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## User Manual for ZPB Infrastructure Access

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## 1 INTRODUCTION

HEMERA is a balloon infrastructure project, funded by the European Commission within its programme Horizon 2020. The project is coordinated by the French space agency CNES and involves a consortium of 13 partners from six European countries and Canada.

The HEMERA project will offer free of charge balloon flights to the user community. The flights of these Zero Pressure Balloons, each carrying around at least 150 kg of payload, are planned from Esrange (northern Sweden) and Timmins (Ontario, Canada).

Launches will be operated by the Swedish company SSC or by the French Space Agency CNES. CNES will work in collaboration with the Canadian Space Agency, when operating in Timmins.

Scientific and/or technologic experiments are assembled into a payload gondola, which is lifted by a balloon with a volume of 150 000 m<sup>3</sup> to an altitude of 30-35 km, depending on total experiment mass. The flight duration at float level is at least 3 hours. It could be longer, up to 40 hours, depending on launch site and season. It is strongly dependent on the meteorological conditions and can thus not be guaranteed.

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

This document describes all the necessary information for a user acceding to the HEMERA ZPB infrastructure access. It defines the requirements that apply to the HEMERA experiments and gives design recommendations. It also includes a description of the ZPB system, the programmatic elements, the pre-flight tests and the campaign schedule and, finally, there is a chapter on safety.

## 2 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:

### **Flight Support Application (Flight Requirements Plan)**

This is a document that all experimenters must complete by indicating their entries and their requests for the experiment accommodation in the payload gondola and the flight profile. Without good information, well before the campaign, it will be impossible to fulfil requirements such as the provision of gases, special tools, etc.

### **Experiment safety**

If there are hazardous items such as chemicals, lasers, radiation, pressure vessels etc. included in the experiments, there is may be a need for further investigation by the Esrange Safety Board or the CNES Safety Authority. This may take some time and should be done early in the preparation phase of the flight.

### **Durability of your experiment**

During the pre-flight tests and the count down, 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 the SSC Payload Manager, or by the CNES Campaign Manager.

### **Radio Frequency interference test**

After the completed flight compatibility 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 for the balloon control, it will not be flown at all. This risk should appear in the Flight Support Application, and should be significantly reduced with respect to compatibility with the on-board frequencies (see table of frequencies at §6.5)

### 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

Only during count down and launch, no one is allowed to be outside on the balloon pad without the permission of the 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.

In the final time slot (30 minutes to 1 hour and 30 minutes – TBC) before launch after the sweet spot tests, there is no more access to the experiments. During launch it will be necessary to remain inside a building.

**Our goal is to have a successful flight with all teams and their experiments. You are always welcome to contact your SSC or CNES Payload Gondola Manager with any questions.**

## 2.1 Definitions

The ZPB system consists of the following components:

### Definition:

- |                            |  |
|----------------------------|--|
| - Aerostat                 | The complete integrated vehicle to perform the flight.   |
| - Balloon                  | The part of ZPB giving lift and atmospheric float capacity.  |
| - EBASS or NSO             | House-keeping unit/gondola to monitor and control the flight.  |
| - Payload gondola          | Experiments assembled into a carrier structure with on-board services.                                       |
| - E-Link or PASTIS         | Telemetry & remote control sub-system (TM/TC).   |
| - Control Center           | Equipment used to monitor and control the vehicle during flight.<br>Including telemetry receiving equipment. |
| - Subsystems               | All systems required for flight control, recovery, and telemetry.  |
| - Ground Support Equipment | Equipment used to control and communicate with various subsystem during test and count down.                 |

### Hierarchy:

```

├─Flight Segment (Aerostat)
|
| └─Balloon
|
| └─EBASS or NSO
|
| └─Payload Gondola
|   |
|   | └─Scientific and/or technologic experiments
|   |
|   | └─Payload service subsystems
|   |
|   | └─E-Link or PASTIS (TM/TC)
|   |
|   | └─Power System (AC)
|   |
|   | └─Thermal Control (AC)
|
|

```

- |
- └Ground Segment
- └Control Center
- └Ground Support Equipment

Note: the experiment could be composed of several modules.

## 2.2 References

NOTE: 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, *Project planning and implementation*, ECSS-M-ST-10C (ESA Publications Division, 6 March 2009)  
<http://ecss.nl/standard/ecss-m-st-10c-rev-1-project-planning-and-implementation/>
- [2] ECSS, *Manual soldering of high-reliability electrical connections*, ECSS-Q-ST-70-08C (ESA Publications Division, 6 March 2009)  
<http://ecss.nl/standard/ecss-q-st-70-08c-manual-soldering-of-high-reliability-electrical-connections/>
- [3] ECSS, *Crimping of high-reliability electrical connections*, ECSS-Q-ST-70-26C Rev 1. (ESA Publications Division, 15 March 2015)  
<http://ecss.nl/standard/ecss-q-st-70-26c-crimping-of-high-reliability-electrical-connections/>
- [4] SSC, ESRANGE Safety Manual, REA00-E60, Ver. 7 (21 May 2013)  
<https://www.sscspace.com/wp-content/uploads/2018/02/esrange-safety-manual.pdf>
- [5] SSC, ESRANGE Space Center, *User's Handbook*, Ver. 2 (11 April 2011)  
<https://www.sscspace.com/wp-content/uploads/2018/02/usershandbook.pdf>
- [6] ECSS, *Space product assurance / Data for selection of space materials and processes*, ECSS-Q-70-71C (ESA Publications Division, 15 October 2014)  
<http://ecss.nl/standard/ecss-q-st-70-71c-materials-processes-and-their-data-selection/>

## 2.3 Abbreviations

AIT	Assembly, Integration and Test
ATC	Air Traffic CoTXntrol
CNES	Centre National d'Etudes Spatiales
CSA	Canadian Space Agency
DSPG	Distributed Single Point Grounding
EAR	Experiment Acceptance Review
EBASS	Estrange balloon piloting system
EGon	Estrange balloon Gondola
EGSE	Electrical Ground Support Equipment
E-Link	Estrange Telemetry & remote control unit (Ethernet up & downlink system)
ESA	European Space Agency
ESD	Electrostatic Discharge
ESRANGE	Estrange Space Center
FSA	Flight Support Application
GMO	Genetically Modified Organisms
HERCULES	Estrange Balloon Launch vehicle
I/F	Interface
IR	Infra-Red
ISO	International Standards Organization
LOS	Line Of Sight
LT	Local Time
Mbps	Megabits per second
NSO	CNES Balloon Piloting System (Nacelle de Servitude Opérationnelle)
OEF	Operational Evaluation Form (TBD)
PASTIS	CNES Telemetry & remote control unit
PFR	Post-Flight Report
PGM	Payload Gondola Manager
PI	Principal Investigator
QA	Quality Assurance
RF	Radio Frequency
RX	Reception
S/W	Software
SSC	Swedish Space Corporation
TBC	To Be Confirmed
TBD	To Be Determined
TC	Tele-Command
TM	Telemetry
TX	Transmission
UV	Ultra Violet
ZPB	Zero Pressure Balloon

## 3 ZPB FLIGHT OVERVIEW AND MILESTONES

### 3.1 Organization

The technical support in the integration and testing phase, as well as the campaign management and operations, is provided by CNES or SSC.

The scientific evaluation of the experiment proposals and the financial support for the subsistence in the balloon launch site (Esrange/Kiruna or Timmins), on the basis of 3 persons during 12 days, are the responsibility of the HEMERA consortium.

The selected experiments for the HEMERA flight will be assembled on a gondola payload, the manager of which will be designated by CNES or SSC. The Payload Gondola Manager will be your point of contact for all technical questions

### 3.2 ZPB flight ticket

In the HEMERA “flight ticket”, the following services are included:

- General management and planning of HEMERA flight.
- Provision of launch vehicle and subsystems necessary for a flight mission with recovery.
- Assembly of selected experiments into the payload gondola.
- Pre-flight testing of the payload gondola (TM & TC).
- Provision of laboratory facilities at the Esrange/Kiruna or Timmins launch site.
- Daytime or night-time launch, operations, piloting and recovery of the gondola payload.
- Data transmission with provisions of real time data from payload.
- Disassembly of the experiments from the payload gondola.

### 3.3 Experimenter’s role

Once selected to participate in the HEMERA ZPB flight, the experiment’s team becomes a part of the mission team for the payload gondola. Its primary responsibility is to ensure the timely delivery of their experiment, which will be a part of the payload gondola, 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 the establishment and conduction of the operational programme through correspondence and fulfilment of the documentation requirements.

The successful operation of experiments is vital to the overall success of the payload gondola flight. Before flight, the experimenters must successfully demonstrate 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. They are also responsible for ensuring that the experiments conform to all required electrical and mechanical interface specifications, meet safety requirements and survive the flight.

### 3.4 Planning

2 weeks after the selection, PIs of the selected experiments will be contacted by the balloon operator, CNES or SSC, with information about the flight schedule, requirements, necessary experiment documentation etc.

- T0 - 6 m Experiment documentation submitted to the operator (CNES or SSC) where T0 = occasion of the balloon flight.
- T0 - 1 m Experiment Acceptance ('paper') Review by PI of the experiment and CNES or SSC.
- T0 Campaign at Esrange/Kiruna or Timmins by SSC or CNES.
- T0 + 1 m Completion of the Operational Evaluation Form for the implementation of the flight.

T0 + 6 m Technical and scientific report by the experimenters submitted to CNES or SSC; popular science report to be submitted to SNSA.

### **3.5 Experimenter documentation requirements**

This documentation shall be provided by the experimenter to the Payload Gondola Manager.

#### **3.5.1 Experiment design documentation**

This documentation provides definition about the size, weight, mechanical aspects of the experiment modules, and details the mechanical and electrical interfaces.

The primary purpose of this documentation is to allow verification that mechanical and electrical design requirements are met in the design of instrument modules (Cf. §6.3 & §6.4).

#### **3.5.2 Flight Support Application (FSA)**

This application form (see summary in appendix 1), which must be completed by the experimenter, 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 are made concerning the experiments. If incorrect information is provided by the experimenter, it may not be possible to provide the support required.

This document gives a complete description of the specific project, including payload information, a list of hazardous materials, experiment requirements on the launch operations, participants expected, etc. This is an important document used to inform all participants in the campaign.

#### **3.5.3 Ground and on-board safety Questionnaire**

The Safety Questionnaire requires detailed input for the campaign risk analysis and safety evaluation, by experimenter completing of a hazard identification matrix (see list of hazard in appendix 2). In this matrix, each source of danger will be identified, with a description of references, control measures, storage mode, etc. It will be joined as an appendix to the FSA document.

#### **3.5.4 Recovery Sheet**

During the campaign, the recovery team requests a single A4 sheet containing dedicated experiment recovery instructions. This recovery sheet shall explain the handling after landing with a short text with colored pictures of the experiment (e.g. how to switch off / disarm the experiment, how to disassemble protruding equipment for transport - see example in Appendix 6).

#### **3.5.5 Preliminary Flight Report Documentation**

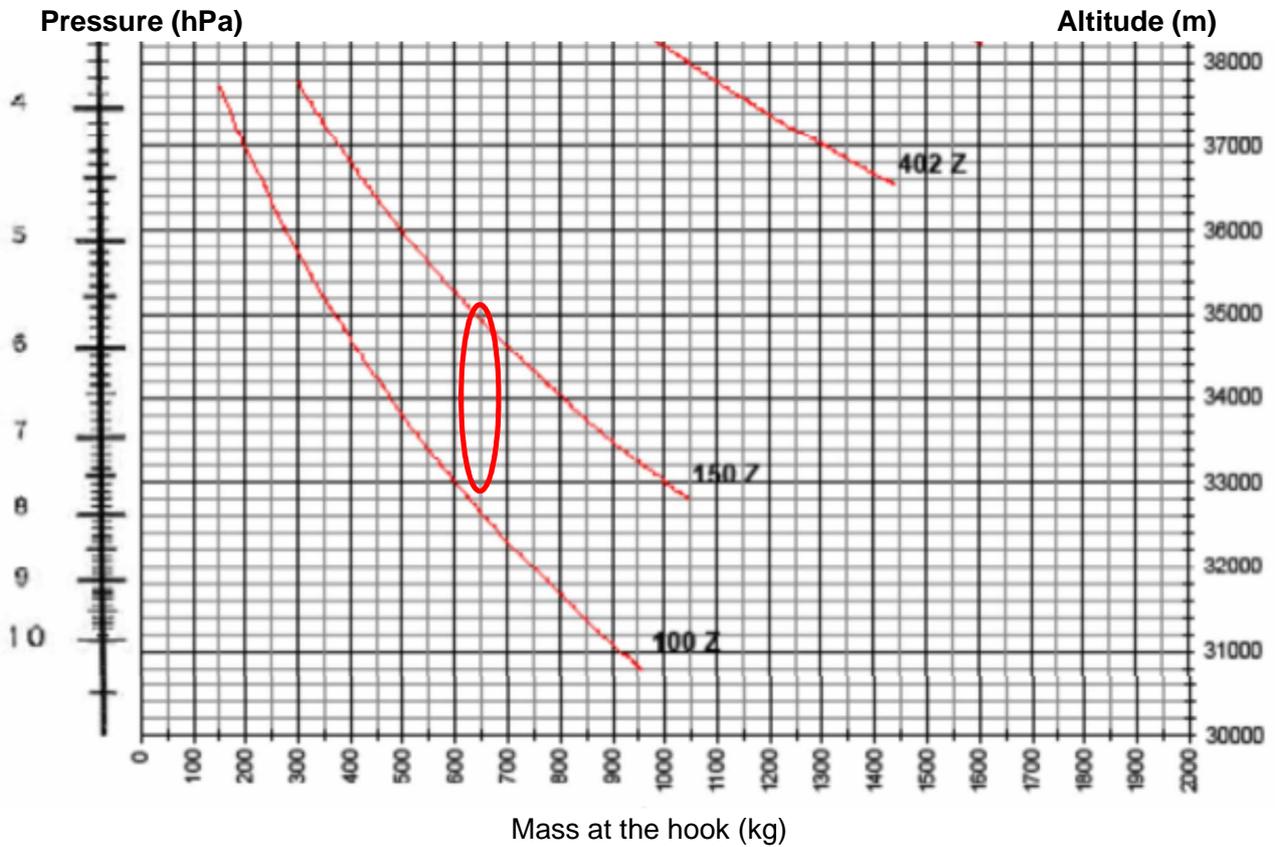
A post-flight report document for inclusion in the Flight Report must be produced following each launch. The experimenter must submit only one to two pages regarding performance of its experiment during the flight and preliminary results when possible. This must be submitted two weeks after the launch campaign (the experiment team is expected to present a preliminary performance overview whilst at the campaign following the flight). A finalized version of this document will be delivered 4 months after the end of the campaign.

#### **3.5.6 Failure Analysis Report**

In case the experiment does not perform as expected resulting in a limited scientific or technologic outcome, the experimenter is required to perform a failure analysis.

