SED

Student Experiment Documentation

Document ID: BX3233_HERCCULES_SED_v1-0_23Ene22.docx

Mission: BEXUS 32-33

Team Name: HERCCULES

Experiment Title: Heat-transfer and Environment Radiative and Convective Characterization in a University Laboratory for Experimentation in the Stratosphere

Team	Name
Student Team Leader:	David González Bárcena
Team Members:	Juan Bermejo Ballesteros
	Alejandro Fernández Soler
	José Miguel Álvarez Romero
	Ángel Grover Pérez Muñoz
	Sergio Marín Coca
	Ángel Luis Porras Hermoso
	Daniel Alfonso Corcuera
	Blanca Boado Cuartero
	Javier Garrido Sola
	Juan Manuel Redondo
	Marina Merchán Bravo
	Pedro Luis Barba Navarrete
University:	Universidad Politécnica de Madrid

Version:	Issue Date:	Document Type:	Valid from:
1	**23 January 2022**	**Spec**	**23 January 2022**

Issued by: David González Bárcena

Approved by: David González Bárcena

CHANGE RECORD

Version	Date	Changed chapters	Remarks
0	2013-12-11	New Version	Blank Book 2013
1-0	2022-01-23	all	PDR

Abstract: Ballooning applications are continuously improving. They have become a very demanding platform for many purposes such as technology demonstration, solar physics, Earth observations, etc. Designs are becoming more and more complex with time. For this reason, characterizing the thermal behaviour of these platforms not only during the floating phase but also during the ascent phase is essential to fulfil the requirements. For this reason, HERCCULES aims at measuring the albedo, the Outgoing Longwave Radiation, the sky temperature, and the solar irradiance during both the ascent and float phases. This will allow the validation of a developed methodology for selecting the worst-case conditions for stratospheric balloon thermal analysis based on Real-data observation. In addition, HERCCULES carries some experiments to quantify the convective heat transfer on heated plates as well as to measure the relative wind speed on an external surface. This will help us to understand how convection behaves in this kind of platforms and temperature results will be used to correlate the thermal models developed with ESATAN-TMS.

Keywords: BEXUS, SED, radiative thermal environment, convection, nadir sensor, albedo, OLR.

Contents

PREFACE

HERCCULES is an experiment developed by Bachelor, Master and PhD students with the aim of improving the thermal analysis and design of stratospheric balloon missions. A multidisciplinary team formed by aerospace, mechanical, computing, telecommunications and electronic engineering students from Universidad Politécnica de Madrid, UPM, (Spain) is in charge of designing, manufacturing, integrating and testing HERCCULES for a successful flight in 2022. The idea comes from the developed research by some of the PhD students for characterizing the thermal environment as well as for improving the convective heat transfer analysis of Long Duration Balloons. Coming from the idea to the reality has been possible thanks to the technical and economic support of the Instituto Universitario de Microgravedad "Ignacio da Riva" (IDR/UPM) and the STRAST group, both from the UPM. The launch will be performed from Kiruna, Sweden and it is supported by the BEXUS/REXUS programme, which 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, including HERCCULES, through a collaboration with the European Space Agency (ESA). EuroLaunch, a cooperation between the Esrange Space Center of SSC and the Mobile Rocket Base (MORABA) of DLR, is responsible for the campaign management and operations of the launch vehicles. Experts from DLR, SSC, ZARM and ESA provide technical support to the student teams throughout the project. REXUS and BEXUS are launched from SSC, Esrange Space Center in northern Sweden.

ABSTRACT

Ballooning applications are continuously improving. They have become a very demanding platform for many purposes such as technology demonstration, solar physics, Earth observations, etc. Designs are becoming more and more complex with time. For this reason, characterizing the thermal behaviour of these platforms not only during the floating phase but also during the ascent phase is essential to fulfil the requirements. For this reason, HERCCULES aims at measuring the albedo, the Outgoing Longwave Radiation, the sky temperature, and the solar irradiance during both the ascent and float phases. This will allow the validation of a developed methodology for selecting the worst-case conditions for stratospheric balloon thermal analysis based on Real-data observation. In addition, HERCCULES carries some experiments to quantify the convective heat transfer on heated plates as well as to measure the relative wind speed on an external surface. This will help us to understand how convection behaves in this kind of platforms and temperature results will be used to correlate the thermal models developed with ESATAN-TMS.

1 INTRODUCTION

1.1 Scientific/Technical Background

Balloon flight applications are continuously improving. They have become a very demanded platform for many purposes such as technology demonstration, solar physics, Earth observations, etc. Designs are becoming more and more complex with time and ensuring the survival of the equipment during the whole flight is essential. From a thermal point of view, the platforms shall deal with a harsh environment very similar to Space. A combination of vacuum high level with the low temperatures of the deep Space and the solar and Earth thermal radiation make the analysis of this platforms to be performed as the Space missions do. However, even being above 99% of atmosphere, the convective heat transfer could not be negligible in some cases where the radiative and the conductive heat exchange is minimized. For this reason, characterizing the thermal behaviour of these platforms not only during the floating phase but also during the ascent phase is essential to fulfil the requirements.

Some missions should take special care with the ascent phase due to the harsh environment to be found in the tropopause [1]. In this case convection effect is even greater than radiation for several reasons. Temperature in the tropopause drops down to values of around -60 °C. The ascent speed produces a relative velocity between the system and the air, which should be taken into account during the analyses using forced convection correlations in the mathematical models [2]. Moreover, the balloon-gondola system “follows” with some lag the wind, but the short-term variations in wind speed induce a relative horizontal speed that in many cases cannot be neglected.

Thermal models of stratospheric balloon payloads are usually performed with ESATAN-TMS, Thermal Desktop, Thermica, etc. They are commonly used softwares for the thermal analysis of space systems. They basically consist of a Geometrical Mathematical Model used for solving the radiative problem, and a Thermal Mathematical Model. One of the biggest limitations that appear when using these softwares for the stratospheric mission analysis is the implementation of the convective heat transfer [3]. Not only does this fact affect Earth stratospheric flight but also it is important when analysing a space system in rarefied atmospheres such as Martian because of the low pressure to be found. For that reason, it is important to well understand how the heat transfer behaves and to know in which situation it should be considered.

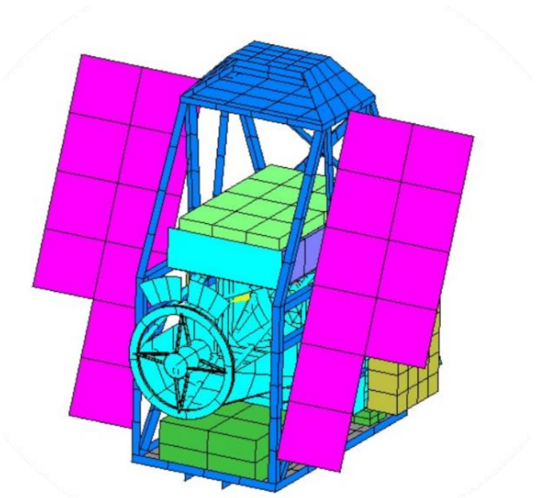


Figure 1-1. SUNRISE III Geometrical Mathematical Model.

The University Institute of Microgravity “Ignacio da Riva” (IDR/UPM) has participated during the last years in the SUNSRISE mission as responsible of the thermal analysis from a system level [4], [5]. This mission consists of a solar telescope on board a Long Duration Balloon. The first one was flown in 2009 and the second one in 2013. The third flight of this balloon-borne solar telescope is currently under its design phase and is expected to be launched in June of 2022. During the design process, the IDR had to face the thermal environment characterization as well as the thermal modelling using ESATAN-TMS. In addition, they have some experience working in the field of rarefied atmospheres as part of the work they performed for the thermal analysis of MEDA, an instrument on board ExoMars 2020 [6].

The experience acquires during the development of the thermal model of SUNRISE III (the Geometrical Mathematical Model is presented in Figure 1-1), showed the necessity of better study this phenomenon through a real flight. This is because the real environment cannot be simulated in a Thermal Vacuum Chamber. Even the radiative thermal environment could be simulated using equivalent temperatures for the radiative interface, the convective thermal environment is quite difficult since the air temperature inside the chamber cannot be independently controlled. In addition, if the convective heat transfer wants to be studied during the ascent phase, it is not possible to use a Thermal Vacuum Chamber due to the huge number of variable parameters that take part on it [7].

In order to perform the thermal analysis, it is important to know the extreme environmental condition which could lead the system to its maximum and minimum temperatures. Being in the stratosphere, albedo, which is the solar radiation reflected by the Earth, and the Outgoing Longwave Radiation (OLR), which is the infrared radiation emitted by the Earth, are the main heat loads over the system together with the Direct Solar radiation [8]. It is well known that the Solar Irradiance change throughout the year due to the distance between the Earth and the Sun. Albedo and OLR strongly depends on the surface and atmospheric characteristics at each point on the Earth and they have a high temporary variability.

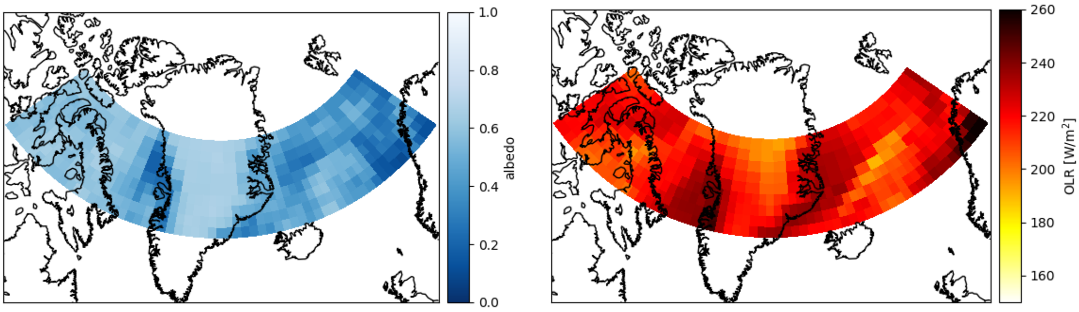


Figure 1-2. Albedo (left) and OLR (right) samples for the flight envelope area of SUNRISE.

Compared to the space thermal environment there are some differences in stratospheric flights. First of all, the thermal environmental conditions should be particularized to the region where the flight would be performed as show in Figure 1-2 for SUNRISE III flight. In Space Systems, global data is used to define the worst-case conditions based on Real-Observation data [9]. Secondly, the residence time of a space system over a point in the Earth is much lower than the residence time of a balloon-borne system. This fact makes that the payload follows a quasi-steady state during the flight (at the float phase). The IDR/UPM have developed a new methodology for characterizing the radiative thermal environment of stratospheric balloons based on CERES data [10]. It allows the particularization to the considered region and the parametrization of the worst-case analysis for the floating and ascent phases. By doing so, the oversizing is minimized, and the costs can be reduced.

1.2 Mission Statement

Convective heat transfer on stratospheric balloon payload must be considered when analysing the ascent phase but it is not always negligible at floating altitude. HERCCULES aims at studying different situations in which convection could play an important role in the heat transfer. Gathered information will improve the thermal modelling of stratospheric balloons.

Characterizing the thermal environment is important to select the worst-cases for the thermal analysis. Measuring the albedo, the OLR, the sky temperature and the Solar Irradiance during the HERCCULES flight will allow to validate the methodology followed for the worst-cases selection based on Real-Observation data from CERES.

1.3 Experiment Objectives

HERCCULES primary objectives can be divided into:

- Convective heat transfer quantification on a horizontal and a vertical flat plate in which the conductive and radiative heat mechanisms are minimized.
- Evaluation of the influence of spacing in the convective heat transfer between vertical flat plates.
- Quantification of the efficiency of a thermal strap in low pressure conditions connected to an external radiator.
- Quantification of the force convection on an external surface by measuring the relative wind speed.
- Thermal environment characterization by measuring:
    - Earth albedo.
    - Outgoing Longwave Radiation.
    - Solar Irradiance.
    - Sky temperature.
    - Air pressure and temperature.

A secondary objective has been also considered for testing a Nadir sensor made of COTS components for use in Space and stratospheric missions.

1.4 Experiment Concept

HERCCULES experiment can be divided into 4 main parts.

Firstly, the ***Environmental Lab*** which will carry the radiative measuring instruments (pyranometer and pyrgeometer) which will provide valuable information required to complete and validate the developed thermal environment characterization models based on satellite data. These 'in situ' measurements will be used to study the rate of change of the thermal environment. Data obtained will be compared with the satellite measured data (1 hour grid) to evaluate the rate of change and the potential effect of not considering the short-term variations.

Secondly, the ***Heat Transfer Lab***, which will be equipped with several temperature sensors to register the temperature of the system during the whole flight. The characteristics of the air at the altitude reached during the BEXUS/REXUS program will allow to quantify not only the heat transfer through air in the continuum regime but also in the asymptotic regime, where free convection takes place. To do so, the Heat Transfer Lab will be configured based on 4 specially designed compartments with different configurations. Data about temperatures and dissipated power will be gathered to verify and correct the thermal mathematical models implemented in ESATAN-TMS. The description of the five experiments which integrate the Heat Transfer Lab are the following:

- **EXP1**: A heated horizontal plate to quantify the free convective heat transfer.
- **EXP2**: A heated vertical plate to quantify the free convective heat transfer.
- **EXP3**: A heated horizontal plate thermally attached to a radiator using a strap. This experiment will measure the efficiency of both the radiator and the thermal strap operating in such conditions.
- **EXP4**: Several vertical plates (with one heated in the middle) to quantify the heat transfer in the continuum regime through the air.

An additional experiment, **EXP5**, will be included for measuring the relative wind speed on an external surface to quantify the force convection.

Not only would the temperature of the heated plates be measured but also the temperature of the envelope in order to decouple the experiments from the outer surfaces and be able of correlating each one with their thermal mathematical model separately.

Thirdly, the ***Attitude Lab*** will include a Nadir sensor, based on IR photodiodes, which will gather measurements during the float phase of the flight that will be later correlated with the expected Nadir direction derived from the estimated attitude. Such correlation will allow to validate the Nadir sensor design. Attitude will be estimated using a Kalman Filter using the IMU, GPS and magnetometer measurements.

Finally, an ***Electronics Box*** would contain the On-Board Computer, the electronics, and the Electrical Power Distribution Subsystem.

1.5 Team Details

1.5.1 Contact Point

Team Address	Instituto Universitario de Microgravedad “Ignacio da Riva” Escuela Técnica y Superior de Ingeniería Aeronáutica y del Espacio (ETSIAE/UPM) Plaza Cardenal Cisneros, 3 28040, Madrid, Spain
Team Leader	David González Bárcena
Phone	+34 910675809
E-mail	herccules.bexus@gmail.com david.gonzalez@upm.es

1.5.2 Team Members

PhD(c). David González-Bárcena

PhD(c). David González-Bárcena (born in Spain, May 21st 1994) is a researcher at Instituto Universitario de Microgravedad „Ignacio da Riva" (IDR) and a PhD candidate currently working at Universidad Politécnica de Madrid (UPM) as an Assistant professor. He got an Aerospace Engineering degree in the Universidad de León and a Space Systems Master's degree in the Universidad Politécnica de Madrid. Currently his research topic is focused on "Planetary and Low-Orbit thermal environment characterization for Space Thermal Design". He is also working in the thermal analysis and design at system level of the balloon-borne solar telescope SUNRISE III and he was the project manager of the TASEC-Lab experiment launched in a stratospheric balloon in July 2021. He would be **the team leader and he would be part of the scientific team.**

PhD(c). Juan Bermejo-Ballesteros

PhD(c). Juan Bermejo-Ballesteros (born in Spain, June 19th, 1992) is a researcher at Instituto Universitario de Microgravedad "Ignacio da Riva" and a PhD candidate currently working at Universidad Politécnica de Madrid. He obtained the bachelor's degree in Aerospace Engineering a MSc in Space Systems in the Universidad Politécnica de Madrid. Currently his research topic is focused on "Flight formations around L2". He is also working in the ADCS of the ANSER mission from Instituto Nacional de Técnica Aeroespacial (INTA). He will be the **payload manager and part of the scientific team**.

PhD(c). Alejandro Fernández-Soler

PhD(c). Alejandro Fernández-Soler (born in Spain, May 12th, 1995) is a researcher at Instituto Universitario de Microgravedad "Ignacio da Riva" and a PhD candidate currently working at Universidad Politécnica de Madrid. He obtained the bachelor's degree in Aerospace Engineering in the Universidad Politécnica de Valencia and a MSc in Space Systems in the Universidad Politécnica de Madrid. Currently his research topic is focused on "Study of the response to disturbances during the ascent phase of a balloon-borne". He is also working on the thermal design and analysis at subsystem level in the cryogenic observatory ARIEL (Atmospheric Remote-sensing Infrared Exoplanet Large-survey). He will be the **responsible of the Thermal Control System** and part of the **scientific team.**

PhD(c). José Miguel Álvarez-Romero

PhD(c). José Miguel Álvarez-Romero (born in Spain, October 8th, 1993) is a PhD candidate at Universidad Politécnica de Madrid, currently working as a researcher at Instituto Universitario de Microgravedad "Ignacio da Riva". He obtained the bachelor's degree in Aerospace Engineering and a MSc in Space Systems in the Universidad Politécnica de Madrid. Currently his research topic is focused on concurrent engineering, space systems engineering and space project management, under the title of "system engineering for concurrent design of in-orbit technological demonstrators". He is also working on other projects as: the communications subsystems and the in-orbit operation of the UPMSat-2, the platform design and development for the MARTINLARA mission or an educational and innovation project named PIRAMIDE. He will be the **responsible of the Outreach Program and the AIT activities.**

M. Eng. Student Ángel Grover Pérez-Muñoz

M. Eng. Student Ángel Grover Pérez-Muñoz (born in Perú, April 28th, 2000) has attained the BSc Degree in Computer Engineering and is a first-year student of the Distributed and Embedded Systems Software master at the Universidad Politécnica de Madrid. Currently, he is a software developer intern at the UPM STRAST research group. He has participated in the COMMSMART project; and in the TASEC-Lab mission as a software developer of its data acquisition system. He is also working on the AURORA project, integrating the QGen code generator with the TASTE tool-set (the ESA development environment dedicated to embedded real-time software). He will be responsible for the **Onboard Computer and Data Handling System.**

PhD(c). Sergio Marín-Coca

PhD(c). Sergio Marín-Coca (born in Spain, August 14th, 1995) is a researcher at Instituto Universitario de Microgravedad "Ignacio da Riva" and a PhD candidate currently working at Universidad Politécnica de Madrid as an Assistant professor. He obtained a bachelor's degree in Aerospace Engineering and a MSc in Space Systems in the Universidad Politécnica de Madrid. His research topic is focused on test, characterization, simulation, and preliminary design of spacecraft electrical power subsystems. Besides, he is collaborating in the mission analysis and platform design of the MARTINLARA mission and in the ground segment operations of the UPMSat-2. He will be in charge of the **Electrical Power Subsystem.**

PhD (c). Mª Blanca Boado-Cuartero

PhD (c). Mª Blanca Boado-Cuartero (born in Spain, July 3rd, 1996) is a PhD candidate at Universidad Politécnica de Madrid, currently working as a researcher at Instituto Universitario de Microgravedad "Ignacio da Riva". She obtained a bachelor's degree in Mechanical Engineering at Old Dominion University (Virginia, USA) and a MSc in Space Systems at Universidad Politécnica de Madrid. Currently her research topic is "Models of topological optimization of structures through additive manufacturing and its application to acoustic devices". She is also working on the mechanical design at subsystem level in the cryogenic observatory ARIEL (Atmospheric Remote-sensing Infrared Exoplanet Large-survey). She will be responsible of the **mechanical design**.

PhD(c). Angel Luis Porras-Hermoso

PhD(c). Angel Luis Porras-Hermoso (born in Spain, May 24th, 1996)**:** He is a researcher at Instituto Universitario de Microgravedad Ignacio da Riva (IDR) and a PhD candidate currently working at Universidad Politécnica de Madrid. He obtained the bachelor's degree in Aerospace Engineering and a MSc in Space Systems in the Universidad Politécnica de Madrid. He was also an intern in GMV Aerospace and Defence where he worked on the development of navigational algorithms based on celestial navigation techniques. Currently his research topic is focused on the development of satellite attitude determination algorithms. He is also working on the in-orbit data processing of UPMSat2 and in the ADCS of the ANSER mission from Instituto Nacional de Técnica Aeroespacial (INTA). He will be the **responsible of the Attitude Determination Subystem.**

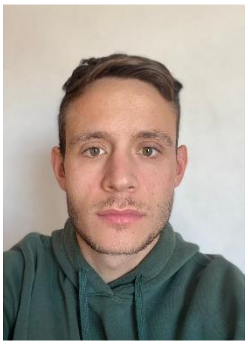
PhD(c). Daniel Alfonso Corcuera

PhD(c). Daniel Alfonso Corcuera (born in Spain, December 15th, 1996): He is currently working as an Assistant Professor at UPM in the Aerospace Systems, Air Transport and Airports Department. He obtained the bachelor's degree in Aeronautical Engineering, a M.Sc. degree in Air Transport Systems Engineering from the Universidad Politécnica de Madrid and a M.Sc. degree in Digital Conception and Innovation from the ESTIA-École Supérieure des Technologies Industrielles Avancées, in France. He is a member of the Instituto Universitario de Microgravedad "Ignacio da Riva" where he develops his research in photovoltaic energy, power distribution, battery modelling and anemometry."

M. Eng. Student Marina Merchán Bravo

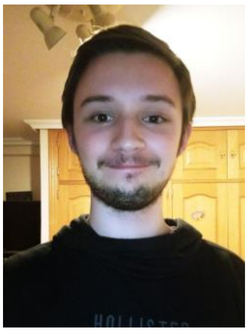
M. Eng. Student Marina Merchán Bravo (born in Spain, September 9 th, 1998): is a last year student of the MSc in Space Systems at Universidad Politécnica de Madrid. She has obtained the bachelor's degree in Aerospace Engineering at Universidad Politécnica de Madrid, taking part on the Erasmus+ Programme at Kingston University on her final bachelor's year. She would be the **responsible of the secondary payload**.

B. Eng. Student Javier Garrido-Sola



B. Eng. Student Javier Garrido-Sola (born in Spain, February 26th, 2000): He is a last year student of Telecommunication Systems Engineering at Universidad Politécnica de Madrid. He would be participating in the program as the **responsible of the Telecommunication Subsystem.**

B. Eng. Student Juan Manuel Redondo



B. Eng. Student Juan Manuel Redondo (born in Spain, June 26th, 2000): He is a last year student of Electronic Engineering at Universidad Politécnica de Madrid. He would be participating in the program as the **responsible of the hardware electronics.**

B. Eng. Student Pedro Luis Barba Navarrete

B. Eng. Student Pedro Luis Barba Navarrete (born in Spain, October 29th, 2000): He is a last year student of Electronic Engineering at Universidad Politécnica de Madrid. He would be participating in the program as **part of the electronics subsystem team.**

2 EXPERIMENT REQUIREMENTS AND CONSTRAINTS

2.1 Requirement ID

This number uniquely identifies each requirement. If a requirement is to be deleted in a later update of this document, its number will not be reused. If a requirement is to be added in a later update of this document, it will be introduced in between other requirements, and the last digit will be used (e.g. R-FU-EPW-215 between R-FU-EPW-210 and R-FU-EPW-220).

The format of the requirement ID is [R/G]-[XX]-[YYY]-[ZZZ] where:

[R/G/C]: Requeriment Severity

- "R" – Shall Requirements, noted R – are mandatory, shall be verified with an accepted verification method and shall be complied with.
- "G" – Should Requirements, noted G – are desirable requirements, with the objective to increase the scientific return or performance of the mission. Their impact on the mission technical complexity and programmatic aspects shall be. Goals may be fulfilled under limited favourable conditions.

[XX]: Requirement source

- "FU" – From a functional requirement.
- "PE" – From a performance requirement.
- "DE" – From a design requirement
- "OP" – From an operational requirement

[YYY]: System/subsystem requirement

"YYY" – Main system/subsystem involved in the requirement, according to the following list:

- "AIT" – Assembly, integration and Test.
- "HTL" – Heat Transfer Lab/Environmental Lab.
- "ATL" – Attitude Lab.
- "MEC" – Mechanics and Structural Subsystem.
- "ELE" – Electronics Subsystem.
- "PRM" – Project Management.
- "EPW" – Electrical Power Subsystem.
- "SFW" – Software Design Subsystem.
- "THE" – Thermal Control Subsystem.

[ZZZ]: Requirement number

"ZZZ" – Unique requirement Identification Number.

2.2 Functional Requirements

Here, the functional requirements are presented in Table 2-1.

Table 2-1. Functional Requirement's list.

ID	Description
R-FU-HTL-010	The experiment shall quantify the convective heat transfer on a horizontal heated flat plate.
R-FU-HTL-020	The experiment shall quantify the convective heat transfer on a vertical heated flat plate.

R-FU-HTL-030	The experiment shall quantify the convective heat transfer between spaced vertical heated flat plates.
R-FU-HTL-040	The experiment shall quantify the convective heat transfer on a thermal strap attached to a radiator.
R-FU-HTL-050	There shall be an air mass flow between the inner gondola air and each experiment internal air during the whole mission.
R-FU-HTL-060	The temperature sensors values of the Heat Transfer Lab plates shall be measured, collected, and stored during the whole mission.
R-FU-HTL-070	The temperature sensors values of the surrounding walls of each experiment shall be measured, collected and stored during the whole mission.
R-FU-HTL-080	The temperature sensors values of the surrounding air of each experiment shall be measured, collected and stored during the whole mission.
R-FU-HTL-090	The temperature sensors values of the air located inside the gondola cavity shall be measured, collected and stored during the whole mission.
R-FU-HTL-100	The dissipated power from the Heat Transfer Lab heaters shall be measured, collected, and stored during the whole mission.
R-FU-HTL-110	The temperature of each heated plate shall be controlled independently during the whole mission.
R-FU-HTL-120	The direct solar flux shall be measured, collected, and stored during the whole mission.
R-FU-HTL-130	The solar flux reflected by the Earth shall be measured, collected, and stored during the whole mission.
R-FU-HTL-140	The Outgoing Longwave Radiation (OLR) from Earth shall be measured, collected, and stored during the whole mission.
R-FU-HTL-150	The Infrared Radiation (IR) from the sky shall be measured, collected, and stored during the whole mission.
R-FU-HTL-160	The experiment 3 radiator shall radiate outside the gondola.
R-FU-HTL-170	The air pressure shall be measured during the whole mission.
R-FU-HTL-180	The atmosphere air speed modulus on at least one external surface of the gondola shall be measured at least during the ascending phase.
R-FU-ATL-190	The Nadir sensor shall determine the nadir direction during the float phase.
R-FU-MEC-200	The structure shall provide protection and support to all subsystems during the whole mission.
R-FU-MEC-210	The structure shall provide physical connection to the upward and downward environmental lab during the whole mission.
R-FU-MEC-220	The structure external brackets shall ensure a maximal vertical defection of 1 cm during the whole mission.
R-FU-ELE-230	The electronic subsystem shall provide an acquisition data interface between the OBC to all sensors during the whole mission.

R-FU-ELE-240	The electronic subsystem shall provide a conditioning circuit for the Electrical Power Control during the whole mission.
R-FU-ELE-250	The electronic subsystem shall provide a common grounding connection for all subsystems.
R-FU-ELE-260	The attitude of the gondola shall be determined, collected, and stored during the whole mission.
R-FU-ELE-270	The position of the gondola shall be determined, collected, and stored during the whole mission.
R-FU-AIT-280	The AIT Plan shall embrace from the conception of the product until the tethers are separated from the balloon.
R-FU-AIT-290	The AIT Plan shall include the verification plan of all requirements.
R-FU-THE-300	The Thermal Control Subsystem shall ensure an appropriate range of operational temperatures during the whole mission.
R-FU-EPW-310	The Electrical Power Subsystem shall regulate and distribute enough power to all subsystems during the whole mission.
R-FU-SFW-320	The OBSW shall acquire, distribute, store and transmit data from all subsystems during the whole mission.
R-FU-SFW-330	The OBSW shall timestamp the stored data during the whole mission.
R-FU-SFW-340	The OBSW shall store and manage the system's and subsystem's operational modes during the whole mission.
R-FU-SFW-350	The GSSW shall provide an interface between the user and the OBSW.

2.3 Performance Requirements

Here, the performance requirements are presented in Table 2-2.

Table 2-2. Performance Requirement's list.

ID	Description
R-PE-HTL-010	All Heat Transfer Lab temperature sensors values shall be stored at a minimum frequency of 0.1 Hz (T = 10 secs) during the whole mission.
R-PE-HTL-020	All Heat Transfer Lab temperature sensors values shall be downloaded at a minimum frequency of 0.1 Hz (T = 10 secs) during the whole mission.
R-PE-HTL-030	All Infrared Radiation sensors values shall be stored at a minimum frequency of 0.1 Hz (T = 10 secs) during the whole mission.
R-PE-HTL-040	All Infrared Radiation sensors values shall be downloaded at a minimum frequency of 0.1 Hz (T = 10 secs) during the whole mission.
R-PE-HTL-050	All Solar Radiation sensors values shall be stored at a minimum frequency of 0.1 Hz (T = 10 secs) during the whole mission.
R-PE-HTL-060	All Solar Radiation sensors values shall be downloaded at a minimum frequency of 0.1 Hz (T = 10 secs) during the whole mission.

R-PE-HTL-070	All Heat Transfer Lab temperatures shall be measured with an accuracy lower than or equal to +/- 1 °C during the whole mission.
R-PE-HTL-080	The Heat Transfer Lab temperature measurement range shall be at least between -80ºC and 60ºC during the whole mission.
R-PE-HTL-090	Air pressure shall be measured with an accuracy of 50 Pa during the whole mission.
R-PE-HTL-100	The Infrared Radiation sensor shall work in a temperature range between -40 °C and 80 °C during the whole mission.
R-PE-HTL-110	The Solar Radiation sensor shall work in a temperature range between -40 °C and 80 °C during the whole mission.
R-PE-HTL-120	The Infrared Radiation sensor shall measure in a wavelength range between 2 to 100 micrometres during the whole mission.
R-PE-HTL-130	The Solar Radiation sensor shall measure in a wavelength range between 0.1 to 2 micrometres during the whole mission.
R-PE-HTL-140	The IR sensors FoV shall be 180º
R-PE-HTL-150	The Solar sensors FoV shall be 180º
R-PE-HTL-160	The atmosphere air speed modulus shall be measured with an accuracy lower than or equal to 1 m/s
R-PE-HTL-170	The atmosphere air speed modulus shall be measured in a range between 3 m/s and 20 m/s
R-PE-HTL-180	The anemometer shall work within a static pressure range at least between 50 - 500 hPa.
R-PE-HTL-190	The anemometer values shall be stored at a minimum frequency of 1 Hz (T = 1 secs) during the whole mission.
R-PE-ATL-200	The anemometer values shall be downloaded at a minimum frequency of 0.1 Hz (T = 10 secs) during the whole mission.
R-PE-ATL-230	The Nadir sensor functional range shall be at least 10º from the Nadir direction during the whole mission.
R-PE-ATL-240	The Nadir sensor temperature range shall be from -20ºC to 80ºC during the whole mission.
R-PE-ELE-250	The electronic shall allow to acquire data at the appropriate accuracy during the whole mission.
R-PE-ELE-260	The electronic subsystem shall operate in the temperature range between -40ºC to 80ºC during the whole mission.
R-DE-ELE-270	The electronic subsystem shall operate in the pressure profile between 100 kPa to 500 Pa.
R-DE-ELE-280	The GPS and magnetometer values shall be stored at a minimum frequency of 1 Hz (T = 1 secs) during the whole mission.
R-PE-ELE-290	The GPS values shall be downloaded at a minimum frequency of 0.1 Hz (T = 10 secs) during the whole mission.
R-PE-ELE-300	The gyroscope and accelerometer values shall be stored at a minimum frequency of 100 Hz (T = 0.01 secs) during the whole mission.

R-PE-ELE-310	The attitude determination accuracy shall be +/- 1 deg.
R-PE-ELE-320	The position determination accuracy shall be TBD.
R-PE-SFW-330	The OBSW shall store the current system' mode at a minimum frequency of TBD Hz.
R-PE-SFW-340	The OBSW shall store the relative time of the mission at a minimum frequency of TBD Hz.
R-PE-SFW-350	The OBSW shall timestamp data within TBD accuracy.

2.4 Design Requirements

Here, the design requirements are presented in Table 2-3.

Table 2-3. Design Requirement's list.

ID	Description
R-DE-HTL-010	The solar sensor for solar flux reflected by the Earth shall be located outside the gondola and faced to Nadir.
R-DE-HTL-020	The solar sensor for direct solar flux measurement shall be located outside the gondola and faced to Zenith.
R-DE-HTL-030	The IR sensor for OLR measurements shall be located outside the gondola and faced to Nadir.
R-DE-HTL-040	The IR sensor for IR from sky measurements for shall be located outside the gondola and faced to Zenith.
G-DE-HTL-050	The FoV of the solar sensor should not be affected by the gondola or the attitude lab.
G-DE-HTL-060	The FoV of the IR sensor should not be affected by the gondola or the attitude lab.
R-DE-HTL-070	The anemometer shall be located normal to one of the vertical surfaces of the gondola.
R-DE-HTL-080	The anemometer shall be located at a maximum distance from the gondola surface of 15 mm.
R-DE-HTL-090	The anemometer shall not disturb the air at the normal component to the measuring surface.
G-DE-ATL-100	The Nadir sensor FoV should not be affected by the gondola.
R-DE-ATL-110	The Nadir sensor development shall be decoupled from the main experiment.
R-DE-MEC-120	The structure shall provide physical access to the E-link and the Gondola Power Supply
R-DE-MEC-130	Experiment shall be structured to withstand the loads specified in the User Manual.
R-DE-MEC-140	The structure shall prevent any electrical shunts
R-DE-MEC-150	The experiment shall be attached to the gondola's rails.

R-DE-MEC-160	The HTL experiment shall be placed in a corner of the gondola.
R-DE-MEC-170	The HTL and the Electronic Box housing envelope shall be lower than TBC.
R-DE-MEC-180	The downward external brackets longitude shall be longer than 0.5 m.
R-DE-MEC-190	The upward external brackets longitude shall be longer than TBC m.
R-DE-MEC-200	The HTL and Electronic Box housing mass shall be less than TBC kg.
R-DE-MEC-210	The external brackets mass shall be less than TBC kg.
R-DE-MEC-220	The experiment shall not disturb or harm the launch vehicle.
R-DE-ELE-230	The OBC shall be connected to the E-Link airbone unit through the Amphenol RJF21B (CODE A) per the BEXUS user manual.
R-DE-ELE-240	All electronic components shall be protected from overcurrents.
R-DE-EPW-250	The maximum continuous power consumption of the HERCCULES experiment shall not exceed 40 W.
R-DE-EPW-260	The total power consumption of the HERCCULES experiment during the pre-flight and flight phases should be below 170 W·h.
R-DE-EPW-270	The Electrical Power Subsystem shall be connected to the battery through the Amphenol PT02E8-4P connector.
R-DE-EPW-280	The Electrical Power Subsystem shall power the system with 12 V, 5 V and 3.3 V voltage lines.
R-DE-EPW-290	The peak power consumption of the HERCCULES experiment shall be below 110 W.
R-DE-EPW-300	The Electrical Power Subsystem shall be powered by the battery of the gondola at least.
R-DE-SFW-310	The OBSW shall downlink telemetry data via the E-Link airborne unit.
R-DE-SFW-320	The OBSW shall be connected to the E-Link airborne unit through the Ethernet network layer protocol.
R-DE-SFW-330	The OBSW shall receive telecommands via the E-Link airborne unit.
R-DE-SFW-340	The GS shall uplink telecommands via the E-Net network from the E-Link ground unit
R-DE-SFW-350	The GS shall be connected to the E-Link ground unit through the Ethernet network layer protocol.
R-DE-SFW-360	The GS shall receive telemetry via the E-Net network from the E-Link ground unit.
R-DE-SFW-370	The GS shall not be connected to the Internet.
G-DE-SFW-380	The GS should access Internet through the Guest Net network provided by the E-Link ground unit.

R-DE-SFW-390	The GS shall be configured with the provided IP address.
R-DE-SFW-400	The OBSW shall be configured with the provided IP address.
G-DE-SFW-410	A switch should be used to distribute the Internet access from the Guest Net.
G-DE-SFW-420	The Software architecture and design should be described in the UML and/or AADL modelling languages, recommended in [1, Annex B.4].
G-DE-SFW-430	C source code should be written following the Barr Group's Embedded C Coding Standard.
R-DE-SFW-440	Changes to the SW after the FST at the EAR shall be kept to a minimum and pass all regression tests.
R-DE-SFW-450	The OBSW shall function in Flight mode even if the vehicle is not, i.e.: Flight mode shall be simulated.
R-DE-SFW-460	The OBSW shall store data during the FST.
R-DE-SFW-470	The C, C++, or Ada shall be used as the programming languages for the OBSW.
R-DE-SFW-480	The OBC Wi-Fi shall be turned off.
G-DE-SFW-490	E-Link dropouts should be simulated to ensure correctness when there is no telemetry available
R-DE-SFW-500	The OBSW shall implement FDIR to deal with E-Link communication timeouts.
R-DE-SFW-510	The OBSW shall send and receive data from zero up to and including 2 Mbps.
R-DE-SFW-520	The GSSW shall send and receive data from zero up to and including 2 Mbps.
R-DE-SFW-530	The OBSW shall store the data collected from all the experiments in different files, i.e.: one file per experiment.
R-DE-SFW-540	The OBSW shall turn off the experiment before landing.

2.5 Operational Requirements

Here, the functional requirements are presented in Table 2-4.

Table 2-4. Operational Requirement's list.

ID	Description
R-OP-HTL-010	The operational modes of the heaters shall be able to be change automatically (safety mode) and by telecommands.
R-OP-HTL-020	The heaters shall work in different operational modes during the whole mission.
R-OP-HTL-030	Control HTL parameters should be included in the housekeeping parameters.
R-OP-MEC-040	Any experiment or part of the experiment located outside of the gondola shall be secured with a safety cable.

R-OP-MEC-050	The experiment shall facilitate safe mounting on the gondola.
R-OP-ELE-060	The electronic subsystem should contain a protection circuit in case of overcurrent or wrong connection with the BEXUS power supply
R-DE-AIT-070	The AIT Plan shall verify the availability and the compatibility of the test facilities.
R-DE-AIT-080	The AIT team shall ensure that the documentation associated with the plan is in accordance with the specifications and quality established in the project.
R-DE-AIT-090	The AIT Plan, as well as the verification plan, shall be limited to the time frames established for the HERCCULES project.
R-DE-EPW-100	The Electrical Power Subsystem shall monitor the voltage and current of the gondola battery and any possible secondary power supply.
R-DE-EPW-110	The HERCCULES experiment shall include a power safe mode
R-DE-SFW-120	The OBSW should provide temperature and voltages for critical electronic components (HK TM defined in the Communication Interfaces section) with a maximum period of 60 seconds.
G-PE-SFW-130	The OBSW should record the error logs from the experiments for future analysis.
R-PE-SFW-140	The OBSW shall implement a command to perform a quick functional test and give the status from all the experiment equipment
R-OP-SFW-150	The OBSW shall support multiple reboot (on and off) sequences.
R-OP-SFW-160	The OBC shall be rebooted if the OBSW is suspended for more than TBD seconds.
R-OP-SFW-170	The connection between the GS and OBSW should be re-established with no errors.
R-OP-SFW-180	The OBSW shall initialize the system considering its latest system mode and relative time of the mission if available.
G-OP-SFW-190	The GSSW software shall store telemetry data in a database.

