Rexus Manual

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1 INTRODUCTION

The Swedish sounding rocket program REXUS provides periodically recurring flight opportunities for student experiments under space conditions. Conducted by EuroLaunch, REXUS is a cost effective, easily accessible experiment facility giving 3 minutes of spaceflight.

The launch campaign periods are short and fast land recovery is obtained at the ESRANGE rocket range.

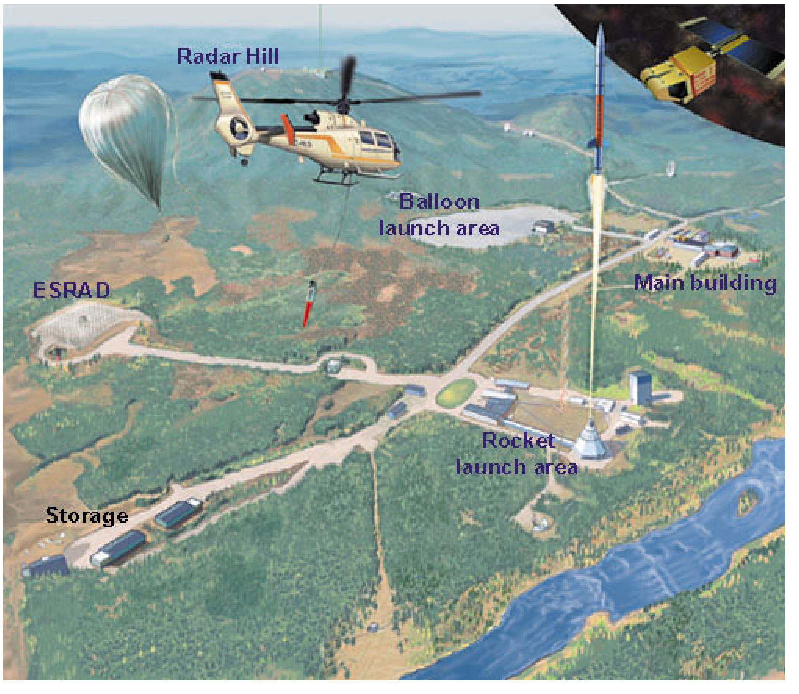


Figure 1-1 ESRANGE Rocket Range

The payload is modularised to provide simple interfaces, large flexibility and independence between experiment modules. Normally two experiment modules with a 35.56 cm (14 inch) diameter can be accommodated in one payload.

All payload service systems necessary for telecommunication, payload control, recovery and during the flight, are included in the system.

The REXUS program is operational with a basic launch schedule of up to two launches every year.

This document comprises all the necessary information for a user of the REXUS system, including the services offered by EuroLaunch in the flight ticket. It defines the requirements that applies to the REXUS experiment modules and gives design recommendations. It also includes a description of the REXUS system, the programmatics, a description of the tests and the campaign and, finally, a chapter on Quality Assurance and Safety.

In case you need additional information on the REXUS system, please contact EuroLaunch project manager or the system engineer of the current project.

1.1 Definitions

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

REXUS	The complete integrated vehicle to perform the flight.
Ground Equipment	REXUS supporting systems on ground.
Esrange Facilities	Equipment used to monitor and control the flight, and telemetry receiving equipment.
Ground Support Equipment	Equipment used to control and communicate with various modules during test and count down.
Rocket Motors	The parts of REXUS giving the accelerating force.
Payload	Experiment modules and all subsystems.
Subsystems	All systems required for flight control, recovery and telemetry.
Experiment Modules	Experiment equipment and the outer structure.

1.2 Abbreviations

AIT	Assembly, Integration and Test
APID	Application Identifier
BF	Body Frame Coordinate System
DLR	Deutsches Zentrum für Luft- und Raufahrt
ECSS	European Cooperation for Space Standardization
EGSE	Ground Service Module control box
EMC	Electro-Magnetic Compatibility
EMI	Electro-Magnetic Interference
ESRANGE	European Sounding Rocket Launching Range
FAR	Flight Acceptance Review
FST	Flight Simulation Test
FRR	Flight Readiness Review
GSE	Ground Support Equipment
HCD	Hot Count Down
HK	House Keeping
H/W	Hardware
ICD	Interface control document
I/F	Interface
IH	Igniter Housing
MFH	Mission Flight Handbook
MTR	Mid Time Review
NCR	Non Conformance Report
REXUS	Rocket EXperiment for University Students
RF	Radio Frequency
RXSM	REXUS Service Module
PCM	Pulse Code Modulation
PI	Principal Investigator
PST	Payload System Test
RNRZ	Randomized NRZ (a signalling modulation)
RXSM	Rexus Service Module
SED	Student Experiment Description
SSC	Swedish Space Corporation
DLR Moraba	DLR Mobile Raketenbasis
S/W	Software
TC	Telecommand
TCU	Telemetry Central Unit
TM	Telemetry

1.3 References

[1] **European Cooperation for Space Standardization ECSS:** *Space Project Management* (ECSS-M-30A, 1996)

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

[3] **SSC Esrange:** *EU A00-E538 Esrange Safety* (Esrange, www.ssc.se/esrange)

[4] **SSC Esrange:** User's Handbook (Esrange, http://www.ssc.se/esrange)

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

2 REXUS PROJECT OVERVIEW AND MILESTONES

2.1 Project Organisation

The technical support in the integration and testing phase, as well as the campaign management and operations is provided by **EuroLaunch**. EuroLaunch was founded in 2003 and is a joint venture of **Esrange** (Swedish Space Cooperation SSC) and the **Mobile Rocket Base MORABA** (German Aerospace Center DLR). The DLR service part concerning integration, testing and student support is provided by the **Institute of Space Systems RY** (DLR) in Bremen. When in this document EuroLaunch is mentioned this means that all three institutions (Esrange, MORABA and RY) may be involved.

The REXUS rockets are launched at the European Sounding Rocket Launching Range Esrange of SSC, near Kiruna in North-Sweden.

The scientific evaluation of the experiment proposals and the financial support of the students are in the responsibility of the **German Space Agency (DLR)** and the **Swedish National Space Board (SNSB)** through cooperation with the **European Space Agency (ESA)**.

At EuroLaunch the following key-positions will be assigned for every flight project:

- Project manager
- System manager
- Mechanical design responsible
- Electrical design responsible
- Telemetry (TM) and Telecommand (TC) systems responsible
- EGSE and software responsible

Additional positions will be assigned if necessary.

The major part of the communication between EuroLaunch and the experimenter shall pass through the Project Managers.

2.2 Project Planning

The detailed project planning and time schedule will be released by EuroLaunch for each flight at the first workshop.

A general progress plan for REXUS flight projects is listed below. Detailed description of reviews and tests are given in chapter 6.

2.2.1 Project Phases [Ref [1]]:

Phase A: **Feasibility Phase**, ends with Form B and the presentation at the workshop

Phase B: Preliminary Design study phase, ends during the student training week with the **Preliminary Design Review (PDR)**

Phase C: Detailed Definition Phase, ends with the **Critical Design Review (CDR)**

Phase D: Production and Qualification Phase, ends with the **Experiment Acceptance Review (EAR)**. The phases C and D are generally inseparable, owing to the integrated nature of the activities.

Phase E: Launch and operation (**campaign**)

Phase F. Post flight analysis and final report

2.2.2 General REXUS Timetable

T-18 m Call for Experiment Proposals

T-16 m Experiment **Submission Deadline**

T-15 m Preliminary experiment selection

T-14 m **Workshop** in ESTEC (ESA) / Bonn (DLR); experiment presentation

T-13.5 m Final experiment selection

T-12 m **Student Training Week** at Esrange or Oberpfaffenhofen, **Preliminary Design Review (PDR)**

T-9 m **Critical Design Review (CDR)**, Start of phase D

T-6 m Mid Term Report (MTR)

T-3 m **Delivery of Experiments** to Esrange (ESA) / Bremen (DLR), EAR

T **Campaign at Esrange**

T+1 m Distribution of the REXUS post flight Report

T+3 m Submission of Student **Experiment Reports**

T+4 m Submission of **Final Report**

2.3 REXUS Flight Ticket

In the **REXUS "flight ticket"**, which is offered to the international student community, the following services are included:

- **General management** and **planning** of the REXUS project
- Provision of **launch vehicle** and subsystems necessary for a spaceflight mission of 2-3 minutes with recovery. Lift-off signals are provided.
- **Integration** of participating modules into the flight configured payload and testing of payload (TM, TC, flight simulation test, dynamic balancing, vibration tests and determination of physical properties).
- **Transport** of modules from the integration facility to Esrange.
- **Payload assembly and testing** at the range during 5 days (nominally).
- Provision of laboratory facilities at the range.
- **Launch** and recovery.
- **Data acquisition** with provisions of real time, quick-look and replay data from modules and payload subsystems (e.g. g-levels).

- **Disassembly** of recovered payload and return of modules for retrieval of processed samples.
- Post flight report.

2.4 Additional services

The following services are available on request:

- Supply of outer structure.
- REXUS TM simulators can be available on request. The electrical input interface to the simulator is the same as in flight configuration.

2.5 Student Experiment Documentation

Each student team will document their experiment setup, the experiment components, interfaces, technical data and the flight requirements in the **Student Experiment Documentation (SED)**. This SED will be a living document during the project. At the end of different project phases should have a certain status and it will be used as a required documentation for PDR, CDR and MTR. The due date for the final version of this document is before launch.

Once selected every experiment team will receive a SED blank book.

After the delivery of the experiment hardware there will be several tests. These tests are performed in accordance with an established test plan and test procedure. The results are documented in test reports and presented during the Experiment Acceptance Review.

Non-conformances shall be recorded in a **Non-Conformance Report (NCR).**

The test procedure shall contain:

- Scope of the test, referring to requirement in specification to be verified
- Test conditions
- Test equipment and set-up
- Step-by-step procedures
- Recording of data
- Success Criteria

All test report, action item lists and NCRs shall be attached to the SED.