## 4 ZPB SYSTEM

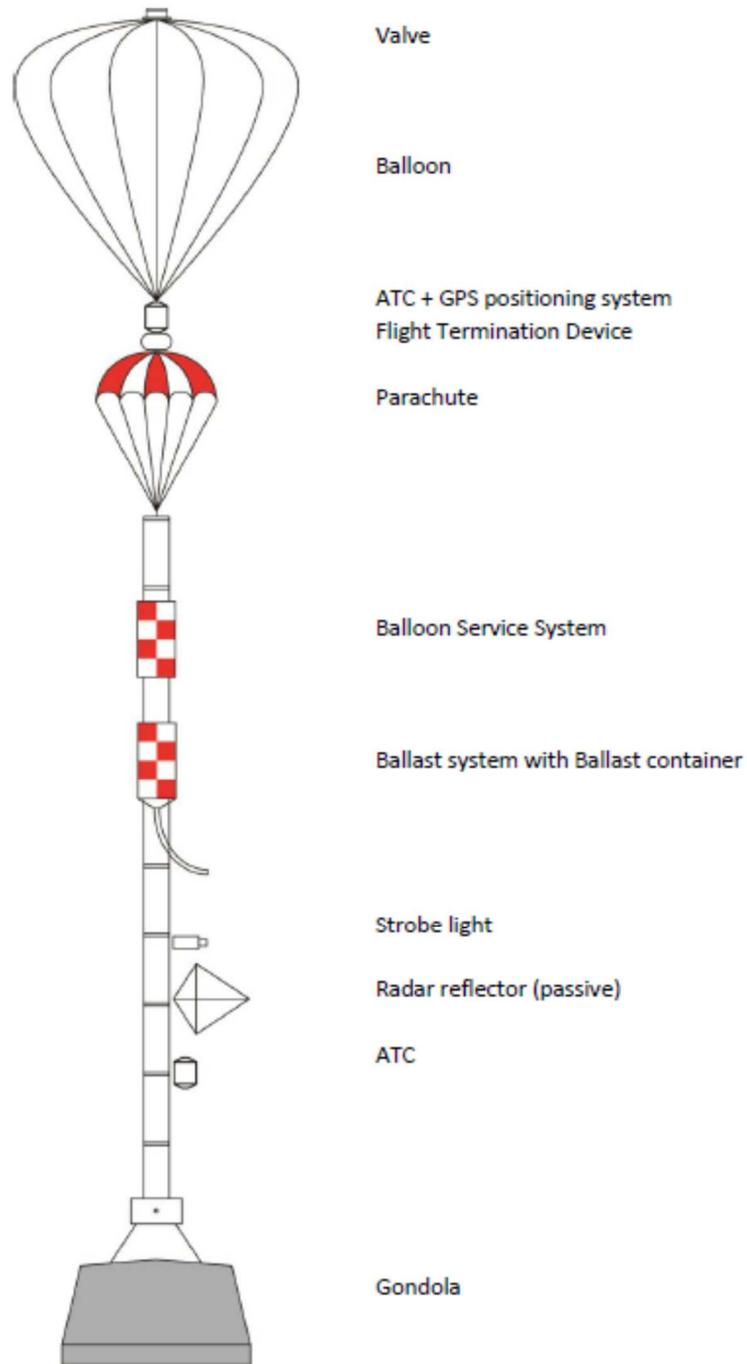
### 4.1 Performance of a typical balloons



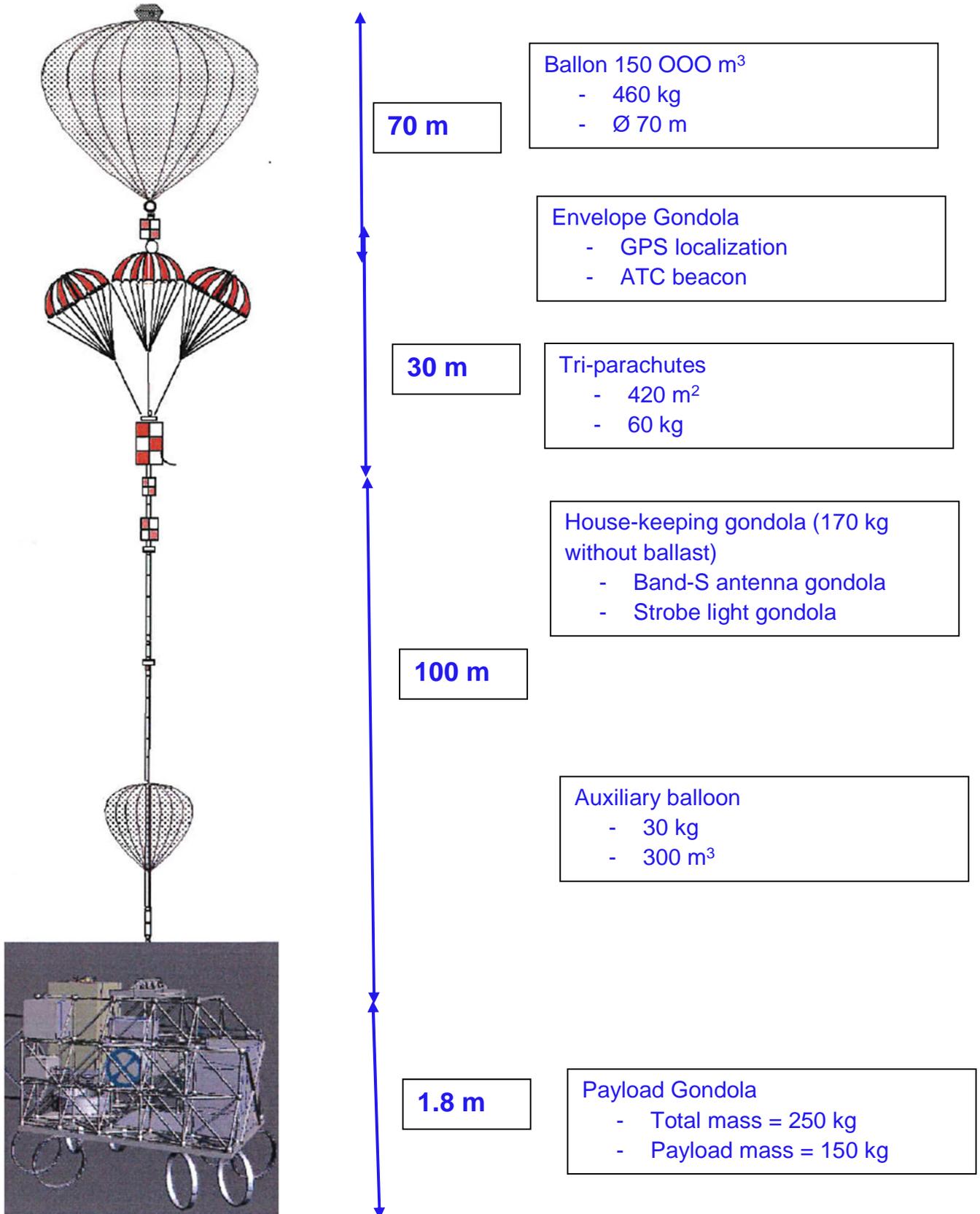
Typical performances for a 150.000 m<sup>3</sup> balloon (150 Z):

- Altitude: < 35 km
- 650 kg at the hook
- 150 kg of instruments assembled in a 250 kg payload gondola.

## 4.2 Flight configuration



**Typical SSC flight configuration**

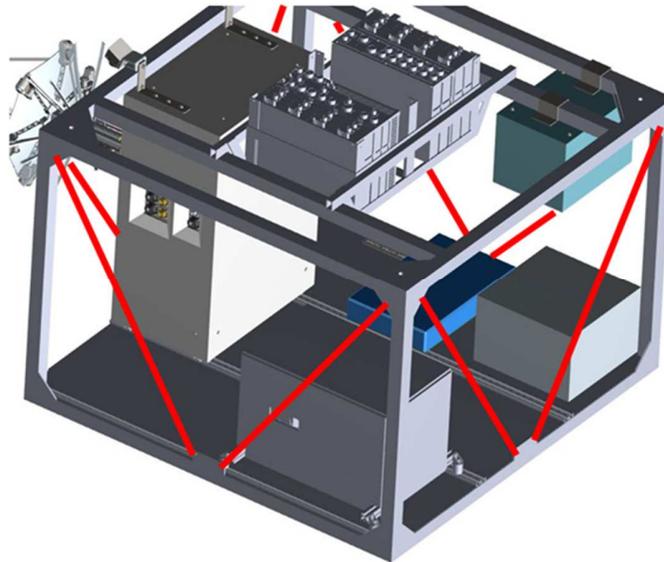


Typical CNES flight configuration

### 4.3 Payload Gondola



**CNES Helios payload gondola**



**Example of SSC payload gondola ('octagon' gondola)**

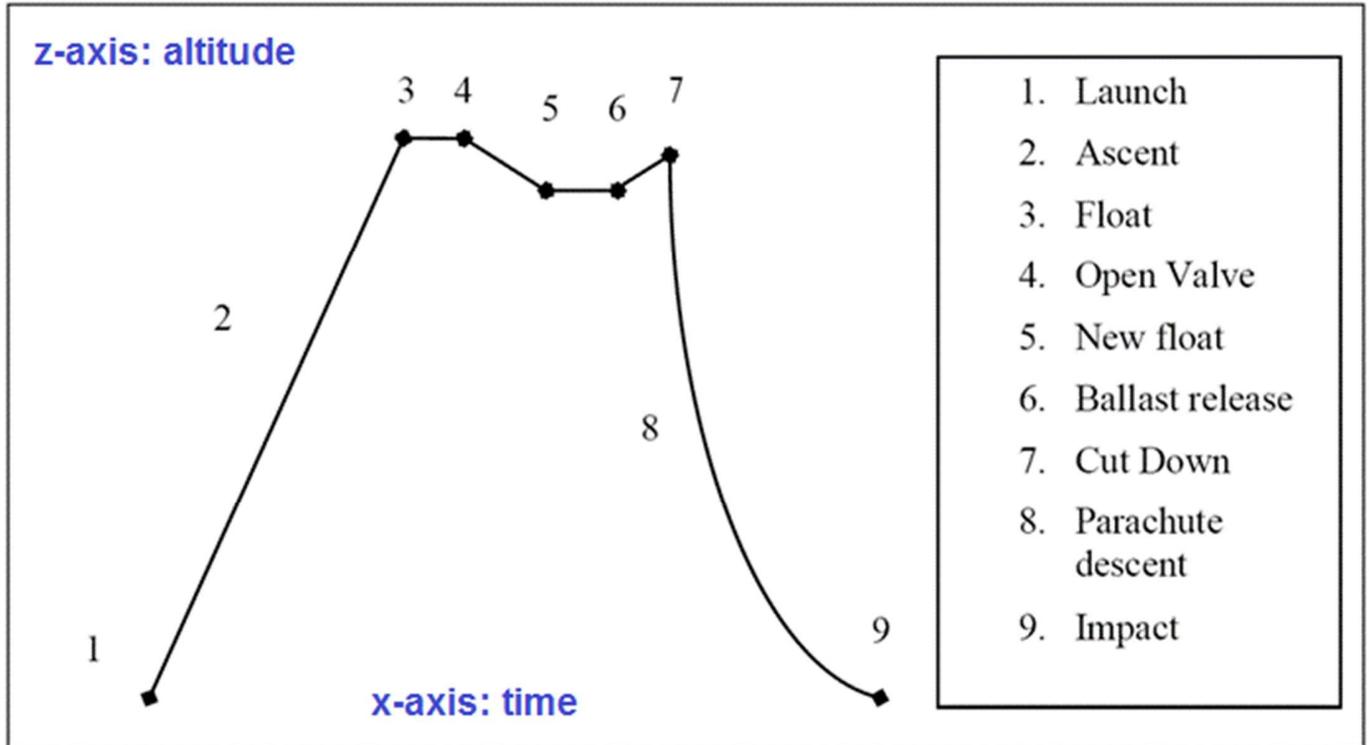
### 4.4 Tracking

The house-keeping gondola (balloon service system) is equipped with GPS receiver and transmits its location. This is the primary tracking method.

Both the balloon envelope and the payload are equipped with an air traffic transponder (ATC).

## 4.5 The different phases of the flight

### 4.5.1 Flight sequence



**Flight profile**

The performance of the balloon may be adapted to the respective mission requirements by ballasting and valve opening operations.

### 4.5.2 Launch

In the SSC launch method, the payload gondola is held by a vehicle, and is released after the balloon take-off.



**Hercules Launch Vehicle with Gondola**



**Launch with Hercules Vehicle**

In the CNES launch method, the payload gondola is lifted off by an auxiliary balloon, during the preparation and when the balloon takes-off.



**Launch with Auxiliary Balloon**

### 4.5.3 Ascent phase

The nominal ascent speed is 5 m/s. Depending on float altitude and variations in speed, this phase takes approximately 2 hours. A slight pendulum movement is experienced. Expect an initial drift above ground of 5-10 m/s.

### 4.5.4 Float phase

The ZPB balloon has vent ducts at its bottom to exhaust excess gas at ceiling/float when the gas expands to completely fill the balloon. At this point, the ascent stops, and the balloon will fly at a constant altitude (float). During float there are only minor changes in altitude ( $\pm 200$  m). If the sun sets during flight, the balloon will begin to descend due to the cooling of the gas. The altitude of the balloon can be controlled by the opening of a valve to exhaust gas (descent) and by dropping ballast (maintain altitude or ascent). The ZPB balloon gives the opportunity to perform scientific in-situ measurements at float level, but also during a slow descent (as requested by experimenters). The minimum pressure attainable is 165 hPa, i.e., an altitude of  $\sim 13.0$  km at standard atmosphere ISO 2533. Slow rate of descent ranges from 1.0 to 5.0 m/s.

After the ascent and before the descent, the minimum flight duration at float is 3 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.

### 4.5.5 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. 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 in the beginning, due to the thin atmosphere. Closer to the ground, it will stabilize at aiming 7.0 m/s.

### 4.5.6 Landing

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

The aiming landing velocity is 7.0 m/s maximum. There is a shock-absorbing material (crash pad or deformable metal tyre) at the bottom of the gondola that lowers the shock load at landing. Nominally, the landing is gentle with no damage to the experiments.

On rare occasions we have seen landing shocks up to 35 g when landing in rocky terrain. A water landing is a risk in Sweden and Canada, that we try to reduce as much as possible by the forecasts of the descent trajectory and landing zone.

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

**Soft landing****Hard landing**

#### 4.6 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 gondola and the recovered balloon back to Esrange or back to Timmins launch base. This procedure can take several hours. If the experiments contain any time critical equipment, it has to be reported and discussed with the Payload Manager in advance.

During the design phase, experimenters should keep recovery accessibility in mind. Each team will be required to produce a short recovery plan detailing how the recovery crew can ensure that the instrument is safe (i.e., any dangerous items are made safe) and how to handle the experiment if necessary. Teams should note that certain items, and Li-ion batteries in particular, cannot be moved into a recovery helicopter without special handling and so these items should be identified early in the programme.

The transport below the helicopter and on the truck can cause strong wind loads and heavy vibrations towards the experiments. The experimenter shall take a rigid design into account and secure loose items from falling off, even after flight.

**Landing in the forest (close to water)**

## 5 TELEMETRY AND REMOTE CONTROL SUBSYSTEMS

### 5.1 SSC E-Link telemetry subsystem

#### 5.1.1 E-Link subsystem overview

Estrange Airborne Data Link (E-Link) is a telemetry system that offers a simplified interface to experiments with a standard Ethernet protocol. The system can also handle asynchronous RS232/422 user interfaces.

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.

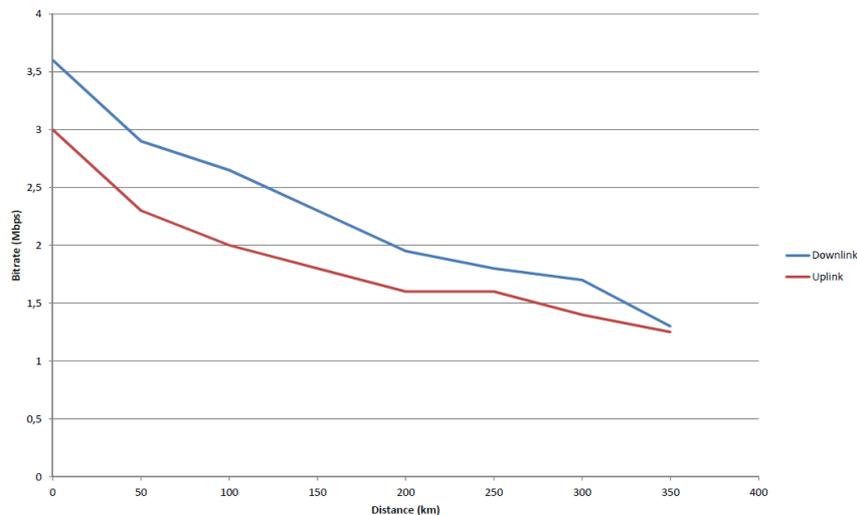
The experimenter is allowed to implement an additional internal Ethernet switch, in case there is more than one connection required.