2.6 Constraints

"C" – External constraint, noted C – are those factors which limit cost, schedule and implementation techniques available to the team and that cannot be overcome. They are presented in Table 2-5.

Table 2-5. Constraint's list

ID	Description
C-010	The vacuum test schedule shall be compatible with the TVAC test calendar
C-020	HERCCULES schedule shall be compatible with the equipment reception time.

C-030	The manufacturing, assembly, integration and testing activities shall be compatible with the COVID-19 restrictions.

3 PROJECT PLANNING

3.1 Work Breakdown Structure (WBS)

In this section every work package is included and classified by project phase and working group referenced to Table 3-3. Responsibilities have been assigned according to abbreviations used in Section 3.3. Work packages included in a subsystem completely corresponds to the members assigned in the corresponding working group.

1	**Project & System Management**	
1.1	**Preliminary Design**	
1.1.1	Requirement's definition / Verification	DGB
1.1.2	Work Breakdown Structure	DGB
1.1.3	Schedule	DGB
1.1.4	Concurrent Engineering Plan	DGB
1.1.5	System Requirement Review	All
1.1.6	Verification Plan	JMA
1.1.7	System's Risk Analysis	DGB
1.1.8	Internal Preliminary Design Review	All
1.1.9	Fundraising / Sponsorship	DGB
1.1.10	Outreach	JMA
1.1.11	SEDv1 Documentation	DGB/JMA
1.1.12	PDR preparation	All
1.1.13	Training Week and PDR	All
1.2	**Detailed Design**	
1.2.1	Concurrent Engineering coordination	DGB/JMA
1.2.2	Prototypes component acquisition	DGB
1.2.3	Outreach	JMA
1.2.4	SEDv2 Documentation	DGB/JMA
1.2.5	Internal CDR	All
1.2.6	CDR preparation	All
1.2.7	CDR	All
1.3	**Manufacturing, Integration and Test**	
1.3.1	SEDv3 Documentation	DGB/JMA
1.3.2	Component acquisition	DGB
1.3.3	Integration plan	All
1.3.4	Internal Integration plan review	All
1.3.5	Wire routing	ELE, MEC
1.3.6	Integration	All
1.3.7	IPR	All
1.3.8	Test procedures	All
1.3.9	Functional test	HTL, ATL, ENV, SFW
1.3.10	TVAC test	TCS, SFW, HTL
1.3.11	Structural test	MEC
1.3.12	Additional tests	All
1.3.13	Internal EAR	All
1.3.14	Outreach	JMA
1.3.15	SEDv4 Documentation	DGB/JMA
1.3.16	EAR preparation	All

1.3.17	EAR	All
1.4	**Utilization**	
1.4.1	Flight preparation	All
1.4.2	Packaging	All
1.4.3	Campaign at Esrange	All
1.4.4	Flight Report Documentation	All
1.4.5	Outreach	JMA
1.4.6	SEDv5 documentation	All
2	**Heat Transfer Lab / Environmental Lab**	**HTL**
2.1	**Preliminary Design**	
2.1.1	Requirement's definition / Verification	
2.1.2	Preliminary Thermal Simulation	
2.1.3	Preliminary component selection	
2.1.4	Operational modes estimation	
2.1.5	Data analysis plan	
2.1.6	Risk Analysis	
2.1.7	SEDv1 Documentation	
2.1.8	Preliminary CAD design	
2.2	**Detailed Design**	
2.2.1	Prototypes component acquisition	
2.2.2	Radiative sensors acquisition	
2.2.3	Differential pressure sensor acquisition	
2.2.4	Prototypes manufacturing	
2.2.5	Vacuum tests	
2.2.6	Operational modes definition	
2.2.7	Radiative sensors test	
2.2.8	EXP5 wind tunnel test	
2.2.9	Final configuration design	
2.2.10	SEDv2 Documentation	
2.3	**Manufacturing, Integration and Test**	
2.3.1	SEDv3 Documentation	
2.3.2	Fight component acquisition	
2.3.3	Experiment support manufacturing	
2.3.4	Experiments Integration Procedure	
2.3.5	SEDv4 Documentation	
3	**Attitude Lab**	**ATL**
3.1	**Preliminary Design**	
3.1.1	Requirement's definition / Verification	
3.1.2	Preliminary CAD model	
3.1.3	Preliminary location study	
3.1.4	Preliminary component selection	
3.1.5	Operational modes estimation	
3.1.6	Data analysis plan	
3.1.7	Risk Analysis	
3.1.8	SEDv1 Documentation	
3.2	**Detailed Design**	

3.2.1 Prototypes component acquisition
3.2.2 Prototypes manufacturing
3.2.3 Simulink coding
3.2.4 Prototypes test
3.2.5 Final configuration design
3.2.6 SEDv2 Documentation

3.3 Manufacturing, Integration and Test
3.3.1 SEDv3 Documentation
3.3.2 Component acquisition
3.3.3 Housing manufacturing
3.3.4 Integration procedure
3.3.5 Sensor Integration
3.3.6 Functional test
3.3.7 SEDv4 Documentation

4 Mechanical Subsystem MEC

4.1 Preliminary Design
4.1.1 Requirement’s definition / Verification
4.1.2 Preliminary component Selection
4.1.3 Preliminary CAD design
4.1.4 I/F definition
4.1.5 Mass Budget
4.1.6 Risk Analysis
4.1.7 SEDv1 Documentation

4.2 Detailed Design
4.2.1 Detailed CAD model
4.2.2 Components I/F definition
4.2.3 CAD wire routing
4.2.4 SEDv2 Documentation

4.3 Manufacturing, Integration and Test
4.3.1 SEDv3 Documentation
4.3.2 Component acquisition
4.3.3 Wire routing blueprints
4.3.4 Structure integration procedure
4.3.5 SEDv4 Documentation

5 Thermal Control Subsystem THE

5.1 Preliminary Design
5.1.1 Requirement’s definition / Verification
5.1.2 Preliminary ESATAN-TMS model
5.1.3 Thermal Environment definition
5.1.4 Preliminary Ascent Phase Analysis
5.1.5 Risk Analysis
5.1.6 SEDv1 Documentation
5.1.7 Preliminary Float Analysis

5.2 Detailed Design
5.2.1 Detailed ESATAN-TMS thermal model
5.2.2 Functional thermal analysis

5.2.3 Prototypes test simulation
5.2.4 SEDv2 Documentation

5.3 Manufacturing, Integration and Test
5.3.1 SEDv3 Documentation
5.3.2 Component acquisition
5.3.3 Thermal control components integration procedure
5.3.4 Thermal model correlation
5.3.5 SEDv4 Documentation

6 Electronics Subsystem ELE

6.1 Preliminary Design
6.1.1 Requirement's definition / Verification
6.1.2 Preliminary electronics design
6.1.3 Component Selection
6.1.4 PCBs layout conceptual design
6.1.5 Risk Analysis
6.1.6 SEDv1 Documentation

6.2 Detailed Design
6.2.1 Detailed electronics design
6.2.2 PCBs design
6.2.3 Electronics simulation
6.2.4 Prototypes component acquisition
6.2.5 Engineering model manufacturing
6.2.6 Engineering model test
6.2.7 SEDv2 Documentation

6.3 Manufacturing, Integration and Test
6.3.1 SEDv3 Documentation
6.3.2 Component acquisition
6.3.3 PCBs manufacturing
6.3.4 PCBs test
6.3.5 SEDv4 Documentation

7 Software Subsystem SFW

7.1 Preliminary Design
7.1.1 Requirement's definition / Verification
7.1.2 Logical architectural design
7.1.3 Physical architectural design
7.1.4 SEDv1 Documentation

7.2 Detailed Design
7.2.1 Detailed On-Board software design
7.2.2 Detailed Ground software design
7.2.3 Coding
7.2.4 Engineering model test (unit testing)
7.2.5 SEDv2 Documentation

7.3 Manufacturing, Integration and Test
7.3.1 SEDv3 Documentation
7.3.2 Integration testing

7.3.3 Validation testing
7.3.4 Qualification testing
7.3.5 SEDv4 Documentation

8 Electrical Power subsystem PWR

8.1 Preliminary Design
8.1.1 Requirement's definition / Verification
8.1.2 Component Selection
8.1.3 Power budget and preliminary calculation
8.1.4 SEDv1 Documentation

8.2 Detailed Design
8.2.1 Detailed power budget
8.2.2 Electrical power Subsystem simulation
8.2.3 Detailed power distribution design
8.2.4 Ground wiring design
8.2.5 SEDv2 Documentation

8.3 Manufacturing, Integration and Test
8.3.1 SEDv3 Documentation
8.3.2 Component acquisition
8.3.3 Electrical Power test
8.3.4 SEDv4 Documentation

3.2 Schedule

A detailed schedule has been developed accounting for every Work Package presented in Section 3.1 and it is included in Appendix E . It has been divided by project phases and subsystem to clearly define the project progress. Here, a Top Level Gantt diagram is shown in Figure 3-1 where different phases are represented with different colours and main task are included. Deliverables and BEXUS reviews have been represented as key project milestones.

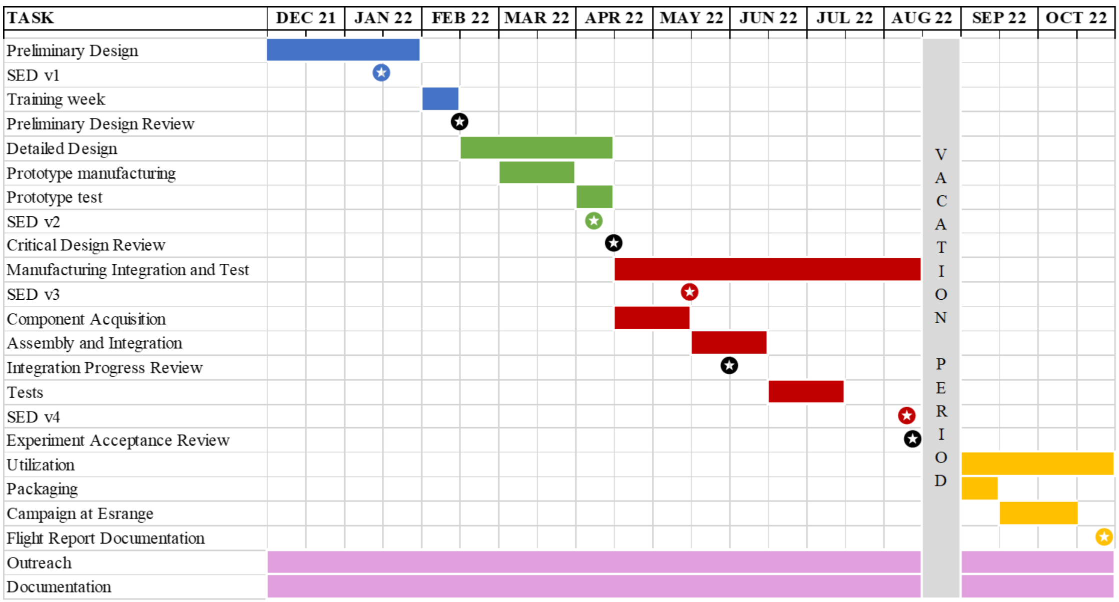


Figure 3-1. Top Level Gant.

Additionally, a checklist for showing the status of the main elements of the HERCCULES experiment has been included in Table 3-1. The preliminary design for most of the elements have been completed. Only electronics and software, which depend on the preliminary design of the rest of the experiment, have not completed the preliminary design.

Table 3-1. Checklist of main elements about their progress status.

Element	Conceptual Designed	Preliminary Designed	Detailed Designed	Ordered	Delivered	Assembled	Tested
EXP 1	☑	☑	☐	☐	☐	☐	☐
EXP 2	☑	☑	☐	☐	☐	☐	☐
EXP 3	☑	☑	☐	☐	☐	☐	☐
EXP 4	☑	☑	☐	☐	☐	☐	☐
EXP 5	☑	☑	☐	☐	☐	☐	☐
Nadir sensor	☑	☑	☐	☐	☐	☐	☐
Pyranometer	☑	☑	☐	☐	☐	☐	☐
Pyrgeometer	☑	☑	☐	☐	☐	☐	☐
Main structure	☑	☑	☐	☐	☐	☐	☐
E-Box	☑	☑	☐	☐	☐	☐	☐
Brackets	☑	☑	☐	☐	☐	☐	☐
SDPU	☑	☐	☐	☐	☐	☐	☐
PCU	☑	☐	☐	☐	☐	☐	☐
TMU	☑	☐	☐	☐	☐	☐	☐
ADU	☑	☐	☐	☐	☐	☐	☐
OBC	☑	☑	☐	☐	☐	☐	☐
OBC Conn	☑	☑	☐	☐	☐	☐	☐
Software	☑	☐	☐	☐	☐	☐	☐
Ground Station	☑	☐	☐	☐	☐	☐	☐

3.3 Resources

3.3.1 Manpower

Here, the skills, experience and availability of each team member is analysed. In addition, actions to be taken in case a team member suddenly becomes unavailable or the project demands more members are also presented.

Skills and experience

The education and field of experience of each member is included in Table 3-2 in order to allocate them in the appropriate working group.

Table 3-2. Skills and experience of each team member.

Member	Abbreviation	Skills and experience
David González Bárcena	DGB	BSc in Aerospace Engineering MSc in Space Systems PhD (c) in Aerospace Engineering (4th year) Experience in project management and thermal analysis and design.
José Miguel Álvarez Romero	JMA	BSc in Aerospace Engineering MSc in Space Systems PhD (c) in Aerospace Engineering (4th year)

		Experience in project management, concurrent design and mechanical and structural analysis.
Alejandro Fernández Soler	AFS	BSc in Aerospace Engineering MSc in Space Systems PhD (c) in Aerospace Engineering (3rd year) Experience in thermal analysis and design.
Ángel Grover Pérez Muñoz	APM	BSc in Computer Engineering MSc in Distributed and Embedded Systems Software (1st year) Experience in embedded real-time software design.
Ángel Porras Hermoso	APH	BSc in Aerospace Engineering MSc in Space Systems PhD (c) in Aerospace Engineering (2nd year) Experience in space attitude determination and control.
Daniel Alfonso Corcuera	DAC	BSc in Aerospace Engineering MSc in Air Transport Systems Engineering MSc in Digital Conception and Innovation PhD (c) in Aerospace Engineering (2nd year). Experience in photovoltaic energy, power distribution, battery modelling and anemometry
Juan Bermejo Ballesteros	JBB	BSc in Aerospace Engineering MSc in Space Systems PhD (c) in Aerospace Engineering (4th year) Experience in concurrent engineering and space attitude determination and control.
Sergio Marín Coca	SMC	BSc in Aerospace Engineering MSc in Space Systems PhD (c) in Aerospace Engineering (2nd year) Experience in concurrent engineering and design of spacecraft electrical power subsystems.
Blanca Boado Cuartero	BBC	BSc in Mechanical Engineering MSc in Space Systems PhD (c) in Aerospace Engineering (2nd year) Experience in spacecraft mechanical design.
Javier Garrido Sola	JGS	BSc in Telecommunication Systems Engineering (4th year) Experience in electronics assembly and programming.
Juan Manuel Redondo	JMR	BSc in Telecommunication Electronics Engineering (4th year) Experience in electronics design.
Pedro Luis Barba Navarrete	PBN	BSc in Telecommunication Electronics Engineering (4th year) Experience in electronics design.
Marina Merchán Bravo	MMB	BSc in Mechanical Engineering. MSc in Space Systems (2nd year). Experience in attitude determination.

Working groups assignments

According to the experience of each member, different working groups have been assigned to accomplish the work packages included in Section 3.1. They are shown in Table 3-3.

Table 3-3. Working groups division.

Group name	Abbreviation	Members
Project Management	PRM	David González Bárcena José Miguel Álvarez
Heat Transfer Lab / Environmental Lab	HTL	Alejandro Fernández Soler Ángel Porras Hermoso Juan Bermejo Ballesteros Daniel Alfonso Corcuera
Attitude Lab	ATL	Marina Merchán Bravo Ángel Porras Hermoso Juan Bermejo Ballesteros
Electronics Subsystem	ELE	Juan Manuel Redondo Pedro Luis Barba Navarrete
Electrical Power Subsystem	PWR	Sergio Marín Coca
Mechanical Subsystem	MEC	Blanca Boado Cuartero José Miguel Álvarez
Thermal Control Subsystem	THE	Alejandro Fernández Soler
Software Subsystem	SFW	Ángel Grover Pérez Muñoz Javier Garrido Sola

Availability and required manpower

An estimation of the available work hours of each member by project phase has been included in Table 3-4. A comparison between the available and required manpower will be also included in future versions of this document.

Table 3-4. Available and required manpower by member and project phase.

		Preliminary Design	Detailed Design	Manufacturing Integration and Test	Utilization (pre-launch)	Utilization (post-launch)	TOTAL/person
Working days		36	47	79	22	55	
Available hours		288	376	632	176	440	
Dedicated hours	DGB	144	188	316	88	110	846
	JMA	108	141	237	66	55	607
	AFS	108	141	237	66	55	607
	APM	108	141	237	66	55	607
	APH	108	141	237	66	55	607
	DAC	72	141	237	44	55	549
	JBB	108	141	237	66	55	607
	SMC	72	94	158	44	55	423
	BBC	108	141	237	66	55	607
	JGS	18	47	79	6	0	150
	JMR	18	47	79	6	0	150
	AHM	0	56	94	0	0	150
	PBN	0	36	79	0	0	115
	MMB	108	141	237	22	0	508
TOTAL/phase		1080	1596	2701	606	550	6533
ESTIMATED/phase		TBD	TBD	TBD	TBD	TBD	0
BALANCE/phase		TBD	TBD	TBD	TBD	TBD	TBD

Actions

The estimated manpower for each phase and member is still TBD. However, actions to be taken in case additional manpower is required can be detailed:

- Re-assignment of task: The technical background of most of the members is wide enough to allow a re-assignment in case additional work is required in a different group.
- Recruitment: Being part of the Polytechnic University of Madrid, it would be easy to find new students to enrol the HERCCULES project as part of the academic programme.

3.3.2 Budget

Here, the total cost budget is presented in Table 3-5. First part of it corresponds to the materials, sensors and experiment manufacturing including margins. Additionally, travelling costs has been considered if necessary as well as assistance to conferences and publications. A thermal vacuum test has been included in the budget, but it would be performed in the IDR facilities. Finally, the personnel costs including PhD students' salary accounting for their dedication to the project has been also quantified based on Table 3-4.

Table 3-5. Total cost budget.

Quantity	Component	Cost/unit [€]	Cost [€]
1	Attitude Lab	2225	2225
1	Heat Transfer Lab / Environmental Lab	18517	18517
1	Electronics	1865	1865
1	Electrical	420	420
1	Mechanical	1675	1675
1	Travelling	20000	20000
1	Merchandising	1000	1000
1	Conferences	4000	4000
2	Publications	1500	3000
1	Thermal Vacuum Test	5000	5000
4853	PhD Students/hour	13	63190
	TOTAL		120892

All expenses would be funded by the IDR. However, we are in touch with some potential sponsors who are interested in participating in the project. A detailed funding summary will be included in future versions of this document.

3.3.3 External Support

The most part of the UPM team is working in a research university institute (Instituto de Microgravedad "Ignacio da Riva") which has a long experience in Space Systems with a multidisciplinary team working in mechanical design, structural analysis, thermal design and testing, etc. IDR/UPM has continuously improved the methodology to apply space thermal design methods to the balloon-borne flights. A research line to characterize the thermal environment and to standardize the thermal analysis is currently ongoing.

In order to get a multidisciplinary team for the BEXUS program a collaboration with other institutes from the UPM has been established. STRAST (Real-Time Systems and Architecture of Telematic Services) is a group specialized in electronics and computing. These two institutes have been working together for a long time. A good proof of it is the successful launch of the UPMSat-2 microsatellite in 2020, which was design by both groups and tested in the IDR/UPM facilities.

Prof. Isabel Pérez Grande would be the professor in charge of the team. She is a Full Professor at UPM, teaching Thermodynamics and Spacecraft Thermal Control. At UPM she is Head of the research group Aerospace Development and Testing since 2005, she has co-authored more than 40 papers in refereed journals, and she participated in both SUNRISE missions as thermal engineer.

In addition, the team would be technically advised by:

- Prof. Ángel Sanz-Andrés (Aerodynamics).
- Prof. Santiago Pindado (Anemometry)
- Dr. Lilian Peinado (Thermal Design).
- Prof. Victor Muntean (Fluid Mechanics).
- Prof. Javier Cubas (Attitude Determination).
- Prof. Juan Zamorano (Software).
- Prof. Javier Malo (Electronics).
- Prof. Javier Pérez (Mechanical Design).

The main sponsor would be the **Universidad Politécnica de Madrid** through the **IDR Institute** and the **STRAST** group. As a previous work before the BEXUS program, we were asking for support of national companies which would collaborate with us providing some advice and helping us with the component acquisition. At the moment, two of them are open to this collaboration but additional support would be look for:

- **BHDynamics** is an electronics company awarded with some national prices as the most innovative start-up at national level. It collaborates with the Instituto Catalán de Nanociencia y Nanotecnología (ICN2), some research institutes and universities. They would help us with the electronics design and manufacturing.
- **Geónica**, with more than 40 years of experience, is a company which design, manufacture, install and maintain Automatic Weather Stations, Systems and Measurement Networks with Data Transmission, Images and Alarms in Real Time for Environmental Monitoring. They would help us with the environmental sensors acquisition.

Additionally, we are looking for sponsorships to finance the experiment cost manufacturing.

3.4 Outreach Approach

The HERCCULES project outreach program is based on a fundamental pillar from which everything is sustained, the website. All news, information, and social networks are organized from there by links.

Webpage

The design of the website is in progress, being the content updated regularly. It is available at a web-space provided by the UPM: https://blogs.upm.es/herccules/. The HERCCULES website is intended to include all necessary sections to provide information about the program, the experiment, the teams, and the development of the project. Currently, the webpage has the following sections:

- The **Homepage,** which include an introduction about the project and the experiment background, the Logo and description, the new entries form the blog and the contact information and location.
- The **Blog entries**, including all new post about the project, the media, the development updates…
- The **Experiment** section include a detailed description of the mission and the different experiments included.
- The **About us** section, which includes:
    - The **Team** subsection, including a picture and a brief description of each team member, including their role in the project.
    - The **Technical support and background** subsection, including the university technical support, a brief introduction to the IDR/UPM institute background and the background of the experiment and its publications.
    - The available **Facilities** for the design, develop and test of the HERCCULES project.
- All the main **Documents** elaborated in the project.
- And the **Sponsors and collaborators**, including the university support, the BEXUS/REXUS Programme sponsors and the HERCCULES sponsors and collaborators.

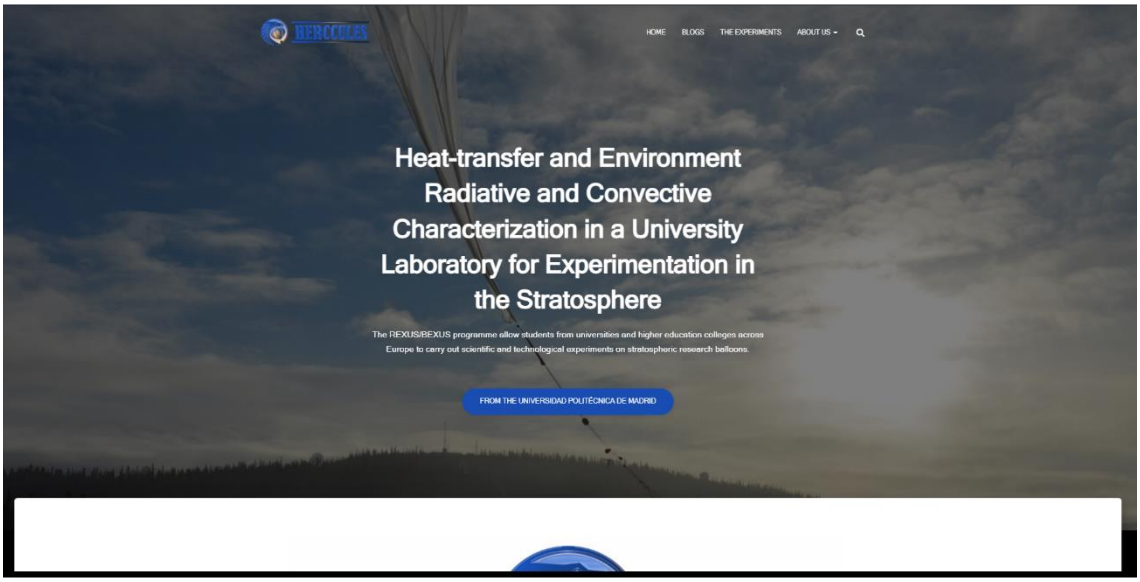


Figure 3-2. HERCCULES website appearance.

Furthermore, there are pictures, news, links to the UPM and the IDR/UPM institute websites, and our social media sites. Nevertheless, the webpage is intended to be updated with more section in the future.

Social Media

Among the different social media options, YouTube and Instagram have been selected as firsts options. We plan to reach a wide range of audience. Therefore, in most cases we will use an everyday language and avoid too detailed information to reach all audience and to keep the interest in the project.

Instagram will be used in order to amplify the audience from the webpage. The news uploaded from the webpage will be re-posted at Instagram with a photo about the new, but at a lower degree of technical information, providing a more personal point of view of the project and its development. Instagram will be used to post photos and videos to awake the interest in our experiment and the REXUS/BEXUS campaign (https://www.instagram.com/herccules.bexus/).

The plan with YouTube channel is to do a video per month, including different information about the project and its development in a more graphical way.

(https://www.youtube.com/channel/UCVSybJ4GQbWcmXOnuy1ah5g?view_as=subscriber)

There is also a twitter belonging to the IDR/UPM institute (https://twitter.com/IDR_Aeronautic) in which news related to the project will also be uploaded, which already has an important weight in the dissemination of scientific information.

Scientific Publications

We have plans in publishing scientific papers presenting the HERCCULES project and its results both in prestigious journals and at dedicated conferences. Members of the team already published/submitted papers about ballooning and thermal convection (including those regarding the TASEC-Lab).

Press and television

The team has in its program the contact with radio programs and television channels, as has been done with previous projects of the research centre. The news is already beginning to be published in different informative media, as well as on the web pages of the IDR/UPM institute.

3.5 Risk Register

Risks have been identified according to the Risk ID and their probability and severity have been evaluated. Both, probability (P) and severity (S) rankings, have been combined to assess the overall risk classification, ranging from very low to very high and coloured green, yellow, orange or red.

Risk ID

- TC – technical/implementation
- MS – mission (operational performance)
- SF – safety
- VE – vehicle
- PE – personnel
- EN – environmental
- SC – schedule
- CS – Costs

Probability (P)

- A – Almost impossible to occur
- B – Small chance to occur
- C – Reasonable chance to occur
- D – Quite likely to occur
- E – Certain to occur, maybe more than once

Severity (S)

- 1 – Negligible – Minimal or no impact
- 2 – Significant – Leads to reduced experiment performance
- 3 – Major – Leads to failure of subsystem or loss of flight data
- 4 – Critical – Leads to experiment failure or creates minor health hazards
- 5 – Catastrophic – Leads to termination of the REXUS and/or BEXUS programme, damage to the vehicle or injury to personnel

Table 3-6. Risk Register.

ID	Risk description	P	S	P x S	Action
CS-SYS-010	Overcosts due to unexpected expenses	B	2	Very low	Considering uncertainty in the cost budget.
EN-SYS-020	Schedule affected by COVID19 pandemic.	D	3	Medium	Planning remote working and accounting for potential restrictions.
MS-ATL-030	Malfunctioning of the control algorithm during flight.	C	1	Very Low	Raw measurements will be recorder recorded to analyse the sensor operation after flight.
MS-ATL-040	The Sun appears in the photodiode's Field of View.	C	2	Low	NO ACTIONS CAN BE DONE. Accepted risk.
MS-ATL-050	Sensor temperature lower than -20ºC.	C	2	Low	Perform thermal analysis prior to flight. Keep the electronics on during launch, fight and recovery operations.
MS-HTL-060	The temperatures of the heated plates reach more than 75 °C (TBC)	A	2	Very low	Decrease power dissipation of the heaters
MS-HTL-070	Temperature difference between the heated plates and the surrounding air reaches values more than 50 °C (TBC)	A	2	Very low	The heater power dissipation of each plate can be controlled by telecommands during the mission
MS-HTL-080	The EXP3 radiator does not radiate to the outer space	A	2	Very low	BEXUS programme does not allowed us. The radiator position shall be discussed. NO ACTIONS CAN BE DONE.
MS-HTL-090	Upward radiative sensors temperature reach values lower than -40°C	B	3	Low	The thermal analysis will be done. Internal heaters will be switched on and foam covering will be used

MS-HTL-100	Downward radiative sensors temperature reach values lower than -40°C	A	3	Very low	The thermal analysis will be done. Internal heaters will be switched on and foam covering will be used
MS-HTL-110	The differential pressure sensors reach temperature values lower than -20°C	A	2	Very low	Thermal analysis will be done to ensure the temperature operational range
MS-MEC-120	Deflection in the Upward Environmental Lab rods modifies the sensors FoV	C	2	Low	Mechanical testing to check experiment integrity
MS-MEC-130	Deflection in the Downward Environmental Lab rods modifies the sensors FoV	C	2	Low	Mechanical testing to check experiment integrity
MS-SYS-140	Fatal failure of other experiment on-board BEXUS affecting HERCCULES	A	5	Low	None
MS-SYS-150	Short flight duration due to local restrictions	C	3	Low	Ensuring the performance and data acquisition during the ascent phase
MS-SYS-160	Fatal landing damage Internal Storage.	B	3	Low	Download relevant data to preform post-flight analysis.
MS-SYS-170	Not enough power to heat the plates during flight	B	4	Low	At the end of float phase, in case the flight happens with nigh conditions, the battery temperature will be very low, decreasing the electrical power available for the experiments Some experiments shall be prioritized
PE-SYS-180	A team member leaves during the design phase.	C	2	Low	Having a polyvalent team to be re allocated in other working groups
PE-SYS-190	Project manager is unavailable during a period of time.	B	3	Low	The Project management working group accounts for an additional member which would be working together with the project manager
PE-SYS-200	A subsystem responsible leaves.	C	3	Low	Recruiting new students.

SC-AIT-210	TVAC is not available for the test campaign	B	4	Low	Book with at least two months of prevision the TVAC/book enough time in case testing takes longer than expected or delays accumulate
SC-AIT-220	The experiment integration may be longer than scheduled	B	3	Low	The AIT schedule shall be included with a correct time margin in order to ensure the AIT plan (integration)
SC-AIT-230	The clean room may be not accessible for the AIT	B	4	Low	The AIT plan shall be developed in collaboration with the clean room responsible to ensure a proper schedule
SC-SYS-240	Delay in components reception.	C	3	Low	Planning a conservative schedule.
SC-SYS-250	Delay in electronics manufacturing.	C	3	Low	Looking for a trustworthy supplier.
SF-AIT-260	Any scheduled test may damage a component	B	4	Low	The AIT plan shall be developed considering the correct test parameters to ensure the proper experiment safety
SF-MEC-270	The main structure does not withstand the loads during transport and flight	A	5	Low	Mechanical testing to check experiment integrity
SF-MEC-280	The Environmental labs can't withstand the loads during transport	A	4	Low	Mechanical testing to check experiment integrity
SF-MEC-290	The Environmental labs cannot withstand the loads during flight	A	5	Low	Mechanical testing to check experiment integrity
SF-MEC-300	Sensors detach from the structure during flight	A	5	Low	Mechanical testing to check experiment integrity and secure with safety cable
TC-AIT-310	Any of the HERCCULES component nor subsystems cannot be correctly integrated	B	4	Low	The AIT responsible shall be concerned about any design update in order to stablish a proper AIT plan or inform the subsystem responsible
TC-AIT-320	Any scheduled test does not provide the expected results	C	2	Low	The AIT schedule shall be included with a correct time margin in order to ensure the AIT plan (test)

TC-ATL-330	Failure of one photodiode/preamplifier or two photodiodes/preamplifiers aligned in the same axis during flight.	A	2	Very Low	Perform pin-to-pin harness verification prior to flight and test all photodiodes/preamplifiers to ensure their operation during flight.
TC-ATL-340	Failure of two photodiodes/preamplifiers in different axis or failure of all the photodiodes/preamplifiers during flight.	A	3	Very Low	Perform pin-to-pin harness verification prior to flight and a functional test prior to launch.
TC-ATL-350	The gondola and other BEXUS experiments interfere with the photodiode's Field of View.	D	2	Low	Future Design iteration to ensure minimum interference in the Field of View of the photodiodes. Information of other BEXUS experiments is required to reduce uncertainties.
TC-ATL-360	Unable to develop the Nadir sensor within the time frame of the mission.	A	2	Low	NO ACTIONS CAN BE DONE. Risk accepted.
TC-ELE-370	Digital buses quality affected by the connection distance	A	2	Very low	Checking during the functional test.
TC-ELE-380	Physical disconnections from the gondola power supply	A	4	Very low	Checking connections during the pre-flight activities.
TC-ELE-390	Physical disconnections of the experiment's devices to the OBC	B	3	Low	Checking connections during the integration process.
TC-ELE-400	IMU does not work properly	A	3	Very low	Unit and functional testing in TVAC.
TC-ELE-410	GPS does not receive NMEA data	B	3	Low	Check GPS configuration from GS.
TC-EPW-420	The experiment consumption has been underestimated	A	3	Very low	Electrical testing to check real consumptions
TC-EPW-430	Overcurrent in an experiment	B	3	Low	All systems will include fuses
TC-EPW-440	Overcurrent in a DC/DC converter	A	4	Low	Use of DC/DC converters of high maximum current
TC-EPW-450	Shortage of electronic components	B	3	Low	Component's selection based on stock availability

TC-EPW-460	Short circuit between PCBs and the structure	A	4	Low	Insulation of the PCBs in contact with the structure
TC-HTL-470	One of the heaters do not switch on	A	2	Very low	The on/off from the heaters will be controlled independently. The heaters will be tested.
TC-HTL-480	Critical temperature sensors (temperature sensors located in the heated plates) failure	A	2	Very low	Temperature sensors will be tested and calibrated
TC-HTL-490	Noncritical temperature sensors failure	A	1	Very low	Temperature sensors will be tested and calibrated
TC-HTL-500	Operational modes do not change neither by telecommands or automatically	A	2	Very low	SW will be tested
TC-HTL-510	Thermal strap breaks during the assembly	A	2	Very low	The thermal strap will be only handled by the AIV engineer
TC-HTL-520	Upward Solar sensor failure	A	2	Very low	Test will be done
TC-HTL-530	Downward Solar sensor failure	A	2	Very low	Test will be done
TC-HTL-540	Upward IR sensor failure	A	2	Very low	Test will be done
TC-HTL-550	Upward IR sensor failure	A	2	Very low	Test will be done
TC-HTL-560	Radiative sensors break during the AITV phase	A	4	Very low	The radiative sensors will be only handled by the AIV engineer
TC-HTL-570	Radiative sensors break at the landing	D	1	Low	No relevant for the mission. Only impact in the budget for future missions.
TC-HTL-580	Anemometer holes become obstructed by condensation	B	2	Very low	NO ACTIONS CAN BE DONE
TC-HTL-590	The anemometer measures differential pressure above/below the design range due to the float altitude	C	2	Low	Based on data from previous experiments, range is optimized for the expected windspeed and absolute pressure values at the most critical phase (tropopause)

TC-HTL-600	Anemometer pressure tubes get disconnected	A	2	Very low	NO ACTIONS CAN BE DONE
TC-HTL-610	Bad anemometer orientation	C	1	Very low	Each pressure intake, plastic tube, sensor connection and screw hole should be identified
TC-HTL-620	Anemometer sensor failure	A	2	Very low	Anemometer output to be tested
TC-SFW-630	Missed OBSW tasks deadlines	B	2	Very low	Conduct an RTA (Response Time Analysis) to ensure the schedulability of the system.
TC-SFW-640	the OBSW reads invalid data from the sensors	C	3	Low	The valid ranges need to be defined rigorously based on previous flight and the team members expertise. Static redundancy can be used to read the redundant units and hide the effects of the fault.
TC-SFW-650	The OBSW cannot control the actuators	B	3	Low	This risk can be avoided with proper electrical connections, this will be assured by performing extensive tests.
TC-SFW-660	The OBSW fails to record TM in the OBC persistent memory	A	3	Very low	Several tests simulating the physical environment will be performed at IDR facilities. In addition, HK and some scientific data downlinked to the GS will be stored in a database.
TC-SFW-670	the OBSW fails to trigger operational modes automatically	A	3	Very low	This risk can be avoided by performing extensive tests. In addition, the OBSW will be able to change between operational modes on request by TCs.
TC-SFW-680	the OBSW fails to trigger operational modes by TCs	D	1	Low	This risk can be avoided by performing extensive tests. In addition, the OBSW logic will be tested independently.
TC-SFW-690	Connection lost between the OBSW and GSSW	D	1	Low	This risk cannot be avoided but handled. The OBSW will implement

					FDIR functions to ensure that it still works when connection to the GSSW is lost. FDIR functionality is going to be tested simulating dropouts and physical connection and disconnections.
TC-SFW-700	The OBSW fails to recover its last status	C	2	Low	The OBSW will save the system and subsystems status (operational modes, the absolute and relative time) periodically. This functionality is going to be tested.
TC-SFW-710	The OBSW fails to switch off the experiments before landing	B	2	Very low	Extensive tests simulating the physical environment (TVAC) since it involves the OBSW and the hardware components and connections.
TC-SYS-720	Wrong or deficient information exchange between subsystems	B	2	Very Llow	Using concurrent engineering methodology with common files in the cloud to provide access to all subsystems.
VE-EPW-730	Malfunction of the Gondola battery	A	4	Low	Activation of the power safe mode in which only the OBC and specific experiments are switched on
VE-HTL-740	Other BEXUS experiments or the gondola interfere with the FOV of the upward radiative sensors	C	2	Low	The gondola will interfere in the FoV. Several analyses will be done with ESATAN-TMS to consider this effect quantifying the gondola reflection. BEXUS programme shall provide the thermo-optical properties of the gondola windshield. Same process will be done with the balloon influence. BEXUS programme shall provide the thermo-optical properties of the balloon film.

VE-HTL-750	Other BEXUS experiments or the gondola interfere with the FOV of the downward radiative sensors	B	2	Very low	The gondola will interfere in the FoV. Several analyses will be done with ESATAN-TMS to take into account this effect quantifying the gondola reflection. BEXUS programme shall provide the thermo-optical properties of the gondola windshield.
VE-HTL-760	Not receive the approval to position the environmental lab outside the gondola	C	2	Low	ACTIONS to be discussed with responsible of BEXUS programme
VE-MEC-770	Mechanical interfaces designed do not fit the Gondola	C	4	Medium	Constant contact with the BEXUS team

4 EXPERIMENT DESCRIPTION

4.1 Experiment Setup

Based on the experiment concept presented in Section 1.4, a description of the experiment Setup is shown in Figure 4-2. According to the division made for the 4 main parts of the experiment, a brief description of the hardware design and the performance is described

The **Environmental Lab**, whose main objective is to characterize the radiative thermal environment would be placed out of the gondola structure through two brackets attached to the upper and lower part of it. On the called Upward Environmental Lab, a pyranometer and a pyrgeometer sensor will be placed as well as in the Downward Environmental Lab. These are commercial components commonly used for meteorological stations. They would be thermally protected from the wind to provide them with a suitable environment.

