BEXUS User Manual

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This is not an ICD document.

Abstract: This document has been created to aid experimenters taking part in a BEXUS 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: BEXUS, manual, interface, testing, design

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INTRODUCTION

The REXUS/BEXUS Programme

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).

Esrange Space Center of SSC is responsible for the campaign management and operations of the BEXUS launch vehicle.

Experts from DLR, DLR MORABA, SSC, ZARM and ESA provide technical support to the student teams throughout the project.

The BEXUS mission

BEXUS experiments are lifted by a balloon with a volume of typically 12 000 m^3 to an altitude of 25-30 km, depending on total experiment mass (40-100 kg). The flight duration is 2-5 hours.

The BEXUS gondola is modularised to provide simple interfaces, good flexibility and independence between experiments. All payload service systems necessary for telecommunication, payload control and recovery are included in the system. High speed telemetry and up-link command control of experiments is provided.

BEXUS User Manual

This document describes all the necessary information for a user of the BEXUS system. It defines the requirements that apply to the BEXUS experiments and gives design recommendations. It also includes a description of the BEXUS system, the programmatic elements, the pre-flight tests and the campaign schedule. Additional recommendations can be found in the last chapter.

If you require additional information on the BEXUS system, please contact SSC.

1 ALWAYS READ THIS

There is a lot 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, lasers (in particular exposed or 'open-path'), radiation, pressure vessels 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.

Transceivers

All equipment that emits or receives RF must have permission by Esrange via the SSC project manager.

Radio Frequency interference test

After the completed RF test it is not permitted to make any changes to the gondola or experiments before flight. If you miss this test during the campaign preparation phase, it may be necessary to remove your experiment or fly the gondola with your experiment turned off.

If your experiment disturbs any of the flight systems, it will not be flown at all.

Weather constraints

It is not possible to guarantee a launch during any specific week, due to weather constraints. Make sure that your experiment can be operated by Esrange staff, in case the launch is postponed beyond the date when you have to leave.

Planning

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

Safety on balloon pad

No one is allowed to be outside on the balloon pad without the permission of the SSC Operations Officer.
Late access to the experiment on the balloon pad has to be part of the countdown procedure and need to be discussed and planned in advance with SSC.

Campaign Requirements Plan

This is a document that is compiled by the SSC payload manager based on inputs and requests from all experimenters. Without good information, well before the campaign, it might be impossible to fulfil a requirement such as the provision of gases, special tools, etc.

You are always welcome to contact your payload manager for any questions.

1.1 Definitions

The BEXUS system consists of the following components according to the SSC definition.

BEXUS	The complete integrated vehicle to perform the flight.
Ground Equipment	BEXUS supporting systems on ground.
EBASS	Balloon service system.
EMPIRE	Esrange Multipurpose Iridium Relay.
E-Link	Ethernet up & downlink.
Esrange Facilities	Main building, restaurant, Aurora hotel and balloon halls.
Ground Support Equipment	Equipment used to control and communicate with various modules during test and count down.
Balloon	The part of BEXUS giving the lifting force.
Payload	Experiments and all subsystems.
Subsystems	All systems required for flight control, recovery, and telemetry.
E-GON	Experiment equipment and the carrier structure.

1.2 References

NOTE: All references documents can be found on the REXUS/BEXUS teamsite along with the manual. The ECSS references link directly to the documents themselves, firstly though, in order to access the documents, registration is required (this is easy and free for the user)

[1] ECSS, *Space project management / Project planning and implementation*, ECSS-M-ST-10C Rev.1 (ESA Publications Division, 2009) (http://ecss.nl/standard/ecss-m-st-10c-rev-1-project-planning-and-implementation/)

[2] ECSS, *Space product assurance / Manual soldering of high-reliability electrical connections*, ECSS-Q-ST-70-08C (ESA Publications Division, 2009) (http://ecss.nl/standard/ecss-q-st-70-08c-manual-soldering-of-high-reliability-electrical-connections/)

[3] ECSS, *Space product assurance / Crimping of high-reliability electrical connections*, ECSS-Q-ST-70-26C (ESA Publications Division, 2017) (http://ecss.nl/standard/ecss-q-st-70-26c-crimping-of-high-reliability-electrical-connections-15-march-2017/)

[4] SSC, Esrange Space Center, *Esrange Safety Manual*, REA00-E60, ver 9 (12June2020) (https://sscspace.com/news-activities/rockets-and-balloon-activities/)

[5] ECSS, *Space product assurance / Data for selection of space materials and processes*, ECSS-Q-70-71C rev. 2 (ESA Publications Division, 15October2014) (http://ecss.nl/standard/ecss-q-st-70-71c-materials-processes-and-their-data-selection/)

[6] *RXBX_REF_SED Template_v6-1_06Feb20*

[7] *RXBX_REF_SED Guidelines_v6-2_29May20*

[8] Saft, *Primary Lithium battery LSH 20 Data Sheet* (https://www.saftbatteries.com)

[9] SEE-BLITZ, *Strobe light Key Features* (http://www.see-blitz.com/keyfeatures.html)

[10] Mircoair Avionics, *T2000 SFL Rev 9 Transponder Data Sheet* (http://www.microair.com.au/admin/uploads/documents/T2000SFLUserManual01R82rev8.pdf)

1.3 Applicable documents

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

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

1.4 Abbreviations

AIT	Assembly, Integration and Test
APID	Application Identifier
ASAP	As Soon As Possible
ATC	Air Traffic Control
BCR	BEXUS Campaign Report
BEXUS	Balloon-borne EXperiments for University Students
CD	Count Down
CDR	Critical Design Review
CRP	Campaign Requirement Plan
DLR	Deutsches Zentrum für Luft- und Raumfahrt
EAR	Experiment Acceptance Review
EAT	Experiment Acceptance Test
EBASS	Balloon piloting system
ECEF	Earth Centered, Earth Fixed
E-GON	Esrange GONdola
EGSE	Electrical Ground Support Equipment
EIT	Electrical Interface Test
E-Link	Ethernet up & downlink system
EMC	Electro-Magnetic Compatibility
EMI	Electro-Magnetic Interference
EMPIRE	Esrange Multi-Purpose Iridium RElay
ESA	European Space Agency
ESD	Electrostatic Discharge
Esrange	Esrange Space Center
FAR	Flight Acceptance Review
FRP	Flight Requirements Plan
FRR	Flight Readiness Review
FST	Flight Simulation Test
GMO	Genetically Modified Organisms
GND	Electrical Ground
G/S	Ground Station
GSE	Ground Support Equipment
H/W	Hardware
HCD	Hot Countdown
HERCULES	Balloon launch vehicle
HK	House Keeping
I/F	Interface
ICD	Interface control document
IFU	Interface Unit
IPR	Integration Progress Review
LOS	Line of sight

LT	Local Time
LTC	Local Tangent Coordinate System
Mbps	Megabits per second
MFH	Mission Flight Handbook
MORABA	MObile RAketenBAsis (DLR)
NC	Not Connected
NCR	Non Conformance Report
PCM	Pulse Code Modulation
PDR	Preliminary Design Review
PFR	Post-Flight Report
PI	Principal Investigator
P/L	Payload
PST	Payload System Test
PTU	Pressure Temperature hUmidity radiosonde
QA	Quality Assurance
RNRZ	Randomized NRZ (a signalling modulation)
RX	Receiver
S/W	Software
SED	Student Experiment Documentation
SNSA	Swedish National Space Agency
STW	Student Training Week
T	Time before and after launch noted with + or -
TBC	To Be Confirmed
TBD	To Be Determined
TC	Tele-Command
TM	Telemetry
TVAC	Thermal / Vacuum Chamber
TX	Transmission
WGS84	World Geodetic System 1984
WT	Walky Talky, handheld radio
ZARM	Center of Applied Space Technology and Microgravity

2 BEXUS PROJECT OVERVIEW AND MILESTONES

2.1 Project Organisation

The technical support during the design, manufacturing, integration and testing phase is covered by SSC and ZARM payload managers as well as by mentors of ESA. The campaign management and operations are provided by SSC.

The DLR service part concerning experiment integration, testing and students support is provided by ZARM in Bremen.

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

ESA Education is the primary point of contact for the SNSA/ESA teams.

ZARM is the primary point of contact for the DLR teams.

The primary point of contact may provide answers to programmatic, technical and reporting queries posed by the teams.

The organisers support the teams in order to see good scientific returns. Information and expertise are available where required for assisting decisions related to the design, components, materials, operation, and any other mission related issues.

Figure 2-1indicates the key positions assigned to SSC staff for every flight project.

Figure 2-1: Key positions assigned to SSC staff

The launch team is responsible for balloon preparation and launch operations.
The instrumentation team is responsible for E-link/Telemetry (TM) and Telecommand (TC) stations, and Gondola electronics.
One person can have dual assignments.
Additional positions will be assigned during the campaign, see chapter 8.4.

During campaign, the communication between SSC staff and the experimenters shall pass through the SSC and ZARM payload managers.

2.2 Project Planning

Time	Project milestones
T-16 m	Call for experiment proposals
T-12 m	Proposal submission deadline
T-11.5 m	Proposal shortlisting
T-10.5 m	Selection workshop at ESTEC (ESA) / Bonn (DLR), presentation of proposals
T-10 m	Final experiment selection
T-9 m	SED v1-0 submitted
T-7.5 m	Student Training Week (STW) at SSC, Esrange Space Center / Sweden or DLR, MORABA facilities / Germany. Preliminary Design Review (PDR)
T-5.5 m	SED v2-0 submitted
T-5 m	Critical Design Review (CDR) at ESTEC (ESA) including soldering course.
T-4 m	SED v3-0 submitted
T-3.5 m	IPR at experimenters' organisation
T-1 m	EAR for DLR experiments at ZARM / Bremen EAR for SNSA/ESA experiments at experimenters' organisation
T-1 m	SED v4-0 and Input for Esrange Safety Board submitted
T-1 m	Provision of input for Ground Safety Plan - issued by SSC
T+0 m	**Campaign at Esrange (September/October)**
T+0.5 m	Flight Report Documentation from experimenters submitted.
T+1 m	Distribution of the BEXUS post flight Report by SSC
T+3 m	SED v5-0 submitted including experiment results
T+6 m	Publication of Final Report
T+8/20	Results seminars (ESA Symposium/PAC Symposium)

Figure 2-2: REXUS/BEXUS programme timeline

2.3 BEXUS Flight Ticket

To be invited to the BEXUS launch campaign, it is mandatory for the experimenters to pass the Experiment Acceptance Review (EAR). The invite to the launch campaign is known as the BEXUS “flight ticket”, included in which are services as outlined in Figure 2-3.

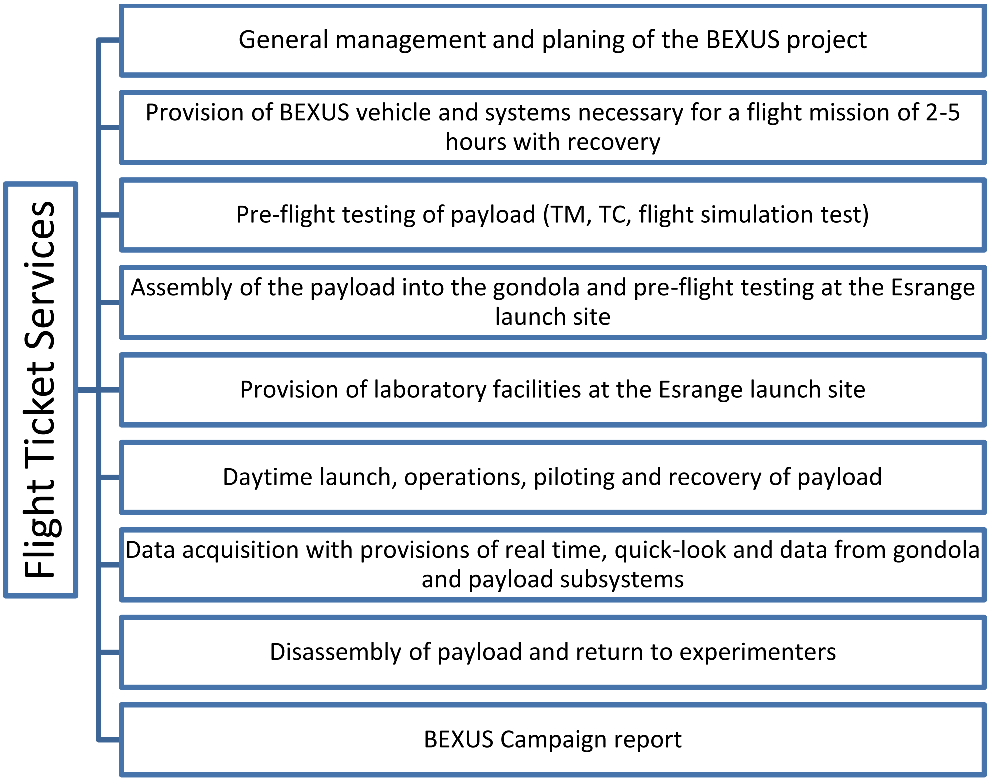

Figure 2-3: Services included as part of the BEXUS flight ticket

2.4 Experimenter’s Role

Once selected to participate in the REXUS/BEXUS programme, the 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, timely processing of data, 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. Final decisions are normally left to the experimenters but if required (by safety or otherwise), the organisers withhold the right to enforce decisions on any issue. Before flight, the experimenters must successfully convince the organisers through 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 necessary support equipment. The organisers can aid with many of these issues, but the teams are responsible for ensuring that these are organized in a timely manner. They are also responsible for ensuring that the experiments conform to all required electrical and mechanical interface specifications, meets safety requirements and survives the flight (chapter 5). The organisers assist in all these issues where possible, but the experimenters must keep in mind that ensuring the resolution of issues is their responsibility.

2.5 Documentation Requirements

2.5.1 Student Experiment Documentation (SED)

The SED provides the organisers from SNSA, DLR, ESA, SSC, ZARM and MORABA with all the important information on a particular experiment. During the phases of experiment development, production and flight, the SED will be the main documentation for experimenters to describe their experiment. Five frozen versions should be provided each of which providing greater detail by experimenters in comparison to the previous version. All documentation relating the requirements of this document can be found at the REXUS/BEXUS website and teamsite (the latter only after selection) including the SED guidelines [7] and SED template documents [6].

2.5.2 Campaign Requirements Plan (CRP)

The CRP is constructed by the SSC payload manager and incorporates information from all experimenters SED. The document details the following information as provided by the experimenters in chapter 6 of the SED:

- Payload descriptions,
- Flight requirements,
- Launch site requirements,
- Mass, power & communication budgets,
- Preparation and tests activities during campaign,
- Timeline and countdown operations.

Any requests for input from SSC must be fulfilled by the experimenters.

This document 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 being made concerning the experiments. These requirements will be made on an individual basis with each of the teams. If incorrect information is provided by the experimenters it may not be possible for the staff to provide the support required and may impact the safety of the flight.

2.5.3 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. Therefore the experimenters are requested to fill out a questionnaire form including all required details. The form will be provided by SSC.

2.5.4 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).

See Appendix C: Examples of recovery sheet.

2.5.5 Flight Report Documentation

The organisers require a post-flight report document for inclusion in the Flight Report that must be produced following each launch. The experimenters must submit only one to two pages regarding performance of their experiment during the flight and preliminary results. 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).

2.5.6 Failure Analysis Report

In case the experiment does not perform as expected resulting in a limited scientific outcome, the experimenter is required to perform a failure analysis. The report needs to be submitted as part of the final SED version 5.0.

3 BEXUS SYSTEM

3.1 BEXUS flight configuration

A typical BEXUS flight configuration consists of a 12,000m^3 balloon type Zodiac 12 SF which is filled with Helium. The total mass may be more than 300kg and the flight train length more than 100m. The BEXUS flight train can be seen in Figure 3-1.