The main features of the system are:

- A standard and easy-to-use interface for payloads: Ethernet 10/100 Base-T Protocol.
- MIL-C-26482-MS3116F-12-10P connectors.
- High data bandwidth, 2 Mbps duplex nominal.
- All electrical parts are approved by FCC and ETSI (standards).
- Fixed IP address allocations.



**E-Link airborne unit**



**E-Link performance vs distance**

#### 5.1.2 Technical specification of the E-Link on-board unit

**Operating frequency:** S-band.

H2020 Grant 730970

<b>Modulation:</b>	DSSS.
<b>Channel bandwidth:</b>	Nominal $\pm 11$ MHz.
<b>Maximum range at LOS:</b>	500 km at 30 km altitude.
<b>Data bandwidth:</b>	2 Mbps duplex nominal, decreasing with range.
<b>User interfaces:</b>	10 Ethernet 10/100 Base. 2 asynchronous duplex RS-232/422 channels.
<b>Power supply:</b>	20 to 38 volts DC.
<b>Operation time:</b>	Nominal > 11 hours.
<b>Weight:</b>	Nominal ~20 kg, including batteries.

### 5.1.3 Technical specification of the E-Link ground unit

<b>Operating frequency:</b>	S-band
<b>Channel bandwidth:</b>	Nominal $\pm 11$ MHz
<b>Maximum range at LOS:</b>	500 km at 30 km altitude
<b>Data bandwidth:</b>	2 Mbps duplex nominal, decreasing with range
<b>User interfaces:</b>	Ethernet 10/100 Base-T (no limit on ground). 2 asynchronous RS-232/422 channels.

## 5.2 CNES PASTIS telemetry subsystem

### 5.2.1 PASTIS subsystem overview

The PASTIS communication interfaces consist of two modules, one at each end of the scientific IP links. These modules are designed for communication between the ground and the on-board experiments and to enable the network to be configured quickly and easily. There is one on-board PASTIS main module, providing the interface with the scientific experiments, and one ground PASTIS main module on the ground, providing the interface with the mission centre. A couple of on-board and ground auxiliary modules can be added to increase the telecommunication services.

The stream of scientific data is sent via an IP tunnel, which means that the ground PASTIS module sends all TC data leaving the mission centre's processors to the on-board PASTIS module via an IP tunnel. The on-board PASTIS module then restores the same TC format as was used on input to the ground PASTIS module. For Telemetry data, the same principle applies between the on-board and the ground PASTIS modules. The system thus operates by combining a pair of PASTIS modules specifically configured for a mission. The PASTIS modules will be configured by CNES to match the needs expressed by the PIs when responding to the Flight Support Application.

### 5.2.2 Technical specification of the on-board PASTIS unit

The main functions of the on-board PASTIS are:

- To provide an Ethernet link with a restricted bandwidth for scientific TM/TC between the NSO and the Payload Gondola.
- To provide 6 Ethernet links to the Payload Gondola. The number of links is reduced to 5 if the auxiliary PASTIS is used, as one of the links is used for communication between the two on-board PASTIS modules
- To provide 12 output type 'open collector' outputs to the Payload Gondola, at 35VDC/0.5 A.

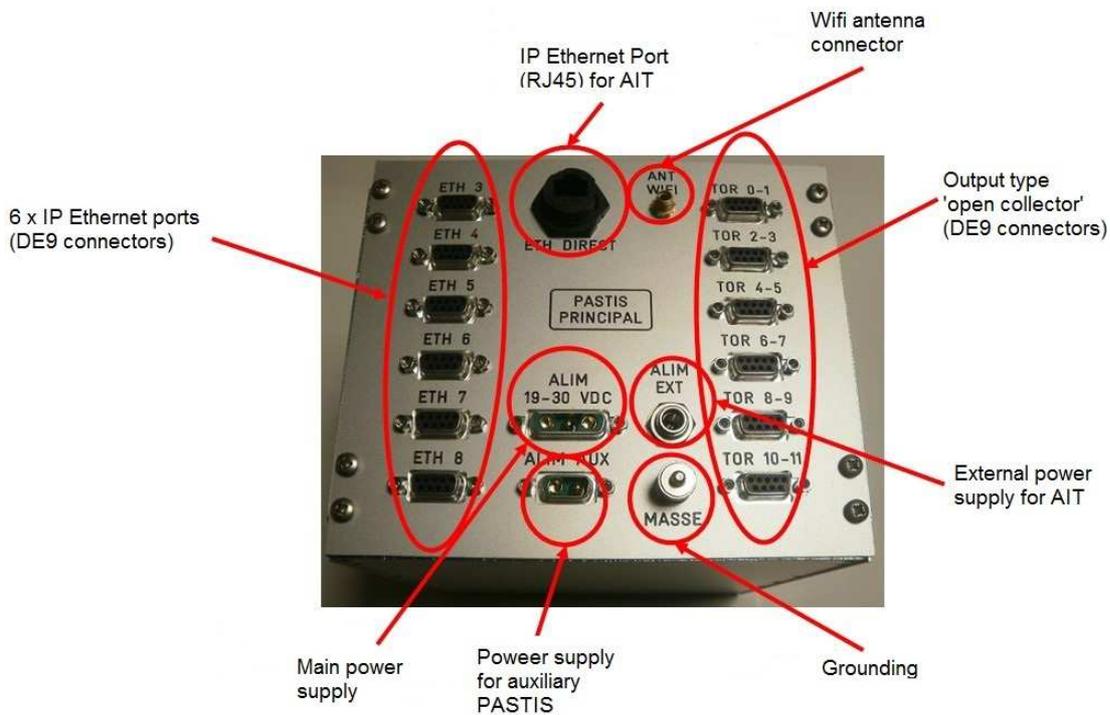
The capacity of the on-board PASTIS can be increased by adding an auxiliary on-board PASTIS, with the following main functions:

- To provide 4 asynchronous two-way links (RS232/422/485) to the Payload Gondola.

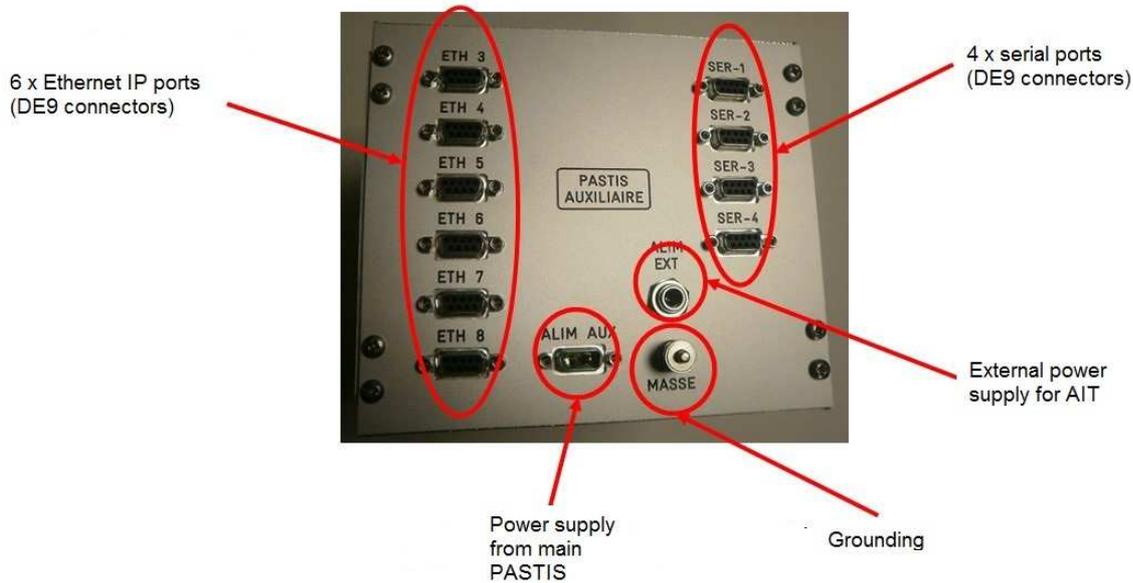
- To provide 5 additional Ethernet links to the Payload Gondola (giving a total of 10 Ethernet links available for science).

**Main characteristics:**

- **Operating frequency:** S-band (share of the RF link with house-keeping data).
- **Data bandwidth:** <70 kbps for the uplink and < 1,5 Mbits/s for the downlink.
- **Maximum range at LOS:** 500 km up to 1000 km with the use of a relay RF station.
- **User interfaces:** 6 to 10 Ethernet links (with auxiliary PASTIS module).  
4 asynchronous duplex RS-232/422 channels (with auxiliary module).
- **Power supply:** 19 to 30 volts DC.
- **Operation time:** Nominal < 35 hours.
- **Weight:** Nominal ~10 kg, including batteries.



**On-board PASTIS main module**

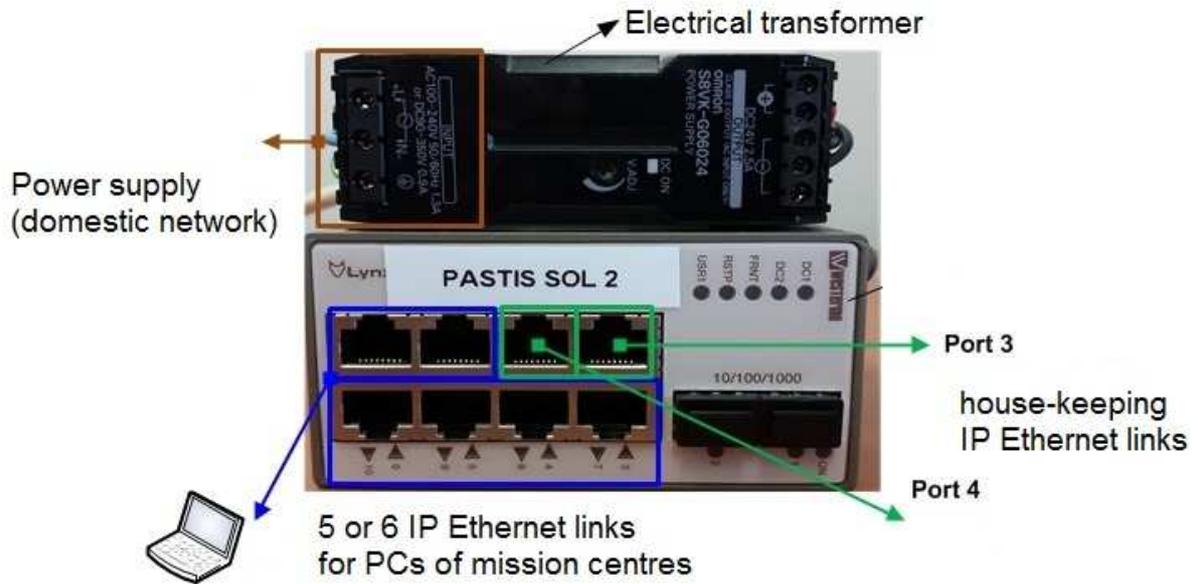


**On-board PASTIS auxiliary module**

### 5.2.3 Technical specification of the PASTIS ground unit

The ground Pastis is a stand-alone router with a power supply. It can also be combined with an IP/Serial gateway. The external interfaces are:

- 8 RJ-45 Ethernet ports: only ports 6 to 10 are available for scientists. The other ports are reserved by CNES for the following connections.
  - o Port 3 is used in the flight configuration to provide a connection between the mission control centre and the on-board PASTIS module via the NOSYCA science switch.
  - o Port 4 is reserved for the direct link between the on-board and the ground PASTIS modules (configuration during gondola integration).
  - o Port 5 is reserved for the NOSYCA ground manager for analysis of network data streams.
- If the auxiliary on-board PASTIS module is used, one of the user ports is assigned for setting up the Ethernet/series gateway. It can be used to connect 8 serial RS232/422/485 ports.



**Ground PASTIS main module**

Port UP  
Connexion to ground  
main PASTIS



Port DOWN  
Connexion to on-board  
main PASTIS

Ports 1 à 4  
Serial ports for PCs of  
missions centres

Power  
supply

**Ground PASTIS auxiliary module**

## 6 EXPERIMENT DESIGN

### 6.1 Environmental factors

#### 6.1.1 Altitude

The maximum altitude at the float level will be 35 km (or somewhat less with more payload mass).

#### 6.1.2 Speeds, acceleration & shocks

##### Ascent

- Speed: average 4 m/s ÷ 5 m/s.
- Duration: 2,0 h ÷ 2,5 h.

##### Floating

- Horizontal speed: = wind speed (0 m/s ÷ 50 m/s).
- Vertical speed (ballasting or valve opening): <  $\pm 3.0$  m/s
- Duration: at least 3.0 hours.
- Balloon rotation: less than 0.1 rpm.
- Conical pendulum motion of flight train:
  - o Frequency: 0.05 Hz.
  - o Amplitude: < 0.1 deg.
- Wobbling/oscillation of the gondola around its centre of gravity below its attachment point at the flight train:
  - o Frequency: 0.5 Hz to 1.0 Hz.
  - o Amplitude: 0.1 deg. to 0.5 deg.

### Descent

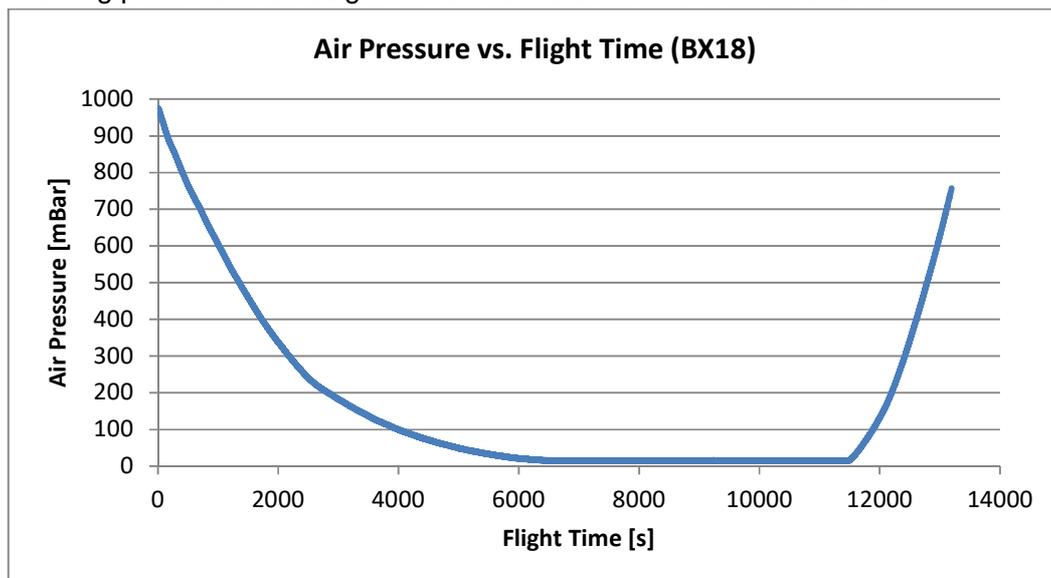
- Free fall (after balloon release) 4 to 6 seconds followed by a parachute opening and a deceleration (10-g vertical and 5-g lateral).
- Decrease in vertical speed with the increasing of the atmospheric pressure, reaching at the most 7 m/s at ground level.
- Potential tumbling of the Gondola after the balloon release causing centrifugal forces.
- Duration: approximately 35 minutes.