Pyrgeometers aims at measuring the infrared thermal radiation in a bandwidth from 2 to 100 µm while the pyranometer aims at measuring the Solar radiation which goes from 0.2 to 2 µm. The selected infrared radiation sensor, IR20 from Hukseflux, will provide the incoming radiation in a bandwidth from 4.5 to 40 µm where most part of the emitted radiation by the sky and the Earth is included. The selected solar radiation sensor, SR20 from Hukseflux, will provide the incoming radiation in a bandwidth from 0.285 to 3 µm where most part of the Solar radiation, accounting with the atmosphere absorption, is located. Ranges of the selected sensors are drawn in Figure 4-1 together with the atmospheric infrared spectrum and perfect blackbody temperatures (black).

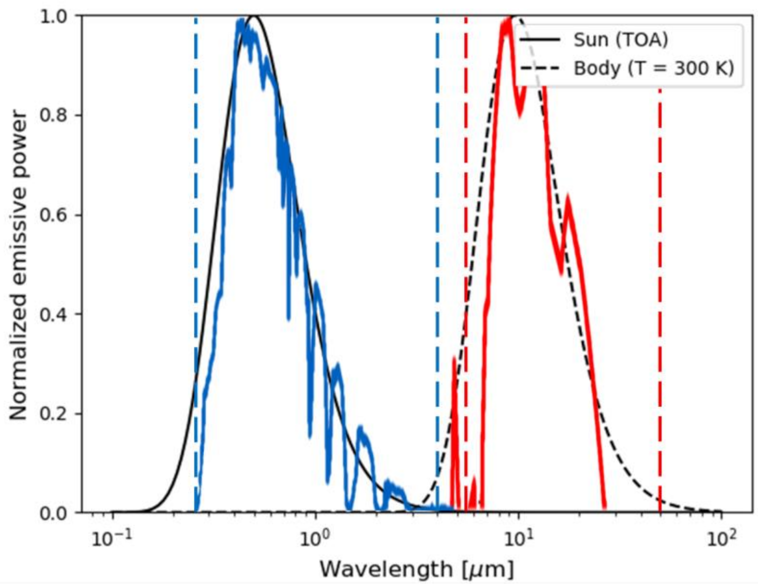


Figure 4-1. Pyranometer and pyrgeometer measuring wavelength (dashed lines).

As Hukseflux state in the User's manual [11], the downwelling longwave radiation from the Earth surface essentially consists of several components:

- Low temperature radiation from the universe, filtered by the atmosphere,
- Temperature radiation emitted by atmospheric gasses and aerosols.
- In presence of clouds or mist, the low temperature radiation from the universe is almost completely blocked by the water droplets.

In contrast, the upwelling longwave radiation is mainly affected by the emitted radiation by the Earth surface. It would only depend on its temperature and infrared emissivity.

As the experiment will be increasing its altitude during the ascent phase, the equivalent sky temperature will be decreasing up to a value of 3 K which is the equivalent blackbody temperature of the deep space.

In contrast, direct solar radiation will account for the “beam” radiation which varies with the cosine of the angle of incidence [11]. The upwelling solar radiation together with the upwelling solar radiation reflected by the Earth would be used for obtaining the Earth albedo during the flight.

IR20 and SR20 has an onboard heater and a temperature sensor. Heating the sensor, measuring the body temperature and using the correction of the temperature response, all contribute to the dependability and accuracy of the measurement.

The **Attitude Lab** would provide the nadir direction of the gondola during the float phase. It is based on the use of commercial photodiodes which would provide a measurement of the infrared radiation coming from its Field of View with the Earth. This is why minimizing the interference with other elements on board the gondola structure is so important. This nadir sensor will be placed in the Downward Environmental Lab and will also carry a temperature sensor for correcting the measurements after the flight.

Inside the gondola structure the Heat Transfer Lab will carry experiments 1 to 4 based on silicon heaters covered by aluminium plates and positioned in different configurations to quantify convective heat transfer. Heater power would be controlled by the electronics based on the configured powers modes during the flight. The ground station user will be also capable of controlling the dissipated power based on the evolution of the temperatures during the flight. For that reason, the plates and cavity temperatures would be monitored from the ground station. In addition, all wall temperatures will be measured. To do so, PT100 thermistors will be used using 3 wire connections. Experiment 4 will quantify the efficiency of an own manufactured thermal strap that will be connected to a radiator facing outside the gondola.

Experiment 5 will be also placed on a surface looking to outside the gondola to measure the relative wind speed using differential pressure sensors.

All these Labs will be connected through D-Sub type connectors to the **Electronic Box** where analogue signals will be converted to digital signals in different PCBs and then processed by the OBC. Electronics have been structured in four different PCBs:

- Sensors Data Processing Unit (SDPU): It is responsible of receiving the pyranometer, pyrgeometer and nadir sensor signals and to convert them into a multiplexed signal to be processed by the OBC. Additionally, it will read the Environmental and Attitude Lab temperatures.
- Power Control Unit (PCU): This PCB would be the responsible of converting the 28.8 V coming from the gondola power supply into a 12 V and a 5 V voltage lines. In addition, a protection circuit would be included as well as a voltage and current measurement system to monitor the state of the battery. Power dissipation of the 4 Heat Transfer Lab Heaters as well as the pyranometers and pyrgeometers would be controlled by using MOSFETs components through the 12 V line.
- Temperature Measurement Unit (TMU): It is the responsible of converting the HTL temperature analogue signals into digital signals. Only one 1-channel ADC is used. Consequently, multiplexers are used to select the 28 PT100s, these are controlled by the OBC.
- Navigation and Attitude Determination Unit (NADU): This PCB will carry a GPS (connected to an external antenna) as well as an Inertial Measurement Unit to correlate the Attitude Lab and the Experiment 5 measurements.

- On Board Computer (OBC): A Raspberry Pi Compute Module 3+ has been selected for controlling and processing the sensors measurements and actuators commands. It will be connected to the E-Link provided by the gondola.

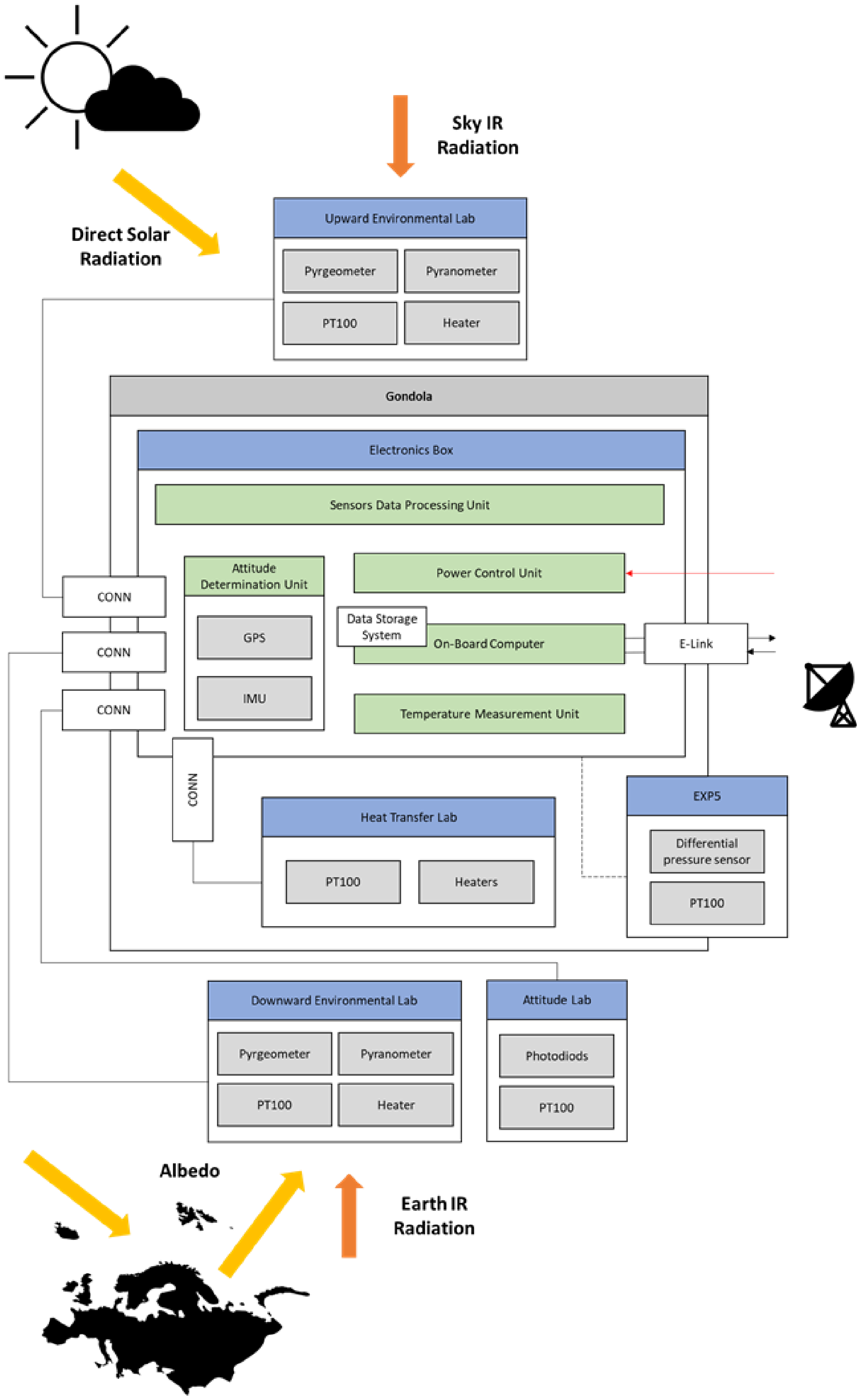


Figure 4-2. Experiment setup diagram.

4.2 Experiment Interfaces

4.2.1 Mechanical

Gondola – Main Structure (E-Box/HTL)

The main structure was fixed to the gondola rails through 8 brackets and 4 intermediate pieces. The rails in the Gondola required M6 screws and hammer nuts, which are not possible to fix directly to the Main Structure, as it uses 15x15 rails and M3 screws. Two 30/30 brackets were fixed to the Gondola rails M6 screws and hammer nuts and to an intermediate piece with M6 screw and helicoil. The intermediate piece has an L shape and was fixed to the structure rail with five M3 screws, two on the side and three on the bottom. The two intermediate pieces used for the lateral brackets were longer on the bottom than the other two as the plate thickness in that side was bigger.

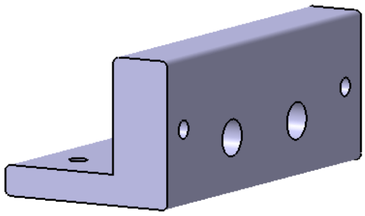


Figure 4-3. Intermediate component for Gondola interface.

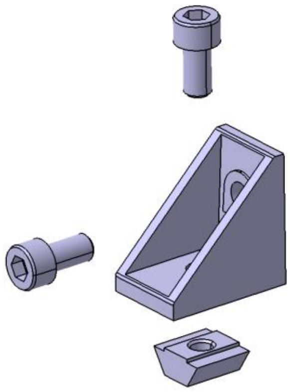


Figure 4-4. Series 6 Brackets.

Gondola – Upward Environmental Lab

The Upward Environmental lab had to be situated on the Gondola roof so that the sensors would not get as many interferences from the it. A clamp was designed to attach the two lab rods to the Gondola. It would close with four M5 screws and it would have rubber on the inside for the clamp to properly work. The rods would be fixed with a M4 screw and nut. For safety reasons, it will be secured with a safety cable.

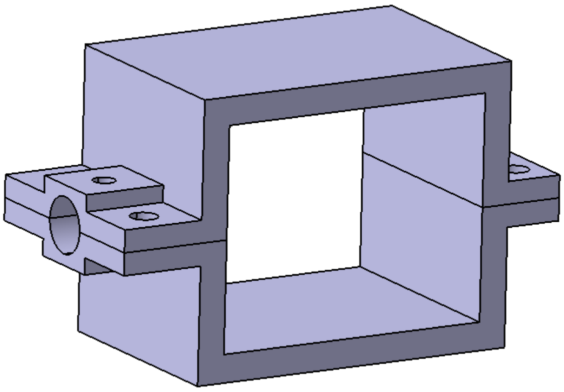


Figure 4-5. Clamp system for the Upward Envrionmental Lab

HTL – E-Box

A very simple and flexible interface was designed for the HTL and the Ebox. The two boxes would be fixed together through a thin flat bracket that allowed for three screws to each box. Three flat brackets were used in total to fix the rails that were in contact between both boxes, located on the top, front and back of the boxes.

The ideal positioning of the experiment in the Gondola along with the interface points can be seen in the following figures.

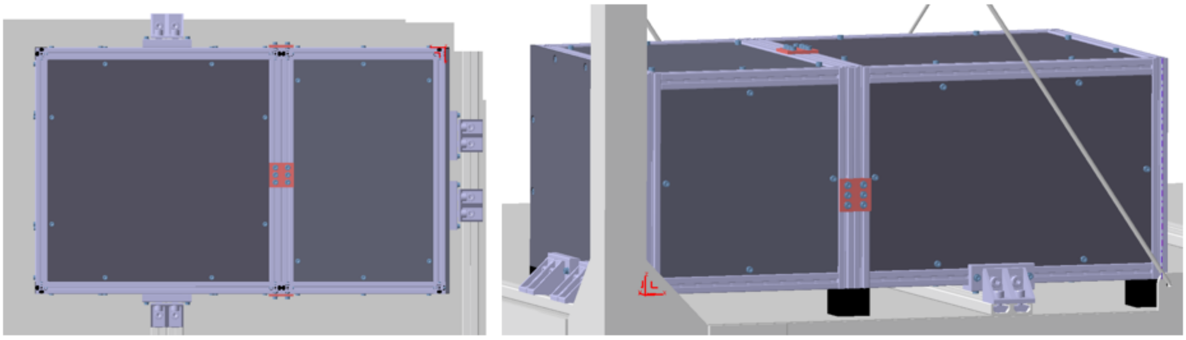


Figure 4-6. I/F to the Gondola and between the HTL and E-Box

Downward Environmental Lab – Main Structure

The downward environmental lab rods are fixed to the Main Structure through a designed component that would be screwed to the bottom of the rail, so that a face would be in contact the Main Structure and the other with the Gondola floor. The rods would be fixed to the piece with an M4 screw. For safety reasons, it will be secured with a safety cable.

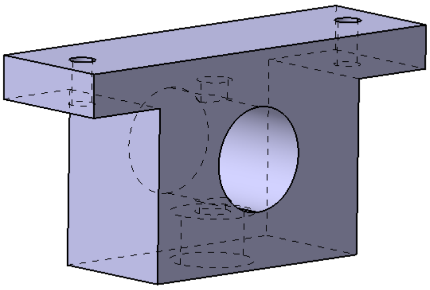


Figure 4-7. Environmental Lab union to the Main Structure

4.2.2 Electrical

E-Link

As described in the BEXUS User Manual and stated in the requirements, the OBC shall be connected to the E-Link airborne unit through the Amphenol RJF21B (CODE A), see Figure 4-8. The OBC does not include any Ethernet module. However, there is one UART and one USB 2.0 available for RJ45 adapters.

Figure 4-8. Amphenol RJF21B connector.

This connector supports UTP Cat 5e per TIA/EIA 568B, i.e.: up to 1 Gbps speed, which is more than enough for the bandwidth budgets of this experiment.

Electrical power supply

The experiment will be powered by one of the 28.8 V battery packs of the BEXUS gondola. This battery will be connected to the experiment through a receptacle MIL-C-26482P connected to a MS3112E8-4P connector that will be mounted in a lateral side of the structure experiment.

4.2.3 Thermal

As it was depicted in Section 4.2.1, the mechanical interface between HERCCULES and the gondola is limited to brackets and six rubber supports. Therefore, the conductive heat flow from the gondola to HERCCULES will not be relevant. This fact is important because if the gondola base is heated by other experiments, there will be no consequences in HERCCULES experiments.

Regarding the radiative thermal loads from the gondola and other experiments, two aspects are relevant. Firstly, due to the low IR emissivity of the HERCCULES faces, the radiative influence may not be relevant. However, knowing the wall temperatures profiles of other experiments during the mission, the radiative influence will be estimated through the TMM developed in ESATAN-TMS.

Besides, due this configuration, HERCCULES may not influence in the thermal behaviour of other experiments.

4.3 Experiment Components

4.3.1 Heat Transfer Lab / Environmental Lab

Quantity	Component	Supplier	Cost [€]	Mass [g]	Description	Status*
2	Aluminium plates EXP1	RS	3.75	3.375	Plate EXP1	To be ordered
2	Aluminium plates EXP2	RS	3.75	3.375	Plate EXP2	To be ordered
2	Aluminium plates EXP3	RS	3.75	3.375	Plate EXP3	To be ordered
6	Aluminium plates EXP4	RS	14.88	379.08	Plates EXP4	To be ordered
16	Delrin supports	RS	10	27	This support shall work as conductively insulator	To be manufactured
2	Radiator		7.5	6.75	Radiator of EXP3	To be manufactured
1	Strap	IDR	0	41.1	PGS strap for EXP3	Confirmed
6	RS Pro Silicon Heater Mat. No 245-499	RS	126.78	30	Heaters EXP1-EXP3 25 x 50 mm, 12 V dc, 1,25 W	To be ordered
40	Temperature sensors PT100 No NB-PTCO-002	RS	1.15	-	100 Ohms, 2.0 mm x 2.3 mm, F 0.3 (B), Ni/Au-wire	To be ordered
2	RS Pro Silicon Heater Mat. No 245-528	RS	26.26	20	Heaters EXP4 50 x 100 mm, 12 V dc, 5W	To be ordered
2	Pyranometer SR20-T2-05	Geonica	1770	500	Net weight including 5m cable. Power include1.5 W heater (Not required)	To be ordered
2	Pyrgeometer IR20-T2	Geonica	3275	500	Net weight including 5m cable. Power include1.5 W heater (Not required)	To de ordered
4	Differential Pressure Sensor LDES050BF6S	Mouser Electronics	96.37	10	Needs to be heated	To be ordered
8	Flexible tube	TBC	4	10	Flexible tube to transmit pressure to sensors.	To be designed

1	Anemometer structure	IDR	20	182.84	Anemometer structure	To be manufactured
8	Tube connectors	IDR	5	4	Connection of tube to anemometer structure	To be designed

4.3.2 Attitude Lab

Quantity	Component	Supplier	Cost [€]	Mass [g]	Description	Status*
6	Photodiode Lms41PD-03	MicroTech BG	50	0.29	Four units for Bexus cargo. To be connected to the PD preamplifier. Cables not included. Shipment cost (Not included) of 50 € shared with all the MicroTech BG components.	To be ordered
2	LED Lms38LED	MicroTech BG	30	0.29	Part of the experimental setup (Not Bexus). Shipment cost (Not included) of 50 € shared with all the MicroTech BG components.	To be ordered
6	Photodiode Preamplifier PAb	MicroTech BG	55	12.5	Four units for Bexus cargo. To be connected to the PDs. Cables not included. Shipment cost (Not included) of 50 € shared with all the MicroTech BG components.	To be ordered
2	LED Control Board MD-1c	MicroTech BG	55	12.5	Part of the experimental setup (Not Bexus). Shipment cost (Not included) of 50 € shared with all the MicroTech BG components.	To be ordered
2	Male Conector L717HDE15P	RS (Amphenol ICC)	1.38	5.08	15-pin high density D-sub Male to be mounted on the sensor.	To be ordered

4	Thermocouple / AD590 / PT1000 (TBC)	TBD	TBD	TBD	Thermal sensor to determine the temperature of the photodiodes.	To be ordered
20	Hex Socket Head Cap Screw ISO 4762 M3x6 SCB3-6	Misumi	0.21	0.82	Stainles Steel screws (A2).	To be ordered
20	Hex Socket Head Cap Screw ISO 4762 M3x12 SCB3-12	Misumi	0.27	1.14	Stainles Steel screws (A2).	To be ordered
40	Washer M3 SPWF3	Misumi	0.17	0.12	Stainles Steel washers (A2).	To be ordered
10	Screwlock D Connector 453-886	RS PRO	1.006		Nickel finish.	To be ordered
50	Threaded Insert UD-43001 (TBC)	Misumi (Tokai Metal Industry)	0.28	0.46	Compatible with Ultem 1010, Ultem 8095 and ABS-M30. Press fit.	To be ordered
1	Nadir Sensor Main Body 1	IDR	156.64	29	Material: Ultem 1010/8095 (TBC), prototype in ABS-M30. Mass provided for Ultem 1010	Designed
1	Nadir Sensor Main Body 2	IDR	111.76	23	Material: Ultem 1010/8095 (TBC), prototype in ABS-M30. Mass provided for Ultem 1010	Designed
1	Nadir Sensor Main Body 3	IDR	102.08	17	Material: Ultem 1010/8095 (TBC), prototype in ABS-M30. Mass provided for Ultem 1010	Designed
1	Nadir Sensor Base	IDR	146.96	22	Material: Ultem 1010/8095 (TBC), prototype in ABS-M30. Mass provided for Ultem 1010	Designed
1	Conector Support	IDR	84.48	3	Material: Ultem 1010/8095 (TBC), prototype in ABS-M30. Mass provided for Ultem 1010	Designed
1	PCB Support	IDR	95.92	TBD	Material: Ultem 1010/8095 (TBC), prototype in ABS-M30. Mass provided for Ultem 1010	Designed

4	Photodiode Support	IDR	78.32	2	Material: Ultem 1010/8095 (TBC), prototype in ABS-M30. Mass provided for Ultem 1010	Designed
5	DMux (TBD)	RS	TBD	TBD	DMux for the 5V and GND imput signals from the gondola. To be shared by the preamplifiers	To be ordered

4.3.3 Electronics

Quantity	Component	Supplier	Cost [€]	Mass [g]	Description	Status*
2	GPS MIKROE-1032	RS Componentes	52	34	Net weight without including the antenna	To be ordered
4	Digital temp. sensor: MAX31820	RS Componentes	3.1	0.217		To be ordered
18	MOSFET: IRFZ44PbF	Mouser Electronics	1.62	2.24	Quantity depends on the amount of heaters	To be ordered
4	Multiplexer TMU: ADG732BCPZ	Mouser Electronics	10.69	0.26	32-Channel Multiplexer	To be ordered
4	ADC TMU: MCP3201	RS Componentes	2.38		Max sampling rate: 100ksps, resolution: 12 bit	To be ordered
8	ADC SDPU: MCP3201	RS Componentes	2.38		Max sampling rate: 100ksps, resolution: 12 bit	To be ordered
4	Multiplexer SDPU: CD74HCT4351E	Mouser Electronics	0.919	1.199	8-Channel Multiplexer	To be ordered
2	Raspberry Pi Compute 3+ 32GB (CM3+)	RS Componentes	0	9	The eMMC and LPDDR2 have the narrowest range, these are rated for -25 to +80 degrees Celsius.	To be ordered
2	RPi CM 3+ I/O board	RS Componentes	92.41	TBC	The CM 3+ will bea attached on top of the CM IO board.	To be ordered
4	PCU	TBD	60	TBC		To be ordered

4	TMU	TBD	60	TBC		To be ordered
4	SDPU	TBD	60	TBC		To be ordered
4	OBC PCB connector	TBD	60	TBC		To be ordered
2	Sensor inercial Absoluto 9 DOF BNO055	BricoGeeK	34.9	? <50	Fair precision, good price, Magnetometer	To be ordered
4	Pressure sensor MS5611-01BA03, Hailege module	TE conectivity	11.49	TBC	-	To be ordered
3	R-78B5.0-2.0	RS	36.81	4	5V 2A DC/DC converter	To be ordered
3	R-78B12-2.0	RS	36.81	4	12V 2A DC/DC converter	To be ordered
2	MS3112E8-4P	MOUSER	30.06	10.807	Gondola power connector	To be ordered
10	SEK100M050ST	MOUSER	3.44	0.479675	DC/DC filter capacitor	To be ordered
10	SEK4R7M050ST	MOUSER	3.44		DC/DC filter capacitor	To be ordered

4.3.4 Mechanical Structure

Quantity	Component	Supplier	Cost [€]	Mass [g]	Description	Status*
12	PAAL-170-270-1	MISUMI	28.74	0.124	lateral walls of HTL and Top/bottom wall of Ebox	To be ordered
4	PAAL-270-270-1	MISUMI	32.83	0.197	top/bottom wall of HTL	To be ordered
2	PAAL-395-195-1-CN12	MISUMI	36.59	0.154	interior wall of HTL	To be ordered
4	PAAL-146-195-1	MISUMI	24.4	0.076	interior wall of HTL	To be ordered
2	PAAL-170-270-5	MISUMI	29	0.807	anemometer wall	To be ordered
4	PAAL-170-170-1	MISUMI	24.4	0.078	Front back wall of Ebox	To be ordered
16	HFS3-1515-200	MISUMI	3.71	0.068	Z direction rail	To be ordered
24	HFS3-1515-270	MISUMI	3.71	0.092	lateral frames of HTL (all), Y direction frames of E box	To be ordered

8	HFS3-1515-170	MISUMI	3.71	0.058	X direction frames of Ebox	To be ordered
104	HBLPBS3	MISUMI	2.76	5.50E-04	blind bracket	To be ordered
312	HNSQ3-3	MISUMI	0.31	1.64E-04	square nut*	To be ordered
4	RDOK10-180	MISUMI	5.97	0.038	support bracket	To be ordered
4	RDOK12-600	MISUMI	10.04	0.183	bracket for Down Env lab	To be ordered
4	RDOK10-500	MISUMI	10.04	0.106	bracket for Up Env lab	To be ordered
16	HBLFSN6-SET-b	MISUMI	1.66	0.016	bracket for Gondola Interface	To be ordered
32	HBLFSN6-_CBM6-12	MISUMI	0	0.006	bracket screw **	To be ordered
16	HNTT6-6_1	MISUMI	0	0.002	hammer nut	To be ordered
6	Union HTL/Ebox	IDR	0	TBD	flat bracket	Designed
8	Gondola I/F piece	IDR	0	0.049	Intermediate piece for gondola I/F	Designed
120	Panel Mount	IDR	0	0.003	insertion panel mount	Designed
2	U.Sensor support plate	IDR	0	0.287	sensor support	Designed
4	T Joint R10	IDR	0	0.016	bracket support union	Designed
8	Ext I/F clamp	IDR	0	0.064	gondola I/F	Designed
2	D.Sensor support plate	IDR	0	0.415	sensor support	Designed
4	T Joint R12	IDR	0	0.017	bracket support union	Designed
4	Soporte Down Env Lab	IDR	0	0.028	Union I/F	Designed
12	Rubber stands	IDR	0	0.027	support	Stock
228	screw M3x6	IDR	0	TBD	ISO 4762	Stock
36	screw M3x8	IDR	0	TBD	ISO 4762	Stock
152	screw M3x10	IDR	0	TBD	ISO 4762	Stock
16	screw M3x16	IDR	0	TBD	ISO 4762	Stock
8	screw M4x16	IDR	0	TBD	ISO 4762	Stock
20	screw M4x20	IDR	0	TBD	ISO 4762	Stock
24	screw M5x16	IDR	0	TBD	ISO 4762	Stock

8	screw M5x25	IDR	0	TBD	ISO 4762	Stock
80	washer 3x6	IDR	0	TBD	ISO 7089	Stock
144	washer3x7	IDR	0	TBD	ISO 7089	Stock
20	washer 4x9	IDR	0	TBD	ISO 7089	Stock
40	washer 5x9	IDR	0	TBD	ISO 7089	Stock
20	nut M4	IDR	0	TBD	ISO 4032	Stock
24	nut M5	IDR	0	TBD	ISO 4032	Stock

4.3.5 Summary

The main mechanical characteristics of the experiment components are summarized in Table , along with the expected Centre of Gravity of the entire experiment.

Table 4-1. Experiment summary.

	HTL	E-Box	Upward Env. Lab	Downward. Env. Lab	TOTAL
Experiment mass:	3.5 kg	3.2 kg	2 kg	2.2 kg	12 kg
Experiment dimensions:	0.3x0.3x0.2 m	0.205x0.3x0.2 m	0.57x0.25x0.2 m	0.35x0.6x0107 m	0.7x0.9x0.96 m
Experiment expected COG:	X:350 Y:150 Z:100	X: 63 Y: 150 Z: 100	X: 320 Y: -303 Z: 764	X: 261 Y: -400 Z: -25	X: 223 Y: 28 Z: 159

The reference axis system (Figure 4-9) was situated in one of the corners of the E-box frame, on the wall that would face to the outside of the gondola.

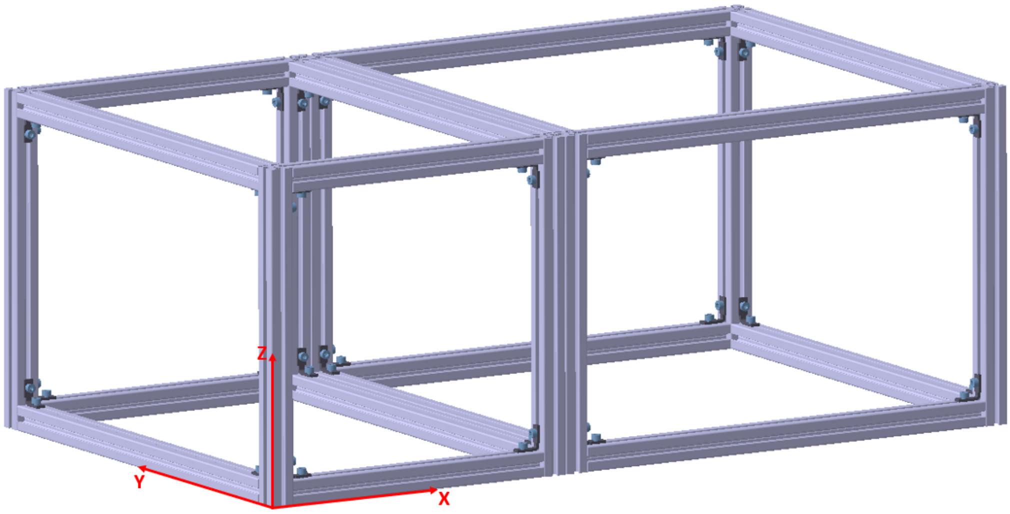


Figure 4-9. Reference Axis system of the experiment

4.4 Mechanical Design

4.4.1 Main structure

The experiment main structure consists of two rectangular boxes, the Heat Transfer Lab and the Electronic box. The frames of these boxes are aluminium extrusions with a 15x15 mm cross-section. The rails allow for an easy interface between both boxes and with other components. The frames were fixed together with blind brackets (Figure 4-10), providing enough stiffness to the box. All components are manufactured by MISUMI.

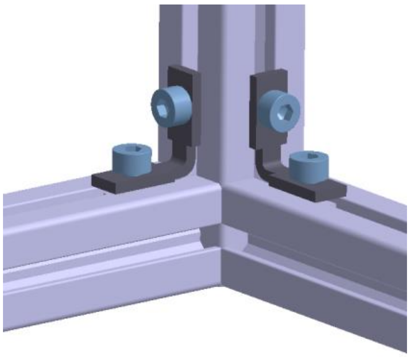


Figure 4-10. Blind brackets.

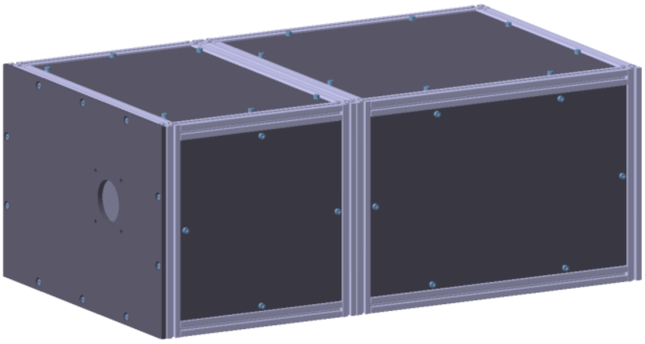


Figure 4-11. Main Structure configuration.

The HTL box has a 30x30x20 cm size and its interior is separated through sheet metal (aluminium) plates into four equal sections that home each of the four experiments. The plates have a 1mm thickness and are fixated to the frames and to each other at the centre with blind brackets.

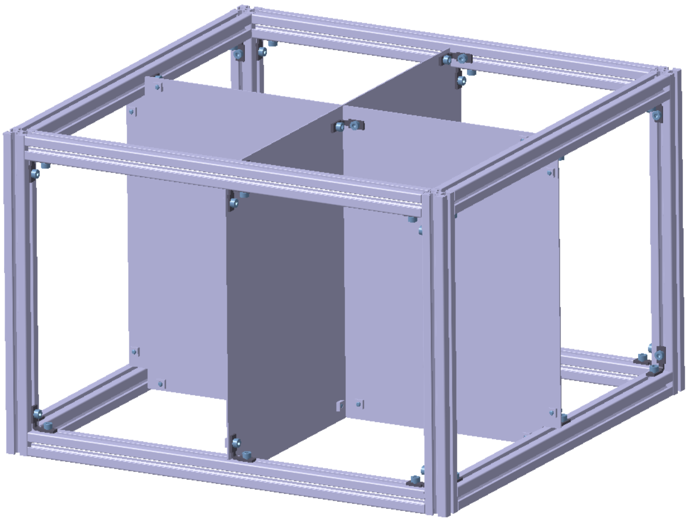


Figure 4-12. HTL interior configuration.

The box walls are also made of aluminium and have a 1 mm thickness. They are fixed to the frames by an insert panel mount that would go on the rails of the frames. As no panel mount was found in the market that could fit the 15x15 rails and M3 screws, one was designed specifically for it.

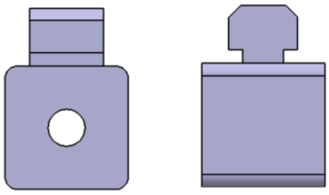


Figure 4-13. Insert panel mount.

The E-Box has a 20x30x20 cm frame. For design simplification and weight saving, the face of the E-Box that would be in direct contact with the HTL will not have a wall, as it is enough with the HTL wall. The plates on the XZ and XY planes were 1mm thick and used the same mounting method as the HTL, but because the anemometer had to be screwed into the E-Box with M5 screws, the plate on the YZ plane had its thickness increased to 5mm and was screwed directly to the frames.

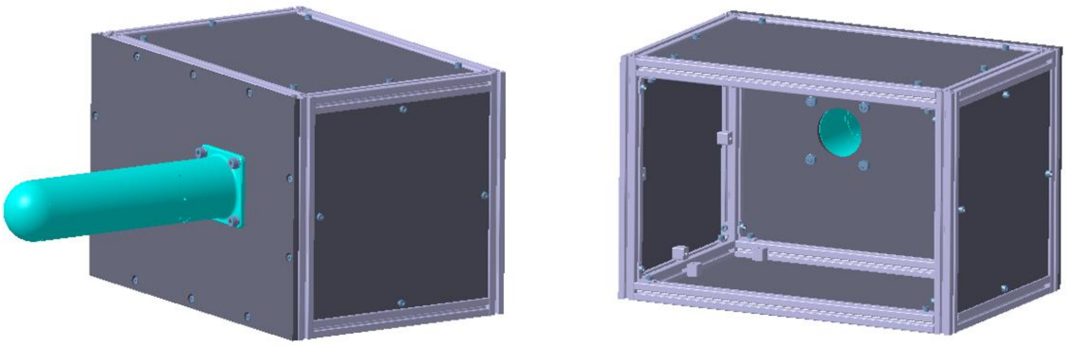


Figure 4-14. E-Box configuration.

4.4.2 Heat Transfer Lab

As it was depicted in Section 1.4, the HTL is composed by five experiments. EXP1, EXP2, EXP3 and EXP4 are located inside an envelope of 300x300x200 mm divided into four equally spaced cavities by four aluminium sheets. The dimensions of the plates that composed each experiment are defined in the following list:

- **EXP1.** The horizontal heated plate with dimension 50x25x1 mm is located in the centre of the cavity.
- **EXP2.** The vertical heated plate with dimension 50x25x1 mm is located in the centre of the cavity.
- **EXP3.** The radiator, with dimensions 50x50x1 mm, is attached to the windshield of the gondola through Velcro union type (TBC). The horizontal heated plate is located in the centre of the cavity but with a distance of 3 cm to the outer face due to limitations with the thermal strap length (115 mm including fittings). In Figure 4-15 it is shown the flexibility of the PGS thermal strap.

Figure 4-15. Thermal strap of HTL EXP3.

- **EXP4.** Three vertical plates with dimension 130x180x1mm are located in the cavity with a distance between them of 45 mm and 10 mm. The intermediate plate is the heated one.

In order to conductively isolate the plates, Delrin support are used. An example of this mounting is shown in Figure 4-16.

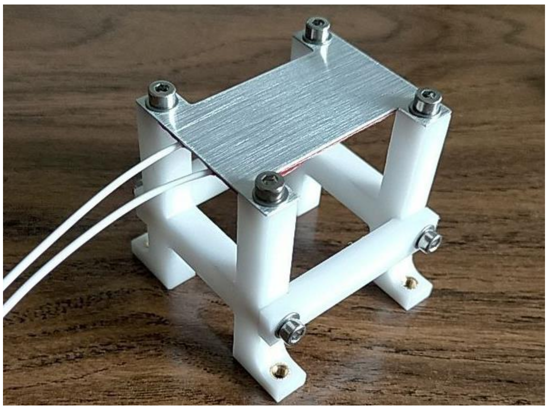


Figure 4-16. Example of conductive insulator support used in TASEC-Lab [12]**.**

Two types of heaters are selected to heat the plates. As EXP1, EXP2 and EXP3 plates have the same dimension, the heaters locate in these plates will be the same. However, as the EXP4 plates have greater dimensions, the selected heaters shall be also greater. The selected heaters are shown in Figure 4-17.

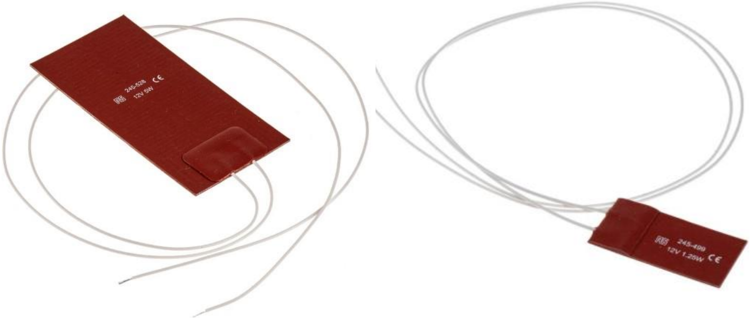


Figure 4-17. Preliminary heaters selected for HTL experiments (EXP4 heater at left and EXP1-3 heater at right).

4.4.3 Environmental Lab

Both the Upward and the Downward Environmental Labs follow the same main design philosophy, but different adjustments were made for each of them due to its specific circumstances of positioning in the gondola and requirements from the experiments.

The Upward Environmental Lab is attached to the gondola roof through the clamp system describe on a previous section. The Upward Environmental Lab only carries the pyrgeometer and the pyranometer, which have a 150 mm diameter, hence the support plate was designed to be as short as possible so that they would touch each other (230 mm). The support plate is connected through the gondola through two parallel rods of length 500 mm and diameter 10 mm, fixated in two points with M4 screws to each to the plate. For additional support, and auxiliary rod of 10 mm diameter is situated perpendicular to the other two rods, connecting them through a T-joint.