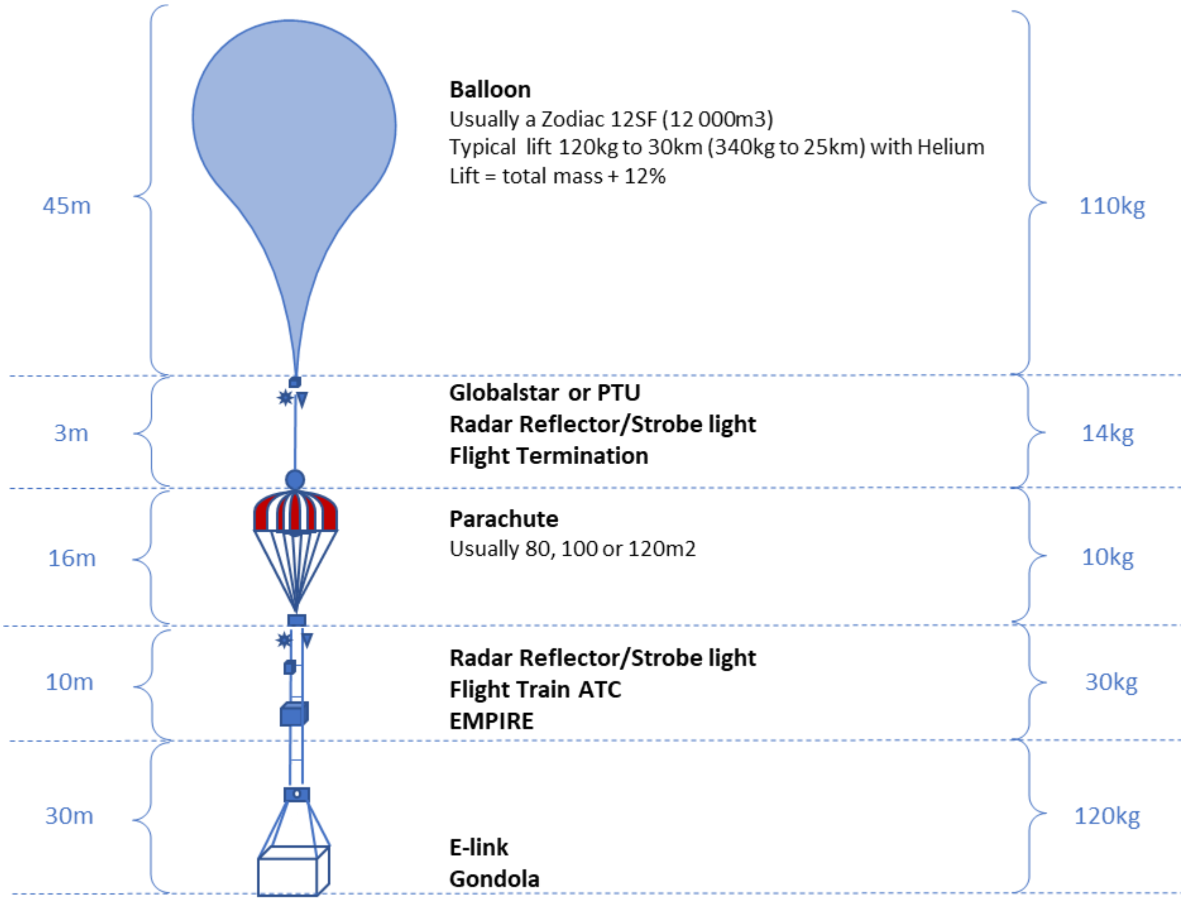

Figure 3-1: Typical BEXUS flight Train

N.B. Values are indicative

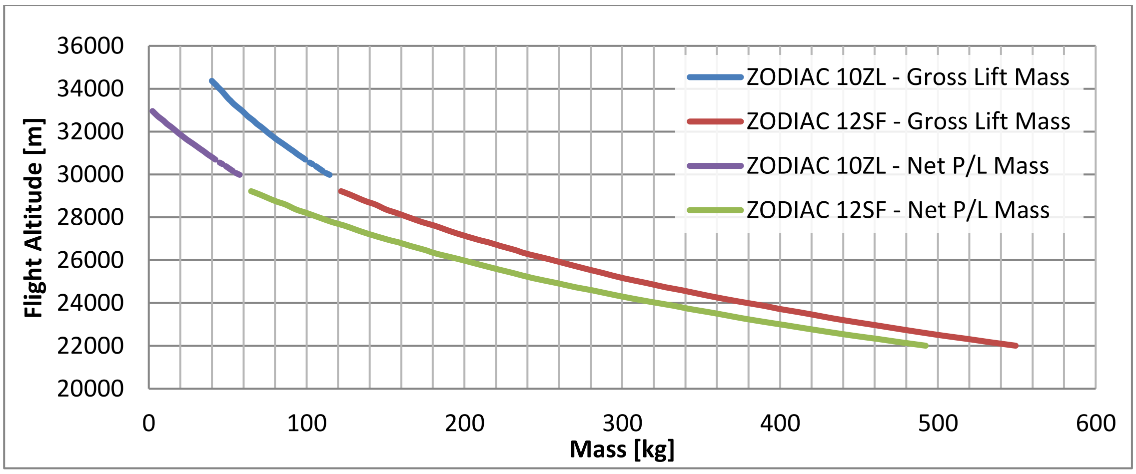

Figure 3-2: Balloon lift capacity using helium, Altitude vs. Gondola Mass (net payload mass estimated by using 57kg flight train)

3.2 Gondolas

There is one primary size of experiment gondola available for the BEXUS programme: Medium Esrange gondola (M-EGON) is a medium-sized gondola with dimensions of 1.16 m x 1.16 m x 0.84 m. It is designed to carry payload loads up to 100 kg.

Reinforcement wires are attached diagonal between the upper corners and the middle of the lower frame. In exceptional cases a removal of single wires can be discussed. The reinforcement wires are distributing the landing forces and preserve the structural integrity of the gondola.

The sides and roof of the gondola is nominally covered with heavy-duty canvas material. A removal, even partially, should be requested to SSC. It is possible to cover the top of the gondola with heavy duty canvas material or aluminium sheeting. This covering is optional and dependent on the gondola configuration.

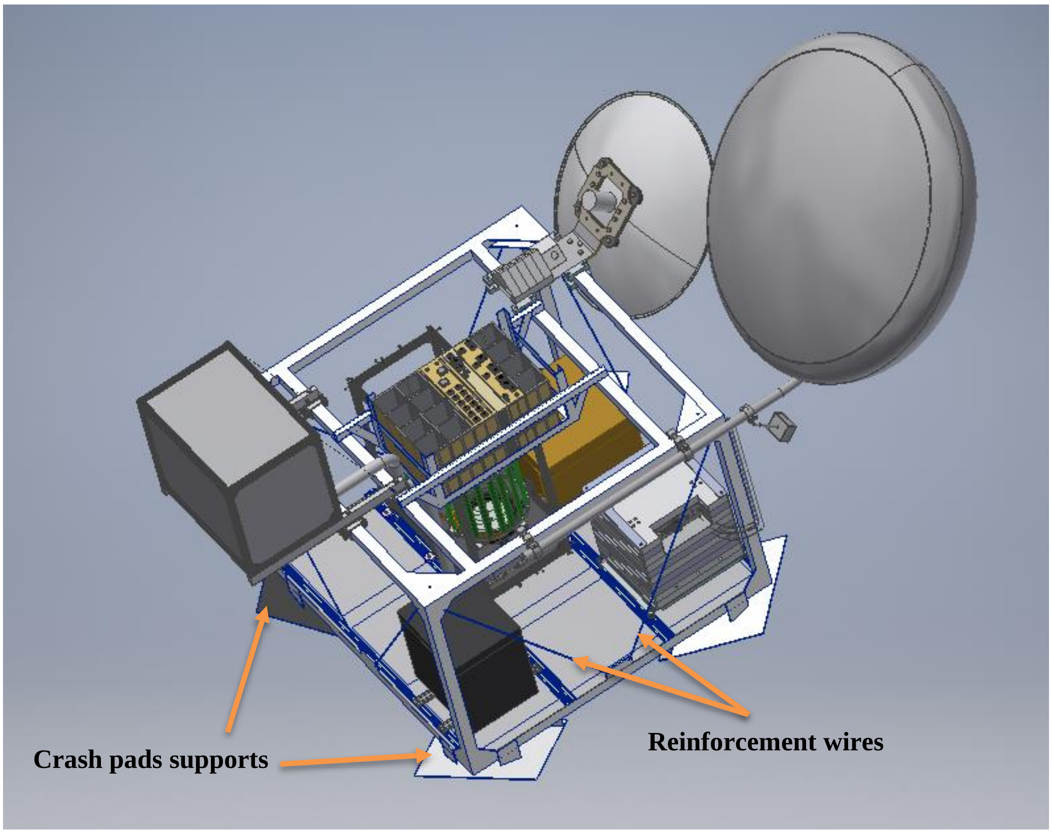

Figure 3-3 BEXUS 31 Gondola with reinforcement wires, crash pads supports and equipped cradle

Figure 3-4: BEXUS-15 Experiment Gondola (M-EGON)

Figure 3-5: Hercules Launch Vehicle with Gondola

3.3 Tracking

The EMPIRE System is equipped with its own GPS receiver and transmits its location (see section 4.2). This is the primary tracking method. E-link system also have its own GPS.

Both the balloon envelope and the payload are equipped with an air traffic transponder and altitude encoder (ATC), to aid tracking. These transponders are triggered by transmission from Kiruna and transmit at 1090 MHz with an output power of 200 W. The transponder is triggered by a dedicated radar signal, the pulses are sent every 6 seconds with an approximate pulse width of 450ns. These transponders are switched off by a barometric switch at around 23 km.

In addition, a Globalstar simplex transmitter is located on the balloon, and sometimes additionally on the gondola and/or flight train. These transmitters transmit at 1615 MHz at around 100 mW. These are used primarily for redundancy and to aid recovery of the balloon material.

3.4 Flight sequence

The typical profile of a stratospheric balloon flight sequence is presented on Figure 3-6.

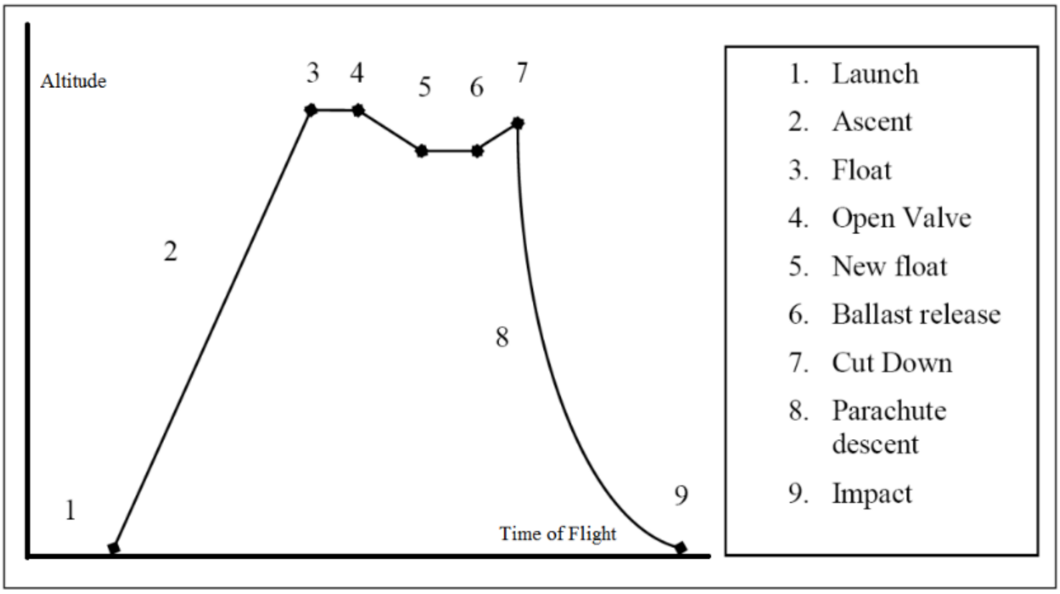

Figure 3-6: Typical Flight Profile of a stratospheric balloon

BEXUS follows the typical profile presented here above. However, Open Valve (4) and Ballast release (6) operations are not normally flown on BEXUS.

The performance of BEXUS flight may be adapted to the respective mission requirements.

3.4.1 Launch

The payload is held by a launch vehicle and is released when the balloon inflation (Helium) is completed.

Figure 3-7: Dynamic Launch with Hercules Launch Vehicle

3.4.2 Ascent phase

The nominal ascent speed is 5 m/s. Depending on float altitude and variations in speed, this phase takes approximately 1.5 hours.

Minor altitude variations occurs before reaching the float phase, a 3-6 m/s of variation can be experienced.

3.4.3 Float phase

When the total mass of the system and the buoyancy of the gas reaches equilibrium, the ascent phase stops.

The payload mass influences the maximum altitude (see Figure 3-2). The final altitude is calculated shortly before launch and may vary between 25 and 30 km. The nominal float time is 1 to 5 hours depending on the direction and wind speed. The flight is terminated by the balloon pilot before it leaves the dedicated landing area. Hence the flight time can vary and it is not depending on total floating time, but on the location of the balloon and the opportunity of safe recovery.

During float, there are minor changes in altitude (±200 m). See Figure 3-8.

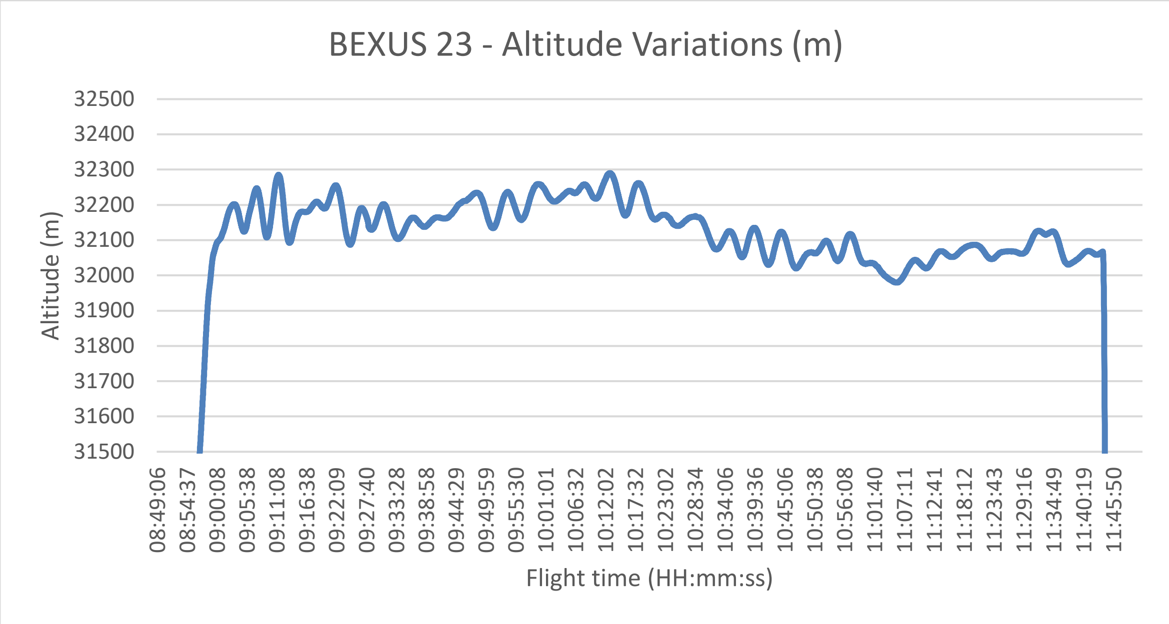

Figure 3-8 BEXUS 23 Altitude variations during float phase

3.4.4 Descent phase

To end the flight, the cutter is activated, causing the balloon to separate from the rest of the flight train and rip open. There is a parachute system that brings down everything below the cutting device.

A small period of reduced gravity will be experienced, but the gondola may tumble and it is suggested that this is not particularly suitable for microgravity experiments.

After the short time of free fall, the parachute inflates and the tug force induced by the sudden deceleration can reach up to several g in all directions

The descent speed is high from the start, due to the thin atmosphere. Closer to the ground, it will stabilize at approximately 7-8 m/s.

3.4.5 Landing

Landing is always planned to be in sparsely-populated areas, preferably without any lakes.

The landing velocity is approximately 7-8 m/s. This is equivalent to a drop from approximately 3 m. There is a shock-absorbing material at the bottom of the gondola that lowers the shock load at landing, the so-called crash pads. Nominally, the landing is gentle with no damage to the experiments.

3.5 Flight trajectory

For details of previous flights, please refer to the past campaign reports and flight data. If these cannot be found on the REXUS/BEXUS website or teamsite, they can be made available upon request.

The total distance covered is different for all missions. Since all flight systems depend of Line Of Sight (LOS) between Esrange and the gondola, the nominal range is between 200 km and 300 km.

Flight profiles are available in numerical form upon request, and some typical examples from previous missions are given below: BEXUS 23, 24 & 26.

