SED

Student Experiment Documentation

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Mission: BEXUS 28

Team Name: DESTINY

Experiment Title:	Detection of Earthquakes through a STratospheric INfrasound studY

Team	**Name**	**University**
Student Team Leader:	Louis Dubois	*École Polytechnique*
Team Members:	Florian Abeillon	
	Samuel Brasil	
	Tristan Bruel	
	Krishan Bumma	
	Matthieu Jeannin	
	Elias Khallouf	
	Clara Piekarski	
	Louis-Arnaud Péchenart	
	Mickaël Rey	
	William Koch	
	Olavi Aikas	
	Ashish Nayak	

Sariah Al Saati
Nathan Vaneberg
Théo Boyer
Elsa Deville
Gatien Fonmartin

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CHANGE RECORD

Version	Date	Changed chapters	Remarks
0	2018-12-09	New Version	
1	2019-01-16	all	PDR
1-1	2019-03-16	1.4	Update figure 1.2
		2	Update requirements according to PDR report
		3.3	Update budget and manpower
		3.5	Reassess S and P, added management risks
		4.2	Update upper box design and attachment mechanism
			Remove fuse protection
		4.3	Update current status and some information. Update experiment mass.
		4.4	Add protection mechanism.
		4.5	Update PCB number and interfacing
		4.6	Update thermal management system information
		4.7	Update battery data
		4.8	Remove TMS failsafe mode
			Update redundancy and synchronisation design
		5	Revise verification matrix, Implement tests for every requirement
		6.1	Update bandwidth, battery characteristics, flight requirements
			Change timeline names
		Appendix A	Add PDR report
		Appendix B	Add outreach pictures
		Appendix C	Add sensitivity and thermal calculations
1.2	2019-04-19	1.5.2	Add new members
		3.2.2	Update anemometer price
		3.3.2	Add sponsors and expected incomes

		3.4	Update Outreach
		3.5	Capture the challenge of having a split site
		4.1	Update clock synchronisation and TMS
		4.3	Update of the components' status
		4.5, C.3, C.4	Add electronic schematics
		4.8	Add telemetry application layer protocol
		5.1	Add verification by testing for requirement D6 (test 9.2)
		6.3	Add infrasound events generation
			CDR
2	2019-04-29	4.4	Add simulation of the eigen modes of the flight train
			Upgrade inlet manufacture
		7.2.2	Improvement of the infrasound propagation simulation
3	2019-07-12		
		1.5.2	New team members
		2.3	Reformulate D9, delete D12
		3.1, 3.2, 3.3	Update organisation following team changes
		3.5	Add MT40, TC10, TC20, TC30
		4.2	Clarify number of GPS receivers and E-link connections used
		4.4.2	Remove battery current
		4.4	Add fixation of the inlet to the barometer
			Success of the production of the inlet
			Description of the fixation system for each component in the boxes
		4.5	Add PCB layouts

		4.6	Remove failsafe mode
			Thermal simulation results
		4.8	Add implementation details, and correct time correlation mistake
		5.1, 5.2	Test planification
		5.3	Success of the tests 7.4 and 7.5
		6	Add details about inlets protection and exploding balloons
		7	Add experiment concept proof
3.1		2.3	Modification of requirement D17
		3.3.2	Update budget (remove gyrometer and crowd-funding campaign)
		4.2.1	Update the fixation system of the Flight Train Box to the Flight Train
		4.4	Update mechanical design and mass calculation
		6.1.1	Update dimensions and mass
		6.1.2	Update Safety risks
		6.1.4	Update the launch site requirements
		6.2	Describe test activity at ESRANGE before flight more thoroughly
		Appendix A	Add IPR results
		Appendix C	Add sensor datasheets
		Appendix D	Add Flight Train Box detachment procedure for recovery
4	2019-09-22		EAR, Pre-Campaign
		4.4	Add mechanical test precisions and balloon experiment description
		4.6	Add thermal tests results

		4.8.2	Add new thermal regulation description
		5.1	Add new tests results
		5.2	Add new tests description
		5.3.1	Add new thermal tests
		5.3.2	Add mechanical tests
		5.3.3	Add tests at CNES description
		6.2	Update activities at Esrange
		Appendix F	Add protocol for the balloons attached to the flight train
		Appendix G	Add explosions requirements
		Appendix H	Add Test procedure at CNES
4.1	2019-10-14	Appendix A	Add EAR Report
		4.4	Add mass measurement
		4.2.2	Update Ethernet connection and grounding plan
		6.1.5 & 6.3	Update flight requirements and countdown for late access procedure
5	2020-03-31		Final report
		4.1 & 4.2 & 4.3	Put the information at the correct tense
		1.5.2	Update the team departments
		3.1	Put the work breakdown up to date
		5.1	Update Verification Matrix
		5.2	Update verification Plan
		7	Update section 7
		9.1	Update abbreviations
		9.2	Update references
		Appendix I	Add appendix
5.1	2020-04-10	8	Add acknowledgements

Abstract: This is the Student Experiment Documentation (SED) of the BEXUS 28 experiment DESTINY, which aim at using stratospheric infrasound measurement to perform seismic study.

Keywords: DESTINY, BEXUS, SED - Student Experiment Documentation, Atmospheric Research, Stratospheric Infrasound, *École Polytechnique*

CONTENTS

PREFACE

DESTINY, which stands for Detection of Earthquakes through a STratospheric INfrasound studY, is a student balloon-borne experiment conducted in the frame of the 12th cycle of the REXUS/BEXUS programme. It aims at using stratospheric infrasound measurements to locate ground seismic events and is a proof of a concept to be used to study the internal structure of Venus. The DESTINY project is a collaboration between *École Polytechnique* and *ISAE-Supaéro*.

ABSTRACT

The internal structure of terrestrial planets such as Mars, Earth and Venus contain key information about the Universe. To investigate the history of our solar system, it is necessary to understand these planets evolution. In this sense, Venus is particularly interesting, being similar on many aspects to the Earth. Yet, the extreme conditions on its surface – 460 °C and 92 atm make it impossible today to use long-lasting landers. The challenge is thus to find a method to probe Venus structure without ground sensors.

One solution, proposed by researchers from *ISAE-Supaéro* and JPL, consists in using balloon-borne barometers to study the infrasonic waves produced by seismic events. The interest of this technique is that at an altitude of 55 km, Venus atmosphere presents earthly conditions: a pressure of 0.5 atm and a temperature of 27 °C. Besides, infrasound signals are amplified throughout their propagation toward the upper layers of the atmosphere – due to the conservation of energy and the decrease in air density – which eases their detection at high altitudes.

The DESTINY experiment aims at testing this method on the Earth's stratosphere. Our goal is to characterize the infrasonic background of the atmosphere to be able to recognize specific signals and locate their origin. As infrasound events we will use ground explosions (see appendix G), but we will also look for other specific signals. To do so, we will measure the phase difference between the signals detected by distant barometers and process it to locate their origin.

1 INTRODUCTION

1.1 Scientific Background

Venus is very similar to Earth, with almost the same radius and mass, yet it has many differences. This makes the study of Venus structure a key element in understanding the history of the Solar system. Especially, probing its internal structure would reveal important clues about the formation of Earth. It could be done by investigating Venus seismic activity, as Venus surface presents volcanoes and faults but seems to lack plate tectonic.

But Venus exploration presents technical difficulties. Indeed, with ground temperatures reaching 400°C and 90 atm, we are unable to send long-lasting landers there. As of today, the longest-lasting lander is the Soviet *Venera 13*, which achieved to operate for a record-breaking duration: 127 minutes. This is nowhere near the weeks needed to peek inside Venus.

The Venus Seismology Study Team from Keck Institute for Space Studies (KISS) studied various solutions that could be implemented to tackle this issue [1]. The solution we will focus on consists in analysing the infrasounds produced by earthquakes, from Venus atmosphere thanks to balloon-borne pressure measurements.

These infrasounds are amplified during their propagation towards the highest layers of the atmosphere, which eases their detection. The advantage of this method is that at an altitude of 55 km, Venus atmosphere presents earthly conditions: 0.5 atm and 27°C. Furthermore, balloons have already been successfully used for short periods of time in the 1985 VEGA mission.

The researchers we are working with already conducted balloon-borne experiments to detect infrasounds [2], but at lower altitudes; the EXIST project, which took part in the BEXUS 24 mission, studied the stratospheric infrasound background. Other experiments showed that explosions could be detected with balloon-borne barometers [3]. Satellites also detected seisms with similar techniques [4].

1.2 Mission statement

The problem we are trying to solve is the following: how can we probe a planet's structure without using a ground sensor? The solution we are studying consists in using atmospheric balloons to detect the infrasound's generated by earthquakes. An appropriate device carried by a stratospheric balloon, or ideally a constellation of balloons, would enable us to analyse and locate the sources of infrasound waves.

1.3 Experiment Objectives

PO1	Characterize the infrasonic background noise during the stratospheric flight
SO1	Extract signals related to geophysical processes from infrasound measurements and identify them
SO2	Locate infrasound sources

1.4 Experiment concept

The device consists of two boxes, one located on the gondola, the other on the flight ladder, as depicted in Figure 1.1. Each one of them embeds a barometer and its acquisition hardware and measures the arrival times difference and the inclination of incoming infrasound waves. This allows us, after backward propagation simulation, to locate the source of these infrasound signals.

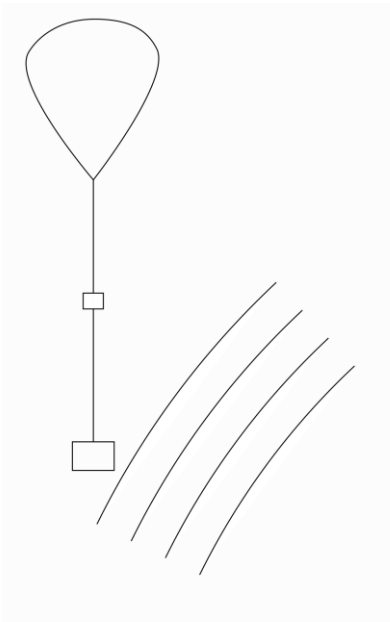


Figure 1.1: Measurement of incoming waves inclination

The primary goal is to take pressure measurements using barometers. Then, it is necessary to know the relative position of the boxes to find the orientation of incoming waves, which is done using an inertial measurement unit (IMU). To get back to the source location, the balloon position is measured with a GPS. Finally, various environmental (external temperature, wind speed) and monitoring (temperature of different sensors, power distribution metrics) signals are gathered to allow the proper operating of the experiment. Both boxes are synchronized on the same time reference, but they operate independently from each other.

All of this data is stored locally and sent remotely to the ground station. In turn, the DESTINY team operates the experiment remotely, sending its commands over the E-Link interface.

Finally, a Thermal Management System (TMS) is implemented onboard to allow components to operate in their required temperature range. It is nominally automated but can be switched to the manual mode.

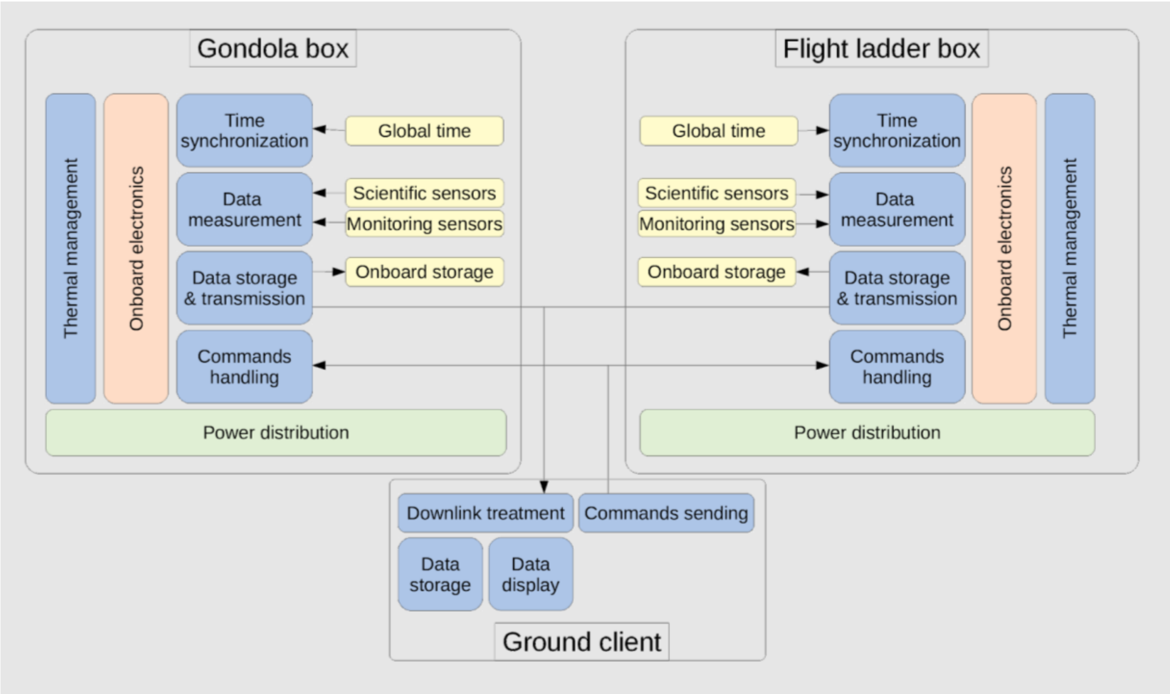


Figure 1.2: Block diagram of the DESTINY experiment

1.5 Team Details

The subject of the study was suggested by David Mimoun, endorsing professor of the project and researcher / professor at *ISAE-Supaéro*. The team consists in people from the French engineering universities *ISAE-Supaéro* and *École Polytechnique*.

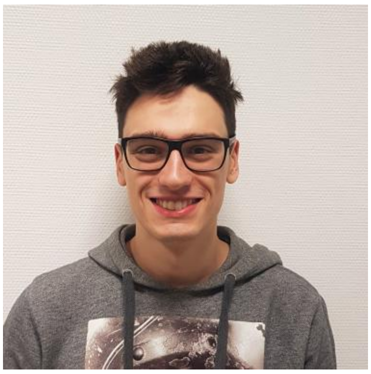
1.5.1 Contact Point

The DESTINY team lives in metropolitan France, which uses the Central European Time and Central European Summer Time (UTC+1 and UTC+2). The best way to get information about the experiment before is through the team email. After the end of the project, in January 2020, the preferred way will be to contact the team leader, or the university contact person.

Team		
	Email	destiny.bexus@gmail.com
Team Leader		Louis Dubois
	Email	louis.dubois@polytechnique.edu
	Address	App. 12.40.10, bât. 12 Bd des Maréchaux 91120 Palaiseau France
	Phone	+33 (0) 7 88 36 15 78
University contact		Lilia Solovyeva
	Email	lilia.solovyeva@polytechnique.edu
Endorsing professor		David Mimoun
	Email	david.mimoun@isae.fr

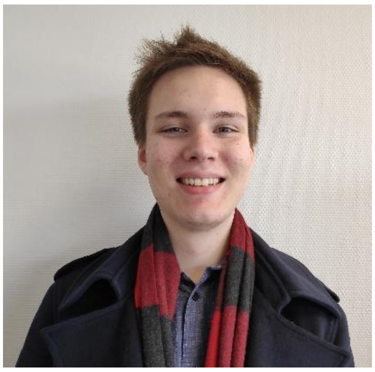
1.5.2 Team Members

This section presents the members of the DESTINY team, including their respective role, educational background and field of work within the team. This project is done in the frame of a mandatory scientific project, and the members will be awarded at least 7 ECTS credits for work related to the experiment. The team consists in students in their fourth year of study, as well as first-year bachelors.