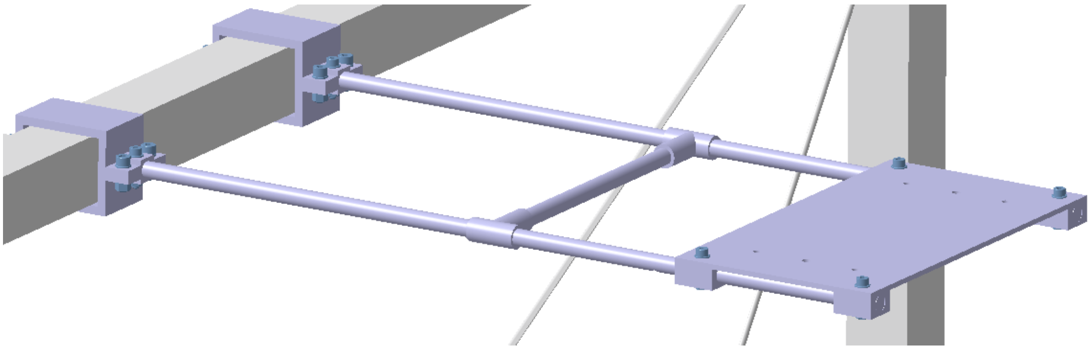


Figure 4-18. Upward Environmental Lab configuration

The Downward Environmental Lab is directly fixated to the Main Structure with the system described in the previous section. The rods are longer (600 mm) and wider (12 mm diameter) than in the Upward Environmental Lab as the Nadir Sensor needed as little interferences from the gondola as possible. The support plate length for the pyrgeometer, pyranometer and the nadir sensor also had to be increased to 350mm to allow room for all three and so that the nadir sensor field of view wouldn't be affected as much by the other two sensors, which is why it also had to be positioned over support stand to increase its height.

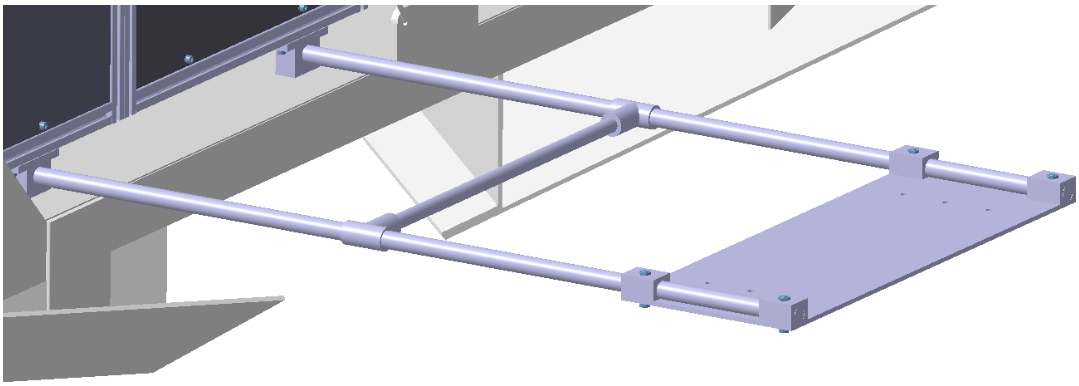


Figure 4-19. Downward Environmental Lab configuration

4.4.4 Attitude Lab

The design proposed for the Nadir sensor is mainly restricted by the photodiode's Field of View, the 50 x 50 x 50 mm envelope, and the manufacturing method based on COTS. All the designed parts are made via 3D-printing at the IDR/UPM facilities with Ultem 8095/ Ultem 1010 (TBC). The sensor carries four photodiodes, encapsulated in an adapter as shown in Figure 420, designed to restrict their Field of View to 10º and to avoid interferences with the gondola or other experiments.

Figure 4-20. Photodiode and adapter for the Nadir sensor.

The main body of the sensor is divided into three different sections, as enumerated in Figure 4-21. Section 1 and 2 are fixated together with four M3 screws and provide the support for the photodiodes' adapters, which are kept in place by compression. Sections 2 and 3 are adhesive bonded. Between these two sections the 15-pin connector is held in place with a custom adapter that is adhesive bonded to the sensor's main body.

Section 3 is fixated with four M3 screws to the Bottom Section of the sensor. This section allows the whole structure to be fixated in four/three points (TBC) (not included within the sensor's envelope) to the Downward Environmental Lab. The remaining space within the sensor contains the four photodiodes' preamplifier boards that are joined to the bottom section via a support structure (TBD).

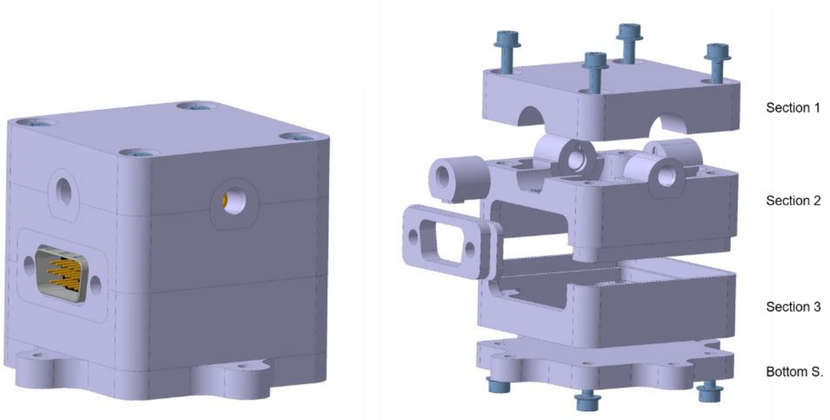


Figure 4-21. Nadir sensor design and its components.

4.4.5 Electronic Box

The electronics mechanical layout is still TBD.

4.5 Electronics Design

The HERCCULES experiment is composed of a set of experiments and subsystems that require PCBs (Printed Circuit Boards) to interface with each other, the OBC and PCU. These PCBs are going to be designed in-house following an incremental prototyping approach, where the circuit designs are tested and improved using breadboards. These prototypes evolve to stripboards and finally to PCBs. In addition, these preliminary models will help the OBSW development and testing.

The static aspects of the electronics subsystem are modelled with SysML (System Modelling Language) internal block diagrams (ibd). These models help to visually represent the physical entities, subsystems, and external components. Some of these blocks are then refined with electronic schematics.

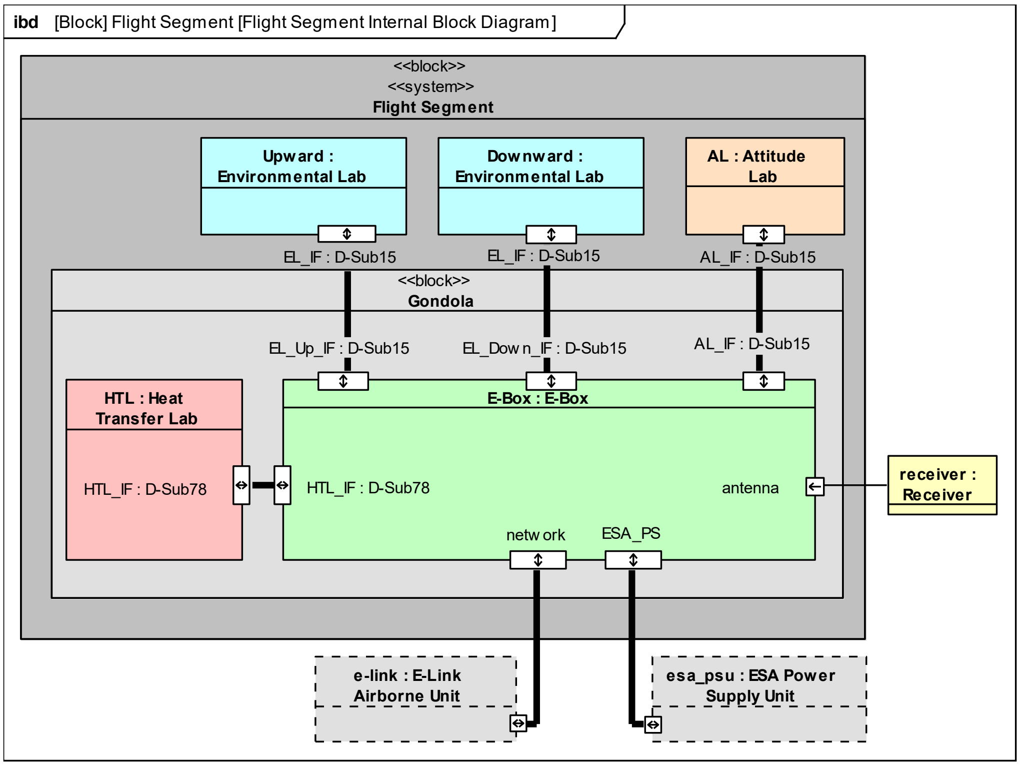


Figure 4-22. High-level block diagram from the experiment

4.5.1 Upward and downward Environmental Laboratory

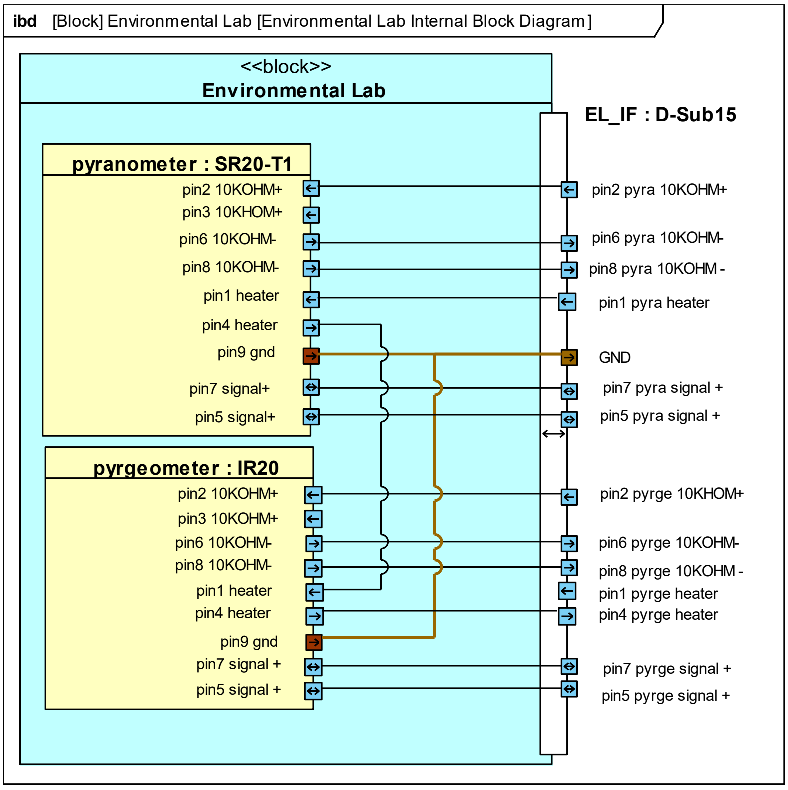


Figure 4-23. Up/Downward Environmental Lab internal block diagram.

4.5.2 Heat Transfer Laboratory

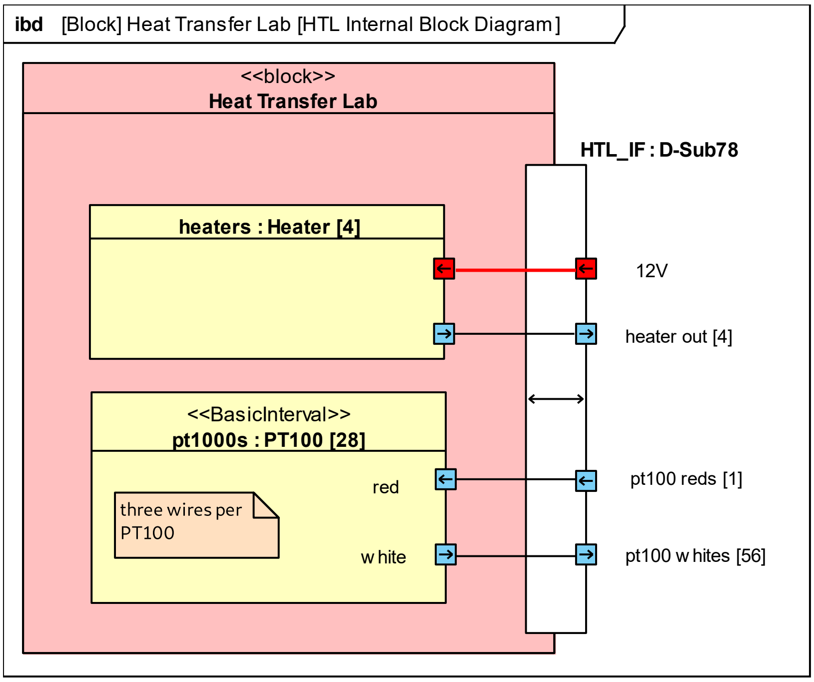


Figure 4-24. Heat Transfer Lab internal block diagram

4.5.3 Attitude Laboratory

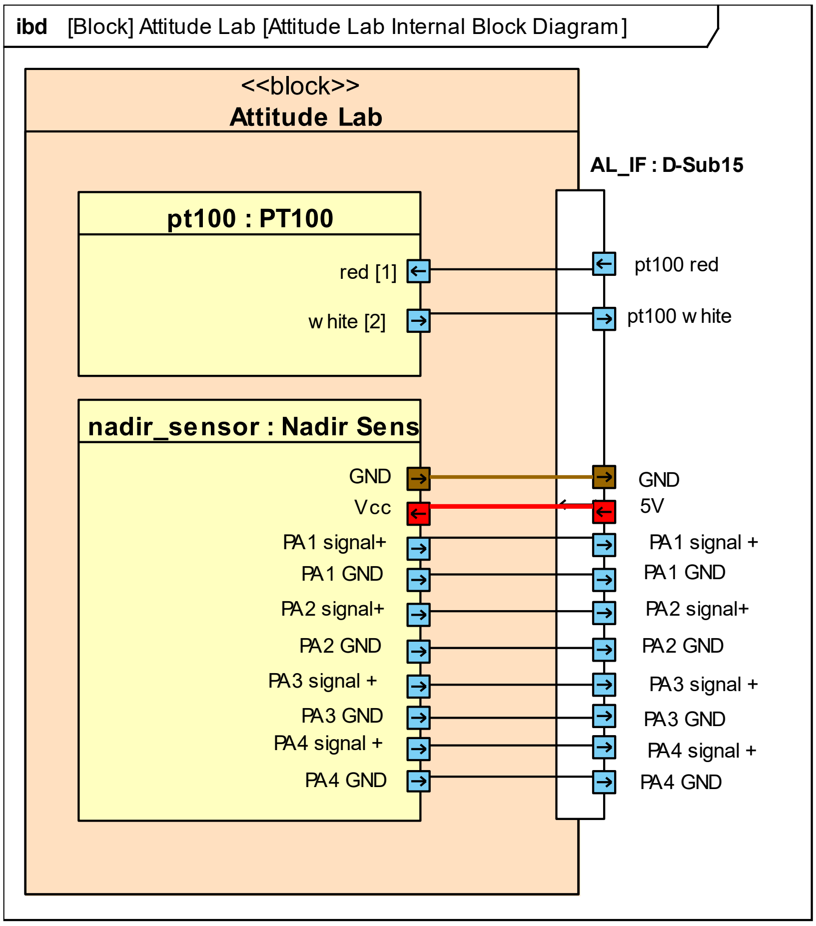
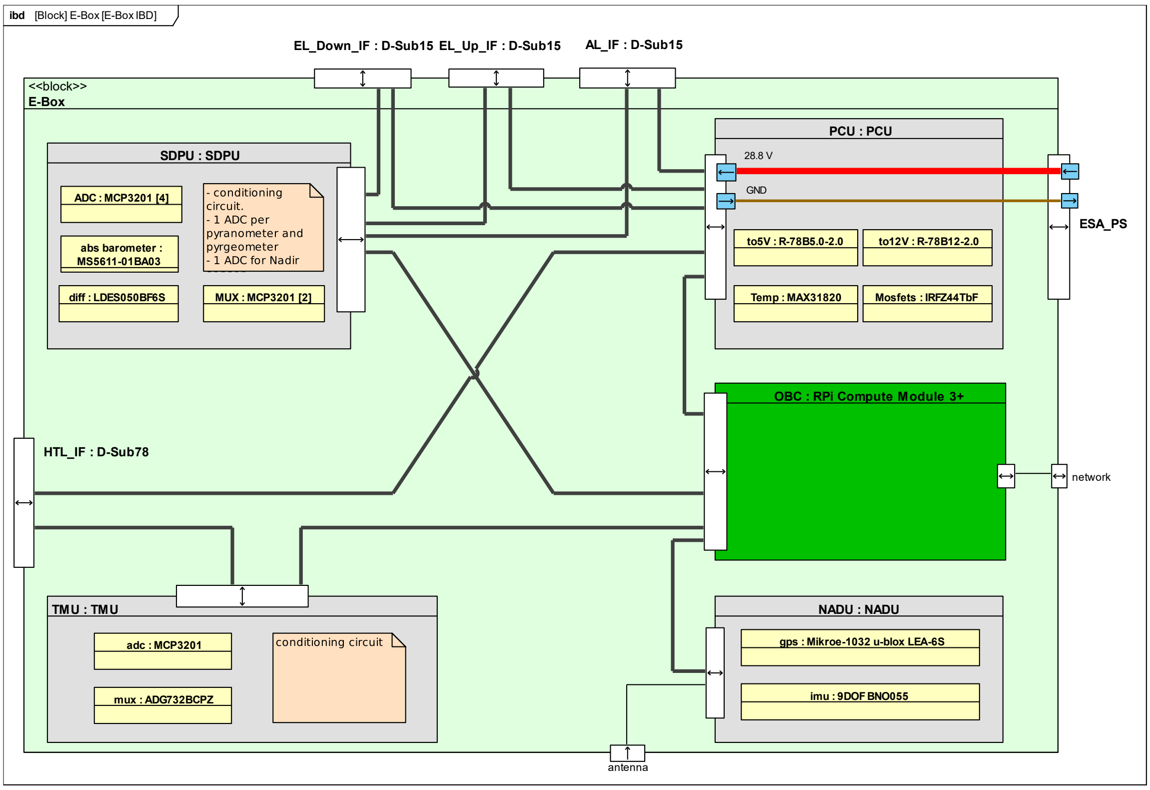


Figure 4-25. Attitude Lab internal block diagram

4.5.4 Electronic Box (E-Box)



Power Control Unit (PCU)

TBD

Sensor Data Processing Unit (SDPU)

TBD

Temperature Measurement Unit (TMU)

TBD

Navigation and Attitude Determination Unit (NADU)

TBD

4.6 Thermal Design

The aim of the Thermal Control System is to guarantee that all the components are inside their temperature range, not only the operational but also the survival. In order to identify the components where active or passive thermal control elements are needed, the operational and survival temperature range of the components are summarized in Table 4-2.

Table 4-2. Component's temperature range.

Component	Subsystem	Operational Temperature Range		Survival Temperature Range	
		Tmin [°C]	Tmax [°C]	Tmin [°C]	Tmax [°C]
Heaters	HTL	-	300	-	300
Pyranometer	ENL	–40	+80	–40	+80
Pyrgeometer	ENL	–40	+80	–40	+80

Differential pressure sensor	HTL	–20	+80	–40	+80
Nadir sensor	ENL	–20	+80	–40	+80
GPS MIKROE-1032	ELE	–40	85	-	-
Digital temp. sensor: MAX31820	ELE	–55	125	-	-
MOSFET: IRFZ44PbF	ELE	–55	175	-	-
Voltage regulator: L7805AB	ELE	–40	125	-	-
Voltage regulator: L7812AB	ELE	–40	125	-	-
Multiplexer TMU: ADG732BCPZ	ELE	–40	125	-	-
Multiplexer TMU: ADG726BCPZ	ELE	–40	85	-	-
ADC TMU: MCP3201	ELE	–40	85	-	-
ADC SDPU: MCP3201	ELE	–40	85	-	-
Multiplexer SDPU: CD74HCT4351E	ELE	–55	125	-	-
Raspberry Pi Compute 3+ 32GB (CM3+)	ELE	–25	80	-	-
RPi CM 3+ I/O board	ELE	–25	80	-	-
Sensor inercial Absoluto 9 DOF BNO055	ELE	–40	85	-	-
SDPU manufacturing	ELE	–40	85	-	-

From the thermal point of view, the most critical components are the pyranometers, the prygeometers and the nadir sensor due to the combination of their position (outside the gondola) and operational temperature range. These elements are exposed to the free air and the relative speed of the gondola. Therefore, during the ascent phase, the convective effects due to the combination of the low air temperature, specially at the tropopause and the relative speed may drive them to its minimum temperatures.

To reduce the impact of the convection in the external elements, two thermal control element types will be used. Firstly, a covering of foam will be used as passive element. Besides, the nadir sensor structure is made by Ultem 8095/ Ultem 1010 (TBC) (low thermal conductivity) working also as insulator. Secondly, the pyranometers and the pyrgeometers have the capability to power their inner heaters (1.5 W) and as the power dissipation of the nadir sensor will be 1.4 W it is possible to switch on the nadir sensor during the ascent phase also as active control.

Regarding the electronics, as the E-Box will be conductively decoupled from the gondola, the operational minimum temperature will not be reached during the whole mission.

4.6.1 Thermal analysis cases

To ensure that all thermal requirements are accomplished during the whole mission, the extreme thermal dimensioning cases have been analysed. Two transient cases defined as the hot and cold operational cases during the ascent phase, and two steady-state cases defined as the hot and cold operational at the float phase.

During the ascent phase, all radiative and convective parameters vary with the altitude so the steady state will not be reached in this phase. At the float altitude, as we are analysing steady states, which may never happen in flight conditions, we are defining an envelope between hot and cold steady states. The thermal environment definition for each thermal case is depicted in Appendix C

The thermal analyses and the nomenclature to use in this document from this point is presented in Table 4-3.

Table 4-3. Thermal analysis cases nomenclature.

Thermal analysis name	Stage	State	ID	Power mode
Hot operational transient case	Ascent	Transient	TR_HOC	Ascent phase
Cold operational transient case	Ascent	Transient	TR_HOC	Ascent phase
Hot operational steady-state case	Float	Steady	SS_HOC	Float phase
Cold operational steady-state case	Float	Steady	SS_COC	Float phase

Due to the convective effects, we expect to reach the minimal temperature at TR_COC and the maximum temperature at SS_HOC.

4.6.2 Power dissipation

The power dissipations that have been considered for the thermal analysis are summarized in Table 4-4.

Table 4-4. Power dissipation for the thermal analysis cases.

Component	TR_COC		TR_HOC		SS_HOC		SS_COC	
	Power dissipa-tion [W]	Duty cycle [%]	Power dissipa-tion [W]	Duty cycle [%]	Power dissipa-tion [W]	Duty cycle [%]	Power dissipa-tion [W]	Duty cycle [%]
Heater EXP1	1.0	100	0.8	100	TBD	TBD	TBD	TBD
Heater EXP2	0.5	100	0.5	100	TBD	TBD	TBD	TBD
Heater EXP3	1.5	100	1.0	100	TBD	TBD	TBD	TBD
Heater EXP4	3.5	100	3.5	100	TBD	TBD	TBD	TBD
Upward pyranometer	1.5	58	1.5	37	TBD	TBD	TBD	TBD
Upward pyrgeometer	1.5	57	1.5	34	TBD	TBD	TBD	TBD
Downward pyranometer	1.5	53	1.5	30	TBD	TBD	TBD	TBD
Downward pyrgeometer	1.5	51	1.5	30	TBD	TBD	TBD	TBD
Nadir sensor	1.5	TBD	1.5	TBD	TBD	TBD	TBD	TBD
OBC	1.5	100	1.5	100	TBD	TBD	TBD	TBD
PCU	1.5	100	1.5	100	TBD	TBD	TBD	TBD

4.6.3 Geometrical and Mathematical Model description

The GMM and TMM of HECCULES have been developed in ESATAN-TMS. In order to properly simulate HERCCULES thermal behaviour, the gondola has been also included based on [13] and the gondola CAD model.

The GMM is presented in Figure 4-26 and Figure 4-27.

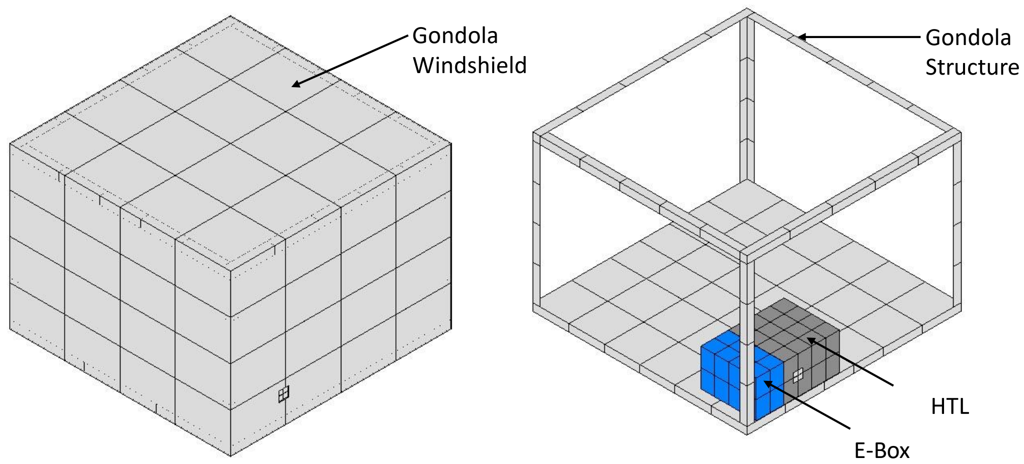


Figure 4-26. GMM of the gondola and HERCCULES. (At right windshield is removed).

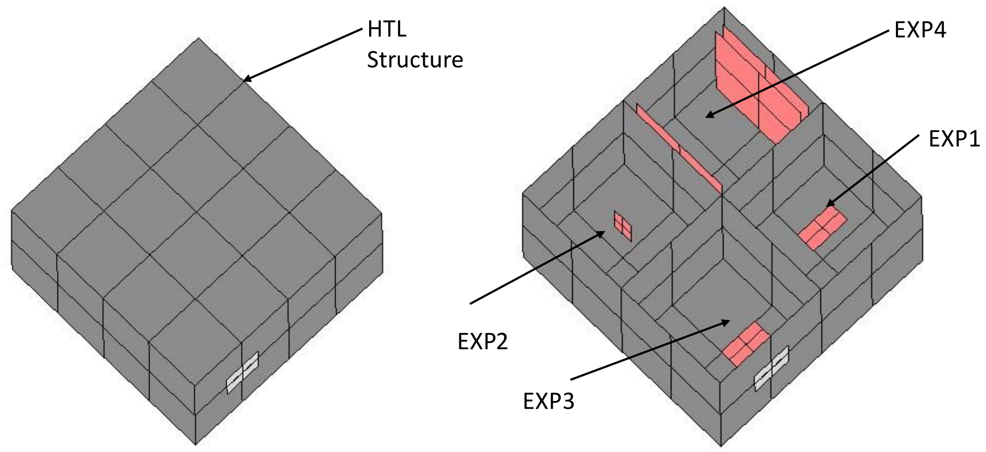


Figure 4-27. GMM of HTL. (Z+ closure panels are removed at right).

Forced convection is considered for the outer elements, whereas natural convection is considered for inner elements. Both types of definitions are based on empirical correlation. Besides, a mass flow between the free air and the gondola inner air has been considered.

4.6.4 Results

In this section, the relevant components temperature (without uncertainty margins) obtained in the different thermal analysis cases are presented.

Ascent Phase.

In this subsection, the results obtained during the ascent phase are presented. Not only has been the simulation implemented for the ascent phase but also for the first moments of the float phase, assuming that there is no variation of thermal environment.

<u>Hot Operational Transient Case</u>

The temperature of HTL external walls and the inner gondola air, compared with the free air is presented in Figure 4-28.

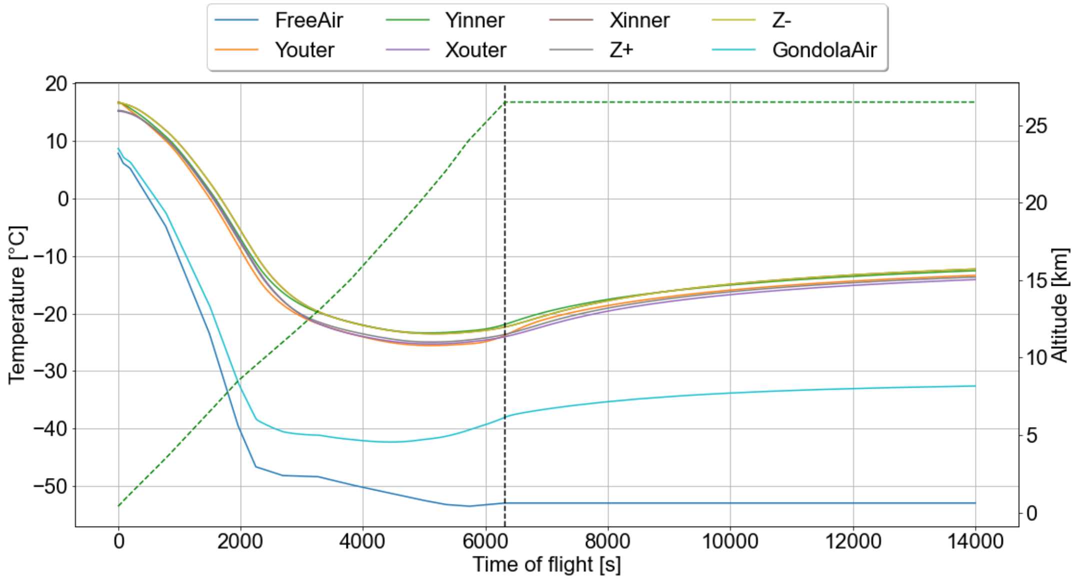


Figure 4-28. HTL structure, inner gondola air and free air temperature at TR_HOC.

The temperature of HTL heated plates and the air of each cavity temperature is presented in Figure 4-29.

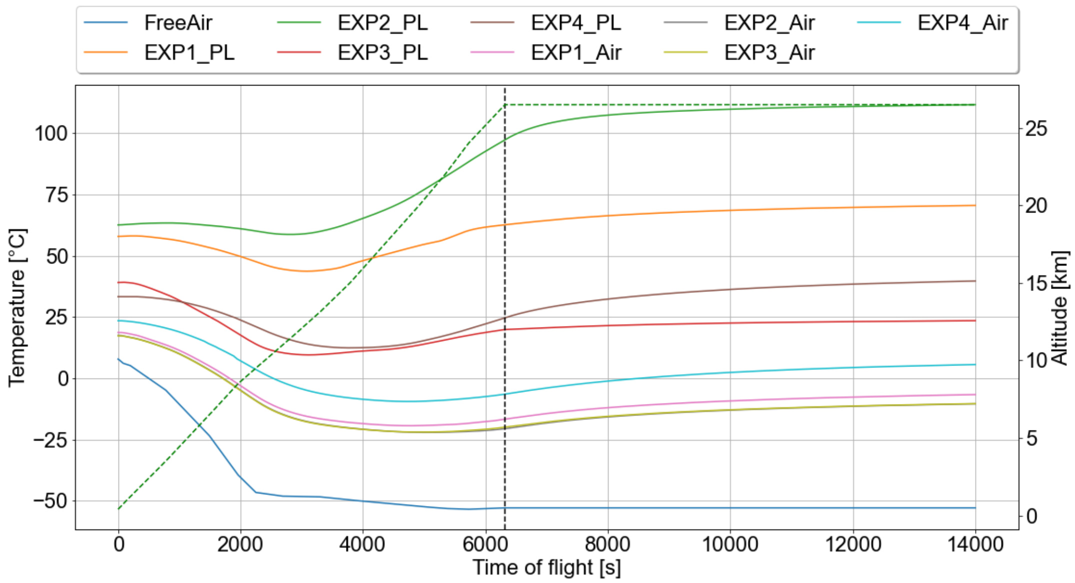


Figure 4-29. Heated plates temperature and HTL air cavities temperature at TR_HOC.

Finally, the temperature of the pyranometer at the Upward and Downward Environmental Lab is compared with the free air in Figure 4-30.

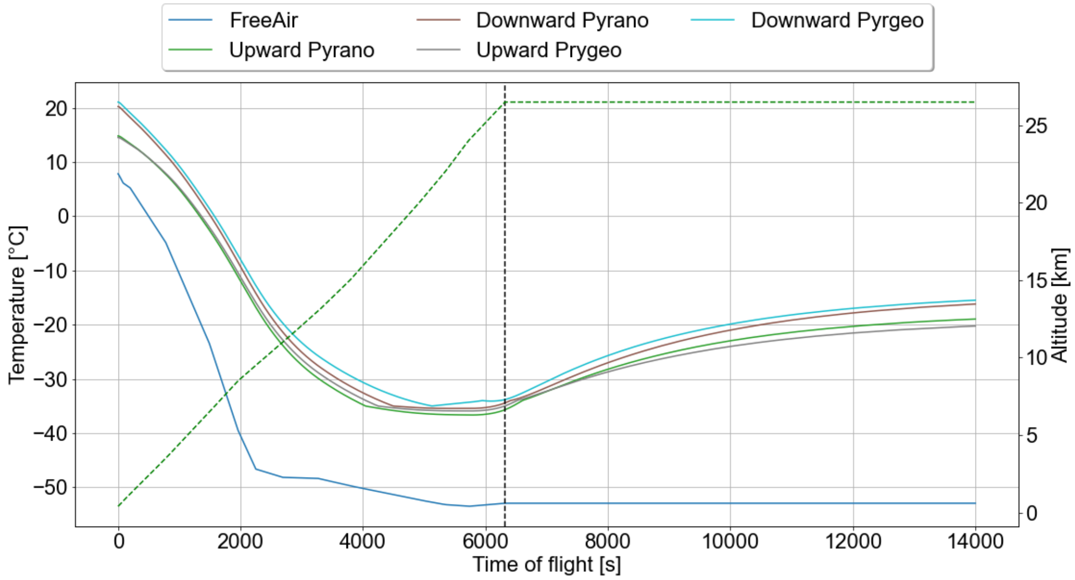


Figure 4-30. Upward and downward radiative sensor temperatures at TR_HOC.

<u>Cold Operational Transient Case</u>

The temperature of HTL external walls and the inner gondola air, compared with the free air is presented in Figure 4-31.

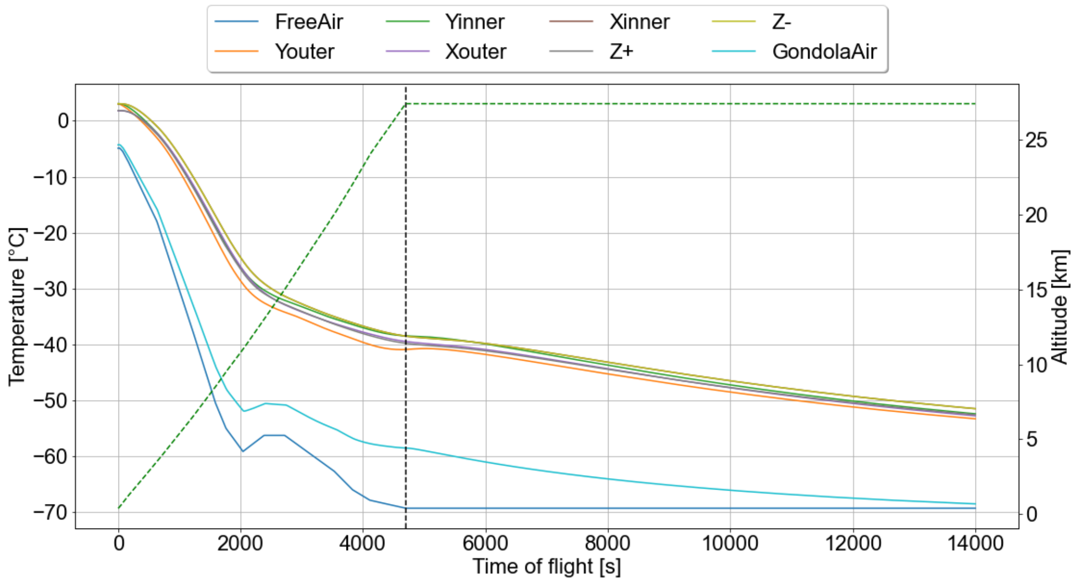


Figure 4-31. HTL structure, inner gondola air and free air temperature at TR_COC.

The temperature of HTL heated plates and the air of each cavity temperature is presented in Figure 4-32.

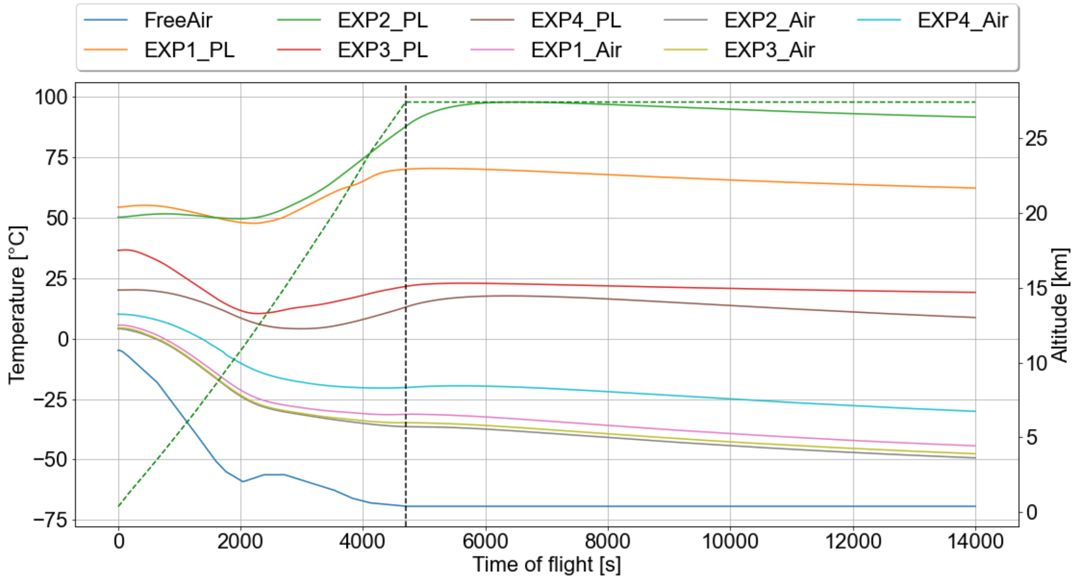


Figure 4-32. Heated plates temperature and HTL cavities air temperature at TR_COC.

Finally, the temperature of the pyranometer at the upward and downward environmental lab is compared with the free air in Figure 4-33.