Flights	Launch day	Launch time	Payload mass
BEXUS 23	07.10.2016	0709 UTC	46,4 kg
BEXUS 24	18.10.2017	1139 UTC	63,3 kg
BEXUS 26	17.10.2018	0544 UTC	30,97kg

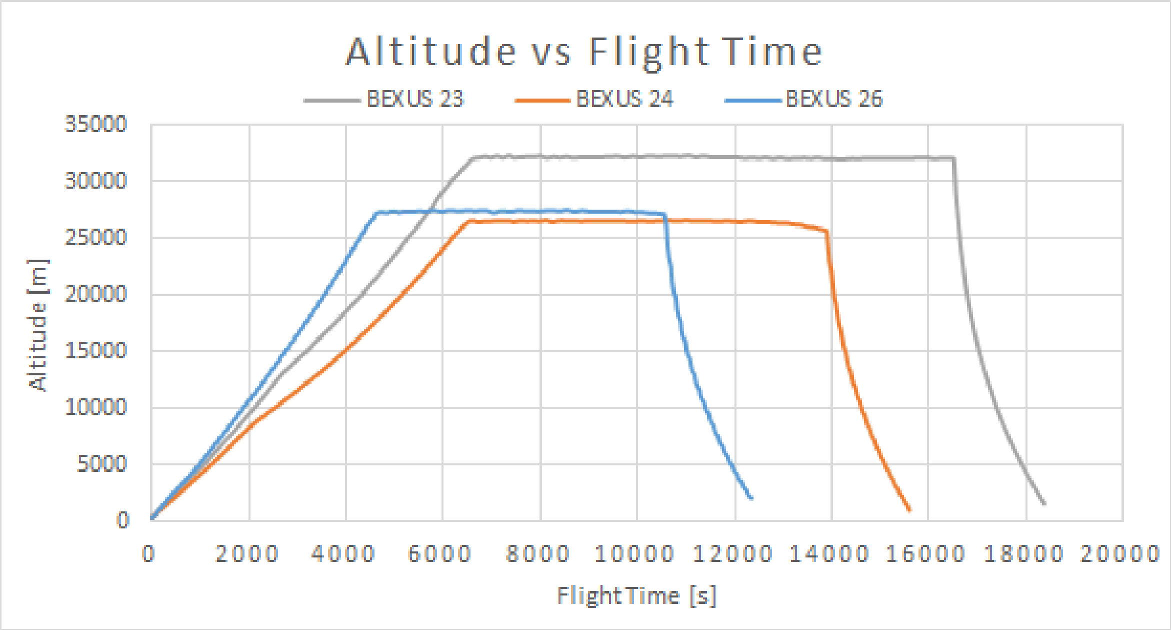

Figure 3-9 Altitude vs Flight Time [BEXUS 23, 24, 26]

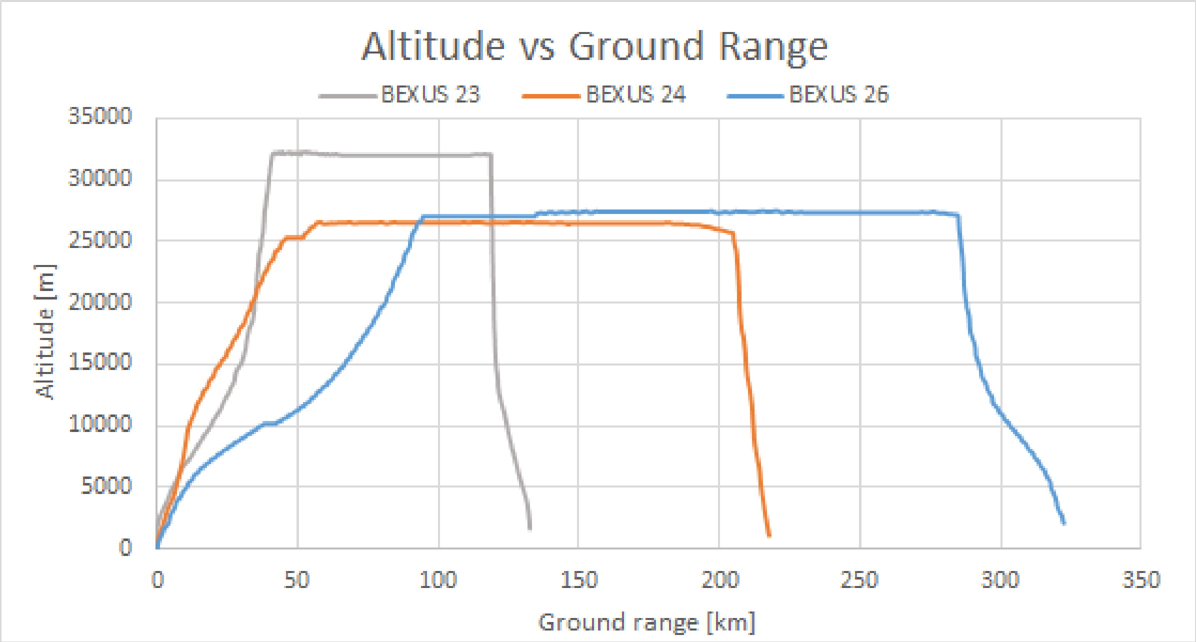

Figure 3-10: Altitude vs. Ground Range [BEXUS 23, 24, 26]

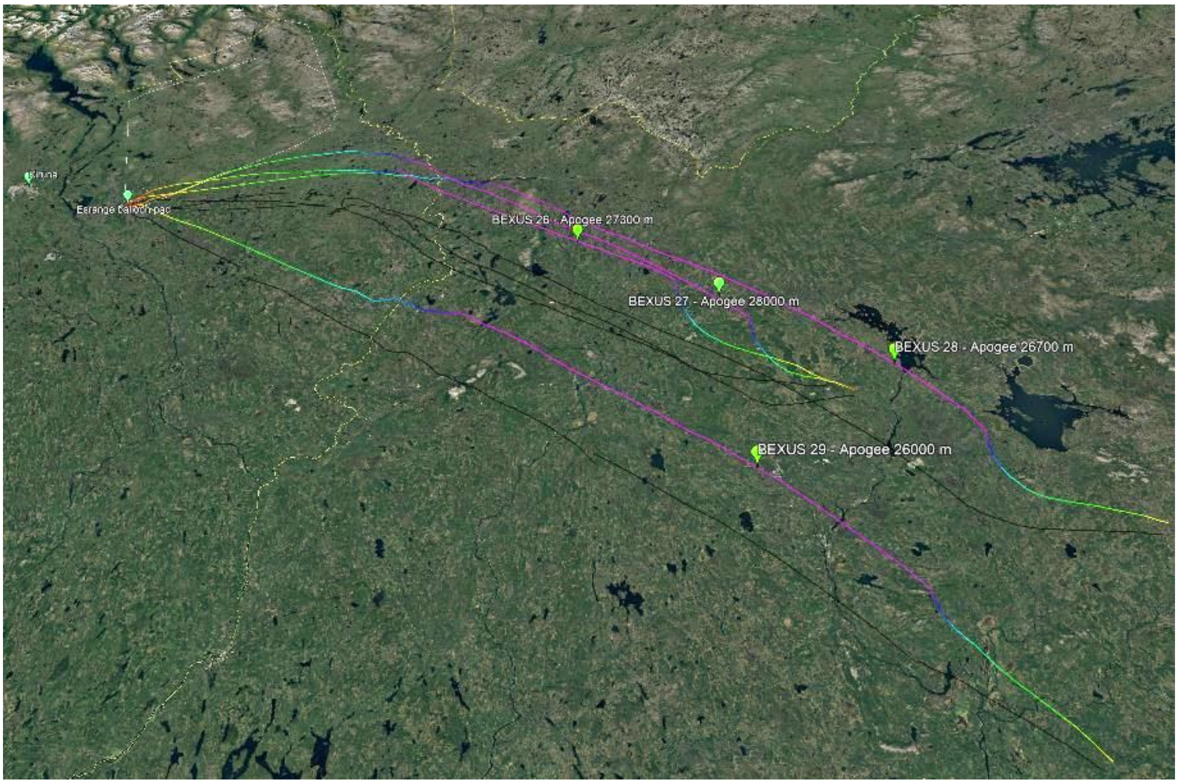

Figure 3-11 Examples of BEXUS Flight Trajectory [BEXUS 26, 27, 28, 29]

3.6 Recovery

Nominally, the recovery is carried out by a helicopter, which provides the transport from the landing site to the nearest road.

From there, a truck will carry the experiments (still mounted on the gondola) and the recovered balloon back to Esrange. This procedure can take a couple of days.

If the experiments contain any time critical equipment, it has to be reported and discussed with the SSC and ZARM payload managers in advance.

Figure 3-12: Landing position of BEXUS-7

Figure 3-13: Landing position of BEXUS-27

4 TELEMETRY SYSTEMS

The two telemetry systems used are E-Link and EMPIRE (or EBASS).

- E-Link is used by experimenters to transfer data to and from ground.
- EMPIRE (or EBASS) is only used by SSC for piloting and housekeeping data.

4.1 E-Link telemetry system

Esrange Airborne Data Link (E-Link) is a telemetry system that offers a simplified interface to experiments with a standard Ethernet protocol. Only the Ethernet interface is provided for BEXUS Experiments.

4.1.1 E-Link System Overview

The E-Link system consists of a ground station and an airborne unit. The ground station consists of an antenna, an antenna controller and a Monitor & Control Unit. The airborne system includes the main unit, an antenna, a battery, and an RF interface unit. One connection is available to each experimenter.

The experimenter is allowed to implement an additional internal Ethernet switch, in case there is more than one connection required.

The main features of the system are:

- Ethernet 10/100 Base-T Protocol
- MIL-C-26482-MS3116F-12-10P connectors (as seen in Figure 4-1)
- High data bandwidth, 2 Mbps duplex nominal
- All electrical parts are approved by FCC and ETSI (standards)
- Fixed IP address allocations

Figure 4-1: E-Link Airborne Unit

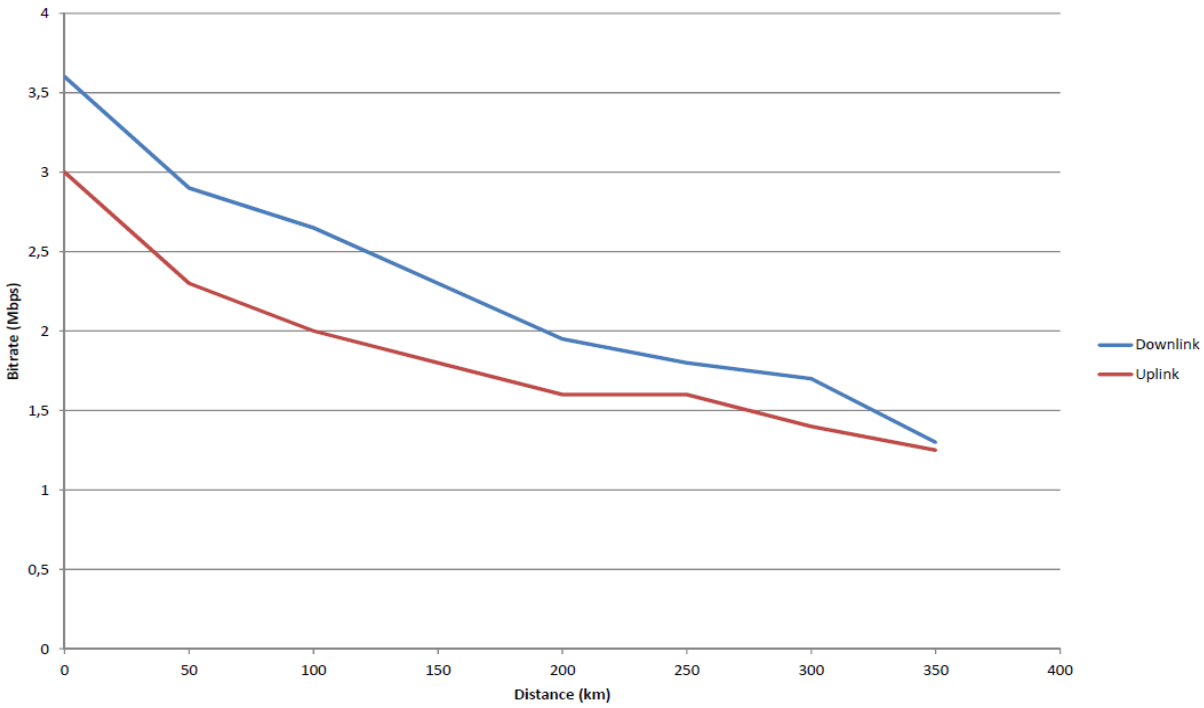

Figure 4-2: E-Link Performance (Mbps) vs. Distance (km)

The experimenters should be aware of the bitrate decline as a function of BEXUS distance as indicated by figure 5-2.

N.B. The E-Link system and all the experiments share the available bandwidth, there is no prioritisation of the E-Link. Consequently, if too much data is sent at the same time, the communication can be lost temporarly. Downlink coordination is essential to ensure that the communication with the experiments is maintained during the flight.

4.1.2 Technical Specification of the E-Link Airborne Unit

Antenna:	Vertical polarised omni
Operating frequency:	S-band
Max output power:	Peak 10 watt
Modulation:	DSSS
Channel bandwidth:	Nominal ±11 MHz
Maximum range at LOS:	500 km at 30 km altitude
Data bandwidth:	2 Mbps duplex nominal, decreasing with range
User interfaces:	2 Ethernet 10/100 Base
Power supply:	20 to 38 volt DC
Operation time:	Nominal > 11 hours
Weight:	Nominal ~20 kg, including batteries

4.1.3 Technical Specification of the E-Link Ground Unit

Antenna:	1.8 meter parabolic dish
Operating frequency:	S-band
Max output power:	Peak 10 Watt

Modulation:	DSSS
Channel bandwidth:	Nominal ± 11 MHz
Maximum range at LOS:	500 km at 30 km altitude
Data bandwidth:	2 Mbps duplex nominal, decreasing with range
User interfaces:	Ethernet 10/100 Base-T

4.2 Esrange Multipurpose Iridium Relay - EMPIRE

This system is used by SSC for piloting of the balloon. It is not used by BEXUS experiments and interference with it must be avoided.

4.2.1 EMPIRE Overview

EMPIRE serves as a balloon flight termination system with the following capabilities:

- **Flight termination**
- **Switchable(on/off) ATC Transponder**
- **Global tracking coverage** (does not need line of sight as EBASS)
- **Housekeeping data**: unit temperatures and GPS
- **Used frequencies**: 1616-1626.5 MHz
- **Used communication system**: IRIDIUM SBD
- **Power**: 12Watt (peak power when EMPIRE is sending, every 10 minutes for 1 second)

4.2.2 Esrange Balloon Service System - EBASS

EBASS was the system used on BEXUS previously. It might still be used by SSC in case of unavailability of EMPIRE. The EBASS system has the following specifications:

- **Transmitting frequency:** 402.2 MHz Nominal (400-405 MHz)
- **Receiving frequency:** 449.95 MHz
- **Output power:** 2.5-5 Watt
- **Antenna type:** Cross Broadband Dipole

Figure 4-3: EMPIRE system

5 DESIGN CONSTRAINTS

5.1 Mechanical design

The balloon gondola (M-EGON) used within BEXUS is shown below. At the bottom bulkhead in each gondola, rails are provided for experiment fixation.

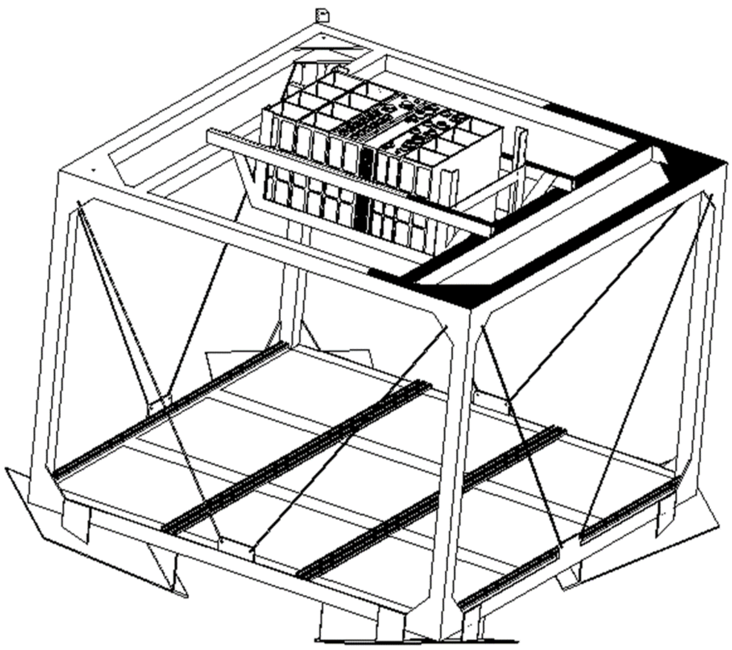

Figure 5-1: M-EGON

Distances between the rails (centre points) are 360 mm. Please see drawing of rails and gondola in Appendix.

- Appendix A: Gondola drawings
- Appendix B: Gondola/Experiment Interface Images

M-EGON CAD model is available on the REXUS/BEXUS teamsite.

5.1.1 Experiment mounting

The BEXUS gondola, M-EGON, enables to mount the experiments using:

- Floor rails (preferred option),
- Vertical bars,
- Roof bars,
- Any other set-up should be discussed well in advance with SSC.

Pictures can be found in Appendix B: Gondola/Experiment Interface Images.

- **<u>Floor rails (preferred option)</u>**

Each experiment must be supplied with several brackets or a bottom plate, in order to facilitate a safe mounting of the experiment. Nominally this happens by bolting the experiment to the gondola rails (see profile in the figure below). Bolt: M6 with 23 mm thread length.

Figure 5-2: Experiment mounting rails and possible mounting solution using anchor bolt (M6)

- **<u>Vertical bars</u>**

Experiments could also be mounted on the vertical bars of EGON using clamps. Be careful, the clamp fixation should be robust and tight. It is recommended to the experimenters to use rubber inside the clamps for a proper clamping.

Figure 6-3: Experiment mounted on EGON vertical bars

Vertical bars have a square profile of 40mm x 40mm.

- **Roof bars**

It is also possible for the experiments to be mounted on the roof bars of the gondola. Be careful, the fixation should be robust and tight. Moreover, the E-link system is also attached to the roof bars. Consult Appendix A: Gondola drawings given for more details.

Roof bars have a square profile of 40mm x 40mm.

Figure 5-3 Experiment mounted on EGON roof bars

Any experiment or part of the experiment located outside of the gondola shall be secured with a safety cable.

For any mounting methods, the experiment should be structured to withstand the loads mentioned in section 5.1.2. It is the experimenters' responsibility to show that the structure and attachment of an experiment is strong enough. This can be done by stress calculations or load tests. Under no circumstances will there be a flight with an experiment that has a risk of falling off the gondola.

5.1.2 Accelerations

The most critical phases in terms of accelerations are the following events:

- Transport prior campaign, rough handling by shipping company personnel. (shock/undefined vibrations),
- Transport on Launch Pad prior launch (undefined vibrations),
- Cut Off sequence during flight (centrifugal forces of tumbling payload, shock),
- Landing (strong shock),
- Transport below the helicopter (strong wind loads and undefined vibrations),
- Transport by truck back to Esrange (undefined vibrations).

The design load used for the payload is:

- Transient excitation (shock) of - 10 g vertically and +/- 5 g horizontally during parachute opening,
- Landing velocity of 7m/s (shock),
- Unspecified random vibrations during transport phases,
- Unspecified shocks during transport phases.

To withstand those accelerations, it is highly recommended to design the experiment hardware according to the specified loads. Those requirements shall be verified by analysis or/and tests. Recommended mechanical tests can be found in section 5.10.3.

