8] from DLR MORABA. This is available on the teamsite in the “References” folder.

7.7.3 Telecommand Interface

The TX-lines of the same RS-422 channel are used to send commands to the experiment. The formatting, failure recognition and correction are also the responsibility of the experiment teams.

Baud rate: 38.4 kbit/s standard

Format: 8 bits, 1 start and stop bit, no parity

The same parameters as on the downlink should be used.

Please see also chapter 4.1.2.

7.7.4 Power Interface

The power (standard 28 V DC) is provided by the RXSM. The supply voltage varies between 24 V and 36 V depending on the condition of the on-board batteries. The experiment should be able to deal with voltage steps, which may occur when switching the RXSM from external (regulated) to internal (battery) power.

The peak power consumption should not exceed 3 A per experiment line during switching, (3 A per experiment line, not total consumption), while the mean value should not exceed 1 A mean (~30 Watts).

The RXSM provides a 2-stage fuse concept to prevent malfunction of the payload system due to an experiment short circuit event:

- I > **3.00 Amps** for more than 500 ms
- I > **20 Amps** for more than 100 µs

Each of those conditions will cut the power for this experiment until manual reset. If this happens before Lift-Off, the circuit can be switched on by the payload engineer.

After Lift-Off, the circuit cannot be switched on again and remains dead.

The power for each experiment can be controlled before Lift-Off by the payload engineer or by a pre-programmed timeline.

Usually, the experiment power is switched off at T+600 s, i.e. before landing.

The experiment must take precautions to limit voltage ripple feedback to the RXSM over the power line to a maximum of 100 mVpp. This can be achieved by using appropriate filters.

It is strongly recommended to always use both power pins for supplying the experiment (Pins 1 & 9 and 8 & 15).

If an experiment needs an independent power supply, special measures must be taken to control, switch and charge batteries properly.

When using own batteries, it is absolutely necessary to be able to switch the system completely dead, when "radio silence" is announced by the Operations Officer (e.g. in case of the arming procedure).

7.7.5 Charging Interface

If an experiment uses its own internal batteries, power (28-34 V, 1 A) can be provided to the experiment via a charging line when the RXSM is switched off.

This line is only for charging purposes, not for operating the experiment when the RXSM is switched off (in case of radio silence). This line is protected with a diode to avoid reverse current and discharging.

7.7.6 Control Interface

The RXSM provides three different control lines for each experiment.

They are implemented as open collector outputs with the capability to sink a current of maximum 50 mA (from ground) for each channel. The 28 V/GND is also structure ground.

An active signal means low impedance to ground. An inactive signal means high impedance to ground.

The user should connect either an optocoupler device or a relay to make this signal available for his experiment. If using a relay, the user is responsible for including a clamp diode close to the coil of the relay.

Available control lines:

- **Start of Data Storage (SODS)**
  This control line can be issued by timeline during flight or it can be initiated by the EGSE system via umbilical.
- **Start of Experiment / Stop of Experiment (SOE)**
  This control line can be issued by timeline or by command during flight.
- **Lift-Off (LO)**
  This signal is triggered when the umbilical connector is removed from the Service Module as the rocket leaves the launcher. At LO, the internal millisecond counter of the RXSM resets. All timeline events are correlated with this event (T+0 s). During bench

testing it is possible to simulate the lift-off condition, but not when the rocket is mounted on the launcher. Test countdowns will usually be stopped before the lift-off event, so in this case SOE/SODS may be given but not LO.

The electric design implies that the LO signal is distributed to **all LO signal pins in parallel**. This means, all LO pins are electrically interconnected. This requires a special treatment when connecting this signal (see below).

Waveform information for signals will be added to this document in the future. The experiment team should contact EuroLaunch to request this information.

7.7.7 Interface Suggestions

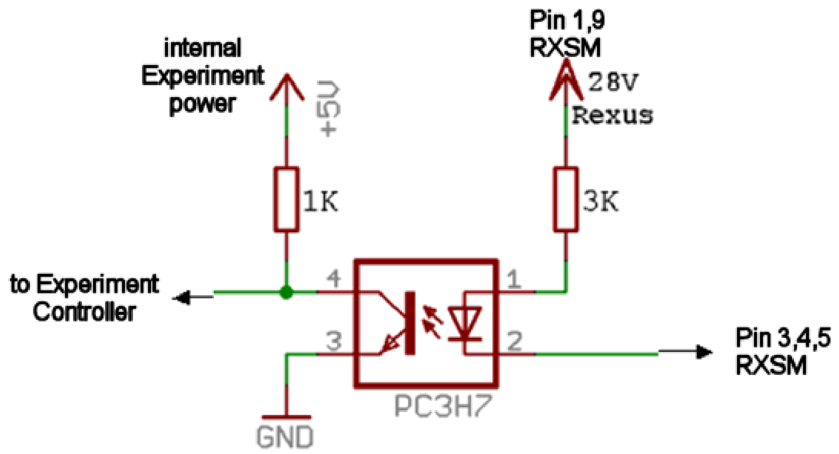

Figure 7-2: Interfacing Example

The example of an electrical interface to the RXSM shown in Figure 7-2 uses an optocoupler. What is important here is the relation of the primary part to the 28 V system power. Never connect this signal directly to your microprocessor input. Due to the fact that the LO signal is interconnected to other experiments, direct connection to a 5 V or 3 V device can cause damage or malfunction. Consider the dissipation created by the pull-up resistors and choose an appropriate resistor configuration.

SOE and SODS signals are not shared with other experiments like the LO-signal.

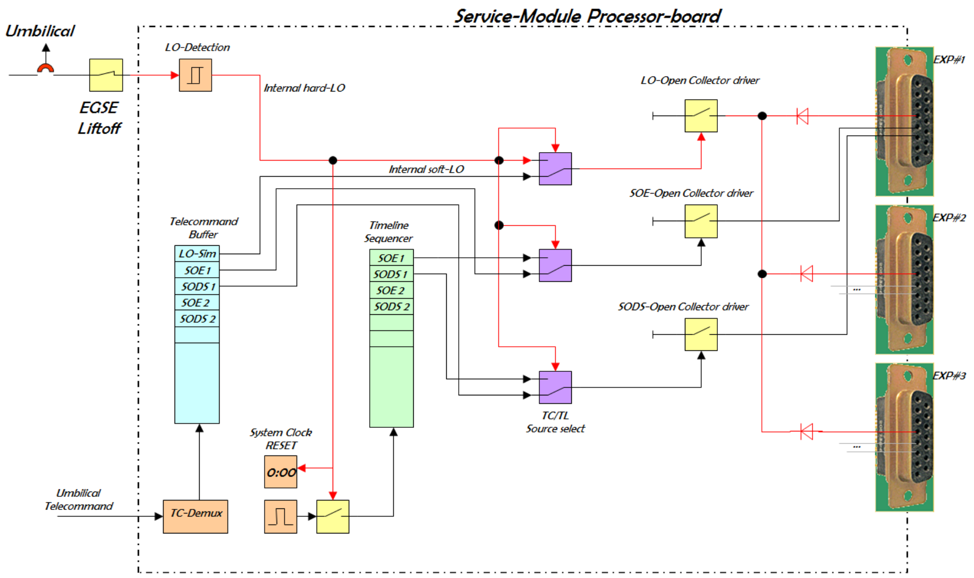

Figure 7-3: RXSM Control lines activation logic

RS422 signals

On the RXSM (E-Box) end (downlink), there is a 1 kΩ resistor between the data lines. On the experiment side (uplink), a 1 kΩ resistor should also be implemented (Figure 7-4).

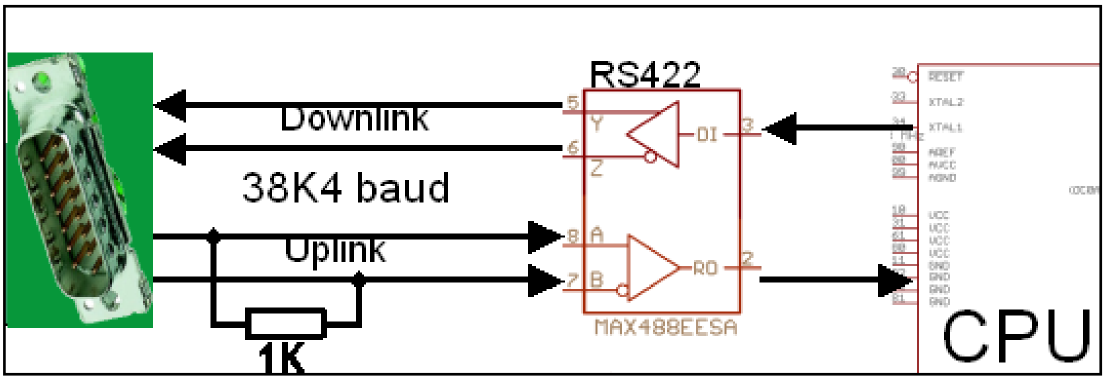

Figure 7-4: RS422 Interfacing Example

7.7.8 Pyro activation Box

To meet the special demands for activating pyrotechnics, a separate switch-box is implemented, referred to as “pyro box”. This is necessary since the RXSM does not have sufficient independent power for switching channels. Furthermore, for firing sensitive pyrotechnics, the pyro box ensures a higher degree of safety and reliability than it would be possible via activation through the RXSM.

The pyro box is connected to a safe/arm connector, to make sure that all installed pyrotechnics are safe (tied to ground – no connection to the activation power line), e.g. when people are close to the payload.

The pyro box offers six channels which can be activated by unused SOE/SODS lines. The activation is "and-wired" with the lift-off condition which avoids accidental activation on ground. All control signals are galvanically isolated from the pyro circuit.

7.8 Interface Description on Ground

The ground systems can be set up in the Scientific Center in the main building on Esrange. The experiment operator receives and commands the data via a RS-232 or an Ethernet (Science-network) port. (See Figure 7-10)

If a service module data recorder is installed on-board (standard configuration), all downlinked data is also stored on-board on a SD-card. After recovery of the payload, all data can be retrieved. Activation times such as SOE or SODS events can be defined by the user.

If necessary, experiments can be switched off either by telecommand (payload engineer), or by timeline. Manual switching can be performed by the payload engineer only **before** Lift-Off.

Details about the data rate as well as the format can be found below:

Reception of experiment data:
Data rate: 38.4 kbit/s
Format: 8 bits, 1 start and stop bit, no parity

If TCP-Port is used: 10.10.13.locadr/800x: x= Exp-IF-No.

Commanding of experiment:
Data rate: 38.4 kbit/s
Format: 8 bits, 1 start bit and stop bit, no parity

If TCP-Port is used: 10.10.13.locadr/800x: x= Exp-IF-No. (full duplex=same port for RX/TX)

7.9 TV Transmitter

If a TV downlink is requested by an experiment, the transmitter will be integrated in the RXSM in combination with a video multiplexer.

Four TV sources can currently be connected to the multiplexer. During the ascent- and free flight phase of the rocket, the TV channel is switched to the experiment. On the descent or/and the re-entry phase, the TV signal is switched to the recovery camera which will monitor the parachute openings. The switching time is determined by the pre-programmed timeline.

As one of the four sources must be connected to the recovery camera monitoring the parachute openings, the maximum number of connections available for experiments is three.

Depending on the demand of TV transmissions from experiments, one or both cameras mounted on the outer shell of the Recovery Module (see chapter 4.1.4) may be connected to the multiplexer. Due to the high demand from experimenters to use the TV transmitter, the use of a camera has to be justified.

During transmission of the TV signal, the received video is recorded. A copy of the recordings can be made available to the team after the flight. It is also possible to convert the video format. This must be arranged with SSC staff and for timely delivery of the video, it is best to arrange this in advance.

Please see also chapter 4.1.3.

The analogue video signal PAL must be 1 V_{PP} on 75 Ω impedance.

7.10 Radio Silence Concept

For ground safety purposes, the range will announce at certain times “Radio Silence”. This is particularly needed, when hazardous work has to be done, for example Arming of the vehicle or Loading the rocket into the launcher.

For the Radio Silence phase, special rules apply:

- Any radio transmission – inside or outside the payload – is forbidden.
- If the payload is mounted to the motor, all systems need to be “dead”. No current flow (except for unavoidable leakages) and no charging of batteries are allowed.
- Ground Support Equipment must be switched off if it is next to the rocket.
- Confirm to the head of operation, Payload Manager or Payload Engineer the off-status of your systems.

For all other experiments having no additional power source, the RXSM will handle this by switching off all the power supply interfaces.

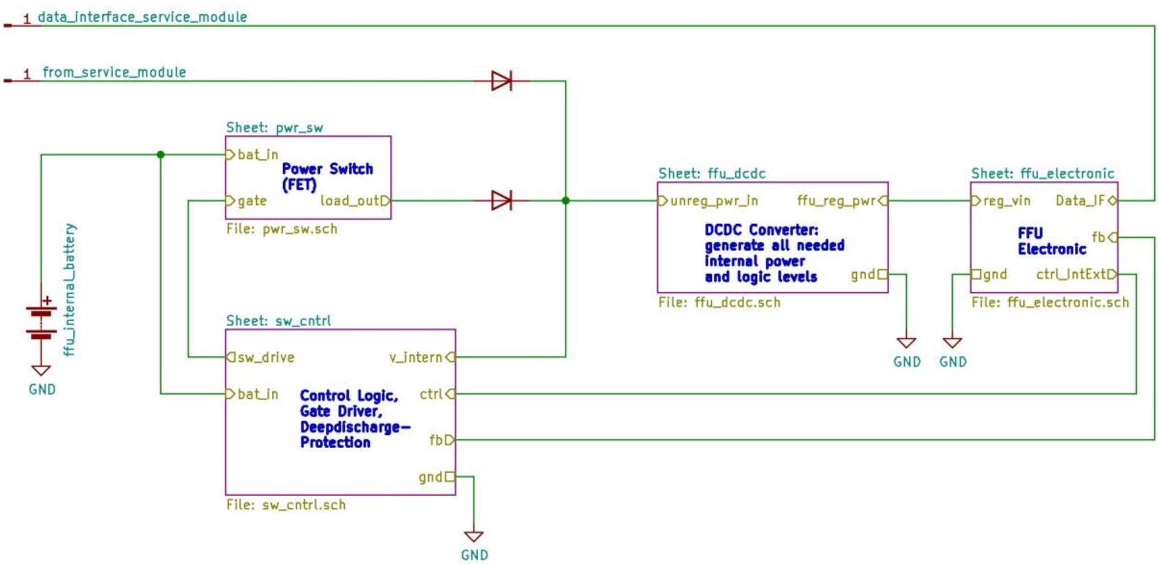

Figure 7-5: Radio Silence functionality diagram

In case your experiment has its own on-board batteries (e.g. FFU or heating system), an additional functionality must be implemented to fulfill the Radio Silence rules. Figure 7-5 shows an example how this could be realized:

1. Initial state: Your experiment is neither powered from RXSM nor from your internal batteries and there is no Radio Silence announced.
    a. As soon as the RXSM powers your electronics, the communication to your ground station is established.
    b. Now you can switch via a control logic to your internal batteries. This means your experiment is now independent from RXSM power.
    c. A status-feedback should be sent to your ground station to ensure the experiment is running on internal power.
2. If Radio Silence is raised, following steps need to be performed:
    a. Switch off your internal batteries and verify its status via the feedback at your ground station.
    b. Power supply from RXSM will be disconnected afterwards.
    c. The complete payload is now ready for Radio Silence.

See also section 8.9, for further information regarding Radio Silence.

7.11 Additional Batteries

If the usage of additional batteries is necessary, make sure to meet the requirements for radio-silence.

Additionally, when working with batteries, please note the following:

- Separate your battery compartment from the rest of the hardware
- Avoid the use of multiple battery compartments
- Batteries should be easily accessible/replaceable and chargeable

EuroLaunch recommends the use of Nickel-Metal Hydride (Ni-MH) batteries, and has a lot of experience in using the SAFT brand of batteries on sounding rockets. Other brands may be used upon consultation with your ZARM/DLR or SSC/ESA supervisor.

Recommended batteries:

- Single use:
    - SAFT LSH Series, (Lithium-thionyl chloride).
- Rechargeable:
    - SAFT Li-ION, Nickel Cadmium or Nickel Metal Hydride series.

7.11.1 General Guidelines

Regardless of the chosen battery chemistry, the following guidelines apply:

- As stated above, batteries should be placed in a separate compartment and should be easily accessible/chargeable.
- Select batteries containing the smallest amount of energy (Wh) possible for your application (still including a proper safety margin).
- It is advisable to calculate with only 80% of the nominal battery capacity.
- Avoid mixing batteries of different manufacturing lots (e.g. different batteries replacing discharged batteries).
- Always provide the correct battery data-sheet.

Furthermore, if working with secondary cells, you should consider measures for proper charging of the batteries taking into account:

- the specified temperature range
- overcharging restrictions
- rated charging current
- as well as cell balance for multi-cell battery stacks

7.11.2 Lithium-Polymer Batteries

If you use lithium-ion batteries (including lithium ion polymer “LiPo”), you should be aware that they are not as temperature resistant as NiMH and require a more sophisticated charging device. Lithium-ion batteries have to be qualified by the manufacturer for transport by sea and air freight. This includes changing conditions in the freight room during air transport without pressure equalization and temperatures changing by 110 K within 30 minutes. Nevertheless, for very high altitudes during the rocket flight, vacuum conditions have to be assumed.

Consider the implications of the applicable transport regulations and avoid designs that require a new certification for transport of the battery stack. To avoid problems, you should only use packaged batteries which are not soldered together.

Lithium-ion and in particular lithium-ion polymer batteries are state-of-the-art technology capable of storing large amounts of electrical energy. However, in the safety critical field of rocketry, the application of lithium-based batteries requires special precautions.

Some advantages of LiPo batteries include:

- compactness (high energy density)
- low mass
- available in various different shapes and sizes
- high voltage stability (during discharge)
- low internal resistance (high current source)

The most critical disadvantages of LiPos compared to NiMH or NiCd are:

- more complex charging and discharging logic required
- mechanically sensitive (very critical regarding high g-forces during ascent/impact)
- not suited for low pressure or vacuum
- risk of fire or explosion when damaged
- high current capability can cause severe damage to deficient circuits (e.g. shorts)
- There is no "standard" cell: large variety of cell chemistries, therefore large variety of critical cell voltages
- From the cell voltage alone, it is not possible to derive the actual state of (dis)charge properly.
- Freezing may destroy a LiPo. Still, LiPos have better performance at low temperatures than NiMH batteries

When considering lithium-polymer batteries, be aware that unfortunately, the information you find on google, Wikipedia, etc. has to be treated with caution. The basics about LiPos are well covered, but details are questionable. In many cases, the information you find there is copied from other questionable sources and data is partially outdated. These references are fine for private model making, but not for safety critical applications such as rocketry!

Cell voltages: cut-off voltages can vary from 3.3 V to 3.0 V (depending on LiPo cell type). Never discharge below these values! Measure the voltage with load applied! End-of-charging voltages can vary from 4.15 V to 4.35 V (cell type dependent). Never exceed these values by more than 0.05 V! Better stay 0.05 V below. Always verify the voltages applied by your LiPo-charger with a proper multi-meter under the expected thermal conditions. Many (even very expensive) chargers measure wrong! Always make sure to double check the appropriate cell voltages for cut-off, end-of-charging as well as the charge and discharge rates with the data-sheet of the selected battery.