### Landing

- Vertical speed: 7 m/s maximum.
- Wind speeds of 5 m/s ÷ 10 m/s can be encountered on landings.
- Deceleration of 10 g vertical and 5 g lateral (typical), up to 35 g on impact.
- Landing nominally on land, with a small risk of water landing.

### 6.1.3 Pressurization & depressurization

The payload shall be designed to be able to support depressurization during ascent and pressurization during descent. Then venting path shall be designed to avoid the contamination of sensors.



**Example of Measured Air Pressure vs. Flight Time**

## 6.2 Thermal environment

### 6.2.1 Thermal environment conditions

Compliance with the operating temperature range of electrical systems must be guaranteed. If necessary, temperature control systems will have to be installed. Detailed thermal environment characteristics is specified in appendix 3.

### 6.2.2 Pre-launch phase

There is little thermal stress on the equipment while in the integration area because work areas are heated or cooled as necessary. In normal conditions, the preparation of the payload is done at a room temperature of approximately  $20 \pm 5$  °C.

### 6.2.3 Count down phase

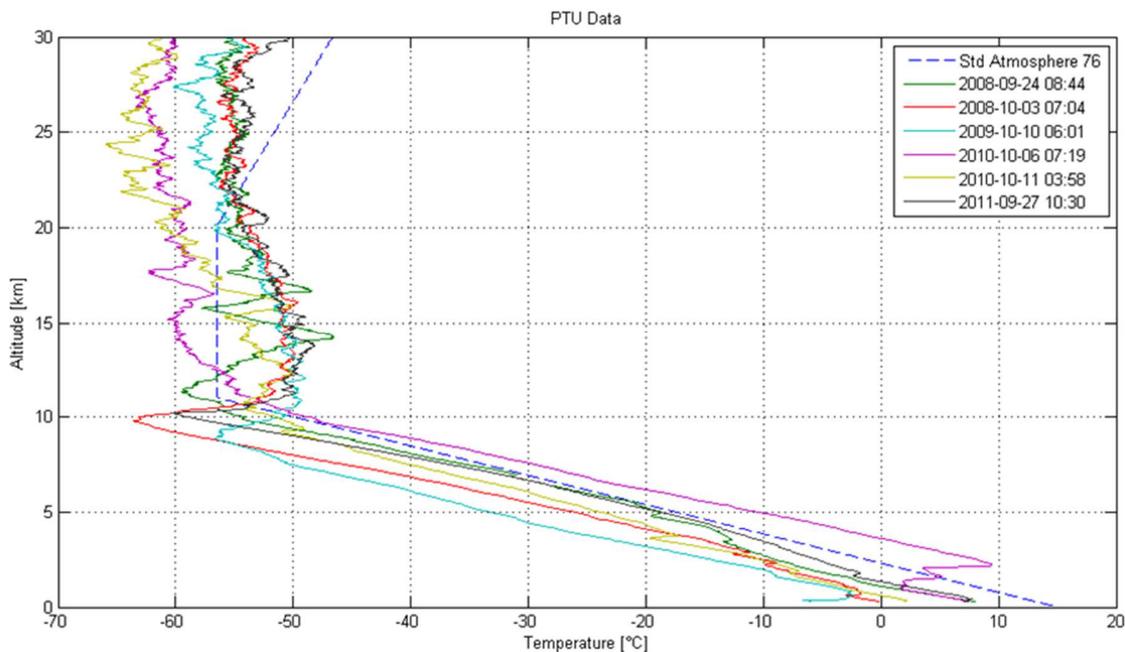
After preparation, the payload is brought outdoors to the launch pad, and the exposure time can be up to several hours at the outdoor temperature ( $-30^{\circ}\text{C} \div +30^{\circ}\text{C}$ ) of the launch pad.

Experience shows that during count down, the experiment modules tends 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.

Also, a cool gondola taken out to the launch pad on a warm, humid day may be affected by condensation. This problem can be avoided by dry gas purging of critical enclosures or by warming the gondola before it leaves the work area.

### 6.2.4 Ascent phase

On ascent, the gondola passes through the coldest layer (troposphere) from about 12 to 21 km. For as long as 60 minutes, the gondola is exposed to temperatures below  $-80^{\circ}\text{C}$ . Frozen condensation formed during ascent through the troposphere usually sublimates before the gondola reaches 21 km. Rate of ascent can average 4 to 6 m/s.



**Examples of atmospheric temperature profiles (meteorological radio sounding)**

Temperatures in the gondola vary depending on the exact configuration, time of flight and float duration. Some detailed recorded information is available on request.

### 6.2.5 Float and slow-descent phase

During daytime flights, depending on the protection against direct sun, the equipment can experience marked temperature differences between shaded and unshaded areas.

### 6.2.6 Descent phase (after separation)

On descent, the gondola encounters the same thermal conditions as during ascent for typically about 35 minutes. As external components cool during descent, water may condense and freeze on the gondola. Moisture accumulation usually begins below 15 km on descent and may damage sensitive, unprotected components or may start corrosion if the equipment is not disassembled and cleaned soon after flight.

### 6.2.7 Operations after landing

The duration of this phase is hard to quantify, as it depends on the duration flight, the distance of the landing area and of the trajectory (road accessibility and relief of the landing area).

## 6.3 Mechanical design

The modules of several experiments will be assembled in a SSC or CNES payload gondola. Payload gondola and mechanical interfaces for modules mounting interfaces are described in appendices 4a (SSC) and 4b (CNES).

The principles for the design, development and implementation applicable to experiment modules must achieve control of the risks specific to their preparation, their flight and their recovery, including:

- Free fall of a component by detaching or tearing away from an experiment module.
- Free fall of an experiment module by detaching or tearing from the payload gondola.

The experiment should be designed to withstand the loads mentioned below, as well as the loads that will be applied during the integration tests. 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 a component or an experiment module that has a risk of falling off the gondola.

The most critical phases in terms of accelerations are the following events (Cf. §6.1.2).

- 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 by truck back to balloon launch base (undefined vibrations).

To withstand those loads during transport and operation it is highly recommended to design the experiment hardware according to the specified loads. Those requirements shall be verified by analysis or/and tests.

The design load to be used for the payload is:

- Transient excitation (shock) of - 10 g vertically.
- Transient excitation of +/- 5 g horizontally.

In addition, the designer should be aware of possible unspecified random vibrations and shocks during landing and transports.

In case of the use of pressure vessels or pressurised systems, the whole system has to be qualified by tests at 1.5 times the working pressure under ambient pressure and during a vacuum test at 5 mbar.

## 6.4 Electrical design

The requirements on the electrical design are the following:

- The problem with Corona effect has to be considered when developing the electrical design.
- In order to avoid a fire that could spread to the rest of the payload gondola, the instrument modules need to be equipped with a circuit breaker (such as a fuse) to prevent overloading of the circuits. Similarly, all cables shall be sized for a current equal or greater than that tolerated by the circuit breaker.
- Instrument modules requiring ventilation or with an integrated ventilation system must be installed according to the manufacturer's instructions. In particular, the minimum distances between devices must be respected.
- To protect the personnel handling the instrument modules from electric shocks and to avoid the accumulation of static electricity in the latter, it is necessary to ensure that static charges are drained away. The system installed to drain static charges must remain constantly functional while the instrument is in use (transport on the launch pad, attachment to the flight train, recovery).
- The connectors of the electrical circuits at risk must be designed in such a way that there is no ambiguity in their connection (mechanical guides, fool proofing / keying device, etc.). They must also be protected against any deterioration, and be equipped with locking systems
- All cables must be insulated, protected and secured.
- Any electrical hazard must be clearly indicated on the equipment module at risk, as well as on the outside of the module by signage.

## 6.5 Radio-frequency constraints

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

Thus, it is necessary to apply for frequency permission at the Swedish Post and Telecom agency or Transport Canada. SSC/Esrange or CSA can either apply on behalf of experimenters or give the information needed to perform such applications. 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.

User	Frequency Band	Flight	Ground
EBASS downlink	400 to 405 MHz	X	
EBASS uplink	449 to 451 MHz	X	
Air Traffic Control (Rx)	1025 to 1035 MHz	X	
Air Traffic Control (Tx)	1089 to 1091 MHz	X	
Satellite Navigation	1164 to 1237 MHz	X	
Satellite Navigation	1260 to 1300 MHz	X	
Emergency Sea Radio	1544 to 1545 MHz		X
Satellite Navigation	1559 to 1591 MHz	X	X
Globalstar	1610 to 1625 MHz	X	

Satellite uplink	2025 to 2120 MHz		X
Satellite downlink	2200 to 2300 MHz	X	
S-band, E-Link	2405 to 2496 MHz (Channels 2-14 in 2.4 GHz-band)	X	X
Satellite downlink	3600 to 3800 MHz	X	
Satellite uplink	7145 to 7235 MHz		X
Satellite downlink	7600 to 8500 MHz	X	
Satellite downlink	10700 to 12750 MHz	X	
Satellite up/downlink	25500 to 27000 MHz	X	X
Satellite downlink	3600 to 3800 MHz	X	

#### SSC frequencies that are not allowed for use by any experiment

User	Frequency Band	Flight	Ground
ARGOS	401,5 to 401,7 MHz	X	
Air Traffic Control (Rx)	1025 to 1035 MHz	X	
Air Traffic Control (Tx)	1089 to 1091 MHz	X	
GPS L2	1227,60 MHz	X	X
GPS L1	1575,42 MHz	X	X
Globalstar	1 610 to 1 625 MHz	X	
Iridium (TM/TC)	1616 to 1626,5 MHz	X	X
NSO uplink (TC)	2024,85 to 2110,15 MHz		X
NSO downlink (TM)	2199,5 to 2290,5 MHz	X	
Wi-Fi 802.11a	5150 to 5350 MHz	X	
Wi-Fi 802.11a	5470 to 5875 MHz	X	

#### CNES frequencies that are not allowed for use by any experiment

## 6.6 Electrical grounding

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

- Provide an equipotential reference plane.
- Minimise the common mode based on the requirements.
- Avoid ground loops.
- Protect against shock hazards due to a high voltage ESD on a frame or box housing due to electrical harness damage.

Several grounding options are available, 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, this should be done in coordination with your contact. A possible good approach for complex experiments is to utilise Distributed Single Point Grounding (DSPG).

If required, an equipotential reference plane to the gondola electric 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.

## **6.7 Operations and durability**

### **6.7.1 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 telemetry system and power and to check for interference with other experiments and balloon systems. These operations are partly performed outdoors during the RF interference test. Also, once carried out, they may have to be repeated several times. The 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 experimenters 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).

### **6.7.2 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.

The experiments could 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 pad. At approximately T- 60 min, the power will be switched over to internal (gondola or experiment) batteries and the external power umbilical will be removed. Note that there will be no access to experiments at that time.

When considering the power budget (see chap. §7.3 for count down 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 supplies 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. It can be necessary 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.

### **6.7.3 Launch process**

### **6.7.4 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 be caught by the experiments, especially if they protrude beyond the gondola.

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.

## 6.8 General design considerations

### 6.8.1 Experiment Accessibility

Bear in mind that designing for accessibility will make your task easier throughout the assembly and testing phases. 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.

### 6.8.2 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.

### 6.8.3 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.

### 6.8.4 Redundancy of safety critical items

Redundancy is mandatory where there are safety or failure risks. It is not as simple for mechanical as electrical but it should be considered during the design process. Redundancy can simply be achieved by separate battery packs, multiple switches, check valves, and other solutions.

### 6.8.5 Mass and Size Considerations

Minimizing mass is commonly overlooked by experimenters. However, keeping mass low where possible serves multiple functions. For payload organization, when experiments are light and small, it gives the Payload Manager more flexibility in selecting locations for each experiment. It can also result in more experiments being flown. 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.

Significant increase of the mass must be reported as soon as possible and discussed with the Payload Manager.

### 6.8.6 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.

### 6.8.7 Shipping

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.

### 6.8.8 Safety

Safety is of the utmost importance to SSC and CNES. Any experiment that is deemed risky to the public, staff or experimenters, by the Payload Gondola Manager, will not fly. Take care to ensure that you perform any simulation, analysis, and testing that will help to convince SSC or CNES, that the experiment is safe to fly and

handle. If there are any items that you can identify as safety risks, keep them in mind during your design as the possibility exists that the experiment will be removed from the vehicle if it poses a danger.

## 6.9 Recommended validation tests

### 6.9.1 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. It permits to verify that there is no problem with Corona effect in vacuum conditions. 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 ZPB 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.

### 6.9.2 Thermal test

A thermal test is mainly performed in order to verify the nominal function of the experiment during the worst-case temperatures that can be experienced during count down, launch and flight. It is the responsibility of the experimenter to perform this test. 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.

Note: to perform the most representative flight environment tests is to have a test chamber having the ability to regulate at the same time in pressure and in temperature. With such a chamber, it is then possible to best simulate the balloon ascent in 2h 00, adjusting the couple pressure / temperature corresponding to the altitude reached with an average speed of 5 m / s.

### 6.9.3 Bench test

All experiments shall 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 (see §7.3), 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 TM/TC 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.

#### **6.9.4 TM/TC testing**

Communication time-outs are a common problem for balloon experiments, in particular if the bandwidth is shared with other experiments. Insufficient error handling of these time-outs results in problems by reconnecting to the TM/TC network.

To avoid this happening during the campaign, it is mandatory to test the reconnection of the experiments beforehand.

#### **Basic Procedure**

- Write an error handling software into the communications programs that explicitly deals with timeouts.
- 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.
- Ensure that the software can reconnect under the above test.
- Monitor dropped packages. There is suitable freeware available for download, e.g. Wireshark (<https://www.wireshark.org/>).
- Create network dumps to analyse and qualify that the experiment does not exceed the bandwidth allocation.

## **7 ACTIVITIES**

### **7.1 Pre-campaign activities**

Delivery of the experiment documentation and the Flight Support Application.

Concerning FSA, as activities in the balloon launch facility (assembly in payload gondola, testing, planning, etc.) are made based on this document, it is important that it is correct and updated if requirements change. Once the FSA is issued, any changes that effect the document must be discussed with the Gondola Payload Manager before implementing the changes.

At the end of the selection of an experiment, additional documentation will be provided by CNES or SSC once the balloon operator (SSC or CNES) and the balloon launch base (Kiruna or Timmins) are determined. This documentation will mainly concern:

- Description of balloon launch base: capabilities, layout, assembly buildings, points of contact, etc.
- Part of the safety rules specific to each balloon operator and to each balloon launch base.

- User manual of the TM/TC system.
- Organization of the operational team, and management of the operations.

## 7.2 The Experiment Acceptance Review

The Experiment Acceptance Review (paper review) concerns only the Payload Gondola with all the on-board accommodated experiments. This review, planned at least 1 month before the campaign (M19, M 31 & M 43 in the general planning of HEMERA), allows to give the green light for the flight. For each experiment, the following documentation is subject to review

- Report of functional test of the experiment, certified by the experimenter.
- Synthesis of the experiment certification (mechanics and electrical).
- Test report of the telecommunication interface with the balloon operator telecommunication subsystem (via Internet - no on-board serial link).

## 7.3 Summary of campaign activities

Here is the list of the main activities that will be carried out as soon as the team arrives at the balloon launch base:

- Kick-off Meeting: formal meeting organised by the Campaign Manager after the arrival of the experimenters and their teams at the campaign site. It is held between the experimenter and balloon operator. It precedes the start of activities concerning the experiment, with an associate schedule.
- Experiment Incoming Inspection: all the mechanical and electrical interfaces of the experiment will be inspected at delivery at the balloon launch base, on the basis of documentation.
- Assembly, Integration Test phase: assembly of the experiment modules with the other experiments into the payload gondola and testing (mainly, connection and testing of the on-board TM/TC system).
- Flight Compatibility Test: when all experiments are assembled in the gondola, a RF interference test is conducted. The gondola is 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.
- Flight Readiness Review: meeting planned, after successful completion of the RF test and ground support stations check out, to ensure the readiness for the flight of all the experimenters on-board of the payload gondola.
- Count down and launch (Cf. §7.4).
- Post-Flight Meeting: after the recovery, this meeting is held to debrief the flight and a short flight performance report is stated (quick-look of data). A short presentation of the performance of each experiment is requested.