2.6 Mission Flight Handbook (MFH)

The mission objectives, the vehicle design and operational constraints will be documented during the project phase in the **Mission Flight Handbook (MFH).** All important information of the MFH, the nominal trajectory and updated vehicle parameters will be frozen in the **Campaign Handbook** at begin of the campaign. A **Post Flight Report** with the flight events and trajectory data will be distributed as soon as possible after launch. All three documents will be provided by EuroLaunch.

3 REXUS SYSTEM

3.1 REXUS vehicle

A typical REXUS vehicle consists of a one-stage rocket, an **Improved Orion**, and the payload. This rocket gives approximately three minutes of spaceflight with a payload mass including service and recovery system up to ~100 kg.

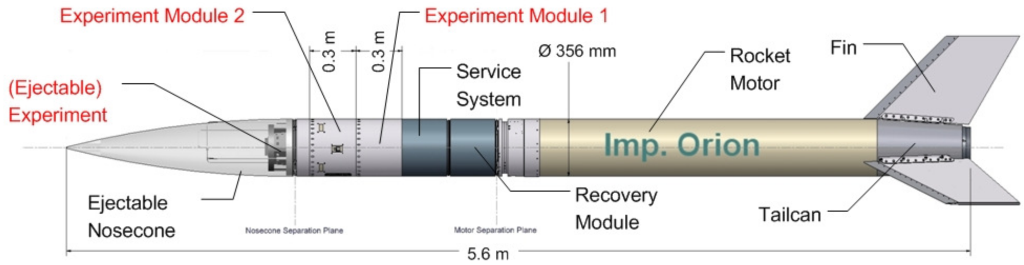


Figure 3-1: REXUS Standard Configuration

A typical configuration is shown in Figure 3-1. Each configuration is designed to optimise vehicle and experiment characteristics.

3.1.1 Service Module

The main encoder, Telemetry & TV transmitter and telecommand receiver are housed in a service module, the **REXUS Service System RXSM**. This service module also contains the accelerometer system, which consists of a three-axial micro-gravity accelerometer unit and three gyros.

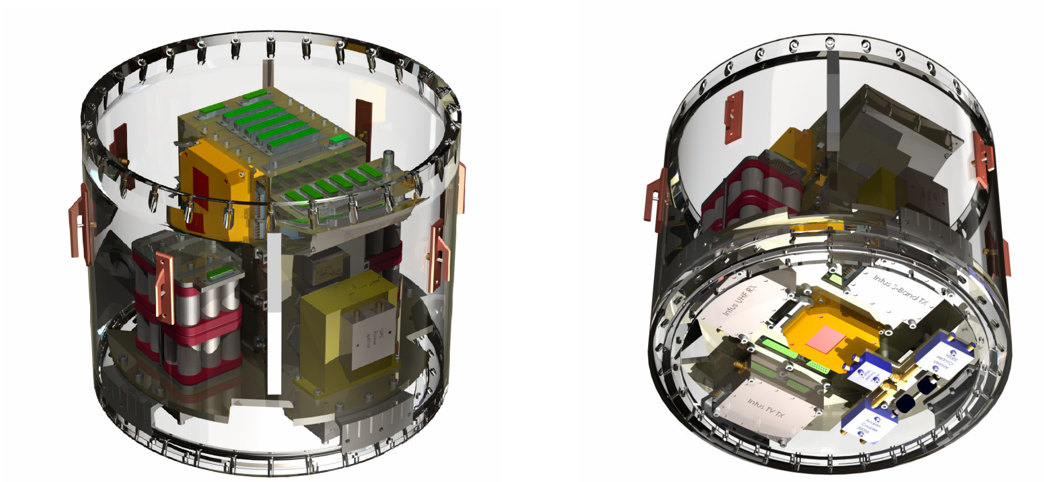


Figure 3-2: REXUS Service System

3.1.2 Rate Control

A de-spin system (the Yo-Yo) can be used to reduce the stabilising spin after the launch phase. This is not part of the REXUS single stage standard configuration

3.1.3 Recovery Module

The recovery module is positioned in the back end of the payload and contains a drogue chute, which deploys the main chute. It also contains a heat shield, which protects the parachutes during re-entry. Barometric switches initiate the pyrotechnic sequence for ejecting the heat shield and releasing the parachutes.

The recovery system is capable of landing payloads with the designated payload mass from approximately 100 km apogee. The system is designed to decelerate from 150 m/s sink velocity to **8 m/s impact velocity**.

3.1.4 Homing aid

The vehicle is equipped with a GPS-receiver from which the service module can receive time and position information during flight. The **GPS-position** is transmitted via the telemetry stream. The recovery team in the helicopter can be equipped with a TM-receiver in order to acquire the GPS-position for quick and easy localisation of the payload. An autonomous homing beacon transmitter is also included in the recovery system. The payload is normally brought back to Esrange within hours after launch.

3.1.5 TV-Channel

One analogue TV channel is available for video transmission of one experiment.

3.2 Body Frame Coordinate System (BF)

This coordinate system is very important for the orientation of rocket components and experiments. CAD Drawings of components and experiments should regard this axis definition. Accelerations are measured with the accelerometers referring to this coordinate system. The longitudinal axis is the roll-axis x_{BF} and the Pitch-Axis y_{BF} and the Yaw-Axis z_{BF} build a right hand system.

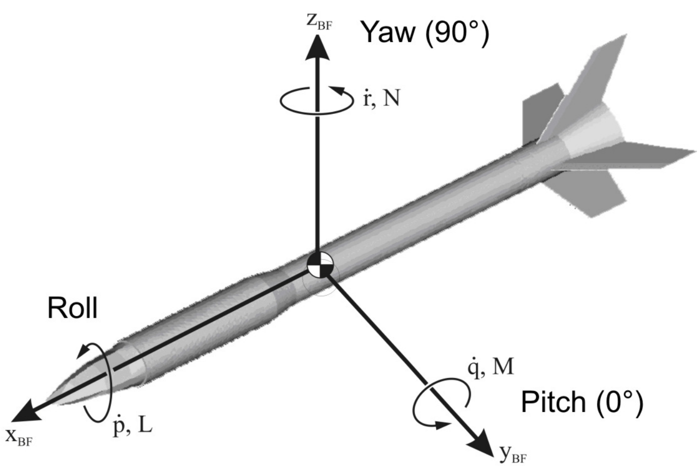


Figure 3-3: Definition of the REXUS BF-System

The BF angle velocities $\dot{q}$, $\dot{r}$ und $\dot{p}$ and the Roll-momentum L, the Pitch-Momentum M and the Yaw-momentum N are defined in Figure 3-3.

The origin of the system is located at the interface between the igniter housing bay and the payload on the longitudinal axis of the REXUS vehicle.

3.3 Performance, Flight Sequence

The performance of the REXUS rocket may be adapted to the respective mission requirements.

In the following tables, the flight sequence & g-levels from a typical REXUS flight with an imp Orion.

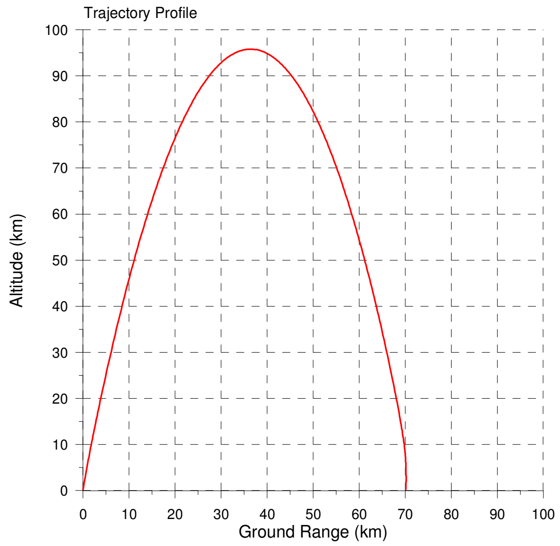
3.3.1 Nominal trajectory

The nominal flight trajectory is dependent on payload mass and configuration. The following table gives an overview on the flight events of REXUS-3. The yo-yo release is not part of the standard configuration.

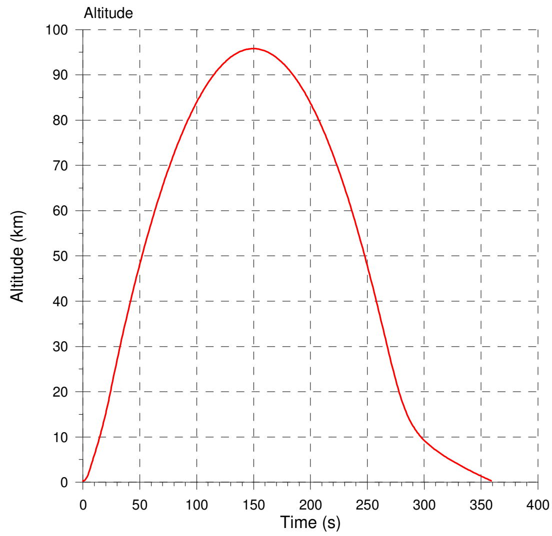
Table 3-1: REXUS-3 Flight Events

EVENT	Time (s)	Altitude (km)	Range (km)
Ignition	0.0	0.305	0.0
Lift-off	0.44	0.316	0.001
Burn-out	26.0	22.4	3.9
Nose Cone Ejection	60.0	57.3	13.2
Yo-yo Release	63.0	59.8	14.0
Experiment Separation	66.0	62.3	14.8
Motor Separation	69.0	64.7	15.5
Apogee	150.0	95.8	35.5
Payload Impact	358.0	0.0	70.2