As a conclusion, EuroLaunch encourages the experimenters to follow these rules:

- If technically possible, use NiMH cells. You save a lot of hassle and money! Just because they are "hip", LiPos are not always the best choice.
- If the use of NiMH batteries is ruled out, consider the feasibility of lithium-iron-phosphate ($LiFePO_4$) batteries. While the cell voltage and energy densities are typically lower than that of other types of lithium-ion batteries, $LiFePO_4$ offer higher thermal and chemical stability, reducing the risk of thermal runaway as well as typically allowing for higher discharge currents. Select LiPo batteries containing the smallest amount of energy (Wh) possible for your application (still including a proper safety margin, of course). **Stay well below 20 Wh!**
- Put batteries in a solid box (e.g. Al, CFRP) for mechanical protection and minimized risk of burst caused by deep discharge or low pressure
- ALWAYS use a deep discharge protection ("LiPo safer"), which monitors each cell of the battery! The battery must disconnect from the load completely. A deep discharged LiPo bloats and is a serious risk for recovery personnel!

- Include protection against over-discharge-current.
- If you plan to charge your Li-ion inside the rocket at the launcher:
    - You **MUST** apply a proper charging circuit with constant current / constant voltage (CC / CV) mode and cell balancing! Use a separate, dedicated circuit / IC. Don't implement the charging and / or balancing logic in your micro-controller, FPGA, Software, etc.
    - Make sure that charging of the batteries is only possible in the specified temperature range of the selected batteries.
    - Include protection against overcharging the batteries.

It is recommended to consider LiPos designed for smartphones. Compared to "standard" cells used in radio-controlled (RC) models, they are chemically (not mechanically!) very stable and safe, deliver slightly higher voltage, and have significantly higher energy densities. The only downside is that they are not designed to deliver extreme currents; in general, no more than 1 A or 1 C. However, high currents inside the rocket are not advisable in any case.

Smartphone batteries are easily available in a large variety of models and are cheap. Typical end-of-charge voltages are 4.35 V (better stop at 4.30 V) and typical cut-off voltages are 3.2 V. Only buy from trusted sources in order to beware of unreliable and potentially dangerous counterfeit products.

Transportation and storage: Always use special LiPo bags, available in many RC model shops. Use one bag per battery. According to transportation regulations, each battery must be well separated from the other and placed inside a non-inflammable compartment, such as a LiPo bag. For transportation on passenger aircraft, the maximum allowed energy per battery is 100 Wh.

7.12 Additional Umbilicals

If there is a need for an external power supply or similar, this can be discussed and possibly an additional umbilical connection could be implemented.

The orientation of the umbilical shall be in accordance with EuroLaunch instructions.

7.12.1 Orientation

Directly after lift-off, all umbilicals get pulled out as soon the rocket moves along the launcher rail. Special connectors with lanyards are used to unlock the connection and move them out of the fin-corridor with an elastic band.

Those connectors need a certain angle to unlock properly. Figure 7-6 shows both possible positions at ±30°, where the launcher rail is at 0° position.

Figure 7-7 shows the appropriate cut-out for an umbilical connection at the nosecone adapter. The position of the umbilical bracket must be considered for the mechanical design of the experiment.

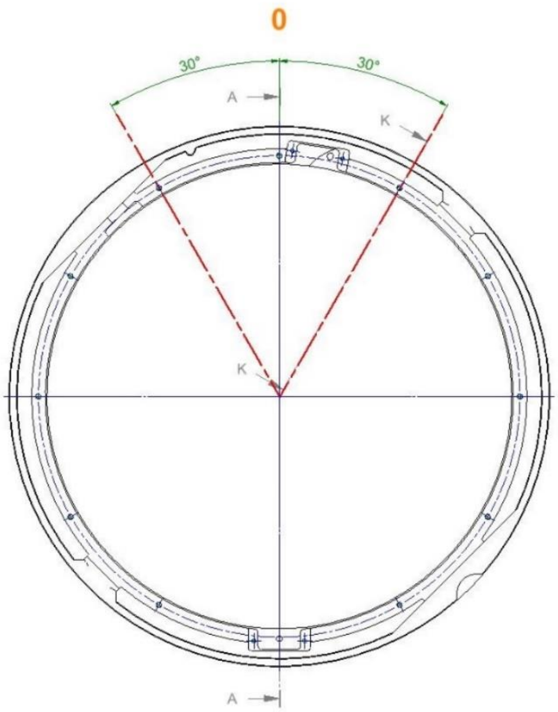

Figure 7-6: Position for umbilical cut-out

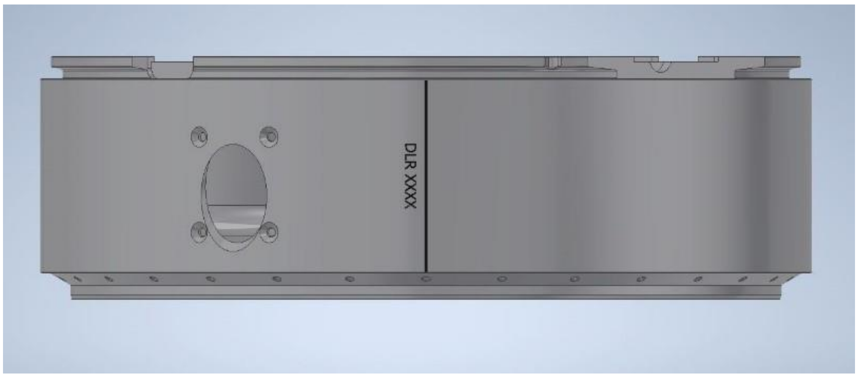

Figure 7-7: Umbilical cut-out at Nosecone Adapter

7.12.2 Electrical Umbilical Provided by Experiment Teams

The module-mounted connector will be mounted on a flange arrangement as shown in Figure 7-8. The connector is male and the socket at the module is female.

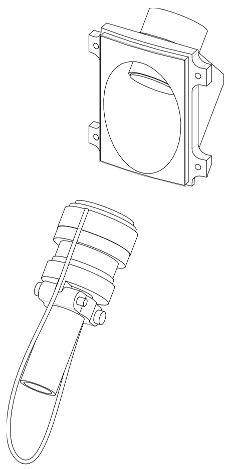

Figure 7-8: Umbilical connector and socket with bracket

The angle for the umbilical bracket must be 45° to provide a clean disconnection, as shown in Figure 7-9.

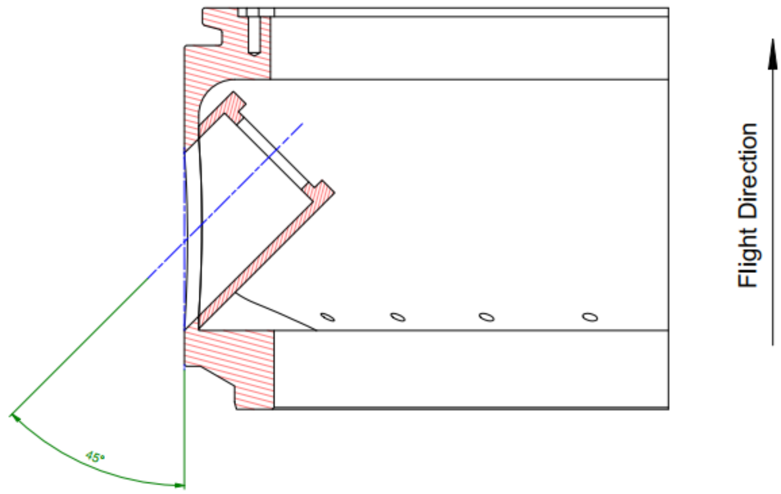

Figure 7-9: Angle of umbilical bracket

7.12.3 High Power Connections

If a high-power connection is required, the experimenter is free to choose the type of connector. However, the connector is subject to EuroLaunch approval. Furthermore, EuroLaunch will decide together with the experimenter where and how to mount the connector.

7.12.4 Ground Support Equipment-Umbilical Interface

An EGSE provides charging and hard-line communication via the Launcher Box and Service Module to the scientific payload (see the cyan EGSE box in Figure 7-10).

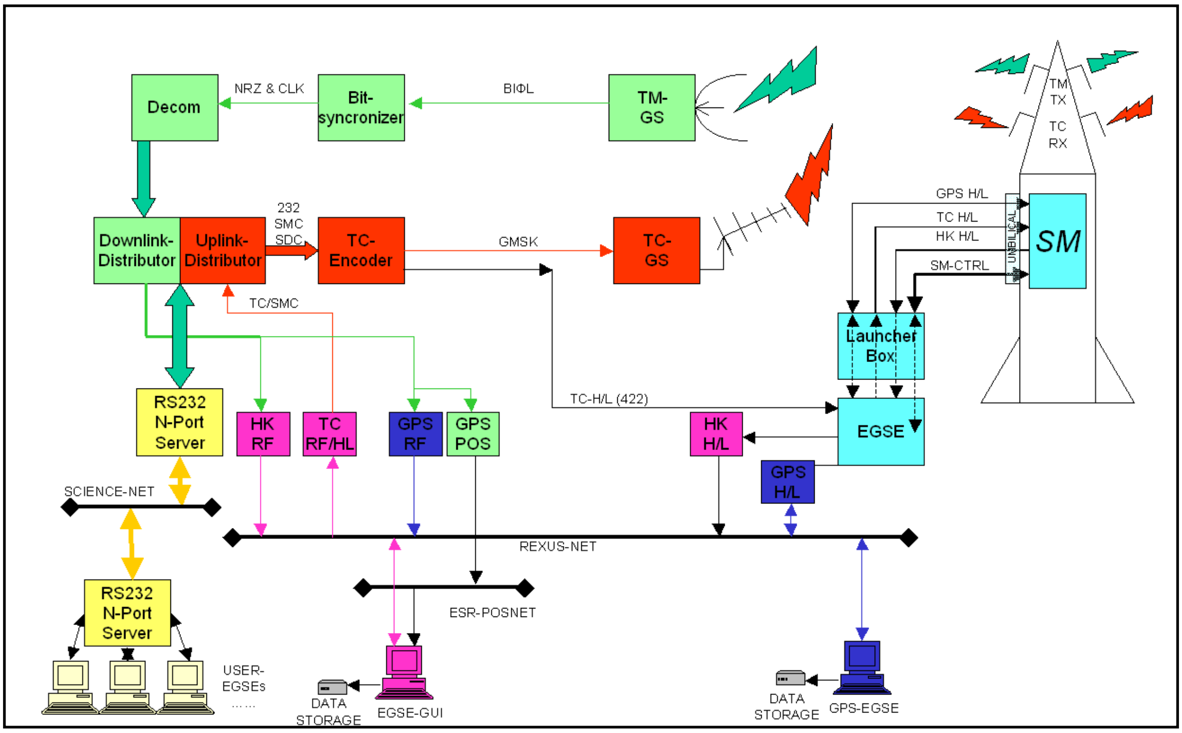

Figure 7-10: Communication Overview

Figure 7-10 shows the communication infrastructure including data/signal paths for a REXUS ground segment configuration.

7.13 Electro Magnetic Compatibility (EMC)

Electromagnetic compatibility (EMC) is the ability of electrical equipment and systems to function acceptably in their electromagnetic environment, by limiting the unintentional generation, propagation and reception of electromagnetic energy which may cause unwanted effects such as electromagnetic interference (EMI) or even physical damage in operational equipment. In particular, rapid current and voltage changes can produce electromagnetic noise, which spreads via various coupling mechanisms.

7.13.1 EMC design

The design shall be such that radiated Electromagnetic Interference (EMI) is kept as low as possible. There shall be no interference with other on-board systems. Note following general design guidelines:

- All power supply cables shall be twisted.
- Data cables shall be twisted.
- In case of EMI problems, shielding of the cables shall be considered.

To ensure reliable operation, the experiment electronics input circuits must have filters as shown in Figure 7-11.

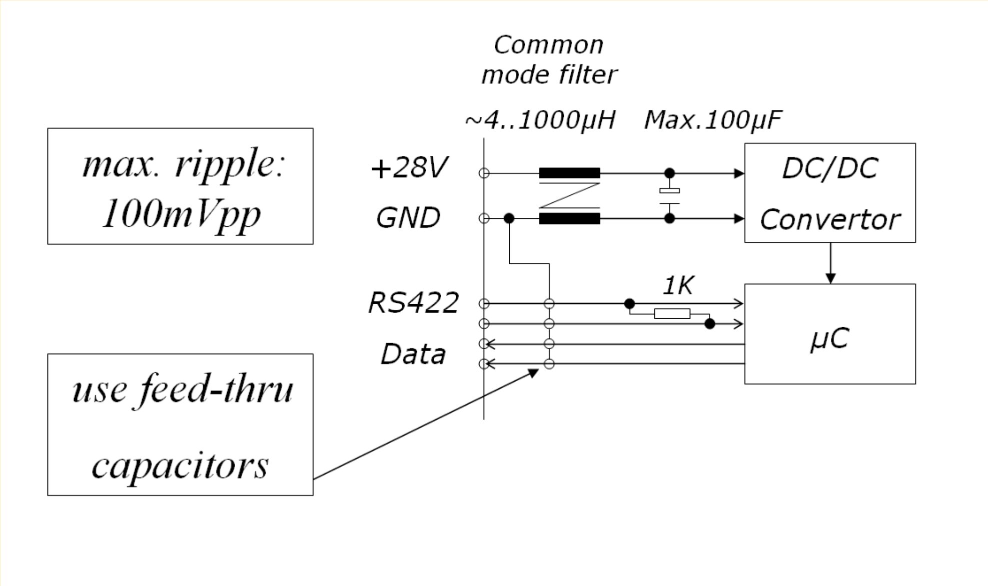

Figure 7-11: EMI Reduction

Spurious wave emission must be minimized within the critical GPS and telecommand frequency ranges. To achieve this, electronic units like oscillators and processors with high clock rates should be installed in shielded housings. Spurious emissions should first be measured on the bench to determine the critical frequencies. These emissions can be suppressed by design or by layout changes through blocking or shielding. Using EMI filters might be an option.

7.13.2 Shielded Housing

The housing should be electrically conductive, made of aluminium or other conducting materials. An appropriate screw connection is necessary as well as electrical feedthroughs. A shielding of ≥ 20 dB should be achieved to keep unwanted emissions sufficiently inside the housing and to shield incident radiation from the outside.

7.13.3 GPS Sensitivity

The radiation levels of the circuitry need to be kept under -115 dBm within the sensitive GPS frequency range (1573 MHz to 1578 MHz). Stronger signals can lead to loss of GPS position. Figure 7-12 shows the maximum emission levels at the antenna port of the GPS receiver.

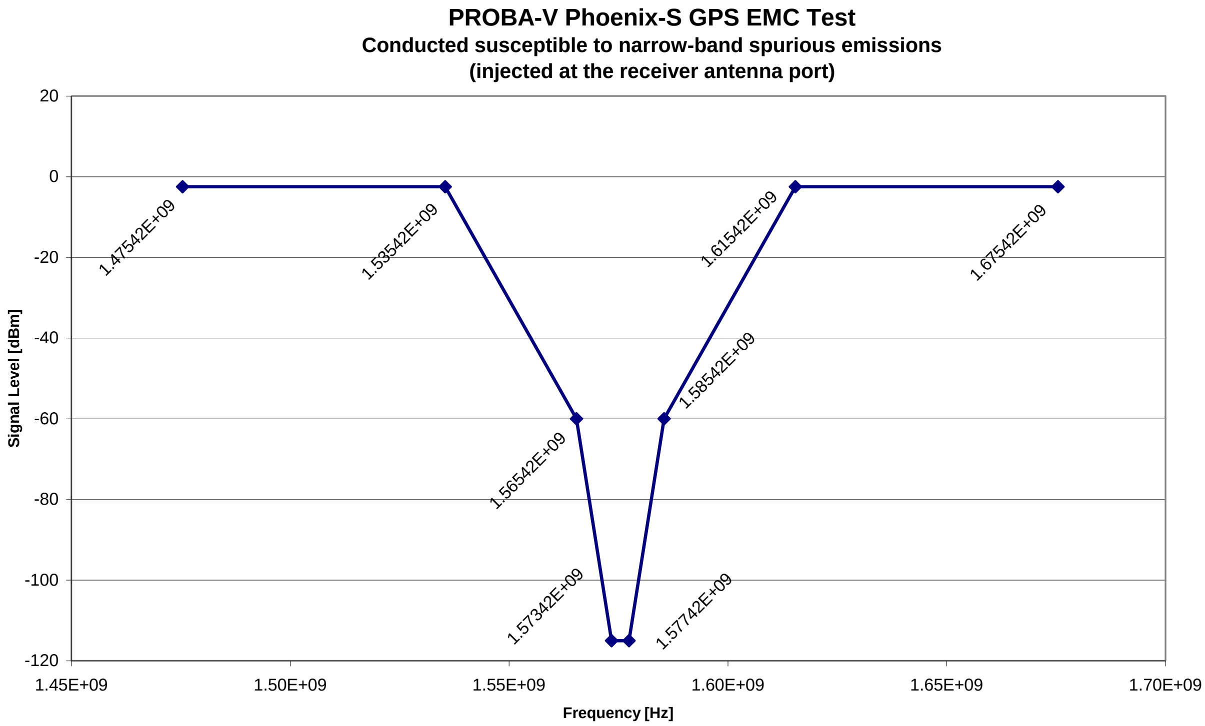

Figure 7-12: Frequency profile for the Proba-V GPS Receiver spurious response test.

7.13.4 TC sensitivity

The telecommand frequencies of 448 MHz and 449.95 MHz should remain free of spurious emissions, i.e. below -100 dBm measured at the telecommand reception antenna. The bandwidth of the telecommand receiver is 200 kHz. Interfering signals in this range can lead to command failures.

7.13.5 Inductive Free Grounding

On large conductive areas, short ground connections have to be implemented. The grounding must be as short as possible using thick wires to achieve low inductances. For example, a 3 cm long and 1 mm thick wire has an alternating-current resistance of $X_L = 300\ \Omega$ at 1.5 GHz. Such impedance is too high for signals within the GPS range.

7.13.6 Sensitive Frequency Ranges of Mission REXUS

The maximum emission levels are summarized in Table 7-4. If the 28 V DC bus is loaded with fast switching DC/DC converters, appropriate filtering may help to keep emissions under the required 100 mVss (see also section 7.13.1). Electric motors have to be equipped with filters to suppress high starting currents and voltage spikes.

Type	Range	Max Value	Comment
GPS	1575,4 MHz ±4 MHz	≤ -115 dBm	Measured at antenna port GPS module
TC	449,95 MHz ±0,2 MHz 448 MHz ±0,2 MHz	≤ -100 dBm	Measured at TC antenna port
28V Bus	20-36 V	≤ 100 mV_{SS}	Measured on 28 V lines (Oscilloscope)

Table 7-4: Limits of spurious emissions and harmonics

7.14 System Grounding Concept

The grounding concept assumes that electronic components are mounted in metallic and conducting structures in order to obtain a hierarchical grounding structure. Figure 7-14 gives an overview over the concept and Figure 7-13 shows the legend for symbols used in this section. Dotted red lines mark the hierarchical paths of the implicit grounding through metallic structures.