## 7.4 Countdown and launch

This phase begins with a set-up briefing consisting of a weather briefing on ground conditions for the duration of the countdown period and on the latest trajectory forecasts. The purpose is to confirm the mission and safety conditions before pronouncing the start of flight preparation operations. These results are presented to all the persons concerned by the flight or flights in preparation.

At the end of this meeting, if the operational system is ready and the mission and safety criteria are met, the flight will be authorised. After this, the decision to fly falls to the experimenters, who assess the state of preparedness of their instruments on-board the payload gondola, and whether the proposed mission is fit to go ahead.

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

Time	Operations	Comments
T-4H30	Decision meeting	
T-4H00	Start of Count Down	
	Start pad preparations	
	Experiments on external power	External Power Supply
	Experiment check-outs	Via TM/TC system (on RF low power)
	Experiments powered off for pickup	
T-2H30	Gondola pick-up	
	Sweet-spot tests	
	Experiments powered on external Power	Hercules power or generator
	Experiment check-outs	Via TM/TC system (RF low power, then high power)
	Final experiment preparations	Latest nominal access to experiments
	Go decision from experimenters	Ready for Line-up
T-1H30	Line-up	
	Final payload preparations	
T-1H00	Balloon unfolding	
	Experiments on gondola/internal batteries	Removal of external power umbilical
	Experiment check-outs	Via TM/TC system
T-0H40	Start of balloon inflation	
0H00	Balloon release	Launch
T+~ xH00	Command cut down followed by recovery	

## 8 EXPERIMENT QUALITY INSURANCE

The major concerns of the Payload Manager related to Quality Assurance (QA) on the experiment level are that the experiment shall fulfil the interface requirements, and that the experiment's modules will fly in a payload gondola without jeopardising the performance of the other systems or experiments. In addition, HEMERA has a strong concern that the experiments shall perform nominally.

**The following advice reflects this concern.**

## 8.1 Materials

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

ECSS-Q-70-71 [6] (Data for selection of space materials and processes) may be used as a supporting information source.

## 8.2 Components

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

## 8.3 Additional quality topics

In addition to the QA issues above, the following topics should be considered.

Procured products and audits:

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

Manufacturing control and inspection:

- For the manufacturing and inspection of critical processes, the personnel should be aware of standards in applicable areas, such as:
  - o Manual soldering according to ECSS-Q-ST-70-08C [2].
  - o Crimping of connections according to ECSS-Q-ST-70-26C [3].
- Specific requirements of the project or product concerning cleanliness, contamination and environment shall be stated in the input to the Flight Requirements Plan.
- When positioning the parts or components, the sensitivity to heating, ESD and electrical disturbances shall be considered.
- Connectors shall be well marked and preferably keyed.

Re-used item:

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

Availability and maintainability:

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

Handling, storage, and packing:

- ESD susceptible components shall be handled in an ESD protected environment.
- Before transport, the product shall be thoroughly packed to withstand the expected loads. The use of a bump recorder is recommended.

## 9 SAFETY AT ESRANGE SPACE CENTER

### 9.1 Personnel safety

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

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

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

The experimenters shall state that the module fulfils the applicable requirements and establish a list of hazardous materials, which shall be communicated to the Payload Manager with the FSA. This information shall always accompany the experiment.

### 9.2 Safety regulation

The Safety Regulations that apply at Esrange may be found in the Esrange Space Center Safety Manual [Ref 4]. It is a requirement that all personnel participating in the campaign shall have read the safety regulation in the User's Handbook [Ref 5] 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 Appendix 7: Esrange safety and security compliance confirmation – balloon.

## 10 SAFETY AT TIMMINS BALLOON BASE

The QSE instructions are applicable to any person involved in the mission and are laid out clearly in the prevention plan.

The CNES QSE department ensures the safety of people, the protection of the environment and the continuous improvement of procedures in this field. It also ensures that personnel are trained to use the equipment, which must be implemented under its normal conditions of use. It also ensures compliance with the standards and regulations in force for the following areas of application: the safety of people and respect for the environment.

For this purpose, it undertakes a risk analysis that takes into account an analysis of risk to the PLG itself but also to broader aspects such as:

- Transport.
- Medical and health aspects.
- Emergency services and repatriation.
- Normal living conditions.
- Working conditions and organisation
- Risks related to the individual and joint activities of personnel from different companies.
- Risks of impact on the environment.
- The security of the mission site.

A prevention plan is drawn up on the basis of this risk analysis, depending in part on the launch site, with the aim of preventing all possible risks to personnel involved in the mission.

This prevention plan of the use of Timmins balloon facility will be presented to the participants at their arrival at the base, and must be accepted by the participants, who thus undertake to abide by it throughout the mission.

## APPENDIX 1: SUMMARY OF FLIGHT SUPPORT APPLICATION

### **General Information**

Experiment / Principal Investigator contact information

Experiment team

Scientific or technologic experiment objective

Brief description of the experiment

General characteristics of the experiment: dimensions, weight and power.

### **Flight information**

Payload history: previous operations of the payload (ground, aircraft, balloon, etc.).

Flight profile

- Preferred launch time.
- Minimum time at float altitude.
- Slow descent.

Specific weather conditions.

Radiosonde and atmospheric data.

Airborne telemetry and telecommunications

- Included in the experiment: frequency, bandwidth and power.
- Utilization of E-Link or PASTIS: IP addressing plan, asynchronous serial link, bandwidth, etc.

Recovery: constraints on recovery time.

### **Support requirement**

Assembly, integration and testing phase.

Launch pad operations before launch: electrical power, etc.

## APPENDIX 2: LIST OF POSSIBLE HAZARDOUS SYSTEMS

Explosive system: pyrotechnics, etc.

Flammables.

Chemical.

Biological items.

Thermodynamic and pure fluid systems (pressurized):

- Pressure vessels (difference, high, low, vacuum, etc.).
- Cryogenic liquids (volume/capacity).

Electrical risks:

- High voltages and currents.
- Static electricity

Batteries:

- Alkaline-MnO<sub>2</sub>.
- Unmodified rechargeable commercial batteries (Ag-Zn, NiMH, NiCd, LI-on).

Any capability of creating an electromagnetic field (ex. RF transmitter), emitting electromagnetic waves, or creating electromagnetic interference.

Ionizing energy.

Emissions and Radiations:

- Radioactive / ionizing.
- Visible, IR, UV, etc.
- Lasers.

Mechanics.

Hazardous ground support equipment.

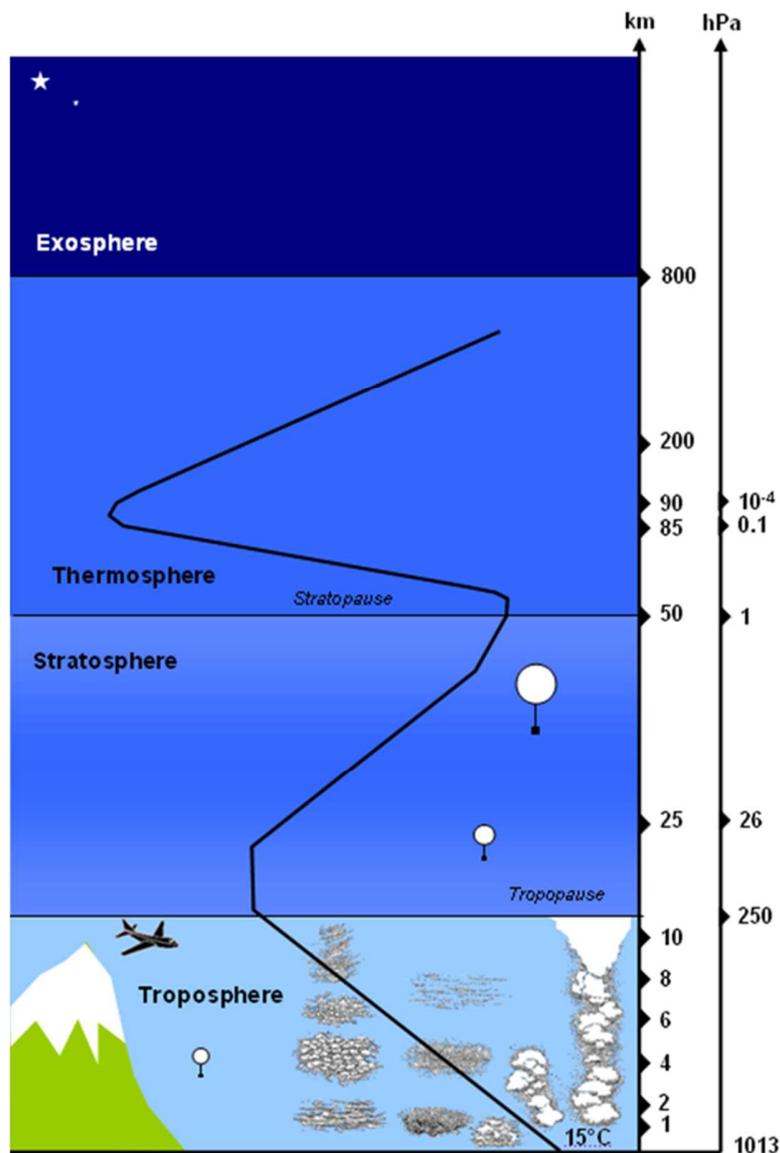
**Note: for ethic reasons, experiments on animals or genetically modified organisms are forbidden (only stem cells are authorized).**

### APPENDIX 3: ATMOSPHERIC THERMAL ENVIRONMENT

#### Air Pressure and Temperature Profiles

Air pressure and temperature profiles along the different phases of the flight are important parameters for determining convection heat transfer affecting the payload gondola. Convection heat flux ( $Q_h$ ) is directly proportional to the temperature difference between the air and the gondola.

Atmospheric pressure diminishes with altitude by a factor of 10 every 16 km approximately as per the Standard Atmosphere reference. Atmospheric pressure is 100 hPa at an altitude of 16 km, 25 hPa at 25 km, 10 hPa at 31 km and 2 hPa at 42 km. Pressure is usually used by balloonists as a vertical coordinate. In the troposphere (the layer of the atmosphere from the ground to the tropopause), there are horizontal pressure variations and the altitude of isobars varies with the occurrence of high- and low-pressure systems.



**Standard Atmospheric Profile along the Pressure and Altitude Scales**

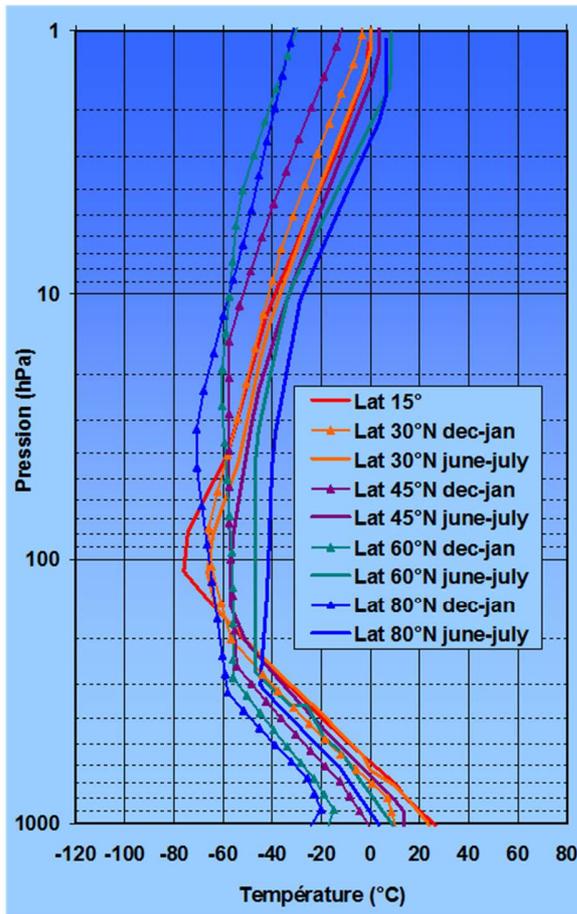
The air temperature in the troposphere decreases on average by 6.5°C every 1 km. The rate of decrease can be altered, however, when a wintertime temperature inversion occurs in the interior of a continent, where the

ground surface cools because it receives very little solar energy. In the stratosphere (from the tropopause to about 50 km), the temperature of the air increases with altitude due to absorption of solar radiation by ozone. The tropopause is defined as the upper limit of the troposphere. Its altitude varies according to the season and geographical area (from 8 km at the poles to 18 km at the equator, approximately). It is also affected by atmospheric phenomena in the troposphere.

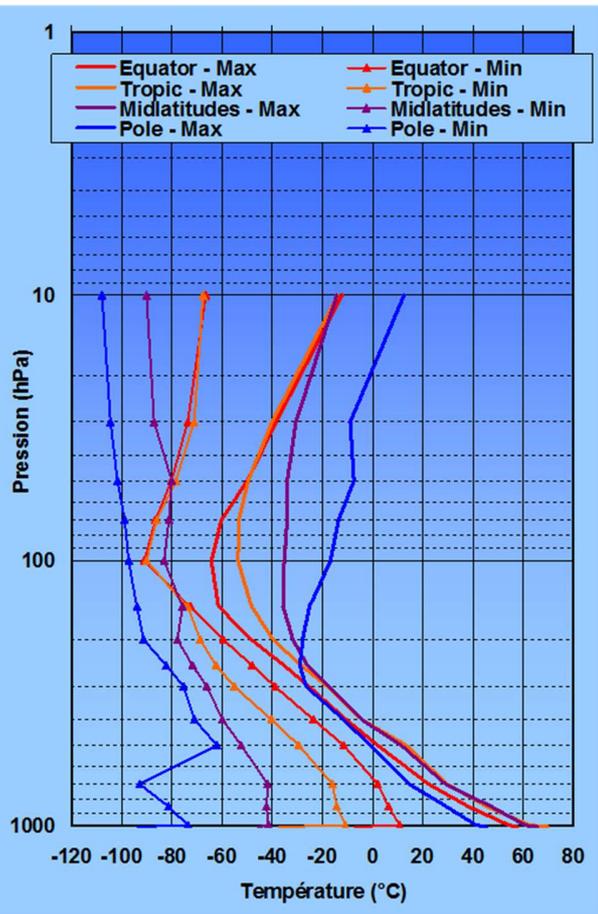
The most “stable” temperature in the troposphere and stratosphere over the course of the year is seen in the equatorial zone, where insolation varies little. The air temperature profile in the tropical zones is similar to that found in the equatorial zone. In the temperate zones, temperatures vary widely with the seasons and with the movement of atmospheric air masses which modify the temperature profile according to where they originate. And last, the polar regions experience the greatest variations in solar radiation, and therefore in temperature.