Florian Abeillon
Thermal design, outreach

Florian is sophomore at *École Polytechnique*, interested in Physics as well as in Computer Science.



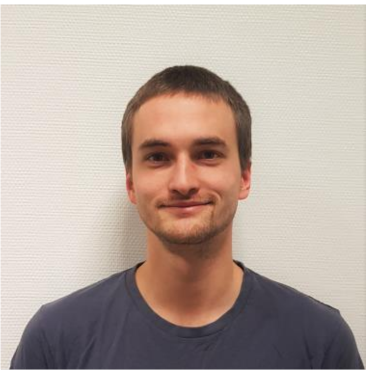
Olavi Aikas

Software

Bachelor student at *École Polytechnique*. My interests lie within mathematics and computer science, notably in the domain of computer graphics.

Samuel Brasil
Data analysis

Second-year student at *École Polytechnique* and former aerospace engineering student at *Instituto Tecnológico de Aeronáutica* (Brazil), interested in Data analysis and Data Science.

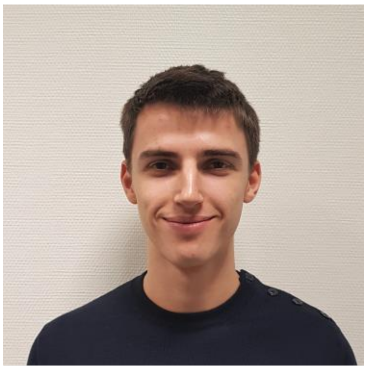


Tristan Bruel
Mechanical design, payload

Second-year student at *École Polytechnique*, interested in Physics.

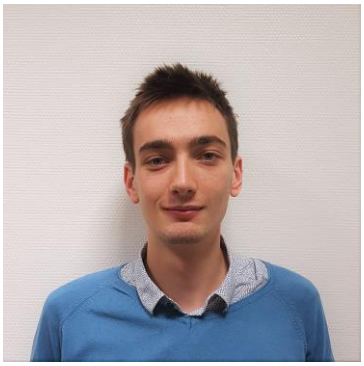
Krishan Bumma
Thermal design, payload

Second-year student at *École Polytechnique*. Specialized in material science.



Louis Dubois
Team leader, project management, electronics

Second-year *École Polytechnique* computer science student, with focus on cybersecurity. Louis is interested in embedded electronics and have already worked on several hobby projects on this field.



Matthieu Jeannin
Data analysis

2nd year student at *École Polytechnique*
Main area of study: Mathematics and Physics

Elias Khallouf
Mechanical design

2nd year student at *École Polytechnique*
Main area of study: Mechanics.

William Koch

Software

Bachelor student at *École Polytechnique* studying Mathematics and Computer Science. I am particularly interested in the applications of machine learning in space flight and autonomous systems, as well as software development.

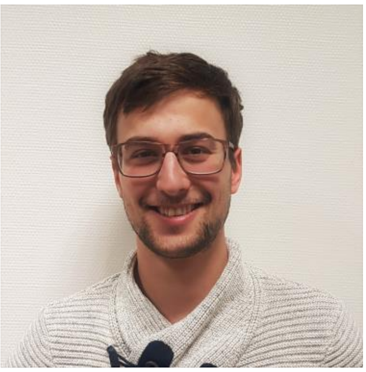
Ashish Nayak

Software

Student in the *École Polytechnique* Bachelor Program and currently pursuing a degree in Computer Science and Mathematics. I am quite interested in the fields of Machine Learning and Data Science and look to pursue a career in it.

Clara Piekarski
Data analysis, project management

2nd year student at *École Polytechnique*
Main area of study: Physics



Louis-Arnaud Péchenart
Electronics

2nd year student at *École Polytechnique,* interested in electronics.

Mickaël Rey
Software, electronics

2nd year student at *École Polytechnique*, interested in computer science and physics. Specialization: Computer Science

Sariah Al Saati
Computing, Mechanics, data analysis

First year student at *École Polytechnique*, Main area of study: Mathematics and Computer Science.
Interested in working in the spatial area.

Théo Boyer
Mechanical design, data analysis

First year student at *École Polytechnique*, Interested in Astrophysics, fundamental physics and space engineering.

Elsa Deville
Mechanical design, data analysis

First year student at *École Polytechnique*, Main area of study: Applied mathematics and physics. Interested in aeronautical engineering.

Gatien Fonmartin
Mechanical design, data analysis

First year student at *École Polytechnique*, interested in Physics and Mechanics, in particular in the aeronautic field.

Nathan Vaneberg
Thermal design, assembly, data analysis

First year student at *École Polytechnique*,
Main area of study: Physics and Informatics.

2 EXPERIMENT REQUIREMENTS AND CONSTRAINTS

2.1 Functional Requirements

F1	The experiment shall measure infrasound.
F2	The experiment shall measure the position of the gondola.
F3	The experiment shall measure the attitude of the boxes.
F4	The experiment shall measure the external temperature.
F5	The experiment should measure relative wind speed and direction near the pressure port (inlets).

2.2 Performance Requirements

P1	The pressure resolution shall be 0.01 Pa.
P2	The pressure measurement frequency shall be 200 Hz.
P3	The experiment shall be able to measure pressure in the range of 700 Pa to 1 atm (100000 Pa).
P4	Incoming waves direction should be known with a 20° margin of error.
P5	Position measurements shall be made with an accuracy of ±5 m.
P6	The position of the gondola measurement rate shall be 1 Hz.
P7	The relative position of the boxes measurement rate shall be 50 Hz.
P8	The relative position of the boxes shall be known with an accuracy of 5° relatively to the vertical axis.
P9	The attitude of the boxes shall be known within ± 10 °.
P10	The attitude measurement rate shall be 50 Hz.
P11	The experiment shall be able to measure external temperatures from -80 °C to 50 °C.
P12	The external temperature measurement rate shall be 0.1 Hz.
P13	The external temperature shall be known with a ±1 °C margin of error.

P14	The wind speed measurement rate should be 2Hz.
P15	The generated infrasound waves shall have an amplitude of 0.1 Pa when they reach the experiment.
P16	All measurements shall be made with the same time reference.

2.3 Design Requirements

D1	The experiment shall operate in the temperature profile of the BEXUS vehicle flight and launch
D2	The experiment shall operate in the vibration profile of the BEXUS vehicle flight and launch
D3	The experiment shall not disturb or harm the launch vehicle
D4	The experiment batteries shall be qualified for use on a BEXUS balloon.
D5	The experiment batteries shall either be rechargeable or shall have sufficient capacity to run the experiment during pre-flight tests, flight preparation and flight.
D6	The batteries in the gondola-mounted experiment shall be accessible from the outside within 1 minute.
D7	The inlets should reduce the noise and should not distort the signal
D8	The data transmission between the two boxes shall not suffer from the length of the cable.
D9	The distance between the two pressure ports should be at least 25 m.
D10	The experiment shall handle vertical acceleration of 10 g.
D11	The experiment should handle horizontal acceleration of 5 g.
~~D 12~~	~~The experiment shall maintain an internal temperature suitable for the components~~
D13	The internal temperature shall be kept in the range 0°C - 60°C
D14	The gondola box shall be attached to the bottom gondola mounting rails

D15	The upper box shall be attached to the flight train thanks to the fixations provided by Esrange
D16	The mass of the gondola box should not exceed 6 kg.
D17	The mass of the box attached to the flight train shall not exceed 5 kg.
D18	The mass of the cable between the two boxes shall not exceed 8 kg.
D19	The team shall be able to start and stop data acquisition from the ground station.
D20	The experiment should be able to handle network unavailability.
D21	The experiment should be able to reset without external intervention in case of loss of control.
D22	The telemetry bandwidth shall not exceed 200 kb/s.
D23	The experiment shall operate in the pressure profile of the BEXUS flight.
D24	The budget of the experiment should not exceed 30 000 €.

2.4 Operational Requirements

O1	The DESTINY team shall be able to send commands from the ground station to the experiment from start-up to shut down.
O2	The DESTINY Team shall be able to select between an autonomous and a manual thermal management system from the ground station.
O3	The experiment shall enter a secure mode before landing.

2.5 Constraints

C1	The mass of the experiment shall not exceed 20 kg.
C6	The *École Polytechnique* cannot provide us with more than 4000€.

3 Project Planning

3.1 Work Breakdown Structure (WBS)

The Work Breakdown Structure of DESTINY can be found in Figure 3.1. It displays main work packages and members responsible for the different departments. For a more detailed list of work packages, see Appendix E - Project Planning.

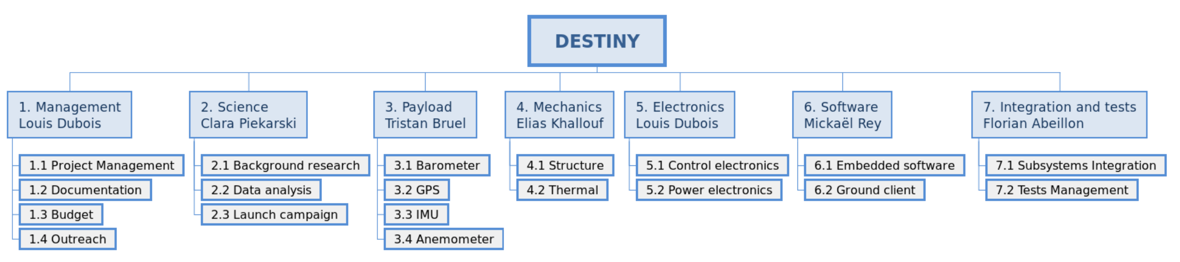


Figure 3.1: WBS

After June, the time allocated by the school for the project ended and a new team needed to take the place of the previous one. The new members composing this team are:

-Sariah Al Saati

-Théo Boyer

-Elsa Deville

-Gatien Fonmartin

Louis, William and Olavis stayed in the team.

It's more difficult to make a breakdown at this stage because the design was almost finished. The experiment needed to be mounted and tested for the flight.

After the launch, Louis, William and Olavis quit the team and all the member worked on the data analysis.

3.2 Schedule

The top-level Gantt chart of the project is displayed in Figure 3.2. For a detailed planning, see Appendix E. The planning will be updated in the course of the project, to reflect progress and to take into account mishaps. A two-month margin of error is planned before launch.

The updated planning after the CDR is displayed in Figure 3.2 bis.

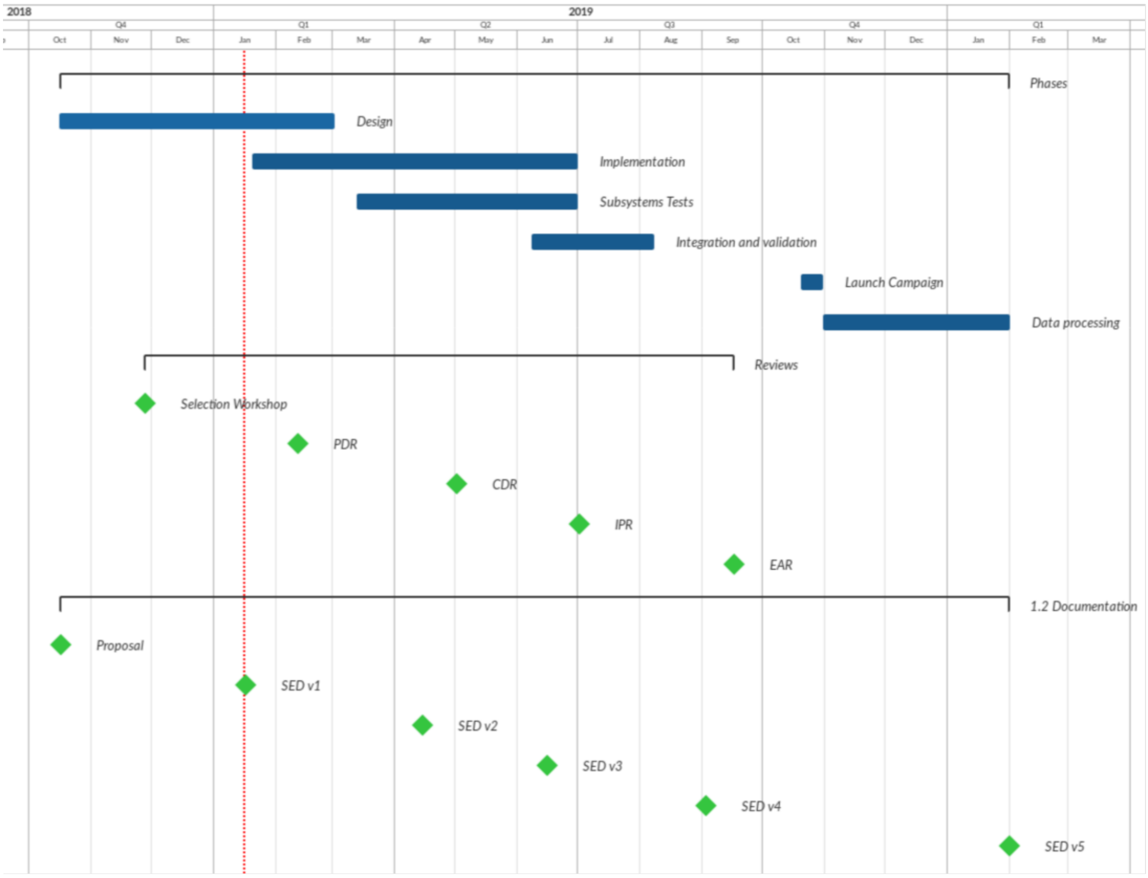


Figure 3.2: top-level Gantt chart

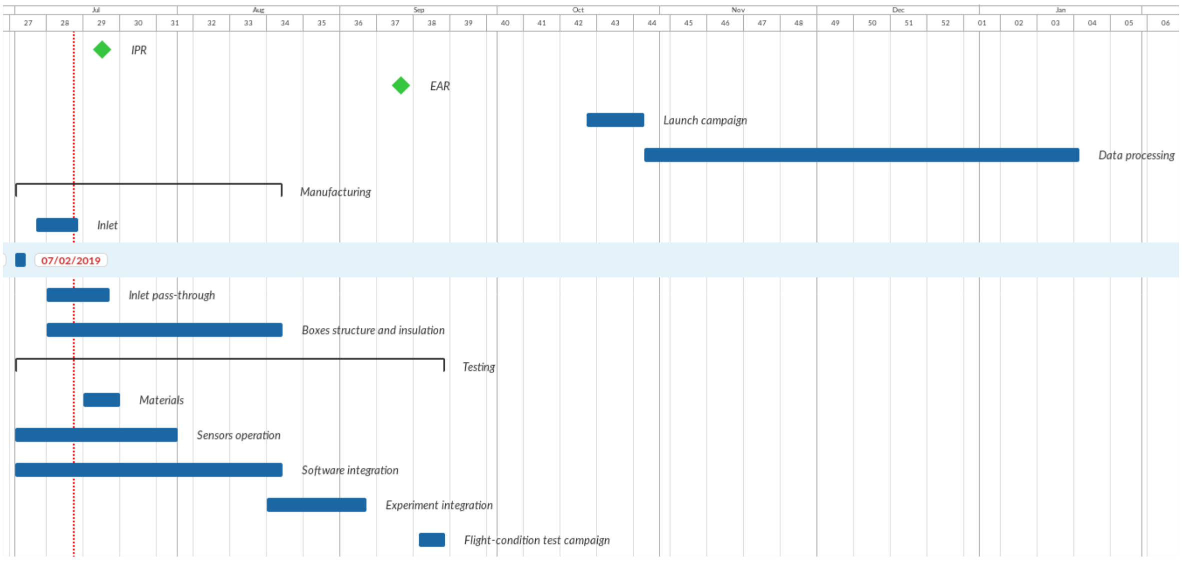


Figure 3.2 bis: post-CDR

3.3 Resources

3.3.1 Manpower

This section describes the work distribution within the team. The DESTINY team is split into 5 main departments: Science, Mechanics, Electronics, Software and

Management. Shortly after the CDR, 9 members left the project, and 5 new joined in. The Table 3.3 sums up the members of these departments, with the remaining ones in italics. Though members are assigned to specific departments, the dispatching is not static. For example, the manufacturing process might occasionally require additional manpower which would come from other departments. Additionally, most of the team will shift toward data analysis before the flight.