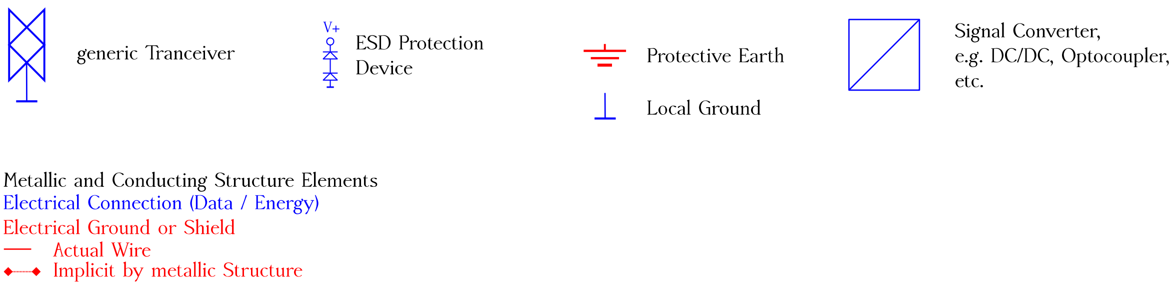

Figure 7-13: Legend for all diagrams used in this section

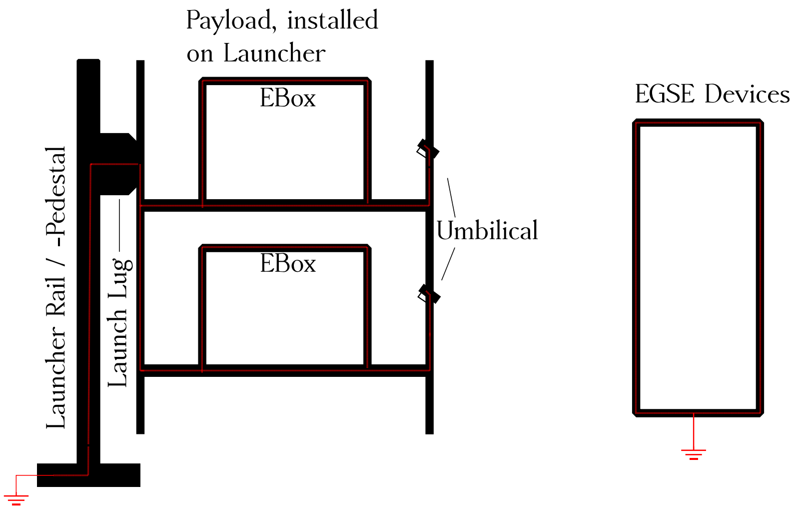

Figure 7-14: Implicit Grounding Overview

For example, a printed circuit board with active components is installed inside the service module electronic box (EBox) and the local ground of the board is somehow connected to this box. The box is fixed on a bulkhead in an electrically conducting way. All bulkheads are installed in the payload structures and the surfaces of these elements are also conducting. The fully integrated payload on the launcher is electrically connected to the launcher by Launch Lugs, Gliding Stones, etc. Finally, the launcher rail and the pedestal are connected at least to the protective earth (PE) of a building.

A closed payload acts as reference ground and high-quality shield for all components inside during flight and on ground. Umbilical cables will break this shield and should therefore also be shielded to extend the grounding down to the EGSE devices where the umbilical shield should be connected at both ends as shown in Figure 7-15.

As for the launcher, the EGSE devices must be connected to PE for safety and to use the same root-point of grounding as for the launcher. It is crucial to have low impedance between the actual two PE signals to avoid ground loops over the umbilical cables! The payload structure should not be used as signal or power return.

7.14.1 Active Components

Several classes of active components are common for sounding rockets: data transmission lines and power or flag signals. Figure 7-15 shows the full picture including these components.

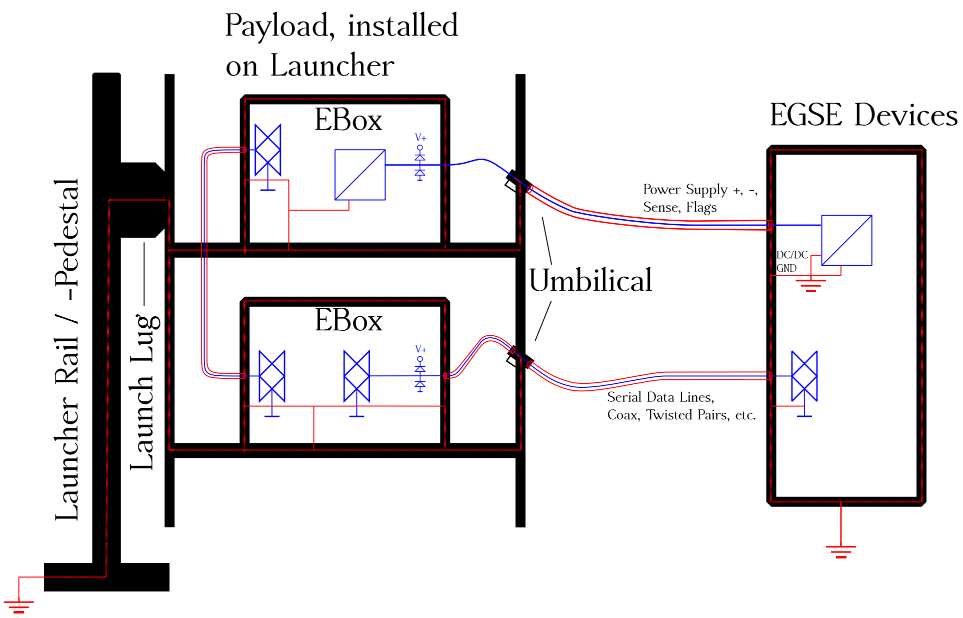

Figure 7-15: Grounding and Active Components

7.14.2 Power and Flags

The upper umbilical shown in Figure 7-15 is an example of a power supply. The negative port of a DC/DC converter should be connected to the local ground of the EGSE device and also to the PE. Flag signals may be treated analogously. However, the bundle of signals from the EGSE to the payload should be shielded and the shield should be connected on both ends to the device case and the umbilical connector backshell. The overall concept can be regarded as a tree with connected branches. To extend this concept, local grounds should be designed as branches of this tree, where the root is connected to the structure ground on a single point.

7.14.3 Serial Data

Two types of serial transmission lines are shown in Figure 7-15, one on-board and another one connecting the payload and the EGSE. Serial transmissions can be the source of high frequency disturbance in the cable harness due to fast switching transmitters. These signals should be shielded and the shield should be connected on both ends to keep the wide spectrum inside the shield.

7.14.4 RF Systems

Antennas of RF transmitters or receivers are electrically connected to the outer surfaces of the payload structure. Coaxial cables are commonly used, and their shielding should be connected to the common payload shield.

7.14.5 ESD Protection

Long or open cables can pick up large electrical charges which are able to destroy electronics. Figure 7-15 shows common protection circuits which should be installed close to the umbilical to avoid damages.

ESD grounding wrist straps can be used to protect electronics from people working on an open payload. Special connecting points can be installed on the outside of the payload to connect the straps. In this case, the path of lowest impedance is the payload structure itself, not the path through the electronics or even the ESD protection devices.

7.15 Navigation and Control System

7.15.1 GNSS-based tracking of rockets and other space vehicles

Over the last two decades, Global Navigation Satellite System (GNSS) receivers have evolved into a standard tool for the tracking and navigation of all kinds of space vehicles, including Low Earth Orbit (LEO) satellites, launch vehicles and sounding rockets. Primarily, such navigation sensors are employed for operational purposes, such as flight safety operations, recovery, post-mission performance analysis, time synchronization and geotagging of scientific measurements. More recently, however, GNSS receivers are also used as scientific instrument e.g. for atmospheric research or Earth observation. Key advantages of GNSS based navigation systems are the worldwide and continuous availability, the achievable accuracy, the availability onboard a space vehicle and the rather moderate costs of such a system compared to e.g. inertial measurement units or ground based tracking systems (radar, laser, optical).

The purpose of this chapter is to provide some useful information and hints regarding the use of GNSS receiver onboard a vehicle such as a rocket, launch vehicle or satellite. It does not provide a general introduction to satellite-based navigation.

7.15.2 Speed and altitude limitations

GNSS receivers are currently available at many different prices and form factors, ranging from single chip solutions at a price of below 100 € and a mass of less than 100 g up to high-end space-qualified receivers for several million Euros and a total mass between 10-20 kg. Except for the latter ones, all commercially available GNSS receivers in the market have built-in limits based on speed and altitude. If a vehicle carrying a GNSS sensor is moving faster than 1000 knots (~500 m/s) and/or at an altitude higher than 60000 ft (~18000 m) the receiver - or at least the message output - is disabled. These limits, also often referred to as "ITAR" (International Traffic in Arms Regulations) or "COCOM" (Coordinating Committee for Multilateral Export Controls) limits, are intended to prevent the use of commercial-off-the-shelf GNSS technology in military applications, such as intercontinental ballistic or tactical missiles. Some manufacturers apply this limit only when both speed and altitude limits are reached, while other manufacturers disable tracking when either limit is reached.

Several manufacturers offer, on request, a version of their product with removed limits. In this case however, the receiver usually falls under national and international export control regulations, which makes the handling and transport of the device considerably more complicated. Typically, the access to such devices e.g. in the laboratory and integration room must be controlled and limited to authorized personnel (be careful with foreign guest students or researchers!). Likewise, each shipment to foreign destinations, sometimes even within the European Union, has to be cleared in advance by the responsible customs office.

7.15.3 Acquisition, Tracking & Navigation

The signal conditions typically encountered on-board a satellite or rocket differ from terrestrial usage by a notably higher line-of-sight velocity and acceleration between the GPS satellites and the spacecraft. While in terrestrial applications maximum Doppler shifts of 4 to 5 kHz are observed, in satellite applications, the peak Doppler shift can amount to almost 50 kHz. In addition, because of the high platform dynamics, the Doppler rates can increase beyond 50 Hz/s. Both effects can have adverse influences on the signal acquisition as well as on the signal tracking. The higher Doppler values require a wider frequency search window in the receiver for a traditional two-dimensional code-phase and frequency acquisition process. This in turn, can significantly extend the Time-To-First-Fix (TTFF), the time required for a GPS receiver to acquire satellite signals and to calculate a first valid navigation solution after switch-on or a loss of signal during the flight. Regarding the significantly higher Doppler rates, the selection of adequate tracking loop settings is required to avoid the loss of signal or steady-state measurement which would consequently lead to positioning errors. Unfortunately, not all GNSS receivers allow the modification of these parameters through the user interface. Even worse, for some receivers it turned out to be difficult to impossible to obtain the required information from the manufacturers. Data sheets often do not provide sufficient details about the selected standard settings or provide misleading information. In these cases, a test with the receiver in a signal simulator environment with a representative rocket trajectory is the only way to verify a proper functioning and good performance of the selected device before the mission.

Another major difference between GPS tracking on ground and in a space mission, at least for high-flying rockets, launchers and satellites, is the rapidly changing visibility to the GPS satellites. While in terrestrial applications, a satellite is typically visible for an hour or more after it has risen above the horizon, the constellation can change completely within minutes in satellite or launcher applications. This requires a continuous re-allocation of the available tracking channels in the receiver. Experience has shown that this can cause problems in some receivers. For rather short rocket missions, however, this might not be of relevance.

7.15.4 Antenna System

GNSS receiver antenna systems also require special attention. Again, the situation onboard a spacecraft largely differs from the use of GNSS technology in terrestrial or airborne applications, e.g. onboard a car or aircraft. Other than for the aforementioned vehicles, a rocket or satellite typically has no defined surface continuously pointing towards the Zenith or in quasi-Zenith direction. Therefore, an antenna system composed of a single antenna or antenna element might not be suitable to ensure a continuous visibility to a sufficient number of GNSS satellites which is essential for the computation of continuous and accurate navigation solutions.

For non-spinning vehicles, a dual- or multi-antenna system might be a feasible solution. In this case, the signals from two or more antennas, mounted around the circumference of the rocket, are passively combined through a RF power combiner before they are fed into the GNSS receiver. For a quasi-static scenario with small rotational motions (rates below a few degrees per second), the motion's influence on the antenna pattern can be ignored and the antenna pattern is almost omnidirectional. A potential draw back of the antenna system described above is the fact that a destructive superposition of signals simultaneously received by both antennas may result in pronounced gain drops at certain viewing angles in the overall antenna diagram (see Figure 7-16). This effect is particularly strong when the diameter of the supporting structure and the resulting separation of the antennas is of similar order as the wavelength of the RF signals (GPS L1 ~ 19 cm). In case of a vehicle spinning fast or tumbling heavily, the relative attitude motion between GNSS satellite and antenna system results in a type of phase and amplitude modulation on the received signal which is typically not tolerated by a GNSS receivers.

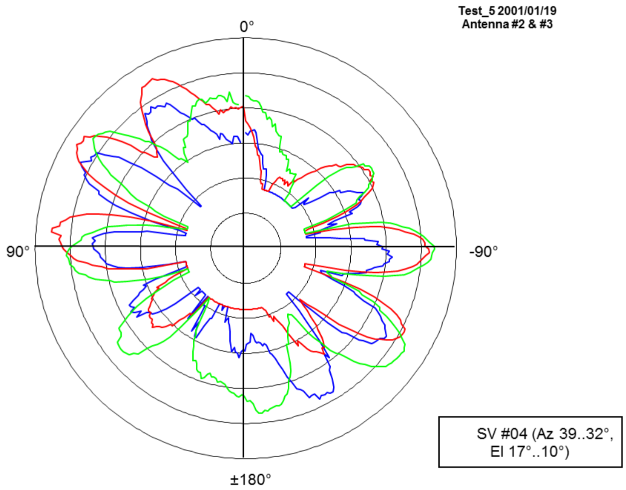

Figure 7-16: Measured antenna pattern in the azimuth plane (plane perpendicular to the boresight axis of the antenna) for a dual antenna configuration with 2λ baseline

In the following paragraphs, the most common antenna types employed in space projects are presented briefly, and their pros and cons for rocket applications are discussed. At the end of this chapter, an example is provided for an antenna system which has been successfully flown in numerous European and international sounding rocket missions.

7.15.5 Patch Antennas

In its most basic form, a microstrip or patch antenna consists of a radiating patch on one side of a dielectric substrate which has a ground plane on the other side as shown in Figure 7-17. The patch is generally made of a conducting material such as copper or gold and can have various shapes. The radiating patch and the feed lines are usually photo etched on the dielectric substrate.

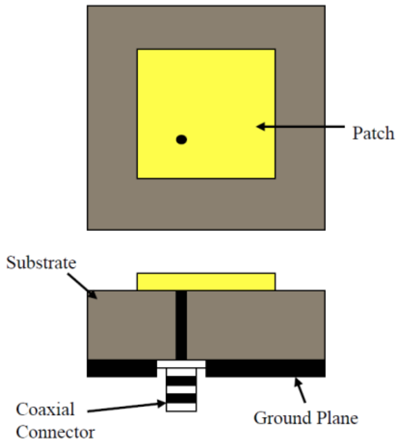

Figure 7-17: Top view and cross section of a probe fed rectangular microstrip/patch antenna

Figure 7-18: GNSS patch antenna (Source: Trimble)

In general, one has to distinguish between active and passive patch antennas. An active antenna accommodates the antenna and a low noise amplifier in a common housing. A passive antenna, in contrast, has no built-in amplifier but needs to be supplemented by an external amplifier (see section 7.15.6). Both concepts have their advantages and disadvantages. The active concept allows for a very compact design. The passive concept, on the other hand, is more flexible and modular, i.e. it allows for the insertion of a band-path or notch filter between patch and Low Noise Amplifier (LNA) to suppress band interferences. The power for the LNA is typically supplied by the receiver through the centre pin of the antenna connector. Caution has to be taken that the selected LNA is compatible with the specifications of the GNSS receiver.

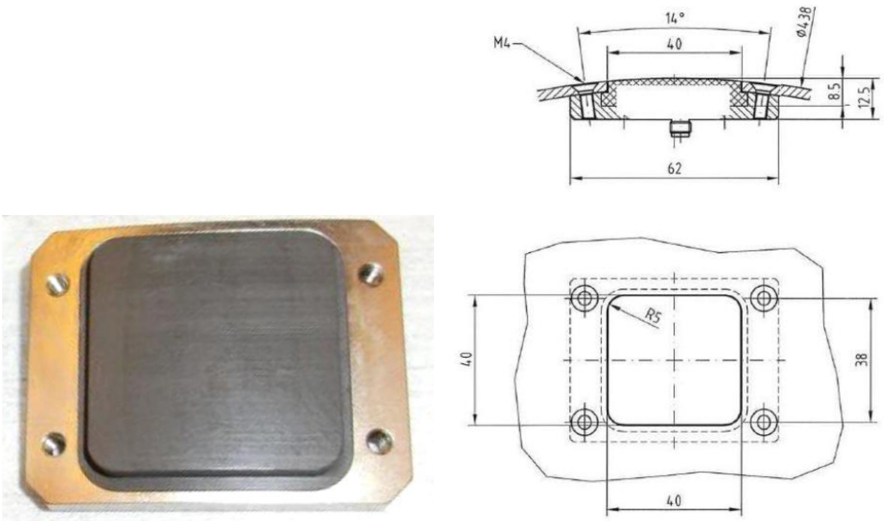

Figure 7-19: Picture and installation drawings of the patch antenna developed by OHB for sounding rocket and launcher applications (Credit: OHB-System AG)

For rocket and launcher applications a specific flush mounted patch antenna has been developed by OHB (formerly Kayser-Threde GmbH). These can be fitted into specific recesses in the outer structure of the rocket and are used to replace e.g. blade antennas in a dual-antenna combination. Despite slightly higher production costs and the increase in integration effort compared to blade antennas, the total costs of such a system are still notably below that of a wrap-around antenna. Several ground tests and flight experience have shown that the patch antenna configuration slightly outperforms the blade antenna combination in terms of obtained carrier-to-noise ratios and multipath mitigation.

7.15.5.1 Wrap-around Antennas

In the domain of RF technology, so-called conformal or wrap-around antennas are certainly the most sophisticated solutions in terms of performance and omnidirectionality of the antenna pattern (see Figure 7-20). Wrap-around antennas are essentially a type of cylindrical microstrip antennas. They promise good signal coverage and continuous satellite visibility even under spinning or tumbling motion. On the other hand, wraparound antennas require a special milling of the sounding rocket structure and occupy a notable fraction of the available payload surface. Apart from that, the use of wrap-around antennas is further restricted by high procurement cost as well as export limitations. Wrap-around antennas are available off-the-shelf for several standard rocket diameters. In general, they are passive and therefore need to be supplemented by a suitable LNA.

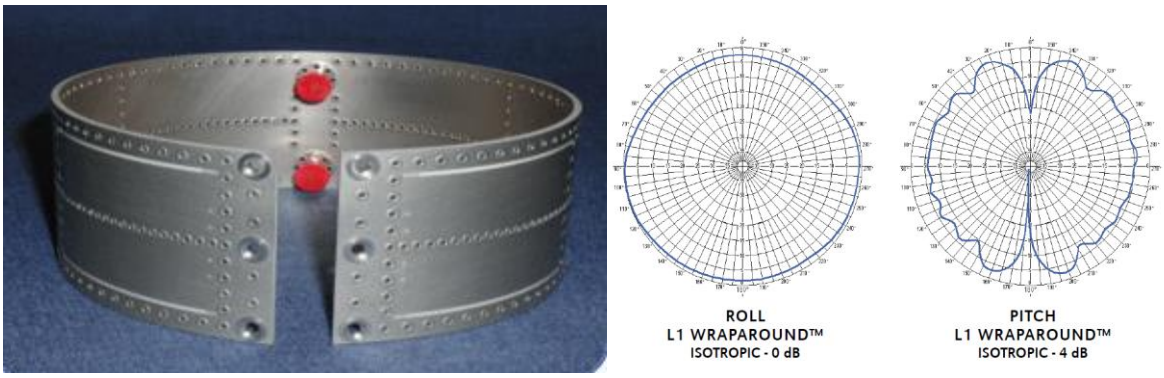

Figure 7-20: Picture of a wrap-around antenna (left) and transmission pattern in horizontal (middle) and vertical (right) direction (Credit: Haigh-Farr Inc.)

7.15.5.2 Blade Antennas

Blade (or hook) antennas (Figure 7-21) are widely employed in aeronautic and aerospace applications for telemetry and telecommand data transmission. They are known for their resistivity against high temperatures and mechanical stress. For use in GPS applications, the antenna design had to be modified to match the GPS frequencies. To achieve a near full sky visibility, a minimum of two antennas is required, attached to the walls of the rocket opposite each other and connected to the receiver via a power combiner. Compared to wrap-around antennas, a blade antenna system can be manufactured at less than 10% of the overall system cost. On the other hand, a blade antenna exhibits linear polarization, which implies a 3 dB gain loss when used with right-hand circularly polarized GPS signals and a lack of multipath suppression. This is not a fundamental disadvantage, since the total gain of the antenna system can be adjusted by suitable amplifiers and since no reflecting surfaces other than the rocket body are present during the flight.