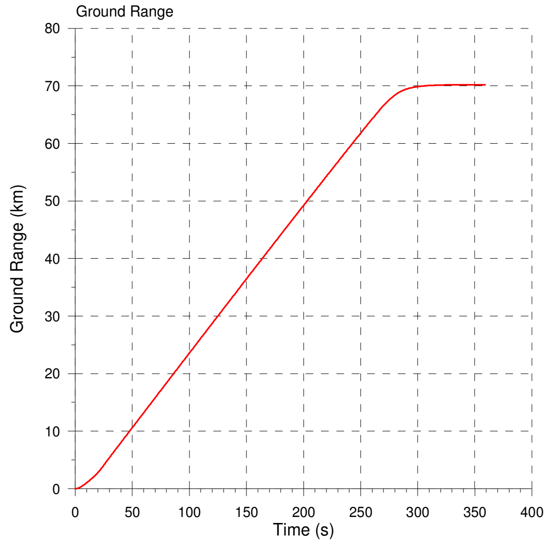
3.3.2 Graphs of a Nominal Trajectory



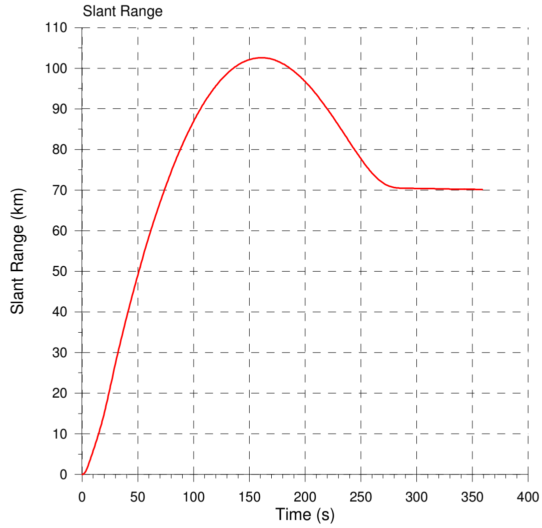
Trajectory Profile



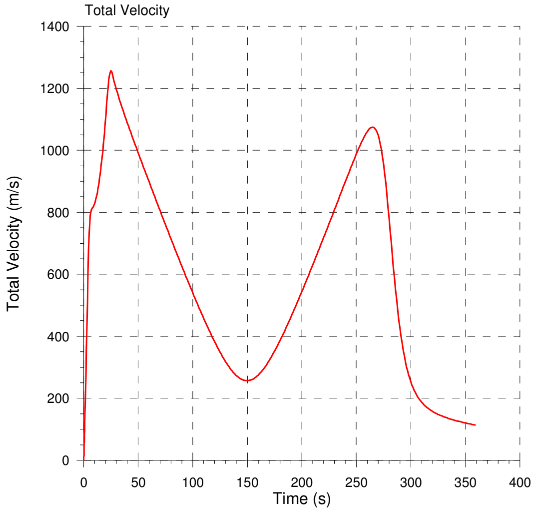
Altitude



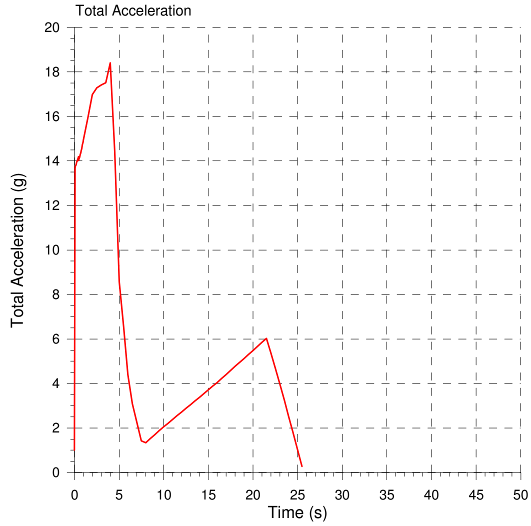
Ground Range



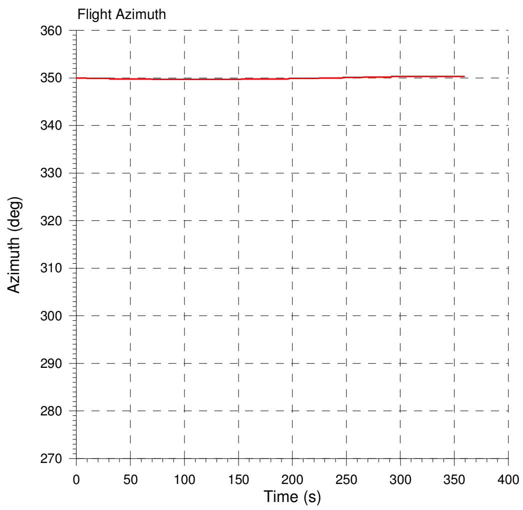
Slant Range



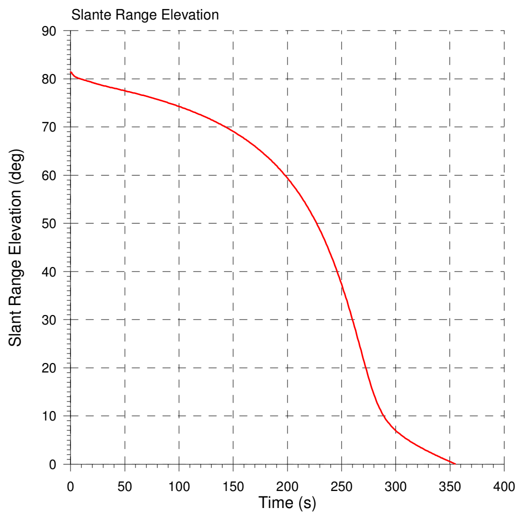
Total Velocity



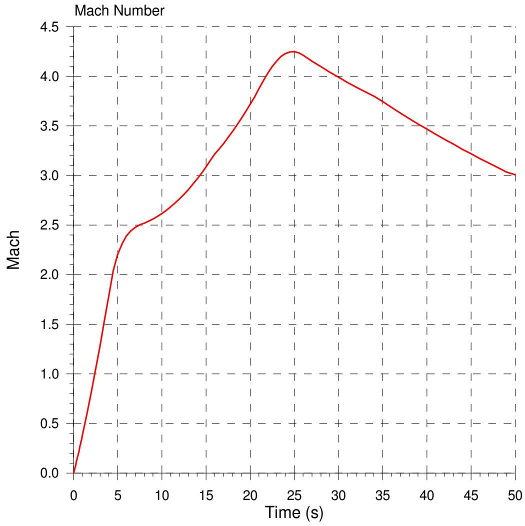
Total Acceleration



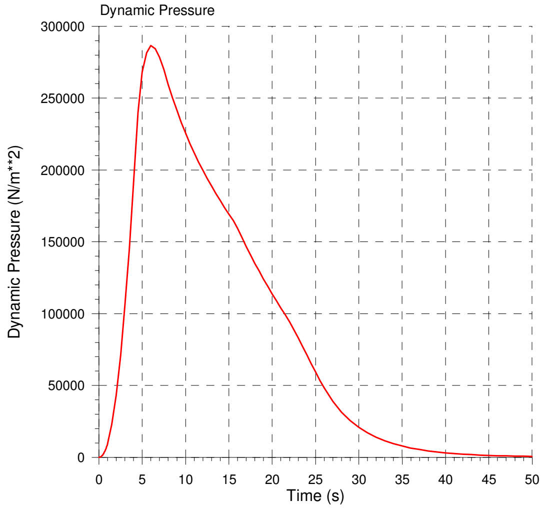
Flight Azimuth



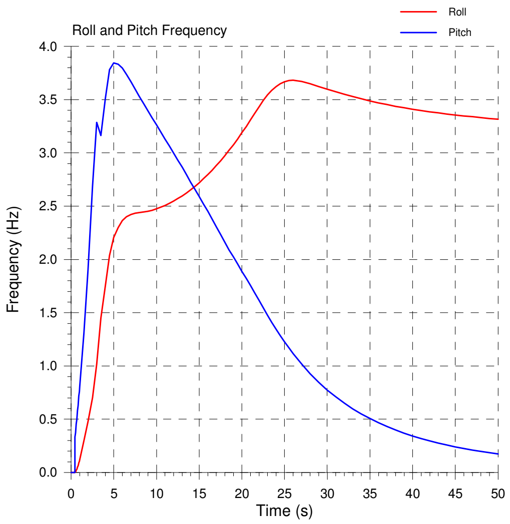
Flight Elevation



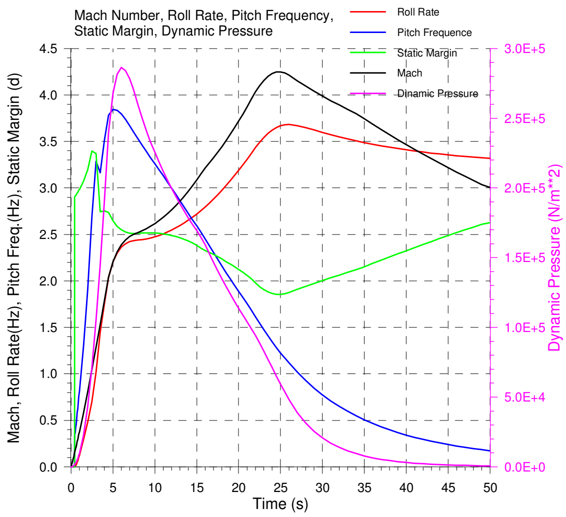
Mach



Dynamic Pressure



Roll and Pitch Frequency



Crossing Frequencies

3.4 The REXUS thermal environment

3.4.1 Pre-launch Phase

The integration of the modules and payload are made in normal room temperature 20±5 °C. After integration, the payload is mounted in the launch tower. The ambient temperature during the transport can be low (down to -30 °C), depending on the outdoor temperature, but the exposure time is short (5-10 minutes).

The thermal environment in the launch tower will be kept under control before launch. The vehicle is in housing with an air temperature of 17±7 °C.