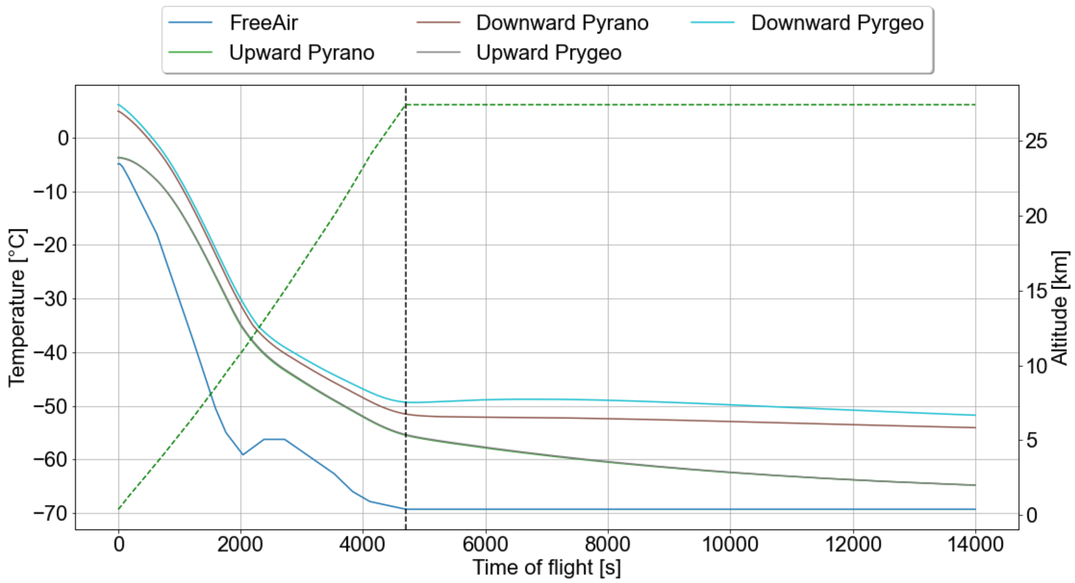


Figure 4-33. Upward and downward radiative sensor temperatures at TR_COC.

Float phase

<u>SS_HOC</u>

TBD

<u>SS_COC</u>

TBD

Conclusions

The radiative sensors are out of range during the TR_COC with the current thermal design baseline. To solve this, the thermal design baseline will include foam covering in the radiative support sensors as well to reduce the convective effects. Besides, the TMM will be improved in the following phase. It must be pointed out, that this case has been defined considering night flight conditions, which will not allow the solar radiative sensor to do valid measurements. Thus, we expect the flight will not be done with night condition.

4.7 Power System

The experiment will include a PCU (Power Control Unit) to control and distribute electrical power, supplied by one 28.8 V BEXUS battery, to the different systems, parts, and sensors. The PCU will be connected to the battery through a MS3112E8-4P connected to a MIL-C-26482P receptacle. Additionally, it will be a dedicated PCB composed by:

- A voltage divider and an ADC to measure the battery voltage.
- Two high efficient DC/DC buck converters that will step-down battery voltage to 5 V and 12 V.
- Filter circuits to reduce the DC/DC output voltages variation during electrical transients.
- Mosfets controlled by the OBC to activate and deactivate the experiment systems, parts and sensors.
- Circuit protections in series with the mosfets to avoid critical failures in the PCU.

Four operative power modes have been defined for the mission, each one corresponding to a different mission phase. These are the pre-launch, launch attempt, ascent and floating phases. In the pre-launch phase, all modules of the experiment are tested to verify its correct operation but only the OBC and the PCU consume power during the whole phase. Regarding the attempt launch phase, all systems except the OBC and the PCU are switch off. In the ascent phase, all modules are switch on except the Attitude Lab. It would be switch on for thermal reasons. Finally, in the floating phase all systems are switch on.

In Table 4-5, Table 4-6, Table 4-7, Table 4-8 and Table 4-9 the power budgets of the different mission phases are shown. A 10-hours mission has been considered and the power consumptions have been estimated with a good safe margin. The peak current and power consumption, the average power and the total discharged energy of the battery is shown in table 4-9. According to these results, the peak current (0.95 A) is far below the recommended maximum continuous current (1.8 A). Additionally, the estimated discharged energy of the battery represents about the 85% of the available capacity of the battery in a worst-case scenario, in which the mean temperature of the battery is between -20ºC and -40ºC (7 Ah). Nevertheless, a safe power mode will be implemented in case the battery runs out of energy during the floating phase. In this case, only the OBC, the PCU and a limited number of experiments will be active.

Table 4-5. Pre-launch phase power budget.

Duration [min]	**Module**	**Duty cycle [%]**	**Peak current [A] (+10% margin)**	**Peak power [W] (+10% margin)**	**Avg. power [W] (+10% margin)**	**Energy [Wh] (+10% margin)**
120	Env. Lab	10	0.5 (0.55)	6 (6.6)	0.6 (0.66)	1.2 (1.32)
	HTL	10	0.17	2	0.2	0.4

			(0.18)	(2.2)	(0.22)	(0.44)
	Att. Lab	10	0.4 (0.44)	2 (2.2)	0.2 (0.22)	0.4 (0.44)
	OBC	100	0.7 (0.77)	3.5 (3.85)	3.5 (3.85)	7 (7.7)
	PCU	100	0.08 (0.09)	1.9 (2.09)	0.86 (0.95)	1.72 (1.89)
TOTAL **TOTAL (+10% margin)**			**0.46** **(0.50)**	**11.4** **(12.54)**	**5.36** **(5.9)**	**10.72** **(11.79)**

Table 4-6 Launch attempt phase power budget.

Duration [min]	**Module**	**Duty cycle [%]**	**Peak current [A] (+10% margin)**	**Peak power [W] (+10% margin)**	**Avg. power [W] (+10% margin)**	**Energy [Wh] (+10% margin)**
90	Env. Lab	0	0 (0)	0 (0)	0 (0)	0 (0)
	HTL	0	0 (0)	0 (0)	0 (0)	0 (0)
	Att. Lab	0	0 (0)	0 (0)	0 (0)	0 (0)
	OBC	100	0.7 (0.77)	3.5 (3.85)	3.5 (3.85)	5.25 (5.78)
	PCU	100	0.03 (0.03)	0.7 (0.77)	0.7 (0.77)	1.05 (1.16)
TOTAL **TOTAL (+10% margin)**			**0.17** **(0.19)**	**4.2** **(4.62)**	**4.2** **(4.62)**	**6.3** **(6.93)**

Table 4-7. Ascent phase power budget.

Duration [min]	**Module**	**Duty cycle [%]**	**Peak current [A] (+10% margin)**	**Peak power [W] (+10% margin)**	**Avg. power [W] (+10% margin)**	**Energy [Wh] (+10% margin)**
90	Env. Lab	55	0.5 (0.55)	6 (6.6)	3.3 (3.63)	4.95 (5.45)
	HTL	100	0.54 (0.6)	6.5 (7.15)	6.5 (7.15)	9.75 (10.73)
	Att. Lab	55	0.4 (0.44)	2 (2.2)	1.1 (1.21)	1.65 (1.82)
	OBC	100	0.7 (0.77)	3.5 (3.85)	3.5 (3.85)	5.25 (5.78)

	PCU	100	0.144 (0.16)	3.6 (3.96)	2.88 (3.17)	4.32 (4.75)
TOTAL **TOTAL (+10% margin)**			**0.86 (0.95)**	**21.6 (23.76)**	**17.28 (19.0)**	**25.92 (28.51)**

Table 4-8. Floating phase power budget.

Duration [min]	Module	Duty cycle [%]	Peak current [A] (+10% margin)	Peak power [W] (+10% margin)	Avg. power [W] (+10% margin)	Energy [Wh] (+10% margin)
300	Env. Lab	100	0.5 (0.55)	6 (6.6)	6 (6.6)	30 (33)
	HTL	100	0.48 (0.53)	5.8 (6.38)	5.8 (6.38)	29 (31.9)
	Att. Lab	100	0.4 (0.44)	2 (2.2)	2 (2.2)	10 (11)
	OBC	100	0.7 (0.77)	3.5 (3.85)	3.5 (3.85)	17.5 19.3
	PCU	100	0.14 (0.15)	3.46 (3.8)	3.46 (3.8)	17.3 (19)
TOTAL **TOTAL (+10% margin)**			**0.83 (0.91)**	**20.76 (22.84)**	**15.36 (16.9)**	**103.8 (114.18)**

Table 4-9. BEXUS battery power budget.

Peak current [A]	Peak power [W]	Avg. power [W]	Energy [Wh]
0.91	23.76	14.67	147

4.8 Software Design

4.8.1 Purpose

The purpose of this section is to describe the S/W design and architecture proposed for the HERCCULES experiment.

The HERCCULES OBSW shall implement the requirements listed in Section 2, which can be summarized in the following high-level features:

- Control and manage the status from all the hardware components.
- Data acquisition and control the following experiments and subsystems:
  - Attitude Determination Subsystem (ADS).
  - Attitude Laboratory (Att. Lab.).
  - Environmental Laboratory (Env. Lab.).
  - Heat Transfer Laboratory (HTL).
  - Power Control Unit (PCU).

- Manage the system and subsystem operational modes and mode transitions.
- OBDH operations: process and perform TCs from the GS and handle the TM data to be downlinked to the GS.
- Onboard storage of the data acquired from all the experiments and additional HK data.
- Context Management, i.e.: save the relative time, the system and subsystem operational modes. So that, in case of failure these data can be restored.
- FDIR functions for the OBSW dependability.

4.8.2 Design

Process Overview

The HERCCULES flight segment has one OBC that will be connected to the experiment equipment[1].

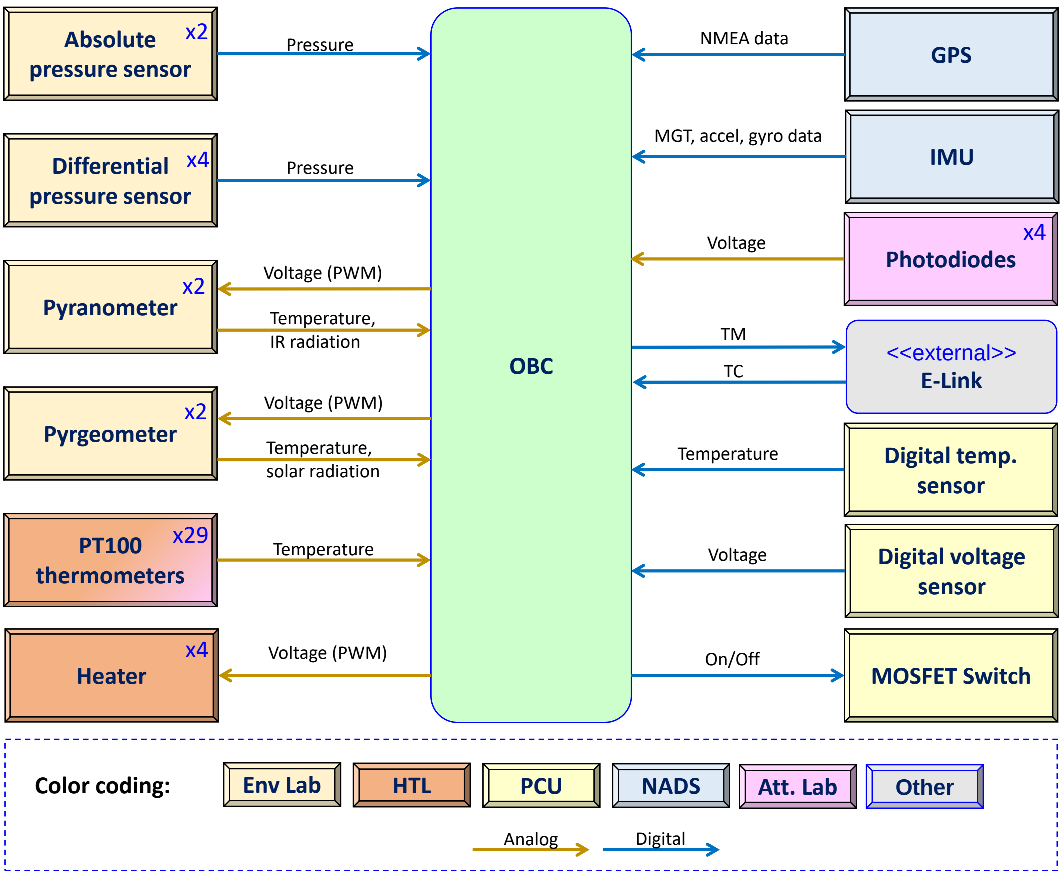


Figure 4-34: Context diagram from the HERCCULES OBC based on AADL (Architecture Analysis & Design Language)

Figure 4-34 depicts the context diagram from the OBC which contains its relationship with the experiment's "terminal" devices, their multiplicity, and the data flow interchanged between them. In general, there exist two types of "terminal" equipment connected to the OBC:

[1] The term "equipment" or "device" are used indistinctly for "sensors and actuators".

a. The first type are devices that can be directly connected to the OBC through digital pins or data buses, such as I2C, SPI, 1-Wire, or UART. The data flow from these devices are represented as **blue arrows**.
b. The second variant conforms to equipment that cannot be connected to the OBC (e.g., analogue sensors or actuators). And to connect them, “mediator” devices such as ADCs, DACs, or MOSFETs are required. The data flow from these devices are represented as **gold arrows**.

The OBSW will be deployed in the OBC and acts as the *requester* starting the commands or data transactions, and the equipment will act as *responders*. Except for the GPS which publishes NMEA data at a rate of 1Hz. In addition, The OBSW will store the acquired data in persistent memory for later ground processing. This process is driven by the system and subsystem’s operational modes (c.f. section 0), which are deduced from the software requirements.

Finally, the OBC will be connected to the ground computer through Ethernet connection via the E-Link System provided for BEXUS experiments. Thus, the TCs and TMs exchanged between the OBSW, and the GS S/W will be carried over the TCP/IP networking protocol.

General and safety related concepts

This section presents the OBSW behaviour against software and hardware errors, and the FDIR techniques applied to tolerate faults.

Hardware redundancy management

HERCCULES applies **static hardware redundancy** (AKA. masking) in some of its experiments’ sensors, such as the Environment Lab. where two pressure sensors are used. This type of redundancy is used to hide the effect of faults. In these cases, the OBSW will read sensors data and detect if these data are within the valid ranges. Therefore, the following scenarios can occur:

i. *All sensors' data are valid*. These data are marked as “valid”. Therefore, software components that depend on these data to perform their operations (such as components that implement control algorithms) will use and “fuse” them calculating their arithmetic mean.
ii. *Some sensors data are invalid.* The faulty data are marked as “invalid”. Software components that require these data will used only the valid redundant ones.
iii. *All sensors' data are invalid.* This means that all sensors' data are marked as “invalid” and the software component that requires this date will not perform its operations since there is no data to work with.

Note that in the three cases, the OBSW does not try to repair or stop the faulty sensors and the invalid data is still recorded. This way, the operators will be able to analyse the data and decide if they are valid or not. In addition, the change from valid to invalid (and vice versa) will be recorded as part of the events logs.

Hardware watchdog timer

In general, watchdog timers are used to figure out if a program has stop working. The HERCCULES experiment OBC has one on-chip hardware watchdog timer that can be configured and restarted (AKA. kicked) by means of its OS services and system calls.

In this case, the watchdog is used to ensure that the whole OBSW is running. Specifically, the “`Watchdod_Kicker`” software component is in charge of “kicking the dog” periodically with a rate twice the watchdog timer frequency. If the timer expires, it means that the OBSW is not working correctly or has stopped. Consequently, a hardware signal is sent to reboot the OBC, which will restart the OBSW.

Interfaces

Communication Interfaces

In the process overview section, we observed the two types of devices connected to the OBC. Table 4-10 presents a more detailed description about the connections between the equipment and the OBC. In particular, the second column shows the number of devices present in the experiment; the third column shows the connection protocol between the device and the OBC; the fourth column shows the connection interface, and the last column contains additional information specific to each equipment. The table colouring is kept compatible with the colour codes presented in Figure 4-34.

Table 4-10: Table of equipment's interfaces

Equipment	Qty	Connection protocol	Connection I/F	Comments
GPS: click module with u-blox LEA-6S	1	UART	OBC UART-1 I/F	Mini USB to USB and SPI are also available.
IMU 9DOF: BNO055	1	I2C	OBC I2C-1 I/F	UART I/F is also available. If there are performance issues because of the shared bus, UART-2 I/F or bit-bang I2C will be considered.
Photodiode LMS41PD-03.	4	Analog	Connected to the PAb board.	N/A
PAb pre-amplifier boards	4	Analog	ADC from SDPU	N/A
PT100 thermistors	1	Analog	ADC from SDPU	N/A
Absolute pressure sensor: MS5611-01BA03	2	SPI	OBC SPI-1 I/F	I2C I/F is also available.
Differential pressure sensor: LDES050BF6S	4	SPI	OBC SPI-0 /IF	N/A
Pyranometer: SR20T2-05	2	Analog	ADC from SDPU	Corresponds to the “internal 10 KOHM”.
		Analog	MOSFET from PCU	Corresponds to the “internal heater”[2].
		Analog	ADC from SDPU	Corresponds to the “IR radiation”, differential voltage output.
Pyrgeometer: IR20-T2	2	Analog	ADC from SDPU	Corresponds to the “Internal 10KOHM”.

[2] The pyranometer and pyrgeometer heaters are connected in series as depicted in Figure 4-23.

		Analog	MOSFETs from PCU	Corresponds to the "Internal heater".
		Analog	ADC from SDPU	Corresponds to the solar radiation, differential voltage output.
Silicon heater	4	Analog	MOSFETs from PCU	N/A
PT100 heater	28	Analog	ADC from TMU	N/A
Dig temp sensor MAX31820	1	1-wire	OBC GPIO I/F	N/A
Dig voltage and current TBD	1	Digital	TBD	TBD
MOSFET: IRFZ44PbF	6	GPIO	OBC GPIO I/F	Used to switch on/off: - The 12V or 5V experiments (except the OBC) supply. - The 4 heaters from HTL.
E-Link System	1	Ethernet	Ethernet adapter	N/A
Ethernet adapter	1	USB	OBC USB 2.0	N/A
ADC MCP3201	6	I2C	OBC I2C I/F	5 located in the SDPU and 1 in the TMU.
MUX: CD74HCT4351E	2	GPIO	OBC GPIO I/F	8:1 MUX located in the SDPU.
MUX: ADG726BCPZ	1	GPIO	OBC GPIO I/F	31:1 MUX located in the TMU.

The table presented the terminal and mediator equipment connected to the OBC. Figure 4-35 depicts the hierarchy from these devices and shows their 1-N relationship with the shared buses and resources such as ADC, I2C, and SPI.

This shared access needs to be managed by the OBSW to avoid access conflicts using "protected" objects. This is addressed later in the Static architecture subsection.

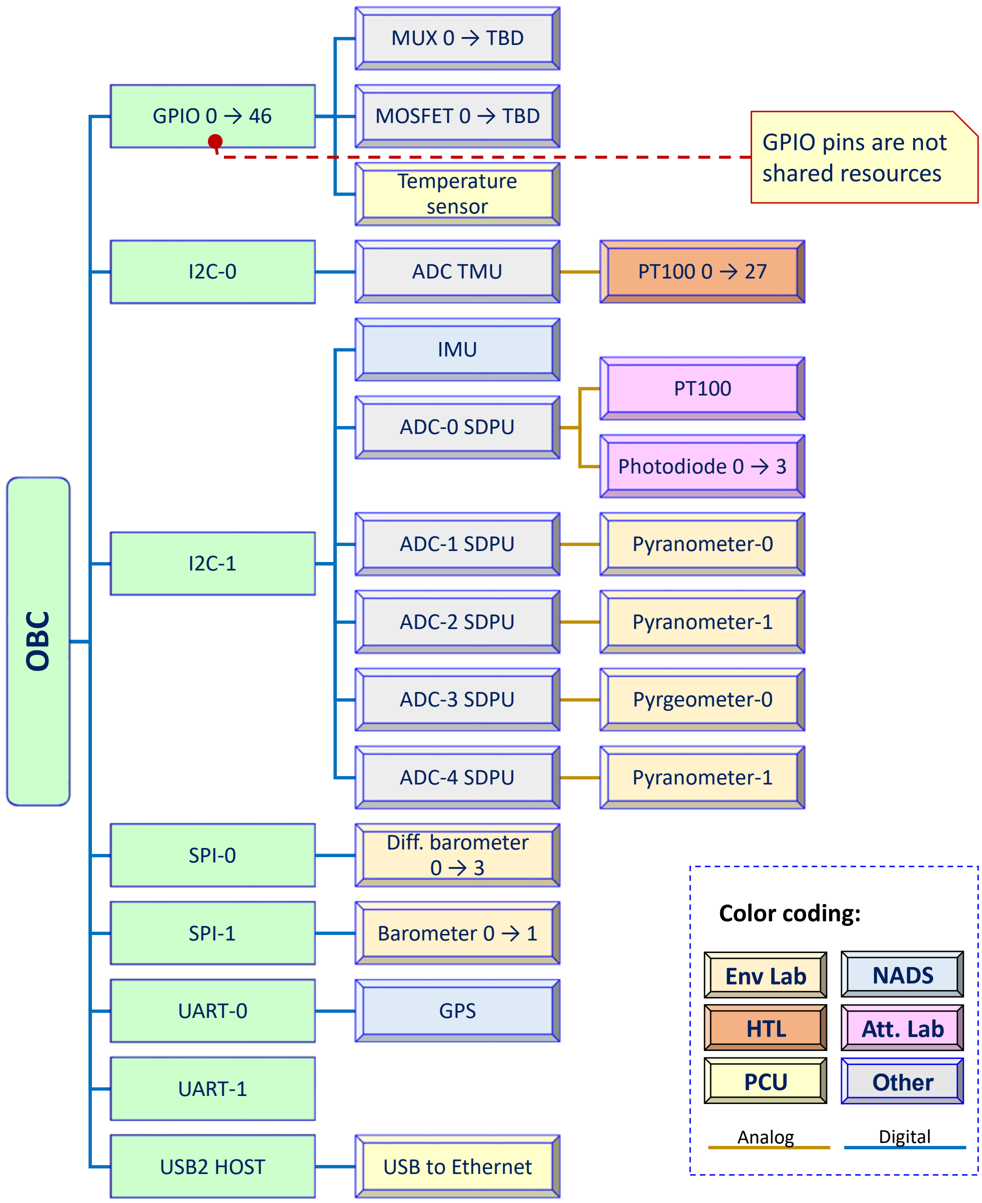


Figure 4-35. Hierarchy of devices and shared buses

Bandwidth requirements

The OBSW must downlink Housekeeping Telemetry and Scientific Telemetry. The first one comprises the health states from the experiment's equipment, and the second one represents the actual data read from the instruments. Their download sampling frequencies are specified in the HERCCULES requirements and Table 4-11 summarizes them. It presents the category of the TM in the first column, the specific variables are shown in the second column, the third column contains the downlink period and the last one contains the variable size in bits.

Table 4-11. Telemetry data downlink periods

Category	Variable	Downlink period (seconds)	Size (Bits)
Housekeeping	Attitude Lab temperature	60	32
	PCU temperature	60	32
	Battery voltage	60	32

	Battery current	60	32
Scientific	HTL PT100 thermistors from plates and air	10	32 × 8
	HTL plates power dissipated	10	32 × 4
	Pyranometers	10	32 × 2
	Pyrgeometers	10	32 × 2
	Differential pressure sensors	10	32 × 4
	Absolute pressure sensors	10	32 × 2
	GPS	10	32 × 5
	Magnetometer	10	32
	Gyroscope	10	32
	Accelerometer	10	32
	Nadir sensor (photodiodes)	60	32 × 4

The software developers have analysed different protocols (other than TCP or UDP) and alternatives to implement the communication between the OBC and GS. One of the more significant findings is the PUS (Packet Utilization Standard) specification from the ECSS which describes not only the formats for TM and TC packets, but also the services that should be implemented by the OBC.

The second major finding was the MQTT protocol (which stands for Message Queue Telemetry Transport). It is a reliable publish-subscribe protocol for distributed embedded systems (constraints in battery, CPU, etc.) and low bandwidth communications. There are open-source implementations for brokers and client libraries that would facilitate the development of the software components responsible for the remote communication. In addition, it offers three levels of Quality of Service that would help to implement reliable communication between the ground and flight segment.

At PDR level and considering the information provided in Table 4-11, MQTT packet overheads of about 7 bytes per variable, and a 20% margin; we estimate that the HERCCULES experiment requires the following bandwidth budgets:

- Downlink: 246.72 bps
- Uplink: 82.56 bps

Data acquisition and storage

The equipment sampling frequencies are specified in the HERCCULES requirements. Table 4-12 presents the category of the data in the first column, the specific variables are shown in the second column, and the third column contains the sampling period.

Table 4-12. Data acquisition sampling periods.

Category	Variable	Sampling period (seconds)
Heat Transfer Lab	HTL PT100 thermistors	10
	HTL plates power dissipated	10
Environmental Lab.	Pyranometers	10
	Pyrgeometers	10
	Differential pressure sensors	1
	Absolute pressure sensors	1
Navigation Attitude Determination System	GPS	1
	Magnetometer	1
	Gyroscope	0.01
	Accelerometer	0.01
Attitude Lab	Nadir sensor (photodiodes)	1

	PT100 Thermistor	10
Power Control Unit	Temperature	1
	Battery voltage	1
	Battery current	1

The collected data will be stored in CSV (comma separated values) format with ASCII encoding (1 byte = 1 character). There will be one CSV file per category. Each row will contain the relative time of the mission in the first column, the second one will contain the system mode, the third column will contain the subsystem mode (if it exists), and the rest of the columns consist of information specific to each experiment or subsystem (e.g.: the sensors collected data, the actuator commands, the actuators status). This format is graphically depicted in Table 4-13, the second column shows the maximum size in bytes based on the worst case possible.

Table 4-13. Row format for the recorded data (CSV).

Field	Relative time (seconds)	System mode	Subsystem mode	Specific information
Size	8 Bytes (ASCII characters)	8 Bytes	8 Bytes	TBD Bytes

The complete format per have not been calculated yet. However, the RPi CM3+ is embedded with one 32 GB eMMC memory. If this is not enough for the required storage, one additional micro-SD card would be used (inserted in the slot provided by the Compute Module I/O board).

Finally, in order to increase the overall performance, the data will be written in non-volatile memory in a lower rate than the sampling frequencies. Therefore, intermediate buffers will be used, and the I/O latencies will be reduced.

Process Flow (dynamic architecture)

The process flow and behaviour of the HERCCULES subsystems are driven by the different system modes[3]. The operational modes of the balloon correspond 1 to 1 to the modes of the OBSW and the architectural design to implement them are based on the concepts described in [14]. Figure 4-36 depicts a UML state machine diagram from the whole system. The **blue arrows** show fall-back mode transitions, i.e.: transitions that are triggered automatically by the OBSW. On the other hand, the **dark grey arrows** represent mode transitions triggered by TC executed by the operator on the ground.

The system can be either on the ground or flying, namely ground or flight modes. However, the system will be in different operational modes at ground and during flight, that is why these are represented as composite states which contains different substates. The meaning of each mode is defined in the following list:

- **Ground mode**: This is the first HERCCULES state and represents that the balloon has not yet launched.
  - **Off mode:** Initially, the whole system is switched off, without an internal or external power supply and no software running. When the system is switched there is a state transition to the Await mode.
  - **Await mode:** When the system is in this mode the HERCCULES experiment is supplied either with an external power supply, the

[3] The terms “mode”, “operational mode”, or “state” are used interchangeably.

Hercules power, or the internal batteries. The OBC is turned on and the OBSW starts executing.

In this mode, the operators on the GS can communicate with the system and perform experiments check outs executing TCs. After 25 minutes, the system is switched to the Pre-Launch mode. In addition, the operator can send a TC to change to the Pre-Launch mode.

- **Pre-Launch mode:** During this mode the sensors are checked again, and data acquisition and data logging starts for the:
  - Attitude Determination System.
  - Barometers.
  - Heat Transfer Lab.
  - HK and OBSW events information.

  After 15 minutes of entering this mode there is a state transition to the flight mode. Alternatively, this transition can be executed at any time by a TC sent by the operator on ground.

- **Flight mode:**
  - **Ascent mode:** When the system is in this mode the HTL starts dissipating constant power and the Environmental Lab switches on beginning the data acquisition. Once the float attitude is reached there is a transition to the Floating mode. Additionally, this transition can be triggered at any time by a TC sent by the operator on the ground.
  - **Floating mode:** This is a composite state, and its sub-modes are explained later in this section. The data acquisition and data logging of the Attitude Lab (i.e.: Nadir sensor) starts.
  - **Descent mode:** Finally, this mode is reached either when the OBSW detects the cut-off or when the operator sends a specific TC. If this mode was entered by error, the operator can send a TC to get back to the floating, or Ascent mode again. During this mode the operator must send a TC to stop **all** the experiments execution, and data logging.

Note that the during flight mode, the operator can send TCs to change between modes without restrictions. However, when descent mode is exited, there is no going back.

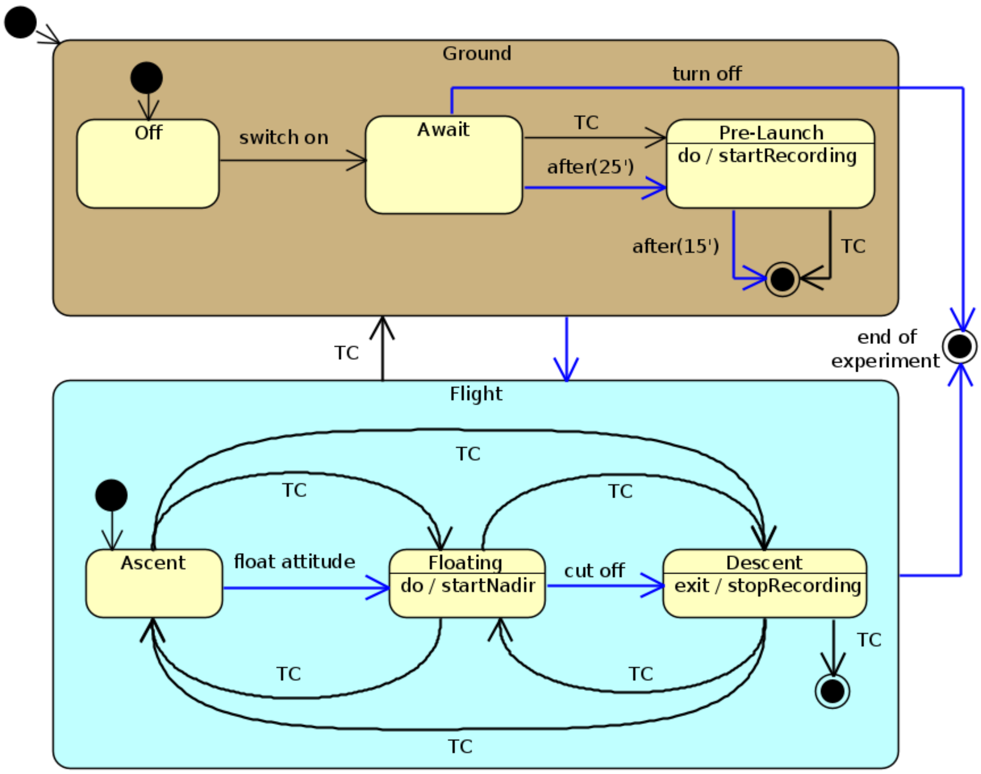


Figure 4-36: Systems operational mode presented as a UML state chart diagram.

Figure 4-37 illustrates the substates from the floating operational mode and these are explained in the following list:

- **Fluctuating**: constant power dissipation is set trying to reach the steady state.
- **Steady 1**: implies a different constant power dissipation mode for achieving a different steady state.
- **Steady 2**: constant temperatures are set for the experiments by means of variable power.

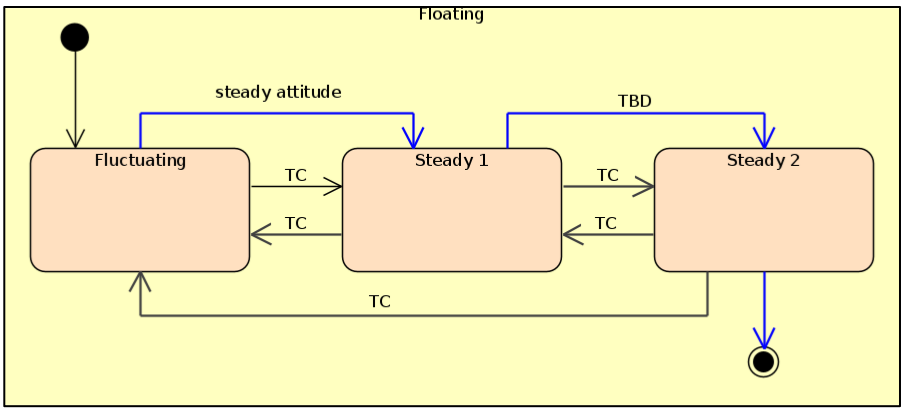


Figure 4-37: Floating sub-modes.

The HERCCULES OBSW is based on a lighter version of the HRT-HOOD methodology adopted and defined by the TASTE toolchain component model. Therefore, the S/W is composed of a hierarchy of objects where the OBSW component represents the top-level or system entity. Figure 4-38 illustrates the objects hierarchy of the system.

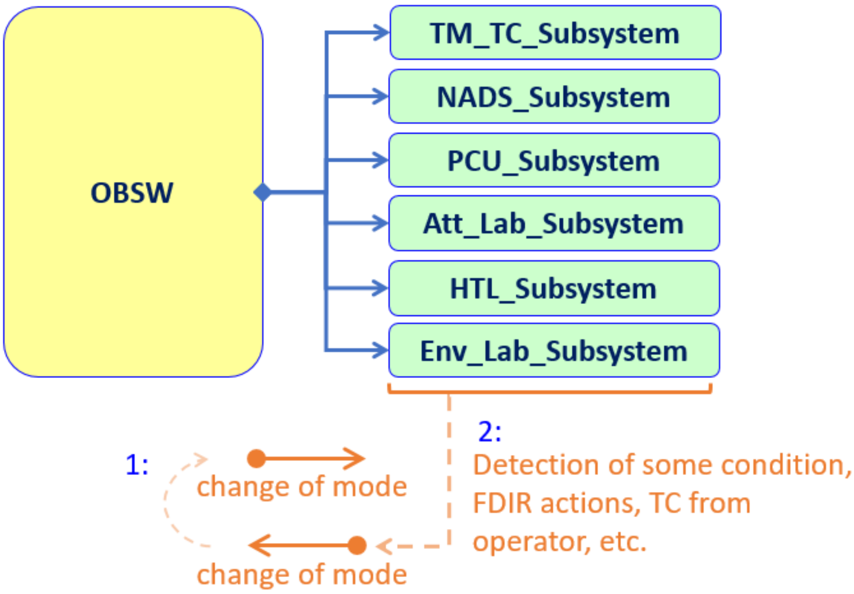


Figure 4-38: OBSW objects hierarchy

The OBSW controls the systems' state through the `Mode_Manager` component. In addition, the OBSW holds (aggregation relationship) the `Experiments` component, which contains the four experiments and other subsystems: Telemetry and telecommand (TMTC), NADS, Power Control Unit (PCU), Attitude Laboratory, HTL, and Environmental Laboratory. The following scenarios depicted in Figure 4-38 can occur:

1. A change in the systems mode affects the behaviour of all other subsystems. The system's mode is not notified to each subsystem but accessed by all of them through a protected variable contained in `Mode_Manager`.
2. The events detected by the subsystems that can provoke a system's change are notified to the OBSW `Mode_Manager`, which changes the system's mode to the corresponding state. Therefore, (1) happens.

The behaviour of these subsystems is driven by the system's operational mode. However, the HTL must deal with safety requirements and has a more complex behaviour, consequently, it has its own internal modes illustrated in Figure 4-39.

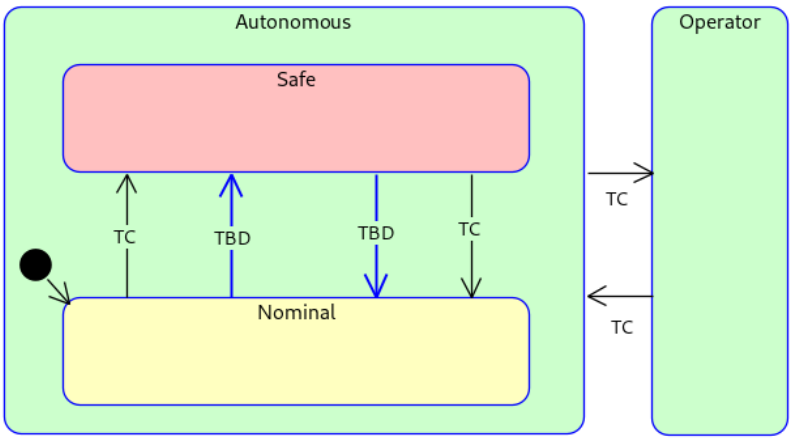


Figure 4-39: Heat Transfer Lab internal operational modes

By default, the HTL is in the Autonomous mode, in which the OBSW controls the heaters autonomously without intervention from the ground. However, when the HTL is in the Operator mode, it sets the heaters to dissipate 0 Watts and gives the control to the operators. Therefore, in the Operator mode, the heaters are controlled only by means of TCs sent by the operator.

When the HTL is in the Nominal mode, it behaves as described before in the system modes. However, if TBD is detected, the OBSW automatically switches to the Safe mode where the HTL does TBD. When TBD stops, the HTL gets back to the System Driven mode and performs the expected behaviour. Note that the operator can trigger these transitions by sending a TC to the OBSW. Here again, the changes between modes can be triggered by TCs without any restrictions. Besides, TBD HTL Autonomous modes will be set in order to separate the ascent phase and the float phase.

Modularisation and pseudo code

Static architecture

The software development process from HERCCULES follows a CBD (Component Based Development) methodology that structures the static architecture using software components. This methodology eases the division of labour and allows reusability from other projects such as TASEC-Lab.

The software requirements listed in Section 2 suggest the decomposition of the OBSW in the following high-level S/W components:

- Hardware Abstraction Layer (`HAL`): The purpose of this layer is to provide a set of operations that facilitate and abstract the access to the hardware devices of the OBC. Specifically, this component:
  - Reads the sensors and actuators values/status on request.
  - Executes commands to control the actuators.
  - Handles concurrency aspects since there are hardware buses or ADCs shared by many devices.

  This hardware access is achieved invoking the services provided by the underlying Operating System (OS).

- `Experiments`: This component contains the implementation from all the experiments. Most of them are only data loggers which read the sensor collected data requested to the `HAL`. In the case of the HTL, this layer will also control the heaters requesting operations to the HTL, too. The functionality of the experiments is driven by the `Mode_Manager`, which contains the operational modes from the system.
- `Data_Logger`: This component offers the Log provided interface that encapsulates the services related to data logging on persistent memory. The `Experiments`, `TM_TC`, and `Mode_Manager` log their data invoking the Log operations from this component.
- `Data_Pool`: This layer represents a common protected data-store containing all the shared data acquired or processed by the experiments. This way, the `TM_TC` component will be able to downlink these data as HK TM. It acts as a mediator between the experiments and other components.
- `Mode_Manager`: As its name implies, this component oversees the system mode management. The management implies setting the system's mode according to the events received through the `Notify_Event` interface. This is a protected component since various components access shared data through the `Get_System_Mode`.

- Telemetry and Telecommands (TM_TC): This component reads and processes TCs sent by the operators from the GS and sends TM to them. It also implements the HK functionality reading TM data from the Data_Pool through the Get required interface.

Figure 4-40 presents a UML Component Diagram which contains the static architecture, i.e.: the non-terminal S/W components described above and the relationship between them. This architecture is based on the principles described in [15]–[17] and was successfully applied in the TASEC-Lab project [12] a reduced version of HERCCULES

This architecture follows the Shared-Data Pattern [18] where the Data_Pool component represents the *common Data-Store* element. In addition, it follows the Process Pipeline Pattern described in [19] which is commonly used to implement data loggers in RTES (Real-Time Embedded Software). Specifically, it is used to communicate the Data_Logger to the client components and manage timing differences.