Figure 7-21: GNSS blade (or hook) antenna for the GPS L1 frequency

7.15.6 Low Noise Amplifier

A low noise amplifier (LNA) is generally required in the antenna branch to amplify the GPS signals to a level suitable for the GPS receiver's RF input and to compensate the losses in the RF cables between the antenna and receiver. While GPS antennas for terrestrial applications often have an LNA already built-in, most of the aforementioned solutions for rockets and space vehicles use passive antennas and thus require external amplification. Since the required amplifiers are not exposed to the outside environment as the antennas on-board a rocket, the electrical and mechanical requirements are less stringent for these devices. This allows the use of commercial products, widely available on the market in many forms and qualities.

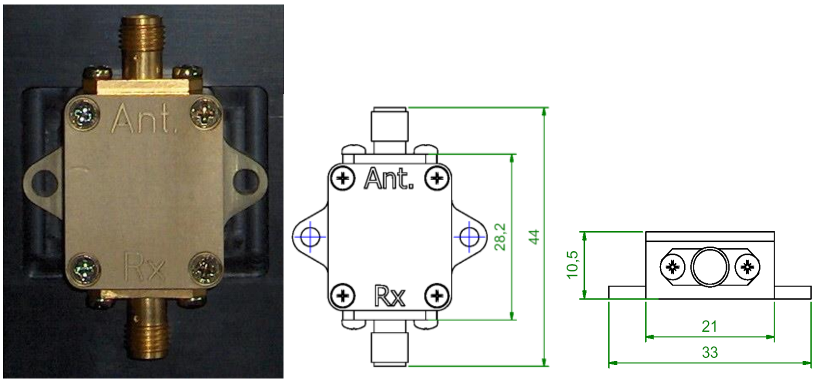

Figure 7-22: Example for a GNSS L1/E1 low noise amplifier (DLR DL1A)

Parameter	Value
Semiconductor	GaAs (0.5 Ωm)
Frequency	1.575 GHz (1.4- 1.8 GHz)

Impedance	50 Ω
Gain (min/nom/max)	25 / 27 / 29 dB
Noise figure (nom/max)	1.15 / 1.4 dB
Input VSWR	2.0:1
Output VSWR	1.5:1
Max. input power	17 dBm
V_{DD} (nom/max)	5 / 10 V
Bias current (min/nom/max)	15 / 20 / 25 mA
Power consumption (typ)	0.1 W
Operating temperature	-40 °C … +85 °C
Storage temperature	-65 °C … +150 °C

Table 7-5: Electrical and environmental parameters of the DL1A low noise amplifier

Some receivers have a built-in signal amplifier in their RF branch. Theoretically, these receivers can be operated directly with a passive antenna. However, experience has shown that this usually works only when the antenna is directly connected to the receiver, without any cable connected between antenna and receiver. It is strongly recommended to perform a functional and performance test with the planned combination of antenna and receiver in a representative configuration, before the final design is frozen.

7.15.7 Exemplary Flight Configuration

Figure 7-23 shows a GNSS antenna system concept, successfully validated in the framework of numerous sounding rocket missions. The configuration employs a tip antenna for the signal reception during the propelled flight phase up to nosecone separation. This makes the system ideally suited for spinning vehicles. After de-spin and nosecone separation, the receiver is switched to the dual-blade antenna sub-system, providing the receiver with GPS signals during the free-flight and re-entry phases. Switching between the individual antennas is accomplished by an RF relay controlled either by a timer or a break-wire in the nose cone. For non-spinning vehicles, the system can be simplified significantly by omitting the tip antenna.

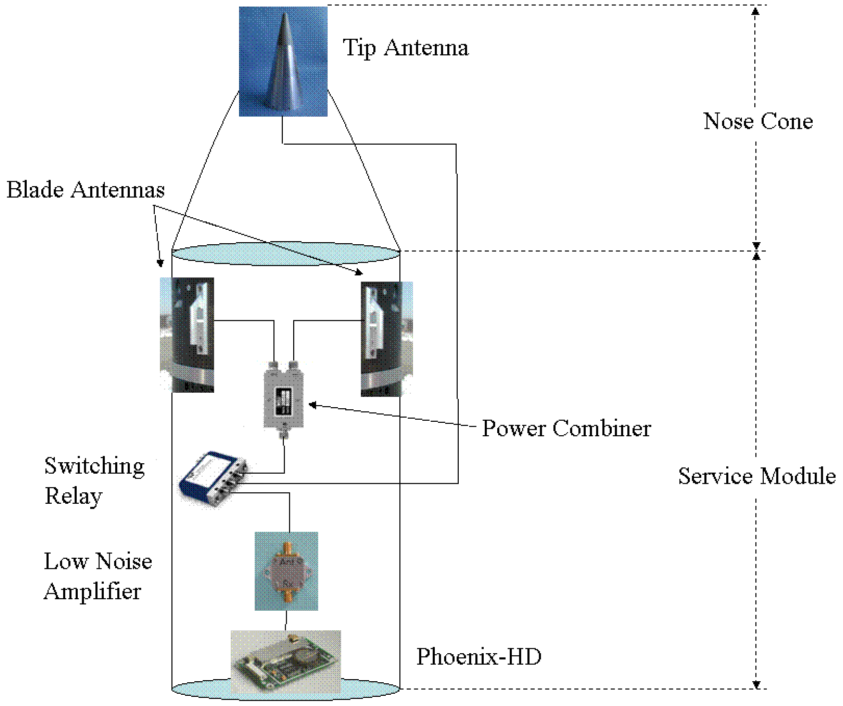

Figure 7-23: Exemplary flight system configuration employing a tip antenna for the propelled part of the flight and a dual-blade antenna combination for the free-flight and re-entry phases.

8 GENERAL DESIGN CONSIDERATIONS

When designing a rocket experiment, future testing efforts should be considered from the beginning, especially regarding accessibility. Fast and simple methods for testing, calibrating, or adjusting important items will save a lot of additional effort if considered early in the design phase.

8.1 Experiment Accessibility

Bear in mind that designing for accessibility will make your task easier throughout the assembly and testing phases. This important aspect is often overlooked by experimenters. It is in your interest that items such as fasteners, switches, battery packs and cable connections are easy to access.

8.2 Availability of Parts

A major issue for many experimenters is late delivery and procurement delays. Rather than relying on the availability of off-the-shelf parts, ensure that they are in stock. This can save a lot of time and money for experimenters. Avoid designs based on parts which are difficult to obtain or irreplaceable where possible.

8.3 Experiment Construction Costs

Consider requesting a minimum of three quotes for the order of components where possible (this is often not possible due to the uniqueness of some components). When designing, remember that the cost for machining can differ greatly depending on early design decisions. Avoid tight tolerances wherever possible, in order to make the design as well the assembly of components easier. Remember to use experience and judgement; the cheapest items are not always the best selection. Although it is a good practice to try to get cheap components, try find an optimal balance between cost and reliability of components. If you are in doubt, contact your ZARM/DLR or SSC/ESA supervisor.

8.4 Redundancy

Redundancy is desirable, in particular if safety or failure risks are involved. For mechanical systems, redundancy is not as simple to achieve as it is for electrical systems, yet it should be considered during the design process nonetheless. In many cases, redundancy can be simply achieved by separate battery packs, multiple switches, check valves, and other solutions.

8.5 Mass and Size Considerations

Mass reduction is an aspect which is often neglected by experimenters. Lighter experiments offer several benefits though: they can be arranged in a more flexible manner, and more experiments can be flown on a single vehicle. It is recommended to provide system design solutions (e.g. component placements, CAD drawings) as soon as possible to evaluate the mechanical design and to implement mass saving measures where feasible.

8.6 Effectiveness of Testing

When designing your experiment, please consider that the experiments need to be tested several times before launch. Both, the overall experiment design and the accessibility of the hardware are of great relevance here. Fast and simple methods for testing, calibrating, or adjusting important items will save experimenters' time and will facilitate tests carried out by EuroLaunch.

8.7 Safety

Safety is of utmost importance to EuroLaunch. Any experiment that is deemed risky to the public, staff or experimenters will not be flown. Ensure that all required simulations, analyses, and tests are performed that will help to convince EuroLaunch that the experiment is safe to fly. If there are any aspects that you can identify as safety risks, keep in mind during the design process that the experiment might ultimately be removed from the vehicle if it poses any danger.

8.8 Pyrotechnics

Pyro Cutters are used for deployments of hatches and/or FFUs on REXUS mainly. To raise the rate of success, we provide this **"**How To**"** with useful hints for correct assembly and suitable cable(s). If there are still open questions, feel free and ask your experts.

The TRW Pyro Cutters are **single-use** items. General information about the TRW Pyro Cutter can be found in Table 8-1 and Figure 8-1.

Product:	TRW Kabeltrenner (Cutter) #77003198
Distributor:	TRW Airbag Systems GmbH Wernher-von-Braun-Straße 1 84544 Aschau am Inn Germany
Provided by	**DLR/ZARM**
Version	Type A
Application	Cutting of steel cables
Temperature Ranges	Working temp.: -40 - 85 °C Storage temp.: -54 - 71 °C
Connectors	Straight version with reversed locking legs: FFR 180-3 Right angle version with reversed locking legs: FFR90-3/FFT90-3
Safe ignition	>1.2 A / 2 ms / -40 °C (99.9999%) → *recommended duration for REXUS ≤1s*

No ignition	<0.4 A / 10 s / +95 °C (99.9%)
Bridge resistance	2.1 +/- 0.4 Ohm
Qualification	AK-LV16 (03-2006) / SAE/USCAR-28 (06-2005)

Table 8-1: General Information of the TRW Pyro Cutter

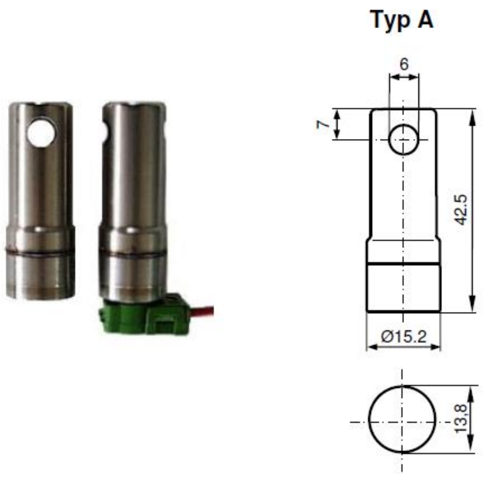

Figure 8-1: Picture and dimensions of the TRW Pyro Cutter

The object to be cut (cable, rope, etc.) has to be guided through the hole of the cutter. Plug the ignition cable on the electrical interface of the cutter. **Listen to the „click“** which indicates a correct plug. During this process, the short-circuit plug on the connection contact is opened and the reversed locking legs reached their final position. The short-circuit plug reliably prevents unintentional pyro activation. When providing the correct electric current, the pyrotechnic charge is ignited. This accelerates the piston of the cutter and cuts the inserted object similar to a chisel. The TRW pyro cutters are not covered by the German Explosives Act. Approvals for postal and rail transport for the Federal Republic of Germany are available.

Safety instructions and preparations

TRW Pyro Cutters and steel cables must be prepared wearing safety goggles and cut resistant gloves to prevent injury from sharp cable ends when handling those cables before and after the cut. Be aware of free-flying small particles during the cut. Ensure a stiff and proper fixation of the pyro cutter, because the entire cable cutter is subject to intense recoil when ignited.

Recommendations regarding cables and cable mounting:

The distributor of the TRW Pyro Cutters provides a datasheet with dimensions and electrical connections only. There are no suggestions for cable material and diameter and also no introduction how the cables have to be assembled optimally.

Table 8-2 lists the results of previous tests.

Position	Diameter [mm]	Number of cables	Kind of cable (see list below)	Success/Failure
1	3.0	1	A	Failure
2	2.0	1	B	Success
3	1.5	2	B	Failure
4	1.5	2	D	Success
5	0.8	4	C	Success
6	2.0	1	E	Failure
7	Thread M3	1	F	Failure
8	Thread M2	1	F	Success
9	3.0	1	G	Success
10				

Table 8-2: Material and diameter test results of TRW cutter.
Cable legend: A – Steel wire rope construction with centre made out of PA, B – 19 fibres Steel wire rope construction 1x19, C – 49 fibres Steel wire rope construction 7x7, D – 133 fibres Steel wire rope construction 7x19, E – Bicycle Spoke 2mm, F – Thread, stainless steel quality A2, G – Dyneema rope HDPE fibers.

To ensure optimal conditions for the cut, the minimum distance between the cutter and the fixation of the steel cable (clamps) must be >=50 mm (see Figure 8-2). The left end shows a designed clamp for the fixation of two ends of the steel cable. The right cable ends are much longer than shown in the image and will be connected to the Hatch or FFU.

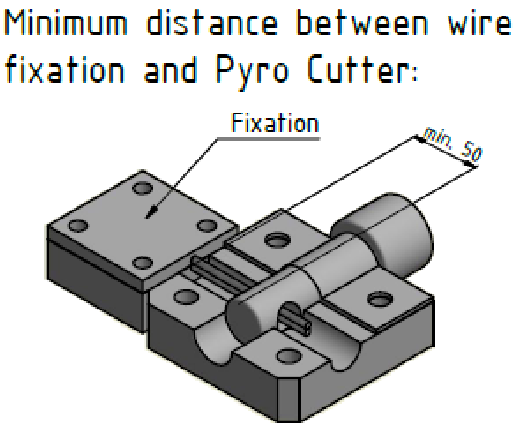

Figure 8-2: Minimum distance between the cutter and the fixation of the steel cable

While fixating the cutter, ensure that the steel cable(s) is in contact with the upper cutting edge of the pyro cutter (see examples in Figure 8-3).

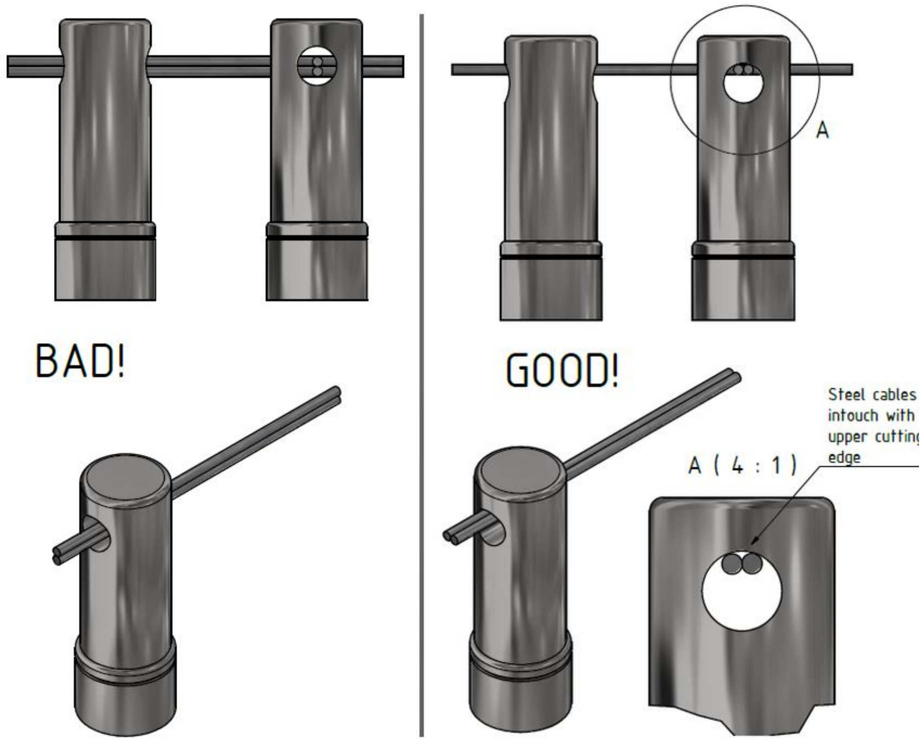

Figure 8-3: Pyro Cutter cable feedthrough

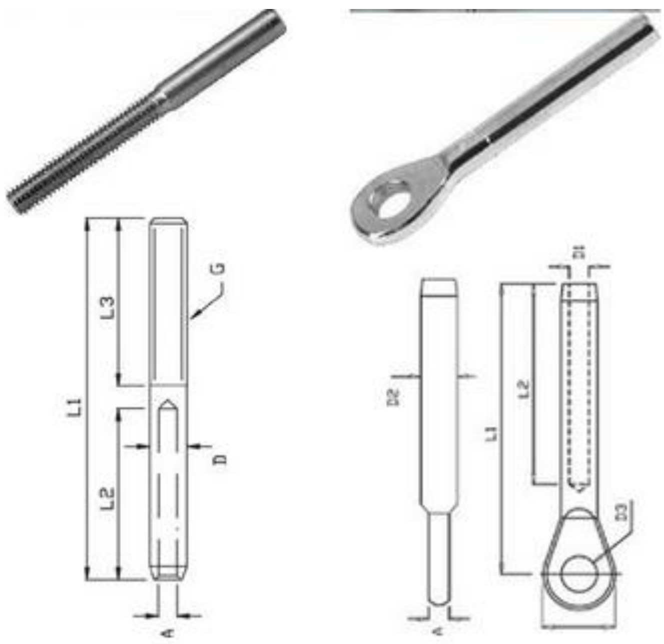

Figure 8-5: Cable with mounted terminals

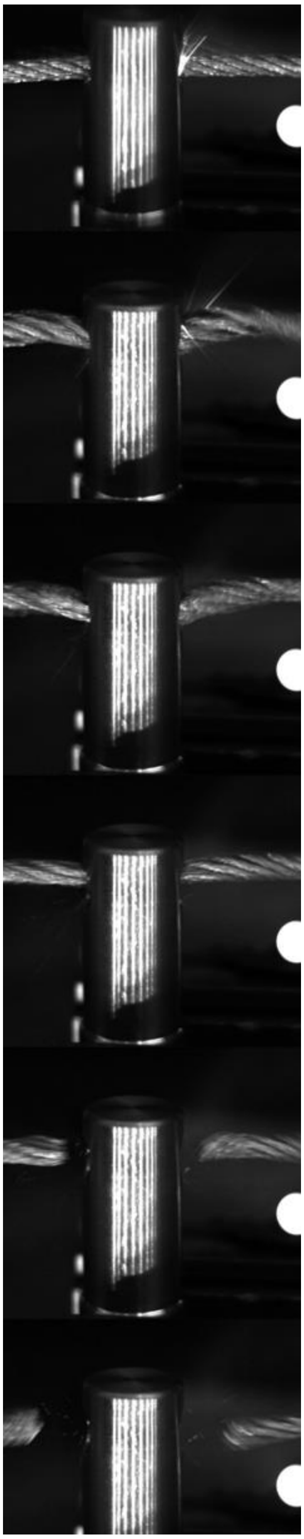

Figure 8-4: Pyro cutter activation

General information:

- Electrical connection: Before plugging the electronic connector, ensure zero potential on the pins.
- Ensure a stiff and proper fixation of the cable ends.
- To prevent slipping of the steel cable inside the clamp, fixate the longer ends separately, too.
- Consider the procedures how to tension the steel cable in a reproducible manner and provide a checklist.
- Perform load tests of the cable fixation.
- Document any preparation and test result.
- Prefer cables with mounted terminals instead of just unprepared cable ends, for example a thread M5 (Figure 8-5, left side) or a loop or a hook or an eyelet (Figure 8-5, right side).
- A manufacturer in Germany of cables with terminals/cable ends is: C.G. Ahrens; www.cgahrens.de
- Consider that the breaking loads of terminals are often less than the steel cables (approximately 50%). Ask for datasheets for the wanted cable configuration.
- **Seal and cover the cutting area to prevent small particles from contaminating the payload, your or others experiments.**

Figure 8-4 shows the pyro cutter activation in steps of 1 ms. (High speed recording with 1000 samples per second, source: ZARM)

8.9 Radio Silence/Dead Payload

The launch range has strict rules regarding Radio Silence, which have to be followed at any time. As a consequence, your experiment must be designed in such a way, that it can be brought in a safe status at any time. This means in particular for experiments with an independent power source (e.g. FFUs, heating systems) to implement a fail-safe functionality to ensure the design is compliant with radio silence requirements (See also chapter 7.10).