5.2 Electrical power

Placed on the outside of the experiment structure/housing, the experiment must have a 4 pin, male, box mount receptacle MIL – C-26482P series 1 connector with an 8-4 insert arrangement (MS3112E8-4P) (Figure 5-4).

Pin A: +

Pin B: -, do not connect to chassis or ground

Pin C: empty

Pin D: empty

Figure 5-4: Amphenol PT02E8-4P

One 28.8 V/1 mA (13 Ah) battery pack can be supplied to each experiment if needed. This battery pack consist of eight SAFT LSH20 batteries in series, each battery has got a built-in 5 A fuse (not changeable), and the combined recommended continuous maximum current draw is 1.8A. Experimenters shall be aware of the characteristics of the batteries under flight and load conditions, example characteristics are shown in Figure 5-5, Figure 5-6 and Figure 5-7.

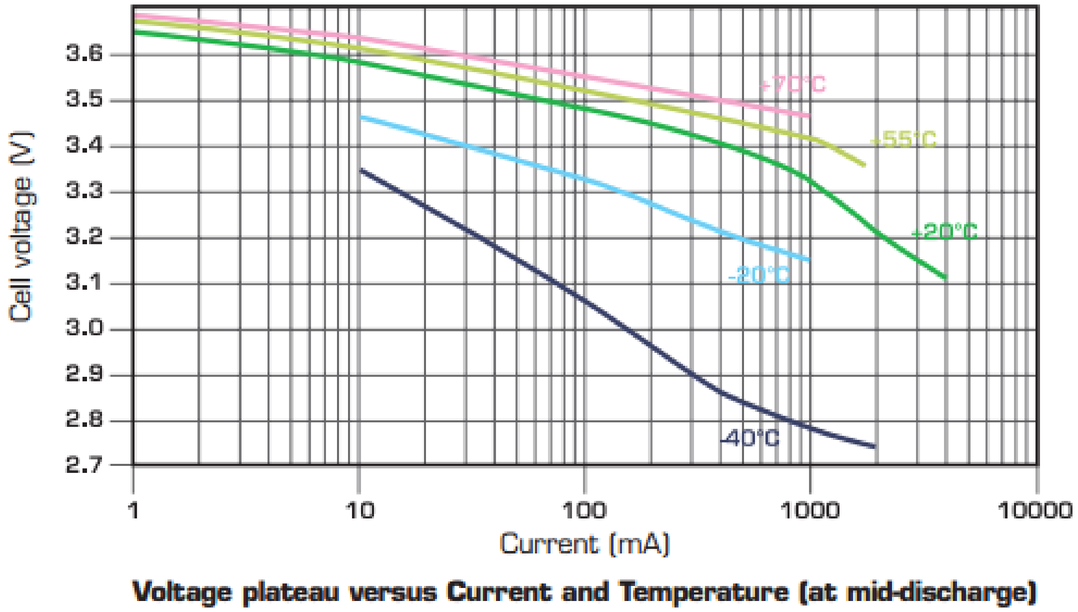

Figure 5-5: Saft (single cell) battery characteristics for varying temperature [8]

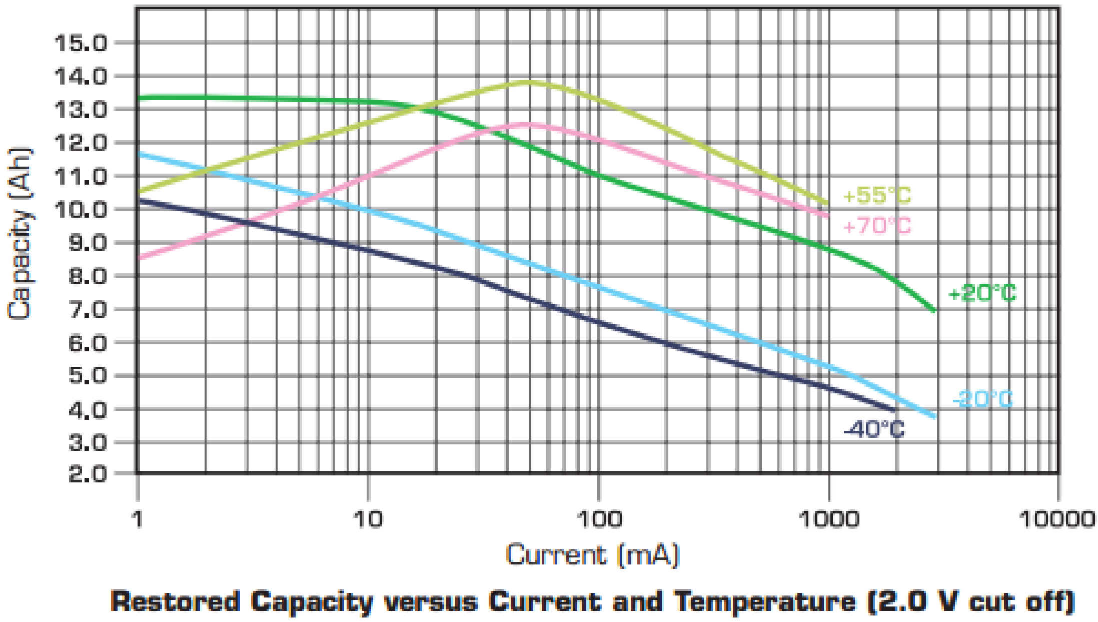

Figure 5-6: Saft (single cell) characteristics (capacity) for varying temperatures [8]

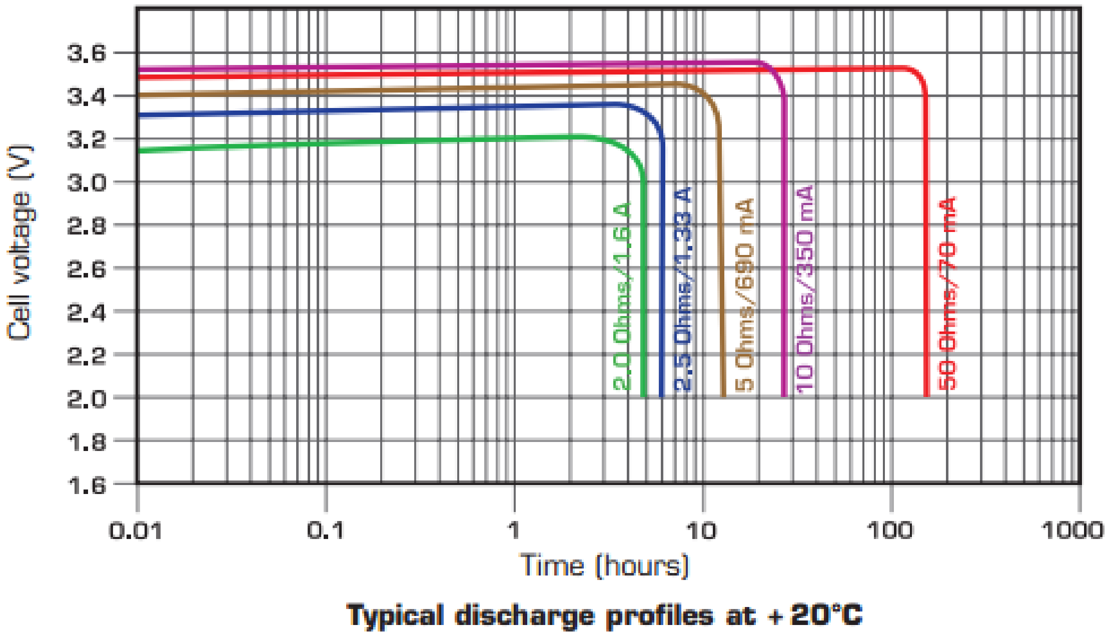

Figure 5-7: Saft (single cell) discharge profile at various loads [8]

The supplied battery packs are only loosely thermally insulated and not actively heated. The expected temperature may vary between flights and is dependent on specific gondola accommodation and flight times but has previously being measured at as low as -40°C during the floating phase.

In **exceptional** cases an experiment can be supplied with an additional battery pack which can be connected either through the same connector (where the batteries are internally decoupled by diodes to avoid current back flow) or through an additional connector. The experiment team should contact SSC project manager and make clear which is required.

If the experimenter chooses to use some other electrical system or batteries, it has to be discussed with SSC before the critical design review (CDR).

5.3 Interface Description for E-Link Experiment Channels

5.3.1 Front panel connector (E-Link side)

The E-Link is a fully transparent connection between the ground based local user and the experiment. This wireless data link can be used for bi-directional purposes the same way as a LAN connection with the experiment. An RJ45 connection will be supplied by SSC for the use between the experiment and the E-link system.

5.3.2 Cable mating connector (Experiment side)

A panel mounted connector for the E-Link is to be used. This connector (Amphenol RJF21B) can be mounted to the front or side panel of the experiment. Insert CODE A should be used for BEXUS. The inside of the connector requires a standard RJ45 (Ethernet) connector. Connector and drilling pattern are depicted below.

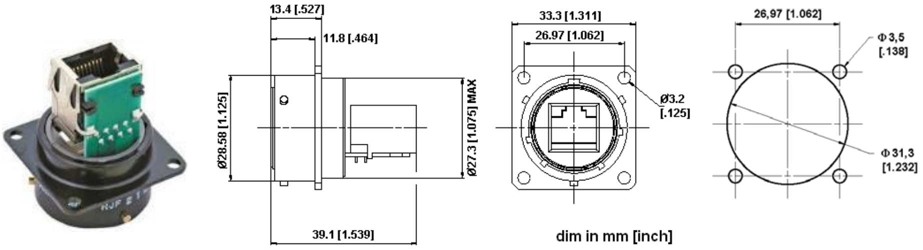

Figure 5-8: Drilling pattern for the RJF21B connector (source: http://datasheet.octopart.com/RJF21B-Amphenol-datasheet-11361.pdf).

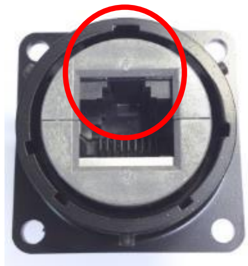

Figure 6-8: Insert CODE A

5.4 Experimenters Ground Station

There are a few fundamental constraints for the ground station design, which have to be taken into account:

- There are two networks provided in the DOME for experimenters
  - Guest Net: This network is distributing internet access on the ground floor and experiment assembly area. It is not allowed to distribute the network via any kind of wireless device. The use of switches is permitted. Connection is provided via Ethernet.
  - E-Net: This network is connected to the experiment network and E-Link during flight. This network is only available in the ground station area of the DOME and must **not** be distributed in any way. Connection is provided via Ethernet.
- No Internet Connection to Experimenters´ Ground Station Computer. During testing and flight, there must not be any physical connection between the experimenters´ ground station computer and the internet!

5.5 Thermal Environment

5.5.1 Pre-Launch Phase

In normal conditions, the preparation of the payload is done at a room temperature of approximately 20±5°C.

After preparation, the payload is brought outdoors to the launch pad. The outdoor temperature at the launch pad in Sept/Oct is normally between 0°C and -15°C and the exposure time can be up to several hours.

5.5.2 Countdown 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 at the launch pad to improve the situation, however it is recommended that heat sensitive experiment modules, or experiment modules that create high temperatures within the gondola, should include temperature regulation in the experiment design.

5.5.3 Flight phase

The thermal environment of the flight may see external air temperatures down to -80°C.

Figure 5-9 below shows temperature graphs of a number of PTU sondes flights during the normal BEXUS campaign period.

Note that the temperature is normally lowest at the tropopause (10-20km), and normally a little higher at float in the stratosphere (>20 km).

Temperatures in the gondola vary depending on the exact configuration, time of flight and float duration. If the sun sets during flight, the balloon will begin to descend due to the cooling of the gas. Some detailed recorded information is available on request.

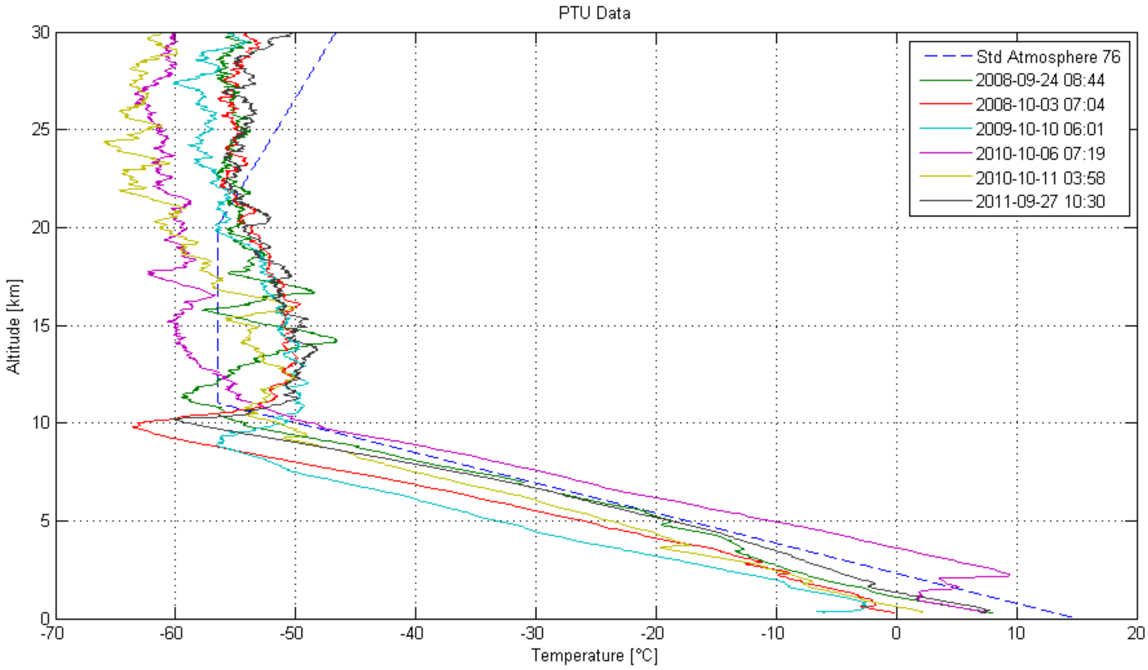

Figure 5-9: PTU Sondes – Atmospheric temperatures graphs

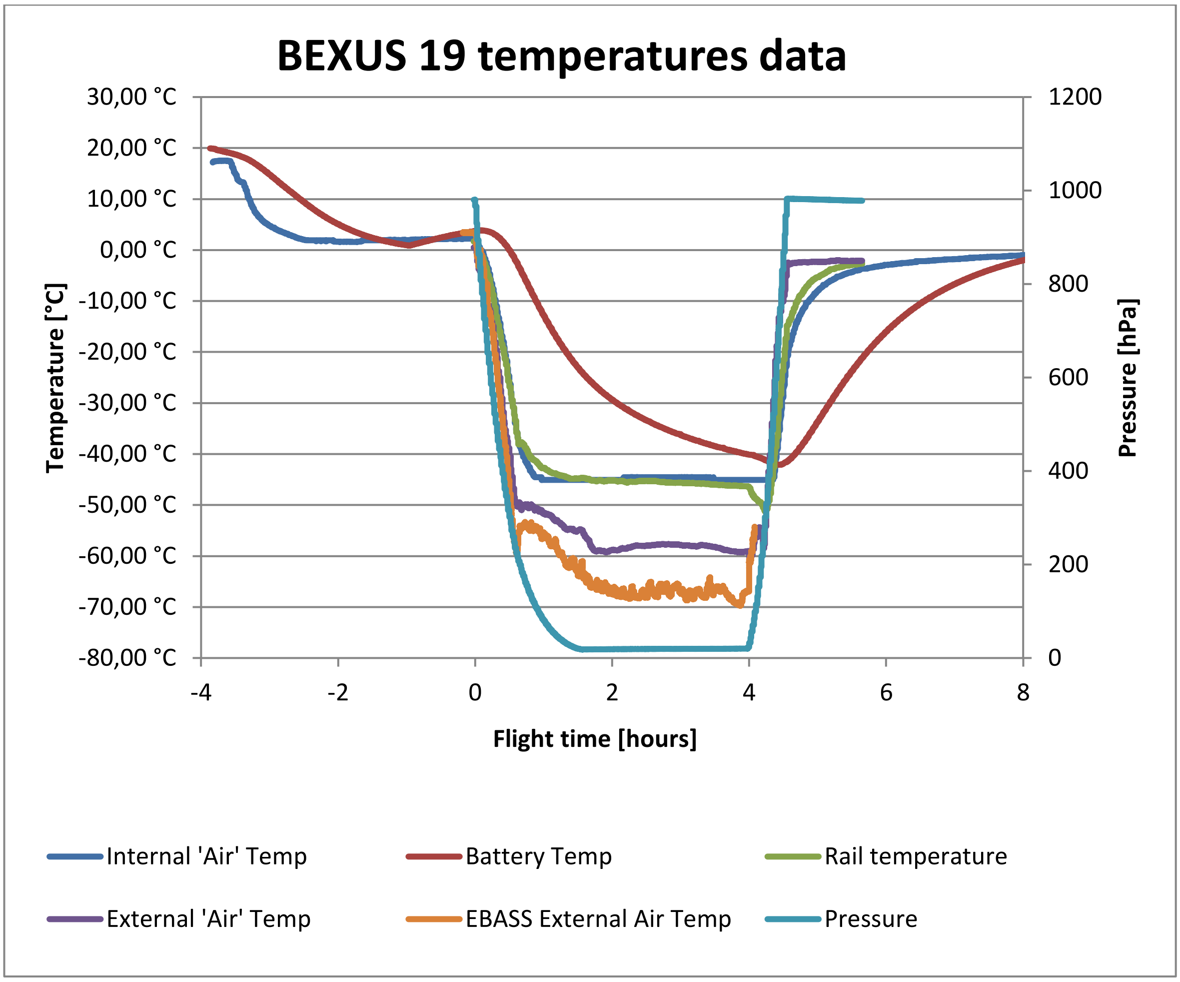

Figure 5-10 BEXUS 19 temperatures data

5.5.4 Post-flight phase

After the impact, the payload will most likely be subjected to snow and cold air in the impact area for a period of typically one to two days. The temperature during the season when BEXUS is launched is normally between 0°C and -15°C. Experiments sensitive to low temperatures must be designed for these post-flight conditions.