Science	**Mechanics**	**Electronics**	**Software**	**Management**
Clara Piekarski Matthieu Jeannin Samuel Brasil *Elsa Deville* *Gatien Fonmartin*	Elias Khallouf Tristan Bruel Florian Abeillon Krishan Bumma *Sariah Al Saati* *Natan Vaneberg*	Louis-Arnaud Péchenart *Louis Dubois*	Mickaël Rey *Louis Dubois* *Olavi Aikas* *William Koch* *Ashish Nayak*	*Louis Dubois* Clara Piekarski Florian Abeillon

Table 3.3: List of departments before the CDR

The electronics department is the weaker in terms of skill set of the team. To ensure the success of the mission, we can count on the advice from the *LMD lab*, and the electronics design and manufacturing is done in collaboration with *ISAE-Supaéro*. This presents a challenge as *ISAE-Supaéro* and *École Polytechnique* are located on different cities.

3.3.2 Budget

ISAE-Supaéro university is the main sponsor of the experiment, financing most of the instrumentation (especially the barometers and the electronics realisation. Then comes *École Polytechnique* which will cover other electrical and mechanical expenses, as well as other expenses for up to 3 000 €. Finally, Saft and LCJ provide us with the batteries and the anemometer.

Table 3.4 displays the expenses related to the DESTINY experiment. Expenses related to testing facilities or manufacturing tools are not listed since they are freely available at *École Polytechnique* and *ISAE-Supaéro* universities.

Table 3.5 displays the incomes that we already received or that we are expecting. For now, they fully cover the expected costs. The *École Polytechnique funds all the minor components.*

Expenses		Amount
Electronics	Power	90 €
	Processing	80 €

	Sensors and actuators	202 €
	Data storage and transmission	288 €
	PCB manufacturing	100 €
	Electronics total	760 €
Mechanics	Boxes manufacturing	100 €
	Insulation material	20 €
	Mechanics total	120 €
Payload	Barometers	14 000 €
	Anemometer	400 €
	Payload total	14 400 €
Others	Travel	1 000 €
	Experiment shipment	600 €
	Others total	1 600 €
	Total	16 880 €

Table 3.4: Budget

Incomes		**Amount**
ISAE-Supaéro	2 barometers	14 000 €
Saft	Batteries	600 €
LCJ	Anemometer	400 €
Ecole Polytechnique	Travel expenses, electronics and building materials	2 500 €
	Total	17 500 €

Table 3.5: Budget incomes

3.3.3 External Support

The experiment can count on the support of François Danis from the *Laboratoire de Météorologie Dynamique* (*LMD*) at *École Polytechnique*, which provides his knowledge of balloon experiments and the possibility to use testing facilities. Olivier Bousquet, from the LMD, provides his expertise on mechanical realisation.

Lilia Solovyeva, as supervisor of the Student Space of *École Polytechnique*, assists the experiment on project management. Jean-Marc Chomaz, Research Professor from the Hydrodynamics Laboratory (*LadHyX*) at *École Polytechnique*, provides his knowledge on fluid dynamics, and advises the team on project management as well.

David Mimoun, Associate Professor at *ISAE-Supaéro*, manager of the Space Systems for Planetology and Applications team at the DEOS, proposed the subject of the experiment to the DESTINY team and follows closely the progress of the project, technically as well as for its management. His team is of great help regarding the electronic design and manufacturing. Additionally, he will make available testing facilities from *ISAE-Supaéro*. Leo Martire, a PhD student working in D. Mimoun's team works on the stratospheric propagation of infrasound. He will be a great help for the data analysis.

3.4 Outreach Approach

The main outreach media of DESTINY are social networks, with its Facebook page, and a dedicated website. The Facebook page is used to communicate about major events concerning the project. The website contains additional information, with a blog part where more detailed articles are published about the progress of the project, a part about the design of the experiment. It also provides the different SED versions to help potential participants better understand the BEXUS programme.

Additionally, an article has been published on the website of *École Polytechnique*, in February 2019, and articles will be published on local newspapers. Presentations have been done to high school students. The team presented its project to the university Space Week, on Thursday 30th January 2019.

Additional information on outreach can be found in Appendix B.

3.5 Risk Register

Risk ID
TC – technical/implementation
MS – mission (operational performance)
SF – safety
MT – material
VE – vehicle
PE – personnel
EN – environmental
MG – management

Probability (P)

A. Minimum – Almost impossible to occur
B. Low – Small chance to occur
C. Medium – Reasonable chance to occur
D. High – Quite likely to occur
E. Maximum – 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

The rankings for probability (P) and severity (S) are combined to assess the overall risk classification, ranging from very low to very high and being coloured green, yellow, orange or red according to the SED guidelines

Probability (P)	1	2	3	4	5
E	low	medium	high	very high	very high
D	low	low	medium	high	very high
C	very low	low	low	medium	high
B	very low	very low	low	low	medium
A	very low	very low	very low	very low	low

Severity (S)

Table 3.6: Risk Register

ID	Risk and non-obvious consequences	P	S	P × S	Action
SF10	Fall of the upper box	A	5	Low	Design a safe attach, with a security system
SF20	Fall of an inlet after deployment of the parachute	B	2	Very low	Secure the fastening mechanism using a flexible rope
MS10	Absence or scarcity of infrasound signals to detect	A	4	Very low	Search for ways of creating infrasound perturbations. Contact mines near Kiruna and SSC to create an explosion. (Appendix G)
MS20	The infrasound produced by the planned events are not powerful enough to be detected by the experiment	C	4	Medium	Configure the barometer to detect very light pressure variations. Do simulations to assess

					the required source power.
MT10	Damaging or loss of a barometer due to a hard landing	D	3	Medium	Design a damping system to protect the sensors from the shock.
MT20	A computer stops working because of unsuitable temperature	A	4	Low	Manage temperature based on internal measurements. Implements safeguards to prevent overheating. Ensure that the temperature will be suitable through simulation.
MT30	A sensor stops working because of unsuitable temperature	A	3	Very low	Manage temperature based on internal measurements. Implements safeguards to prevent overheating. Ensure that the temperature will be suitable through simulation.
MT40	A barometer is damaged due to a tough landing	B	3	Low	Use dampers.
VE10	Infrasound emitted by other experiments jam measurements	C	4	Medium	Characterize the perturbation to reduce noise during data analysis. Get information about the time these perturbations occur.
MG10	A member of the team had to leave the project prematurely	B	3	Low	Find in advance potential new members. If the project is at an advanced state, redistribute the workload between remaining members.
MG20	Lack of manpower to fulfil all the tasks	A	4	Very low	Find in advance potential new members, and recruit them if needed before CDR.
MG30	Lack of funds	A	4	Very low	Find sponsors and prepare low-cost alternatives.
TC10	The experiment arrives too late in Kiruna	A	5	Low	Send it early.

TC20	Manufacturing is delayed due to external actors	B	2	Low	Prepare alternative solutions
TC30	An issue is not found during the test campaign	A	3	Low	Real conditions test in a stratospheric chamber.

Regarding the creation of an explosion - to ensure that we can detect a given signal - we recently contacted Johan Kero, who works at the IFR, Kiruna. He offered to help us getting an agreement with nearby mines to perform a blast. ~~Currently an arrangement for an explosion in Vidsel air base (230km south of Esrange) is almost settled, and~~ Mr Kero is investigating the possibility to perform a blast in the open air mine of Mertainen.

4 EXPERIMENT DESCRIPTION

4.1 Experiment Setup

The DESTINY device consists of two boxes. The first one is placed inside the gondola, while the second one is hanged about 30 m above, on the flight train. They essentially operate in the same way, independently of each other. After acquisition of the measurements of the sensors listed in Table 4.1, data are stored on an SD card and on the internal flash memory and sent to the ground station using the E-Link system. Additionally, the boxes constantly listen to incoming commands from the ground station through the E-Link system.

Sensor	Gondola box	Flight ladder box
Barometer	X	X
External thermometer	X	X
Internal thermometer	X	X
Anemometer	X	
GPS receiver	X	X
IMU	X	X
Battery monitoring	X	X

Table 4.1: Content of the boxes

Each box embeds a Thermal Management System (TMS) which are mainly used at low altitudes to heat the components. It consists of thermal pads driven by a controller, which is based on temperature measurements made by sensors built in the different integrated components as well as additional ones for components that lack one. For safety reasons, the TMS can be switched to manual and safeguard modes.

The power supply of the gondola is used to power the gondola box, and the flight train box has its own batteries.

The experiment has different phases:

- During initialisation, the different sensors are started and configured, and the boxes establish a connection to the ground station. From now on, commands can be sent from the ground station. The TMS is turned on, operating in automatic mode.
- Before take-off, the different sensors are tested to ensure that they are working properly.

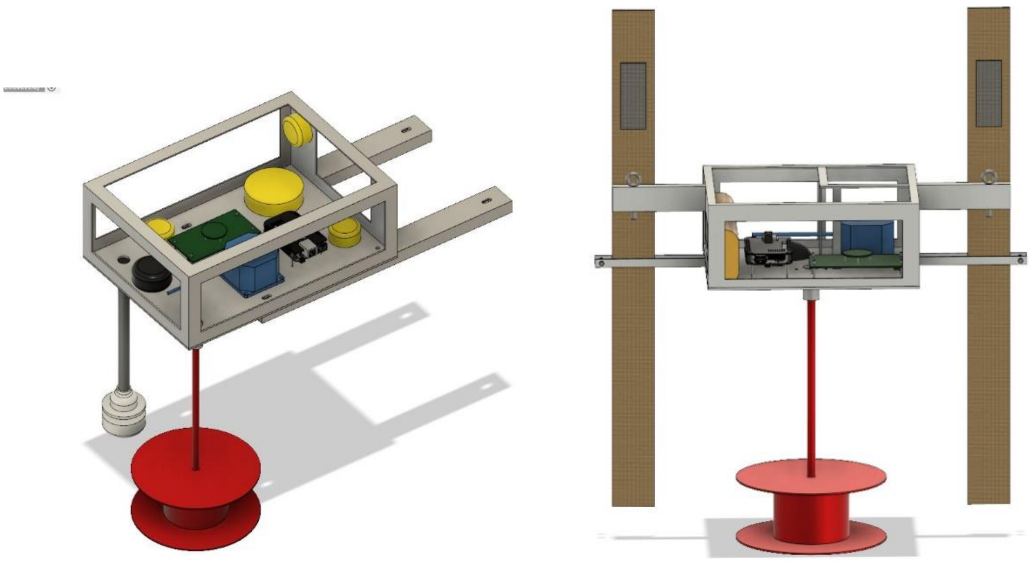
- Shortly before take-off, data gathering starts: sensors operate at their nominal measurement rate, store and transmit data to the ground.
- Shortly before landing, the systems enter secure mode: data stops being stored onboard to avoid corruption but keep being transmitted to the ground station.
- After landing all the subsystems are shut down.

Raw data are stored and transmitted to the ground. No treatment is done on them, except for internal temperature measurements which are used by the TMS.

4.2 Experiment Interfaces

4.2.1 Mechanical

~~The upper box will be attached to the flight train. It will be fixed with shackles to a sewed fixation (made by ESRANGE) using a M5 D anchor shackle. Two bars will stick out of the top of the box - as represented in figure 4.2 - and on which a M6 eye bolt will be attached. This bolt will then be connected to the shackles. Two other bars will stick out of the bottom of the box from both sides of the flight train so as to prevent the rotation of the box (see figure 4.3 and APPENDIX G). An additional shackle will be attached around the box and to the sewed parts of the flight train as additional security measures.~~



~~*Figure 4.2: Attachments of the boxes (lower box on the left, upper box on the right)*~~

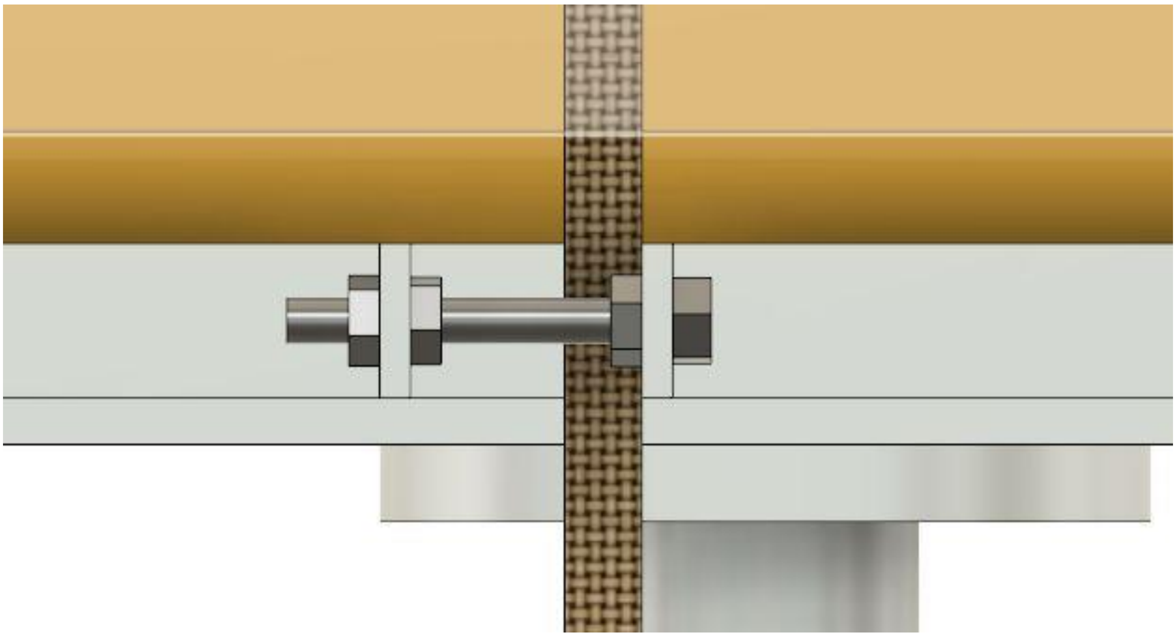


Figure 4.3: Details of the bolted bars

The nuts between the bars will make sure they remain at a bigger distance than the thickness of the trail from each other. In addition, this will allow an easy detachment of the box for recovery (Appendix F).