9 STRUCTURAL ANALYSIS GUIDELINES

9.1 General

For some experiments, a structural analysis could be necessary to investigate the influences of loads during the rocket flight. In general, this is recommended for every experiment. Please consult your ZARM/DLR or SSC/ESA supervisor.

In the following, some guidelines concerning structural analyses are given with respect to the field of aerospace engineering, especially, but not limited, to lightweight airframe structures. These guidelines shall be seen as a short reminder/summary and not as a reference or text book.

9.2 Unit System

In the field of aerospace engineering, the SI unit system shall be used for structural analyses. The gravitational acceleration is assumed to be g = 9.81 m/s². Thus, the mass to weight ratio is m/w = 0.1019 s²/m.

Parameter	*SI* units
length	[m]
time	[s]
frequency	[Hz]
force	[N]
moment	[Nm]
pressure, stress	[N/mm^2]
density	[kg/m^3]
mass	[kg]

Table 9-1: SI-Unit System

Always perform a unit system consistency check when performing a FEM analysis.

9.3 Materials

For structural analyses of components, the geometry as well as the material properties are crucial. Approved and recommended material databases are:

- ESA Material Handbooks
- Werkstoffhandbuch der Deutschen Luftfahrt
- Metallic Materials Properties Development and Standardization (MMPDS) Handbook, Etc.

Non-approved references are for example:

- diverse material data sheets from material suppliers
- material data from the internet
- software databases

9.4 Analyses

Depending on the structural load envelope, two general conditions can be identified: quasi-static and dynamic loading. For both of them, the following analyses might be relevant.

9.4.1 Strength Analysis

A strength analysis investigates the stress state of a certain structure under a certain loading condition. The resultant stress state is then compared to the allowable stress of the material of the structure. In addition, a margin of safety is calculated. Most of the stress-states cannot assume to be universal-axial (e.g. idealised tensile rod). Thus, bi-axial or even tri-axial stress states might occur. In the case of multi-axial stress states, an equivalent stress has to be determined using a suitable hypothesis (e.g. von-Mises for ductile metallic materials) for the structure’s material. This equivalent stress is then compared to the allowable stress of the material and a margin of safety is calculated.

9.4.2 Stiffness Analysis

Apart from the stress state, a structural design can be derived from possible deformations/deflections and from its stiffness. A typical example for a stiffness driven design is a simple beam bridge which sustains the stress introduced by a person walking across, but if the bridge bends too much, eventually it sinks below the water level, and the bridge is considered unusable. Therefore, structural stiffness is another important part of analysis. However, finding the allowable loads is not always as simple as it is for the beam bridge problem.

9.4.3 Buckling Analysis

Most lightweight structures have a thin walled, slender design. Thus, stability problems are the major design focus, when these structures are exposed to compressive loads. In these cases, it is mandatory to perform buckling analyses since buckling failures quite often occur at much lower stresses than the material's compressive strength.

9.5 FEM Modelling

Simulations using the Finite Element Method (FEM) are an essential part of the structural development process. FEM software became more and more user-friendly on one side, but since these programs can often be regarded as "black boxes", it is very important to check the model assumptions and verify them.

9.5.1 Geometry and Mass Properties Check

Check that the FEM model's masses, CoG, inertia moments and dimensions are in accordance with the engineering drawings and plausibility calculations. Check that the coordinate systems of the model (e.g. load systems, Boundary Conditions (BC) systems, global system, material systems) are consistent with regard to origin, axes assignments and orientation.

9.5.2 Type of Solver/Solution

Depending on the structural problem, consider the following:

- Are the expected deformations small? Yes → linear analysis, No → nonlinear analysis
- Are contact problems involved? No → linear analysis, Yes → nonlinear analysis
- Is nonlinear material behaviour expected? No → linear analysis, Yes → nonlinear analysis
- Eigenfrequency, buckling and dynamic analyses require solver/solution types different from those of static problems!

9.5.3 Mesh Check

During and after the FEM modelling, the quality of the respective idealised geometry needs to be verified regarding following aspects:

- Type of elements (shell, beam, bar, rod, solid, etc.) adequate for the structural problem to be investigated.
- Mesh density.
- Quality of elements: Taper, aspect ratio, skew angle, Jacobian ratio, etc..
- Coincident elements and/or nodes.
- Free nodes.
- Free edges/faces.
- Correct material assignment.
- Correct element properties assignment.

For most of these mesh quality checks, internal checker of respective FEM software are available. For other checks, an engineering decision based on a fundamental understanding of structural mechanics as well as further FEM analyses are needed.

9.5.4 Solver Input Check

Once the FEM model has been prepared and is ready for simulation, a thoroughly check of the solver input data is strongly recommended. A FEM computation can be divided into pre-processing, processing and post-processing; these individual steps are either done by different software applications or different parts of the same software. However, the communication between these steps is done via input and output data files. It may happen that errors occur during the pre-processing phase and remain undetected during the whole simulation resulting in incorrect results. A check of the solver input data file is therefore essential. This also implies that communication between different design parties shall be done exclusively by exchanging the solver input and/or output data files; this is state of the art in aerospace industry!

9.5.5 Free-Free Check

The free-free check shows that the model behaves as a rigid body when unconstrained. Therefore, all constraints are removed and an Eigenmode solution is performed. As a result, six Eigenfrequencies close to zero (< 10-2) with rigid body motions in all six Degrees of Freedom (DOF) should be observed. If more than six Eigenfrequencies close to zero are observed, there might be additional DOF, e.g. due to loosely connected components. If less than six Eigenfrequencies are observed, there are illegal constraints in the model.

9.5.6 1-g Check

The 1-g check verifies that the model provides meaningful results under a 1-g inertial loading. All constraints are applied to the model and a unit gravity loading of 1-g is applied to each translational DOF. The respective results should show reaction forces and moments only be obtained at the constrained locations. The reaction forces should add up to the total weight for the model in the input loading direction and should be zero for all other directions for a linear solution.

9.5.7 Residual Loads, Deformations and Strain Energy Check

This check verifies that the residual loads, deformations and strain energy are close to zero in an unconstrained model condition when performing an Eigenmode solution. Any non-zero values indicate geometry modelling errors or numerical round-off errors.

9.5.8 Unit Temperature Check

The unit temperature check verifies that the model provides accurate displacements induced by temperature loading. Here, one node of the model is constrained in all six DOF and all expansion coefficients as well as reference temperatures are set to the same value and a unit temperature increase is applied. As a result, all strains and stresses throughout the model should be zero. A comparison of the distortion shall be performed by cross-checking with a simple hand calculation.

9.5.9 Dedicated Load Case

When a load is applied, check the model for singularities, small deformations, force equilibrium and residuals. For this purpose, a realistic load case and appropriate constraints shall be used. As a result, the constraint forces and moments shall be in equilibrium with the applied external forces and moments. No inappropriate singularities should exist in the model. The normalised value of residual loading should be small (e.g. NASTRAN Epsilon < 10-8).

9.6 Results

A structural analysis is finished with a meaningful interpretation of the results. It is not enough to present numbers or color-coded plots alone. Please consider the following important steps.

9.6.1 Singularities

Singularities generally reduce the accuracy of the model and should be corrected or constrained. For linear analyses, they can be caused by:

- Missing Elements.
- 2D Shells with normal rotation unconstrained (e.g. NASTRAN).
- Solid model with unconstrained rotational DOF at the corners (e.g. NASTRAN)
- Incorrect beam offset modelling.
- Incorrectly defined multiple point constraints
- Mechanisms (e.g. hinge) and free bodies.
- Low rotational stiffness.
- Abrupt stiffness changes.

9.6.2 Post Processing

The post-processing of the results is generally performed by the software's post-processor. Both, the solver settings and the post-processor settings are highly relevant:

- Check non-interpolated result plots for peak values (most likely occurring at erroneous elements).
- Verify that plots show data in the correct coordinate system.
- Check results of the interpolation method.

9.6.3 Plausibility

For plausibility purposes the FEM results shall be reviewed:

- Check single point constraint forces for correct reaction of the respective structural problem.
- Check global deformation of the model showing the expected behaviour.
- Compare the FEM result's magnitude with simple analytical hand calculations.
- Compare with test results, if available.
- Use engineering judgement.

9.6.4 Margin of Safety

When presenting the results, calculate the margins of safety for each result against each material allowable and list them in a table.

10 ENVIRONMENTAL TESTS PERFORMED BY THE EXPERIMENT TEAMS

Environmental tests are performed in order to verify a nominal function of the experiment during the 'worst case' environment exposed to during countdown, launch and flight.

10.1 Vacuum Test

Vacuum tests are not only carried out for experiments which will be operated under vacuum conditions, but also help to verify that (electrical) systems show nominal performance in the absence of convective cooling. It is the responsibility of the experiment team to perform this test.

Basic Procedure:

- The experiment shall be placed in a vacuum chamber (pressure below 0.5 mbar).
- Experiment data shall be monitored and recorded during the test.
- The experiment shall be operating during the lowering of the pressure in the vacuum chamber. The experiment shall be in a similar mode as during the real ascent of the flight.
- After the functional test/flight sequence, it is recommended that the experiment is kept in operation for additional 15 minutes, in order to detect any leakages or overheating problems.
- When testing high voltage subsystems (U > 40 V), corona effects shall be searched for within the pressure interval of 1-20 mbar.

10.2 Thermal Test

To verify the characteristics and behaviour in space environment, a system must undergo extensive thermal testing during the verification process. Unlike mechanical tests which mainly test the behaviour during the launch phase, thermal vacuum tests focus on the qualification of the operational phase in space. Thermal tests have to be performed on subsystems which will be operated under vacuum conditions as well as for the verification of (electrical) systems, in order to demonstrate nominal performance in the absence of convective cooling.

The extreme ambient conditions space structures are exposed to place highest demands on materials and reliable functioning of the entire systems. In thermal test facilities, inaccuracies of theoretical computer models are detected facilitating the optimisation of these models. Under simulated space conditions, the reliable functioning of components and systems is tested. The scope of thermal test is to verify the performance of the rocket payload during the worst-case temperatures which can be experienced during the transport, countdown and flight.

The heating of the outer structure during ascent is normally not included or tested. It is the responsibility of the experiment team to perform this test. It is recommended to test the experiment if the temperature application in Table 10-1 applies to your situation:

Situation	Temperature [°C]	Time frame
Pre-Launch		
Unheated wheeled transport	- 30	Days
Integration area	20 ± 5	
Roll out	- 30 till 20	Hours
Countdown		
Launcher housing	17 ± 7	Days
Unheated Launcher housing	- 30 till 25	24 h
Flight (depends on the project)		
Post Flight	-30 till 25	Days

Table 10-1: Temperature values experienced by the experiments

Basic Procedure:

- The experiment shall be placed in a thermal chamber. The Ground Support Equipment (GSE) shall be connected via the umbilical. The telemetry and telecommand checkout system shall be connected via the interface harness.
- Experiment data shall be monitored and recorded during the test.
- The temperature shall preferably be measured at several places in the experiment.
- Low temperature test:

  Adjust the temperature in the thermal chamber to -10 °C. When the measured temperatures in the experiment have been stabilised, perform a functional test/flight sequence. Be aware of condensation problems if the test is performed at normal humidity.
- High temperature test:

  Adjust the temperature in the thermal chamber to +45 °C. When the measured temperatures in the experiment have been stabilised, perform a functional test/flight sequence. During the transition from low to high temperature, the experiment shall be in operation and data shall be recorded.

10.3 Vibration Test

A vibration test shall be performed to verify that the individual experiment as well as the complete payload stack can withstand the vibration loads during the launch of the REXUS single stage Improved Orion vehicle. It is the responsibility of the experiment team to perform the vibration test of the individual experiment. The individual vibration test should be performed before the Integration Week (ITW) at an institution selected by the experiment team. At latest, the individual test shall be performed during the ITW at ZARM. The respective test requirements are based on specifications from the NASA Sounding Rocket Hand Book (NSRHB), where Table 10-2 has been taken from.

	Vehicle Level One	Vehicle Level Two
SINE	Sweep Rate: 4 oct./min. Test Profile: 3.0 in./s 10-144 Hz 7.0 g 144-2000Hz **THRUST AXIS ONLY**	Sweep Rate: 4 oct./min. Test Profile: 3.84 in./s 5-24 Hz 1.53 g 24-110 Hz 3.50 g 110-800 Hz 10.0 g 800-2000 Hz **THRUST AXIS ONLY**
RANDOM	Duration: 20 sec./axis Thrust Axis Spectrum: 10.0 grms 0.051 g^2/Hz 20-2000 Hz Lateral Axis Spectrum: 7.60 grms 0.029 g^2/Hz 20-2000 Hz	Duration: 10 sec./axis Spectrum: 12.7 grms 0.01 g^2/Hz 20 Hz 0.10 g^2/Hz 1000 Hz (on 1.8 db/oct. slope) 0.10 g^2/Hz 1000-2000 Hz **SAME IN ALL AXES**
TEST INFO	**LEVEL 1 VEHICLES** Single Stage Improved Orion Terrier MK12 – Improved Orion Terrier MK12 – Malemute Terrier MK12 – Lynx	**LEVEL 2 VEHICLES** Single Stage Black Brant Terrier MK12 – Improved Malamute Terrier MK70 – Improved Orion Terrier MK70 – Malamute Terrier MK70 – Improved Malamute Terrier MK70 – Lynx Terrier MK70 – Oriole Black Brant IX Black Brant X Black Brant XI and XIa Black Brant XII and XIIa

Table 10-2: Specified vibration loads taken from NSRHB

10.3.1 Acceptance and Qualification Testing

From (NASA Sounding Rockets Program Office, 2015), DLR MORABA has adopted **vehicle level one as acceptance level** and **vehicle level two as qualification level**. The NSRHB gives the following guidelines for both levels:

Qualification Testing

New component designs are required to undergo design qualification testing. These tests expose items to environments that are more severe than those experienced throughout the mission. This ensures that the design is sound and that there is high confidence that failure will not occur during a mission. Components that undergo qualification testing are not used for actual flight. Typically, a Qualification procedure is followed for components and a Qualification Report shows the results.

Acceptance Testing

Previously qualified component designs and all fully assembled payloads (new or re-fly) must undergo acceptance testing, which exposes test items to the environments that mimic those experienced during a mission. These tests are the final gauge for determining the launch worthiness of a component or payload.

As DLR MORABA follows a prototype approach also qualification tested hardware can be used as actual flight hardware as long as no failures have been identified. According to the NSRHB acceptance test requirements, vibration testing has to be performed on fully assembled payload level. However, if a complete payload stack cannot be tested due to test house or shaker limitations, DLR MORABA requires vibrations testing to be done on module level only, but using the qualification level (vehicle level two) instead.

10.3.2 Sine and Random Loading

For both vehicle levels one and two, sine as well as random test loads are specified by the NSRHB. Hereby the random test is mandatory for each performed vibration test as specified in Table 10-2, whereas the decision for an additional sine test is up to the individual experiment conditions and the responsible payload as well as test manager/engineer. The flow chart in Figure 10-1 serves as a guideline for the required tests.

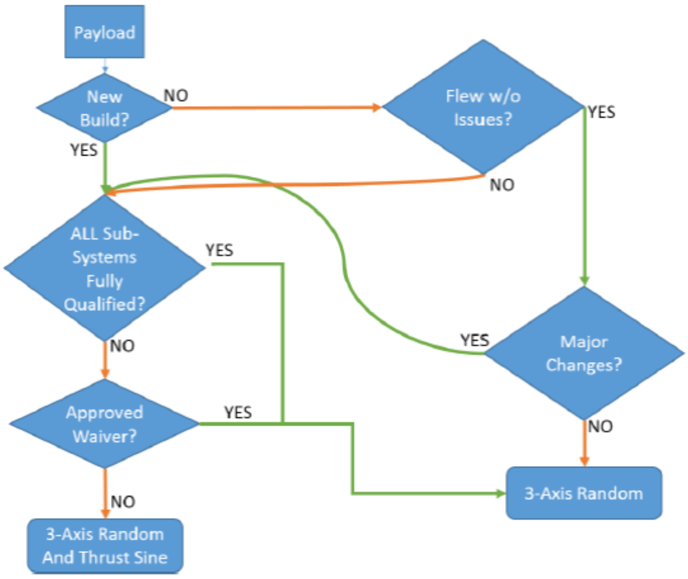

Figure 10-1:Sine/Random test decision flow chart taken from NSRHB

The test duration to be applied for random testing shall be 50 s each run and has been adapted by DLR MORABA compared to the NSRHB specifications.

10.3.3 Resonance Search

Each sine and random test run have to be imbedded in a sine search run before and after testing, where the relevant Eigenfrequencies of the test setup have to be measured and compared with each other, identifying possible resonance cases as well as damages/changes in the test setup's mechanical behaviour. The sine search run shall be performed according to the specifications given in Table 10-3.

Working axis:	X, Y, Z	
Frequency range & level:	20 - 2000 Hz	0,25 g
Sweep rate:	2 oct/min	
Control strategy:	Maximum control of C1, C2	

Table 10-3: Sine search run specifications

In the case of serious resonance loads, respective notching can be performed during sine load testing.

10.3.4 Basic Procedure

The following bullet points shall give a basic guideline for a typical vibration test cycle:

- Decision to be taken for acceptance or qualification level test loads → see section 10.3.1
- Decision to be taken for pure random or additional sine load test run → see section 10.3.2

- The experiment shall be mounted on the vibration table with a suitable fixture. Critical parts shall be equipped with accelerometers, in order to track the response curves.
- Vibration run in x, y and z-axis shall be performed as specified → see Table 10-2
- Before and after each load test run, a resonance search run at specified level shall be performed to evaluate the significant Eigenfrequencies and damages/changes of the test setup → see section 10.3.3.
- Functional tests and inspection shall be performed after each test load run.

11 PRE-CAMPAIGN ACTIVITIES

11.1 Esrange Safety Board (ESB)

Every campaign or project at Esrange has to be accepted by the Esrange Safety Board (ESB). For standard payloads, the acceptance by ESB is normally given without difficulty. If there are hazardous items included in the experiments such as chemicals, free falling objects, lasers, radiation, etc., there may be a need for further investigation. This may take some time and should be examined early in the design process, preferably well ahead of the start of the launch campaign.

11.2 Ground Safety Plan - Questionnaire

The ground safety policy at Esrange Space Center is to conduct operations with a minimum of risk to all personnel involved. It is required that all systems are designed in such a way that a minimum of two independent unlikely failures must occur in order to expose personnel to a hazard.

Thus, following steps are important:

1. Identify all the known hazards associated with the project.
2. Identify all situations that require ethical evaluation (e.g. experiments on live animals, GMO etc.)
3. Implement safety criteria.
4. Minimize exposure of personnel to hazardous systems.
5. Establish safe operating procedures.
6. Plan for contingencies.

The Ground Safety Plan - Questionnaire (GSP-Q) provides input to Esrange to enable safe handling on ground as well as in flight of Range User equipment. It is mandatory for you to prepare the GSP-Q and return it to Esrange. The information provided will be used by the Esrange Safety Board (see section 11.1) to assess the safety of equipment provided by you.

11.3 Flight Requirements Plan (FRP)

The MORABA Project Manager provides all parties involved in the campaign with the Flight Requirements Plan (FRP). The FRP gives a complete description of the specific project, including payload description, a list of hazardous materials, experiment requirements on the launch operations, tools required, participants, etc. The purpose of this important document is to inform all participants about the campaign.