3.4.2 Count Down Phase

Experience shows that during count down, 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 heat sensitive experiment modules, include a temperature regulation in the design. See also chapter 4.2 for thermal requirements.

3.4.3 Flight Phase

Thermal environment of the outer structure of a front-end positioned parallel bay module on an Improved Orion motor flight can reach 110°C at 50 seconds after lift-off. Peak temperatures above 200 °C are reached during re-entry phase. This will of course be transferred to internal parts, especially items mounted on the skin.

3.4.4 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. The temperature during the season when REXUS is launched is normally between 0 °C and -30 °C. Experiments with samples sensitive to low temperatures after the flight, must be designed for these post flight conditions.

4 MECHANICAL DESIGN OF EXPERIMENTS

A configuration of an experiment module is shown in Figure 4-1 and Figure 4-2. Different types of mechanical interfaces between the experiment deck and the outer structure are possible, such as Radax joints. Eurolaunch will assist in defining suitable mounting positions, joints and screws.

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

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

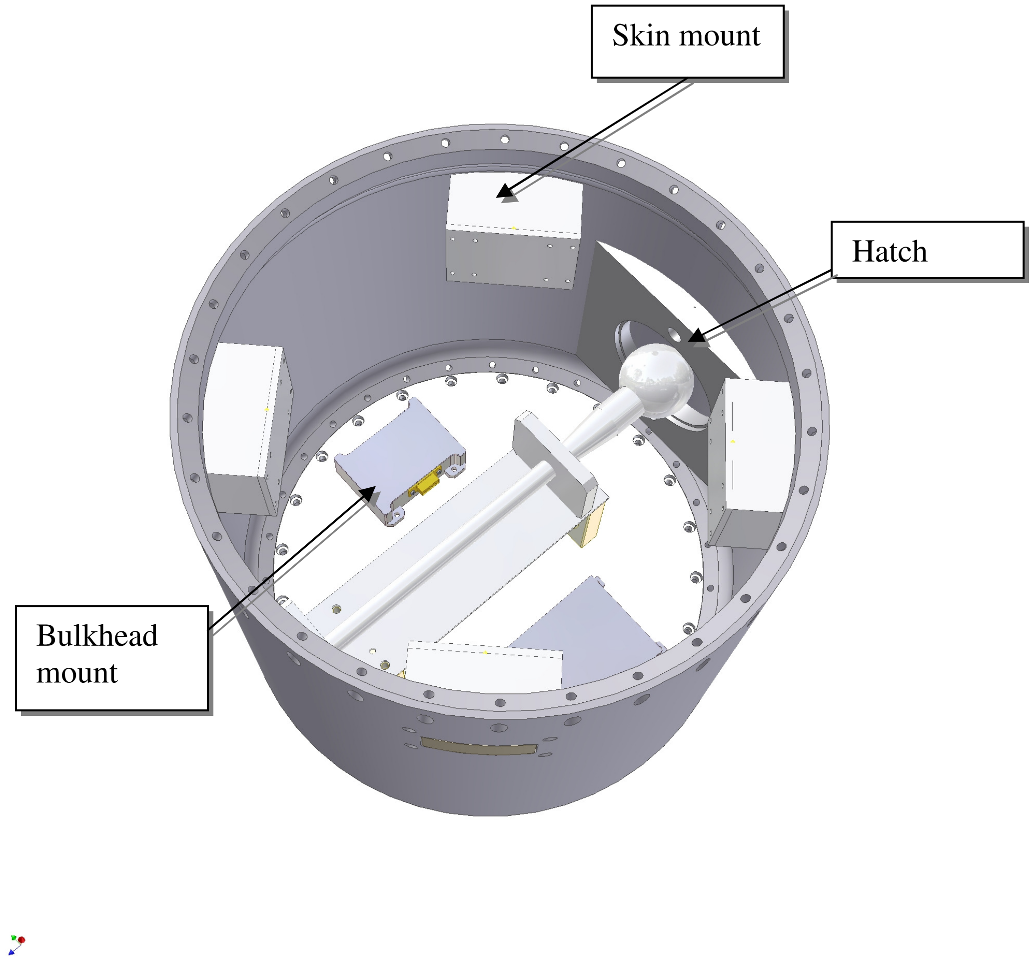


Figure 4-1: Experiment Module

Figure 4-2: REXUS Nose Cone Experiment

4.1 Baseline Module design

Baseline for the mechanical design is that the outer structure is made of a minimum 4 mm thick Aluminium cylinder. This structure is normally supplied by EuroLaunch.

Any exception from the baseline must be agreed with EuroLaunch.

4.2 REXUS modules thermal requirements

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

4.2.1 Heating of the outer structure

Module internal thermal dissipation must not heat up the outer structure more than 10 °C over the ambient temperature.

4.2.2 Temperature at the feed-through cable

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

4.2.3 Heat radiation in the module interfaces

Module internal thermal dissipation must not heat up parts facing other modules to more than +50 °C.

4.2.4 Convection between connecting modules

The heat transport through 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.

4.3 Hatches

Hatches for late access should be oriented so that access is possible when the payload is on the launcher. Hatches must be mounted before launch. The figure below gives a recommended design of a hatch.

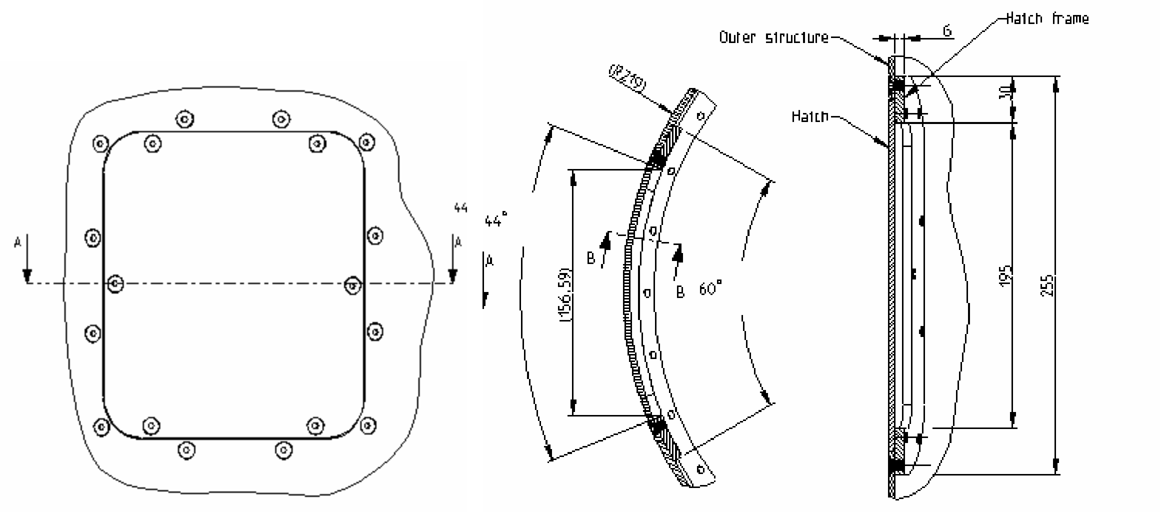


Figure 4-3: Hatch Example

4.4 Exhaust openings

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

4.5 Dimensioning loads during launch, flight and recovery

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

4.5.1 Acceleration

The typical longitudinal acceleration history (for an Improved Orion rocket motor combination) is shown in shown in chapter 3.3.

4.5.2 Re-entry Loads

The typical deceleration during **re-entry** is not above **20 g**.

4.5.3 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 gentle with no damage on the experiment modules.

4.6 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.

4.6.1 Vehicle Characteristics

Momentum wheels, cavities partially filled with liquids, etc. will only be accepted after a successful analysis on the impact on the vehicle performance.

4.6.2 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.

4.6.3 Vibrations

Vibrations induced by movement of components in the payload will also cause disturbances on 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 $5*10^{-5}$ (0-25 Hz). This level changes from flight to flight and is depending on the experiment modules' sensitivity to vibrations.

4.7 *Mass balance and mass* properties

The centre of gravity of each module shall be as close as possible to the x-axis. Mass balancing of the modules, adding ballast weights, does not have to be performed, since the total payload will be mass-balanced, thereby saving total ballast weight. This work is performed by EuroLaunch.

The accuracy should be as follows:

Total mass		±0.5 kg
Mass distribution		±0.25 kg per 10 cm
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	±2 cm
	Y	±2 cm
	Z	±2 cm

5 ELECTRICAL DESIGN OF EXPERIMENTS

5.1 General

The electrical interfaces between the experiments are limited to data and command wires connecting each experiment to the REXUS Service Module RXSM. The lift off signal is distributed via the communication interface.

The interface between the experiments and the SM is identical for all experiments. The TM interface is described in chapter 5.2.

An electrical cabling scheme will be prepared for each payload configuration.

The feed through harness for REXUS will be designed and built by EuroLaunch.

5.2 Telemetry System

The REXUS telemetry system is designed and manufactured by Eurolaunch. It consists of the TM/TC master, located in the RXSM and TM/TC users distributed in the experiment part of the payload.

The maximum number of users in the experiment payload is 5. Each user is powered from the RXSM.

The output from the main encoder modulates an S-band transmitter providing the ground link.

TM/TC master to TM/TC user:

The interface between master and each user in the TM/TC system is implemented using two serial connections, one in each direction. Each interface connection is a symmetrical pair, driven by an RS-422 driver.

Type: Asynchronous serial link

Signal std: RS422

5.3 Telecommand System

The telemetry system incorporates a telecommand function. Each experiment module can be individually addressed by ground commands. The telecommand receiver operates in the L-band.

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

5.4 Interface Connector Description to REXUS Service Module

5.4.1 Objectives

Standard Interfaces has been implemented to make the communication between the PCM System, Command System and the experiments easier. If one experimenter isn't able to include these standard interfaces in his experiment EuroLaunch may support him with the tools (data acquisition unit) to be compliant with these standards.