5.6 Ambient Pressure Conditions

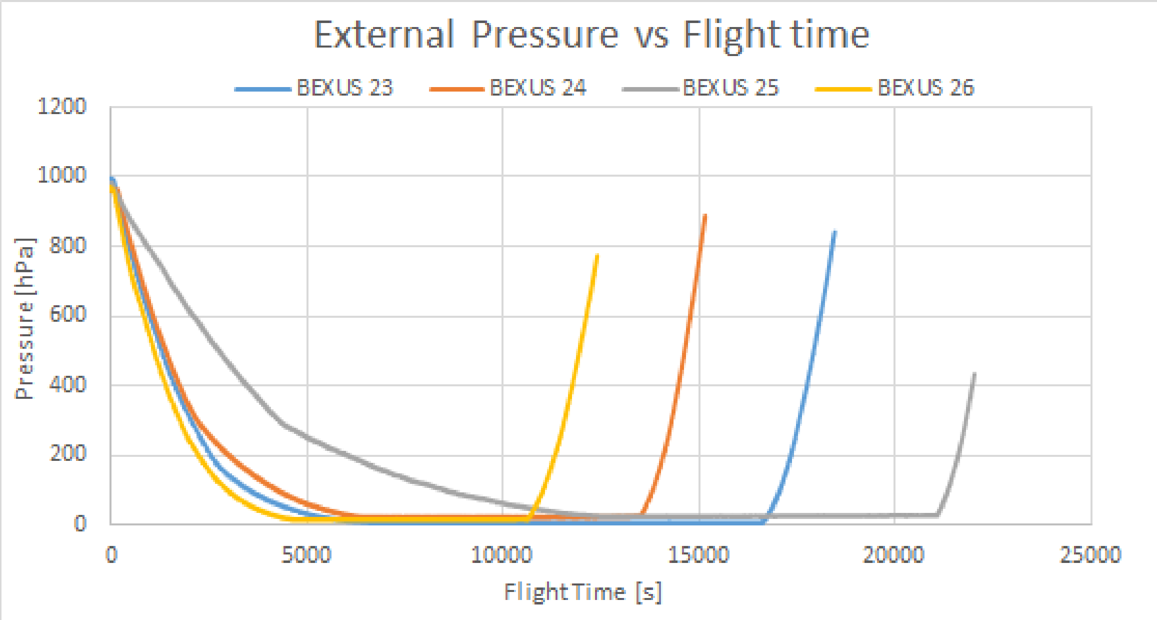

Figure 5-11: Measured Air Pressure vs. Flight time [BEXUS 23, 24, 25, 26]

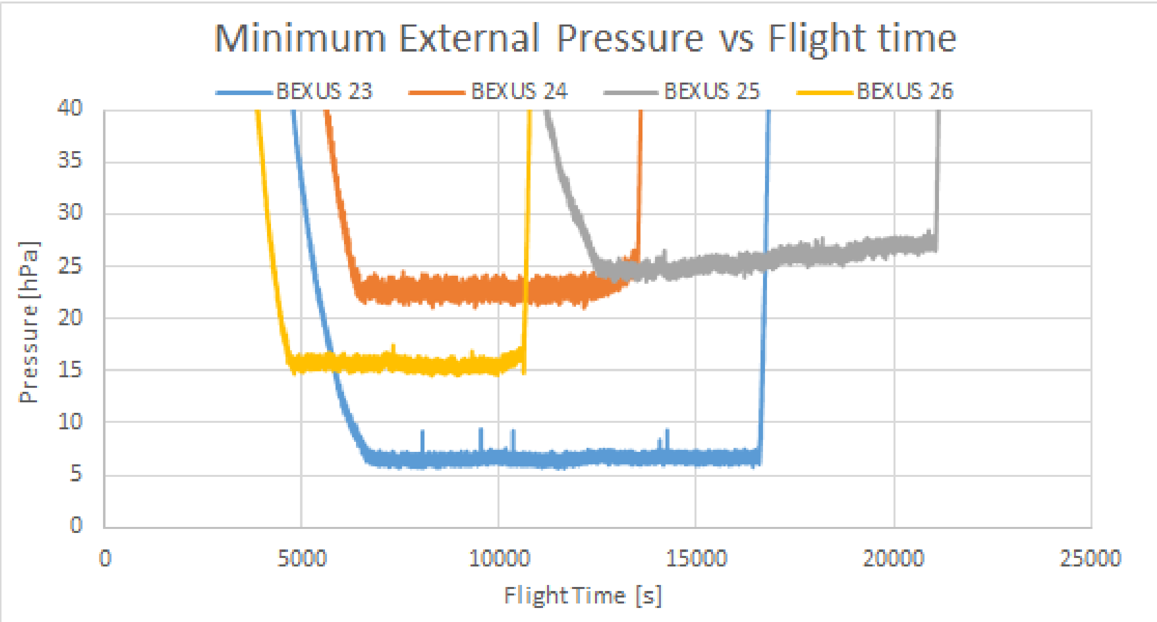

Figure 5-12: - Minimum External Pressure vs. Flight Time [BEXUS 23, 24, 25, 26]

As clearly visible in figure 5-12, which is a zoom view of figure 5-11, the typical pressure which the BEXUS Gondola is exposed to during the floating phase is between 5 and 25 mbar. The acceptance level for experiments is 5mbar.

5.7 Radio frequency constraints

For every transmitter or receiver that will be used at Esrange during a campaign, information must be given to SSC well in advance, in order to receive permission to transmit RF.

It is necessary to apply for frequency permission. SSC will apply on behalf of the experimenters. The information required in advance includes parameters such as transmitting frequency, radiated power, bandwidth of signal, antenna, antenna pattern, and modulation type.

At Esrange, the reception of weak satellite signals might be jammed and special care must therefore be taken regarding when and how RF transmitting occurs.

The following frequencies are used in safety, telemetry, and recovery systems and are therefore not allowed for use by any experiment:

Table 5-1: Frequencies that are not allowed for use by any experiment

400-405 MHz	PTU radiosonde	
400-405 MHz	EBASS downlink	
449-451 MHz	EBASS uplink	
1025-1035 MHz	Air Traffic Control	
1089-1091 MHz	Air Traffic Control	
1616-1626 MHz	Iridium/Globalstar	
2456-2478 MHz	E-Link	
2025-2120 MHz	Satellite uplink	
2200-2300 MHz	Satellite downlink	
7450-7900 MHz	Satellite downlink	
8025-8500 MHz	Satellite downlink	
10700-12750 MHz	Satellite downlink	
25500-27000 MHz	Satellite downlink	

5.8 Electrical Grounding

Having a well-considered and documented grounding concept for your experiment is important, in particular:

- To provide an equipotential reference plane
- To minimise the common mode based on the requirements
- To avoid ground loops
- To protect against shock hazards due a high voltage ESD on a frame or box housing due to electrical harness damage

Several grounding options are available to teams, such as single point grounding, multi-point grounding and hybrid systems. Different approaches will be suitable for different experiments. In special cases (due to scientific requirements), a total isolation approach may be required.

A good approach for power complex BEXUS experiments is to utilise Distributed Single Point Grounding (DSPG).

If required, an equipotential reference plane to the gondola can be provided. This means that grounding to the gondola chassis is possible.

It is also important to consider the grounding scheme of any EGSE used, as problems can also arise during testing due to physical connection with the experiment's EGSE.

5.9 Operations and durability

5.9.1 Operations

During the pre-flight tests and the count down, the experiments must be turned on and off several times to test systems such as E-Link and power and to check for interference with other experiments and balloon systems. These operations are partly performed outdoors during the RF interference test under difficult conditions. Also, once carried out, they may have to be repeated several times. BEXUS experiments should be designed with these operations in mind. The procedures to turn an experiment on and off should be kept simple and should be possible with a minimum set of tools in a short period of time. In addition, the teams should be able to quickly confirm that an instrument has been turned on and is functioning correctly by looking at their data (i.e., a quick functional test).

5.9.2 Power

Operations during the pre-flight tests have a significant impact on the experiment's power and memory budget. Make sure that there is enough battery, memory, etc. to survive these activities, in addition to that which is required for the flight.

All experiments must have a power connector for external power (even if own internal batteries are used), power will be supplied via this connector from the gondola power system or a power source on the launch vehicle (Hercules). At approx. T-1h the power will be switched over to internal (gondola or experiment) batteries and the external power umbilical (between Gondola and Hercules) will be removed. Note that there will be no access to experiments at that time.

When considering the power budget (see chap. 8.5 for countdown and launch), the possible wait times when the experiment is turned on but cannot be accessed should be taken into account (most commonly testing and launch attempts).

Be prepared to have power supplied for 2 hours of testing, 2 hours on ground and for a flight time of 6 hours as a minimum (tot. 10 hours minimum).

Be prepared for possible aborted launch attempts as it is not uncommon to go through a countdown 2 or 3 times before a launch is achieved. Refurbishment between countdowns should be minimised as much as possible and should not invalidate testing.

5.9.3 Hercules impact

Although relatively rare, for experiments that protrude from the gondola, it should be considered that an impact with the Hercules during the launch is a possibility. Location on the gondola, housings and materials can be selected to minimize a component failure in the case of a collision.

5.9.4 Landing considerations

Due to the unpredictable nature of the gondolas' landings, the experimenters should be prepared for a wide range of possible environmental influences for a period of typically one or two days. Submersion of the experiments in water is possible. If this will be an issue for the experimenters, precautions should be taken already during the design phase. During the landing, organic matter and soil may become lodged in the experiments, especially if they protrude beyond the gondola. On rare occasions, landing shocks up to 35 g have been experienced when landing in rocky terrain. A water landing is softer but comes with another problem, since the gondola is not watertight.

Orientation is also not guaranteed and the gondola may be on its side or upside down at landing.

Figure 5-13: Soft landing (BEXUS 14)

Figure 5-14: Hard landing (BEXUS 15)

If the experiment protrudes beyond the gondola, sacrificial joints (or other contingency plans) should be considered if it is foreseen that an impact could damage the experiment or the gondola seriously. The integrity of the gondola hardware must not be endangered by any experiment components.

5.10 Recommended Tests for Experimenters

Before planning any tests, it is important to remember that tests are expensive and not easy to perform within the required time-frame. A good technical design based on simple thermal and vacuum analysis may reduce the risk of failure.

In particular, considering the flight duration and the low temperature and pressure which the experiments will be exposed to, particular attention should be paid to:

- Any sensors placed outside the gondola
- The conduction between the experiment and the gondola
- Other components which could cool down the experiments (e.g. components pumping external air to the experiment, etc.)

Before designing any passive or active thermal control, a thermal analysis should be made, considering mostly conduction and solar radiation, but also other thermal exchanges, such as convection (at lower altitudes) and albedo (for any part of the experiment outside the gondola).

5.10.1 Vacuum test

This test is applicable not only for experiments which will take place under vacuum conditions, but also helps to verify that systems, mainly electrical, have nominal performance in the absence of convective cooling. Additionally, any experiments with sealed chambers should be vacuum tested to ensure survival. A margin of 1.5 times the working pressure is required. It is the responsibility of the experimenter to perform this test, if necessary.

Basic Procedure

- The experiment shall be integrated and placed in a vacuum chamber (pressure below 5 mbar).
- Experiment data shall be supervised 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 BEXUS flight.
- After this functional test / flight sequence has been performed, it is recommended that the module is kept operating for an additional 15 minutes, in order to detect any leakages or overheating problems.

5.10.2 Thermal test

A thermal test is mainly performed in order to verify the thermal analysis and the design of the experiment. It is the responsibility of the experimenter to perform this test, if necessary. The heating of the outer structure/gondola is normally not included or tested.

Basic Procedure

- The experiment shall be integrated and placed in a thermal chamber.
- Experiment data shall be supervised and recorded during the test.
- The temperature shall preferably be measured in several places in the experiment.
- **Low temperature test:**
- Regulate the temperature in the thermal chamber, preferably down to – 80°C but at least to -40°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.

If possible, it would be better to combine the thermal and vacuum test in a unique test in a Thermal-Vacuum Chamber (TVAC).

5.10.3 Mechanical Test

Mechanical tests are necessary to ensure performance of the experiment during flight after possible shocks that occur during launch. If not, it is possible that the balloon will be launched with the experiment non-operational. There are two major risks to be identified, structural integrity and experiment durability. It is the responsibility of the experimenters to perform this test, if necessary.

Basic Procedure 1 – Verifying the static loads defined in section 5.1.2

- The experiment should be placed on a solid surface with a clear area around the test area.

- The experiment should then be loaded with between 10 and 30 times the experiment's own weight (depending on the structural design) in a stable and secure manner.

Basic Procedure 2 – Verifying the shock requirements defined in section 5.1.2

- An area should be cleared in which the experiment can be safely dropped (the persons carrying out the procedure should be wearing a sufficient level of safety gear).
- The experiment should be dropped from a height of 1-3 metres onto a padded surface.
- Afterwards, the experiment should be checked for full functionality by system tests but a visual check is also important to see if any cabling or mechanisms have been affected.

Basic Procedure 3 – Verifying the vibration requirements defined in section 5.1.2

- The experiment should me mounted in the back of a car or in a trailer using the same mechanical interface as for the mounting in the BEXUS gondola.
- The experiment should be driven over a bumpy road or rough terrain for several minutes.
- Afterwards, the experiment should be checked for full functionality by system tests but a visual check is also important to see if any cabling or mechanisms have been affected.

5.10.4 Bench Test

All experiments should carry out a bench test of their experiment before transport. The test should be carried out for a maximum duration mission (2 hours wait before launch, 6 hours flight and possibly a wait time before recovery when appropriate). This test should be carried out as there are many issues which arise only after long duration of operation.

Where possible, this is best done using the same power system as for flight (with voltage and temperature monitoring of the batteries). Possible issues that have occurred in the past are microcontroller malfunction with low power and battery rupture due to overdrawn current.

The experiment should be supervised at all times in case of a failure. It is the responsibility of the experimenters to perform this test, if necessary.

Basic Procedure

- The experiment should be assembled as for flight in a safe area removed from interference (both environmental and human).
- Monitoring of temperature and voltages for critical electronic components should be set up where desired.
- The experiment should be run through a simulated countdown of about 2 hours (chap. 8.5) (including Ethernet connection, external/internal power and wait period after switching on). During this period, procedures for interaction with the experiment should be tested.
- Following simulated launch, the experiment should be run as desired for ascent, float and descent of 6 hours. Here, the possibility of E-Link dropouts should be simulated

where appropriate to ensure that correct operation of the experiment will occur when there is no telemetry available.

- Experimenters should also seriously consider running the experiment as they plan for another 24 hours to simulate the wait time on ground before recovery.
- Test variation of supply voltage between 24V-32V and operate the experiment under different conditions.

5.10.5 E-Link Testing

To assure the experiment of handling timeouts in the connection to the ground station, it has to be tested. Insufficient error handling results in problems by reconnecting to the E-Link network.

Ethernet timeouts can occur, while connected to E-Link by hardline or via RF. In particular, if the bandwidth is shared with other experiments. To avoid this happening during the campaign, it is mandatory to test the reconnection of the experiments forehand.

Basic Procedure

1. Write an error handling software into the communications programs that explicitly deals with timeouts.
2. Conduct a simple test by connecting and disconnecting the Ethernet connection multiple times in different stages and modes of the experiment. This will highlight any issues with error handling.
3. Ensure that the software can reconnect under the above test.
4. Monitor dropped packages. There is suitable freeware available for download, e.g. Wireshark (https://www.wireshark.org/).
5. Create network dumps to analyse and qualify that the experiment does not exceed the bandwidth allocation.
6. Test the Ground Station traffic. Disable network options and search for traffic on experiment connections using Wireshark.

5.11 General Design Considerations

5.11.1 Experiment Accessibility

Bear in mind that designing for accessibility will make your task easier throughout the assembly and testing phases. Accessibility is also important during the recovery phase.

This is an important point that is often overlooked by experimenters. It is in your interest that items such as switches, battery packs and cable connections are easy to access. Considering access to fasteners is also worth the time.

5.11.2 Availability of Parts

A major issue for many experimenters is late delivery and procurement delays. Rather than merely basing a design on parts from catalogues, ensure that they are available, this can save a lot of time and money for experimenters. Avoid designs based on hard to procure items or irreplaceable items where possible.

5.11.3 Experiment Construction Costs

Consider enforcing a three-quote minimum on components where possible (this is often not possible due to the specialized nature of items). When designing, remember that the cost for machining can differ greatly depending on early design decisions. Avoid close tolerances wherever possible, not only is it cheaper but it can save time with assembly. Remember to use experience and judgement; the cheapest items are not always the best selection.

5.11.4 Mass and Size Considerations

Minimizing mass is commonly overlooked by experimenters. However, keeping mass low where possible serves multiple functions. For payload organisation, when experiments are light and small, it gives the organisers more flexibility in selecting locations for each experiment. In order to do this, early system design solutions must be generated so that the mechanical engineers can determine the best approaches to minimizing size and weight.

Perhaps most importantly, lighter payloads will generally allow a higher float altitude (see Figure 3-2).