The first version of the FRP will be distributed before the Integration week. For the compilation of the FRP, inputs are extracted from the SEDs and/or requested from every experiment team, regarding interfaces, telemetry, power consumption and special experiment requirements.

11.4 On-board Camera Permission

This section is applicable for any experiment having at least one on-board camera pointing or likely pointing on Swedish land during the flight.

The experimenters are responsible to request the permission of photos/videos publication to the following authorities.

- **Esrange Security:**

  The experimenters shall request the **Esrange photography application form** to SSC take photos/videos of Esrange Space Centre. The application form shall be filled in and send back to SSC **prior to EAR**.

  Photos/videos shall be approved by SSC before publication.

- **Lantmäteriet (Swedish land)**

  The experimenters shall request approval from the Swedish authority Lantmäteriet before publishing photos/videos of the Swedish land.

  The request shall be done **after flight** by uploading photos/videos on Lantmäteriet website.

No publication or storage on a Cloud is allowed until approval.
The experiments shall notify SSC when approval is received.

For further information, see:
https://www.lantmateriet.se/en/webb/permit-for-dissemination-of-geographical-data/

11.5 Experiment Acceptance Review (EAR)

The manufacturing phase ends with the Experiment Acceptance Review (EAR). At the EAR, the experiment should be ready for delivery to EuroLaunch.

The EAR consists of:

- Experiment checkout/functional tests
- Experiment mass properties determination
- Mechanical and electrical interface checkout
- Electrical Interface Test (EIT)
- Flight Simulation Test (FST)

The EAR is performed by the Payload Managers from ZARM and SSC and supported by EuroLaunch, together with a representative from the student experiment team.

11.6 Payload Assembly and Integration Tests

This chapter covers the assembly of the payload and the tests conducted on the entire payload once it is assembled completely. It also defines the requirements regarding the status of the experiment modules upon delivery to the payload Assembly and Integration Tests (AIT).

The payload integration tests are performed at MORABA premises and/or premises leased by EuroLaunch. Nominally, these tests start five weeks before the planned start of the launch campaign.

At the beginning of the payload integration tests, all experiments comprising the REXUS payload must be made available to EuroLaunch. During some of the tests being performed, technical personnel trained to handle the experiment and ground support equipment shall accompany the experiment. During the AIT, the experiment must be in flight configuration. If the use of a dummy mass is required, this must be approved by EuroLaunch.

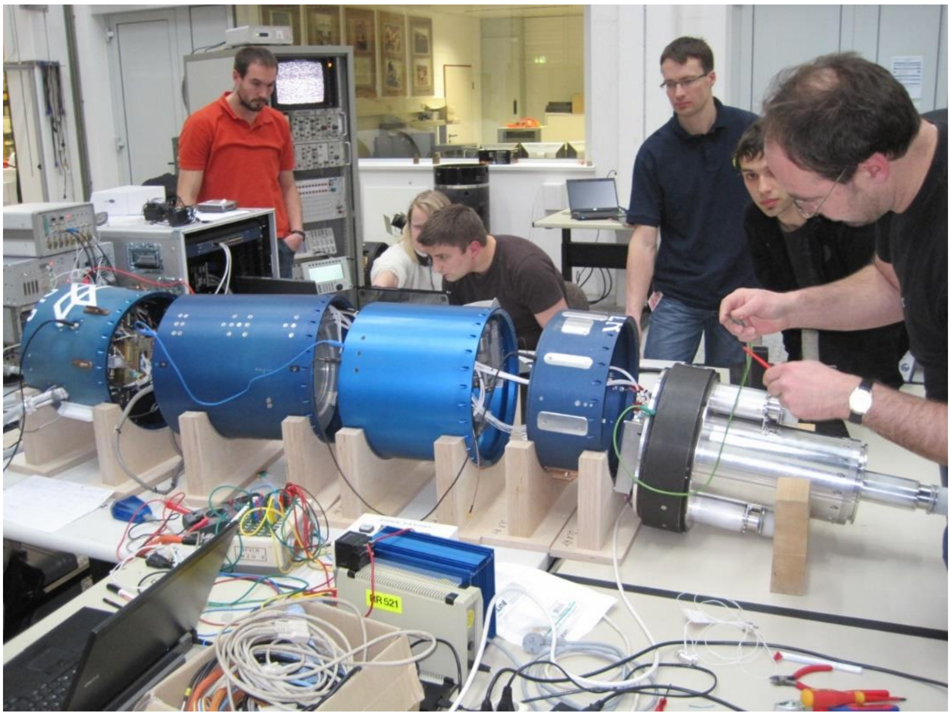

Figure 11-1: System Bench Test (REXUS-7 at DLR MORABA)

11.6.1 Experiment Status by Delivery

EuroLaunch strongly recommends that the experiment teams conduct the following qualification/acceptance tests before delivering the experiment:

- Electrical/functional tests
- Vibration tests
- Environmental tests
- Mechanical interface checkout
- Electrical interface checkout

Students should ensure that there is enough time to repair or fix any problems which arise during these tests.

11.6.2 Experiment Incoming Inspection

The experiment's mechanical and electrical interfaces will be inspected at delivery to the scientific payload Integration Week, Bench Test and launch campaign. In general, the Integration Week includes only the experiment modules, whereas the Bench Test includes the experiment modules, the service system, and if required for payload operation, the recovery system. The tests performed are very similar, but after the Bench Test, no further modifications can be made to the experiment modules.

11.6.3 Payload Assembly

The payload assembly will be performed during Integration Week and Bench Test. The experiments, other modules and subsystems will be mated to the payload. All the mechanical and electrical interfaces will be checked and tested systematically during the assembly.

11.6.4 Electrical Interface Test

The electrical interface test will verify the compatibility of the interfaces and the functioning of the respective hardware. Interface compatibility for critical signals, protection automatisms and voltage regulations will be checked systematically during assembly. Detailed procedures must be defined for each individual module or subsystem. This test is performed by EuroLaunch and the ZARM/SSC Payload Manager. The electrical interface test will be performed during Integration Week with a service system simulator. During the Bench Test, the complete payload including all subsystems (e.g. Service System, Recovery System) will undergo communication tests.

11.6.5 System Electrical Test and EMI-Check

These tests shall be performed with all flight hardware electrically operational and as far as possible, operating in flight configuration.

Telemetry transmission will be executed first via cable and then via the telemetry transmitter. All signals will be verified at the telemetry ground station. All subsystems shall be monitored via the dedicated Ground Support Equipment (GSE).

These tests are performed by EuroLaunch together with a representative from each student experiment team during the Bench Test.

11.6.6 Flight Simulation Test

This test shall be performed with the payload in flight configuration, as far as possible. The test procedure shall include the countdown procedure list and follow the nominal countdown timetable.

This test is performed by EuroLaunch together with a representative from each student experiment team during the Bench Test.

It is important that any modification made to hardware or software, after the Flight Simulation Test (FST), is restricted to a minimum. Non-conformances discovered during the test can be corrected, but care must be taken to verify that no further malfunctions are induced by the correction. All corrections after the FST shall be documented and reported to EuroLaunch. The test will be reproduced during the campaign.

Basic Procedure

- The experiment payload shall be integrated as in-flight configuration. The Ground Support Equipment (GSE) shall be connected via the umbilical. The telemetry and telecommand checkout system shall be connected via the interface harness.
- Module data shall be monitored and recorded during the test.
- A nominal realistic countdown procedure shall be followed, including at least one payload checkout. Switching between external and internal power shall be done at the nominal time (T-5 minutes).
- At lift-off, the umbilical shall be disconnected and the payload shall be controlled via TM/TC. The experiment sequence shall be as close as possible to the flight sequence.

It is also useful to perform a test with “unexpected” performance and to practise possible countermeasures. Examples of abnormal occurrences are:

- Interruption in internal power supply,
- Reset of on-board processor,
- Malfunction of subsystems, e.g. illumination is suddenly switched off.

11.6.7 Mass Properties Measurement and Balancing

Following the above testing, the integrated payload is shipped to Esrange, Sweden, where the mass properties of the integrated payload are measured and balanced. The following measurements are performed during Spin & Balance at Esrange:

- Payload Mass,
- Centre of gravity,
- Spin (Tip Indicator Run-Out, Static and Dynamic Imbalance),
- Moments of inertia.

During the balancing, the payload is subject to ~3 Hz spin for several minutes. Experiment teams do not have to be present for these tests.

11.7 Bend Test

A bend test is normally not performed. However, if such a test is necessary, the payload will be attached at the payload/rocket motor interface and a force will be applied perpendicular to the structure, giving rise to a torque on the payload/rocket motor interface. The deflection will be measured at three positions along the payload body.

If needed, these tests are performed by EuroLaunch.

11.8 Transport and Logistic

DLR MORABA will manage the transport and logistic of your experiment from DLR Oberpfaffenhofen (Bench Test) to Esrange (campaign). Therefore, you have to check some export details beforehand (three to four months before campaign).

11.8.1 Export Control

The export regulations of Germany, European Union and United States of America (see links below) have to be followed. The purpose of these regulations is, among other things, to prevent support of terrorist organizations or warlike actions.

Therefore, you have to list all items, check the delivery notes and ask your seller about any restrictions in case of the transport to Sweden.

- https://www.bafa.de/DE/Aussenwirtschaft/Ausfuhrkontrolle/Gueterlisten/gueterlisten_node.html
- https://www.bis.doc.gov/index.php/regulations/export-administration-regulations-ear

11.8.2 Dangerous Goods

Make sure that the packaging is suitable, approved for the good to be transported and labelled appropriately. You must highlight these items in your packing list and write down the dangerous goods information. Marking and labeling are important steps when preparing dangerous good for transportation. Marking means a descriptive name, identification number, instructions, cautions, weight, specification, or UN marks, or combinations thereof, required on outer packagings of hazardous materials or dangerous goods. Labels identify the specific primary and subsidiary hazards posed by the materials in a dangerous goods package. Whereas labels communicate the hazards associated with the freight (note the information in your packing list), markings ensure that the shipment is handled in such a way that spills, accidents and exposure are prevented. Therefore, they must be applied appropriately, provide the correct information, and comply with the regulations. Old labels have to be removed from the packaging. Figure 11-2 and Figure 11-3 give an overview about dangerous good labels and markings, respectively. Specific care has to be taken when transporting batteries (see also chapter 7.11).

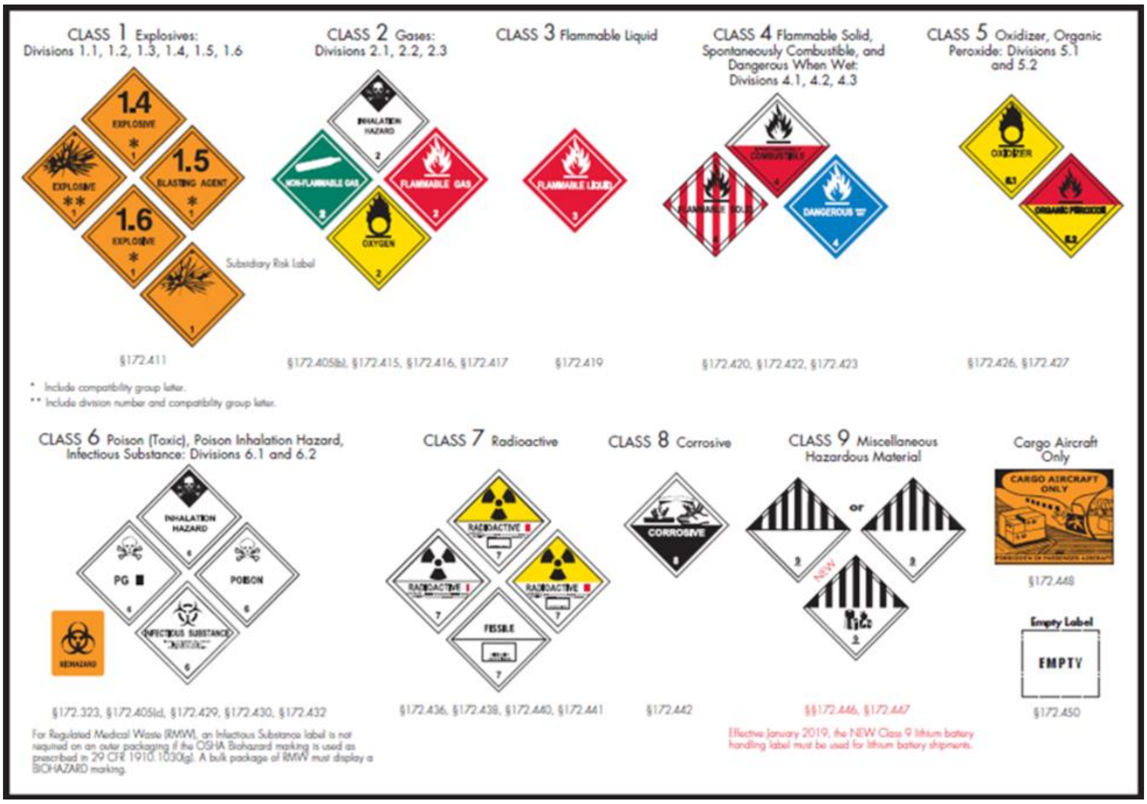

Figure 11-2: Hazardous material warning labels

Figure 11-3: Hazardous material markings [source: https://www.faa.gov/hazmat/safecargo/how_to_ship/mailing_labeling/]

11.8.3 Transport

Your experiment as well as your additional equipment will be sent to Esrange by container truck after the Bench Test.

Note: the truck will be on the road for a few days. Pack your equipment with regard to the weather conditions! (The container may be exposed to temperatures down to -20 °C) The container is equipped with a GPS and temperature tracker.

If any item can’t withstand the low temperatures, you should take it with you.

12 LAUNCH CAMPAIGN

The duration of a REXUS launch campaign is approximately 11 days excluding travel days. This does not allow any time for errors or delays, so it is important to be well prepared. Normally, the REXUS campaign takes place during spring time.

The Esrange Safety Briefing is setup virtually before the campaign. On campaign, there is a status meeting every morning in one of the Esrange conference rooms in order to discuss upcoming activities. An example campaign schedule is shown below.

Day 0	Travel day	
Day 1	Staff morning Meeting	Operation
	Morning Meeting & Welcome	Polaris
	Esrange round trip	
	Individual Experiment Preparation Team leader meeting with PMs	Payload integration building
	RXSM and Recovery System Preparation DLR EGSE Preparation DLR TM Station Preparation MRL preparation	Payload integration building DLR TM MRL
Day 2	Staff morning Meeting	Operation
	Morning Meeting	Polaris
	Individual Experiment Preparation Experiment Com Checks with RXSM	Payload integration building
	RXSM and Recovery System Preparation Recovery System Com Check Motor Adapter Fit Check DLR TM Station Preparation	Payload integration building DLR TM
Day 3	Staff morning Meeting	Operation
	Morning Meeting	Polaris
	Experiment Com Checks with RXSM Ground & Flight Safety and Recovery Meeting	Payload integration building
	Rocket A Bench Test	Payload integration building

	Final system check (ejection mechanisms)	
	DLR TM Station Preparation Arming Procedure Meeting	DLR TM Payload integration building
Day 4	Staff morning Meeting	Operation
	Morning Meeting	Polaris
	MET Briefing	Operation
	Rocket A Payload Assembly	Payload integration building
	Rocket A Flight Simulation	Payload integration building / Scientific Center
Day 5	Staff morning Meeting	Operation
	Morning Meeting	Polaris
	MET Briefing	Operation
	Rocket B Bench Test	Payload integration building
	Rocket A Recovery System Arming Rocket A Motor Mating Rocket A Roll Out to Launcher Rocket A Rigging Rocket A Boxing Rocket A Countdown procedure meeting	Rocket Preparation Hall MRL Payload integration building
	Team Photo	TBD
Day 6	Day off/Reserve Day	
Day 7	Staff morning Meeting	Operation
	Morning Meeting	Polaris
	Rocket A Test Countdown	Blockhouse/Scientific Center
	Rocket A Hot Countdown opportunity	Blockhouse/Scientific Center
	Recovery opportunity of Rocket A Scientific Payload	Payload integration building
	Rocket B Payload Assembly	Payload integration building
Day 8	Staff morning Meeting / MET Briefing	Operation
	Morning Meeting	Polaris
	Rocket A Hot Countdown opportunity	Blockhouse/Scientific Center

	Recovery opportunity of Rocket A Scientific Payload opportunity	Payload integration building
	Earliest Rocket A Experiment Post Flight Actions	Payload integration building
	Rocket B Flight Simulation	Payload integration building / Scientific Center
Day 9	Staff morning Meeting / MET Briefing	Operation
	Morning Meeting	Polaris
	Rocket A Experiment Post Flight Actions	Payload integration building
	Rocket B Recovery System Arming Rocket B Motor Mating Rocket B Roll Out to Launcher Rocket B Rigging Rocket B Boxing Rocket B Countdown procedure meeting	Rocket Preparation Hall MRL Payload integration building
Day 10	Staff morning Meeting/MET Briefing	Operation
	Morning Meeting	Polaris
	Rocket B Test Countdown Rocket B Hot Countdown opportunity Recovery opportunity of Rocket B	Payload integration building
	Rocket A Experiment Post Flight Actions	Payload integration building
Day 11	Rocket B Hot Countdown opportunity	Blockhouse/Scientific Center
	Rocket B Recovery opportunity	Payload integration building
	Rocket B Experiment Post Flight Actions	Payload integration building
	Post Flight Meeting	Polaris
	Post Flight Meeting staff	Operation
	Campaign Dinner	Space Inn/Pool Room
Day 12	Reserve Day/Departure Day	

Table 12-1: Example campaign schedule (green: only organisers)

12.1 Description of Esrange Space Center

All the necessary information for users of Esrange can be found at:

- https://www.sscspace.com/

There following information can be found:

- range description (capabilities, layout, environment...),
- range administration (communications, accommodation, freight, supplies...),
- safety regulations,
- instrumentation (telemetry, tracking, observation, scientific...),
- operations (assembly, checkout, flight control, recovery, requirements, procedures),
- satellite facilities.

12.2 Safety

Safety always comes first at Esrange. Before the start of a campaign, a safety briefing will be held. It is mandatory for all visiting personnel to attend this briefing.

12.2.1 Radio Silence

See section 7.10, for relevant information regarding Radio Silence and safety related issues.

12.2.2 Network

In the payload integration building, there is a network provided for experimenters. It is not allowed to distribute the network via any kind of wireless device. The use of switches is permitted. Access is provided via Ethernet interfaces.

It is not allowed to create a hot spot in the payload integration building. All electronic devices have to be switched off in Danger (explosives) areas.

12.3 Planning

Experiment teams are strongly advised to think through all aspects of their experiments, the set-up, all tests, the behaviour during launch and flight phases and to make a detailed plan of the implementation of their experiments, the involved responsibilities and roles (team member, Esrange staff, etc.) and the times spent on each work package.

It is best practice to prepare a checklist including even the smallest aspects such as flipping a switch.

Without accurate assembly plans and checklists, there is a significant risk of failures and delays during the campaign. All these aspects should be documented in the SED.

12.3.1 Equipment

Basic measurement equipment and toolboxes can be made available. If you need some special tools or equipment, make sure to either bring them with you or state that as input to the Flight Requirements Plan in chapter 6 of your SED.

12.4 Ground Support Equipment (GSE)

Ground support equipment is support equipment used to provide background services and operational support to your experiment. GSE can be a vacuum pump, heat exchanger or battery charger. This type of equipment stays on the ground and is mostly located directly at the launcher.

12.5 Assembly of Rockets and Payloads

12.5.1 Assembly of Rockets

All assembly and preparation activities for the rockets are the responsibility of the EuroLaunch launch team and the Payload Manager.