The installed command and telemetry system delivers a fully transparent up and downlink channel for each experiment. The same user software for controlling and monitoring of the experiment data can be used during the test phase and during flight.

5.4.2 Interface Description Onboard

Each experiment obtains its own interface connector. On this connector all communication lines, power lines and control lines are implemented. A DSUB 15 m connector is used to perform the interface, and it has a standard pin allocation.

5.4.2.1 Telemetry Interface

A RS 422 interface is responsible for the transfer of the experiment data to the PCM System. The baudrate must be adjusted to the maximum data throughput, while the formatting, the failure recognizing and correction is in the responsibility of the experimenter.

Baudrate: adjusted to the maximum data throughput, 38.4 kbaud standard

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

If the experimenter is not able to implement a unit to perform the sampling of digital and analogue data and to transfer them to the PCM System via a serial interface a so called data acquisition unit could be made available by EuroLaunch.

5.4.2.2 Command Interface

A **RS 422 interface** supplies the appropriate commands to each experiment. The formatting, failure recognizing and correction is also in the responsibility of the user.

Baudrate: 19200 Baud

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

If the experimenter isn't able to receive commands via a serial RS 422 interface a data acquisition unit may be made available to receive the serial commands and convert these commands into open collector outputs.

5.4.2.3 Power

The power (standard 28 V) is delivered by the service module. The supply voltage can vary between 24 V and 35 V depending the condition of the onboard batteries.

The peak power consumption should not step over 3 Amps during switching, while the mean value should be lower than 1 Amp. The power for each experiment can be controlled by hard-line commands via umbilical or, if available, by RF commands during flight.

If a user needs an extraordinary power system he is responsible for the charging, measurement of his batteries via umbilical lines.

5.4.2.4 Charging Capability

In case of internal batteries within the individual experiment, there is a charging line to provide power (28-34V)@500mA to the experiment when the Service Module is switched off.

This line is only for charging purposes, not for operating the experiment when the S/M is switched off (in case of radio silence).

This line is protected with a diode to avoid reverse current and discharging.

5.4.2.5 Control Lines

The service module supplies 4 different control lines for each experiment which are implemented as open collector outputs with the capability to drive 0.2 Amps for each channel.

The 4 control lines are as follows:

a. **Start of Recording/ Data Storage (SODS)**

b. **Lift-Off (LO)**

c. **Start of Experiment (SOE)**

d. **User defined Time Event (UTE)** (optional)

An activation of the control lines means a sink current of up to 0.2 Amps. This sink current could be used to switch a relay or to control a current through an optocoupler.

If using a relay the user is responsible to include a clamp diode close to the coil of the relay.

5.4.3 Standard Experiment Interface for REXUS Payloads

The interface connector should be a DSUB 15 S. Up to 5 interface connectors should be available to deliver power, to control the experiments and to exchange data in both directions.

Table 5-1: Standard Experiment Interface

Pin Nr	Name	Remarks
1	+28 V	Battery Power (< 3 Amps consumption)
2	spare	
3	SODS	Start of data storage (open collector)
4	SOE	Start of experiment / Stop of experiment (open collector)
5	LO	Lift off (open collector)
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 (< 3 Amps consumption)
10	28V charging PWR	Experiment charging (use 28V GND for return)
11	spare	
12	UTE	User defined Timer Event
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

5.4.3.1 Lift-Off (LO)

This signal is derived from the extraction of the umbilical connector from the Service Module. It is also an open collector output. An active signal means a current flow of up to 200 mAmps.

5.4.3.2 Start of Data Storage (SODS)

This control line can be issued by time line during flight or it can be initiated by the EGSE system via umbilical. An active signal means a current flow (< 200 mA) from +28 V to ground. The user should connect either an opto coupler device or a relay to make this signal available for his experiment.

5.4.3.3 Start of experiment / Stop of experiment (SOE)

This control line can be issued by time line or by command during flight. It is also an open collector output. An active signal means a current flow of up to 200 mAmps. The user should connect either an optocoupler device or a relay to make this signal available for his experiment.

5.4.3.4 User Defined Timer Event (UTE)

This control line can be issued by time line or by command during flight. It is also an open collector output. An active signal means a current flow of up to 200 mAmps. The user should connect either an optocoupler device or a relay to make this signal available for his experiment.

5.4.4 Interface Description on Ground

The user of an experiment receives his experiment data via a **RS 232 interface**, and he can control his experiment by sending commands via the same RS 232 interface over the umbilical or over a RF command link, if available.

If a recorder is onboard it can be switched on just before lift-off. The SOE and the UTE can be defined by the user, and they are controlled by time lines on board.

If necessary experiments can be switched off either by RF commands, or by time lines.

Reception of experiment data:

Baudrate: depending on data throughput

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

Commanding of experiment:

Baudrate: 19 200 Baud

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

5.5 Additional Batteries

EuroLaunch recommends using Ni-Metalhydride batteries and has a large experience in using the SAFT brand of batteries on sounding rockets. Other brands that are possible to use, but it is wise to contact the project manager for advice. Lithium batteries should not be used if possible.

Recommended batteries:

Single use: SAFT LSH Series, (Lithium-thionyl chloride)

Rechargeable: SAFT Li-ION, Nickel Cadmium or Nickel Metal Hydride series.

5.6 Umbilicals

5.6.1 Orientation

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

5.6.2 Electrical umbilical provided by experimenters

The module-mounted connector will be mounted on a flange arrangement as shown below.

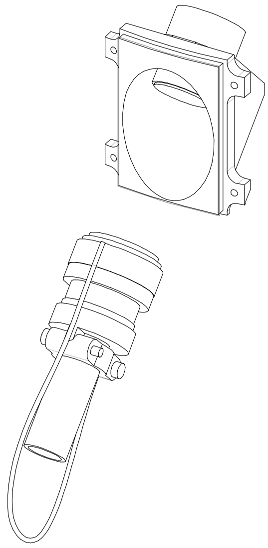


Figure 5-1: Umbilical

5.6.3 High Power Connections

If high power connection is required, the experiment designer is free to choose type of connector. The connector is however subject to EuroLaunch approval. Furthermore EuroLaunch will decide, after discussions with the experiment designer, where and how the connector shall be mounted.

5.6.4 Ground Support Equipment-Umbilical interface

Payloads are provided with Ground Support Equipment providing charging and hard-line communication.

5.7 Electro Magnetic Compatibility

The design shall be such that radiated **Electromagnetic Interference (EMI)** is kept as low as possible, it shall not interfere with other onboard systems. General guidelines of the design are as follows

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

6 EXPERIMENT REVIEWS AND TESTS

6.1 Kick-Off Meeting

The REXUS project Kick-Off Meeting shall be held right after the final selection of the student experiments.

6.2 Preliminary Design Review, PDR

The Preliminary Design Review (PDR) ends the study phase (phase A/B). It will be at the student training week. Minutes of meeting shall be written including an action item list.

6.3 Critical Design Review, CDR

In the phase C/D a Critical Design Review, CDR, is performed after the detailed design is finished but before the manufacturing starts (2-3 months after PDR). Minutes of meeting shall be written including an action item list. The minutes shall be forwarded to EuroLaunch.

6.4 Progress Report / Mid Term Report

About two month after the CDR a Mid Term Report (MTR) has to be prepared by the experimenter. This report shall guarantee a satisfied work progress. The report shall also identify certain problems which are necessary to be solved prior to experiment delivery.

In the report the experimenter shall present the following points:

- Experiment development status
- Time schedule compatibility
- Experiment dimensions and weight
- Identification of problems
- List of hazard materials
- Approach to solve problems
- Interface compatibility

6.5 Vacuum test

Applicable for experiment to be used under vacuum conditions, but is also applicable to verify that systems, mainly electrical, have nominal performance in absence of convective cooling. This is the responsibility of the experimenter to perform.

Basic Procedure:

- The experiment shall be integrated and placed in a vacuum chamber (pressure below **0.5 mBar**).
- Experiment data shall be supervised and recorded during the test.
- The experiment shall be operating during lowering of the pressure in the vacuum chamber. The module shall, if be in a similar mode as during the real ascent of the REXUS.

- After the functional test/flight sequence has been performed it is recommended that the module is kept operating for 15 minutes to detect any leakage/overheating problems.
- When testing high voltage subsystems, corona effects shall be searched for in the pressure interval 1-20 mBar.

6.6 Thermal test

The thermal test is mainly performed in order to verify a nominal function of the experiment during the worst case temperatures during countdown and launch. The heating of the outer structure during ascent is normally not included or tested. This is the responsibility of the experimenter to perform.

Basic Procedure:

- The experiment shall be integrated and 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.
- Module data shall be supervised and recorded during the test.
- The temperature shall preferably be measured in 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 stabilised, perform a functional test/flight sequence. Be aware of condensation problems if the test is performed in normal humidity.
- High temperature test:

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

6.7 Vibration test

The vibration test is made to verify that the individual experiment can withstand the vibration loads during the launch of REXUS. This is the responsibility of the experimenter to perform.

Basic Procedure:

The experiment shall be mounted on the vibration table with a suitable fixture. Critical parts shall have additional accelerometers mounted to track resonances. Functional tests and inspection shall be performed after each axis of vibration.

Vibration in X, Y and Z-axis as specified in Figure 6-1 for the Nike-Improved Orion vehicle.