Significant increase of the mass must be reported as soon as possible and discussed with the payload manager. **Not fulfilling the set mass requirement may lead to deselecting from the flight, even in a late stage of the program.**

5.11.5 Effectiveness of Testing

When designing your experiment, please take into consideration the testing in the future. This is an issue of accessibility, but also of design. Fast and simple methods of testing, calibrating, or adjusting important items will save experimenters' time. This will also make it simpler for testing carried out by the organisers.

5.11.6 Shipping before campaign

When designing your experiment, please take into consideration the need for shipment, possible configurations, and storage/transport requirements. Please remember that you will be responsible for packing your equipment after launch. Return shipping will be discussed with you once you arrive on the range.

Considering that Esrange is a remote place, this should be taken into account, when it comes to shipping times. To be sure and safe, that your goods arrive in time before the campaign, please consider two weeks of delivery time and do not trust any promises of shipping in 24 hours.

N.B. Lithium Batteries:

Check with shipping company the requirements in terms of the transport of Lithium Batteries. It is no problem to receive shipments including Lithium Batteries at Esrange. But in case it is needed to send them home, the shipment has to fulfil the new Swedish regulations (since 1st Jan 2017) and Esrange has to be informed prior to shipment. Please contact the SSC payload manager at the beginning of the campaign, if you wish to do so.

Please take into account:

- Number of items,
- Dangerous contents, add Safety Data Sheets (SDS),
- Special requirements for treatment or storage,

- Are any of the goods Export Controlled?

It is recommended to the experimenters to use the disposal option at Esrange instead of shipping back the batteries.

5.12 Safety requirements

The BEXUS 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.

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 regulation in prior to their arrival at Esrange Space Center. Each team leader will have to sign a document to verify that all team members have been provided with a copy of the safety manual. See **Error! Reference source not found.**

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

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

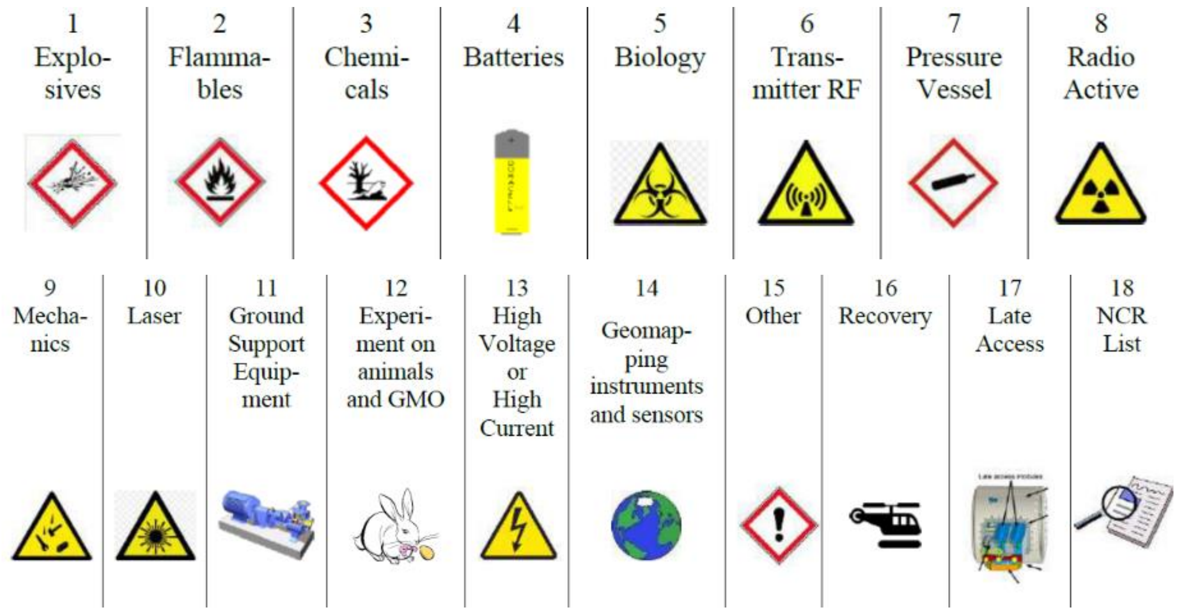

Figure 5-15 - Esrange risks table (GSP-Q)

The experimenters shall state that the experiment fulfils the applicable requirements and establish a list of hazardous materials, which shall be communicated to SSC Esrange Safety Board no later than the EAR via the GSP-Q (see 2.5.3).

This information shall always accompany the experiment.

Any experiment that is deemed risky to the public, staff or experimenters will not be flown. Experimenters should perform any simulation, analysis and testing that will help to convince SSC, that the experiment is safe to fly and handle. If there are any items that can be identified as safety risks, contact SSC.

N.B. An experiment will be removed from the vehicle if it poses a danger.

5.12.1 Pressure Vessels requirements

All ground support pressure systems must meet Swedish law and regulations (AFS 2016:1) 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 to control exposure.

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

5.12.2 On-board batteries requirements

Teams should note that certain items, Li-ion batteries in particular, cannot be moved into a recovery helicopter without special handling. These items should be identified early.

5.12.3 On-board cameras permission

This section is applicable for any experiment having at least one on-board camera pointing or likely pointing on Swedish and/or Finnish 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 Center. 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.

More information:
https://www.lantmateriet.se/en/webb/permit-for-dissemination-of-geographical-data/

- **Defcom (Finnish land)**

The experiments shall request the **Defcom aerial application** form to SSC. The experimenters shall fill in and send it back to SSC **prior to IPR**.
SSC will send a single application to the Finnish Defence Command, Defcom, for all experimenters.

6 PRE-CAMPAIGN ACTVITIES

6.1 Esrange Safety Board (ESB)

Every campaign or project at Esrange has to be accepted by the Esrange Safety Board. If there are hazardous items such as chemicals, lasers, radiation, biology, mechanical systems (such as high energy mechanical devices), RF transmitters, or high voltage/current. included in the experiments or on the ground during preparation, there may be a need for further investigation. This may take some time and should be done early in the design process, well ahead of the start of the campaign.

To simplify the procedure, the experimenters are required to fill out the GSP-Q, Esrange Ground Safety Plan Questionnaire (section 2.5.3) about three weeks before the campaign. The questionnaire is provided to experimenters by SSC.

Sources of hazard, which are not declared prior to the ESB may lead to deselection from the flight opportunity, even in a late stage of the programme.

6.2 Campaign Requirements Plan (CRP)

See 2.5.2 for Campaign Requirements Plan description.

The first version of the CRP will be distributed after the IPR. As plans are made based on the CRP it is important that it is correct and updated if requirements change. Once the CRP is issued any changes that impact the document must be discussed with the SSC payload manager before implementing the changes.

6.3 Experiment Acceptance Review (EAR)

The Experiment Acceptance Review (EAR) ends the qualification and production phase of the project. The EAR is performed to judge the readiness of the experiment for the launch campaign.

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),
- Experiment acceptance decision: Passed/Conditional pass/Failed. If a conditional pass is elected, the immediate action items should be discussed, along with appropriate deadline(s).

The EAR is performed by the SSC or ZARM payload manager, together with experimenters at the location of the students' university, at ZARM, at SSC or at ESA facilities.

6.3.1 Experiment Status at EAR

It is strongly recommended that the experimenters conduct the following qualification/acceptance tests before delivering the experiment:

- Vacuum test,
- Thermal test,
- Mechanical test (static load, shock and vibrations tests),
- Mechanical interface checkout,
- Electrical interface checkout,
- Electrical/functional tests,
- Bench test.

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

6.3.2 EAR proceedings

During EAR, mechanical and electrical interfaces of the experiment are checked. Functional tests, a demonstration of the fully integrated experiment and an end-to-end test are performed by the SSC or ZARM payload manager.

All pending actions shall be completed for the EAR. An acceptance decision is made as a conclusion of the review: passed / conditional pass / failed.

More information can be found in the SED guidelines [7].

7 CAMPAIGN ACTIVITIES BEFORE START OF COUNTDOWN

7.1 Description of Esrange Space Center

All the necessary information for a user of Esrange can be found at: www.sscspace.com under ‘SSC Worldwide/Esrange Space Center’.

Its main content is:

- 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.

7.2 Safety briefing

Safety always comes first at Esrange. Before the start of a campaign, a virtual safety briefing will be held.

It is mandatory for all visiting personnel to attend this briefing.

If a safety issue arise during a campaign, there might be a need for an additional Safety Board meeting before a launch is possible.

7.3 Time schedule

The BEXUS launch campaign takes place over approximately 10 days. This does not allow any time for errors or delays and it is important to be well prepared.

Every morning, there is a status meeting in one of the conference rooms, where the upcoming activities are discussed.

A more detailed schedule will be issued closer to the campaign week. Depending on how the preparation work progresses and the weather forecasts, there might be changes during the campaign week itself.

Table 7-1: Typical BEXUS Campaign schedule

Day	Action	Location
0	Nominal day of student arrival	
1	SSC, DLR, ESA, ZARM Team introduction Campaign Information Experiment Preparation Individual Experiment Tests[1]	Polaris Polaris DOME/CATH DOME/CATH
2	Morning meeting Experiment Preparation Individual Experiment Tests[1]	Polaris DOME/CATH DOME/CATH
3	Morning meeting Gondola Interference Tests[2]	Polaris DOME/CATH
4	Morning meeting BX n Flight Compatibility Test (FCT)[3] 0900 BX n+1 FCT[3] 1200 Meteorology briefing Flight Readiness Review (FRR)	Polaris PAD PAD Polaris
5	Morning meeting **1st launch opportunity**	Polaris
6	Morning meeting **2nd Launch opportunity**	Polaris
7	OPTIONAL: Launch opportunities Experiment inspection / Preliminary data analysis Packing / Experiments shipment preparation Experiment results presentations Feedback session Campaign Dinner	 DOME DOME Polaris Space Inn/ Pool Room
8	Reserve launch Day	
9	Reserve launch Day	
10	Nominal day of student departure	

Note:	Test:	Comment:
1	Individual Experiment Tests	Each experiment is: • Mounted into gondola • Power connection checked and connected to gondola power • E-link connector checked • Ground station connected directly to experiment • Communication and functional test • Dismount – only if needed

2	Interference Test	Gondola Interference Test Part I (Hardline)
		• Experiments remain (or are re-mounted in the gondola)
		• Experiments connected to the **E-Net** and gondola power supply.
		• G/S set up in ground station area
		• Communication and functional test
		    ○ Experiment by experiment
		    ○ All experiments
		Gondola Interference Test Part II (E-Link)
		• Experiments connected to the **E-Link**
		• RF Interference Check with E-link (low power)
		• Communication and functional test
		    ○ Experiment by experiment
		    ○ All experiments

3	Flight Compatibility Test (FCT)	Gondola moved to the balloon launch pad (by Hercules): • Check for interference with EBASS / EMPIRE etc. • Experiments switched on, one after the other • All experiment systems must be running on Battery Power • Mass measurement Long waiting times (3-4 h) possible **Notice that after this test:** • No more experiment preparation is allowed. • Only the batteries can be exchanged/charged.
*	Note I: Working after Dinner (1900) is NOT nominal and should be avoided where possible. Note II: Working through meal times is NOT nominal, but is possible for operational reasons, and takeaway meals can be collected from the restaurant. Takeaway meals will not be available for those who simply wish to eat elsewhere or at a different time not due to operational reasons.	

7.4 Preparation and Test activities

The experimenters are strongly advised to think through all aspects of the experiment: the build-up, the tests, the launch preparation, the flight phase, the recovery instructions and the post-flight tasks (ex: hardware inspection, experiment dismounting, preliminary data analysis).

With this input, make a detailed plan of all tasks to be done for each campaign day. For each task:

- Assign team member(s) (or SSC staff if applicable),
- Estimate task duration,
- Identify needed tools.

A checklist is the key item to success: even the smallest thing, such as flipping a switch, should be in the list. A good checklist includes a verification method such as checking torque (and writing it down) or taking a photo.

Without good build-up plans and checklists there is a significant risk of failures and delays during the campaign week. All of this should be documented in the SED.

7.5 Assembly of balloons and payloads

7.5.1 Assembly of balloons

All assembly and preparation activities related to the balloon and its subsystems are the responsibility of the SSC team. This is normally done in the Basilica building.

7.5.2 Assembly and checkout of payloads

Payload assembly and preparations are conducted by the SSC and ZARM payload managers together with SSC staff and the experimenters. Working space in the balloon launch area will be allocated to each team.

Figure 7-1: From left to right: the Dome, the Chapel, Cathedral and Basilica preparation & assembly buildings

7.5.3 Equipment

There is one professional soldering station located in the DOME assembly hall. There is also basic measurement equipment and toolboxes available to borrow.

Please note that Esrange is situated in a remote location. Therefore, acquiring any equipment could be difficult once arrived at the site.

If you need some special tools or equipment, be sure to either bring it with you, or specifically state that you need it when you give input to the Campaign Requirements Plan.

Figure 7-2: Standard Equipment Set at Esrange

Figure 7-3: Standard Power Supply at Esrange (Max. 2.5 A)

7.6 Flight Simulation Test (FST)

When all experiments are operating nominally and if there is enough time for this test, a simulated count down and flight sequence is performed.

It is important that any changes/modifications made to H/W or S/W after the Flight Simulation Test are restricted to a minimum. 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.

Basic Procedure

- The experiment shall be integrated and in-flight configuration. The telemetry and telecommand checkout system or simulator shall be connected via the interface harness.
- Experiment data shall be supervised and recorded during the test.
- A nominal realistic count down and flight procedure shall be followed.

7.7 Flight Compatibility Test (FCT)

When all experiments are installed in the gondola, an RF interference test is conducted. The gondola is picked up by the launch vehicle and placed together with all other transmitting/electrical hardware at the same distances as in a real flight. A test with all electronic equipment as well as experiments operating on internal power in flight mode is then performed. If an experiment is causing interference with EMPIRE or E-Link it will not be granted permission to fly. If there is interference between two experiments, the problem will be discussed and a solution or compromise will be found. After the FCT, the gondola is sealed and there are no further changes possible to any experiment. During countdown there are very limited possibilities to fix any problem. If there is no quick fix available, the experiment may have to fly with limited functionality or in switched-off mode.

During the FCT, the experiments run on the internal batteries.

7.8 Flight Readiness Review - SSC Stations (FRR-SSC)

The Flight Readiness Review – SSC Stations (FRR-SSC) is conducted by the Campaign Manager, after successful completion of the RF test and ground support stations checkout.

The purpose of the FRR is to authorise start of the countdown phase

In order to do this, it is necessary:

- To ensure that all stations are ready for the flight. For this, each station manager shall give a status report at the meeting. In addition, the Payload Manager is requested to state the operative status of the experiments
- 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 review the countdown list

- To inform all relevant personnel of the safety regulations applicable during the countdown phase.

7.9 Flight Readiness Review - Science (FRR-SCI)

The Flight Readiness Review - Science (FRR-SCI) is conducted by the Payload Manager, after successful completion of the RF test and ground support stations checkout as well.

Purpose of the review is:

- To ensure that all experiments are ready for the flight. For this, each appointed team leader shall give a status report at the meeting. In addition, the team leader is requested to state the operative status of the experiment.
- To review the countdown list.
- To inform all relevant personnel of the safety regulations applicable during the countdown phase.
- to inform all relevant personnel of general arrangements implied during the countdown phase

8 CAMPAIGN ACTIVITIES: COUNTDOWN & FLIGHT

8.1 Weather constraints

Wind, flight trajectory and visibility are important variables taken into consideration before starting a count down. There are no magic numbers and the decision to start a countdown is solely in the hands of Esrange personnel.

N.B. It is not possible to guarantee that a launch can take place on one of the 5 days allocated during the campaign week. Plan and prepare so that it is possible for someone else to operate and document the functions of your experiment if the launch is postponed to a later opportunity. This should be documented in the SED.

8.2 Balloon launch conditions

Launch period:	September / October
Launch window:	06.00 - 16.00 LT
Ground wind:	less than 4 m/s
Vertical visibility:	more than 75 m

Conditions should be sufficient for helicopter recovery on the same day for a short flight or on the next day for other cases. This does not mean that the gondola will be returned the same day.

8.3 Safety on the balloon pad

SSC has the overall responsibility for safety and has the Veto right in all safety issues during all activities within the Esrange base area. In the case of clients/guests with stronger safety rules than those of Esrange, the stronger rules will apply.

No one is allowed on the pad during countdown without the permission of the Operations Officer.

There are several heavy vehicles with limited visibility moving on the pad. To be visible to the drivers, Esrange provides participants with fluorescent safety vests. It is mandatory to wear these when entering the launch pad. You will only be allowed access to the launch pad when permitted by the Operations Officer.

When E-link is in a high-power-transmitting mode there is a 10-meter safety distance around the gondola. This is marked with cones.

At launch, everyone must be inside the balloon pad buildings and remain there until instructed otherwise.

8.4 Personnel during the launch

8.4.1 Campaign Manager

The campaign manager reviews the Campaign Requirements Plan and puts it into action. The campaign manager is responsible for the services to be delivered by SSC towards the customer.

8.4.2 Payload Manager

This person acts as the contact point for the experimenters during the countdown. The payload manager relays questions between the experimenters and the Operations Officer, via WT or telephone. The payload manager also informs the Operations Officer about status of the Gondola and the experiments and informs him/her when the PL is ready for pick up. The payload manager communicates with the Electronic Supervisor and the electronic team regarding the E-Link telemetry status.

8.4.3 Operations Officer

The Operations Officer handles the countdown and is the focal point for all activities.

8.4.4 Launch Officer

The Launch Officer (LO) handles all personnel and equipment related to the launch. The LO is also responsible for safety on the launch pad.