Figures below shows the extremes of air temperature that could be encountered by flights launched from various latitudes and time of the year. You may find that there are significant differences of the minimum and maximum temperature profiles between ISO model and GGUAS model (NOAA) for the Equator, the Tropic, the Mid or Tempered and the Pole latitudes

ISO 5878 average temperatures

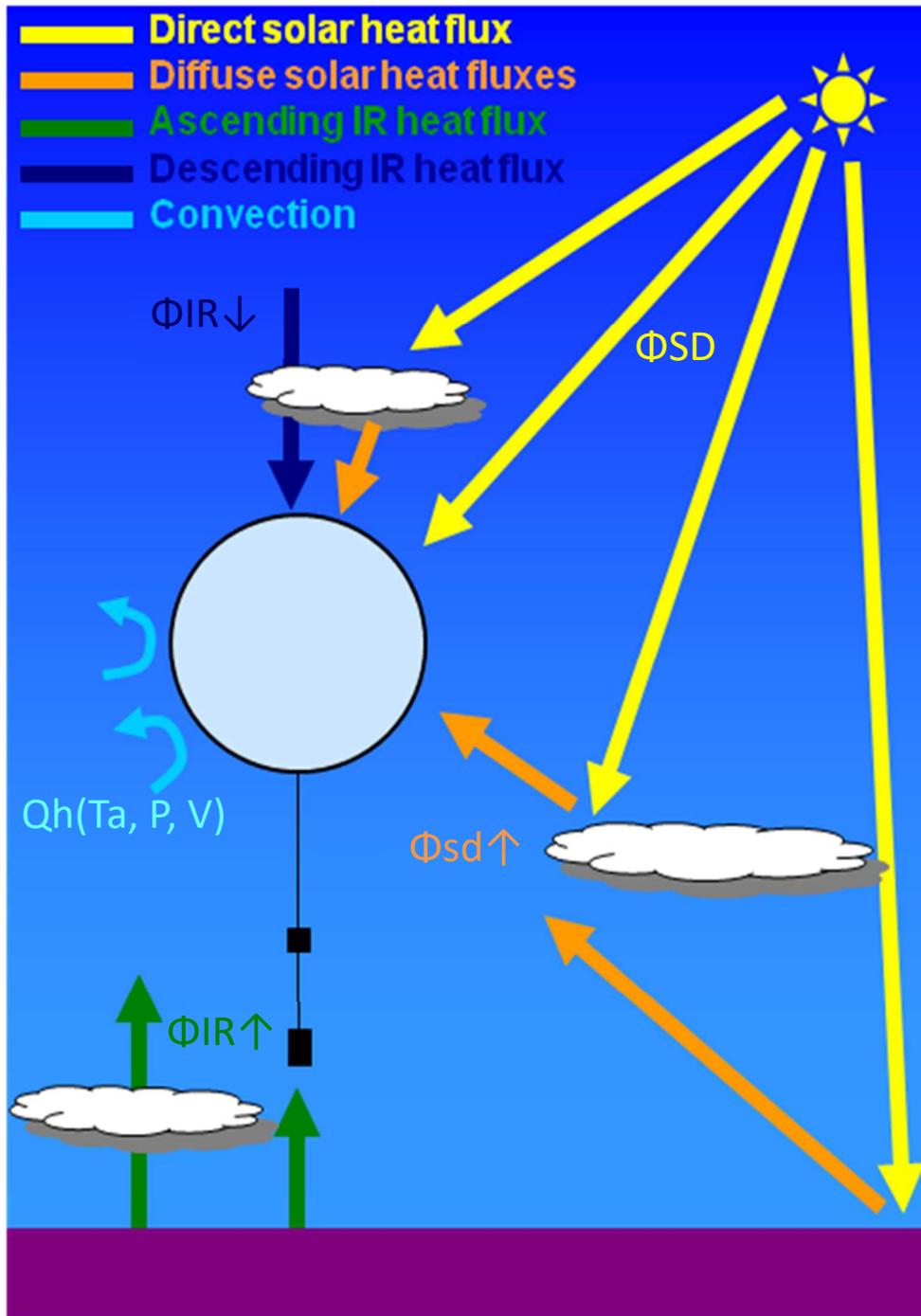


Results of the GGUAS model (NOAA)



Atmospheric Temperature Profiles for Various Latitude and Period of the Year

## Heat Transfer Modes



### Heat Transfer Modes and Thermal Environment Parameters for Payload Gondolas

As illustrated, the payload gondola, with its experiments, is exposed to direct solar flux, diffused solar flux reflected from the ground and the clouds (according to their respective albedo,  $A_G$  and  $A_C$ ), upward infrared (IR) flux from the ground and the clouds at low altitude, downward IR flux from the sky and clouds at high altitude, and convection heat flux from surrounding air which is a function of air temperature, pressure and relative velocity.

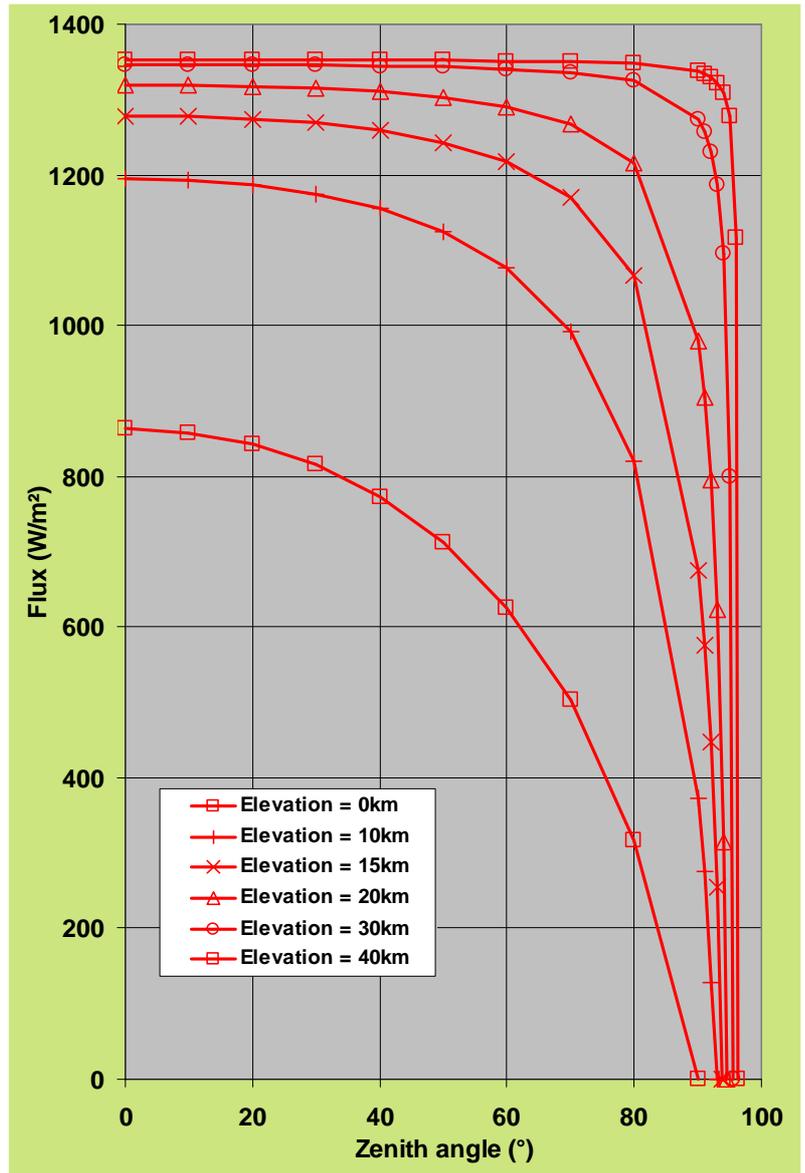
### Direct Solar Flux

Beyond the atmosphere, direct solar flux ( $\Phi_{SD}$ ) is equivalent to the solar constant. Within the atmosphere, the direct solar flux is attenuated by diffusion and absorption by components of the atmosphere. It depends in this case on altitude and on the position of the sun relative to the zenith (given by the zenith angle of the sun). Due to the rarified air in the upper layers of the atmosphere, during the course of the day, a payload gondola at float altitude will see a density of direct solar flux close to the solar constant over a wide range of solar zenith angles.

Due to the eccentricity of the earth's orbit, insolation varies over the year.

	Solar constant
Winter solstice	1415 $\pm$ W/m <sup>2</sup>
Spring equinox	1382 $\pm$ W/m <sup>2</sup>
Summer solstice	1326 $\pm$ W/m <sup>2</sup>
Autumn equinox	1362 $\pm$ W/m <sup>2</sup>

The solar constant averages 1371 W/m<sup>2</sup> over the year.



Solar constant and example of direct solar flux density in atmosphere.

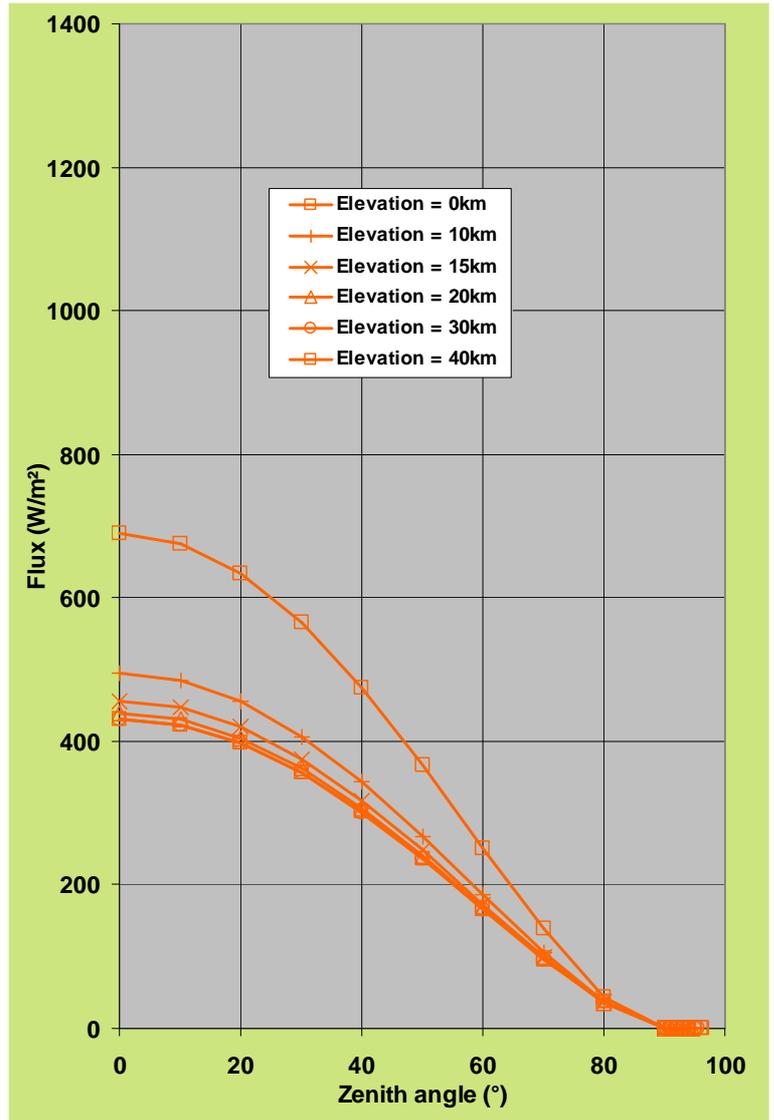
### Upward Diffuse Solar Flux ( $\Phi_{sd\uparrow}$ ) or Albedo

Upward Diffuse Solar Flux ( $\Phi_{sd\uparrow}$ ) or Albedo results from diffuse reflection of direct solar flux from the ground and from diffuse reflection and transmission of solar flux by clouds. It depends on the albedo coefficient (or coefficient of reflection,  $A$ ) of the area overflow (Earth surface or clouds) as per ( $\Phi_{sd\uparrow} = A \cdot \Phi_{SD}$ ).

Like direct solar flux, this reflected solar flux is subject to attenuation caused by diffusion and absorption by components of the atmosphere. In the stratosphere, the density of albedo flux can be high (of the order of 400  $W/m^2$ ) when flying over ground covered with new snow, for example.

Type of cloud	Albedo coefficient ( $A_n$ )
Cumulonimbus	~1
Cumulus	0.56 to 0.81
Altostratus	0.39 to 0.59
Stratus 200 m thick	0.1 to 0.5
<b>Average <math>A_n</math></b>	<b>0.5</b>

Earth surface	Albedo coefficient ( $A_T$ )
New snow	0.8 to 0.9
Old snow	0.45 to 0.7
Desert	0.24 to 0.28
Grass	0.15 to 0.3
Dry soil	0.08 to 0.14
Wetland	0.08 to 0.09
Woodland	0.04 to 0.1
Ocean	0.03
<b>Average <math>A_T</math></b>	<b>0.29</b>



Examples of albedo coefficients and albedo flux densities with clear sky when ground albedo coefficient is 0.8 (new snow).

**Infrared Radiation**

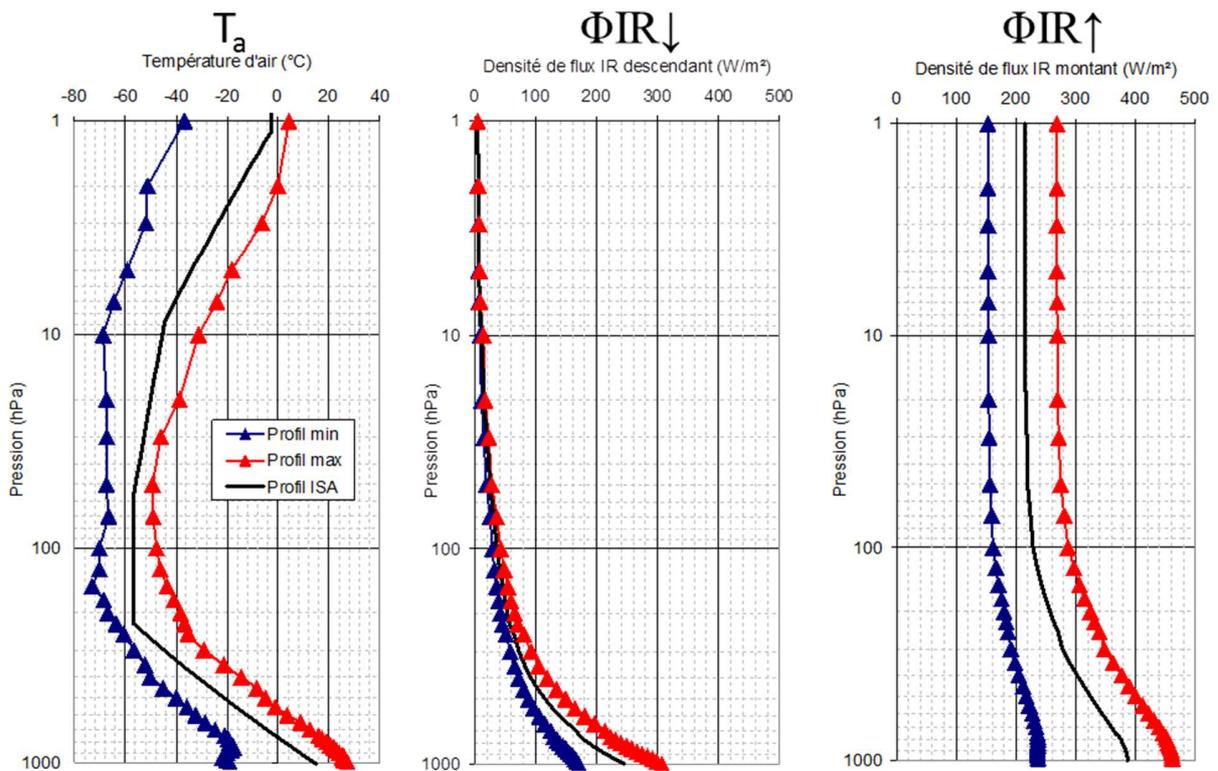
The aerostat is exposed to upward infrared flux and downward infrared flux.

The upward infrared flux ( $\Phi_{IR\uparrow}$ ) is often referred to as terrestrial infrared flux because it comes primarily from the ground. The diffuse infrared radiation emitted by the earth's surface is partly transmitted by the air and the clouds, which also emit in the infrared.

CNES models indicate that in ISA it amounts to about 390 W/m<sup>2</sup> at 1000 hPa and about 220 W/m<sup>2</sup> at 2 hPa with clear skies.

Downward infrared flux ( $\Phi_{IR\downarrow}$ ) is the diffuse infrared radiation emitted and transmitted by the air and the clouds (when the aerostat is in the troposphere).