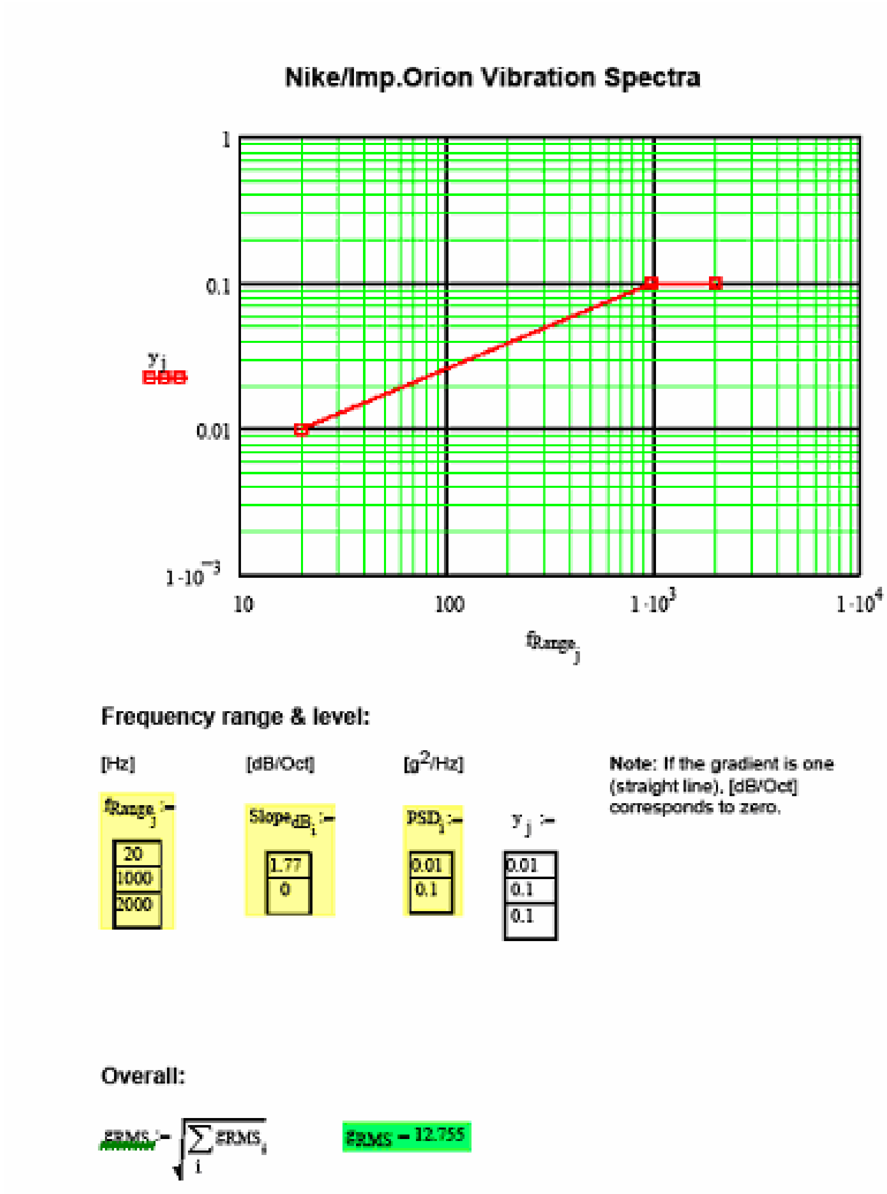


Figure 6-1: Nike-Imp.Orion Vibration Spectra

6.8 Experiment Acceptance Review, EAR

The manufacturing phase should end with the **Experiment Acceptance Test (EAT)** after delivery of the experiment. The EAT is similar to the **Payload System Test (PST)**.

The EAT consist of:

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

The EAT is performed by EuroLaunch together with the experiment responsible student.

6.8.1 Electrical Interface Test

See Chapter 6.9.6.

6.8.2 Flight Simulation Test

This test shall be performed with the payload in flight configuration as far as possible. The test procedure shall include the count down procedure list and follow the nominal count down timetable. It is also important that the experiment is in flight configuration and that the PI is present.

It is important that the changes/modifications are restricted to a minimum, done to H/W or S/W after the Flight Simulation Test. Non-conformances discovered during the test can of course 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 during a relevant review.

Basic Procedure

- The experiment payload shall be integrated and in flight configuration. The Ground Support Equipment, EGSE, shall be connected via the umbilical. The telemetry and telecommand checkout system shall be connected via the interface harness.
- Module data shall be supervised and recorded during the test.
- A nominal realistic count down procedure shall be followed, including at least one payload checkout. Switching between external and internal power shall be done at the nominal time (T-2 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 train countermeasures.

Examples of abnormal tests are:

- Interruption in internal power supply

- Reset of onboard processor
- Malfunction of subsystems e.g. illumination is suddenly switched off

6.9 PAYLOAD ASSEMBLY AND INTEGRATION TESTS

This chapter deals with the assembly of the payload and the tests conducted on the integrated payload. It also defines the requirements regarding the status of the module by delivery of it to the Payload Assembly and Integration Tests (AIT).

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

At the start of the payload integration tests, all experiments comprising the REXUS payload must be made available to SSC. During some of the tests to be 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 use of dummies is required, this must be agreed by EuroLaunch.

6.9.1 Experiment Status by Delivery

EuroLaunch recommends the experimenter to conduct the following qualification/acceptance tests on module level as a minimum:

-electrical/functional tests
-vibration tests
-environmental tests
-mechanical interface checkout
-electrical interface checkout

6.9.2 Experiment Incoming Inspection

All Experiment mechanical and electrical interfaces will be inspected at delivery to the AIT.

6.9.3 Payload Assembly

The experiment, other modules and subsystems will in due order be mated to the payload. All the mechanical and electrical interfaces will be checked and tested systematically during the assembly in accordance with chapter 6.9.5 and 6.9.6.

6.9.4 Payload System Tests

The Payload System tests comprises

- Module checkout
- Payload mass properties determination and balancing
- Payload spin test
- System Electrical test 1 + EMI-check
- System Electrical test 2
- Flight Simulation test

6.9.5 Mechanical Interface Test

The mechanical joints are checked by mounting the module to the interfacing modules.

Orientation of umbilicals, feed-through harness, venting holes, etc is checked. This test is performed by EuroLaunch during the payload assembly.

6.9.6 Electrical Interface Test

The electrical interface test will verify the compatibility of the interfaces and the functioning of the concerned hardware. Interface compatibility for critical signals, protection automatisms and voltage regulations will be checked systematically during assembly. Detailed procedures have to be defined for every unique module/subsystem.

The test is performed by EuroLaunch.

6.9.7 Module Checkout

The module is connected to the telemetry system and all channels used are checked with the module powered and simulating experiments.

The test is performed by EuroLaunch and the Experiment responsible personnel.

6.9.8 Mass Properties and Balancing

The mass properties of the payload are measured and aligned. The following measurements are performed by EuroLaunch:

- Payload Mass
- Centre of gravity
- Spin
- Moments of inertia

6.9.9 Spin test

During the balancing the payload is subject to ~3Hz spin for several minutes.

6.9.10 Bend Test

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

These tests are, if needed performed by EuroLaunch.

6.9.11 System Electrical Test 1 and EMI-check

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

Telemetry transmission will be done 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 EGSE.

These tests are performed by EuroLaunch together with experiment responsible personnel.

6.9.12 Payload vibration Test

A complete vibration test is normally not performed.

6.9.13 Flight Simulation Test

The payload will be ready for the FST after successful results in the tests above. Umbilicals shall be connected and the payload shall be in vertical position. Each module shall be monitored and controlled by the module ground support equipment.

When all modules are operating nominally, a complete count-down and flight sequence is performed.

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

6.10 Flight Acceptance Review

Upon completion of payload integration tests described in chapter 6.9, the Flight Acceptance Review, FAR shall be held.

The result from the tests shall be reviewed and problems will be discussed.

The objective of the FAR is to obtain system acceptance and to authorise start of the campaign. Agreements shall specify whether to proceed on schedule or not, if the FAR is unsuccessful due to failure of any experiment.

6.11 Flight Readiness Review

The launch readiness review is conducted by the EuroLaunch co-ordinator at campaign and after completion of experiment module preparation, payload integration and test, payload integration on launcher, GSE installation in blockhouse, payload checkout, ground support stations checkout and test count down.

The purpose of the meeting is:

- to authorise 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 each appointed system responsible shall give a status report at the meeting.
- to ensure that all experiments are ready for the flight. For this, each appointed experiment module manager shall give a status report at the meeting. In addition, the PI is requested to state the operative status of the experiment.
- to review the count down list
- to inform all relevant personnel of the safety regulations applicable during the count down phase.

to inform all relevant personnel of general arrangements implied during the count down phase (canteen hours, information systems etc.).

7 LAUNCH CAMPAIGN

The REXUS project manager provides Esrange Space Center, as well as all parties involved in the project, with the campaign handbook. This document comprises a description of the specific project such as payload data, list of hazardous materials, experiment requirements on launch operations, participants etc.

Action	Date
Start of campaign	***Day 1***
Preparation of Experiment modules and Service Systems	***Day 1 – 3***
Range Compatibility Tests	***Day 1- 3***
Bench test, and Experiment module check on launcher	***Day 3-5***
Payload Assembly, and Payload Test	***Day 3-5***
Motor Separation Test, and Flight Simulation Test	***Day 3-5***
Launcher Preparations Blockhouse Preparations	***Day 3-5***
P/L to launcher Payload Checkout	***Day 5***
Test Countdown, and Launch Readiness review	***Day 6***
First Hot Countdown	***Day 7***

7.1 Description of Esrange Space Center

All the necessary information for a user of Esrange can be found in the Esrange Users's handbook, Ref.(1). Its main contents are:

-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, cost...)

-Satellite facilities

7.2 Assembly of rockets and payloads

7.2.1 Assembly of rockets

All assembling and preparations of the rockets are taken care of by the EuroLaunch launch team.

7.2.2 Assembly and checkout of payloads

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

7.3 Countdown and Launch

During the count down phase important count down information is displayed on "PA video monitors" at various locations of the range.