8.4.5 Safety Officer

The safety for third parties is the concern of the Safety Officer (SO). The SO authorises to send commands to end the flight.

8.4.6 Electronic Supervisor

Handles all issues related to EMPIRE (or EBASS) and FCT.

8.4.7 Gondola Electronics

Handles all issues related to gondola electronics systems.

8.4.8 Esrange Telemetry Station

The Esrange Telemetry Station (ETM) handles the receiving, transmitting and recording equipment during preparations and launch.

8.4.9 Balloon Pilot (if EBASS is used)

The Balloon Pilot handles the balloon piloting system and monitors the housekeeping data.

8.5 Countdown and launch

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

The nominal lift off time is planned for between 0600 and 1600 LT. The launch window is determined by the payload preparation time, hold requirements and the time of daylight.

The decision to start the countdown is taken at a weather briefing immediately before the planned start of countdown. This decision is based on dedicated weather forecasts, as well as wind data possibly obtained by a meteorological balloon released from Esrange. 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. Be sure to design your experiment so it can handle not only the flight but also tests and at least 2 hours of CD (on internal batteries) in case of possible holds.

Experimenters' ground equipment will be situated in a preparation building; transparent communication with the experiment is provided via a designated Ethernet network.

The schedule below indicates a standard count down timeline relative to launch (T = 0). A final version of these actions is issued at the pre-flight meeting.

Time & DP	Science	Comment
Day Before Flight after decision for Launch Attempt		
T-5H00		
T-3H30	**Start of count-down**	
		Gondola in Dome BEXUS Gondola on external power End-to-end tests via E-Link (low power) Experiments powered off
T-2H45	**Gondola Pick up**	
	Tests outside Dome	BEXUS Gondola on Hercules power. Experiments powered on. Experiments powered on Hercules Power Access for experiment teams: End-to-end tests via E-Link Closing of gondola where possible Report ready for line up
T-2H00	**Line up**	
		Experiments remain powered on Hercules power Gondola at line up Last access for experiment teams:

		Experiments on Hercules Power Check that experiments have nominal function Final closing of Gondola Report ready for balloon unfolding
T-1H00	**Balloon unfolding**	
		Gondola power umbilical removal BEXUS Gondola on internal power Check that experiments have nominal function Report ready for inflation
T-0H30	**Start of inflation**	
		Radio discipline Launch officer priority
T-0H02	**Ready for balloon release**	
0	**Lift-off** **Balloon release**	
~T+1H30	**Balloon on float**	
T+2H00		
	Termination of flight	Confirm termination OK for all teams. Go for termination.
	End of flight	
	Recovery	

8.6 Post-Flight Activities

8.6.1 Recovery

SSC uses Globalstar system to get the landing point of the gondola.

During the flight, the payload trajectory will be tracked by means of the transmitted GPS-data in the TM ground stations.

During the descent of the payload, the prediction on the impact point coordinates is reported to the helicopter from Esrange. The helicopter starts their operation to locate the payload after the impact. At the impact site, the helicopter crew disassembles the flight train for transport by truck back to Esrange. Any actions that should be performed on your experiment (such as securing samples, powering off, plug removal) shall be detailed in a simple annotated recovery sheet, a copy of which will be flown in the gondola and provided to the recovery crew.

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

8.6.2 Transport back to Esrange

The helicopter drops off the payload on the nearest road.

A truck then picks up the payload and drives back to Esrange.

8.6.3 Return of experiments

When the truck arrives to Esrange, SSC takes out the BEXUS systems. Then, each experimenter team will get back their experiment one after the other. Order is decided by SSC or ZARM payload manager.

This is then the time for experimenters to proceed to hardware inspection (outside / inside). Experimenters are encouraged to conduct preliminary data analysis before the Post-Flight Meeting.

8.6.4 Post-Flight Meeting

The Post-Flight Meeting is held to debrief the flight and state a short flight performance report. All campaign participants are invited (experimenters, REXUS/BEXUS organisers, SSC staff).

A short presentation of the performance of each experiment is requested.

9 ADDITIONAL RECOMMENDATIONS

The REXUS/BEXUS organisers want to ensure that the experiments will work nominally during the whole mission. It is the responsibility of the experimenters to ensure that the experiment fulfils the design constraints presented in section 5.

9.1 Payload interferences

The experimenters shall keep in mind that they are sharing the BEXUS systems with other experiments: the gondola and the communication system. A particular attention to mechanical interferences and data budget (data rate uplink/downlink) will be discussed at CDR with all experiments flying on the same BEXUS mission.

9.1.1 Experiments sensitivity

The experimenters shall have a deep knowledge of their experiment. Thus, it is the responsibility of each experimenter to identify any specific sensitivity and report it to SSC or ZARM payload manager. Indeed, it might turn into additional recommendations to the other experiments. Any specific needs shall appear in the Campaign Requirements Plan (CRP).

Examples: An experiment could be sensitive to high voltage, to vibrations, to pollution like outgassing, to heat…

9.1.2 Experiments disturbances

It is important for any experimenter to assess what are the disturbances that its own experiment can generate. Indeed, those disturbances might affect the other systems. It is the responsibility of each experimenter to report the possible disturbances to the SSC or ZARM payload manager as soon as possible in the development of the experiment (should be clear at CDR, at the latest).

Examples: An experiment could create vibrations due to activation of a motor, could generate electromagnetic interferences, could exhaust gas, could generate heat…

9.2 Materials & components selection

The selection of material and components is a key point for the experimenters. Indeed, mechanical properties are a criteria of selection but not the only one.

Experimenters shall always check **availability** of the material (time lead, existing supplier…). Always anticipate and have spare parts (don't forget to bring those spare parts to the campaign).

Experimenters should of course check the **affordability** of the materials and components selected by checking price, possible taxes and shipping costs and ensure that the project can afford them and have spares.

Experimenters should keep in mind that any selected material shall be suitable for BEXUS flight and post-flight conditions.

Example of materials: some greases or motors are not suitable for vacuum conditions, plastic material become brittle at low temperatures…

As an aid the ECSS-Q-70-71 [6] (*Data for selection of space materials and processes*) may be used.

Example of components: some motors are not able to be run under vacuum environment.

Finally, the experimenters should check the reliability **of components selected.** For electronic components, MIL-std specified types are recommended.

9.3 Maintainability

During the design phase, the experimenters should pay attention to accessibility of the experiment and components. Experimenters should identify the components that should be regularly checked / mounted-dismounted (like batteries or SD-cards) and ensure that it is easy to access after the full experiment integration. Easy access means short time to perform the maintenance, minimize the use of tools, prefer the use of standard tools and minimize the necessary know-know to perform the maintenance (more a maintenance task is specific and complicated, less people could do it which represents a risk for the project).

Maintainability can also be done by testing. Hence, it is recommended to the experimenters to plan well in advance the maintenance tests necessary to be performed during long-storage period (> 1 month) or after transport for example.

9.4 Handling

Experimenters are also the users of their experiment, hence it is absolutely necessary to think about the operations from the early days of the project. How to operate the experiment for testing, for flight and after flight is essential to be defined.

Experimenters shall identify any precautions that should be observed when operating their experiment.

Examples:

- ESD susceptible components shall be handled in an ESD protected environment.
- After operation, some components might be hot, then gloves should be used by the operators, a caution sign should be added on the hot surface.
- For any mechanisms, especially deployment mechanisms, parts could fly over, operators should wear protective gloves and safety straps should be used on ground.

9.5 Packing & Storage

Before transport, the experiments and associated hardware shall be thoroughly packed to withstand the transport loads. The use of a bump recorder is recommended.

It is advised to experimenters to take pictures of the hardware before packing and especially before transport. Those pictures could then be used when reopening box for comparison and ensure that the hardware has not been damaged during transport or storage.

Storage shall be planned. It is recommended to get storage box for the experiment and for the parts early in the project.

For long-term storage (> 1 month), the experimenters should define storage conditions: temperatures range and humidity level. The experimenters should also define the storage configuration of the hardware (ex: batteries are not stored within the experiment, springs are not loaded…). Experimenters should also plan regular tests for hardware and team know-how maintenance.

9.6 Re-used item

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

It is critical for the experimenters to have knowledge of re-used item history and to keep contact with responsible persons that worked and/or developed the re-used item.

9.7 Quality Assurance

To go further, the experimenters could learn and apply quality management:

- <u>Procured products and audits</u>

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.

- <u>Manufacturing control and inspection</u>

For the manufacturing and inspection of critical processes, the experimenters 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
- Connectors shall be marked and can be keyed to avoid human mistakes

10 COORDINATE SYSTEM DEFINITION

This chapter will give a short overview on the coordinate systems that are used for the BEXUS onboard sensors, 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 10-1 Coordinate Systems

ECEF	Earth Centered, Earth Fixed
WGS84	World Geodetic System 1984
LTC	Local Tangent Coordinate System

The global reference system **World Geodetic System 1984** (WGS84) is used for the BEXUS GPS position data. This system is based on the ECEF system. The Local Tangent Coordinate System (LTC) is important for observation of the vehicle from Launcher, Tracking or Radar Station. Details are described in Ref [11].

10.1 Earth Centered, Earth Fixed (ECEF)

If a 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 coordinate system rotates with the Earth with the primary axis x always through the Greenwich Meridian.

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

$$\vec{r}_{ECEF} = \begin{pmatrix} x_{ECEF} \\ y_{ECEF} \\ z_{ECEF} \end{pmatrix} = d \cdot \begin{pmatrix} \cos\varphi_{gc} \cdot \cos\theta \\ \cos\varphi_{gc} \cdot \sin\theta \\ \sin\varphi_{gc} \end{pmatrix} \qquad \text{Eq. 10-1}$$

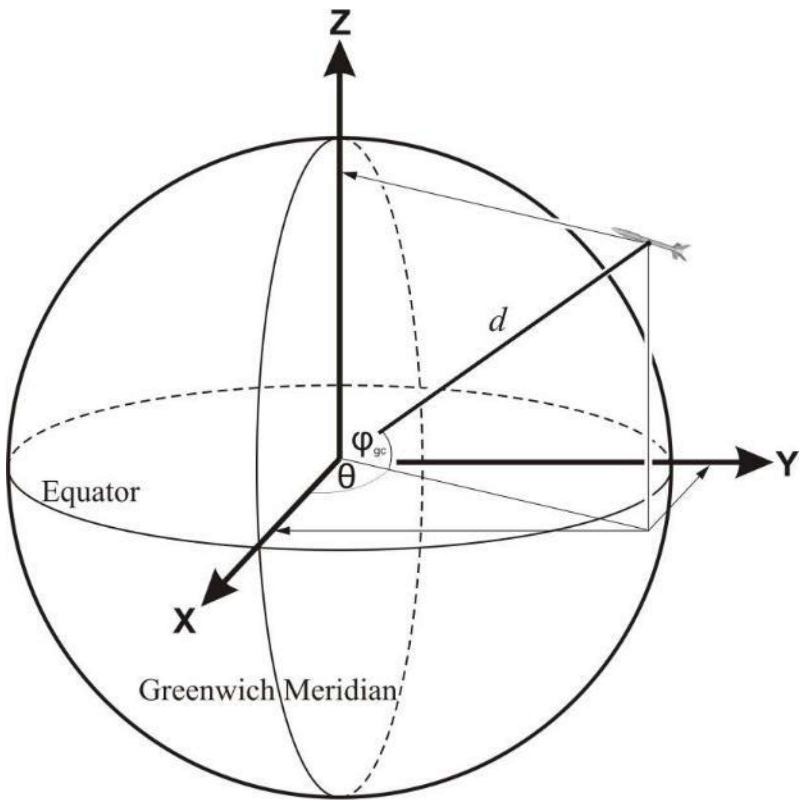

Figure 10-1: ECEF Coordinate System

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:

$$f_\oplus = \frac{R_\oplus - R_{Pole}}{R_\oplus} \qquad \text{Eq. 10-2}$$

The WGS84 Ellipsoid has a flattening of $f_\oplus = 1/298.257223563$ and the equator radius, $R_\oplus$, is 6378137 m [Ref [11]]. The Earth eccentricity, $e_\oplus$, can be calculated with the following equation:

$$e_\oplus = \sqrt{1-(1-f_\oplus)^2} \qquad \text{Eq. 10-3}$$

The position of the vehicle 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 plan. 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:

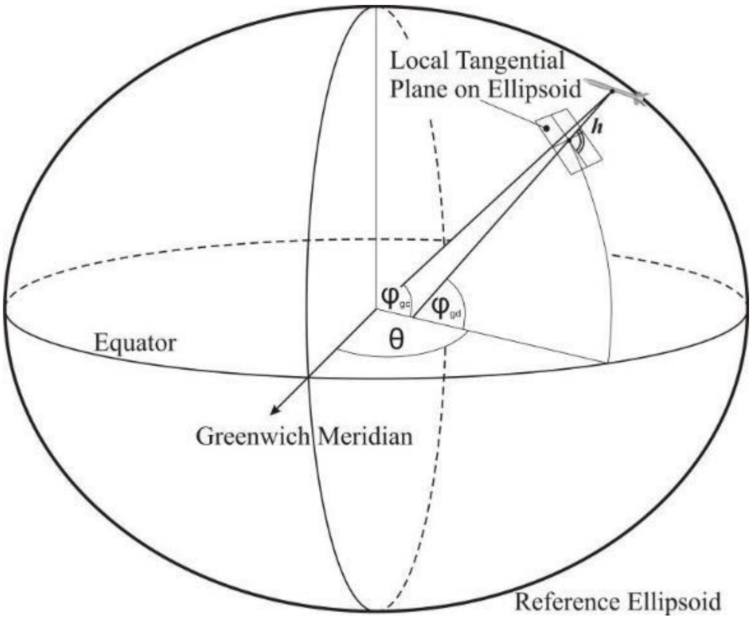

Figure 10-2: WGS84 Reference Ellipsoid

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

10.2 Local Tangential Coordinate System (LTC)

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.

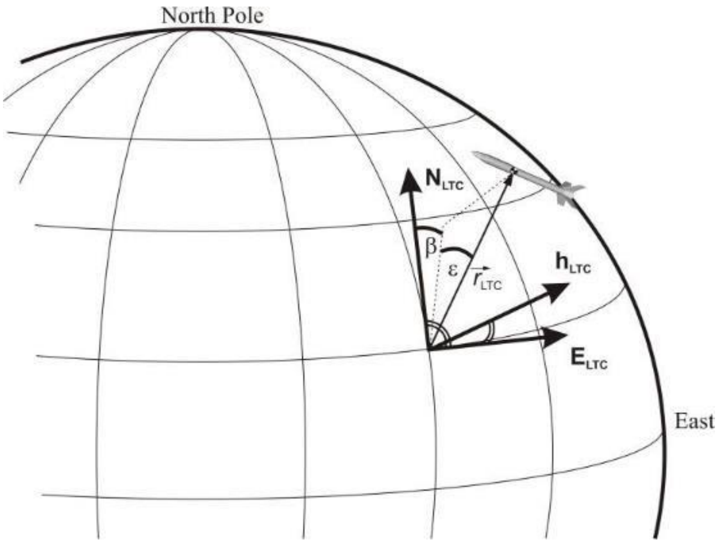

Figure 10-3: Local Tangent Coordinate System (LTC)

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

$$\beta = \arctan\left(\frac{east_{LTC}}{north_{LTC}}\right)$$ Eq. 10-4

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

$$\varepsilon = \arctan\left(\frac{h_{LTC}}{\sqrt{east_{LTC}^2 + north_{LTC}^2}}\right)$$ Eq. 10-5

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

$$\begin{pmatrix} east_{LTC} \\ north_{LTC} \\ h_{LTC} \end{pmatrix} = d \cdot \begin{pmatrix} \sin\beta \cdot \cos\varepsilon \\ \cos\beta \cdot \cos\varepsilon \\ \sin\varepsilon \end{pmatrix}$$ Eq. 10-6

The distance d between the vehicle and the observation location is also called Slant range.