The main box will be fixed inside the gondola. Two bars will be bolted to the gondola rails. The main box will be bolted to those two bars just as shown in Figure 4.2.

Type:	**Size:**	**Amount:**
Bolt	M4	2
Nut	M4	6
Bolt	M6 eye	2
Bolt	M6	6
Nut	M6	8
Washer	M6	8

Table 4.3: Estimated number of bolts, screws, nuts and washers for both boxe

The upper box is attached to the flight train. As shown in the picture below, one bar supports the whole box. This bar is attached to the flight train using two M6 eyebolts connected to two M4 D shackles sown onto the flight train by Esrange. To prevent the rotation of the box around the bar, straps is used to stabilize the box from below. As an additional security measure, straps are attached around the box and to the sewed parts of the flight train to prevent the falling of the box. This design makes it easy for the recovery team to detach the box.

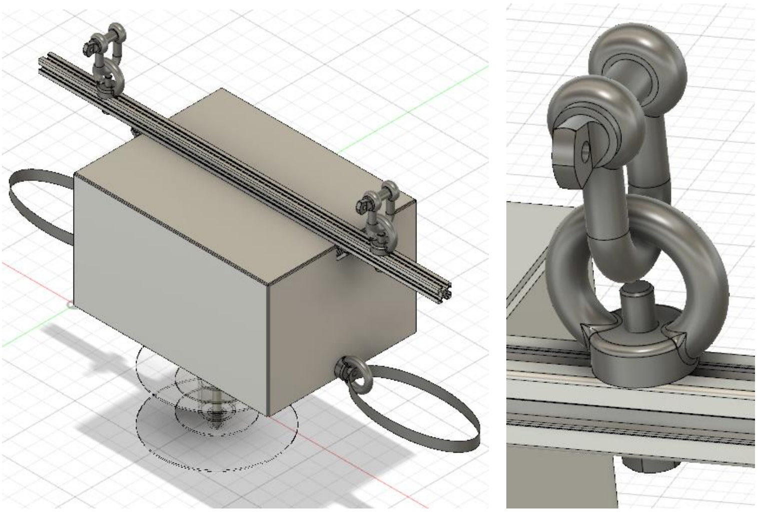


Figure 4.2: Fixation of the flight train box

As the boxes are designed using T6 slot aluminium profile bars, the gondola box is attached to the T8 slot profile bar located in the gondola using compatible brackets.

4.2.2 Electrical

E-Link

Both boxes are interfaced with the E-Link system by providing RJF21B connectors. To provide such an interface close to the E-Link module, the Ethernet cable coming down from the flight train box is connected to the gondola box, which in turn provides two RJF21B sockets (one to linked to the gondola box computer, the other to the flight train box computer) where the E-Link can be connected, using RJF6B connectors.

Two E-Link interfaces are thus required. Downlink is used for telemetry, through the UDP protocol, chosen for its speed and reduced overhead. The nominal telemetric data rate is reached shortly before take-off, when data acquisition starts. Uplink is used for telecommand, through the TCP protocol, chosen for its robustness. It is mostly used during pre-launch and to change the experiment phase.

Uplink	Protocol	TCP
	Data rate	Maximum 2 kbit/s

		Typically left unused
Downlink	Protocol	UDP
	Data rate	173 kbit/s

Electrical power supply

The gondola box uses the gondola power supply, namely a 28.8 V battery pack consisting of eight SAFT LSH20, connected using a MIL-C-26482 MS31 12E-8-4-P connector. Because it is far above the gondola, the flight train box embeds its own power supply.

The expected consumption of the gondola box is in average 13 W and can reach 40 W at low altitudes.

Grounding

~~A distributed single-point grounding will be used.~~

The gondola box chassis ground is linked to the gondola, so it is insulated from the signal ground to prevent ground loops. The signal ground of all the sensors is connected by the BeagleBone Black. Finally, the cables shielding is connected to the chassis ground of the related components, which is connected to the signal ground by the BeagleBone Black. However, all the internal components are insulated from the box.

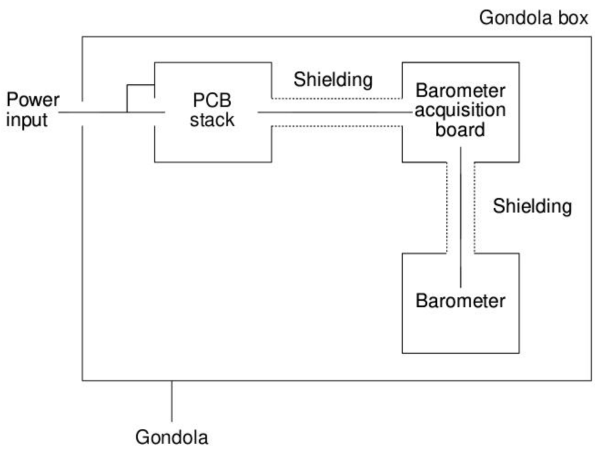


Figure 4.21: Gondola box grounding

Since the flight train box embeds its own battery, its grounding is slightly different from the gondola box. The box chassis ground is connected to the signal ground by the power switch. Additionally, the barometer acquisition board and the electronics stack share the same chassis ground.

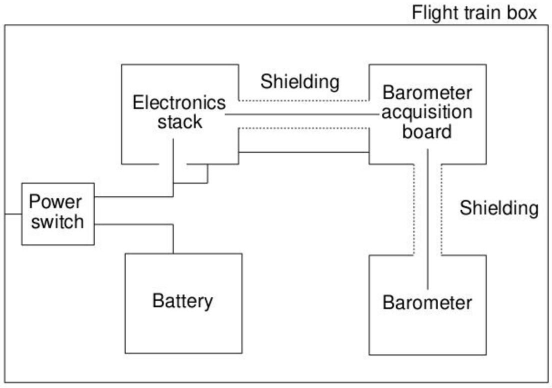


Figure 4.22: Flight train box grounding

4.2.3 Radio Frequencies

Each box embeds a GPS receiver, listening to GPS and GLONASS signal, operating on the following UHF domain frequencies:

GPS	1575.42 MHz
GLONASS	1598 to 1605.5 MHz

Table 4.23: RF used

4.3 Experiment Components

The main components of the experiment are listed in Table 4.5, and the mass and dimensions characteristics of the boxes are summed up in Table 4.6 and 4.7.

Component	Notes	Nb	Dimensions (cm)	Mass (kg)	Price	Current status	Supplier
Paroscientific 2000 Barometer	Very high resolution	2	6.67×6.67×4.81	0.43	7 000€	Delivered	Lent by *ISAE-Supaéro*
Element14 Robotic Cape	Embeds an MPU9250 IMU	2	8.63 × 5.33 × 2	0.013	46 €	Delivered	Farnell
u-blox NEO M8 GPS	Accurate, low-cost and suitable for	1	9×4×2	0.40	20 €	Delivered	bangood.com

	high altitude						
LCJ ultrasonic anemometer	Ultrasonic anemometers seem to be the most appropriate considering flight conditions.	1	Ø 7.4 H 14	0.51	400€ offered by LCJ	Received	LCJ
AD590KF		4	0.5 × 0.2 × 0.1	0.003	26.72€	Delivered	Farnell
IST PT100 P0K1.161.6W .K.010		2	0.12×0.12 × 0.08	0.001	14 €	Delivered	Farnell
BeagleBone Black		2	8.63 × 5.33 × 2	0.037	45 €	Delivered	Farnell
Ethernet cable		1	40m	1.5	50 €	Delivered	Farnell
Kingston 16 Go microSD UHSI	Waterproof	2	0.11 x 0.15 x 0.01	0.0002 5	19 €	Delivered	Kingston technolo gy
Saft 6S1P LSH20		3	18.8 × 3.4 × 6.7	0.620	Undefined	Delivered	Sponsore d by Saft
Minco polyimide thermofoil HK6907	Described as reliable by other experiments	2	2.5 × 5	0.027	40 €	Delivered	Minco
Upper box casing	Aluminium	1	25 x 22 x 17	2.2	0 €	Built	
Upper box isolation	Styrofoam	1	35 x 32 x 27	0.5		Delivered	
Gondola box casing	Aluminium	1	35 x 25 x 12.5	2.2	0 €	Built	
Gondola box isolation	Styrofoam	1	45 x 35 x 35	0.67		Delivered	

Table 4.31: List of main components

Mass estimation (in kg):	3.9
Mass measurement:	5.10
Experiment dimensions (in m):	0.45 x 0.35 x 0.225

Experiment expected COG (centre of gravity) position:	0.25x0.08 m from the corner of the gondola (figure 4.3.1)

Table 4.32: Gondola box summary table

Mass estimation (in kg):	4.3
Mass measurement:	5.92
Experiment dimensions (in m):	0.32 x 0.35 x 0.27
Experiment expected COG (centre of gravity) position:	0.10x0.125 m from the corner of the box (at the centre)

Table 4.33: Upper box summary table

Total mass (estimation in kg):	8.2
Total mass (measurement in kg):	11.02

4.4 Mechanical Design

The upper box is attached to the gondolas flight trail, while the other is set inside the gondola as shown below.

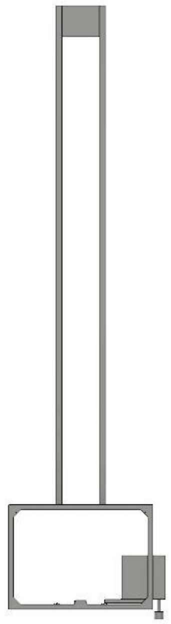


Figure 4.41: The complete mechanical setup (not to scale)

The bottom box has to exceed the gondolas borders (18cm) in order to fix the inlet.

The upper box is fixed 2m below the EBASS or the EMPIRE setting it at a height of about 33m from the bottom of the flight train.

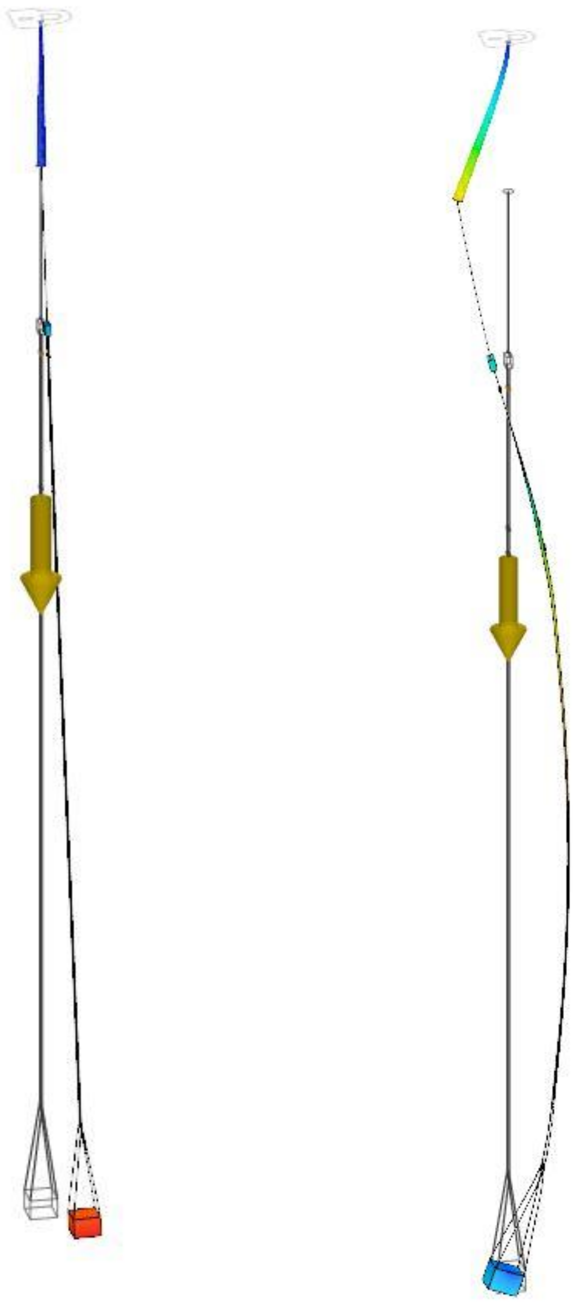


Figure 4.42: Simulation of the eigen modes of the flight train

For protection purposes, the barometers are installed on dampers to shield them from impacts and vibrations.

The inlet is a sacrificial component; it will probably be destroyed upon landing. To connect the inlet to the barometer, a through wall fixed with plastic screws will be used to secure the inlet's aluminium shaft in the box. This system protects the barometer in case of a tough landing: the through wall will break or the screws won't resist, allowing the inlet to break free without causing any damage to the inside of the box. We will use the same device to connect the anemometer to the beagle bone.

We want to make sure that the inlet and its metal shaft don't damage our barometer by pulling it out during landing. To do so, we will use two flexible pipes and two Swagelok connectors – SS-10M0-6-6M and SS-6M0-6-2 models – respectively as intermediaries between the shaft of the inlet and one sacrificial tube, and between this tube and the barometer, as shown in the picture below. The connector will be firmly linked to the box.

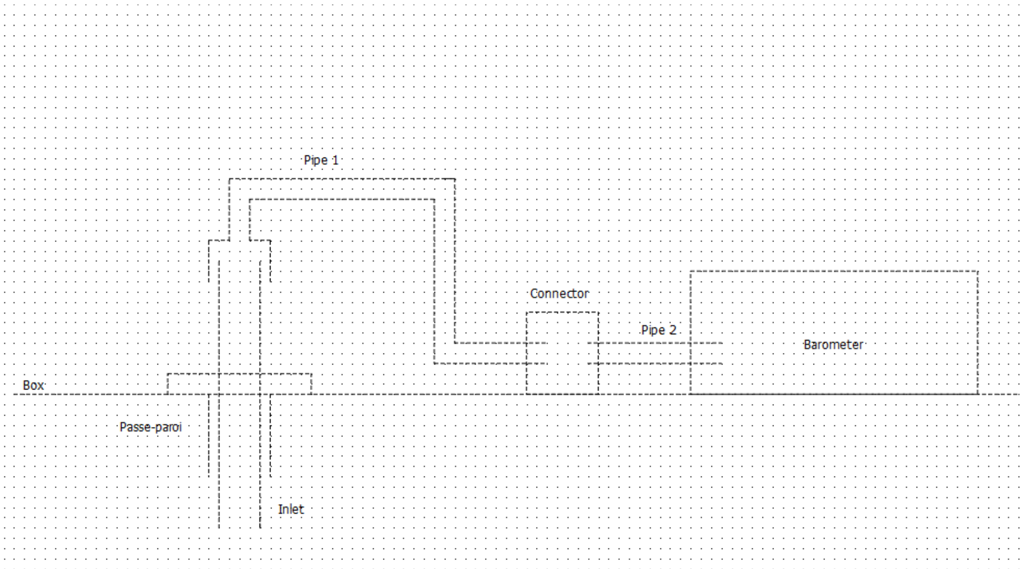


Figure 4.43: Link between the inlet and the barometer.

Both boxes were built from 20*20mm T6 slot aluminium profile bars. 2mm aluminium plates – cut at the laboratories of Ecole Polytechnique - are closing the box.

Mass calculations of the upper box can be seen in Table 4..