The count down phase starts with the test count down. It is normally executed during normal working hours. During the test count down, all payload events up to lift off shall be executed, late access activities shall be executed, all supporting ground facilities are operating. Dummy units may be used during the test count down but requires Eurolaunch approval.

Normally the count down payload events starts at 3 hours before launch.

After completion of the preparatory work and the test count down, the FRR is held, see chapter 6.11. Pending the outcome of the test count down, and the discussions during the FRR, the Hot Count Down list may be adjusted.

Nominally, the first "Hot Count Down" is started the day after the test count down. The nominal lift off time is planned for. 05.00 to 20.00 local time. The launch window is determined by the payload preparation time, hold requirements and the time of daylight.

The decision to start the count down is taken at a weather briefing immediately before planned start of count down. The decision is based on dedicated weather forecasts and wind data obtained by weather balloons released from Esrange. If the weather conditions are unsuitable for launching the vehicle, the launch will be delayed until the flight conditions are fulfilled.

7.4 Recovery

The helicopters are equipped with tracking receivers for the payload beacon signal, and can also be equipped with a payload TM receiver for data reception of the payload's GPS position.

During the 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.

During the descent of the payload, the prediction on the impact point co-ordinates is reported to the helicopters from Esrange. The helicopters start their localisation operation immediately after the impact. At the impact site, the helicopter crew disassembles time critical samples from the payload for quickest possible return to the range laboratories. If early recover is required, a second helicopter is acquired for carrying the payload back to the range.

The whole operation is normally completed within two hours after launch.

After the recovery, a Post Flight Meeting is held to debrief the flight and a short flight performance report is stated.

8 EXPERIMENT QUALITY ASSURANCE

EuroLaunch major concern of QA on experiment level is that the experiment shall 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 has a strong concern that the experiments shall perform nominally.

The following advice reflects these concerns.

8.1 Materials

In addition to normal concerns when choosing materials, special attention shall be paid to out gassing phenomena due to vacuum environment during flight.

As an aid the ESA-document PSS-07 (QRM-01) may be used.

8.2 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.

8.3 Additional quality topics

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

8.3.1 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 operations.

8.3.2 Manufacturing control and inspection

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

- Manual soldering according to ESA PSS-01-708
- Crimping of connections according to ESA PSS-01-726

Specific requirements of the project or product concerning cleanliness, contamination and environment shall be stated in the Technical Specification.

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

Connectors shall be well marked and preferably keyed

8.3.3 Re-used Item

It is important to consider the complete history of the re-used item, by consulting the hardware logbook or former project log-book; to be sure that it does not include any hidden failures.

8.3.4 Availability and Maintainability

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

8.3.5 Handling, storage and packing

ESD susceptible components shall be handled in ESD protected environment.

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

8.4 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

All the above mentioned laws and regulations are available at www.av.se/inenglish/lawandjustice/workact

The experimenter shall state that the module fulfils the applicable requirements and establish a list of hazardous materials, which shall be communicated to EuroLaunch no later than the MTR. This information shall always accompany the experiment.

8.5 Safety at Esrange Space Center

The Safety Regulations that applies at Esrange may be found in Esrange Space Center Safety Manual. Ref. [3]. It is a requirement that all personnel participating in the campaign shall have read the safety regulation in Ref. [3] prior to their arrival at Esrange Space Center.

9 COORDINATE SYSTEM DEFINITION

This chapter will give an overview on the coordinate systems that are used for a REXUS onboard sensor, GPS and tracking systems. Knowledge about the coordinate definition and transformations is important for the analysis of sensor data during the flight and for the post flight analysis. The following table lists the used coordinate systems.

Table 9-1 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

9.1 Earth Centered Inertial System (ECI)

This system originates ate the center of the Earth, as the name implies, and is designated with the letters 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 is 90° North Pole. This coordinates system is not rotating. It is assumed to be fixed inertial in space. See Figure 9-1.

Before giving a definition of the vernal equinox, some expressions of the Earth motion around the Sun have to be explained. The ecliptice is defined as the mean plane of the Earth' orbit around the Sun. The term comes from the fact that eclipses of the Moon occur only when the Moon is close enough to this plane and is between the Earth and the Sun. When the Sun is viewed from Earth, it appears to move along the ecliptic. It does not move exactly on the ecliptic because this path is defined as the mean plane of the Earth's orbit. The Earth's equatorial plane extends the equator from the Earth. The angle between the Earth's mean equator and the ecliptic is called the obliquity of the ecliptic ε. This angle is about 23.5°, although it does vary slightly over time due to perturbations. The line of intersection of the two planes is called the line of nodes, like for the satellite orbit plane and the Earth's equatorial plane. The Sun occupies a position along this intersection twice a year and they are called equinoxes[1], vernal equinox when the Sun is at the ascending node[2] and the autumnal equinox when the Sun is at the descending node[3]. The seasons cited are for the Northern hemisphere. When the Sun is at an equinox, the Earth experiences equal times of day and night because

[1] Equinox originates in the Latin root *aequinoctium* meaning equal day and night
[2] In spring about March 21
[3] In autumn about September 23

the Sun's declination is zero. The direction of the vernal equinox is designated ♈ and often referred to as the first point of Aries. The symbol designates the ram[4].

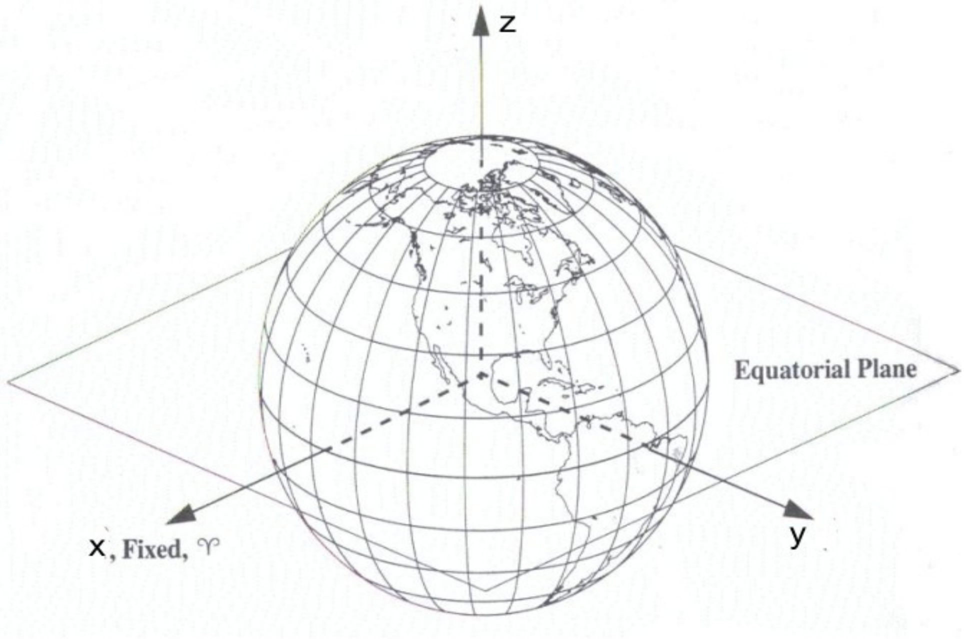


Figure 9-1: Earth-Centered Inertial System (ECI) [Ref. [5]]

A position in the ECI-System can be defines in **Cartesian coordinates** (x_{ECI}, y_{ECI}, z_{ECI}) or in polar coordinates (Right Ascension α, Declination δ, geocentric distance r) [Ref. [2]].

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. 9-1 [Ref. [2]]

$$\alpha = \arctan\frac{y}{x}$$ Eq. 9-2 [Ref. [2]]

$$\delta = \arctan\frac{z}{\sqrt{x^2 + y^2}}$$ Eq. 9-3 [Ref. [2]]

$$r = \sqrt{x^2 + y^2 + z^2}$$ Eq. 9-4[Ref. [2]]

As with the heliocentric coordinate system, the equinox and plane of the equator move very slightly over time, so a truly inertial references frame for the Earth is

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[4] It comes from the fact that the direction of the vernal equinox pointed to the constellation Aries during the lifetime of Jesus from Nazareth (~ 4 B.C. – 30). In 2006, due to precession, the vernal equinox points in direction of the constellation Pisces.

impossible to realize. An inertial coordinate system can be almost achieved if it refers to a particular epoch[5] 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 is used since 1984. The x_{ECI} axis points in direction of the mean vernal equinox and the z_{ECI} axis points in direction of the mean rotation axis of the Earth on January 1, 2000 at 12:00:00:00 TDB which coreresponds to a Julian date JD 2451545.0.

9.2 Earth Centered, Earth Fixed (ECEF)

If the geocentric coordinate system rotates with the Earth, it results in **Earth-Centered 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 coordinates system is rotating.