CNES models indicate that in ISA it is about 250 W/m<sup>2</sup> at 1000 hPa. In clear sky conditions, it then diminishes steadily to a few W/m<sup>2</sup> in the stratosphere due to the rarified air in the higher layers of the atmosphere.



**Densities of upward ( $\Phi_{IR\uparrow}$ ) and downward ( $\Phi_{IR\downarrow}$ ) infrared flux in clear sky conditions from CNES model based on temperature ( $T_a$ ) profiles**

**Symbols and units**

- ΦSD: direct solar flux (W/m<sup>2</sup>)
- Φsd↑: upward diffuse solar flux or albedo (W/m<sup>2</sup>)
- A<sub>T</sub>: Albedo coefficient from Earth
- A<sub>n</sub>: Albedo coefficient from clouds
- Φ<sub>IR↑</sub>: upward IR flux (W/m<sup>2</sup>)
- Φ<sub>IR↓</sub>: downward IR flux (W/m<sup>2</sup>)
- Q<sub>h</sub>: convection heat flux (W/m<sup>2</sup>)
- P: pressure (hPa)

- P<sub>0</sub>: pressure at ground level (= 1013hPa)
- T<sub>a</sub> or T: air temperature (°C)
- V: velocity (m/s)

## Radiation

Concerning radiation, the protection of the aerostatic system's flight control equipment has been dimensioned on the basis of the following results from balloon flights made during previous campaigns. These data can serve as a reference for assessing the protections to be provided for the most sensitive instruments, and depending on the time they will remain exposed.

Extract from the report of the ONERA study "*Impact de l'Environnement Radiatif Naturel Atmosphérique sur les nacelles électriques embarquées sur ballons*" (Impact of the Natural Atmospheric Radiation Environment on the electrical gondolas carried by balloons) written by G. Hubert and referenced RF 1/20635 DESP – November 2012.

"The flux of neutrons in the atmosphere varies with altitude and latitude. In Figure 3-a, showing the variation of the neutron flux as a function of altitude for a latitude of 43°N, we note that the flow increases with the altitude, reaching a maximum at 18 km ( $\sim 1.25 \text{ n.cm}^{-2}.\text{s}^{-1}$ ), known as the Pfozter maximum, and declining thereafter. This evolution is the result of the interaction between the cosmic particles, whose flow increases with altitude, and the atmosphere, whose density decreases with altitude (given by the US Standard Atmosphere, 1962).

Figure 3-b shows the flow of neutrons in the atmosphere for a range of energies from 1 to 10 MeV as a function of latitude and for an altitude of 10.7 km. We note that this flow is very low at the equator ( $\sim 0.2 \text{ n.cm}^{-2}.\text{s}^{-1}$ ) and reaches a maximum value ( $\sim 1.4 \text{ n.cm}^{-2}.\text{s}^{-1}$ ) at the Poles. We find the same behaviour regarding latitude as that of cosmic rays arriving in the atmosphere (minimum flows in equatorial regions and maximum in polar regions). Since the production of neutrons in the atmosphere is directly linked to incident cosmic particles, neutron flux is also dependent on latitude.

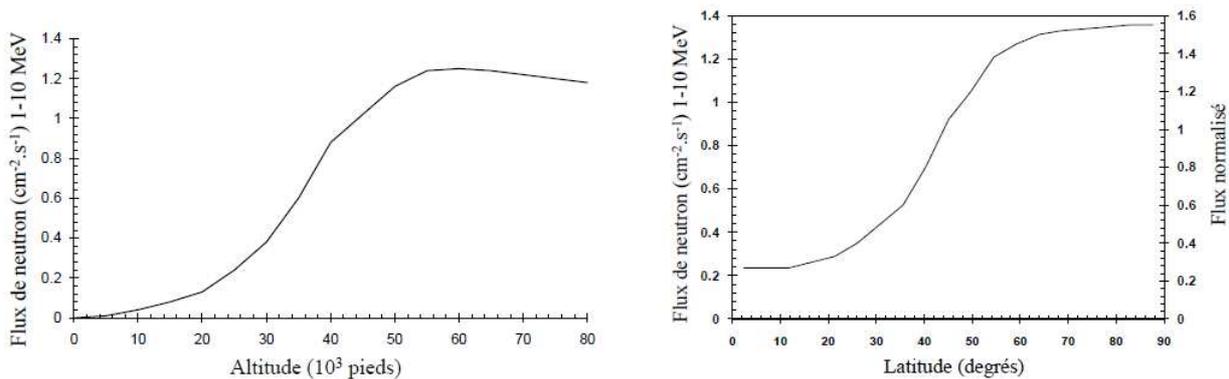


Figure 3-a Flux de neutrons dans l'atmosphère ( $1 < E < 10 \text{ MeV}$ ) en fonction de l'altitude. On remarque un flux maximum de  $\approx 1,25 \text{ n/cm}^2.\text{s}$  pour une altitude de  $\approx 60000$  pieds ( $\approx 18 \text{ km}$ ). Figure 3-b. Flux de neutrons dans l'atmosphère ( $1 < E < 10 \text{ MeV}$ ) en fonction de la latitude pour une altitude  $\approx 10,7 \text{ km}$ . On remarque un flux quasiment nul ( $\approx 0,2 \text{ n.cm}^{-2}.\text{s}^{-1}$ ) au niveau de l'équateur (champ magnétique terrestre fort) et un flux maximum ( $1,4 \text{ n.cm}^{-2}.\text{s}^{-1}$ ) au niveau des pôles (champ magnétique terrestre faible).

It is quite common practice to consider only neutrons and to ignore other types of particles. However, we must not neglect the proton component, which can also be at the origin of Single Event Effect. This is particularly true for balloon applications. Up to altitudes of about 18-20 km, it is justifiable to consider only neutrons; however, for high altitudes (typically higher than 25 km), protons can become the majority component (this depends on the latitude considered). For example, at an altitude of 40 km, neutrons can be ignored, while the protons are in the majority. Moreover, when studying high energies ( $>$  about 100 MeV), the proton component is the most important.

In other words, in the framework of balloon applications, characterisation of atmosphere's natural radiative environment requires that we consider both neutrons and protons. Regarding the effects, it is admitted that the induced effects are equivalent for energies of about 50 MeV and above."

Here is another reference concerning the assessment of levels of radiation in the stratosphere:

### RADIATION MEASUREMENTS IN THE STRATOSPHERE

Denis Pantel, Yago Gonzalez, Mickael Gedion, Frédéric Wrobel, Jean-Roch Vaillé, Frédéric Saigné

Université Montpellier 2, UMR-5214, CC083, Place Eugène Bataillon, 34095 Montpellier CEDEX 5

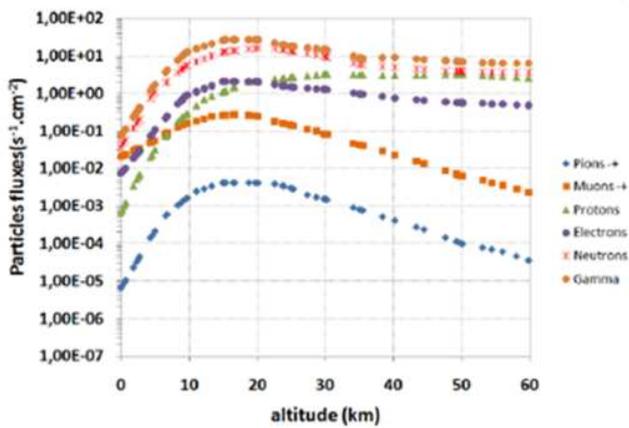


Figure 1 : Particles fluxes as a function of altitude [7].

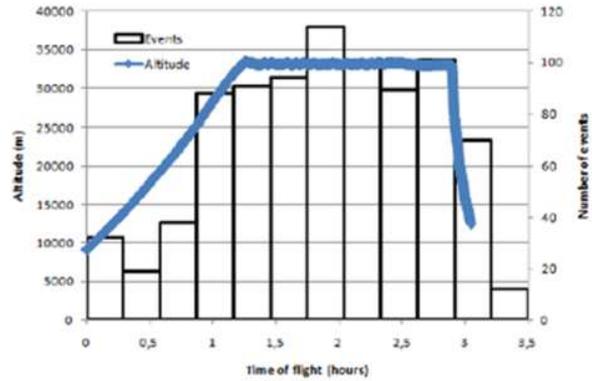


Figure 9 : Comparison between the evolution of the number of detected events as a function of time of flight and altitude profile.

## APPENDIX 4a: SSC PAYLOAD GONDOLA

### M-Egon Payload Gondola

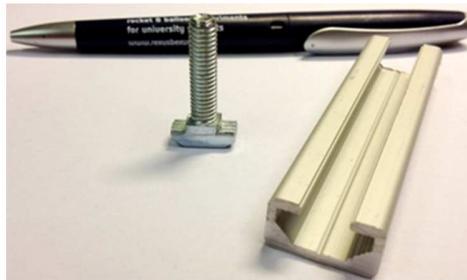
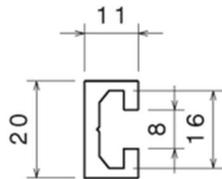
The balloon gondola (M-Egon) used within BEXUS is shown below. At the bottom bulkhead in each gondola rails are provided for experiment fixation.

Distances between the rails (center points) are 360 mm. See drawing of rails and gondola in Appendix A: Gondola drawings and more gondola images in Appendix C: Gondola/Experiment Interface Images  
3D CAD Models are available.



**M-Egon Payload Gondola**

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

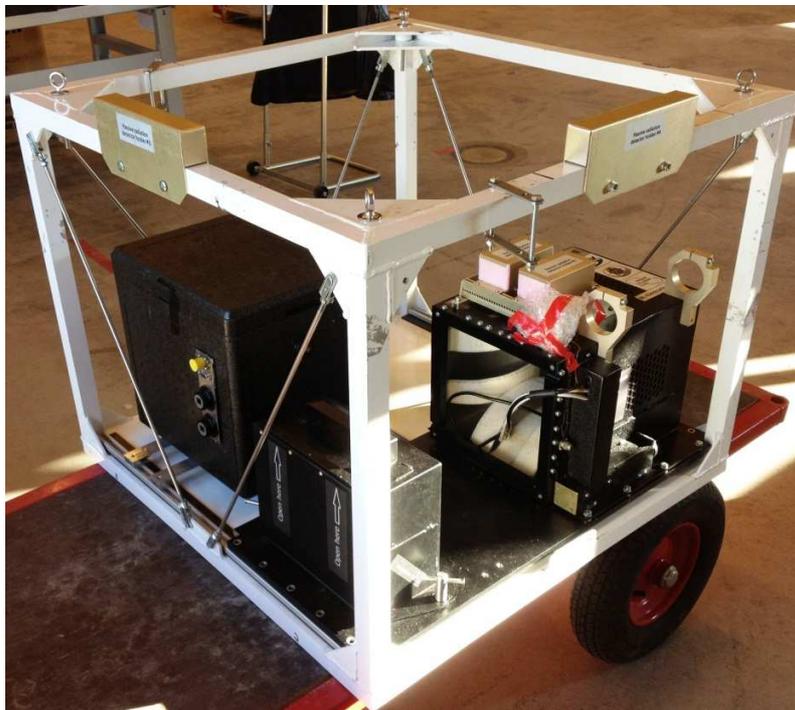


**Experiment mounting rails and anchor bolt (M6)**

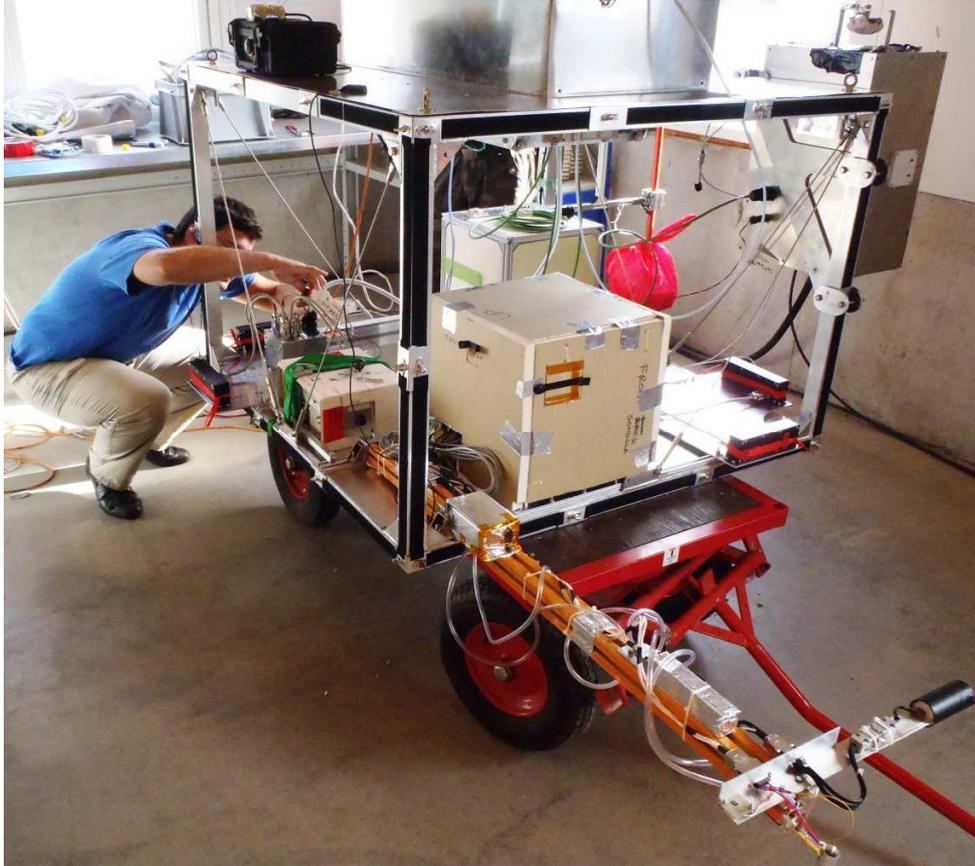
## Payload Gondola / Experiment and Interface Images



Exterior with experiment equipment mounted to the outside of the Gondola



Interior showing connections to gondola frame and rails



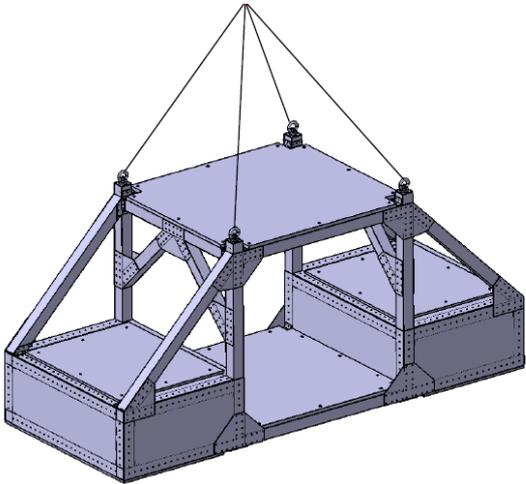
**Figure showing different mounting techniques**

## APPENDIX 4b: CNES PAYLOAD GONDOLA

These are the main gondolas that CNES can make available to scientists within the HEMERA project.