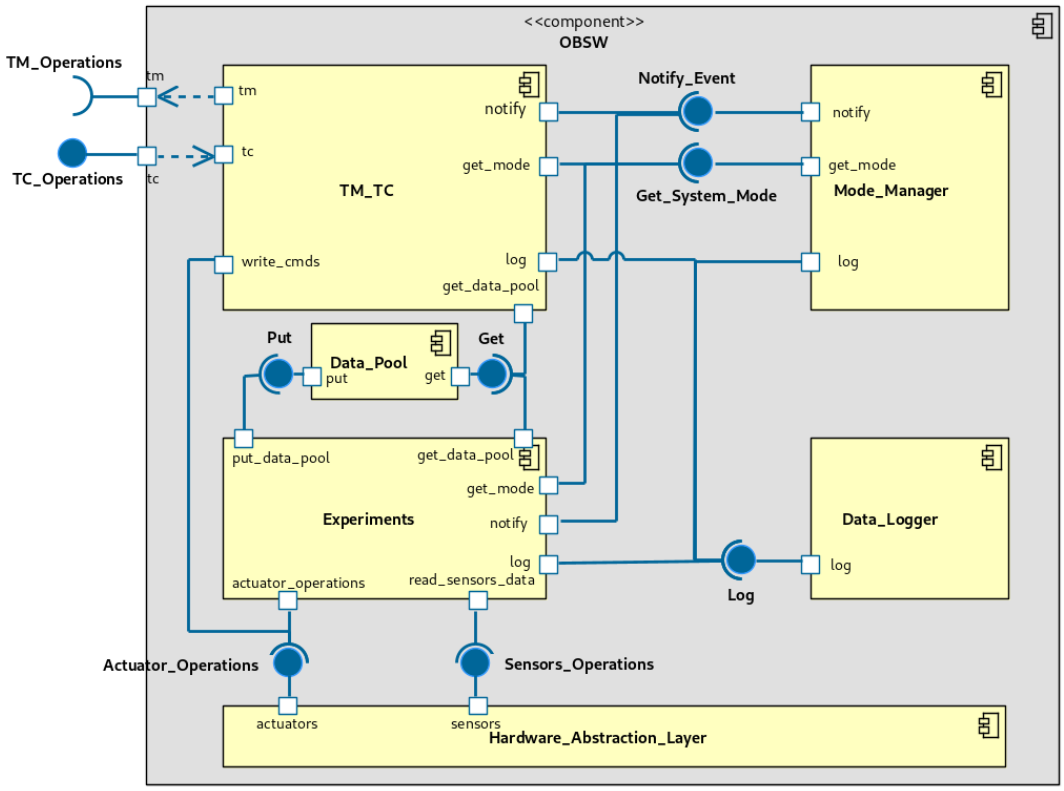


Figure 4-40: High-level UML components diagram for the OBSW.

4.8.3 Implementation

Development tools

The ASSERT Set of Tools for Engineering (**TASTE**) [20] is a toolset supported and developed by the European Space Agency together with academics and European space industry partners. This tool follows a Component-Based Development (CBD) approach and automatic code generation for the development of heterogeneous real-time embedded systems (RTE). To do so, TASTE offers four views (like the 4+1 view architecture [21]):

- *Data View* describes the data types used in the system (data exchanged between components of the Interface View).
- *Interface view* describes the heterogeneous components of the system. The term "heterogeneous" refers to the different programming languages and modelling tools in which components can be implemented or modelled.
- *Deployment View* maps the functions from the Interface View on hardware. Thanks to this view, the communication of remote components is possible (e.g., through serial ports, sockets, etc).
- *Concurrency View*, provides a complete view of the system, giving the ability to perform schedulability analysis and simulate system execution.

We opted for TASTE to support the software development of this experiment for mainly two reasons:

1. It will simplify the implementation of the embedded software thanks to its CBSE approach, and the abstraction provided through its four views, encapsulating the details of the underlying platform, such as: OS, remote communications, drivers, programming languages, etc.
2. The Ravenscar computational model and the restrictions followed by TASTE during the code auto-generation process guarantees the meeting of real-time requirements for determinism, schedulability analysis, and memory boundness. So, the real-time execution behaviour of our system is correct by construction.

Git is going to be used as the CVS (Control Version System) for this project. It is widely used in the industry and keeps track of the S/W development history and allows the developers to collaborate throughout the development process.

Finally, the **GitLab** platform was chosen as the server for the remote repositories since it is free and offers functionalities such as CI (Continuous Integration) that is going to be exploited in this project.

Operating System and programming libraries

The Raspberry Pi OS was chosen in this experiment because it is the official supported OS (Operating System) for the Raspberry Pi single board computers. In addition, it is a Debian based OS and comes with pre-installed programming libraries, drivers, and tools to access GPIO pins and interact with the hardware component of the system. Most Linux distros like RPiOS are compliant to POSIX, but not certified because the compliance check. RPiOS includes system calls that let us define the scheduling policy of the threads and assign priorities like SCHED_FIFO, which implements the fixed-priority real-time scheduling.

In our experiment, the use of this OS will facilitate the development of the software modules that require access to the sensors and actuators thanks to the provided Unix driver interfaces (i.e., open, close, read, and write defined in `unistd.h`, and `ioctl` signature defined in `ioctl.h`).

The following list shows the interfaces available in the RPi CM 3+ and the libraries used to access them pro-grammatically:

- *1-Wire interface*. The Raspberry Pi supports one-wire on any GPIO pin thanks to the `w1-gpio` Linux module (GPIO 4 by default and configurable through dynamic overlay).
- *I2C bus*. In Linux, i2c devices are controlled by a kernel driver (i2c-dev module). It is also possible to access these devices from user space, through the `/dev` interface, including the `sys/ioctl.h` and `linux/i2c-dev.h` header files.

- *SPI bus*. Like I2C, it is possible to perform SPI communication through the spi_bcm2708 kernel driver, and from user space including the `linux/spi/spidev.h` and some more header files.
- *UART serial port*. As in the previous interfaces, serial ports are represented by files (usually following the `/dev/tty*` pattern). And the configuration of this ports is made accessing the data structures defined in `termios.h` and additional header files.

4.9 Ground Support Equipment

4.9.1 Purpose

The purpose of this section is to describe all equipment from the ground station (GS), its S/W architecture and design proposed for the HERCCULES experiment.

The GSSW shall implement the following high-level features:

- Display the data sent by the flight segment.
- Store TM data in a database.
- Send commands to the flight segment.
- Provide an intuitive GUI (Graphical User Interface) to send TCs and receive TM.

Figure 4-41 illustrates the context diagram of the GS computer (GSC). The operator at ground will send TCs and receive TMs through a GUI deployed on the GS computer, which is connected to the E-Link ground unit to communicate with the flight segment. In addition, all the telemetry received will be stored on a database.

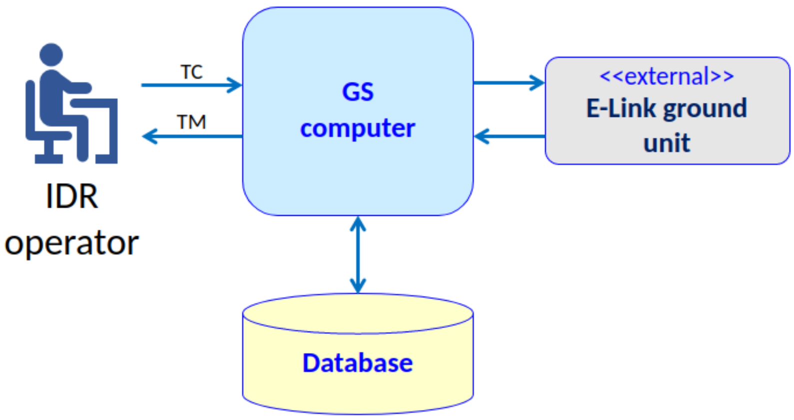


Figure 4-41: GS computer context diagram

4.9.2 Process overview

In essence, the operator will be able to send/receive TM and TCs from/to ground through the GSSW GUI. The communication between the GSSW and the OBSW is hidden to the experiments using the E-Link systems provided to the BEXUS experiments as shown in Figure 4-42.

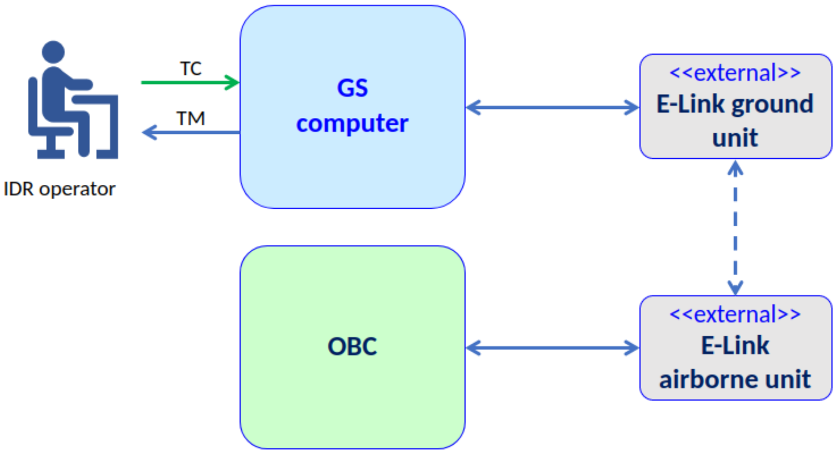


Figure 4-42: GSSW and OBSW data flow

4.9.3 Software architecture

Figure 4-42 depicts the GSSW architecture that is based on the Model-View-Presenter (MVP) design pattern. The MVP pattern is an approach to design GUIs that allows the division of the "business logic" from the presentation options and styles. In addition, this figure shows the connection from the GSSW to the OBSW through the provided interface `TM_Operations` and required interface `TC_Operations`. These interfaces are deployed over the E-Link system as depicted in Figure 4-43.

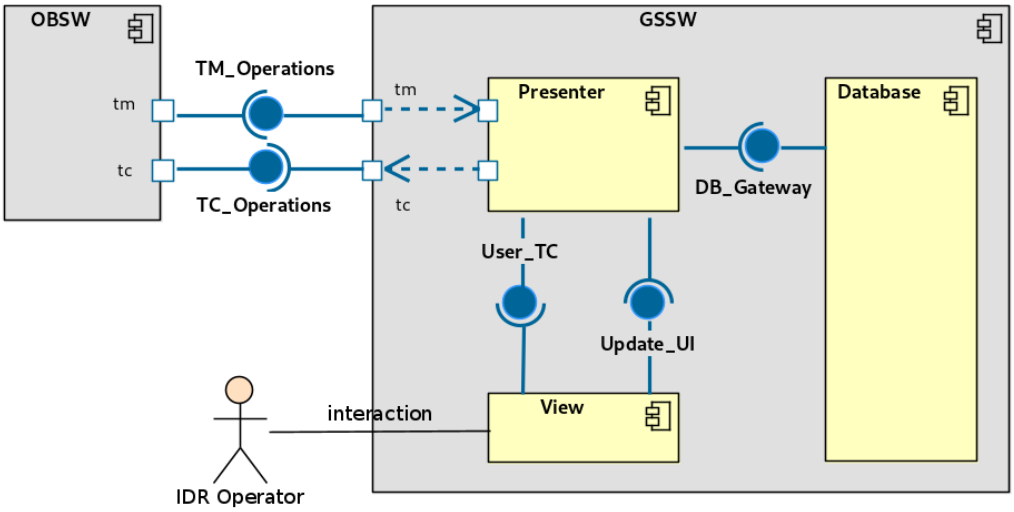


Figure 4-43: GSSW UML component diagram

The OBSW represents a remote MVP model located at the gondola. The components that conform the `GSSW` are described in the following list:

- `Presenter`: This component receives TMs through its `TM_Operations` provided interface, transforms this data to an easy to consume format, displays the, using the `Update_UI` interface, and saves it in persistent memory by means of the `DB_Gateway` interface. This component sends TCs (requested from the `User_TC` interface) to the OBSW calling the functions and methods from the `TM_Operations` required interface.
- `View`: This component implements the visual presentation to the user by means of GUI frameworks such as Qt. It also listens to the user input events/actions such as mouse clicks. The user actions are communicated to the Presenter

which will handle it and probably update the view through the `Update_UI` interface.

- `Database`: This component offers its services through the `DB_Gateway` interface which contains operations that save TM in persistent memory.

4.9.4 Required equipment

The following list contains the required equipment that is part of the experiment ground segment, i.e.: equipment that does not fly.

- Two laptops (one for backup) for the GS with the following characteristics:
  - TASTE virtual machine (VM) installed. This is because, the VM contains the required environment to execute the graphical user interface.
  - With the latest GSSW executable installed.
  - Not connected to the Internet.
  - Ethernet port (adapter is valid) for the connection to the E-Net.
  - Configured with the E-Net IP provided to the experiment.
- Switch to distribute the Guest Net network to additional laptops.
- USB C multiport dongle if additional interfaces are required.
- Crossover Ethernet cable to directly connect the GSC with the OBC and perform some equipment testing.

4.9.5 Programming Languages and development tools

At first, we are planning to use the autogenerated GUI components from the TASTE toolchain (described in Section 4.9.5) to implement the `View` component. These autogenerated GUIs are implemented in Python using the Qt framework. Figure 4-44 shows the autogenerated TASTE GUI which was successfully used in the TASEC-Lab experiment and offered an intuitive interface to the IDR team members.

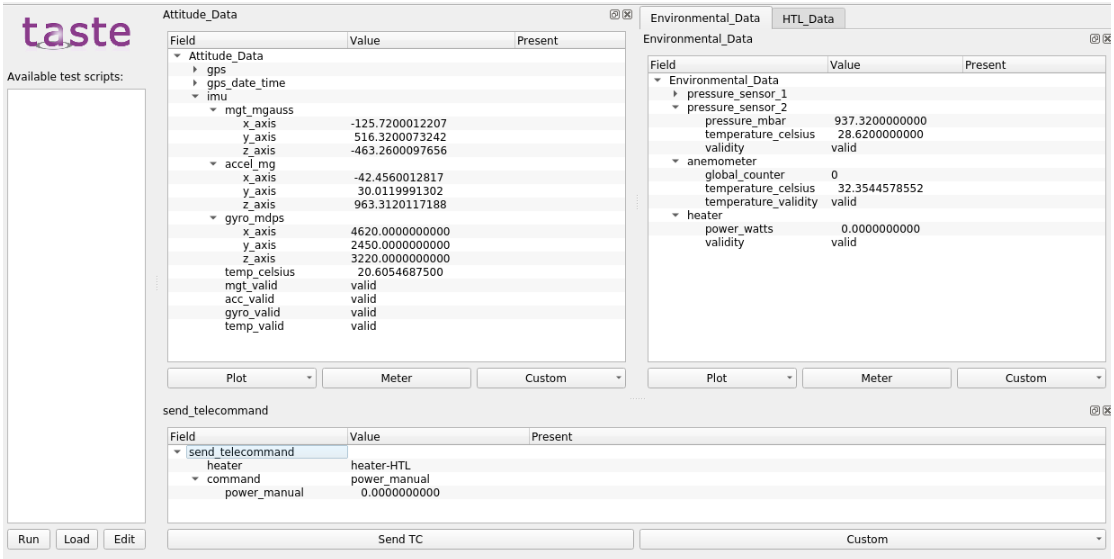


Figure 4-44. TASTE GUI used in the TASEC-Lab.

The usage of autogenerated components will reduce development costs (man-hours) and the effort distribution will decrease throughout the whole life cycle.

Finally, the Presenter and Database components will be implemented in the C++ programming language since it offers libraries (STL, Standard Template Libraries) that will facilitate their development.

5 EXPERIMENT VERIFICATION AND TESTING

5.1 Verification Matrix

The verification matrix is made following the standard of ECSS-E-10-02A. There are four established verification methods:

- Verification by test (T): It is performed by subjecting the experiment to a physical test.
- Verification by inspection (I): It is performed by simply inspecting/looking at the experiment.
- Verification by analysis or similarity (A): It is performed by proving that a part of the experiment is similar to a part that has already been flown successfully and is going to be flown in the same conditions. If the conditions are different, it must be proven that the conditions in which the previous experiment has been flown are still applicable.
- Verification by review-of-design (R): It uses design documents (schematics, engineering drawings, etc.) to show that the experiment will perform as expected.

Table 5-1. Verification table.

ID	Requirement text	Method	Reference	Status	Verification Result
R-FU-HTL-010	The experiment shall quantify the convective heat transfer on a horizontal heated flat plate.	R, T – TVAC functional test	T010	TBD	None
R-FU-HTL-020	The experiment shall quantify the convective heat transfer on a vertical heated flat plate.	R, T – TVAC functional test	T010	TBD	None
R-FU-HTL-030	The experiment shall quantify the convective heat transfer between spaced vertical heated flat plates.	R, T – TVAC functional test	T010	TBD	None
R-FU-HTL-040	The experiment shall quantify the convective heat transfer on a thermal strap attached to a radiator.	R, T – TVAC functional test	T010	TBD	None
R-FU-HTL-050	There shall be an air mass flow between the inner gondola air and each experiment internal air during the whole mission.	T, A – TVAC functional test	T010	TBD	None
R-FU-HTL-060	The temperature sensors values of the Heat Transfer Lab plates shall be measured, collected, and stored during the whole mission.	T, I – TVAC functional test	T010	TBD	None
R-FU-HTL-070	The temperature sensors values of the surrounding walls of each experiment shall be measured, collected	T, I – TVAC functional test	T010	TBD	None

	and stored during the whole mission.				
R-FU-HTL-080	The temperature sensors values of the surrounding air of each experiment shall be measured, collected and stored during the whole mission.	T, I – TVAC functional test	T010	TBD	None
R-FU-HTL-090	The temperature sensors values of the air located inside the gondola cavity shall be measured, collected and stored during the whole mission.	T, I – TVAC functional test	T010	TBD	None
R-FU-HTL-100	The dissipated power from the Heat Transfer Lab heaters shall be measured, collected and stored during the whole mission.	T, I – TVAC functional test	T010	TBD	None
R-FU-HTL-110	The temperature of each heated plate shall be controlled independently during the whole mission.	T, I – TVAC functional test	T010	TBD	None
R-FU-HTL-120	The direct solar flux shall be measured, collected and stored during the whole mission.	T, I – Radiative test	T020	TBD	None
R-FU-HTL-130	The solar flux reflected by the Earth shall be measured, collected and stored during the whole mission.	T, I – Radiative test	T020	TBD	None
R-FU-HTL-140	The Outgoing Longwave Radiation (OLR) from Earth shall be measured, collected and stored during the whole mission.	T, I – Radiative test	T020	TBD	None
R-FU-HTL-150	The Infrared Radiation (IR) from the sky shall be measured, collected and stored during the whole mission.	T, I – Radiative test	T020	TBD	None
R-FU-HTL-160	The experiment 3 radiator shall radiate outside the gondola.	I, R	–	TBD	None
R-FU-HTL-170	The air pressure shall be measured during the whole mission.	T, I – TVAC functional test	T010	TBD	None
R-FU-HTL-180	The atmosphere air speed modulus on at least one external surface of the gondola shall be measured at least during the ascending phase.	T, I – Wind tunnel test	T030	TBD	None
R-FU-ATL-190	The Nadir sensor shall determine the nadir direction during the float phase.	T, I – Nadir functional test	T040	TBD	None

R-FU-MEC-200	The structure shall provide protection and support to all subsystems during the whole mission.	A, I	–	TBD	None
R-FU-MEC-210	The structure shall provide physical connection to the upward and downward environmental lab during the whole mission.	I	–	TBD	None
R-FU-MEC-220	The structure external brackets shall ensure a maximal vertical defection of 1 cm during the whole mission.	A, I	–	TBD	None
R-PE-HTL-010	All Heat Transfer Lab temperature sensors values shall be stored at a minimum frequency of 0.1 Hz (T = 10 secs) during the whole mission.	T, I – Functional test	T070	TBD	None
R-PE-HTL-020	Heat Transfer Lab temperature sensors from the plates and air shall be downloaded at a minimum frequency of 0.1 Hz (T = 10 secs) during the whole mission.	T, I – Functional test	T070	TBD	None
R-PE-HTL-030	All Infrared Radiation sensors values shall be stored at a minimum frequency of 0.1 Hz (T = 10 secs) during the whole mission.	T, I – Functional test	T070	TBD	None
R-PE-HTL-040	All Infrared Radiation sensors values shall be downloaded at a minimum frequency of 0.1 Hz (T = 10 secs) during the whole mission.	T, I – Functional test	T070	TBD	None
R-PE-HTL-050	All Solar Radiation sensors values shall be stored at a minimum frequency of 0.1 Hz (T = 10 secs) during the whole mission.	T, I – Functional test	T070	TBD	None
R-PE-HTL-060	All Solar Radiation sensors values shall be downloaded at a minimum frequency of 0.1 Hz (T = 10 secs) during the whole mission.	T, I – Functional test	T070	TBD	None
R-PE-HTL-070	All Heat Transfer Lab temperatures shall be measured with an accuracy lower than or equal to +/- 1ºC during the whole mission.	R, A	–	TBD	None

R-PE-HTL-080	The Heat Transfer Lab temperature measurement range shall be at least between -80ºC and 60ºC during the whole mission.	R, A	–	TBD	None
R-PE-HTL-090	Air pressure shall be measured with an accuracy of 50 Pa during the whole mission.	T, I – TVAC functional test	T010	TBD	None
R-PE-HTL-100	The Infrared Radiation sensor shall work in a temperature range between -40 °C and 80 °C during the whole mission.	R, A	–	TBD	None
R-PE-HTL-110	The Solar Radiation sensor shall work in a temperature range between -40 °C and 80 °C during the whole mission.	R, A	–	TBD	None
R-PE-HTL-120	The Infrared Radiation sensor shall measure in a wavelength range between 2 to 100 micrometres during the whole mission.	R	–	TBD	None
R-PE-HTL-130	The Solar Radiation sensor shall measure in a wavelength range between 0.1 to 2 micrometres during the whole mission.	R	–	TBD	None
R-PE-HTL-140	The IR sensors FoV shall be 180º	R	–	TBD	None
R-PE-HTL-150	The solar sensors FoV shall be 180º	R	–	TBD	None
R-PE-HTL-160	The atmosphere air speed modulus shall be measured with an accuracy lower than or equal to 1 m/s	T, R – Wind tunnel test	T030	TBD	None
R-PE-HTL-170	The atmosphere air speed modulus shall be measured in a range between 3 m/s and 20 m/s	R	–	TBD	None
R-PE-HTL-180	The anemometer shall work within a static pressure range at least between TBC.	R	–	TBD	None
R-PE-HTL-190	The anemometer values shall be stored at a minimum frequency of 1 Hz (T = 1 secs) during the whole mission.	T, I – Functional test	T070	TBD	None
R-PE-ATL-200	The anemometer values shall be downloaded at a minimum frequency of 0.1 Hz (T = 10 secs)	T, I – Functional test	T070	TBD	None

	during the whole mission.				
R-PE-ATL-230	The Nadir sensor functional range shall be at least 10º from the Nadir direction during the whole mission.	R	–	TBD	None
R-PE-ATL-240	The Nadir sensor temperature range shall be from -20ºC to 80ºC during the whole mission.	R, A	–	TBD	None
R-PE-ELE-250	The electronic shall allow to acquire data at the appropriate accuracy during the whole mission.	R	–	TBD	None
R-PE-ELE-260	The electronic subsystem shall operate in the temperature range between -40ºC to 80ºC during the whole mission.	R, A	–	TBD	None
R-DE-ELE-270	The electronic subsystem shall operate in the pressure profile between 100 kPa to 500 Pa.	T, I – TVAC functional test	T010	TBD	None
R-DE-ELE-280	The GPS and magnetometer values shall be stored at a minimum frequency of 1 Hz (T = 1 secs) during the whole mission.	T, I – Functional test	T070	TBD	None
R-PE-ELE-290	The GPS values shall be downloaded at a maximum period of 60 seconds during the whole mission.	T, I – Functional test	T070	TBD	None
R-PE-ELE-300	The gyroscope and accelerometer values shall be stored at a minimum frequency of 100 Hz (T = 0.01 secs) during the whole mission.	T, I – Functional test	T070	TBD	None
R-PE-ELE-310	The attitude determination accuracy shall be +/- 1 deg.	R, A	–	TBD	None
R-PE-ELE-320	The position determination accuracy shall be TBC.	R, A	–	TBD	None
R-PE-SFW-330	The OBSW shall store the current system' mode whenever it changes.	T, I – Functional test	T070	TBD	None
R-PE-SFW-340	The OBSW shall store the relative time of the mission at a minimum period of 30 seconds.	T, I – Functional test	T070	TBD	None
R-PE-SFW-350	The OBSW shall timestamp data within TBD accuracy.	R	–	TBD	None

R-DE-HTL-010	The solar sensor for solar flux reflected by the Earth shall be located outside the gondola and faced to Nadir.	I	–	TBD	None
R-DE-HTL-020	The solar sensor for direct solar flux measurement shall be located outside the gondola and faced to Zenith.	I	–	TBD	None
R-DE-HTL-030	The IR sensor for OLR measurement shall be located outside the gondola and faced to Nadir.	I	–	TBD	None
R-DE-HTL-040	The IR sensor for IR from sky measurement for shall be located outside the gondola and faced to Zenith.	I	–	TBD	None
G-DE-HTL-050	The FoV of the solar sensor should not be affected by the gondola or the attitude lab.	I, R	–	TBD	None
G-DE-HTL-060	The FoV of the IR sensor should not be affected by the gondola or the attitude lab.	I, R	–	TBD	None
R-DE-HTL-070	The anemometer shall be located normal to one of the vertical surfaces of the gondola.	I	–	TBD	None
R-DE-HTL-080	The anemometer shall be located at a distance from the gondola TBD.	I	–	TBD	None
R-DE-HTL-090	The anemometer shall not disturb the air at the normal component to the measuring surface.	I, R	–	TBD	None
G-DE-ATL-100	The Nadir sensor FoV should not be affected by the gondola.	I, R	–	TBD	None
R-DE-ATL-110	The Nadir sensor development shall be decoupled from the main experiment.	R	–	TBD	None
R-DE-MEC-120	The structure shall provide physical access to the E-link and the Gondola Power Supply	I, R	–	TBD	None
R-DE-MEC-130	Experiment shall be structured to withstand the loads specified in the User Manual.	A, T – Mechanical test	T060	TBD	None
R-DE-MEC-140	The structure shall prevent any electrical shunts	R, I	–	TBD	None
R-DE-MEC-150	The experiment shall be attached to the gondola's rails.	I	–	TBD	None
R-DE-MEC-160	The HTL experiment shall be placed in a corner of the gondola.	I	–	TBD	None

R-DE-MEC-170	The HTL and the Electronic Box housing envelope shall be lower than TBC.	I	–	TBD	None
R-DE-MEC-180	The downward external brackets longitude shall be longer than 0.5 m.	I, R	–	TBD	None
R-DE-MEC-190	The upward external brackets longitude shall be longer than TBC m.	I, R	–	TBD	None
R-DE-MEC-200	The HTL and Electronic Box housing mass shall be less than TBC kg.	T, R – Mechanical test	T060	TBD	None
R-DE-MEC-210	The external brackets mass shall be less than TBC kg.	T, R – Mechanical test	T060	TBD	None
R-DE-MEC-220	The experiment shall not disturb or harm the launch vehicle.	I, R	–	TBD	None
R-DE-ELE-230	The OBC shall be connected to the E-Link airborne unit through the Amphenol RJF21B (CODE A) per the BEXUS user manual.	I, R	–	TBD	None
R-DE-ELE-240	All electronic components shall be protected from over currents.	I, R	–	TBD	None
R-DE-EPW-250	The maximum continuous power consumption of the HERCCULES experiment shall not exceed 40 W.	I, R	–	TBD	None
R-DE-EPW-260	The total power consumption of the HERCCULES experiment during the pre-flight and flight phases should be below 170 W·h.	I, R	–	TBD	None
R-DE-EPW-270	The Electrical Power Subsystem shall be connected to the battery through the Amphenol PT02E8-4P connector.	I, R	–	TBD	None
R-DE-EPW-280	The Electrical Power Subsystem shall power the system with 12 V, 5 V and 3.3 V voltage lines.	I, R	–	TBD	None
R-DE-EPW-290	The peak power consumption of the HERCCULES experiment shall be below 110 W.	I, R	–	TBD	None
R-DE-EPW-300	The Electrical Power Subsystem shall be powered by the battery of the gondola at least.	I, R	–	TBD	None
R-DE-SFW-310	The OBSW shall downlink telemetry data via the E-Link airborne unit.	I, T – Software test	T050	TBD	None

R-DE-SFW-320	The OBSW shall be connected to the E-Link airborne unit through the Ethernet network layer protocol.	I	–	TBD	None
R-DE-SFW-330	The OBSW shall receive telecommands via the E-Link airborne unit.	I, T – Software test	T050	TBD	None
R-DE-SFW-340	The GS shall uplink telecommands via the E-Net network from the E-Link ground unit	I, R	–	TBD	None
R-DE-SFW-350	The GS shall be connected to the E-Link ground unit through the Ethernet network layer protocol.	I, R	–	TBD	None
R-DE-SFW-360	The GS shall receive telemetry via the E-Net network from the E-Link ground unit.	I, R	–	TBD	None
R-DE-SFW-370	The GS shall not be connected to the Internet.	I, R	–	TBD	None
G-DE-SFW-380	The GS should access Internet through the Guest Net network provided by the E-Link ground unit.	I, R	–	TBD	None
R-DE-SFW-390	The GS shall be configured with the provided IP address.	I, R	–	TBD	None
R-DE-SFW-400	The OBSW shall be configured with the provided IP address.	I, R	–	TBD	None
G-DE-SFW-410	A switch should be used to distribute the Internet access from the Guest Net.	I, R	–	TBD	None
G-DE-SFW-420	The Software architecture and design should be described in the UML and/or AADL modelling languages, recommended in [1, Annex B.4].	R	–	TBD	None
G-DE-SFW-430	C source code should be written following the Barr Group's Embedded C Coding Standard.	R	–	TBD	None
R-DE-SFW-440	Changes to the SW after the FST at the EAR shall be kept to a minimum and pass all regression tests.	I, R	–	TBD	None
R-DE-SFW-450	The OBSW shall function in Flight mode even if the vehicle is not, i.e.: Flight mode shall be simulated.	I, R	–	TBD	None
R-DE-SFW-460	The OBSW shall store data during the FST.	R	–	TBD	None
R-DE-SFW-470	The C, C++, or Ada shall be used as the	R	–	TBD	None

	programming languages for the OBSW.				
R-DE-SFW-480	The OBC Wi-Fi shall be turned off.	I	–	TBD	None
G-DE-SFW-490	E-Link dropouts should be simulated to ensure correctness when there is no telemetry available	I, R	–	TBD	None
R-DE-SFW-500	The OBSW shall implement FDIR to deal with E-Link communication timeouts.	I, R	–	TBD	None
R-DE-SFW-510	The OBSW shall send and receive data from zero up to and including 2 Mbps.	I, R	–	TBD	None
R-DE-SFW-520	The GSSW shall send and receive data from zero up to and including 2 Mbps.	I, R	–	TBD	None
R-DE-SFW-530	The OBSW shall store the data collected from all the experiments in different files, i.e.: one file per experiment.	I, R	–	TBD	None
R-DE-SFW-540	The OBSW shall turn off the experiment before landing.	I	–	TBD	None
R-OP-HTL-010	The operational modes of the heaters shall be able to be change automatically (safety mode) and by telecommands.	T, I – Functional test	T070	TBD	None
R-OP-HTL-020	The heaters shall work in different operational modes during the whole mission.	T, I – Functional test	T070	TBD	None
R-OP-HTL-030	Control HTL parameters should be included in the housekeeping parameters.	T, I – Functional test	T070	TBD	None
R-OP-MEC-040	Any experiment or part of the experiment located outside of the gondola shall be secured with a safety cable.	I	–	TBD	None
R-OP-MEC-050	The experiment shall facilitate safe mounting on the gondola.	I	–	TBD	None
R-OP-ELE-060	The electronic subsystem should contain a protection circuit in case of overcurrent or wrong connection with the BEXUS power supply	R, I	–	TBD	None
R-DE-AIT-070	The AIT Plan shall verify the availability and the compatibility of the test facilities.	R	–	TBD	None

R-DE-AIT-080	The AIT team shall ensure that the documentation associated with the plan is in accordance with the specifications and quality established in the project.	R	–	TBD	None
R-DE-AIT-090	The AIT Plan, as well as the verification plan, shall be limited to the time frames established for the HERCCULES project.	R	–	TBD	None
R-DE-EPW-100	The Electrical Power Subsystem shall monitor the voltage and current of the gondola battery and any possible secondary power supply.	R, T – Functional test	T070	TBD	None
R-DE-EPW-110	The HERCCULES experiment shall include a power safe mode	R, T – Functional test	T070	TBD	None
R-DE-SFW-120	The OBSW should provide temperature and voltages for critical electronic components by request.	T, I – Software test	T050	TBD	None
G-PE-SFW-130	The OBSW should record the error logs from the experiments for future analysis.	T, I – Software test	T050	TBD	None
R-PE-SFW-140	The OBSW shall implement a command to perform a quick functional test and give the status from all the experiment equipment	T, I – Software test	T050	TBD	None
R-OP-SFW-150	The OBSW shall support multiple reboot (on and off) sequences.	I, R	–	TBD	None
R-OP-SFW-160	The OBC shall be rebooted if the OBSW is suspended for more than TBD seconds.	I, R	–	TBD	None
R-OP-SFW-170	The connection between the GS and OBSW should be re-established with no errors.	T, R – Software test	T050	TBD	None
R-OP-SFW-180	The OBSW shall initialize the system considering its latest system mode and relative time of the mission if available.	A, I	–	TBD	None
G-OP-SFW-190	The GSSW software shall store telemetry data in a database.	T, I – Software test	T050	TBD	None

5.2 Verification Plan

Table 5-2. Test description for the TVAC functional test (T010).

Test number	T010
Test type	TVAC functional test
Test facility	Instituto Universitario de microgravedad "Ignacio Da Riva" (IDR/UPM)
Tested item	Heat Transfer Lab (HTL) experiment
Model	Flight Model
Procedure, Test level and duration	The experiment will be tested inside the vacuum chamber under similar pressure conditions expected during the BEXUS float phase. The I/F temperatures of the chamber (baseplate and shroud) will be defined according to the worst scenario from the thermal point view to verify all the components will work inside their operational temperature range. The Thermal Mathematical Model (TMM) will be correlated with this test. Besides, the air pressure measurements will be compared with TVAC pressure sensor.
Test campaign duration	TBD
Test campaign date	TBD
Test completed	No
Requirements verified	No

Table 5-3. Test description for the radiative test (T020).

Test number	T020
Test type	Radiative test
Test facility	Instituto Universitario de microgravedad "Ignacio Da Riva" (IDR/UPM)
Tested item	Heat Transfer Lab (HTL) experiment
Model	Flight Model
Procedure, Test level and duration	The measurements of the solar and IR radiation sensors will be tested in regard to proper functionality.
Test campaign duration	TBD
Test campaign date	TBD
Test completed	No
Requirements verified	No

Table 5-4. Test description for the wind tunnel test (T030).

Test number	T030
Test type	Wind tunnel test
Test facility	Instituto Universitario de microgravedad "Ignacio Da Riva" (IDR/UPM)
Tested item	Anemometer
Model	Prototype
Procedure, Test level and duration	The measurements of the differential pressure sensors will be tested for calibration at different angles and windspeeds. Very low windspeeds will be used to compensate the absolute pressure/density difference.
Test campaign duration	TBD
Test campaign date	TBD
Test completed	No
Requirements verified	No

Table 5-5. Test description for the nadir functional test (T040).

Test number	T040
Test type	nadir functional test
Test facility	Instituto Universitario de microgravedad "Ignacio Da Riva" (IDR/UPM)
Tested item	Attitude Lab
Model	Flight model
Procedure, Test level and duration	Test all the components work properly. Check that nadir direction can be computed simulating Earth IR radiation in TVAC. Test Procedure: TBD

Test campaign duration	TBD
Test campaign date	TBD
Test completed	No
Requirements verified	No

Table 5-6. Test description for the software test (T050)

Test number	T050
Test type	Software test
Test facility	Instituto Universitario de microgravedad “Ignacio Da Riva” (IDR/UPM)
Tested item	All sensors and actuators
Model	Flight Model
Procedure, Test level and duration	<u>Test procedure</u>: 1. Ensure that all equipment is connected. 2. Connect the OBC with the GS S/W through a simulated E-Link system, limiting the bandwidth to 500 Kbps. 3. Analyse the HK data in real time, and check that the operating mode are correct. Trigger mode changes through TCs. 4. Connect and disconnect 5. Check that there is recorded data in the OBC and that it is consistent compared to the data received in real time. During this procedure (i) the E-Link connection shall be disconnected and reconnected to ensure that the FDIR OBSW still works even if the connection is lost; (ii) the experiment shall be powered on and off to ensure that the OBSW starts automatically after a reboot; (iii) pressure changes shall be simulated by software or hardware. <u>Test duration</u>: The OBSW will run for 8 hours to detect errors that only arise after long duration operation.
Test campaign duration	TBD
Test campaign date	TBD
Test completed	No
Requirements verified	No

Table 5-7. Test description for the mechanical test (T060)

Test number	T060
Test type	Mechanical test
Test facility	Instituto Universitario de microgravedad “Ignacio Da Riva” (IDR/UPM)
Tested item	Entire experiment
Model	Flight Model
Procedure, Test level and duration	Test all the mechanical components work properly and have the proper properties (mass).
Test campaign duration	TBD
Test campaign date	TBD
Test completed	No
Requirements verified	No

Table 5-8. Test description for the functional test (T070)

Test number	T070
Test type	Functional test
Test facility	Instituto Universitario de microgravedad “Ignacio Da Riva” (IDR/UPM)
Tested item	All experiment
Model	Flight Model
Procedure, Test level and duration	Test all the components work properly. Test operational modes and its changes work properly
Test campaign duration	TBD
Test campaign date	TBD
Test completed	No
Requirements verified	No

5.3 Verification Results

Table 5-9. TVAC functional test (T010) result overview.

Verification number	*T010*
Type of test	*TVAC functional test*
Facility	*Instituto Universitario de microgravedad “Ignacio Da Riva” (IDR/UPM)*
Verified item	
Verification description	*Verify all components work properly inside their operational temperature range* *Correlation of the TMM*
Expected results	*-Temperatures, power dissipation, pressure measurements*
Obtained Results	-
Conclusions	-

Table 5-10. Radiative test (T020) result overview.

Verification number	*T020*
Type of test	*Radiative test*
Facility	*Instituto Universitario de microgravedad “Ignacio Da Riva” (IDR/UPM)*
Verified item	*Solar and IR radiation sensors*
Verification description	*Compare the measurements with reference data.*
Expected results	-
Obtained Results	-
Conclusions	-

Table 5-11. Wind tunnel test (T030) result overview

Verification number	*T030*
Type of test	*Wind tunnel test*
Facility	*Instituto Universitario de microgravedad “Ignacio Da Riva” (IDR/UPM)*
Verified item	*Anemometer*
Verification description	*Check the response of the anemometer to the expected input (pressure/density-compensated windspeed).*
Expected results	*Temperatures, absolute pressure, windspeed modulus, windspeed direction, differential pressure set.*
Obtained Results	-
Conclusions	-

Table 5-12. Software test (T040) result overview.

Verification number	*T040*
Type of test	*Software test*
Facility	*Instituto Universitario de microgravedad “Ignacio Da Riva” (IDR/UPM)*
Verified item	*All sensors and actuators*
Verification description	*TBD*
Expected results	-
Obtained Results	-
Conclusions	-

Table 5-13. Nadir functional test (T050) result overview.