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

$$\vec{r}_{ECEF} = \begin{pmatrix} x_{ECEF} \\ y_{ECEF} \\ z_{ECEF} \end{pmatrix} = d \cdot \begin{pmatrix} \cos\varphi_{gc} \cdot \cos\theta \\ \cos\varphi_{gc} \cdot \sin\theta \\ \sin\varphi_{gc} \end{pmatrix} \qquad \text{Eq. 9-5}$$

[5] Greek root: hold point

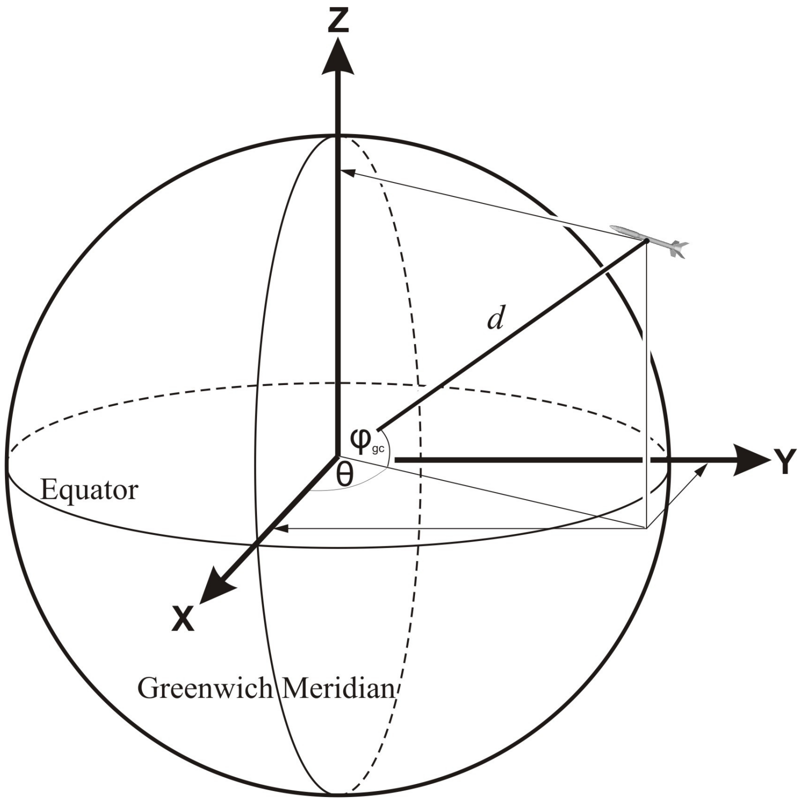

Figure 9-2: ECEF Coordinate System

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 en 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. 9-6 [Ref. [2]]

The WGS84 Ellipsoid has a flattening of $f_\oplus = 1/_{298.257223563}$ and the equator radius $R_\oplus$ is 6378137 m [Ref. [2]]. The Earth eccentricity $e_\oplus$ can be calculated with following equation.

$$e_\oplus = \sqrt{1-(1-f_\oplus)^2}$$ Eq. 9-7 [Ref. [2]]]

The position of the Rocket is given in geodetic coordinates relative to the reference ellipsoid. The **geodetic longitude θ** corresponds to the geocentric longitude. Not like 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 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 the following figure:

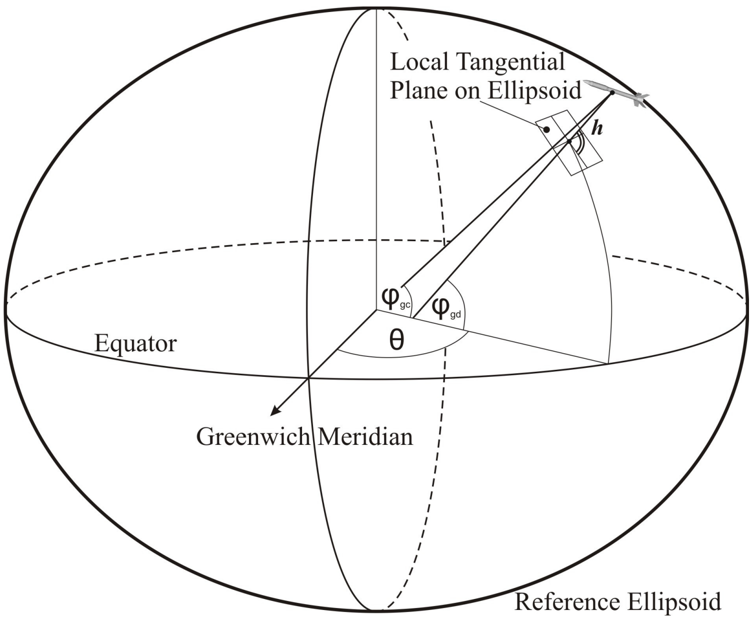

Figure 9-3: WGS84 Reference Ellipsoid

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

9.3 Local Tangential Coordinate System (LTC)

This system is important for observation of the rocket from Launcher, Tracking or Radar Station. 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.

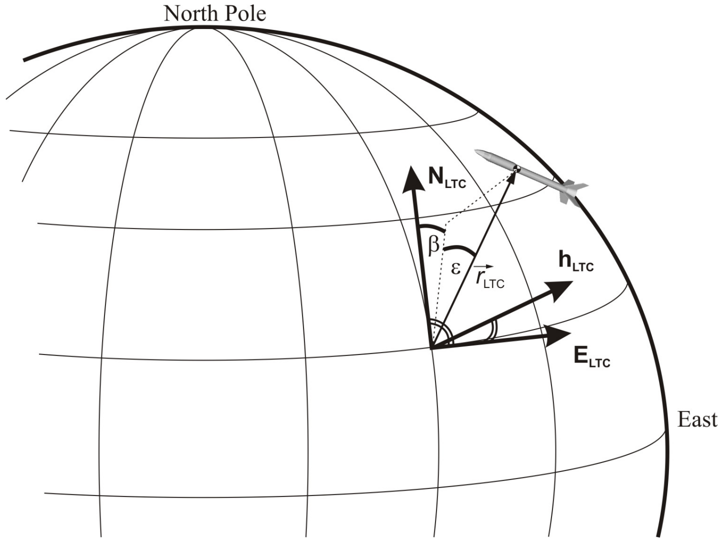

Figure 9-4: Local Tangent Coordinate System (LTC)

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 following equation:

$$\beta = \arctan\left(\frac{east_{LTC}}{north_{LTC}}\right)$$

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:

$$\varepsilon = \arctan\left(\frac{h_{LTC}}{\sqrt{east_{LTC}^2 + north_{LTC}^2}}\right)$$

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

$$\begin{pmatrix} east_{LTC} \\ north_{LTC} \\ h_{LTC} \end{pmatrix} = d \cdot \begin{pmatrix} \sin\beta \cdot \cos\varepsilon \\ \cos\beta \cdot \cos\varepsilon \\ \sin\varepsilon \end{pmatrix}$$

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

9.4 Vehicle Carried Vertical Frame (VCVF)

This system moves with the rocket and the origin is the center of gravity of the rocket. 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 build a right hand system and is perpendicular to the local plane. Only the equator it is oriented exactly to the earth center.

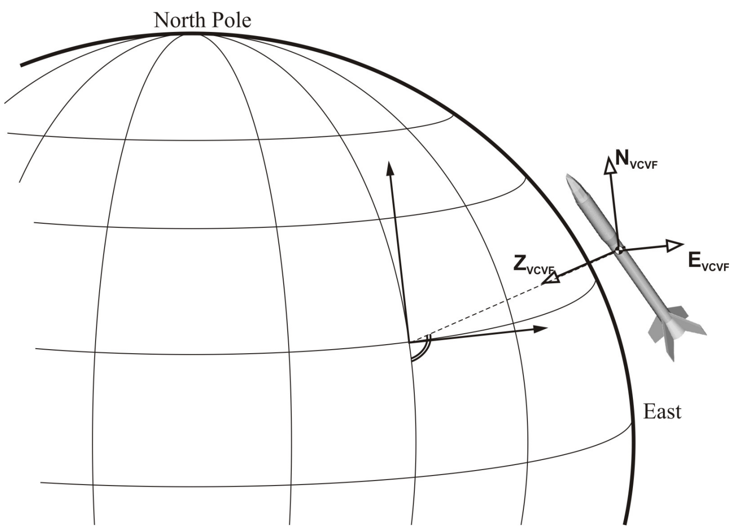

Figure 9-5: Vehicle Carried Vertical Frame

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

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

$$\beta = atn\left(\frac{v_{east}}{v_{north}}\right)$$

The next figure shows the orientation of the angles:

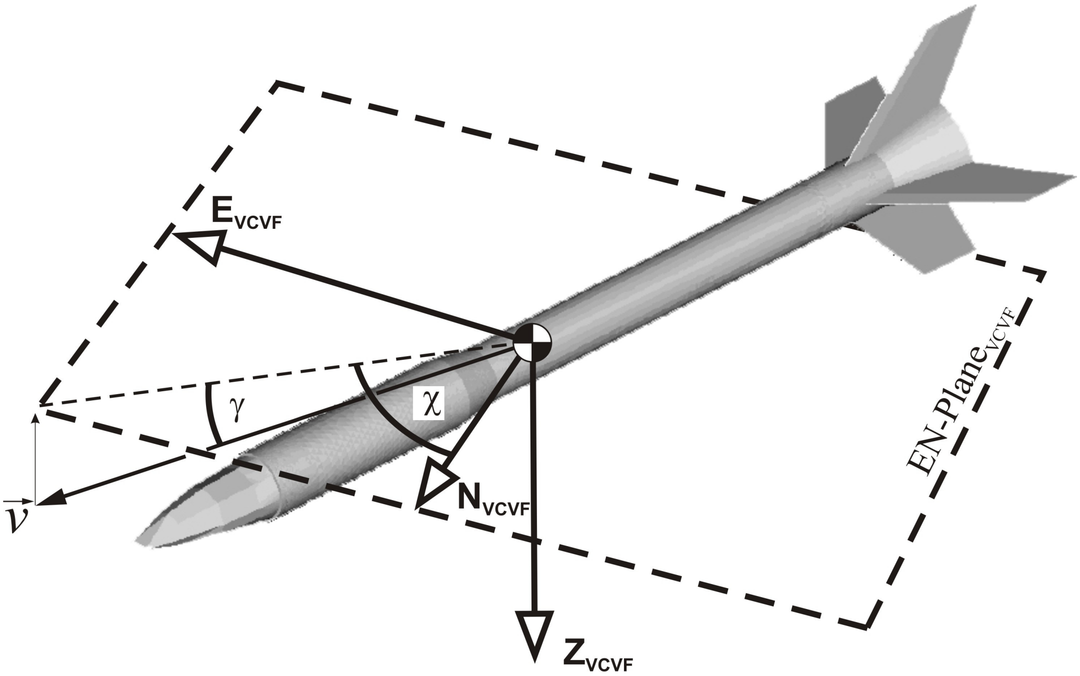

Figure 9-6: Flight Path Angle and Heading Angle