APPENDIX A: GONDOLA DRAWINGS

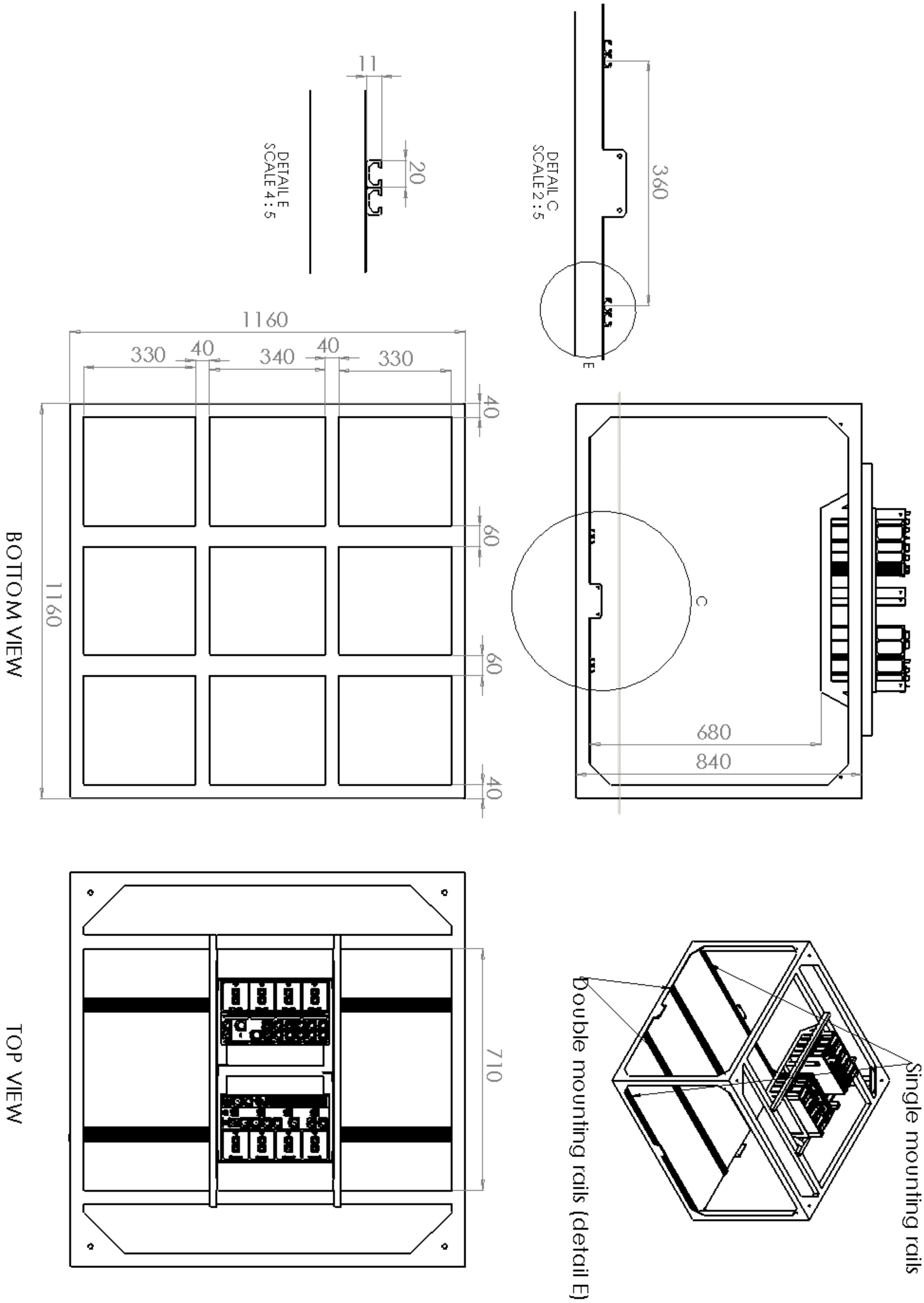

Figure A-1: Gondola dimensioned drawing

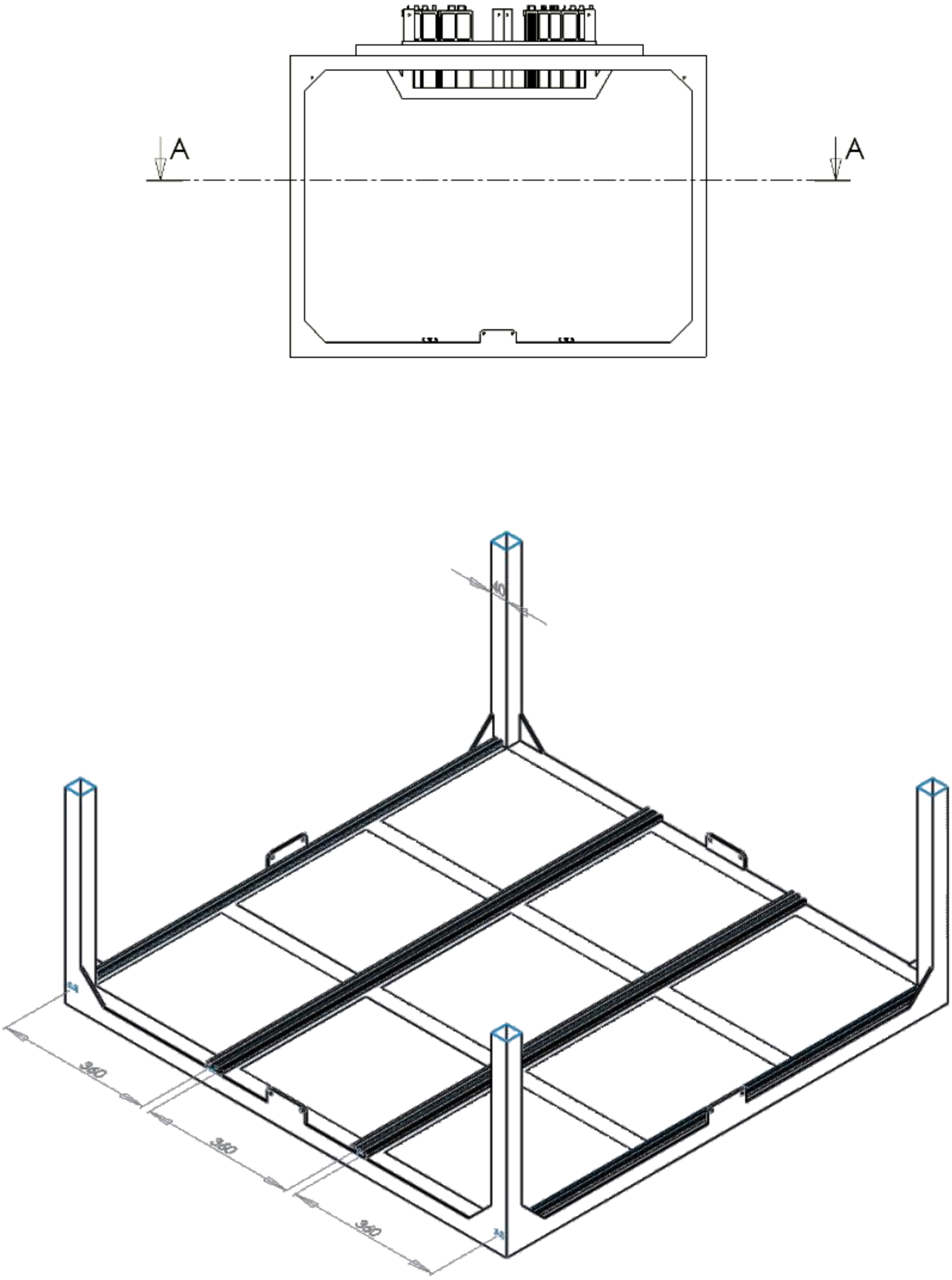

Figure A-2: Section view (A-A: Isometric) of gondola floor

APPENDIX B: GONDOLA/EXPERIMENT INTERFACE IMAGES

Figure B-1: BEXUS-8 exterior with experiment equipment mounted to the outside of the Gondola

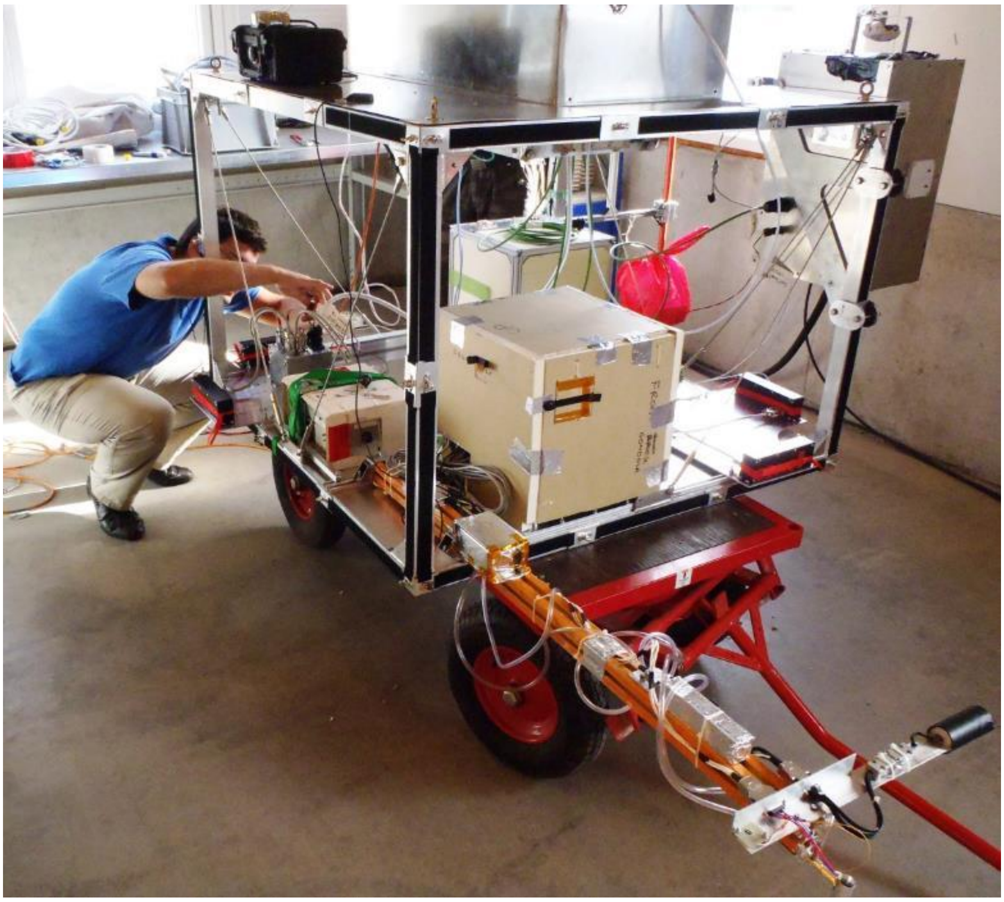

Figure B-2: BEXUS-15 showing different mounting techniques

APPENDIX C: EXAMPLES OF RECOVERY SHEET

RECOVERY SHEET
ARCADE-R2 EXPERIMENT

1 - Switch off the three power connectors (turn counter clockwise and pull out)

2 - Keep in contact the external body to the PROXBOX and lock the external body to the mechanical rail by the given screw

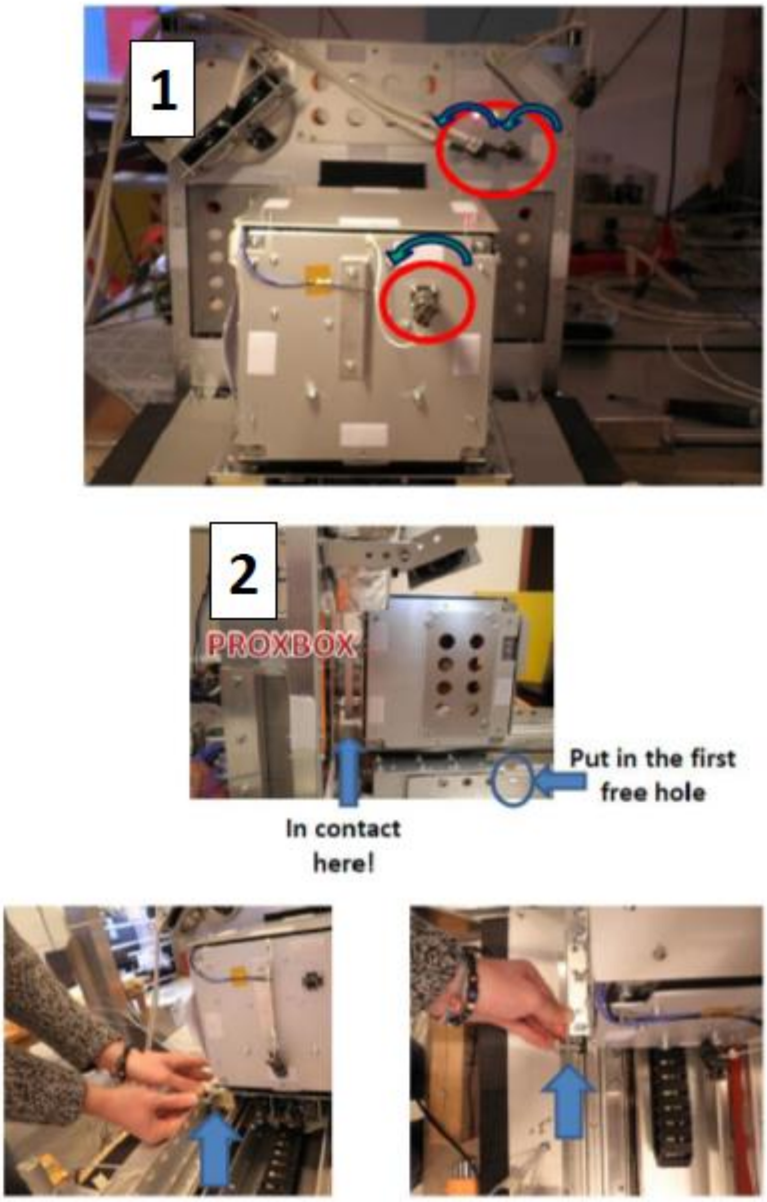

Figure CB-0-1: Example of Recovery Sheet of the Team ARCADE-R2 Experiment of BEXUS 17

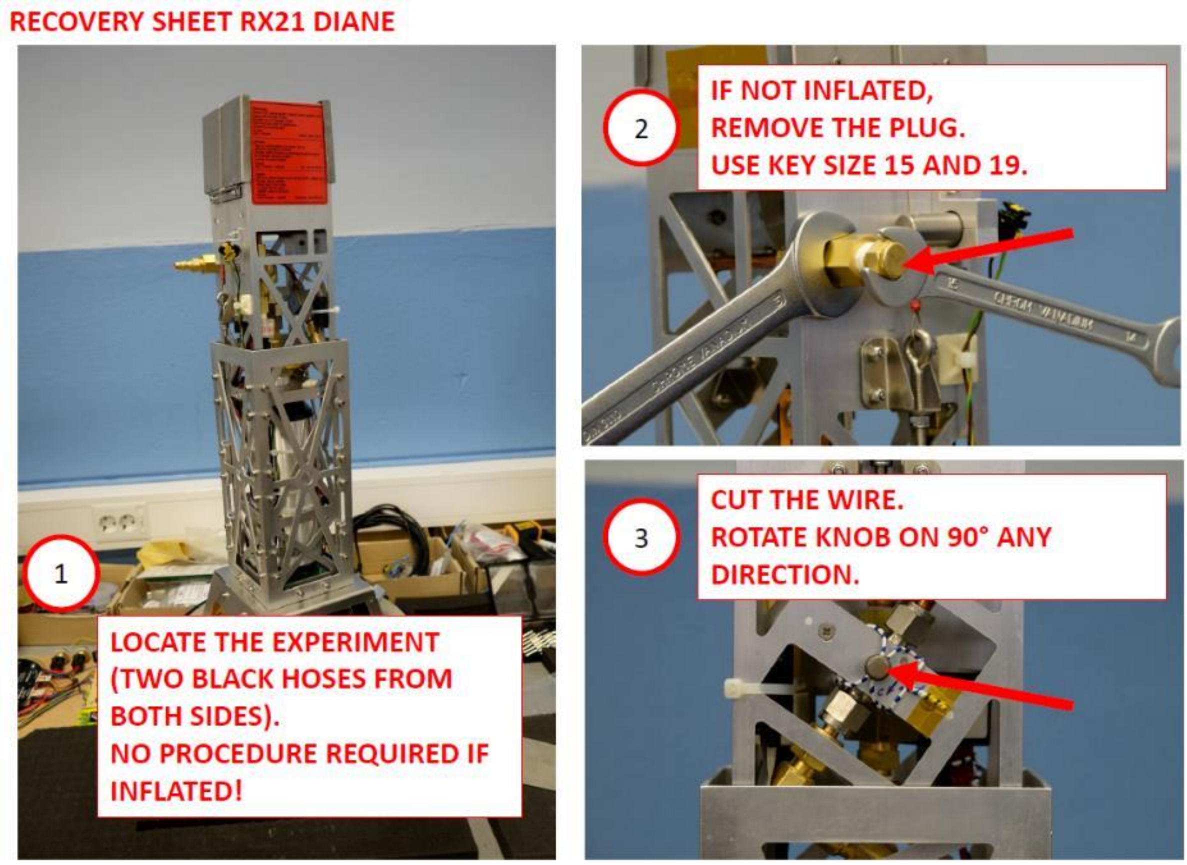

Figure C-0-2 Example of Recovery Sheet of the Team DIANE Experiment of REXUS 21

APPENDIX D: RADIO DISCIPLINE

Please observe the following regarding radio communication:

- Use functional names, avoid personal names
- Use basic English
- Spell by analogy if necessary
- Use 'pro-words' below to minimize the risk of misreading
- No horse play or bad language
- Minimize radio traffic
- Speak loud and clearly

Table D-1: Radio pro-words and meaning

Pro words	Meaning
Affirmative	YES
Negative	NO
Active	Work commanded is in progress, completion will be reported
Break – Break	I must interrupt this conversation because of an urgent message.
Correction	You have made a mistake. You should have said (or performed) or, I have made a mistake; I should have said
Disregard	Disregard what I have just said. It is not applicable or is in error
Execute	Carry out the instruction
Go ahead	I am on the net. Proceed with your transmission
I say again	I am repeating the message for clarity
Out	I have completed this conversation
Proceed	Go ahead with your task
I copy	I received your last message satisfactorily and understand
I copy, Wilco	I have received your message, understand it, and will comply
Say again	Repeat your last communication
Speak slower	You are talking too fast
Standby	I must pause for time or wait a few moments
Verify	Check status or correctness
Roger	Acknowledge your transmission

Table D-2: Call sign during pad preparation

Functional names	Function in the balloon processes
Operations	Operations Officer
Launch Officer	Launch Officer on balloon pad
Electronics	Electronic responsible person at launch pad (for EBASS / EMPIRE)
Assistant Electronics	Assistant electronic responsible at launch pad (for EMPIRE)
E-Link	E-Link operator
Gondola Electronics	Gondola Electronics responsible person
Safety	Safety Officer
TM	Telemetry station
Pilot	Balloon Pilot
Science	Payload responsible