Component	**Mass (kg)**
Box	2.2
Barometer	0.43
Robotic Cape	0.013
BeagleBone	0.037
Batteries	0.7

Thermofoil	0.027
Inlet	0.2
Isolation	0.5
Dampers	0.2
Bolts & nuts	~0.1
Total (estimation)	4.3
Total (measurement)	5.92

Table 4.44: Mass of the upper box

The total mass is 4.3kg, that is below our limit of 5kg (requirement D17).

The centre of gravity of the upper box is expected to be at the centre of the box. The centre of gravity of the lower box is expected to be at a distance of 25 x 8 cm from the corner of the gondola - just as shown if the figure below.

Figure 4.45: The figure shows the 25cm position of the centre of gravity from the corner of the gondola

We managed to manufacture the pressure port (the inlet) out of Plexiglas. The central tube linking the port to the sensor is made of aluminium in order to prevent it from breaking during launch. The tube will be fixed to the box thanks to the mechanism described above in figure 4.43, to protect the barometer.

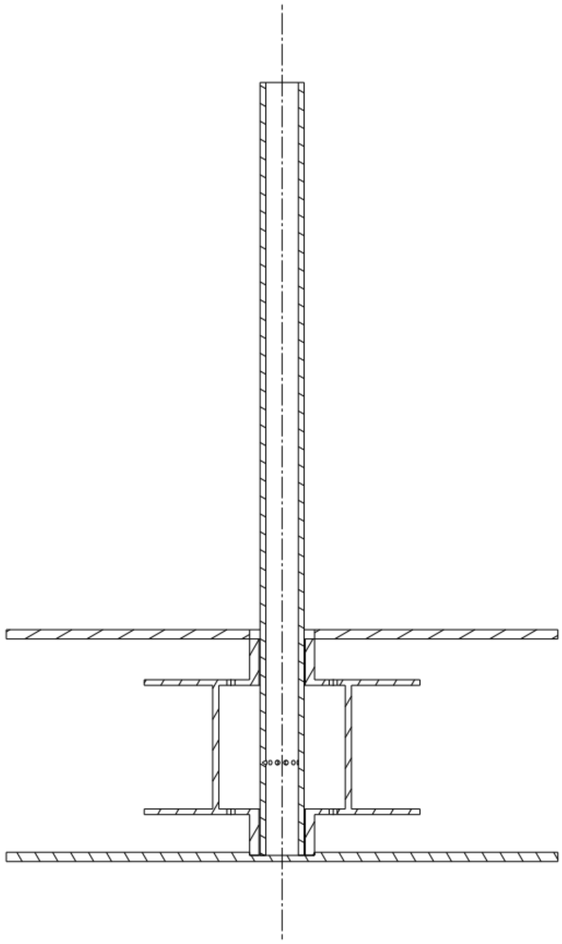


Figure 4.46.1: cross sectional view of the port

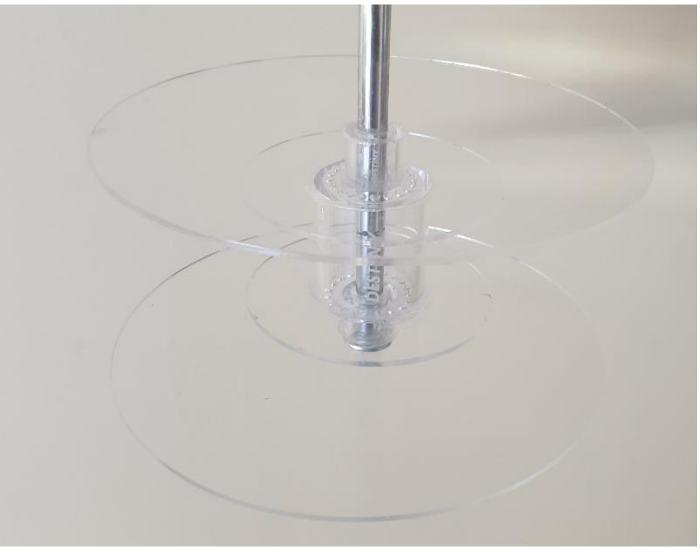


Figure 4.46.2: The final design of the inlet

We tested the efficiency of the inlets (see test 10 and 16) to be assured of their utility.

We 3D-printed a support to secure the battery in the upper box. We checked (test 7.5) that 3D printed plastic can resist the extreme temperatures of the experiment.

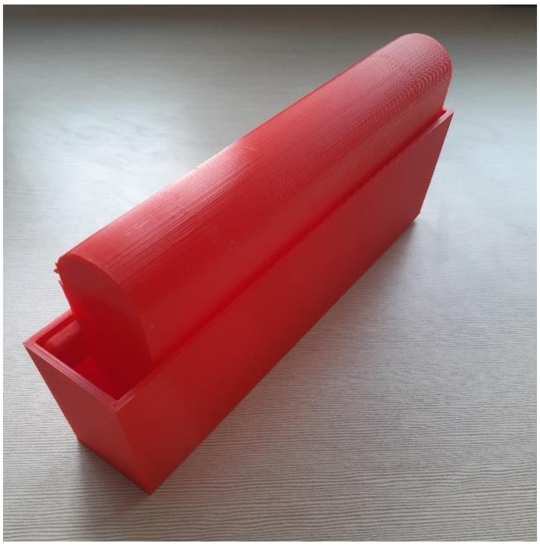


Figure 4.47: The battery support (below) holding a 3D-printed battery dupe

The two figures below summarize the disposition of the components in the different boxes as intended initially.

Here is the current layout of the components in both boxes.

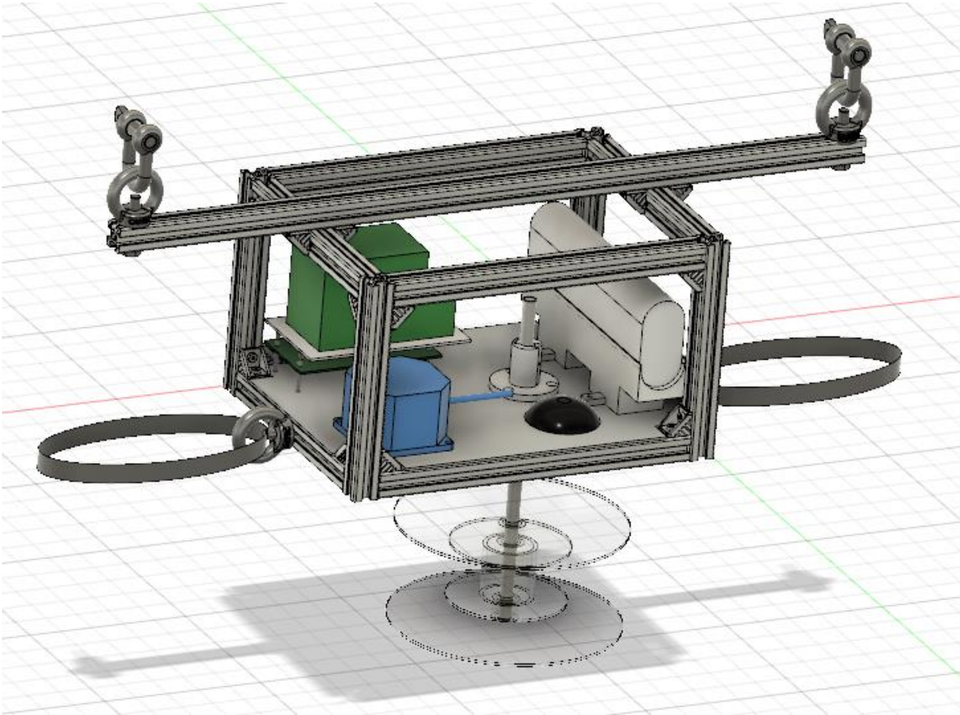


Figure 4.48.1: Flight train box inner disposition

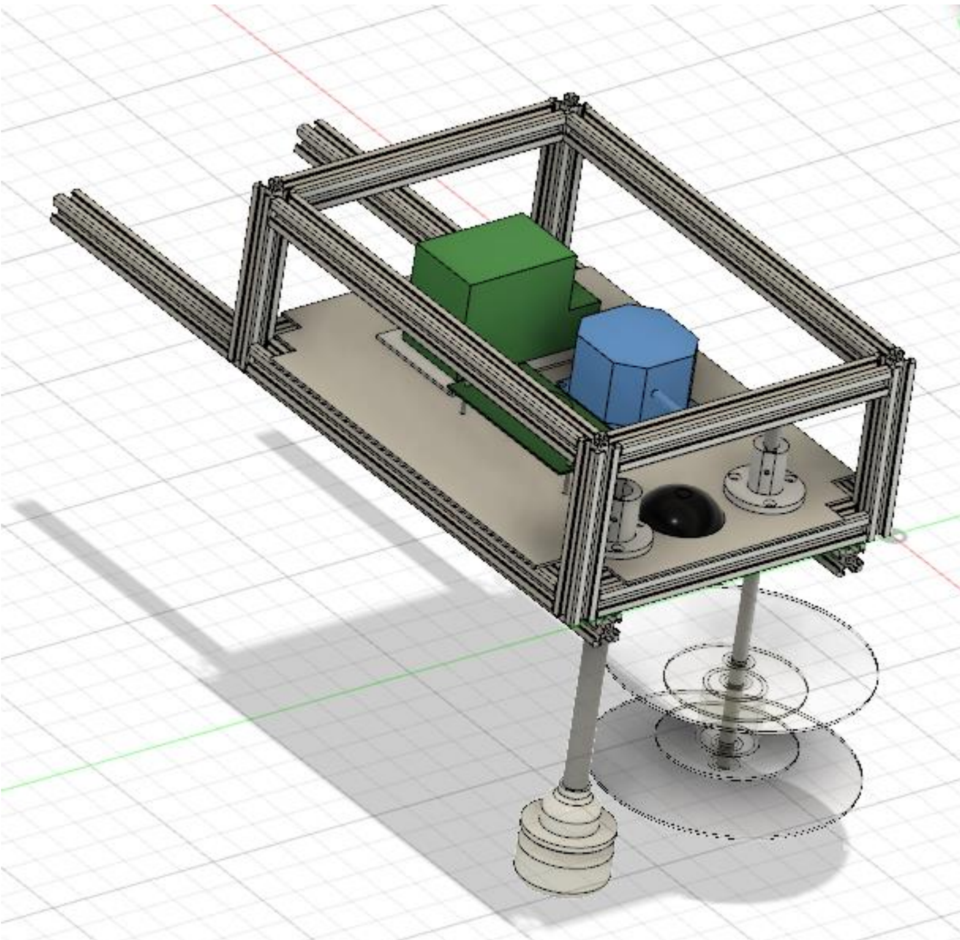


Figure 4.48.2: gondola box inner disposition

The tables below summarise the different types of fixation intended for the elements in the boxes. In the Flight Train Box, the BBB will be fixed on the electronic card using 4 M3 nylon spacers. This disposition was chosen to gain place in the box.

Component	Fixation
GPS	Double sided sellotape
Inlet	3 M4 bolts and nuts
Electronic card	4 M3 nylon spacers
Barometer	4 M4 bolts and nuts
Heater	Thermal glue
Total	11 bolts and nuts + thermal glue + 8 M3 nylon spacers (see text above)

Table 4.49: Fixations in the gondola box

Finally, we will fix 4 balloons to the flight train between the upper box and the gondola box. They will be attached with simple ropes and will be filled to explode at 5 km, 10 km, 15 km and 20 km of altitude (see appendix F). To do the maths and predict the altitude of explosion of the balloons, we tested them by different ways (see test 11).

4.5 Electronics Design

The two boxes of the experiment are similar in their organisation. Both embed a BeagleBone Black as the main processor. Plugged in it is a Robotic Cape, a daughter board that provides convenient sockets and which embeds an Invensense MPU9250 IMU. Additionally, two custom PCBs are used for power distribution, and to interface the sensors with the BeagleBone Black. These PCBs are–stacked between the Robotic Cape and the BeagleBone Black, providing direct access to its headers. Sensors are connected to the custom PCB using JST and DB-9 connectors. Finally, an acquisition board is used to gather pressure measurements, providing a serial interface, and connected to the custom PCB. Overall, five PCBs are used, including two custom PCBs that must be designed and manufactured.

One custom PCB is used to regulate battery voltage and driver heaters. Its design is presented in section 4.5.1. The other one adapts logical levels of the different components to the BeagleBone Black levels. Its design is presented in section 4.5.2.

The global organisation of each boxes is displayed in Figures 4.48.1 and 4.48.2.

For detailed information about power distribution, refer to paragraph 4.7 Power System.

A distributed single-point grounding is used.

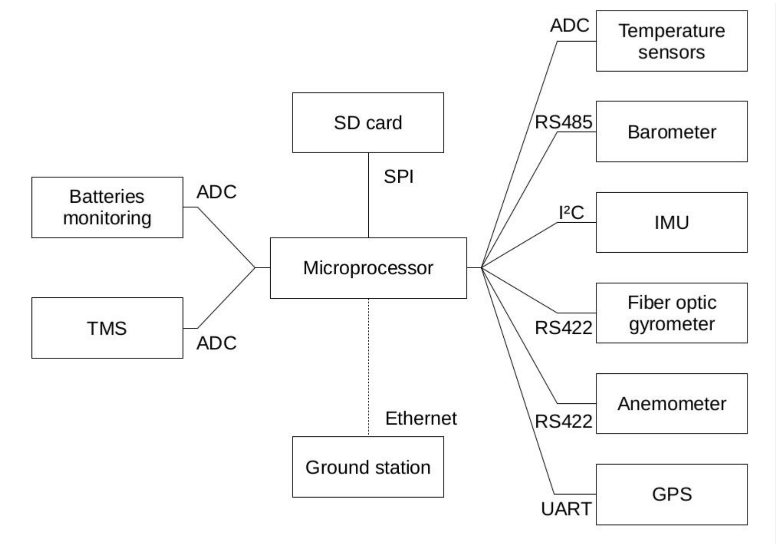


Figure 4.50: Gondola box global organisation

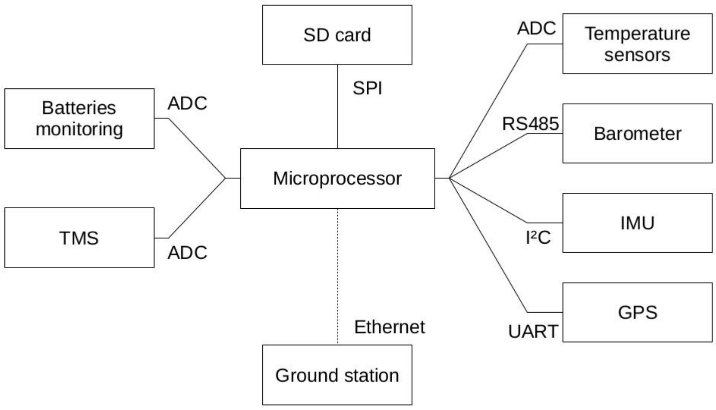


Figure 4.51: Upper box global organisation

4.5.1 Power interface board

The first function of the power interface board is to regulate the voltage of the battery. A Traco Power 15-2412N is used to lower it down to 12 V so that it can be used to power the different components of the experiment.

Additionally, it provides a way to monitor the regulated tension and the tension of the battery, as well as their supply current, using two of the BeagleBone Black embedded ADC.