12.5.2 Assembly and Checkout of Payloads

Payload assembly and preparations are conducted by the REXUS Payload Manager together with EuroLaunch staff. Working space in the launching area will be allocated by Esrange.

12.6 Flight Simulation Tests (FST)

The Flight Simulation Tests (FST) will be usually performed during Bench Test and during the campaign.

The payload will be ready for the final Flight Simulation Tests (FST) after successful checkouts. Umbilicals shall be connected and the payload shall preferably be in a vertical position. Each experiment shall be monitored and controlled by the experiment GSE.

When all modules are operating nominally, a short countdown and flight sequence will be performed. This test can be repeated many times if found necessary or desirable to do so.

All telemetry and telecommand signals will be recorded in the telemetry ground station during the test.

At least, one test will be performed in preparation for the countdowns. A lift-off signal will be given by removing the umbilical.

During the test, the experiment operators will be in the Science Center and should consider these tests not only as test of their individual experiment but also as test for the implemented procedures and discipline during countdowns. This not only supports launch preparation, but also facilitates testing and makes it less stressful for everyone involved.

Consider in your design that this test will be able to be conducted with ease (and without access) and that it will not have a negative effect on your experiment. In particular, think *about possible performance impacts on your experiment when signals (Lift-off, SOE etc.) are executed during the test and before flight.*

12.7 Test Countdown

After the last test, the rocket and payload will be rolled out to the launcher and mounted. Normally, a Test Countdown is performed.

For the experimenter, the Test Countdown will be run in the same sequence as for the Flight Simulation Test. However, there are a few important differences. Please consider and record how these differences may affect your experiment.

- no lift-off signal will be given (umbilical remains connected)
- late access will be performed
- this is a full countdown test (e.g. check temperature)

Think about how your experiment will respond if all other signals except the lift-off signal are executed.

Since the Test Countdown will be as close as possible to a full countdown sequence (without launching the rocket), this is perhaps the most important opportunity to determine that the full experiment operation procedure is satisfactory. The countdown procedure should be finalized during the Flight Simulation Tests. However, best practice is to have the countdown procedure ready in advance by testing without signals, reviewing the procedure and by performing simulations if possible.

At this stage in the campaign, experimenters often find themselves stressed, but it is important to remain calm. Due to the length of the Test Countdown, it is important to treat it just like a real launch. Please have a look in the countdown section below describing the experimenters' roles and consider your actions during all tests.

12.8 Flight Readiness Review (FRR)

The Flight Readiness Review (FRR) is conducted after completion of the experiment module preparation, payload integration and test, payload integration on launcher, GSE installation in the blockhouse, payload checkout, ground support stations checkout and test countdown.

The purpose of the review is:

- To authorise the start of the countdown phase, i.e. the launch.
- To ensure that all ground and payload service systems essential for a successful launch, flight and recovery are operating nominally. For this purpose, the person responsible for each system shall give a status report at the meeting.
- To ensure that all experiments are ready for the flight. For this purpose, each appointed experiment module manager shall give a status report at the meeting. In addition, the experiment team leaders are requested to state the operative status of the experiments.

13 COUNTDOWN AND LAUNCH

13.1 Weather Constraints

Wind, flight trajectory and visibility are important variables taken into consideration before starting a countdown. The decision to start a countdown is solely in the hands of EuroLaunch.

Note: It is not possible to guarantee that a launch can take place on one of the days allocated during the campaign. Experiment teams should be prepared to hand over the operation of their experiment to someone else if the launch is postponed to a later opportunity.

13.2 Launch Conditions

Launch period:	Usually first two weeks in March
Launch window:	Usually 06:00 – 16:00 LT
Visibility:	Sufficient for helicopter flight

13.3 Countdown and Launch

During the countdown phase, important countdown information is displayed on Public Announcement (PA) video monitors at various locations around the launch site.

The nominal lift off time is planned for between 06:00 and 16:00 LT. The launch window is determined by the payload preparation time, hold requirements and the daylight period. The maximum launch window duration is 11 hours.

The decision to start the countdown is taken at a weather briefing (MET) immediately before the planned start of countdown. This decision is based on dedicated weather forecasts and wind data obtained by a meteorological balloon released from Esrange shortly before the flight. If the weather conditions are unsuitable for launching the vehicle, the launch will be delayed until the flight conditions are fulfilled.

The general launch procedure may be subject to changes. Experiments should be designed to handle not only the flight but also 3 hours of CD plus some possible holds.

The experiment teams' ground equipment will be situated in the Scientific Center in the main building.

13.3.1 Countdown List

The schedule in Table 13-1 indicates the standard countdown actions relative to launch (T = 0). The final CD list will be issued after the FRR.

In case of experiments with late access, the final integration has to be completed prior to the arming procedures. See section 5.3.1 for the mechanical requirements of late access hatches.

Time	Action
-3H	**DECISION TO START COUNTDOWN**
-2H45	**START OF COUNTDOWN**
	SEND QUESTION LIGHT
-2H35	START PL & EXP CHECKOUTS
-1H55	PL CHECKOUTS COMPLETED
POSSIBLE HOLD	
	CONFIRM TRANSMITERS AND PAYLOAD ARE **OFF**
	RADIO SILENCE IN THE LAUNCH AREA
-1H55	LATE ACCESS
-1H30	ARM THE RECOVERY SYSTEM
-1H05	ARM THE VEHICLE SYSTEM, CONNECT FIRING LINE
-1H	REMOVE ROOF
	ELEVATE LAUNCHER TO NOMINAL SETTINGS
POSSSIBLE HOLD / POSSIBLE RESTART POINT	
	END OF RADIO SILENCE
-45M	START FINAL PL CHECK
	OSCILLATOR ON
-20M	PRELIMINARY SETTINGS
-15M	START FINAL EXPERIMENT CHECK
-10M	ALL EXPERIMENTS ON
-5M	PAYLOAD ON INTERNAL POWER
-5M	FINAL LAUNCHER SETTINGS
	SEND QUESTION LIGHT
	RECORDERS ON, VIDEO RECORDERS ON
-1M50	ANSWER LIGHT
-45S	ALL STATIONS GREEN
-25S	LAUNCH AUTHORIZED
-5S	PUSH FIRE BUTTON
0	**FIRE**
	REPORT APOGEE
	REPORT LOS
+20M	ALL EXP OFF

Table 13-1: Example of a REXUS Countdown

13.4 Science Center, Operations and Communication

Please note, this information is subject to change depending on launch requirements and operational decisions.

Experiment teams will be located in the Science Center during the Flight Simulation Test, Test Countdown and Hot Countdown (Launch). The central point of communication will be the respective Payload Manager from ZARM/SSC. All communications from the experiment team will go through this focal point. This requires that one member from each team – e.g. the Team Leader – is the contact point for the Payload Manager. It must be clear which person from each experiment assumes this role, and they must be located in such way that they can always attract the attention of the Payload Manager (line-of-sight is a requirement) but also where they can receive information seamlessly from team members operating the experiment at the ground-stations.

The communication between the point of contact team members and the respective Payload Manager will be arranged during the launch week. If you have queries on that or if you would like to review practices, this can be done beforehand. A good time to consider your arrangements is during the Bench Tests of the payload where you will first trial the experiment with the service system.

During countdown, all team members (and any observing personnel) must keep the noise to the lowest possible level that neither distracts nor disrupts experiment team operations. This includes not breaking the line-of-sight between the Payload Manager and the point of contact for teams, not blocking anyone’s vision of the countdown clock and minimizing movement within the Science Center.

At T-20 minutes, the doors will be closed and people will no longer be able to enter or leave the building. Please make sure, your team is prepared for this situation. At this point, experimenters must “sit down, be quiet and be still”.

Experimenters must monitor their own experiments carefully and consider any risks that could affect their experiments. If something occurs that endangers the success of their experiments, contact the Payload Manager quickly and clearly so that the issue can be resolved. Please inform the Payload Manager beforehand about any issues that can be foreseen, but do not forget to reflect on any actions that may affect your experiment in a negative way as it may not always be possible for the Payload Manager to monitor every experiment.

During campaign, it is the Payload Manager’s responsibility to ensure that teams are communicating clearly.

After the launch of the rocket, many teams still have to do a lot of work and are busy with monitoring their experiments. Although there might be a premature desire to celebrate the launch, it is very important for everyone in the Science Center to maintain discipline and to consider every action and possible events (the unforeseen included).

13.5 Recovery

The recovery system includes an Iridium Transceiver which will transmit the GPS position constantly every 30 s after touchdown via satellite to a ground station at the range. This information is forwarded to Flight Safety who will update the recovery crew.

Furthermore, the helicopters may be equipped with direction finders for payload beacon signals. In the case of a RECCO tag, the recovery crew will have a RECCO detector that they bring in the helicopter.

During the rocket flight, the payload trajectory will be tracked by means of the transmitted GPS-data and by use of a slant range system in the TM ground stations.

The prediction on the impact point coordinates is reported to the helicopter crew from Esrange. The helicopter crew starts to locate the payload after touchdown. At the landing site, the crew disassembles time critical samples from the payload for the quickest possible return to the Esrange laboratories. The recovery crew can also interact with the experiment modules (e.g. inserting disarm plug). If this is required by the experiment team, it should be clearly included in the SED and additionally indicated on an illustrated recovery sheet as well as discussed with the crew during the campaign.

The whole operation is normally completed within four hours after the launch.

14 POST LAUNCH ACTIVITIES

14.1 Post flight meeting

After the recovery, a Post Flight Meeting is held to debrief the recovery activities and a short flight performance report is stated. A short presentation of the performance of each experiment is requested.

14.2 Disassembly of the payload

The day after launch, disassembly and packing will start. It is the responsibility of the teams to decide about and arrange transportation of their experiment and equipment. All items left at Esrange will be thrown away, and destruction costs for hazardous items may be charged to the experiment teams. All materials left behind should be clearly labelled to determine the best disposal method.

14.3 Campaign report

Esrange will issue a campaign report within one month.

15 EXPERIMENT QUALITY ASSURANCE

The major concerns of EuroLaunch related to Quality Assurance (QA) on the experiment level are that the experiments fulfil the interface requirements and that the module can fly in a REXUS payload without jeopardising the performance of the other systems or experiments. In addition, EuroLaunch is interested in the nominal performance of the experiments.

The following advice reflects these concerns.

15.1 Materials

In addition to usual considerations regarding the selection of materials, special attention shall be paid to outgassing phenomena due to the vacuum environment during flight. For more information see reference [5].

15.2 Components

All electrical and mechanical components must have a reliability that is consistent with the overall reliability of the payload. For electronic components, MIL-std specified types are recommended.

15.3 Additional Quality Topics

In addition to the QA-topics described above, the following topics shall be addressed, if required by EuroLaunch:

15.3.1 Procured Products and Audits

Careful planning of the procurement and manufacturing must be made for identification of long lead items. Preferably, a flow chart shall be made which shows the sequence of steps necessary to be conducted.

15.3.2 Manufacturing Control and Inspection

For the manufacturing and inspection of critical processes, the personnel should be aware of standards in applicable areas, such as:

- Manual soldering according to ECSS-Q-ST-70-08C,
- Crimping of connections according to ECSS-Q-ST-70-26C,

Specific requirements of the project or items concerning cleanliness, contamination and environment shall be stated as input to the FRP in chapter 6 of your SED.

When handling and storing any parts or components, the sensitivity to heating, ESD and electrical disturbances shall be considered.

Connectors shall be well labelled.

15.3.3 Re-used Items

It is important to consider the complete history of any re-used item, by consulting the hardware logbook or former project logbook. It must be ensured that any hidden failures are excluded.

15.3.4 Availability and Maintainability

Spare parts for components susceptible to failure shall be available during the payload AIT and the launch campaign. The design shall allow for easy and fast replacements of such components.

15.3.5 Handling, Storage and Packing

ESD-susceptible components shall be handled in an ESD-protected environment.

Before transport, the components shall be carefully packed to withstand the expected loads. The use of a bump recorder is recommended.

15.4 Personnel Safety

The REXUS experiments and dedicated equipment must fulfil safety requirements according to Swedish law. The Swedish Work Environment Act is a general act that is backed up by special laws and regulations in different fields. The Swedish work environment authority issues these regulations.

Special provisions apply (among others) to the following fields:

- Explosives,
- Inflammable material,
- Chemical hazards,
- Electrical facilities,
- Radiological work.

The above-mentioned laws and regulations can be found at

https://www.av.se/en/work-environment-work-and-inspections/

The document for ground safety is the GSP-Q (see section 11.2). This document is sent to the teams before Bench Test to be filled. SSC uses this document for assessing risks. However, the teams shall present all safety risks no later than CDR. If additional safety risks are identified after CDR, the teams shall contact EuroLaunch ASAP.

15.5 Safety at Esrange Space Center

The safety regulations that apply at Esrange may be found in the Esrange Space Center Safety Manual [4]. It is a requirement that all personnel participating in the campaign shall have read the safety regulations prior to their arrival at Esrange Space Center.

15.6 European Cooperation for Space Standardization (ECSS)

The ECSS standards are designed to increase the efficiency of space industry. Due to the shorter time scales of a typical REXUS cycle, the projects cannot fully conform to the ECCS standards. Nevertheless, ECSS standards give good examples and instructions for proven working procedures and guidelines for achieving high quality results in the space sector. However, as the scope of the ECSS standards lies on high budget commercial and scientific projects, their implementation into REXUS experiment is not mandatory.

15.7 Redundancy

Redundancy is a desirable goal of the experiment's design, especially when there are safety or failure risks involved. The implementation of redundant mechanisms in the case of mechanical systems is not equally simple as for electrical parts but it should be considered during the design process. Good examples for redundant components are the usage of separate battery packs, multiple switches or check valves.

15.8 Test procedure

Test procedures shall reflect the tests conducted to fulfil specified requirements. They shall be written as checklists including the detailed steps of each test, and also allow for the recording of observations, remarks and data (time, physical parameters such as pressure, temperature e.g.). For reference, see the example checklist shown in Table 15-1.

Test Chronology						
Project :						
Place :						
Date :						
Name of Chronologist :						
Test Item :						
Testnumber :						
Action :	**start**	**end**	**count**	**OK**	**remark**	
	time		**down**			**responsible**
			time			
Information to facility responsible			- 2 hours			test leader
Information to safety center			- 2 hours			test leader
Preparation of test rig			- 1 hour			engine/bench operator
Preparation of test speciman			- 1 hour			engine owner
Preparation of measurement system			- 1 hour		pretest of thrust	measurement expert
					pretest of temperature	measurement expert
Activation of safety measures			-30 min		closing armaplated window	safety officer
					red light on	
announcement			-20 min		M 11 / 5 at minus 20 minutes	chronist
Installation of speciman on the bench			-20 min			engine/bench operator
Test readiness check			-12 min			test leader & team
					measurement	
					ignition	
					safety	
Opening of N2 and N2O valves			-10 min			engine/bench operator
closing of igniter circuit						engine/bench operator
Information to control room			-5 min		test position ready for test	engine/bench operator
					leaving test position	
announcement			-5 min		M 11 / 5 at minus 5 minutes	chronist
test position evacuated						engine/bench operator
final test readiness			-3 min		test position evacuated	test leader & team
					visual contact to test position	
					measurement ready	
					video recording ready	
announcement			-1 min		M 11 / 5 at minus 1 minute	chronist
final count down			- 5 sec			test leader
ignition command			0.0			test leader
Record of first observations			+ 20 sec		igniter was activ	chronist
					gas bottle released	
					combustion was started	
					data received	
save recorded data			+ 5 min			measurement expert
first bench access			+ 5 min			test leader, bench operator
open igniter circuit			+ 8 min			bench/engine operator
			+ 9 min		use special helmet	bench/engine operator
test position clear for test team			+ 12 min			test leader
dismount sensors			+ 15 min			bench/engine operator
return speciman to assembly hall			+ 20 min			bench/engine operator
reduce safety measures			+ 25 min			safety officer
disassemble speciman			+ 25 min			engine owner

Table 15-1: Example for a test procedure

A COORDINATE SYSTEM DEFINITION

This chapter gives an overview over the coordinate systems that are used for the REXUS on-board sensors, GPS and tracking systems. It is important to have profound knowledge about the coordinate definitions and transformations for the analysis of sensor data during the flight and for the post flight analysis. Table A-1 lists the coordinate systems used.

Table A-1: Coordinate Systems

ECI	Earth Centred Inertial
ECEF	Earth Centred, Earth Fixed
WGS84	World Geodetic System 1984
LTC	Local Tangent Coordinate System
VCVF	Vehicle Carried Vertical Frame

A.1 Earth Centred Inertial System (ECI)

As the name implies, this system originates at the centre of the Earth's mass. Vectors or variables expressed relative to it are denoted with the index x_{ECI}, y_{ECI} and z_{ECI}. The fundamental plane is the Earth equator. The x_{ECI}-axis points towards the vernal equinox. The y_{ECI}-axis points to the North Pole. This coordinate system is not rotating. It is assumed to be inertially fixed in space, see Figure A-1.

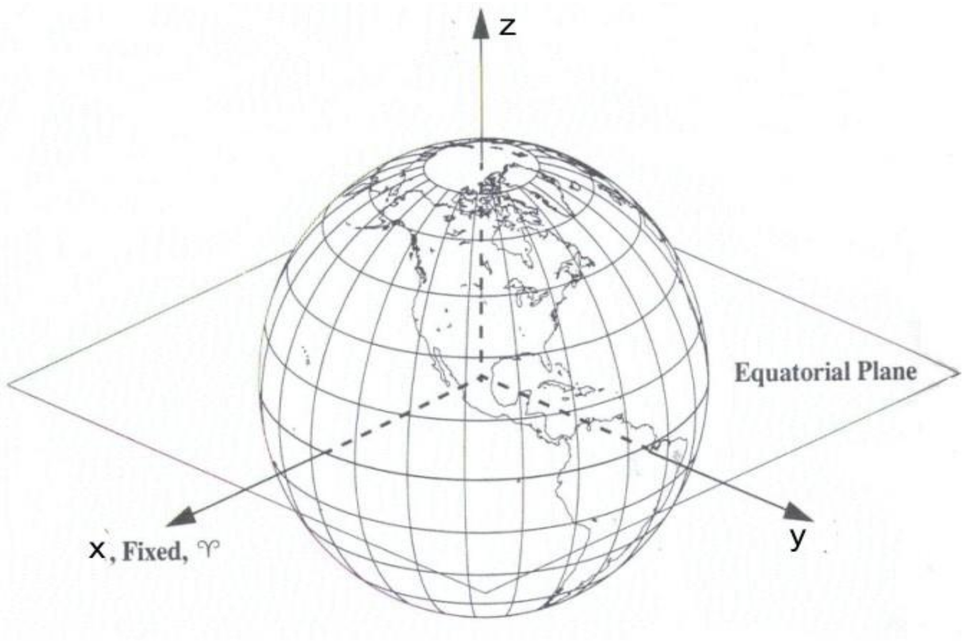

Figure A-1: Earth-Centred Inertial System (ECI) [Ref. [13]]

A position in the ECI-System can be defined in **Cartesian coordinates** (x_{ECI}, y_{ECI}, z_{ECI}) or in polar coordinates (Right Ascension α, Declination δ, geocentric distance r) [Ref. [12]].

The transformation between the coordinates is done with following equation:

$$\vec{r} = \begin{pmatrix} x \\ y \\ z \end{pmatrix} = r \cdot \begin{pmatrix} \cos\delta \cdot \cos\alpha \\ \cos\delta \cdot \sin\alpha \\ \sin\delta \end{pmatrix}$$ Eq. A-1 [Ref. [12]]

$$\alpha = \arctan\frac{y}{x}$$ Eq. A-2 [Ref. [12]]

$$\delta = \arctan\frac{z}{\sqrt{x^2 + y^2}}$$ Eq. A-3 [Ref. [12]]

$$r = \sqrt{x^2 + y^2 + z^2}$$ Eq. A-4 [Ref. [12]]

As with the heliocentric coordinate system, the equinox and plane of the equator move very slightly over time, so a truly inertial reference frame for the Earth is impossible to realize. A close approximation can be achieved by referring to a specific epoch and it is specified how the vectors are transformed to and from this time. Calculations that transform vectors to and from this epoch are usually called Reduction Formulas.