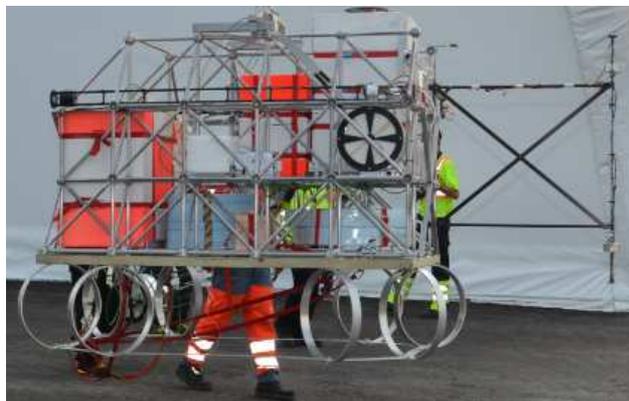
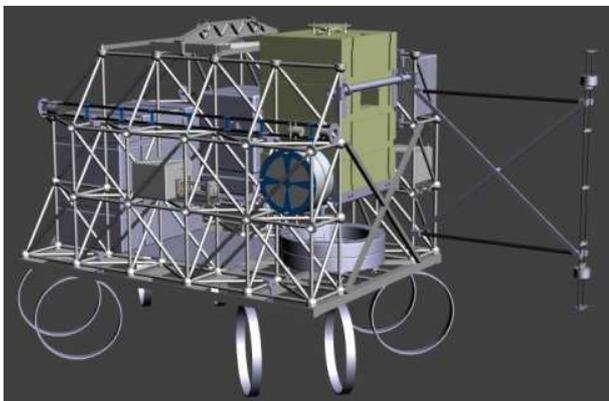
### BANA Payload Gondola

At just 1 m x 0.80 m x 1 m, this small 80 kg structure is particularly suitable for technological flights and can carry payloads of up to 170 kg. There are few services possible on this gondola, and there is no pointing system.



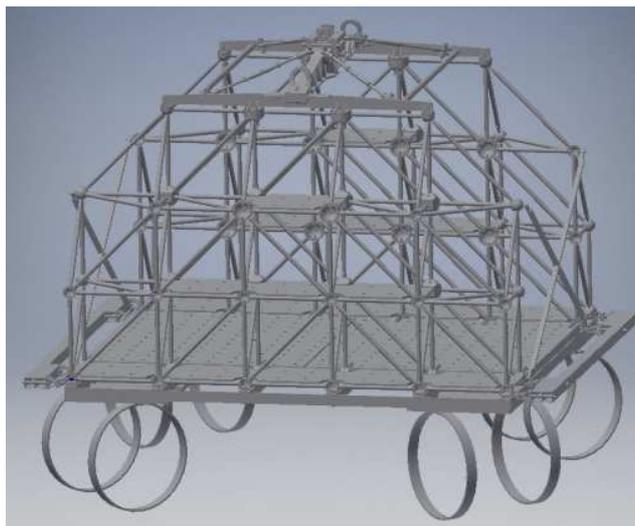
### HELIOS Payload Gondola

This gondola built from aluminum bars and balls can carry equipment on the floor or in the walls of the structure. It weighs 90 kg and can carry payloads of up to 180 kg. It measures 2.06 m x 1.43 m x 1.44 m and its architecture makes it easy to incorporate medium-sized instruments.



### CARMENCITA Payload Gondola

This gondola constructed from bars and balls is currently at the design stage. It will weigh 190 kg and be able to carry payloads of up to 410 kg. It will measure 2.45 m x 1.85 m x 2.20 m and its upper beam will be able to include a pivoting and pointing system.



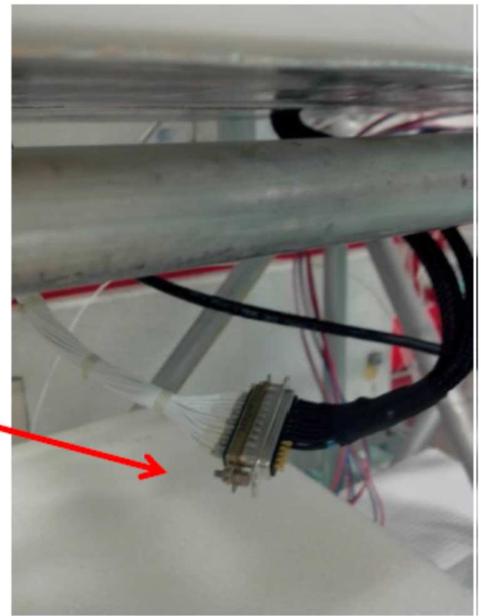
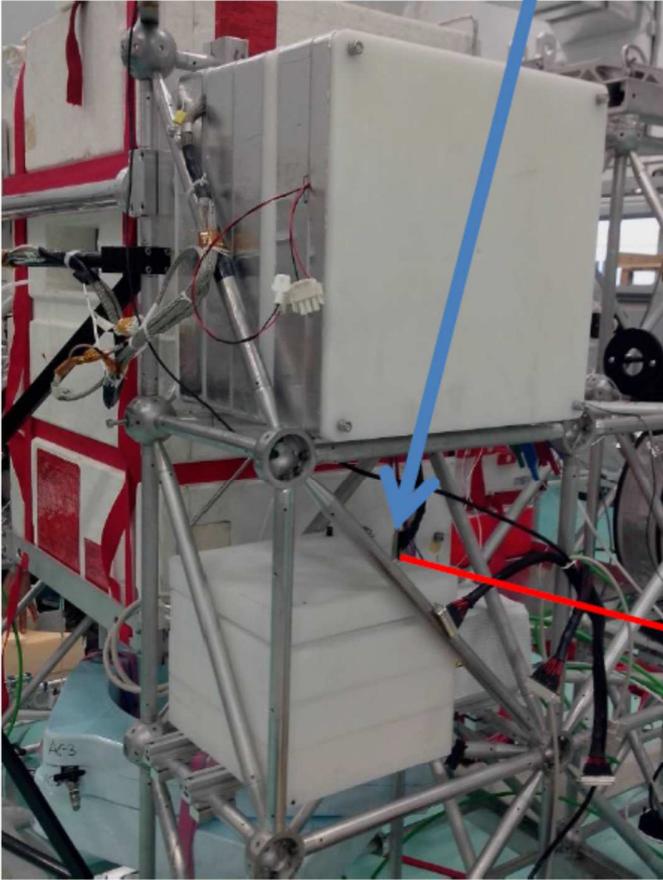
## APPENDIX 5: SUMMARY OF FLIGHT CHARACTERISTICS

	CNES	SSC
<b>Zero Pressure Balloons flight characteristics:</b>	<p>Balloon volumes: 150,000 m<sup>3</sup></p> <p>Flight levels: ~15 km (120 hPa) up to ~33 km (7 hPa)</p> <p>Combined payload gondolas: 250 up to 450 kg</p> <p>Flight profiles: constant ceiling / slow descent</p> <p>Flight durations: up to 38 hours</p> <p>Ascent speed: 5 m/s</p> <p>Slow descent speed: 1 to 5 m/s</p> <p>Landing velocity: 5 to 7 m/s (shock absorbers)</p>	<p>Balloon volumes: 150,000 m<sup>3</sup></p> <p>Flight levels: ~15 km (120 hPa) up to ~35 km (5,6 hPa)</p> <p>Payload gondola up to 250-450kg (150 kg of experiments included)</p> <p>Flight profiles: constant ceiling / slow descent</p> <p>Flight durations: up to 48 hours during turn around period (spring &amp; autumn – otherwise 4-5 hours)</p> <p>Ascent speed: 4-5 m/s</p> <p>Slow descent speed: 1 to 5 m/s</p> <p>Landing velocity: 5 to 7 m/s (shock absorbers)</p>
<b>Payload requirements for ZPB:</b>	<p>Typically, 150 kg of payload mass per flight</p> <p>Nominally 5 experiments per flight</p> <p>Minimum of 5 kg per experiment</p> <p>Volume constraints in link with gondola sizes</p>	<p>Typically, 150 kg of payload mass per flight</p> <p>Nominally 5 experiments per flight</p> <p>Volume constraints in link with gondola sizes</p> <p>Standalone regarding power supply</p>
<b>Available gondola (L x l x h)</b>	<p>BANA: 2 m x 0.8 m x 1 m</p> <p>HELIOS: 2.06 m x 1.43 m x 1.44 m</p> <p>CARMENCITA: 2.45 m x 1.85 m x 2,20 m</p>	<p>EGON-L: 1,45m x 1,45m x 0,95m (LxWxH)</p>
<b>Campaign sites and period</b>	<p>Kiruna (Sweden): summer season</p> <p>Timmins, Ontario (Canada): summer season</p> <p>Aire-sur-l'Adour (France): all year but especially for SB</p> <p>Equatorial site (TBD)</p>	<p>Estrange, Kiruna (Sweden): all seasons: lat. 67° 53'N, long 21° 04'E.</p> <p>Wind directions: Summer to west, winter to east, turn around period spring &amp; autumn.</p> <p>3 large buildings for balloon and payload preparation</p> <p>Laboratories, Clean Room</p> <p>Large balloon pad: 450x500m</p> <p>Impact area for free falling objects – 5 600 km<sup>2</sup></p>

<b>On-board communication device:</b>	TC max rate: 70 kbit/s TM max rate: 1500 kbit/s 4 asynchronous links: RS232, RS422 or RS485 6 to 10 Ethernet links in UDP or TCP 12 STOR links	2 Mbps duplex nominal, decreasing with range. 10 Ethernet 10/100 Base 2 asynchronous duplex RS-232/422 channels.
<b>On-board optional services</b>	Secured Li-Ion power source: ~-28 V (up to 1000 W) Pointing rotator: azimuth control < 1 arcmin High performance pointing (stellar sensor): < 1 arcsec Axis and elevation control, door opening, actuators, ... Thermal monitoring Date and GPS location On-board cameras On-board accelerometers	Relays for external use - on/off, upon request Accelerometer upon request
<b>Other services during campaign or flight</b>	Meteorological data Daily meteorological soundings Flight trajectory in real time-	Meteorological data Daily meteorological soundings upon request Flight trajectory in real time
<b>Sounding Balloons from Aire-sur-l'Adour</b>	Flight levels: <ul style="list-style-type: none"> <li>- ~35 km (6 hPa) with a 2000 g balloon</li> <li>- ~38 km (4.5 hPa) with a 3000 g balloon</li> </ul>	

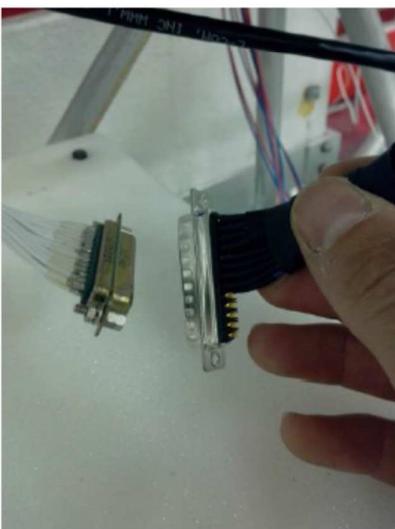
## APPENDIX 6: EXAMPLE OF RECOVERY SHEET

1/Open flight connector of this box here

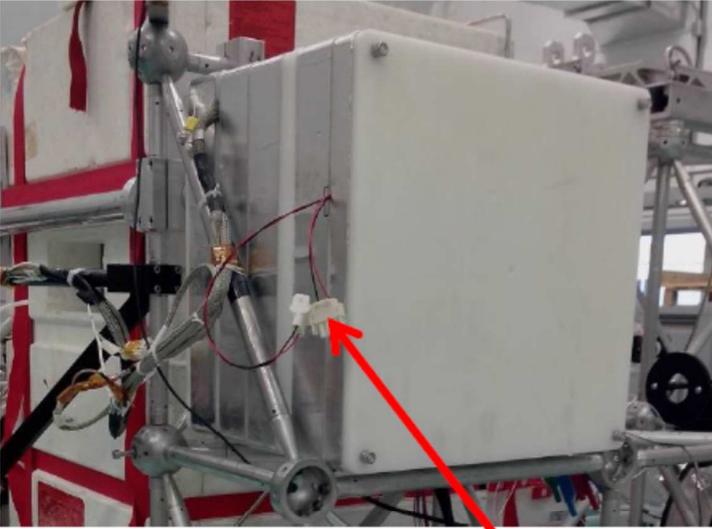


zoom

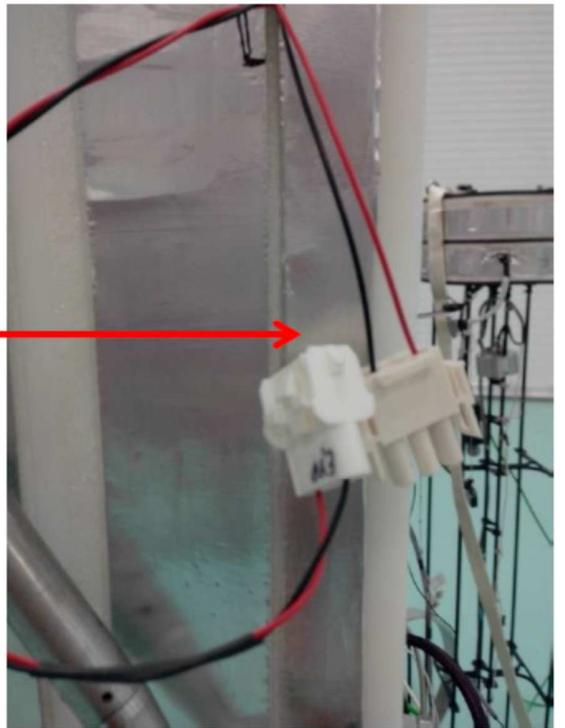
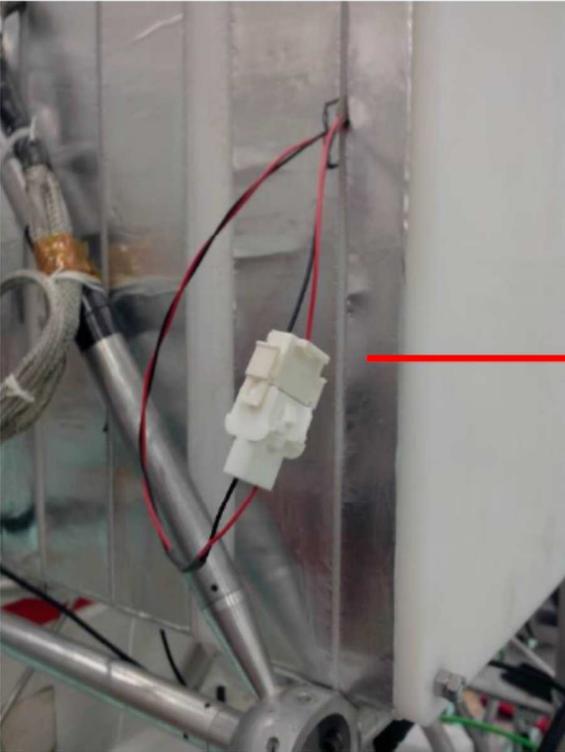
After opening with a screw driver :



And the other one here on the left side of the electronic box :



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## APPENDIX 7: ESRANGE SAFETY AND SECURITY COMPLIANCE CONFIRMATION – BALLOON

This document clarifies the basic safety and security conditions for the campaign at the Esrange Space Center.

This document shall be signed by the customer's (range user's/prime contractor's) Mission Manager/Project Manager and by the Esrange Project Manager. One copy of this document and of the *Esrange Safety Manual* (ESM, REA00-E60), is submitted to the customer's Mission Manager/Project Manager.

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

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

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

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

### Customer Positions and Responsibilities

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

### SSC Esrange Positions and Responsibilities

**Esrange Project Manager** is responsible for the campaign coordination at Esrange and is the contact point between Esrange and the customer. He/she shall also superintend all safety and security regulations and arrangements related to the campaign.

**Head of Esrange Launch Team** is responsible for the ground safety in the launch areas and also all work with explosives at Esrange.

**Operations Officer (OP)** coordinates all operational work and is the interface with the customer and with Swedish and foreign authorities during **countdown, flight and recovery**.

**Safety Officer/Flight Control Officer (SO)** is responsible for flight safety during **countdown and flight**. He/she decides in coordination with the customer when to abort a flight.

**Launch Officer (LO)** is during **countdown** responsible for the ground safety in the launch areas and also all work with explosives at Esrange.

We accept the content of the text above.

Date .....

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Customer Mission Manager/Project Manager                      Esrange Project Manager