Finally, the power interface board allows the BeagleBone Black to drive the two heaters using power MOSFETs.

The schematics of the power interface board are listed in Appendix C.3.

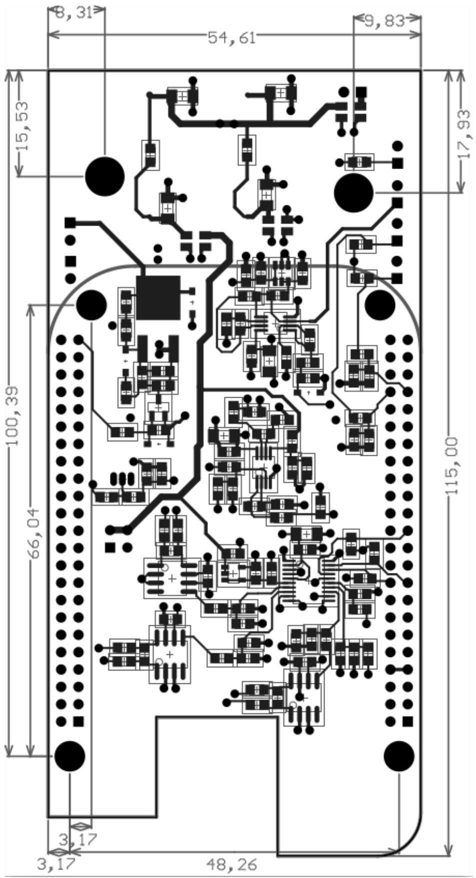


Figure 4.52: Power interface board layout

4.5.2 Sensors interface board

The sensors interface primarily powers sensors, allowing the BeagleBone Black to power them on and off using its GPIO, using the regulated tension provided by the power interface board.

It is also used to adapt tension levels between the BeagleBone Black and the different sensors embedded in the box, using MAX232 and MAX3488 integrated circuits.

The schematics of the sensors interface board are listed in Appendix C.4.

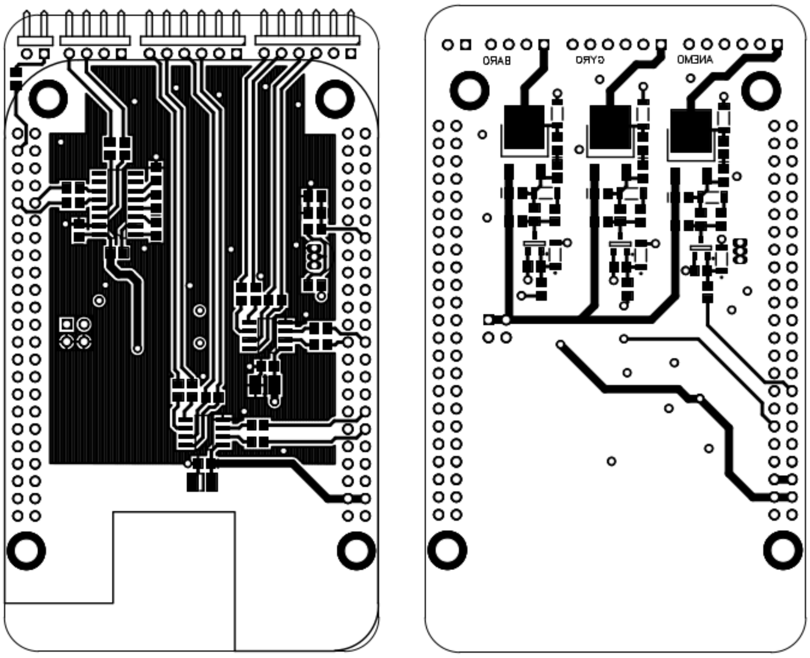


Figure 4.53: Sensor interface board layout (top and bottom)

4.6 Thermal Design

Every electrical component is certified to withstand temperatures up to -40 °C, except for the BeagleBone which is not supposed to be used under 0 °C.

Component	Temperature range
Paroscientific 2000 Barometer	-54 °C to +107 °C
KVH DSP 1760 fibre optic gyrometer	-40 °C to +75 °C
Element14 Robotic Cape	-40 °C to +70 °C
u-blox NEO M8 GPS	−40 °C to +85 °C
TI LM35H temperature sensor	−55°C to 150°C
BeagleBone Black	0 °C to 60 °C
Saft LSH20 lithium battery	-60 °C to +85 °C

Table 4.6: Operating temperature ranges of the components

There are two challenges due to the experiment's conditions: the very low temperature during the waiting phase, and the thin atmosphere once in high altitude.

To be sure that the experiment survives the pre-launch and the ascent, a 5cm-thick extruded polystyrene (XPS) insulation layer will be placed around the payload. The XPS sheets have been bought and will be built using Tangit PVC-U glue.

Additionally, they have been chosen for their capacity to withstand vacuum without expanding. We have been advised to use PVC glue by the meteorology lab of *École Polytechnique* as they use it for similar insulation. The insulation will be built when the aluminium frame is finished, so that we can choose the best option for fixation. To access the electrical components more easily, one side of the insulation will be removable and fixed with tape.

Plus, we will use several small Minco polyimide heaters to maintain the BeagleBone Black at a decent temperature (above 0°C). The heaters will be placed on a heatsink to ensure a good thermal conductivity as well as to avoid any overheating of the onboard computer. Even though, a test showed that the BeagleBone can be used at temperatures as low as -40°C.

The temperature of the BeagleBone will be measured with an AD 590 thermometer.

The temperature of the batteries will also be measured with an AD 590 and heated through a heatsink by a Minco heater. However, the batteries have been specially designed by SAFT to work in that range of temperature.

A heatsink will be placed on the power interface board because of the high current (700 mA) running through it.

Heatsink design

The heatsink, manufactured by *ISAE-supaéro*, located on the BeagleBone is dimensioned for high altitude use, to prevent overheating efficiently. At the bottom we have an aluminium plate to dissipate the heat. There are also spacers connecting the different parts of the BBB. These are meant to drain heat from the DC/DC converters towards the mechanical support.

~~We are planning to use a thick layer of heat transfer tape~~. This kind of double-sided tape is used to glue LED light strips while maintaining a good thermal conductivity for a polymer (2W/m.K). The drawbacks are the loss of thermal conductivity compared to thermal paste (equivalent to lower-end thermal paste) and the thicker layer of matter. On the other hand, some transfer tapes are thick and could fill gaps to ensure an optimum contact with the surface.

The Skovis DS002 UV adhesive acrylic tape is supposed to have good thermal conductivity as well as good adhesive properties and is certified from –40 to 120°C.

Thermal simulation

We did a thermal simulation of the gondola box and the flight train. The goal was to make sure that the elements will not overheat during the experiment. The program used was Fusion 360.

For both boxes, we implemented the worst-case scenario, in which the air was the hotter. For the upper box, we considered an external temperature of -40°C. For the gondola box, we considered the same external temperature and an internal temperature of 0°C. ~~In both cases, the results of the simulation were that none of the components will get overheated during the experiment.~~ In the case of the flight train box, there are no risk of overheating. But for the gondola box, the beagle bone black is overheating.

However, the simulation we did does not properly simulate the air in the boxes. In our simulation, the air has an infinite thermal conductivity, therefore the only way to transfer energy between components is by conduction. To analyse this risk we have done a simulation with the beagle bone black alone an making him radiating with an external temperature of 0°C. In this case, we see that the beagle bone is not overheating.

Thermal control

The thermal control system should be able to maintain the temperature of the BeagleBone Black above 0 °C.

~~The heaters will be controlled proportionally if the temperature drops below a certain threshold, with a safeguard to prevent overheating. Additionally, it will be possible to control the heaters manually.~~

The heaters are controlled with a bang-bang regulator and it is possible to control them manually if necessary.

The thermal calculations for the flight train box are in the Appendix C. According to those calculations, a 5W heating power is enough to maintain the temperature inside the box well above 273K. A much lower power should be effectively used as the only part that has to be heated is the BeagleBone.

4.7 Power System

Before launch, and when the balloon is in the lower layer of the atmosphere, active heating will be necessary: power consumption will be higher in this phase. Then, upon reaching higher altitudes heaters will scarcely be used. Finally, the experiment will be shut down shortly after landing.

The gondola box relies on the gondola power supply, namely a pack of 8 Saft LSH20 lithium batteries in series, providing a total 104 Wh.

The upper box relies on an 6S1P battery made of Saft LSH20 [5] cells. The nominal 102 Wh capacity (20 °C, 20 mA) of the battery makes the experiment able to handle long pre-flight phase (up to 3h) at low temperature (-20 °C).

Table 4.71 and 4.73 show the estimated power budget of the experiment, providing details about main components' consumption, without considering heating, which is displayed in Tables 4.72 and 4.74. The total energy consumption of both boxes is summed up in table 4.75.

Component	**Voltage (V)**	**Current (A)**	**Power (W)**	**Energy (Wh)**
BeagleBone Black	5	0.4	2	12
Ultrasonic anemometer	12	0.0035	0.042	0.252
GPS	3.3	0.02	0.06	0.36
IMU	3.3	0.004	0.013	0.078
Barometer	6	0.001	0.008	0.048
		Total	2.081	12.7

Table 4.71: Gondola box power consumption except for heating

Phase	**Voltage (V)**	**Duration (h)**	**Avg. current (A)**	**Avg. power (W)**	**Energy (Wh)**
Pre-launch	28	1	0.5	5	5
Ascent		1.5	0.25	2.5	4
Float		3	0	0	0
Descent		0.6	0.25	7	2
				Total	11

Table 4.72: Gondola box heating power consumption

Component	**Voltage (V)**	**Current (A)**	**Power (W)**	**Energy (Wh)**
BeagleBone Black	5	0.4	2	12
IMU	3.3	0.004	0.013	0.078
Barometer	6	0.001	0.008	0.048
		Total	2.1	12.1

Table 4.73: Upper box power consumption except for heating

Phase	**Voltage (V)**	**Duration (h)**	**Avg. current (A)**	**Avg. power (W)**	**Energy (Wh)**
Pre-launch	28.8	1	0.63	5	5
Ascent		1.5	0.31	2.5	4
Float		2.5	0	0	0
Descent		0.6	0.31	2.5	2
				Total	11

Table 4.74: Upper box heating power consumption

	Max input current (A)	Total consumption (Wh)
Gondola box	1	78
Upper box	0.7	47.3

Table 4.75: Summary of experiment consumption

The different components need different input tensions, provided by different DC-DC regulators. They are summed up in Table 4.76.

	Input (V)	Output (V)	Power (W)
Gondola box	28.8	5	2
		6	0.0078
		28	21
Upper box	21.6	5	2

		6	0.0078
		28	12

Table 4.76: The different tensions levels

The other components (IMU, GPS, and SD card) are directly plugged in the Robotic Cape of the BeagleBone Black card and hence powered by it.

4.8 Software Design

The software of the DESTINY experiment is divided into two parts: the ground client, and the embedded software which acts as a server. The experiment is driven by two BeagleBone Black boards, one in each of the boxes B1 and B2, running an embedded Linux distribution. They operate sensors, store measurements and manage the internal temperature. They communicate with the ground client which consists in a GUI displaying monitoring information and allowing the DESTINY team to send commands to the experiment, while storing received measurement locally.

4.8.1 Experiment phases

Depending on the current phase, the embedded software behaves differently. The experiment starts in *pre-launch* mode and goes to another mode either after a command from the ground client or after a timeout event. The different operating modes are listed in Table 4.81.

Mode	Description
Initialisation	Communication with the ground client is initiated. The TMS is initiated. Sensors are started, configured and calibrated. Only housekeeping sensors are polled. Housekeeping data is stored and transmitted to the ground client.
Acquisition	All measurements are made at their nominal rate. Measurements are stored and transmitted to the ground client.
Secure	Measurements are made at their nominal rate. Measurements are not stored, but they are transmitted to the ground client.
Shut down	All subsystems are shut down.

Table 4.81: Experiment phases

4.8.2 Thermal management system

Besides the main experiment modes, the TMS has two different operating modes. In *automatic TMS mode*, which is the nominal operating mode, the heaters are controlled with bang-bang regulator. It means that if the temperature of the battery/the BBB drops some degrees below a control temperature, the heaters will function at maximum power. Conversely, if the temperature rises some degrees over the control temperature, the heaters will stop. There is in total 3 regulators (one for each BBB and one for the battery) calibrated against the temperature of the component it is meant to heat (the BBB or the battery). They use the internal temperature measurements provided by the integrated components embedded sensors as well as specific thermometers. In *manual TMS mode*, which is only activated upon failure of the automatic mode, either due to inadequate settings or to temperature sensors errors, the TMS sets the heaters power according to commands from the ground client.

Automatic TMS mode	Heaters are controlled automatically using internal temperature measurements
Manual TMS mode	Heaters are controlled by commands from the ground client

Table 4.82: TMS operating modes

4.8.3 Data handling

Once measurements are gathered from sensors, they are stored on two flash memory devices (the BeagleBone Black 4 GB eMMC onboard storage, and an external microSD 16 GB card). Then, they are sent to the ground client through the E-Link interface, in raw values. According to Table 4.83.1 and 4.83.2, the total bitrate is 150 kbit/s for the whole experiment, and the total amount of stored data is 3.90 Gbit. This is an upper bound value assuming 7 hours of measurements. Then, data is sent to the ground station through UDP, using Protocol Buffers as application layer protocol. This induces an 85 % efficiency of transmission, so the whole experiment E-Link use will be 173 kbit/s. This value may be subject to changes. Indeed, if needed, only part of the measurements could be sent to the ground client, reducing the E-Link bitrate.

Sensor	**Rate (Hz)**	**Size (bit)**	**Bitrate**	**Total storage**
IMU	400	138	55.2 kbit/s	1.4 Gbit
Fibre Optic Gyrometer	400	32	12.8 kbit/s	0.32 Gbit

Barometer	200	32	12.8 kbit/s	0.32 Gbit
GPS	1	48	48 bit/s	1.21 Mbit
Anemometer	20	28	560 bit/s	14.1 Mbit
Temperature Sensors	0.1	32	3.2 bit/s	80 kbit
Monitoring Data	1	160	160 bit/s	4 Mbit
		Total	82 kbit/s	2.18 Gbit

Table 4.83.1: Data rates of the gondola box

Sensor	**Rate (Hz)**	**Size (bit)**	**Bitrate**	**Total storage**
IMU	400	138	55.2 kbit/s	1.4 Gbit
Barometer	200	32	12.8 kbit/s	0.32 Gbit
Temperature Sensors	0.1	32	3.2 bit/s	80 kbit
Monitoring Data	1	160	160 bit/s	4 Mbit
		Total	68 kbit/s	1.72 Gbit

Table 4.83.2: Data rates of the upper box

4.8.4 Commands handling

Each BeagleBone Black runs a TCP server listening for commands from the ground client. These commands are of two types, *General mode commands* and *TMS mode commands*, see Table 4.84 for their list.

Additionally, to mitigate a potential failure of the TCP server, the BeagleBone Black can be accessed with SSH.