Verification number	*T050*
Type of test	*Nadir functional test*
Facility	*Instituto Universitario de microgravedad "Ignacio Da Riva" (IDR/UPM)*
Verified item	*Nadir experiment*
Verification description	*TBD*
Expected results	-
Obtained Results	-
Conclusions	-

Table 5-14. Mechanical test (T060) result overview.

Verification number	*T060*
Type of test	*Mechanical test*
Facility	*Instituto Universitario de microgravedad "Ignacio Da Riva" (IDR/UPM)*
Verified item	*Entire experiment*
Verification description	*Check the mechanical properties and responses from the experiment*
Expected results	*TBD*
Obtained Results	-
Conclusions	-

Table 5-15. Functional test (T070) result overview.

Verification number	*T070*
Type of test	*Functional test*
Facility	*Instituto Universitario de microgravedad "Ignacio Da Riva" (IDR/UPM)*
Verified item	*Entire experiment*
Verification description	*Check the temperature, voltage, pressure,…, measurements stored are OK.*
Expected results	*-Measurements of temperature, voltage, pressure,..*
Obtained Results	-
Conclusions	-

6 LAUNCH CAMPAIGN PREPARATION

6.1 Input for the Campaign / Flight Requirement Plans

6.1.1 Dimensions and Mass

A summary is included in Table 6-1.

Table 6-1. Experiment mass and volume.

	HTL	E-Box	Upward Env. Lab	Downward. Env. Lab	TOTAL
Experiment mass:	3.5 kg	3.2 kg	2 kg	2.2 kg	12 kg
Experiment dimensions:	0.3x0.3x0.2 m	0.205x0.3x0.2 m	0.57x0.25x0.2 m	0.35x0.6x0107 m	0.7x0.9x0.96 m
Experiment expected COG:	X:350 Y:150 Z:100	X: 63 Y: 150 Z: 100	X: 320 Y: -303 Z: 764	X: 261 Y: -400 Z: -25	X: 223 Y: 28 Z: 159

6.1.2 Safety Risks

Table 6-2. Experiment safety risks.

Risk	Key Characteristics	Mitigation
Heat Transfer Lab plates could reach temperatures higher than 60 ºC.	-	The dissipated power will be switch off before landing.
Environmental Lab will be located in two brackets outside the Gondola.	-	A structural test will be performed to ensure the BEXUS loads. In addition, a safety wire will be included.

6.1.3 Electrical Interfaces

Electrical Interfaces are defined in Table 6-3.

Table 6-3. Electrical interfaces applicable to BEXUS.

BEXUS Electrical Interfaces		
E-Link Interface: E-Link required? Yes		
	Number of E-Link interfaces:	1
	Number of required IP addresses:	1
	Data rate – downlink (max. and average):	0.25 Kbit/s
	Data rate – uplink (max. and average):	0.09 Kbit/s
	Interface type (RS-232, Ethernet):	Ethernet
Power system: Gondola power required? Yes		
	Peak power and current consumption:	23.8 W and 0.9 A
	Average power and current consumption:	16.8 W and 0.59 A
	Total power and current consumption after lift-off	147 Wh and 5.9 Ah
Power system: Experiment includes batteries? No		

6.1.4 Launch Site Requirements

The team has listed the following requirements for the launch site:

- The team shall have access to power outlets
- The teams shall have access to internet (Wi-fi or Ethernet)
- The launch site shall provide the equipment that appears in Table 6-4.

Table 6-4. Required equipment at launch site.

Required equipment at launch site
Power supply with the capability to feed the experiment at 28 V, 1.5 A
2 multi-socket adaptors
2 large table
10 chairs
1 Multimeter
Calibrated temperature sensor
Gloves
Calliper

6.1.5 Flight Requirements

Preliminary information about the flight requirements are summarized in Table 6-5.

Table 6-5. Flight Requirements applicable to BEXUS.

Optimal altitude	A minimum float altitude of 20 km is required to fulfil the requirements.
Preferred path	N/A
Minimum float time	3 hours.
Ground track length	N/A

Light/dark condition	Light for scientific purpose and thermal issues.

6.1.6 Accommodation Requirements

The anemometer (HTL EXP5) and the radiator (HTL EXP3) in the Main Structure require that two of the walls of the Main Structure face the outside of the Gondola and are situated as close as possible to the edge, so the ideal position for it is on one of the corners of the Gondola. The Upward and Downward Environmental Labs need to be located outside of the Gondola for the sensors to properly provide the information required to complete and validate the thermal environment characterization models. Figure 6-1 Ideal positioning of the experiment shows the team´s preferable position for the entire experiment.

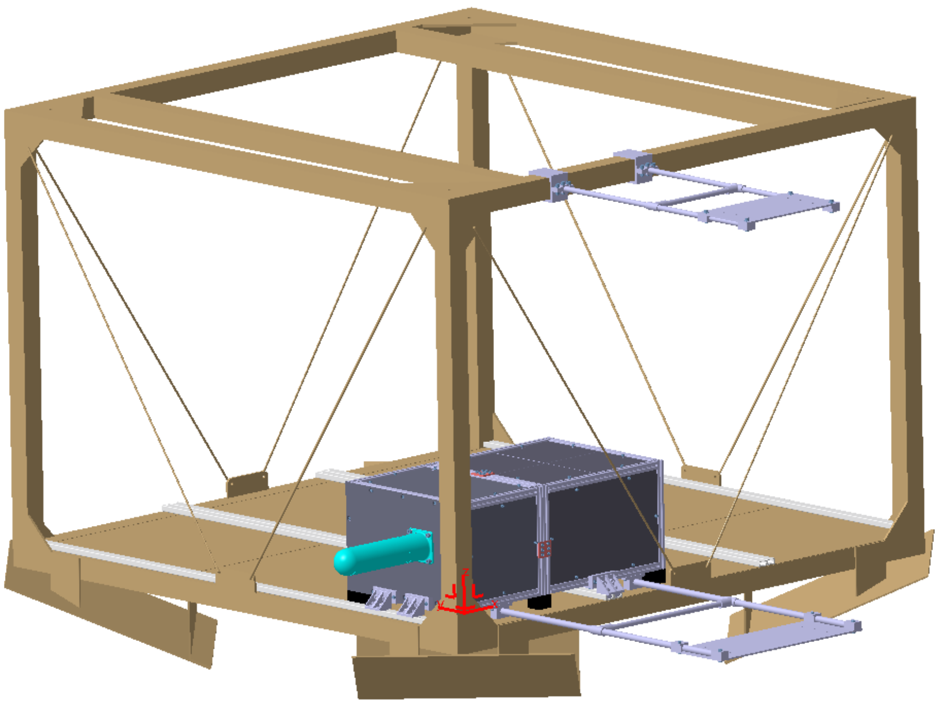


Figure 6-1 Ideal positioning of the experiment

Besides, as the anemometer shall measure outside the gondola, it is required to cut the windshield for this objective. Likewise, the EXP3 radiator requires to be uncovered so it is also required to cut the windshield allowing us to attach the thermal strap to the radiator.

The Upward and Downward Environmental Lab arms require to go through the windshield, for this reason the windshield shall be cut to allow this.

6.2 Preparation and Test Activities at Esrange

A preliminary planning has been developed for the pre-flight activities.

Table 6-6 - List of planned activities.

Time/Day	Main Task	Responsible	Comments
Day 1	Team briefing.	Team leader	-Reminder of scheduled task
	Equipment and tools verification	Ground Equipment responsible	-Tools and equipment check list needed
	Experiment unpackage and visual inspection	Integration team	
	Experiment integration	Integration team	
	Ground station set up	Ground station responsible	
	Team briefing.	Team leader	-Task status -Problems encountered -Closing activities
Day 2	Team briefing.	Team leader	-Experiment status -Reminder of scheduled and pending task.
	Functional test	Software	-Ensure proper operation of experiment sensors and heaters
	Communication test	Software/ electronics	-Check data downlink/ uplink data reception.
	Team briefing.	Team leader	-Task status -Problems encountered -Closing activities
Day 3	Team briefing.	Team leader	-Experiment status -Reminder of scheduled and pending task.
	Mechanical compatibility test	Integration team	-Ensure correct mechanical integration of the different parts of the experiment with the gondola and between them -Ensure correct electrical connection between the different boxes
	Flight compatibility test	Whole team	
	Flight readiness review (FRR)	Whole team	Necessary to review before every launch attempt
	Team briefing.	Team leader	-Task status, -Problems encountered -Closing activities

Launch day	Mounting the HTL main box in the gondola	Integration team	
	Mounting Environmental lab boxes	Integration team	
	Environmental lab sensors functional test	software	Ensure electrical connection between the electronic box and Environmental lab
	Programmed pre-flight, flight and postflight activities	TBD	

6.3 Timeline for Countdown and Flight

Timeline for Countdown is still TBD.

6.4 Post-Flight Activities

Post-Flight activities are still TBD.

7 DATA ANALYSIS AND RESULTS

7.1 Data Analysis Plan

7.1.1 Heat Transfer Lab

The data analysis of the HTL will be divided into two different assignments due to the methodology will be different. On the one hand, the data obtained from EXP1-EXP4 and on the other hand the data obtained from EXP5.

Regarding EXP1-EXP4, our ESATAN-TMS thermal model will be correlated with the temperature measurements. Each cavity will be analysed separately. Defining the surrounding wall temperature and the surrounding air temperature as boundary according to the flight measurements, the only variable to correlate will be the temperature of each plate, with the convective heat flow as the unique parameter to estimate.

Regarding EXP5, the wind speed and direction will be estimated with the set of 4 values of differential pressure and their respective orientations. Due to the nature of the differential pressure sensors, the values will have to be corrected in terms of absolute pressure and temperature to obtain the real differential pressure values. Then, differential pressure values will be correlated with data from the calibration test, considering the density difference.

7.1.2 Environmental Lab

Radiative data acquired by the Environmental Lab will be used to validate a new methodology for characterizing the thermal environment of stratospheric balloon flights based on Real Observation data according to [2]. Obtained data will be compared with CERES [10] processed data for obtaining the worst-case profiles during the ascent phase as well with the predicted radiative environment. The presence or not of short-term variations in the measured values will be analysed and compared with the hour averaged values provided by CERES. This data will be also used for the thermal analysis of the HERCCULES experiment post-flight.

7.1.3 Nadir Sensor

In order to correlate the nadir direction obtained with the sensor it is necessary to estimate independently the nadir direction in the experiment body axes. This independent measurement could be obtained using an inclinometer. However, given that the attitude of the experiment could be useful to fully calculate the thermal environmental conditions, it was decided to derive the nadir direction from the experiment's attitude. To obtain the experiment's attitude the data from accelerometers and gyroscopes is going to be filtered using and Extended Kalman Filter (EKF) using magnetometer and GPS measurements to correct the estimated attitude and position. Once the experiment's attitude is calculated the nadir direction can be derived and compared to the results obtained with the nadir sensor.

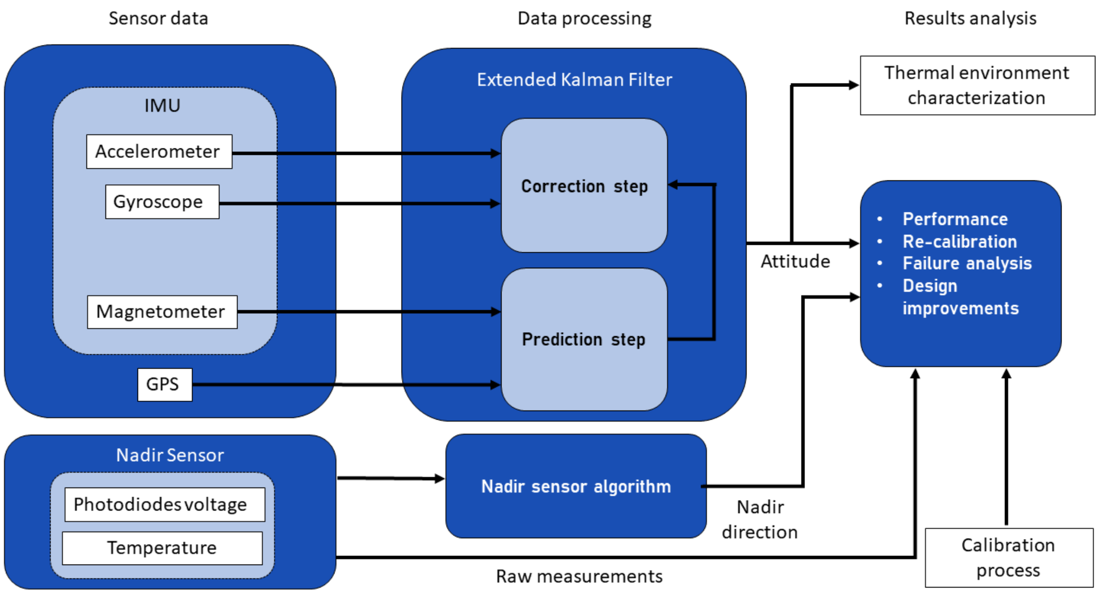


Figure 7-1. Preliminary scheme of the attitude and nadir sensor data analysis.

It is possible that the nadir sensor could calculate wrong the nadir direction. For this case the raw measurements obtained from the photodiodes and its temperature will be also recorded. With this data it is possible to detect failures in the design, calibration or algorithm of the instrument. Furthermore, this data it is useful to study in detail the performance and quality of the calibration method used and to detect other variables that could affect the performance of the instrument and were not considered. A post-process scheme is shown in Figure 7-1.

7.1.4 Thermal Mathematical Correlation

In order to validate our methodology [7] defining the worst thermal environment scenario, our ESATAN-TMS TMM will be correlated with the temperature measurements. We will compare our predictions for the Hot case and the Cold case with the flight data as it shown in Figure 7-2 during the ascent phase, and during the float phase.

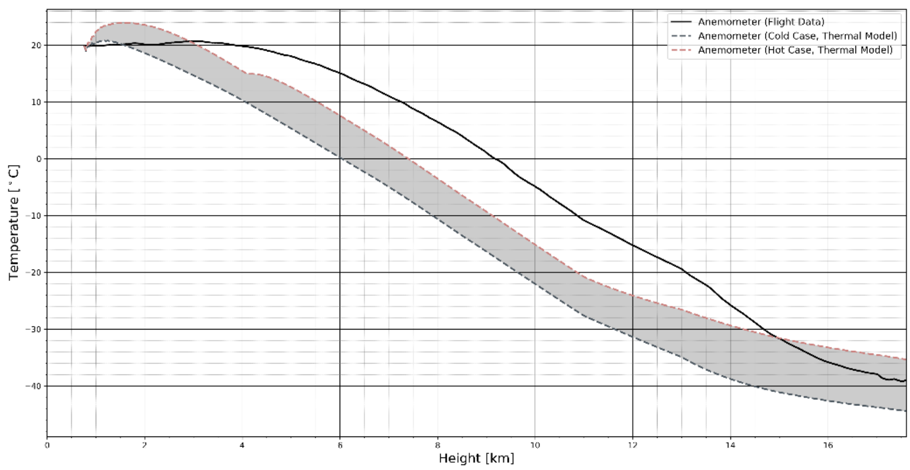


Figure 7-2. Envelope temperature predicted comparing the flight temperatures.

7.2 Launch Campaign

TBD

7.3 Results

TBD

7.3.1 Input to Campaign Report

TBD

7.4 Lessons Learned

7.4.1 Preliminary Design Phase

- A good communication between all subsystems is important to reach an appropriate design.
- Work Packages helps to structure and follow the design process.
- An updated schedule is important to avoid delays in the project.
- The time for the requirements definition should not be underestimated.
- It is necessary to correctly define the project for attracting potential sponsors.
- Electronics require more time than expected. For this reason, we have included a new member.
- Project management requires considerable time coordinating all subsystems and planning all activities to be done during the project.
- Ensuring a good SED documentation between many people is complicated. A latex template would be very useful and friendly.

8 ABBREVIATIONS AND REFERENCES

8.1 Abbreviations

AADL Architecture Analysis and Design Language

AIT Assembly, Integration and Test

AKA As known as

ASSERT Automated proof-based System and Software Engineering for Real-Time applications

ATL Attitude Lab

CAD Computer-Aided Design

CD Continuous Delivery

CDR Critical Design Review

CI Continuous Integration

CM 3+ Raspberry Pi Compute Module model 3 +

COG Centre of Gravity

COTS Commercial Off-The-Shelf

CRP Campaign Requirement Plan

DLR Deutsches Zentrum für Luft- und Raumfahrt

EAT Experiment Acceptance Test

EAR Experiment Acceptance Review

ECTS European Credit Transfer System

EIT Electrical Interface Test

ELE Electronics subsystem

EPM Esrange Project Manager

ESA European Space Agency

Esrange Esrange Space Center

EKF Extended Kalman Filter

EPW Electrical Power Subsystem

ESTEC European Space Research and Technology Centre, ESA (NL)

ESW Experiment Selection Workshop

EXP Experiment

FAR Flight Acceptance Review

FOV	Field of View
FST	Flight Simulation Test
FRP	Flight Requirement Plan
FRR	Flight Readiness Review
GPS	Global positioning system
GS	Ground Station
GSC	Ground Station Computer
GSE	Ground Support Equipment
GSSW	Ground Station Software
HAL	Hardware Abstraction Layer
HK	House Keeping
HTL	Heat Transfer Lab
H/W	Hardware
ICD	Interface Control Document
I/F	Interface
IO	Input Output
IDR/UPM	University institute of Microgravity “Ignacio Da Riva”
IMU	Inertial Measurement Unit
IR	Infrared
IPR	Integration Progress Review
LO	Lift Off
LT	Local Time
LOS	Line of Sight
Mbps	Mega Bits per second
MFH	Mission Flight Handbook
MEC	Mechanical and Structure Subsystem
MORABA	Mobile Raketen Basis (DLR, EuroLaunch)
MVP	Model-View-Presenter
OBC	On-Board Computer
OBDH	On-Board Data Handling
OBSW	On Board Software

OLR	Outgoing Longwave Radiation
OP	Oberpfaffenhofen, DLR Center
OS	Operating System
PCB	Printed Circuit Board (electronic card)
PDR	Preliminary Design Review
PRM	Project management
PST	Payload System Test
RBF	Remove Before Flight
Rx	Receiver
SDL	Specification and Description Language
SED	Student Experiment Documentation
SFW	Sofware design subsystem
SNSA	Swedish National Space Agency
SODS	Start Of Data Storage
SOE	Start Of Experiment
SPI	Serial Peripheral Interface
SS	Steady-State
STRAST	Real-Time Systems and Telematic Services Architecture
STW	Student Training Week
SW	Software
SysML	System Modeling Language
T	Time before and after launch noted with + or -
TASEC-Lab	Thermal Analysis Support and Environment Characterization Laboratory
TASTE	The ASSERT Set of Tools for Engineering
TC	Telecommand
TM	Telemetry
Tx	Transmitter
TBC	To be confirmed
TBD	To be determined
THE	Thermal subsystem

TMM	Thermal Mathematical Model
TR	Transient state
TVAC	Thermal Vacuum Chamber
UART	Universal Asynchronous Receiver Transmitter
UML	Unified Modelling Language
UPM	Universidad Politécnica de Madrid
WBS	Work Breakdown Structure
ZARM	Zentrum für Angewandte Raumfahrttechnologie und Mikrogravitation

8.2 References

[1] I. Pérez-Grande, A. Sanz-Andrés, N. Bezdenejnykh, and P. Barthol, “Transient thermal analysis during the ascent phase of a balloon-borne payload. Comparison with SUNRISE test flight measurements,” *Applied Thermal Engineering*, vol. 29, no. 8–9, pp. 1507–1513, Jun. 2009, doi: 10.1016/J.APPLTHERMALENG.2008.07.002.

[2] D. González-Bárcena, A. Fernández-Soler, I. Pérez-Grande, and Á. Sanz-Andrés, “Real data-based thermal environment definition for the ascent phase of Polar-Summer Long Duration Balloon missions from Esrange (Sweden),” *Acta Astronautica*, vol. 170, pp. 235–250, May 2020, doi: 10.1016/J.ACTAASTRO.2020.01.024.

[3] D. González-Bárcena, I. Pérez-Grande, Á. Sanz-Andrés, J. Piqueras-Carreño, I. Torralbo, and T. Magnetograph, “Challenges in the thermal analyses of the ascent and float phases of SUNRISE III,” Jul. 2020, Accessed: Jan. 21, 2022. [Online]. Available: https://ttu-ir.tdl.org/handle/2346/86426

[4] P. Barthol *et al.*, “The Sunrise Mission,” *Solar Physics 2010 268:1*, vol. 268, no. 1, pp. 1–34, Nov. 2010, doi: 10.1007/S11207-010-9662-9.

[5] S. K. Solanki *et al.*, “The Second Flight of the Sunrise Balloon-borne Solar Observatory: Overview of Instrument Updates, the Flight, the Data, and First Results,” *The Astrophysical Journal Supplement Series*, vol. 229, no. 1, p. 2, Mar. 2017, doi: 10.3847/1538-4365/229/1/2.

[6] L. Peinado, V. Muntean, and I. Pérez-Grande, “A free convection heat transfer correlation for very thin horizontal wires in rarefied atmospheres,” *Experimental Thermal and Fluid Science*, vol. 122, p. 110295, Apr. 2021, doi: 10.1016/J.EXPTHERMFLUSCI.2020.110295.

[7] D. González-Bárcena, A. Fernández-Soler, I. Pérez-Grande, and Á. Sanz-Andrés, “Real data-based thermal environment definition for the ascent phase of Polar-Summer Long Duration Balloon missions from Esrange (Sweden),” *Acta Astronautica*, vol. 170, pp. 235–250, May 2020, doi: 10.1016/J.ACTAASTRO.2020.01.024.

[8] A. González-Llana, D. González-Bárcena, I. Pérez-Grande, and Á. Sanz-Andrés, “Selection of extreme environmental conditions, albedo coefficient and Earth infrared radiation, for polar summer Long Duration Balloon missions,” *Acta Astronautica*, vol. 148, pp. 276–284, Jul. 2018, doi: 10.1016/J.ACTAASTRO.2018.05.016.

[9] B. Anderson, C. Justus, G. B.-N. T. Memorandum, and undefined 2001, “Guidelines for the selection of near-earth thermal environment parameters for spacecraft design,” *dept.aoe.vt.edu*, Accessed: Jan. 21, 2022. [Online]. Available: http://www.dept.aoe.vt.edu/~cdhall/courses/aoe4065/NASADesignSPs/tm211221.pdf

[10] B. A. Wielicki, B. R. Barkstrom, E. F. Harrison, R. B. Lee, G. L. Smith, and J. E. Cooper, “Clouds and the Earth’s Radiant Energy System (CERES): An earth observing system experiment,” *journals.ametsoc.org*, Accessed: Jan. 21, 2022. [Online]. Available: https://journals.ametsoc.org/view/journals/bams/77/5/1520-0477_1996_077_0853_catere_2_0_co_2.xml

[11] Hukseflux, “SR20 Pyranometer user manual.” Accessed: Jan. 21, 2022. [Online]. Available: www.hukseflux.com

[12] D. González-Bárcena *et al.*, “TASEC-Lab: A COTS-based CubeSat-like university experiment for characterizing the convective heat transfer in stratospheric balloon missions,” *Submitted to Acta Astronautica*, 2021.

[13] RX / BX Organisers, “BEXUS User Manual.” 2021. [Online]. Available: https://rexusbexus.net/bexus/bexus-user-manual/

[14] J. Eickhoff, “The FLP microsatellite platform: Flight operations manual,” in *Springer Aerospace Technology*, 2016.

[15] STRAST/UPM, “GitHub - STR-UPM/OBDH_LABS: Code for the MUSE/OBDH course laboratory.” https://github.com/STR-UPM/OBDH_LABS (accessed Jan. 21, 2022).

[16] A. Alonso, E. Salazar, J. de la P.-J. de T. Real—JTR, and undefined 2013, “Design of on-board software for an experimental satellite,” *dit.upm.es*, Accessed: Jan. 21, 2022. [Online]. Available: http://web.dit.upm.es/~str/papers/pdf/alonso&13a.pdf

[17] J. Eickhoff, *Onboard Computers, Onboard Software and Satellite Operations*, vol. 53, no. 9. 2019.

[18] M. Keeling, “Design it! : from programmer to software architect”, Accessed: Jan. 21, 2022. [Online]. Available: https://www.oreilly.com/library/view/design-it/9781680502923/

[19] I. Sommerville, *Software engineering (10th edition)*. 2016.

[20] ESA, “TASTE A tool-chain targeting heterogeneous embedded systems, using a model-based development approach,” *https://taste.tools/*.

[21] P. B. Kruchten, “The 4+1 View Model of Architecture,” *IEEE Software*, vol. 12, no. 6, 1995, doi: 10.1109/52.469759.

[22] ECMWF, “European Centre for Medium-Range Weather Forecasts.” https://www.ecmwf.int/ (accessed Jan. 21, 2022).

APPENDIX A – EXPERIMENT REVIEWS

A.1 Preliminary Design Review – PDR

TBD

A.2 Critical Design Review – CDR

TBD

A.3 Integration Progress Review – IPR

TBD

A.4 Experiment Acceptance Review – EAR

TBD

APPENDIX B – OUTREACH AND MEDIA COVERAGE

Publication	Description	Link
ETSIAE News	A brief description about the selection of the HERCCULES project and the BEXUS/REXUS Programme.	Link
ESA News	The selection of the teams published by ESA.	Link
Actualidad Aeroespacial	A brief description about the selection of the HERCCULES project and the BEXUS/REXUS Programme.	Link
ETSIAE News	HERCCULES Team last project launch, TASEC-Lab.	Link

APPENDIX C – ADDITIONAL TECHNICAL INFORMATION

C.1 Thermal environment definition.

In order to properly simulate the thermal behaviour of the different components, the thermal environment must be defined. Hot and cold operational cases are defined not only at the float phase but also during the ascent phase.

Ascent phase

During the ascent phase, the radiative thermal loads (direct Sun flow, albedo, OLR from Earth, IR from the sky) change not only with the altitude but also with the SZA [7]. Also, the convective parameters (air pressure, air temperature, air wind speed, ascent velocity) change with the altitude. Therefore, in order to define the worst scenarios from the thermal point of view these parameters must be evaluated.

Following the methodology depicted in [7], it is defined the thermal environment based on CERES (radiative loads) and ECMWF [22] (convective parameters) data (from 2018-2020) considering the launch period from September to October and launch window from 06.00 to 16.00 LT [13]. The launch window has a relevant impact in the thermal environment, as at different hours, the SZA varies and then the radiative loads.

The variation of the SZA at Esrange is shown in Figure C-1.

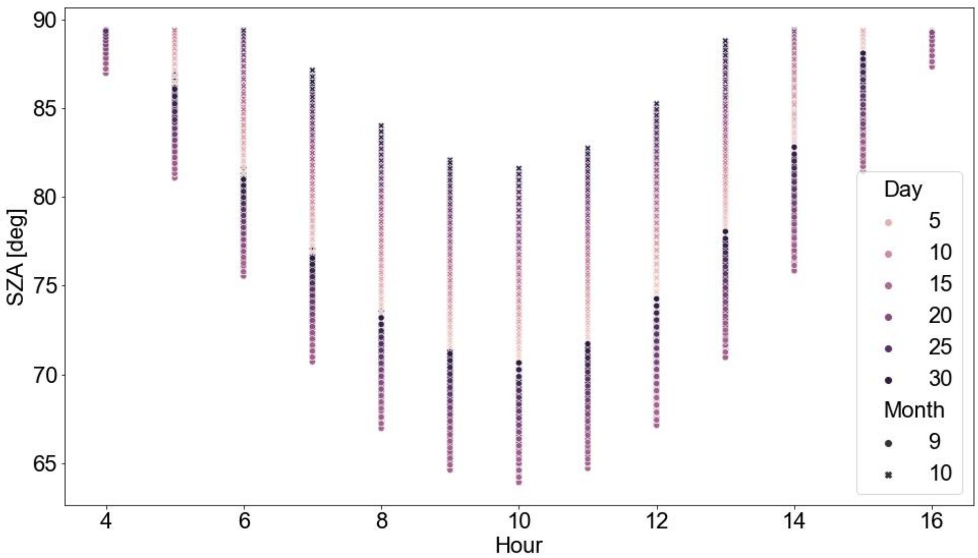


Figure C-1. Variation of SZA during the launch period and launch window at the launch site.

Therefore, thermal radiative loads at the hot operational case are defined where the SZA is the lowest, and at the cold operational case is defined where the SZA is maximum.

<u>Hot operational case (TR HOC)</u>

The hot operational case is defined at 10.00 UTC to define the radiative loads, considering white paint. They are shown in Figure C-2 and Figure C-3.

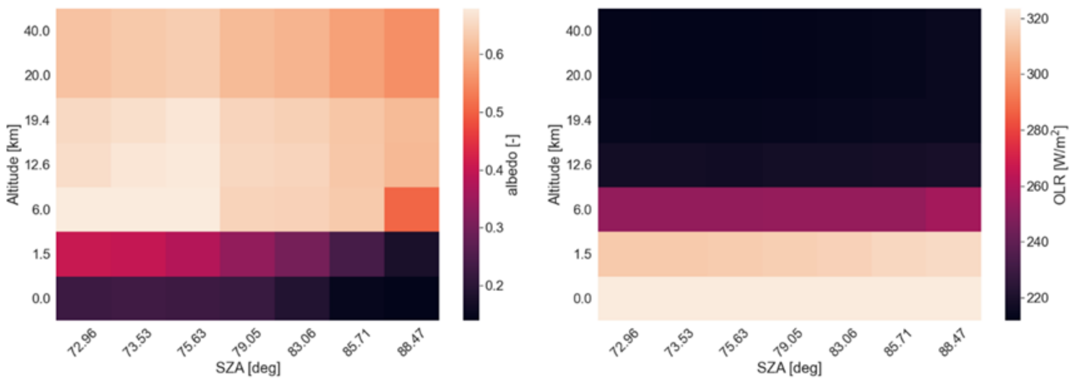


Figure C-2. Albedo (at left) and OLR (at right) variation with altitude and SZA for hot operational case.

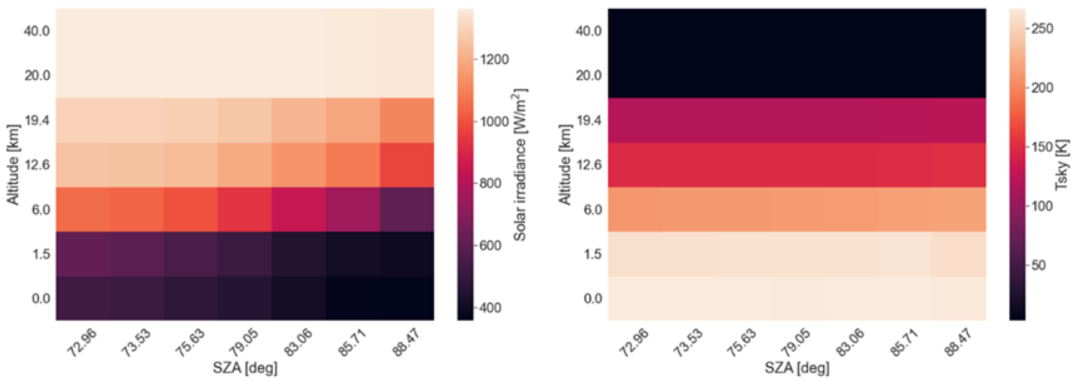


Figure C-3. Solar irradiance (at left) and sky temperature (at right) variation with altitude and SZA for hot operational case.

In Figure C-4 and Figure C-5, the air temperature and the air pressure, respectively comparing the hot and cold operational cases are shown.

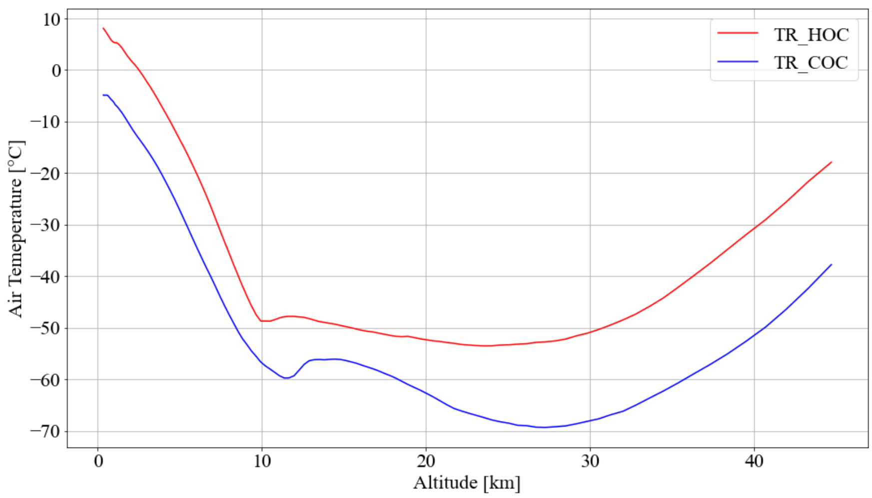


Figure C-4. Air temperature variation during the ascent phase.

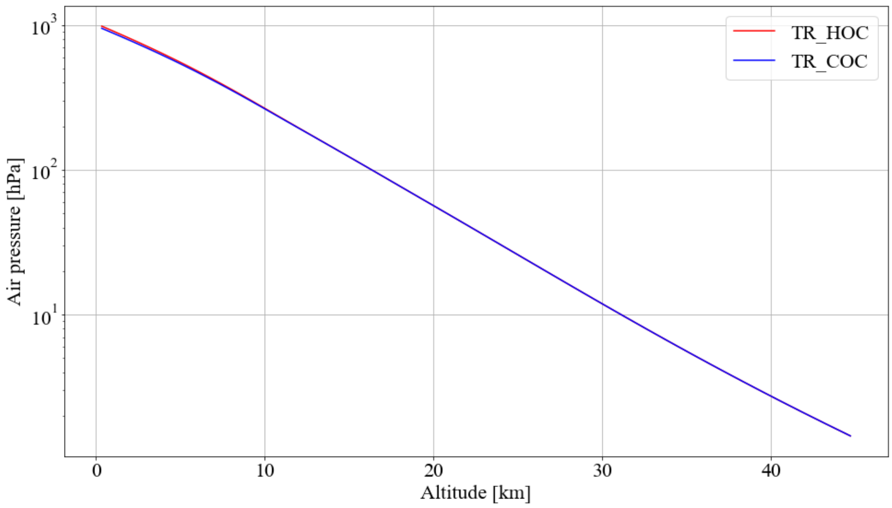


Figure C-5. Air pressure variation during the ascent phase.

The ascent velocity is defined based on BEXUS 22-26, considering the cold case the mission where the float altitude is reached in the minimal time, and vice-versa for the hot case. Both cases are shown in Figure C-6.

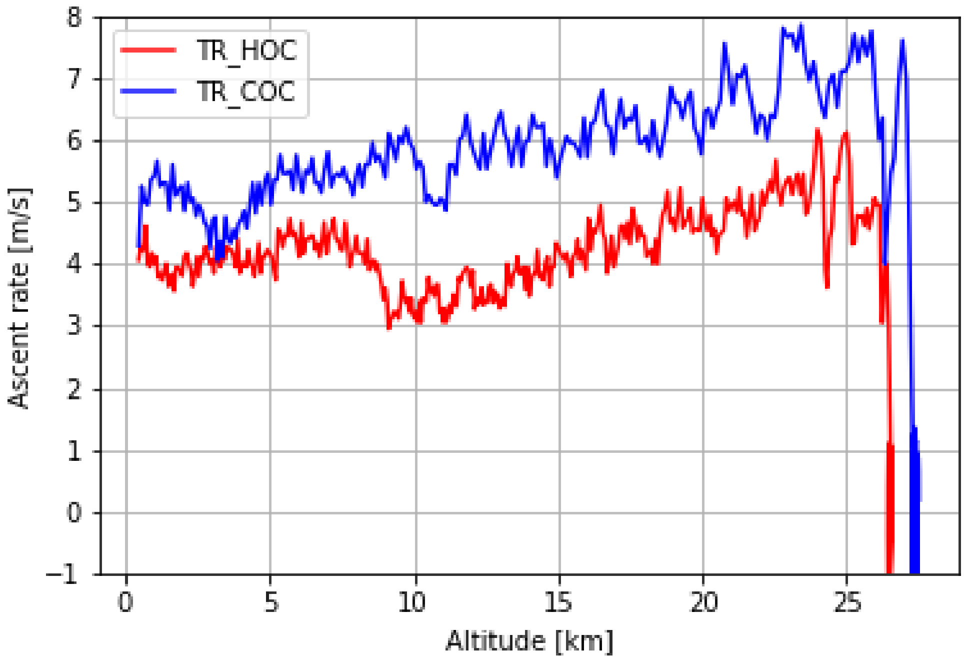


Figure C-6. Ascent velocity profile with the altitude during the ascent phase.

<u>Cold operational case (TR COC)</u>

The cold operational case is defined at 16.00 UTC once the Sun has already fallen. They are shown in Figure C-7 and Figure C-8.

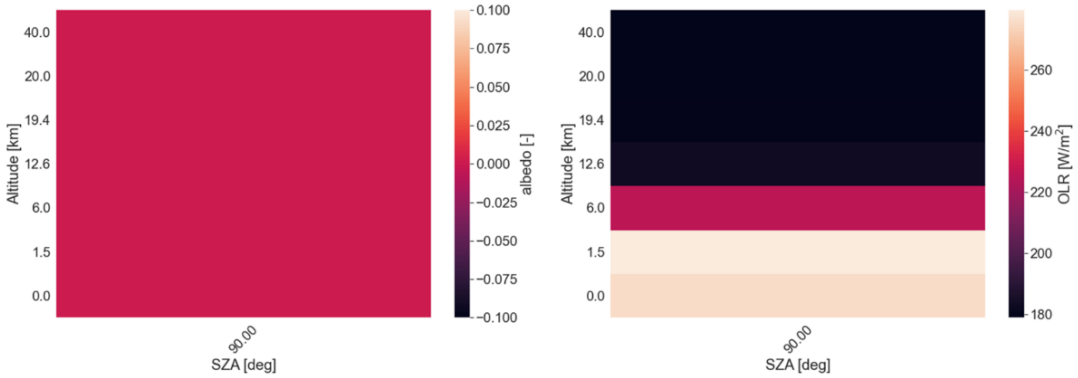


Figure C-7. Albedo (at left) and OLR (at right) variation with altitude and SZA for cold operational case.

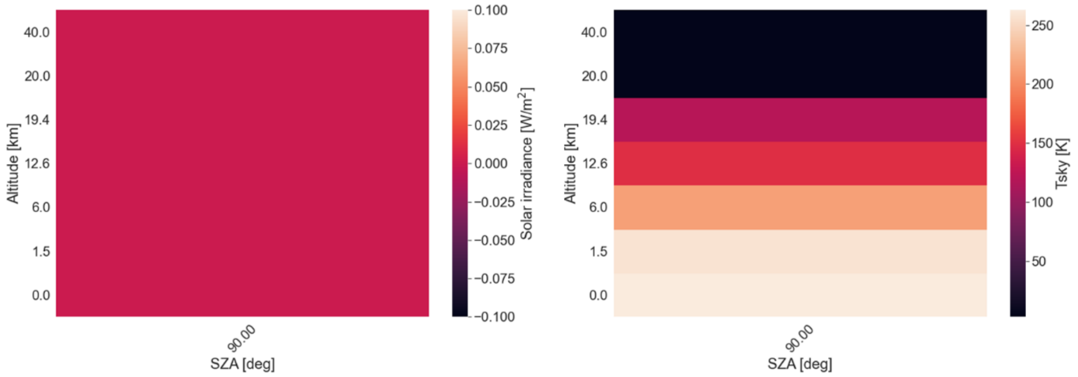


Figure C-8. Solar irradiance (at left) and sky temperature (at right) variation with altitude and SZA for cold operational case.