The **ECI reference system** for the REXUS data is the J2000.0 system. This has been used since 1984. The x_{ECI}-axis points in the direction of the mean vernal equinox and the z_{ECI}-axis points in the direction of the mean rotation axis of the Earth on January 1, 2000 at 12:00:00:00 Barycentric Dynamical Time (TDB) which corresponds to a Julian date (JD) 2451545.0.

A.2 Earth Centred, Earth Fixed (ECEF)

If the geocentric coordinate system rotates with the Earth, it results in the **Earth-Centred Earth-Fixed Coordinate System**, abbreviated as ECEF. The main difference with this system is that the primary axis is always aligned with a particular meridian. The x_{ECEF}-axis points toward the Greenwich-Meridian which is defined as longitude 0°. This coordinate system is rotating.

The position of an object is defined with the **geocentric Latitude φ_{gc}**, which is measured positive in the direction North of the equator, the **Longitude θ**, which is measured positive in the direction East from the Greenwich Meridian and the distance d from the Earth's centre.

$$\vec{r}_{ECEF} = \begin{pmatrix} x_{ECEF} \\ y_{ECEF} \\ z_{ECEF} \end{pmatrix} = d \cdot \begin{pmatrix} \cos\varphi_{gc} \cdot \cos\theta \\ \cos\varphi_{gc} \cdot \sin\theta \\ \sin\varphi_{gc} \end{pmatrix}$$ Eq. A-5

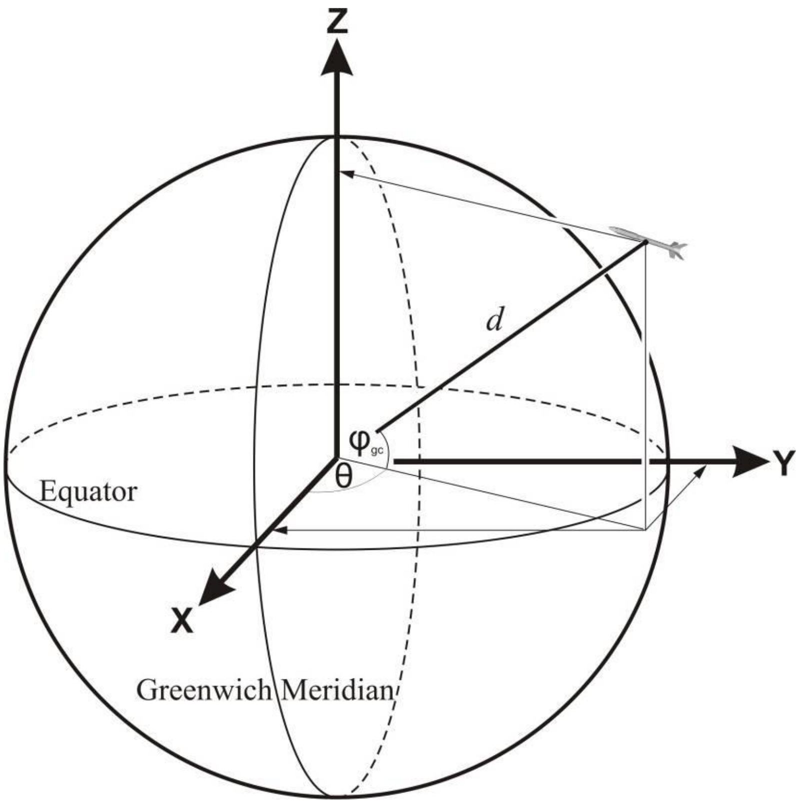

Figure A-2: ECEF Coordinate System

A.3 World Geodetic System 1984 (WGS84)

The global reference system **World Geodetic System 1984** (WGS84) is used for the REXUS GPS position data.

The reference ellipsoid is rotation-symmetric and every plane cuts the ellipsoid to an ellipse with the flattening $f_\oplus$, which is defined with the relative difference of the equator and pole radius.

$$f_\oplus = \frac{R_\oplus - R_{Pole}}{R_\oplus}$$ Eq. A-6 [Ref. [12]]

The WGS84 Ellipsoid has a flattening of $f_\oplus = 1/298.257223563$ and the equator radius $R_\oplus$ is 6378137 m [Ref. [12]]. The Earth's eccentricity $e_\oplus$ can be calculated with the following equation.

$$e_\oplus = \sqrt{1-(1-f_\oplus)^2}$$ Eq. A-7 [Ref. [12]]

The position of the rocket is given in geodetic coordinates relative to the reference ellipsoid. The **geodetic longitude θ** corresponds to the geocentric longitude. Unlike the geocentric latitude φ_{gc}, which is the inclination of the position vector to the equatorial plane, the geodetic latitude φ_{gd} describes the angle between the equatorial plane and the normal to the reference ellipsoid. It is positive to the North and negative to the South.

The difference of geodetic and geocentric latitude is shown in Figure A-3.

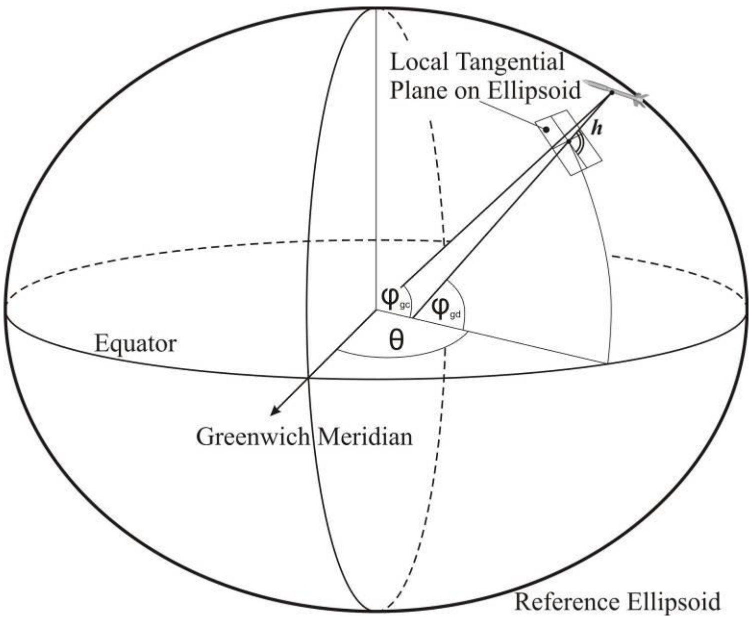

Figure A-3: WGS84 Reference Ellipsoid

The flattening of the Earth is very small because the difference between the Earth's radius at the equator and the poles is less than 22 km. Therefore, the difference between geodetic and geocentric latitude is 12 minutes of arc.

A.4 Local Tangential Coordinate System (LTC)

This system is important for the observation of the rocket from the Launcher, Tracking or Radar Stations. The LTC system rotates with the Earth. The E-axis points to East, the N-axis points to the North and the Z-axis is the zenith that is perpendicular to the tangential plane at the observation location (usually Launcher). This location is defined by the geodetic latitude φ_{gd} and geodetic longitude θ.

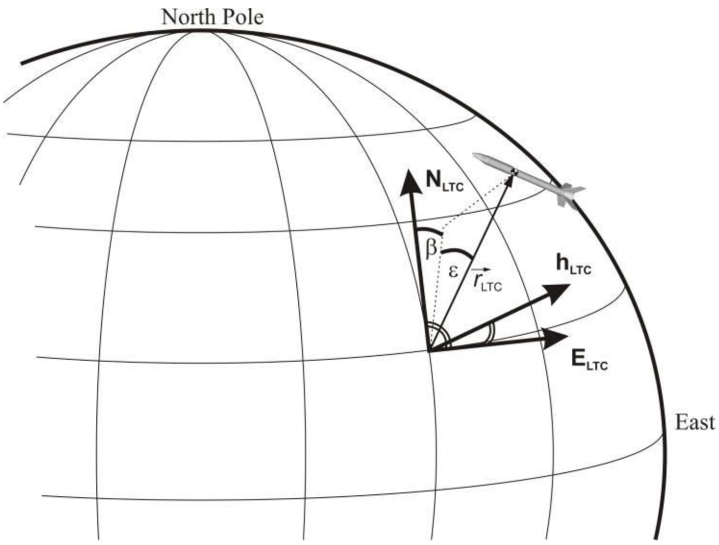

Figure A-4: Local Tangent Coordinate System (LTC)

Two observation angles define the position of the rocket from the observation location. The azimuth β is measured clockwise around the observation location starting in direction North. It varies between 0° and 360° and is calculated with the following equation:

$$\beta = \arctan\left(\frac{east_{LTC}}{north_{LTC}}\right) \qquad \text{Eq. A-8}$$

The **Elevation** ε is measured between the horizon and the rocket position It varies between -90° and 90° and is calculated with the following equation:

$$\varepsilon = \arctan\left(\frac{h_{LTC}}{\sqrt{east_{LTC}^2 + north_{LTC}^2}}\right) \qquad \text{Eq. A-9}$$

The transformation between azimuth and elevation to Cartesian LTC-coordinates is done with following equation:

$$\begin{pmatrix} east_{LTC} \\ north_{LTC} \\ h_{LTC} \end{pmatrix} = d \cdot \begin{pmatrix} \sin\beta \cdot \cos\varepsilon \\ \cos\beta \cdot \cos\varepsilon \\ \sin\varepsilon \end{pmatrix} \qquad \text{Eq. A-10}$$

The distance d between the rocket and the observation location is also called slant range.

A.5 Vehicle Carried Vertical Frame (VCVF)

This system moves with the rocket and the origin is the centre of gravity of the rocket. The velocity and acceleration that are calculated with the GPS data are usually also given in this coordinate system.

The N_{VCVF}-axis points to the local North and the E_{VCVF}-axis to the local East. The Z_{VCVF}-axis builds a right-hand system and is perpendicular to the local plane. Only at the equator, it is oriented exactly to the Earth's centre.

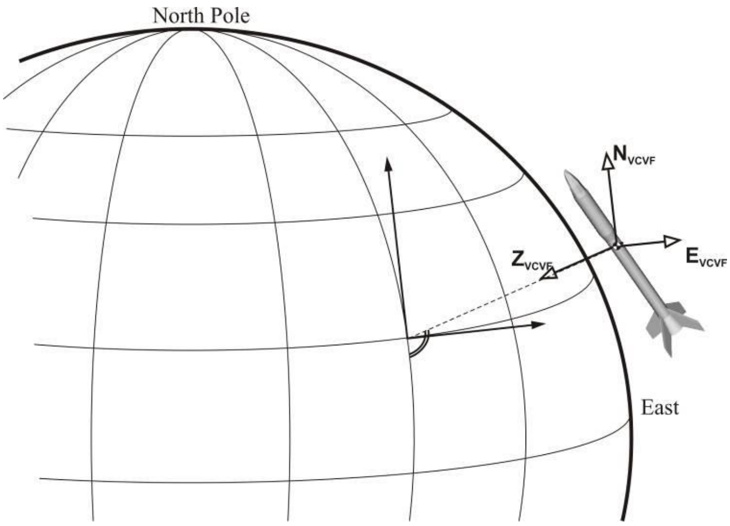

Figure A-5: Vehicle Carried Vertical Frame

As already mentioned, velocity is given in this coordinate system. The Flight Path Angle γ and the Heading Angle β can be directly calculated with the following equations:

$$\gamma = atn\left(\frac{-v_z}{\sqrt{v_{north}^2 + v_{east}^2}}\right)$$ Eq. A-11

$$\beta = atn\left(\frac{v_{east}}{v_{north}}\right)$$ Eq. A-12

Figure A-6 shows the orientation of the angles.

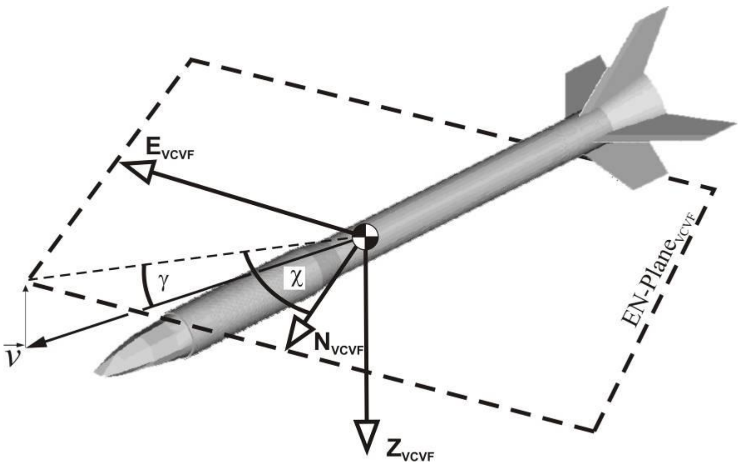

Figure A-6: Flight Path Angle and Heading Angle

B ESRANGE SAFETY AND SECURITY COMPLIANCE CONFIRMATION - ROCKET

This document clarifies the basic safety and security conditions for the campaign

…………………………..…………………………………….. at the Esrange Space Center.

This document shall be signed by the customer's (range user's/prime contractor's) Mission Manager/Project Manager and by the Esrange Project Manager. One copy of this document and of the *Esrange Safety Manual* (ESM, EUA00-E538) is submitted to the customer's Mission Manager/Project Manager.

Swedish law and Swedish safety and security regulations apply to all activities at Esrange.

The *Esrange Safety Manual* provides safety regulations and criteria associated with launching of sounding rockets, UAV´s and stratospheric balloons and must be followed by all parties involved.

Temporary and complementary regulations may be issued at any time via the Esrange Project Manager and conveyed to the Mission Manager/Project Manager.

If the customer has own rules that are more stringent, the customer's rules shall be respected when relevant and applicable.

Customer Positions and Responsibilities

Mission Manager/Project Manager is responsible for the customer's work at Esrange and is responsible to see that all customer and customer's contractor personnel follow existing rules and instructions. He/she is the contact point between the customer and Esrange.

Project Scientist is appointed by the customer and responsible for the scientific mission.

Payload Engineer is appointed by the customer and responsible for the technical function of the payload.

SSC Esrange Positions and Responsibilities

Esrange Project Manager is responsible for the campaign coordination at Esrange and is the contact point between Esrange and the customer. He/she shall also superintend all safety and security regulations and arrangements related to the campaign.
Head of Esrange Launch Team is responsible for the ground safety in the launch areas and also all work with explosives at Esrange.

Operations Officer (OP) coordinates all operational work and is the interface with the customer and Swedish and foreign authorities during **countdown, flight and recovery**.
Safety Officer (SO) is responsible for flight safety during **countdown and flight**. He/she will also control access to the launch areas and issue access permit badges where applicable.
Launch Officer (LO) is responsible for the ground safety in the launch areas during **countdown** and also all work with explosives at Esrange.
Flight Control Officer (FCO) is appointed when a flight includes a flight termination system. He/she decides to **abort a flight** if the vehicle deviates from a safe trajectory.

We accept the content of the text above. Date ……………………………………

…………………………..………………….. ……………………………………..
Customer Mission Manager/Project Manager Esrange Project Manager

C ABBREVIATIONS

AC	Alternating Current
AIT	Assembly, Integration and Test
APID	Application Identifier
ASAP	As Soon As Possible
BC	Boundary Conditions
BF	Body Frame Coordinate System
BX	Balloon EXperiment for University Students (BEXUS)
BNC	Bayonet Neill-Concelman, standard for coaxial connectors
CC / CV	Constant Current / Constant Voltage
CD	Countdown
CDR	Critical Design Review
CoG	Centre of Gravity
CPU	Central Processing Unit
CRC	Cyclic Redundancy Check
CSM	Checksum
DC	Direct Current
DLR	Deutsches Zentrum für Luft- und Raumfahrt (German Aerospace Center)
DOF	Degrees of Freedom
DTM	Operation Call sign for DLR telemetry station
EAT	Experiment Acceptance Test
EAR	Experiment Acceptance Review
ECEF	Earth Centred, Earth Fixed Coordinate System
ECI	Earth Centred Inertial Coordinate System
ECSS	European Cooperation for Space Standardization
EGSE	Electric Ground Support Equipment (e.g. Service Module control box)
EIT	Electrical Interface Test
EMC	Electro-Magnetic Compatibility
EMI	Electro-Magnetic Interference
ESA	European Space Agency
ESB	Esrange Safety Board
ESD	Electro-Static Discharge
ESRANGE	Esrange Space Center
ESR	ESRANGE
ETM	Operational Call sign for Esrange telemetry station
EXP	Experiment
E-Box	Electronics Box
FAR	Flight Acceptance Review
FEC	Forward Error Correction
FEM	Finite Element Method
FET	Field Effect Transistor
FPGA	Field Programmable Gate Array
FRP	Flight Requirements Plan

FRR	Flight Readiness Review
FST	Flight Simulation Test
GaAs	Gallium Arsenide
GMO	Genetically Modified Organism
GMSK	Gaussian Minimum Shift Keying
GND	Ground
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
GS	Ground Station
GSE	Ground Support Equipment
GSP-Q	Ground Safety Plan - Questionnaire
HCD	Hot Countdown
HF	High Frequency
HK	House Keeping
H/L	Hard Line
H/W	Hardware
IC	Integrated Circuit
ICD	Interface control document
IH	Igniter Housing
I/F	Interface
IPR	Integration Progress Review
ITW	Integration Week
LB	Launcher Box
LEO	Low Earth Orbit
$LiFePO_4$	Lithium-iron-phosphate battery
LiPo	Lithium Polymer battery
LNA	Low Noise Amplifier
LO	Lift-Off (Signal)
LT	Local Time
LTC	Local Tangent Coordinate System
Min	Minute
MET	Meteorological Briefing
mo	Month
MFH	Mission Flight Handbook
MORABA	Mobile Raketenbasis (DLR)
MRL	Medium Range Launcher
NCR	Non-Conformance Report
NiMH	Nickel-metal hydride battery
NSRHB	NASA Sounding Rocket Handbook
NSROC	NASA Sounding Rocket Operations Contract
PA	Public Announcement (e.g. video monitors)
PAL	Phase Alternating Line
PCM	Pulse Code Modulation
PDR	Preliminary Design Review

PE	Payload Engineer
PI	Principal Investigator
PL	Payload
PSD	Power Spectral Density
PST	Payload System Test
PTS	Swedish Post and Telecom Agency
QA	Quality Assurance
RADAX	Radial-Axial
RC	Radio-controlled
REXUS	Rocket-borne Experiments for University Students
RF	Radio Frequency
RFW	Request for Waiver
RNRZ	Randomized NRZ (a signalling modulation)
RX	Rocket Experiments for University Students (REXUS)
RXSM	REXUS Service Module
RX/TX	Receiver/Transmitter
SAF	Safety Officer
SCI	Project Scientist
SDC	Serial Data Commands
SED	Student Experiment Documentation
SM	Service Module
SMC	Service Module Commands
SNSA	Swedish National Space Agency
SODS	Start/Stop of Data Storage (Signal)
SOE	Start/Stop of Experiment (Signal)
SSC	Swedish Space Corporation
STW	Student Training Week
S/W	Software
T	Time before and after launch noted with + or -
TBC	To Be Confirmed
TBD	To Be Determined
TDB	Barycentric Dynamical Time
TC	Telecommand
TCU	Telemetry Central Unit
TM	Telemetry
TTFF	Time-To-First-Fix
TV	Television
UTE	User-defined Timer Event (Signal)
VCVF	Vehicle Carried Vertical Frame
WGS84	World Geodetic System 1984
WT	Walkie Talkie
ZARM	Zentrum für angewandte Raumfahrttechnologie und Mikrogravitation