	Command	**0**
General mode	`ACK`	Reset the TCP watchdog timer. Used as an acknowledgement signal.

commands	`INIT`	Put the experiment in Initialisation mode. Used in case a reinitialization of the devices is needed.
	`ACQUIRE`	Put the experiment in Acquisition mode. Used shortly before take-off, or after a successful reinitialization.
	`TAKEOFF`	Starts the secure mode and shut down timers. Sent during take-off.
	`CUTOFF`	Updates the secure mode and shut down timers with new values. Sent during cut off.
	`TOSECURE`	Put the experiment in Secure mode. Used shortly before reaching the ground.
	`SHUTDOWN`	Shut down the experiment. Used if the experiment did not shut down after landing.
TMS mode commands	`TOMANUAL`	Put the TMS to manual mode. Used in case the internal temperature goes out of its safe range
	`SETHEATER H P`	Set the power of the heater H to P. Used if the TMS is in manual mode, has no effect if it is in automatic mode.
	`TOAUTO`	Put the TMS to automatic mode. Used after ToManual has been sent, if the DESTINY team think that the automatic mode is more appropriate.

Table 4.84: Ground client commands

4.8.5 Safety measures

To recover measurements in case of a loss of E-Link connexion and stored data corruption, the data storage system uses redundancy. Each box duplicates measurements on an internal flash memory and on an external SD card. In addition, data storage is stopped shortly before landing, which mitigates the risk of data corruption due to erroneous inputs from a BeagleBone Black.

To mitigate the risk of a failure of the TCP server listening for commands from the ground, a watchdog timer is used to trigger the establishment of a new connection with the ground station. It is reset by every incoming command from the ground, including the `ACK` command which is periodically sent from the ground station.

In case of an extended loss of E-Link connection with the ground, the DESTINY team is not able to change the operating mode of the experiment. This could lead to data loss if, for example, the experiment is partially damaged during landing and corrupts stored measurements while trying to access an SD card. To prevent this, timers are used to automatically switch the experiment to secure mode or shut it down.

4.8.6 Time correlation

Data acquisition must be precisely timed, which is done in post-treatment using time correlation. The GPS is used as time reference, both boxes polling their respective GPS receiver. For details about the sensitivity of the system to time measurement, see Additional Technical Information.

4.8.7 Implementation details

The control software is written in C++, with a purely object-oriented approach.

Each sensor is represented by an implementation of a **Sensor** interface. Then, a **SensorManager** object gathers all the measurements at their corresponding rates and transmits them to different implementations of the abstract **DataSender** class. Those are of two types: **LocalLogger** is in charge of saving measurements onboard, on the persistent memory, and **UDPDataSende**r can send measurements through the network using UDP.

The commands are processed by a **CommandsHandler** object which is subscribed to a TCPServer object, parsing its packets.

Finally, each heater is controlled by a **Heater** object, which is subscribed to a set of **TemperatureSensor** objects used for the pseudo proportional loop.

4.9 Ground Support Equipment

The ground segment consists of a computer running a client developed to interact with the flying part of the experiment. Although the experiment is designed to be able to operate fully autonomously, its nominal operation mode implies the sporadic reception of commands from the ground station and telemetry sending. The ground client thus has the following functionalities:

- To receive telemetry through E-Link and store it locally.
- To allow the DESTINY team to send commands to the experiment through E-Link.t
- To display the experiment measurements to allow the DESTINY team to monitor the internal state of the system.

It is implemented using Python with the PyQt binding of the Qt library for the GUI.

During the mission preparation, a power supply like the power supply provided by BEXUS is required to conduct tests.

5 EXPERIMENT VERIFICATION AND TESTING

5.1 Verification Matrix

The four verification methods are:

- Verification by test (T)
- Verification by inspection (I)
- Verification by analysis (A) or similarity (S)
- Verification by review-of-design(R)

ID	Requirement text	Method	Reference	Status	Verification Result
P1	The pressure resolution shall be 0.01 Pa	R	Review of design 1.1	Done	0.014 Pa: the calibration of the barometer prevents us from reaching the requirement
P2	The pressure measurement frequency shall be 200 Hz	T	Test 1	Done	180Hz: the calibration of the barometer prevents us from reaching the requirement
P3	The experiment shall be able to measure pressure in the range of 700 Pa to 1 atm (100 000 Pa).	R	Review of design 1.2	Done	
P4	Incoming waves direction should be known with a 20° margin of error.	R, A	Review of design 2.1 ~~Analysis 1.1~~	Done	We had 5° margin of error
P5	Position measurements shall be made with an accuracy of ±5 m	R	Review of design 2.2	Done	

P6	The position of the gondola measurement rate shall be 1 Hz	T	Test 2	Done	
P7	The relative position of the boxes measurement rate shall be 50 Hz.	T	Review of design 2.3 ~~Analysis 1.2~~	Done	
P8	The relative position of the boxes shall be known with an accuracy of 5° relatively to the vertical axis.	R, A	Review of design 2.4 ~~Analysis 1.3~~	Done	
P9	The attitude of the boxes shall be known within ± 10 °	T	Test 3	Not done	
P10	The attitude measurement rate shall be 50 Hz.	T	Test 4	Done	
P11	The experiment shall be able to measure external temperatures from -80 °C to 50 °C	R	Review of design 3.1	Done	
P12	The external temperature measurement rate shall be 0.1 Hz.	T	Test 5	Done	Final frequency: 1 Hz
P13	The external temperature shall be known with a ±1 °C margin of error	T, R	Review of design 3.2	Done	
P14	The wind speed measurement rate should be 2 Hz.	T	Test 6	Done	Final frequency: 1Hz
P15	The generated	A	Analysis 1	Not done	

	infrasound waves shall have an amplitude of 0.1 Pa when they reach the experiment.				
P16	All measurements shall be made with the same time reference.	T		Not Done	Done during data processing
D1 D12 D13	The experiment shall operate in the temperature profile of the BEXUS vehicle flight and launch The internal temperature shall be kept in the range 0°C - 60°C	A, T	Test 7.1 Test 7.2 Test 7.3 Test 7.4 Test 7.5 Test 7.6 Analysis 2	Done	
D2 D10 D11	The experiment shall operate in the vibration profile of the BEXUS vehicle flight and launch The experiment shall handle vertical acceleration of 10 g, horizontal acceleration of 5 g	A	Analysis 3 Test 8.1, 8.2, 8.3, 8.4	Done	
D3	The experiment shall not disturb or harm the launch vehicle	I	Inspection 1	Done	
D4	The experiment batteries shall be qualified for use on a BEXUS balloon	R	Review of design 4.1	Done	
D5	The experiment batteries shall either be rechargeable or shall have sufficient capacity to run the	R, A	Review of design 4.2	Done	A second battery will be used during pre-flight tests

	experiment during pre-flight tests, flight preparation and flight.				
D6	The batteries in the gondola-mounted experiment shall be accessible from the outside within 1 minute	T	Test 9	Done	
D7	The printed inlets should reduce the noise and should not distort the signal	T	Test 10 Test 16	Done	
D8	The data transmission between the two boxes shall not suffer from the length of the cable.	T	Test 12	Done	
D9	The distance between the two boxes should be at least 25 m.	I	Inspection	Done	The final distance was 33m
D14	The gondola box shall be attached to the bottom gondola mounting rails	R	Review of design 5.1	Done	ok
D15	The upper box shall be attached to the flight train thanks to the fixations provided by Esrange	R	Review of design 5.2	Done	ok
D16	The mass of the gondola box should not exceed 6 kg.	R	Review of design 5.3	Done	ok
D17	The mass of the box attached to the flight train shall not exceed 5 kg	R, T	Review of design 5.4 Test 13	ROD Done Test done	GB: 5.1 kg FTB: 5.92 kg

D18	The mass of the cable between the two boxes shall not exceed 8 kg	R	Review of design 5.5	Done	ok
D19	The team shall be able to start and stop data acquisition from the ground station.	T	Test 14.1	Done	
D21	The experiment should be able to reset without external intervention in case of loss of control.	T	Test 14.2	Done	
D22	The telemetry bandwidth shall not exceed 200 kb/s.	R, T	Review of design 6.1 Test 14.3	R done T done	R6.1 OK (cf tables 4.83.1 and 4.83.2) T14.3 OK
D23	The experiment shall operate in the pressure profile of the BEXUS flight	T	Test 15.1, 15.2	Done	
O1	The DESTINY team shall be able to send commands from the ground station to the experiment from start-up to its shutdown.	R, T	Review of design 6.2 Test 14.4	Done	
O2	The DESTINY team shall be able to select between an autonomous and a manual thermal management system from the ground station.	R, T	Review of design 6.3 Test 14.5	Done	
O3	The experiment shall enter a secure mode before	R, T	Review of design 6.4	Done	

	landing.		Test 14.5		

5.2 Verification Plan

Test number	Test 1
Test type	Payload, pressure tests
Test facility	*École Polytechnique*'s lab, vacuum chamber
Tested item	The barometer
Model	Flight model
Procedure, Test level and duration	Objective: to check the frequency of the barometer Test level: qualification
Test campaign duration	1 afternoon
Test campaign date	September 2019
Test completed	Yes: final frequency 180Hz Precision: 0.014 Pa
Requirements verified	P1, P2, P3

Test number	Test 2
Test type	Payload
Test facility	*École Polytechnique*
Tested item	The GPS
Model	Flight model
Procedure, Test level and duration	Objective: To check that the position of the gondola measurement rate shall be 1 Hz. Procedure: Use a chronometer to measure the frequency of the measurements made by the GPS.
Test campaign duration	1 afternoon
Test campaign date	September 2019
Test completed	Yes: final frequency: 1Hz
Requirements verified	P6

Test number	Test 3
Test type	Payload
Test facility	*École Polytechnique*
Tested item	Inertial navigation
Model	Flight model
Procedure, Test level and duration	Objective: To check that the attitude of the boxes shall be known within ± 10 ° Procedure: Suspend each of the beagle bones inside a box, jolt the box and see the results given by the inertial navigation system.
Test campaign duration	1 day
Test campaign date	September 2019
Test completed	No
Requirements verified	P9

Test number	Test 4
Test type	Payload
Test facility	*École Polytechnique*
Tested item	Inertial navigation
Model	Flight model
Procedure, Test level and duration	Objective: To check that the attitude measurement rate shall be 50 Hz. Procedure: Use a chronometer to measure the frequency of the attitude measurements made by the inertial navigation.
Test campaign duration	1 day
Test campaign date	September 2019
Test completed	Even if we don’t already have the treatment process of the measures, as the frequency of the inertial navigation is up to three times the requirement, the attitude measurement rate will be reached.
Requirements verified	P10

Test number	Test 5
Test type	Payload
Test facility	*École Polytechnique*
Tested item	Thermometer
Model	Flight model
Procedure, Test level and duration	<u>Objective:</u> To check that the external temperature measurement rate shall be 0.1 Hz. <u>Procedure:</u> Use a chronometer to measure the frequency of the temperature measurements made by the thermometers.
Test campaign duration	1 afternoon
Test campaign date	September 2019
Test completed	Yes: final frequency 1Hz
Requirements verified	P12

Test number	Test 6
Test type	Payload
Test facility	*École Polytechnique*
Tested item	Anemometer
Model	Flight model
Procedure, Test level and duration	<u>Objective:</u> To check that the wind speed measurement rate should be 2 Hz. <u>Procedure:</u> Use a chronometer to measure the frequency of the wind speed measurements made by the anemometer.
Test campaign duration	1 afternoon
Test campaign date	September 2019
Test completed	Yes
Requirements verified	P14

Test number	Test 7.1
Test type	Thermal
Test facility	*CNES (Toulouse)*
Tested item	The 2 boxes
Model	Flight model
Procedure, Test level and duration	Low temperature insulation tests. Accommodation: cold chamber (which can reach -70°C) Procedure: progressively reduce the temperature of the cold chamber, check that the temperature control system of the box works Level: flight for the gondola box, qualification for the upper box
Test campaign duration	1 day
Test campaign date	September 2019
Test completed	Yes: the test has been completed using CNES facilities in Toulouse.
Requirements verified	D1

Test number	Test 7.2
Test type	Thermal
Test facility	*École Polytechnique*
Tested item	BeagleBone Black
Model	Flight model
Procedure, Test level and duration	Test the operation of the BeagleBone Black at low temperature Accomodation: cold chamber (which can reach -50°C) Procedure: progressively reduce the temperature of the cold chamber, from 22°C to -50°C. The BeagleBone sends temperature data each second. We test the different connexions and functions. Level: qualification model
Test campaign duration	1 day
Test campaign date	March
Test completed	Yes

Requirements verified	D1

Test number	Test 7.3
Test type	Thermal
Test facility	*École Polytechnique*'s lab, cold chamber
Tested item	Pressure port (Inlet)
Model	Qualification model
Procedure, Test level and duration	Objective: To check that the inlets can endure the temperature encountered during the flight Procedure: Cold chamber test
Test campaign duration	1 day
Test campaign date	September 2019
Test completed	Yes
Requirements verified	D1, D12, D13

Test number	Test 7.4
Test type	Thermal
Test facility	*École Polytechnique*'s lab, cold chamber
Tested item	Anemometer
Model	Qualification model
Procedure, Test level and duration	Objective: To check that the anemometer can endure the temperature encountered during the flight Procedure: Cold chamber test
Test campaign duration	1 day
Test campaign date	July 2019
Test completed	Yes
Requirements verified	D1, D12, D13

Test number	Test 7.5
Test type	Thermal
Test facility	*École Polytechnique*'s lab, cold chamber
Tested item	3D printed plastic
Model	Qualification model
Procedure, Test level and duration	Objective: To check that the 3D printed plastic can endure the temperature encountered during the flight Procedure: Cold chamber test
Test campaign duration	1 day
Test campaign date	July 2019
Test completed	Yes
Requirements verified	D1, D12, D13

Test number	Test 7.6
Test type	Thermal
Test facility	*CNES (Toulouse)*
Tested item	The 2 boxes
Model	Flight model
Procedure, Test level and duration	Vacuum test. Accomodation: cold chamber at ambient temperature Procedure: progressively reduce the pressure of the vacuum chamber, check that none of the components overheat Level: flight for the gondola box, qualification for the upper box
Test campaign duration	1 day
Test campaign date	September 2019
Test completed	Yes: the test has been completed using CNES facilities in Toulouse.
Requirements verified	D1

Test number	Test 8.1
Test type	Mechanical
Test facility	*École Polytechnique*'s lab
Tested item	Boxes and attachments
Model	Qualification model
Procedure, Test level and duration	Static load Objective: To check that the boxes and fixations can endure the flight. Procedure: Fix the boxes similarly to the balloon attachments and load them with 50 kg (lower box) and 40 kg (upper box) masses.
Test campaign duration	1 day
Test campaign date	September 2019
Test completed	Yes
Requirements verified	D2, D10, D11

Test number	Test 8.2
Test type	Mechanical
Test facility	*École Polytechnique*
Tested item	Boxes and fixation
Model	Qualification model
Procedure, Test level and duration	Dynamic test: 10 g and 3 m fall Objective: To check that the boxes and fixations can endure the flight. Procedure: Fix the boxes similarly to the balloon attachments load them with 2 kg masses and drop them from 3 to 4m high.
Test campaign duration	1 day
Test campaign date	September 2019
Test completed	Yes: instead of dropping the box with masses fastened, the masses were dropped on the boxes
Requirements verified	D2, D10, D11