Float phase

Hot operational case (SS_HOC)

TBD

Cold operational case (SS_COC)

TBD

C.2 Preliminary location study for the Nadir sensor

To ensure that requirements R-PE-ATL-230 and G-DE-ATL-100 are fulfilled a preliminary location study for the Nadir sensor has been done. This approach considers the gondola's envelope as well as the equipment of the HERCCULES experiment. This information is sufficient for a preliminary analysis but data regarding the other on-board experiments will be required to properly define the sensor's location.

To analyse it, a simplified CAD model was developed, as shown in Figure C-9, taking into consideration that the sensor shall be placed under the Downward Environmental Lab (Purple box).

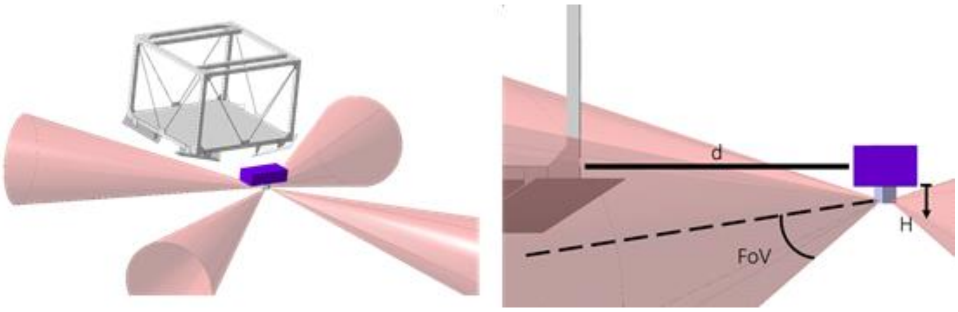


Figure C-9. Simplified CAD model defined to analyse the Nadir sensor's FoV.

Solutions were provided for different distances from the gondola (*d*) and for the sensor's location regarding the Downward Environmental Lab, providing the following results for the Field of View, summarized in Table C-1. The solutions that account for a positive *H* value imply the design of a support structure for the sensor. Configurations 1 (centred) and 2 (right-side) state the location of the sensor under the Downward Environmental Lab regarding the previous figure.

Table C-1. Solutions provided for the Nadir sensor's FoV.

			Additional Support	
Config.	**FoV [º]**	***d* [mm]**	**Required [Y/N]**	***H* [mm]**
1	15	860	N	0
2	13	700	N	0
2	14	700	Y	10
2	10	500	N	0
1	10	500	Y	10
2	10	400	Y	17

The preferred configurations have been highlighted in green. These solutions will be iterated along the project to ensure that the requirements are meet.

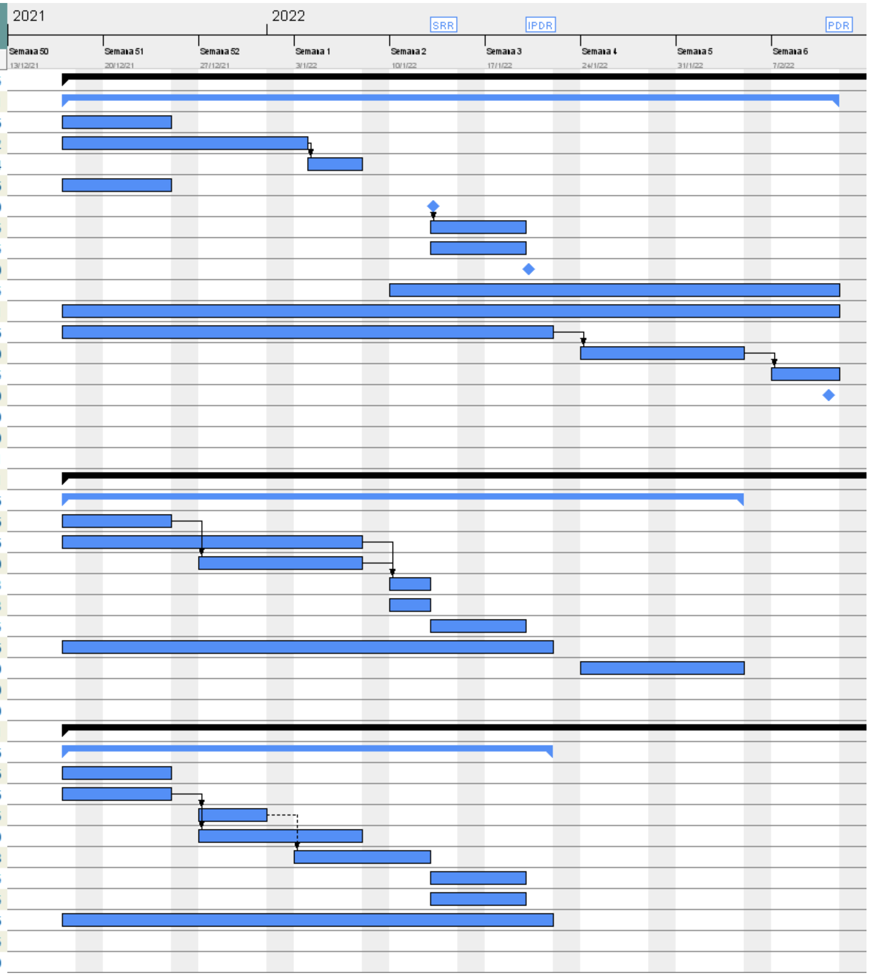
APPENDIX D – CHECKLISTS

TBD

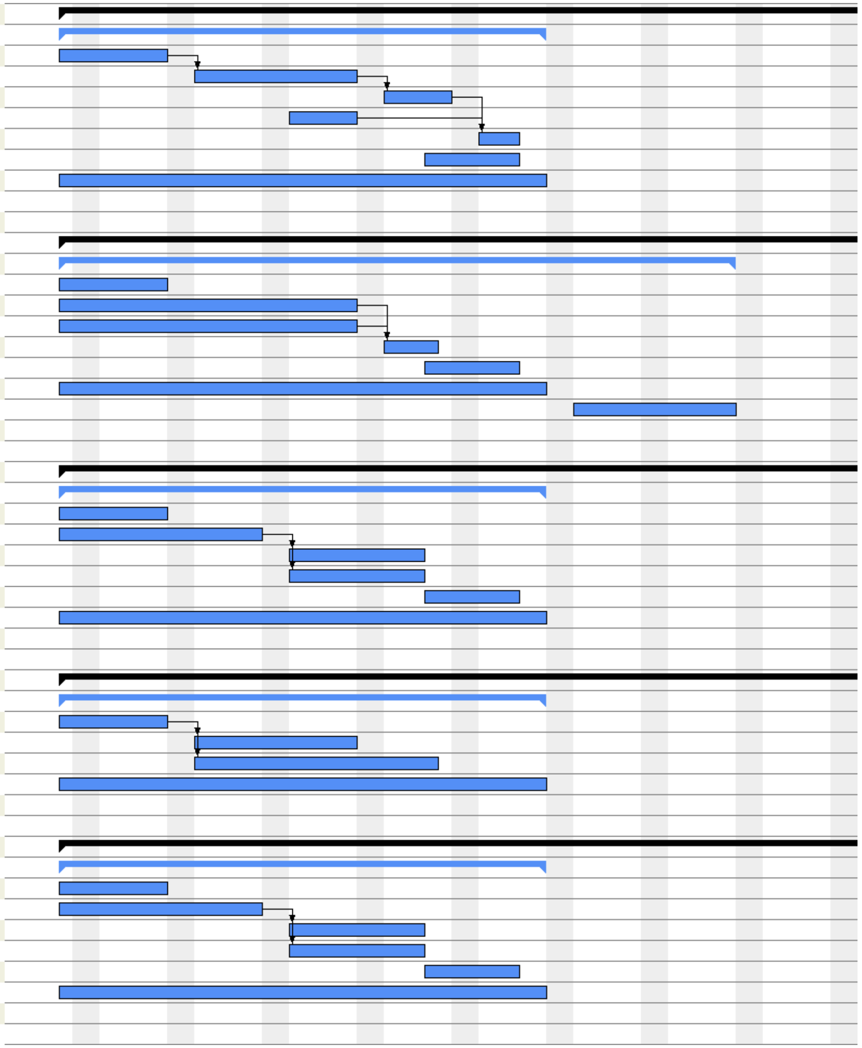
APPENDIX E – GANTT CHART

Phase B – Preliminary Design

Número de esq...	Nombre	Fecha de inicio	Fecha de fin	Duración
1	Project and System Management	17/12/21	22/12/22	265
1.1	Preliminary Design	17/12/21	11/2/22	41
1.1.1	Requirements definition / Verification	17/12/21	24/12/21	6
1.1.2	Work Breakdown Structure	17/12/21	3/1/22	12
1.1.3	Schedule	4/1/22	7/1/22	4
1.1.4	Concurrent Engineering Plan	17/12/21	24/12/21	6
1.1.5	SRR	13/1/22	13/1/22	0
1.1.6	Verification Plan	13/1/22	19/1/22	5
1.1.7	System's Risk Analysis	13/1/22	19/1/22	5
1.1.8	IPDR	20/1/22	20/1/22	0
1.1.9	Fundraising / Sponsorship	10/1/22	11/2/22	25
1.1.10	Outreach	17/12/21	11/2/22	41
1.1.11	SED v1 Documentation	17/12/21	21/1/22	26
1.1.12	PDR preparation	24/1/22	4/2/22	10
1.1.13	Training week and PDR	7/2/22	11/2/22	5
1.1.14	PDR	11/2/22	11/2/22	0
1.2	Detailed Design	14/2/22	22/4/22	50
1.3	Manufacturing, Integration and Test	25/4/22	12/8/22	80
1.4	Utilization	1/9/22	22/12/22	81
2	Heat Transfer lab / Environmental Lab	17/12/21	12/8/22	171
2.1	Preliminary Design	17/12/21	4/2/22	36
2.1.1	Requirements definition / Verification	17/12/21	24/12/21	6
2.1.2	Preliminary Thermal Simulation	17/12/21	7/1/22	16
2.1.3	Preliminary component selection	27/12/21	7/1/22	10
2.1.4	Operational modes estimation	10/1/22	12/1/22	3
2.1.5	Data analysis plan	10/1/22	12/1/22	3
2.1.6	Risk Analysis	13/1/22	19/1/22	5
2.1.7	SED v1 Documentation	17/12/21	21/1/22	26
2.1.8	Preliminary CAD design	24/1/22	4/2/22	10
2.2	Detailed Design	14/2/22	22/4/22	50
2.3	Manufacturing, Integration and Test	25/4/22	12/8/22	80
3	Attitude Lab	17/12/21	12/8/22	171
3.1	Preliminary Design	17/12/21	21/1/22	26
3.1.1	Requirements definition / Verification	17/12/21	24/12/21	6
3.1.2	Preliminary CAD model	17/12/21	24/12/21	6
3.1.3	Preliminary location study	27/12/21	31/12/21	5
3.1.4	Preliminary component selection	27/12/21	7/1/22	10
3.1.5	Electronics design	3/1/22	12/1/22	8
3.1.6	Data analysis plan	13/1/22	19/1/22	5
3.1.7	Risk analysis	13/1/22	19/1/22	5
3.1.8	SEDv1 Documentation	17/12/21	21/1/22	26
3.2	Detailed Design	14/2/22	15/4/22	45
3.3	Manufacturing, Integration and Test	25/4/22	12/8/22	80

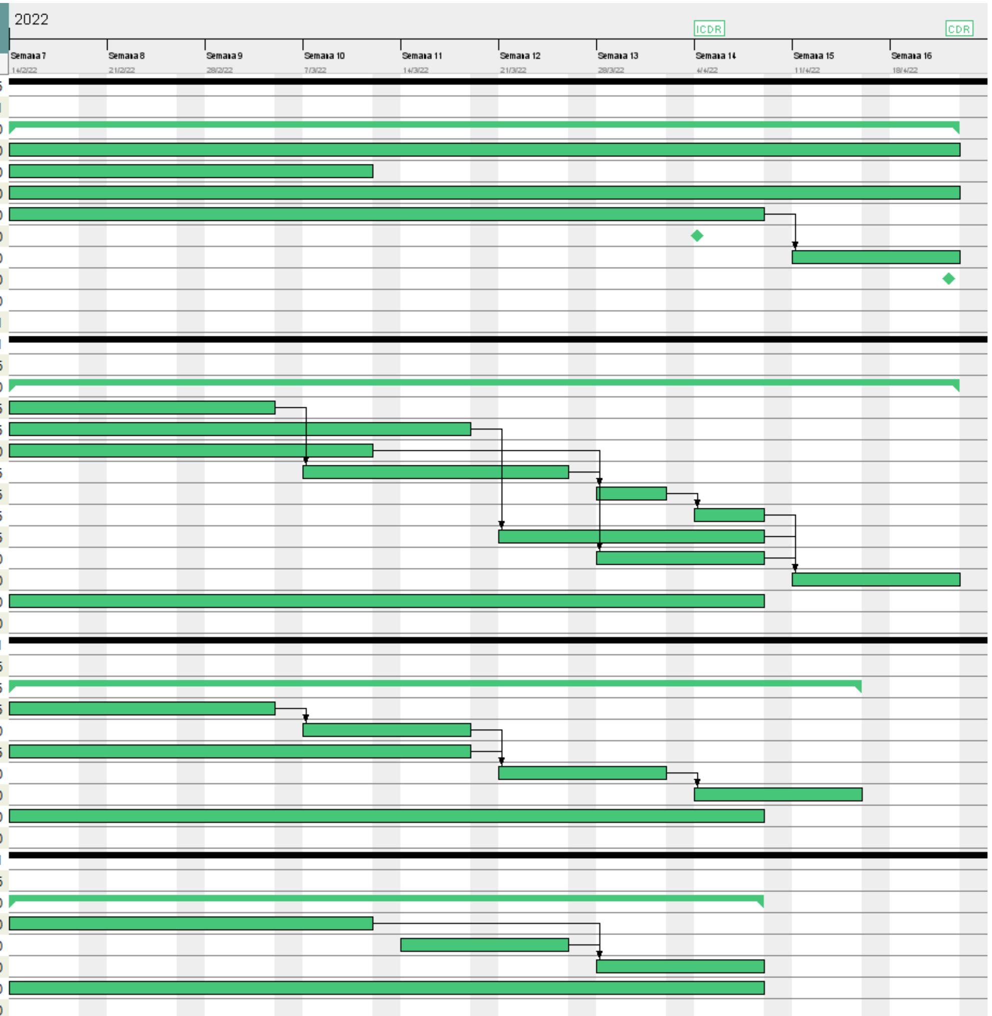


4	Mechanic Subsystem	17/12/21	12/8/22	171
4.1	Preliminary Design	17/12/21	21/1/22	26
4.1.1	Requirements definition / Verification	17/12/21	24/12/21	6
4.1.2	Preliminary CAD design	27/12/21	7/1/22	10
4.1.3	Preliminary component selection	10/1/22	14/1/22	5
4.1.4	I/F definition	3/1/22	7/1/22	5
4.1.5	Mass Budget	17/1/22	19/1/22	3
4.1.6	Risk Analysis	13/1/22	19/1/22	5
4.1.7	SED v1 Documentation	17/12/21	21/1/22	26
4.2	Detailed Design	14/2/22	8/4/22	40
4.3	Manufacturing, Integration and Test	25/4/22	12/8/22	80
5	Thermal Control Subsystem	17/12/21	12/8/22	171
5.1	Preliminary Design	17/12/21	4/2/22	36
5.1.1	Requirements definition / Verification	17/12/21	24/12/21	6
5.1.2	Preliminary ESATAN-TMS thermal model	17/12/21	7/1/22	16
5.1.3	Thermal environment definition	17/12/21	7/1/22	16
5.1.4	Preliminary ascent phase analysis	10/1/22	13/1/22	4
5.1.5	Risk analysis	13/1/22	19/1/22	5
5.1.6	SEDv1 Documentation	17/12/21	21/1/22	26
5.1.7	Preliminary float analysis	24/1/22	4/2/22	10
5.2	Detailed Design	14/2/22	8/4/22	40
5.3	Manufacturing, Integration and Test	25/4/22	12/8/22	80
6	Electronics Subsystem	17/12/21	12/8/22	171
6.1	Preliminary Design	17/12/21	21/1/22	26
6.1.1	Requirements definition / Verification	17/12/21	24/12/21	6
6.1.2	Preliminary electronics design	17/12/21	31/12/21	11
6.1.3	Preliminary component selection	3/1/22	12/1/22	8
6.1.4	PCBs layout conceptual design	3/1/22	12/1/22	8
6.1.5	Risk analysis	13/1/22	19/1/22	5
6.1.6	SEDv1 Documentation	17/12/21	21/1/22	26
6.2	Detailed Design	14/2/22	22/4/22	50
6.3	Manufacturing, Integration and Test	25/4/22	12/8/22	80
7	Software Subsystem	17/12/21	12/8/22	171
7.1	Preliminary Design	17/12/21	21/1/22	26
7.1.1	Requirements definition / Verification	17/12/21	24/12/21	6
7.1.2	Logical architectural design	27/12/21	7/1/22	10
7.1.3	Physical Architectural design	27/12/21	13/1/22	14
7.1.4	SEDv1 Documentation	17/12/21	21/1/22	26
7.2	Detailed Design	14/2/22	22/4/22	50
7.3	Manufacturing, Integration and Test	25/4/22	12/8/22	80
8	Electrical Power Subsystem	17/12/21	12/8/22	171
8.1	Preliminary Design	17/12/21	21/1/22	26
8.1.1	Requirements definition / Verification	17/12/21	24/12/21	6
8.1.2	Preliminary electrical design	17/12/21	31/12/21	11
8.1.3	Preliminary component selection	3/1/22	12/1/22	8
8.1.4	Power Budget and preliminary calculations	3/1/22	12/1/22	8
8.1.5	Risk analysis	13/1/22	19/1/22	5
8.1.6	SEDv1 Documentation	17/12/21	21/1/22	26
8.2	Detailed Design	14/2/22	8/4/22	40
8.3	Manufacturing, Integration and Test	25/4/22	12/8/22	80

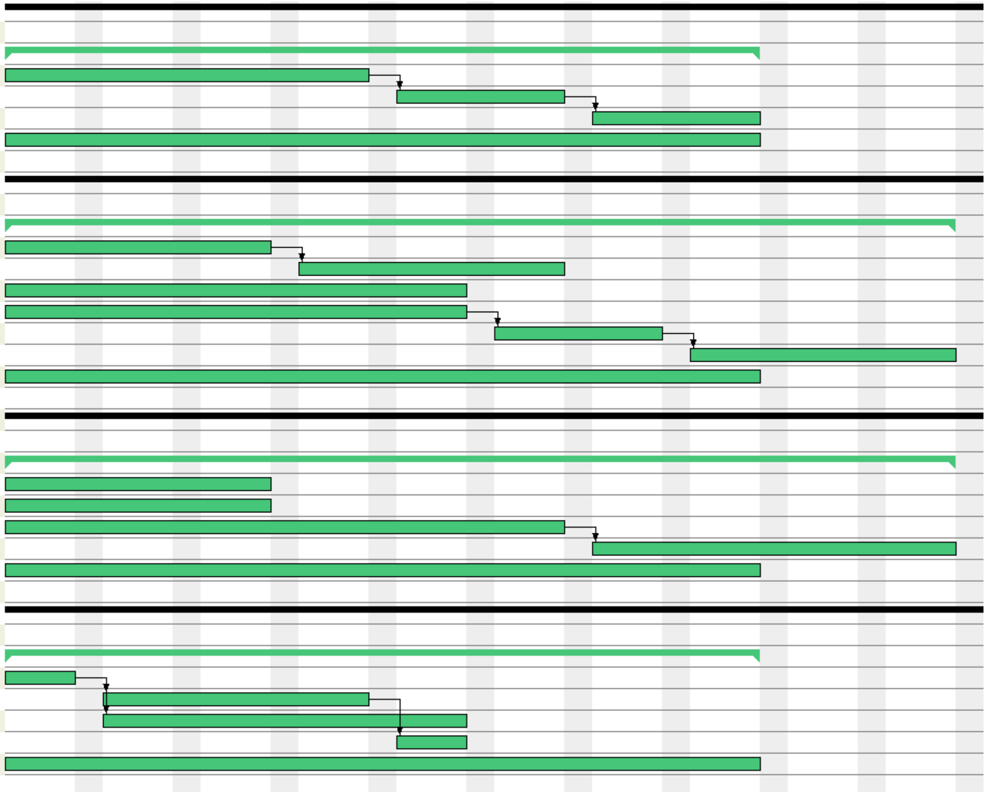


Phase B – Detailed Design

Número de esq...	Nombre	Fecha de inicio	Fecha de fin	Duración
1	Project and System Management	17/12/21	22/12/22	265
1.1	Preliminary Design	17/12/21	11/2/22	41
1.2	Detailed Design	14/2/22	22/4/22	50
1.2.1	Concurrent Engineering coordination	14/2/22	22/4/22	50
1.2.2	Prototypes components acquisition	14/2/22	11/3/22	20
1.2.3	Outreach	14/2/22	22/4/22	50
1.2.4	SEDv2 Documentation	14/2/22	8/4/22	40
1.2.5	ICDR	4/4/22	4/4/22	0
1.2.6	CDR preparation	11/4/22	22/4/22	10
1.2.7	CDR	22/4/22	22/4/22	0
1.3	Manufacturing, Integration and Test	25/4/22	12/8/22	80
1.4	Utilization	1/9/22	22/12/22	81
2	Heat Transfer lab / Environmental Lab	17/12/21	12/8/22	171
2.1	Preliminary Design	17/12/21	4/2/22	36
2.2	Detailed Design	14/2/22	22/4/22	50
2.2.1	Prototypes component acquisition	14/2/22	4/3/22	15
2.2.2	Radiative sensors acquisition	14/2/22	18/3/22	25
2.2.3	Differential pressure sensors acquisition	14/2/22	11/3/22	20
2.2.4	Prototypes manufacturing	7/3/22	25/3/22	15
2.2.5	Vacuum test	28/3/22	1/4/22	5
2.2.6	Operational modes definition	4/4/22	8/4/22	5
2.2.7	Radiative sensor test	21/3/22	8/4/22	15
2.2.8	Anemometer wind tunnel test	28/3/22	8/4/22	10
2.2.9	Final configuration design	11/4/22	22/4/22	10
2.2.10	SEDv2 Documentation	14/2/22	8/4/22	40
2.3	Manufacturing, Integration and Test	25/4/22	12/8/22	80
3	Attitude Lab	17/12/21	12/8/22	171
3.1	Preliminary Design	17/12/21	21/1/22	26
3.2	Detailed Design	14/2/22	15/4/22	45
3.2.1	Prototypes component acquisition	14/2/22	4/3/22	15
3.2.2	Prototypes manufacturing	7/3/22	18/3/22	10
3.2.3	Coding	14/2/22	18/3/22	25
3.2.4	Prototypes test	21/3/22	1/4/22	10
3.2.5	Final configuration design	4/4/22	15/4/22	10
3.2.6	SEDv2 Documentation	14/2/22	8/4/22	40
3.3	Manufacturing, Integration and Test	25/4/22	12/8/22	80
4	Mechanic Subsystem	17/12/21	12/8/22	171
4.1	Preliminary Design	17/12/21	21/1/22	26
4.2	Detailed Design	14/2/22	8/4/22	40
4.2.1	Detailed CAD model	14/2/22	11/3/22	20
4.2.2	Components I/F definition	14/3/22	25/3/22	10
4.2.3	CAD wire routing	28/3/22	8/4/22	10
4.2.4	SEDv2 Documentation	14/2/22	8/4/22	40
4.3	Manufacturing, Integration and Test	25/4/22	12/8/22	80

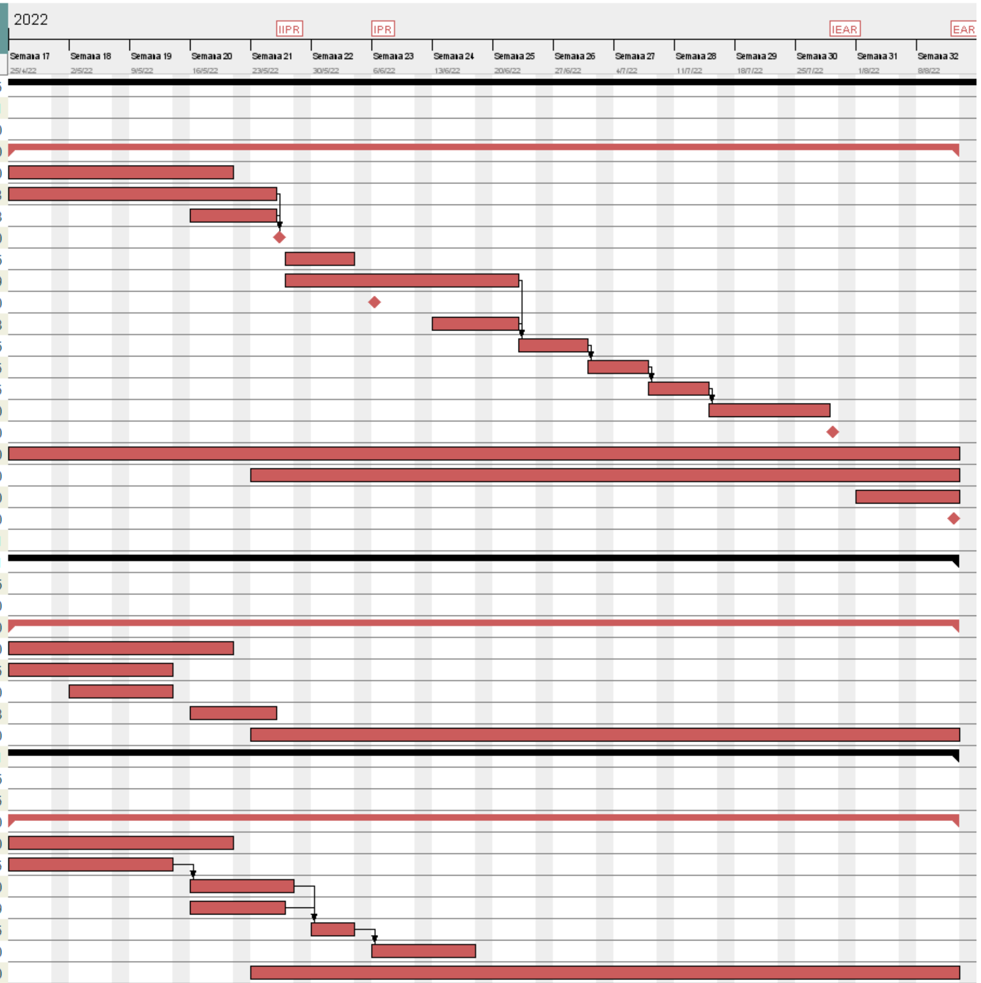


5	Thermal Control Subsystem	17/12/21	12/8/22	171
5.1	Preliminary Design	17/12/21	4/2/22	36
5.2	Detailed Design	14/2/22	8/4/22	40
5.2.1	Detailed ESATAN-TMS thermal model	14/2/22	11/3/22	20
5.2.2	Functional thermal analysis	14/3/22	25/3/22	10
5.2.3	Prototypes test simulation	28/3/22	8/4/22	10
5.2.4	SEDv2 Documentation	14/2/22	8/4/22	40
5.3	Manufacturing, Integration and Test	25/4/22	12/8/22	80
6	Electronics Subsystem	17/12/21	12/8/22	171
6.1	Preliminary Design	17/12/21	21/1/22	26
6.2	Detailed Design	14/2/22	22/4/22	50
6.2.1	Detailed electronics design	14/2/22	4/3/22	15
6.2.2	PCBs design	7/3/22	25/3/22	15
6.2.3	Electronics simulation	14/2/22	18/3/22	25
6.2.4	Prototypes components acquisition	14/2/22	18/3/22	25
6.2.5	Engineering model manufacturing	21/3/22	1/4/22	10
6.2.6	Engineering model test	4/4/22	22/4/22	15
6.2.7	SEDv2 Documentation	14/2/22	8/4/22	40
6.3	Manufacturing, Integration and Test	25/4/22	12/8/22	80
7	Software Subsystem	17/12/21	12/8/22	171
7.1	Preliminary Design	17/12/21	21/1/22	26
7.2	Detailed Design	14/2/22	22/4/22	50
7.2.1	Detailed On-Board software design	14/2/22	4/3/22	15
7.2.2	Detailed Ground software design	14/2/22	4/3/22	15
7.2.3	Coding	14/2/22	25/3/22	30
7.2.4	Engineering model test (Unit testing)	28/3/22	22/4/22	20
7.2.5	SEDv2 Documentation	14/2/22	8/4/22	40
7.3	Manufacturing, Integration and Test	25/4/22	12/8/22	80
8	Electrical Power Subsystem	17/12/21	12/8/22	171
8.1	Preliminary Design	17/12/21	21/1/22	26
8.2	Detailed Design	14/2/22	8/4/22	40
8.2.1	Detailed Power Budget	14/2/22	18/2/22	5
8.2.2	EPS simulation	21/2/22	11/3/22	15
8.2.3	Detailed power distribution design	21/2/22	18/3/22	20
8.2.4	Ground wiring design	14/3/22	18/3/22	5
8.2.5	SEDv2 Documentation	14/2/22	8/4/22	40
8.3	Manufacturing, Integration and Test	25/4/22	12/8/22	80

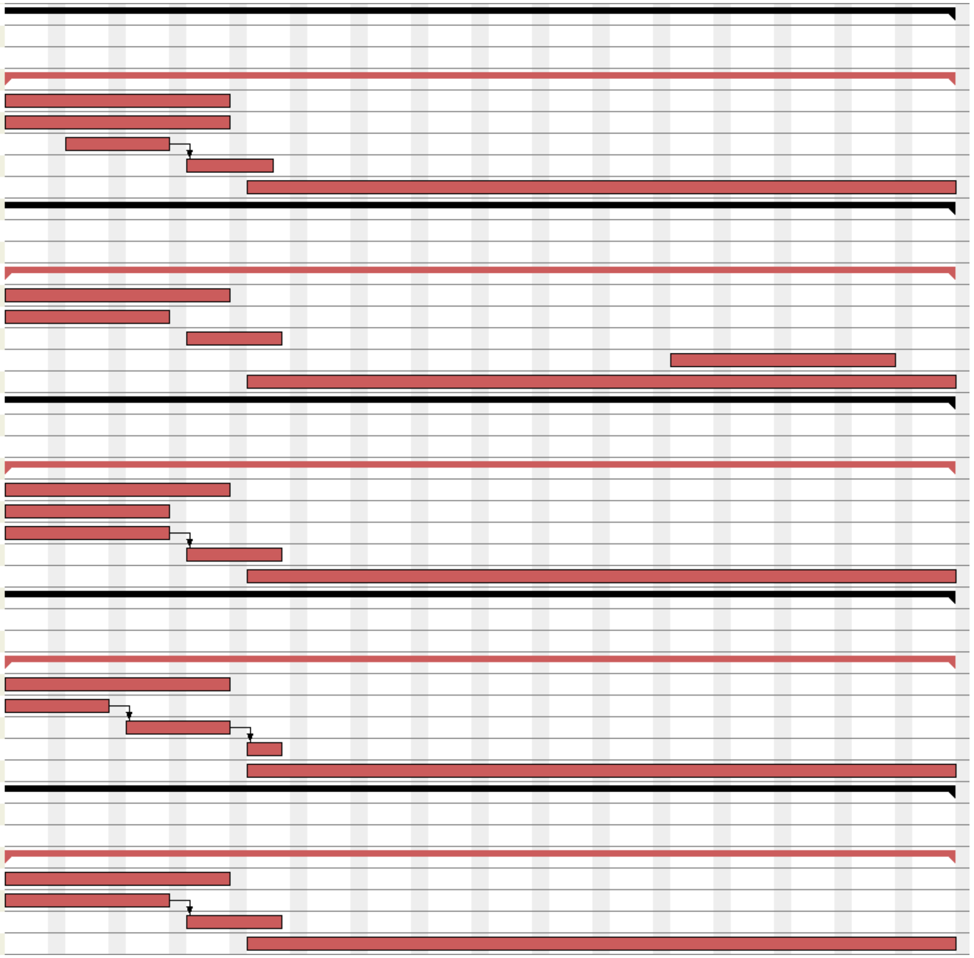


Phase C – Manufacturing, Integration and Test

Número de esq...	Nombre	Fecha de inicio	Fecha de fin	Duración
1	Project and System Management	17/12/21	22/12/22	265
1.1	Preliminary Design	17/12/21	11/2/22	41
1.2	Detailed Design	14/2/22	22/4/22	50
1.3	Manufacturing, Integration and Test	25/4/22	12/8/22	80
1.3.1	SEDv3 Documentation	25/4/22	20/5/22	20
1.3.2	Component acquisition	25/4/22	25/5/22	23
1.3.3	Integration plan	16/5/22	25/5/22	8
1.3.4	IIPR	26/5/22	26/5/22	0
1.3.5	Wire routing	27/5/22	3/6/22	6
1.3.6	Integration	27/5/22	22/6/22	19
1.3.7	IPR	6/6/22	6/6/22	0
1.3.8	Test procedures	13/6/22	22/6/22	8
1.3.9	Functional test	23/6/22	30/6/22	6
1.3.10	TVAC test	1/7/22	7/7/22	5
1.3.11	Structural test	8/7/22	14/7/22	5
1.3.12	Additional tests	15/7/22	28/7/22	10
1.3.13	IEAR	29/7/22	29/7/22	0
1.3.14	Outreach	25/4/22	12/8/22	80
1.3.15	SED v4 Documentation	23/5/22	12/8/22	60
1.3.16	EAR preparation	1/8/22	12/8/22	10
1.3.17	EAR	12/8/22	12/8/22	0
1.4	Utilization	1/9/22	22/12/22	81
2	Heat Transfer lab / Environmental Lab	17/12/21	12/8/22	171
2.1	Preliminary Design	17/12/21	4/2/22	36
2.2	Detailed Design	14/2/22	22/4/22	50
2.3	Manufacturing, Integration and Test	25/4/22	12/8/22	80
2.3.1	SEDv3 Documentation	25/4/22	20/5/22	20
2.3.2	Flight component acquisition	25/4/22	13/5/22	15
2.3.3	Experiments supports manufacturing	2/5/22	13/5/22	10
2.3.4	Experiments integration procedure	16/5/22	25/5/22	8
2.3.5	Copy_SED v4 Documentation	23/5/22	12/8/22	60
3	Attitude Lab	17/12/21	12/8/22	171
3.1	Preliminary Design	17/12/21	21/1/22	26
3.2	Detailed Design	14/2/22	15/4/22	45
3.3	Manufacturing, Integration and Test	25/4/22	12/8/22	80
3.3.1	SEDv3 Documentation	25/4/22	20/5/22	20
3.3.2	Flight component acquisition	25/4/22	13/5/22	15
3.3.3	Housing manufacturing	16/5/22	27/5/22	10
3.3.4	Integration procedure	16/5/22	26/5/22	9
3.3.5	Sensor integration	30/5/22	3/6/22	5
3.3.6	Functional test	6/6/22	17/6/22	10
3.3.7	SED v4 Documentation	23/5/22	12/8/22	60



4	Mechanic Subsystem	17/12/21	12/8/22	171
4.1	Preliminary Design	17/12/21	21/1/22	26
4.2	Detailed Design	14/2/22	8/4/22	40
4.3	Manufacturing, Integration and Test	25/4/22	12/8/22	80
4.3.1	SEDv3 Documentation	25/4/22	20/5/22	20
4.3.2	Flight component acquisition	25/4/22	20/5/22	20
4.3.3	Wire routing blueprints	2/5/22	13/5/22	10
4.3.4	Structure integration procedure	16/5/22	25/5/22	8
4.3.5	SED v4 Documentation	23/5/22	12/8/22	60
5	Thermal Control Subsystem	17/12/21	12/8/22	171
5.1	Preliminary Design	17/12/21	4/2/22	36
5.2	Detailed Design	14/2/22	8/4/22	40
5.3	Manufacturing, Integration and Test	25/4/22	12/8/22	80
5.3.1	SEDv3 Documentation	25/4/22	20/5/22	20
5.3.2	Flight component acquisition	25/4/22	13/5/22	15
5.3.3	TCS components integration procedure	16/5/22	26/5/22	9
5.3.4	Thermal model correlation	11/7/22	5/8/22	20
5.3.5	SED v4 Documentation	23/5/22	12/8/22	60
6	Electronics Subsystem	17/12/21	12/8/22	171
6.1	Preliminary Design	17/12/21	21/1/22	26
6.2	Detailed Design	14/2/22	22/4/22	50
6.3	Manufacturing, Integration and Test	25/4/22	12/8/22	80
6.3.1	SEDv3 Documentation	25/4/22	20/5/22	20
6.3.2	Flight component acquisition	25/4/22	13/5/22	15
6.3.3	PCBs manufacturing	25/4/22	13/5/22	15
6.3.4	PCBs test	16/5/22	26/5/22	9
6.3.5	SED v4 Documentation	23/5/22	12/8/22	60
7	Software Subsystem	17/12/21	12/8/22	171
7.1	Preliminary Design	17/12/21	21/1/22	26
7.2	Detailed Design	14/2/22	22/4/22	50
7.3	Manufacturing, Integration and Test	25/4/22	12/8/22	80
7.3.1	SEDv3 Documentation	25/4/22	20/5/22	20
7.3.2	Integration testing	25/4/22	6/5/22	10
7.3.3	Validation testing	9/5/22	20/5/22	10
7.3.4	Qualification testing	23/5/22	26/5/22	4
7.3.5	SED v4 Documentation	23/5/22	12/8/22	60
8	Electrical Power Subsystem	17/12/21	12/8/22	171
8.1	Preliminary Design	17/12/21	21/1/22	26
8.2	Detailed Design	14/2/22	8/4/22	40
8.3	Manufacturing, Integration and Test	25/4/22	12/8/22	80
8.3.1	SEDv3 Documentation	25/4/22	20/5/22	20
8.3.2	Flight component acquisition	25/4/22	13/5/22	15
8.3.3	Electrical Power test	16/5/22	26/5/22	9
8.3.4	SED v4 Documentation	23/5/22	12/8/22	60



Phase D – Utilization

Número de esqu...	Nombre	Fecha de inicio	Fecha de fin	Duración
1	Project and System Management	17/12/21	22/12/22	265
1.1	Preliminary Design	17/12/21	11/2/22	41
1.2	Detailed Design	14/2/22	22/4/22	50
1.3	Manufacturing, Integration and Test	25/4/22	12/8/22	80
1.4	Utilization	1/9/22	22/12/22	81
1.4.1	Flight preparation	1/9/22	9/9/22	7
1.4.2	Packaging	12/9/22	16/9/22	5
1.4.3	Campaign at Esrange	29/9/22	5/10/22	5
1.4.4	Flight Report Documentation	6/10/22	18/10/22	9
1.4.5	Outreach	1/9/22	22/12/22	81
1.4.6	SEDv5 Documentation	6/10/22	22/12/22	56
2	Heat Transfer lab / Environmental Lab	17/12/21	12/8/22	171
3	Attitude Lab	17/12/21	12/8/22	171
4	Mechanic Subsystem	17/12/21	12/8/22	171
5	Thermal Control Subsystem	17/12/21	12/8/22	171
6	Electronics Subsystem	17/12/21	12/8/22	171
7	Software Subsystem	17/12/21	12/8/22	171
8	Electrical Power Subsystem	17/12/21	12/8/22	171