Test number	Test 8.3
Test type	Mechanical
Test facility	*École Polytechnique*
Tested item	Electronics
Model	Flight model
Procedure, Test level and duration	Objective: To check that the electronics can endure the transportation and the vibration of the balloon. Procedure: Mounting on a vibrating table and driving on a bumpy road with the electronics attached to the boxes.
Test campaign duration	1 day
Test campaign date	September 2019
Test completed	Yes
Requirements verified	D2, D10, D11

Test number	Test 8.4
Test type	Mechanical
Test facility	*École Polytechnique*
Tested item	Fixation of the inlet
Model	Proto-flight model
Procedure, Test level and duration	Objective: To check that the inlet comes off during the landing without damaging the barometer Procedure: Fix the inlet to a box and drop it from 3 to 4m high
Test campaign duration	1 day
Test campaign date	September 2019
Test completed	Yes: the fixation with the screw permits the inlet to slide along it when a knock happens.
Requirements verified	D2, D10, D11

Test number	Test 9
Test type	Mechanical
Test facility	*École Polytechnique*
Tested item	Upper box
Model	Flight model
Procedure, Test level and duration	Objective: To check that the batteries in the upper box experiment shall be accessible from the outside within 1 minute Procedure: Once the upper is fully assembled, time us taking out the battery.
Test campaign duration	1 day
Test campaign date	September 2019
Test completed	Yes: a slab has a hinges system which enable an efficient access to the box.
Requirements verified	D6

Test number	Test 10
Test type	Mechanical-Acoustic
Test facility	*École Polytechnique*'s lab
Tested item	Inlet
Model	Flight model
Procedure, Test level and duration	Objective: To check the performance of the inlets Procedure: Measure the variation of pressure induced by external noise sources with a barometer equipped or not with the inlet
Test campaign duration	1 day
Test campaign date	August 2019
Test completed	Yes
Requirements verified	D7

Test number	Test 11
Test type	Mechanical
Test facility	*IASE-Supaéro's lab*
Tested item	Balloons
Model	Flight model
Procedure, Test level and duration	Objective: To check that the balloons explode at the theoretical pressure predicted and check their maximum volume. Procedure: Put a balloon filled at a precise volume into the vacuum chamber and decrease the pressure until the balloon explode. Then record the pressure.
Test campaign duration	1 day
Test campaign date	September 2019
Test completed	Yes
Requirements verified	Not linked to a requirement

Test number	Test 12
Test type	Software
Test facility	*École Polytechnique*
Tested item	Both boxes
Model	Flight model
Procedure, Test level and duration	Objective: To check that the data transmission between the two boxes shall not suffer from the length of the cable. Procedure: Link the two boxes with the 50m long ethernet cable and try sending information from one box to the other
Test campaign duration	1 day
Test campaign date	August 2019
Test completed	Yes
Requirements verified	D8

Test number	Test 13
Test type	Mechanical
Test facility	*École Polytechnique*

Tested item	Upper box
Model	Flight model
Procedure, Test level and duration	<u>Objective:</u> To check that the mass of the box attached to the flight train shall not exceed 5 kg. <u>Procedure:</u> Weigh the box fully mounted.
Test campaign duration	1 day
Test campaign date	September 2019
Test completed	Yes : the final mass exceeded 5kg
Requirements verified	D17

Test number	Test 14.1
Test type	Software
Test facility	*École Polytechnique*
Tested item	Software
Model	Flight model
Procedure, Test level and duration	<u>Objective:</u> To check that the team shall be able to start and stop data acquisition from the ground station.
Test campaign duration	1 day
Test campaign date	September 2019
Test completed	Yes
Requirements verified	D19

Test number	Test 14.2
Test type	Software
Test facility	*École Polytechnique*
Tested item	Software
Model	Flight model
Procedure, Test level and duration	<u>Objective:</u> To check that the experiment should be able to reset without external intervention in case of loss of control.
Test campaign duration	1 day

Test campaign date	September 2019
Test completed	Yes
Requirements verified	D21

Test number	14.3
Test type	Operational
Test facility	*École Polytechnique*
Tested item	Embedded software
Model	Flight Model
Procedure, Test level and duration	Objective: To check that the experiment doesn't use too much bandwidth. Procedure: Start the experiment in flight-like operating mode. Measure the bandwidth from a connected external computer.
Test campaign duration	1 day
Test campaign date	September 2019
Test completed	Yes: we should not exceed 175kb/s; we have 45kb/s for each box.
Requirements verified	O3

Test number	14.4
Test type	Operational
Test facility	*École Polytechnique*
Tested item	Ground client, embedded software
Model	Flight Model
Procedure, Test level and duration	Objective: To check that the operating team can send commands to the experiment, and that it responds adequately.

	Procedure: Send all expected commands to both boxes, they should respond adequately. Send unexpected commands, they should be discarded.
Test campaign duration	1 day
Test campaign date	September 2019
Test completed	Yes: the interface is designed to return an error message when the command is inadequate.
Requirements verified	O1

Test number	14.5
Test type	Operational
Test facility	*CNES (Toulouse)*
Tested item	Embedded software
Model	Flight Model
Procedure, Test level and duration	Objective: To check that the experiment can operate fully autonomously, switching into secure mode in time. Procedure: Start the experiment for its nominal duration. Check afterward its timeline is correct.
Test campaign duration	1 day
Test campaign date	September 2019
Test completed	Yes
Requirements verified	O2, O3

Test number	Test 15.1
Test type	Vacuum test
Test facility	*École Polytechnique*'s lab, vacuum chamber
Tested item	The 2 whole boxes
Model	Flight model for the gondola box, qualification model for the upper box
Procedure, Test level and duration	Low pressure conditions

	Procedure: Vacuum chamber test to ensure the electrical circuit does not overheat Level: qualification for the upper box, flight for the gondola box.
Test campaign duration	1 day
Test campaign date	September 2019
Test completed	Yes
Requirements verified	D23

Test number	Test 15.2
Test type	Mechanical
Test facility	*École Polytechnique / CNES (Toulouse)*
Tested item	Inlet
Model	Flight model
Procedure, Test level and duration	Objective: To check that the inlets can endure the pressure encountered during the flight Procedure: Vacuum chamber test Flight level
Test campaign duration	1 day
Test campaign date	September 2019
Test completed	Yes
Requirements verified	D23

Test number	Analysis 1
Test type	Physics
Test facility	*École Polytechnique*
Tested item	
Model	
Procedure, Test level and duration	Objective: to check which infrasound sources will be powerful enough to be detected when they reach the gondola

	<u>Procedure</u>: computer simulation of the path of the incoming waves and the decrease of their amplitude with altitude
Test campaign duration	First meaningful results should be obtained by February, but the simulation will be improved until April.
Test campaign date	January-April
Test completed	Yes
Requirements verified	P15

Test number	Analysis 2
Test type	Thermal
Test facility	*École Polytechnique / CNES (Toulouse)*
Tested item	The whole system
Model	Flight model
Procedure, Test level and duration	Low pressure conditions <u>Procedure:</u> Simulations on Fusion 360 to predict the thermal behaviour of the experiment Level: flight for the gondola box, qualification for the upper box
Test campaign duration	1 week
Test campaign date	September
Test completed	Yes
Requirements verified	D1, D12, D13

Test number	Analysis 3
Test type	Mechanical analysis
Test facility	*École Polytechnique*
Tested item	Boxes and fixations
Model	Flight model
Procedure, Test level and duration	<u>Objective:</u> To make sure the device can endure the flight. <u>Procedure</u>: Simulation of the flight and the landing.
Test campaign duration	1 month

Test campaign date	March
Test completed	Yes
Requirements verified	D2, D10, D11

Test number	Test 16
Test type	Mechanical/data analysis
Test facility	*École Polytechnique*
Tested item	Inlets, bottom of the boxes
Model	Flight model
Procedure, Test level and duration	Objective: To make sure the inlets have the same behaviour and can reduce the noise due to the wind during the flight. Procedure: Take only the bottom of the two boxes next to each other (cf photo) with the electronical system and the barometer ready to acquire. Tests of acquisition of pressure data: • Drop of a heavy object on the ground with and without inlets • Door slammed with and without inlets • Exposure to the same wind for 30 seconds while repeating the previous steps
Test campaign duration	1 day
Test campaign date	September
Test completed	Yes
Requirements verified	D7

5.3 Verification Results

5.3.1 Thermal tests and verification

Test 7.1

Test 7.1.0:

Objective: Check that the temperature control system (heatsink) of the boxes work.

Procedure: A first test has been conducted at Ecole polytechnique in order to have a first idea of how the heatsinks work and regulate the system. We used a cold chamber in which we placed each box, then we brought the enclosure to -30°C and waited 10 minutes for the boxes to reach this temperature. Then we activated the heaters fixed on each BeagleBone and let them work for 20 minutes, which permitted to follow the evolution of the system.

Results: The results were conclusive but needed to be done in conditions more extreme: low pressure and a temperature of -70°C

Test 7.1.1:

Objective: Test of the barometer + analysis of the behaviour of the experiment under conditions of low temperature and pressure.

Thermal environment:

Time(h)	Temperature(°C)	Pressure(mBar)	Indications
10h22	20	1000	/
11h08	-15	0.005	/
12h30	-15	0.005	Return to ambiant condition

Results:

The test showed that the variation of the temperature of the components goes slowly. We can deduct from these data the thermal constants of the various components.

Test 7.1.2:

Objective: Simulate the launch of the experiment à Esrange and check if none of the components are too cold.

Thermal environment:

Time	Temperature(°C)	Pressure(mBar)	Indications
15h06	20	1000	/
16h04	-70	500	/
16h20	-70	100	/
16h38	-70	100	Return to ambient conditions

Result: Our heaters can stabilise the temperature of our electricals components at a constant temperature of -20°C approximatively when the temperature inside the cold chamber reaches -70°C and the pressure reaches 100mBar. Under these conditions, the components are functioning. The temperature of the battery was maintained above -5°C during the experiment.

Test 7.2

Thermal test for the BeagleBone Black (BBB) without any protection or regulation system.

Objective: To test the lowest limit of temperature for the different functions and connexions of the BBB.

Temperature: From 22°C to -50°C.

Result: The BBB sends the temperature.

Test 7.4

Thermal test for the anemometer without any protection or regulation system

Objective: To check that the anemometer still functions in temperatures between 20° and - 40°C.

Procedure: We put the anemometer, a small ventilator and the Beagle Bone in a cold chamber and gradually brought the temperature down to - 40°C.

Result: The anemometer can stand the temperatures of the experiment.

Test 7.5

Thermal test for the 3D printed plastic used in several of the components without any protection or regulation system.

Objective: To check that the 3D printed plastic doesn't become friable under temperatures between 20° and - 40°C.

Result: The 3D printed plastic showed no sign of becoming more fragile in extreme temperatures.

Test 7.6:

Objective: Put the chamber at vacuum condition to verify that none of the components will overheat during the flight.

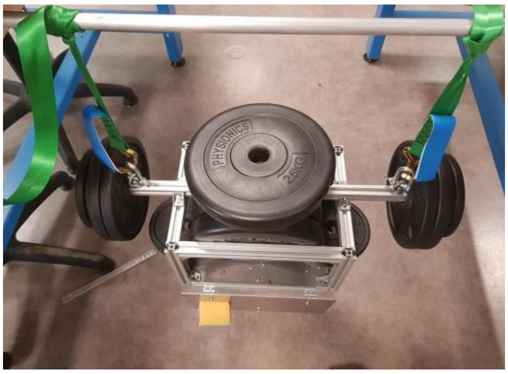
Thermal environment:

Time(min)	Temperature(°C)	Pressure(mBar)	Indications
8h49	20	1000	/
8h58	20	10	/
11h33	20	10	Return to ambient conditions

Results: None of the electricals components overheated. The maximal temperature of the component was below 40°C.

5.3.2 Mechanical tests and verification

The static and dynamic tests made confirm the resistance of the boxes:



Static tests (left: upper box; right: lower box)

5.3.3 Test campaign at CNES

From September 16th to 20th, the team went to Toulouse to conduct the final experiences where we tested the good functioning of the whole components, the interface and the general command of the boxes.

We spent the first two days at *ISAE-Supaéro* with our tutor, for him to look at the progress of the project, and for us to really be prepared in term of protocols for our experiments at the CNES.

From Wednesday to Friday, we were at the CNES centre, in Aire-sur-l'Adour, to simulate the experience in real conditions. We had access to a cold and vacuum chamber which permit to simulate different scenarios the system can encounter during the real flight. We did three experiences:

- A cold vacuum to calculate the thermal constants of the system
- The coldest scenario in which the temperature can reach -70°C
- The hottest scenario in which was a vacuum test at 5 mBar

These experiences also aimed at calibrating the thermal regulation system: the system should protect the BBB from reaching -70°C, but shouldn't heat up too much the experience under the hottest scenario.

We also put a loudspeaker in the thermal chamber to see how the barometer is functioning at low temperature.

6 LAUNCH CAMPAIGN PREPARATION

6.1 Input for the Campaign / Flight Requirement Plans

The DESTINY experiment is composed of two boxes: one inside the gondola, attached to the bottom, and the other one attached to the flight train 30m above the gondola. The two boxes are linked by an Ethernet cable.

Two inlets come out of the boxes; they are pointing to the ground. It is very important that the bottom inlet does not touch the ground before the launch. When the gondola is stored, moved in a trolley or in the launch vehicle, it shall be elevated enough so that the inlet does not touch the ground.

Finally, four balloons of different volumes will be attached to the flight train in order to provide sources of infrasound during the ascent. They will explode at different times during the ascent. More information on the scientific background can be found in Annex F.

6.1.1 Dimensions and Mass

	Upper box	Lower box (in the gondola)	Cable linking the boxes	Total
Experiment mass (in kg):	5.92	5.10	1,5	12.52
Experiment dimensions or module size	0.32x0.35x 0.27	0.35x0.45x 0.225	3 m	
Experiment expected COG (centre of gravity) position:	0.1x0.125 (m) From the corner of the upper box	0.25x0.08 (m) From the corner of the gondola	X	X

Table 6.11: Experiment mass and volume

6.1.2 Safety Risks

Risk	Key Characteristics	Mitigation
The inlets break away	Dimensions: 20 cm long pole	Safe attachment, tests

	Mass: 0.2 kg	
The upper box breaks away	Dimensions : 0.3x0.35x0.27 Mass : 5.92 kg	Safe attachment (reinforced) Backup strap and shackles.
Flight of a lithium-ion battery	Type: LSH 20 (Li-SOCl2) Total Capacity: 13Ah	Specific compartment in order to separate and stabilize the battery

Table 6.12: Experiment safety risks

6.1.3 Electrical Interfaces

The two Ethernet sockets used to connect the experiment to the E-Link module are located on the gondola box, requiring only two cables going from the E-Link module to the gondola with Amphenol RJF6B Ethernet connector.

BEXUS Electrical Interfaces		
E-Link Interface: E-Link required? Yes		
	Number of E-Link interfaces:	2
	Number of required IP addresses:	2
	Data rate – downlink (max. and average):	170 Kbit/s max. and average
	Data rate – uplink (max. and average):	0.5 Kbit/s max. and 0 bit/s average
	Interface type (RS-232, Ethernet):	Ethernet
Power system: Gondola power required? Yes		
	Peak power and current consumption:	15 W and 0.5 A
	Average power and current consumption:	8 W and 0.3 A
	Total power and current consumption after lift-off	50 Wh and 1.7 Ah
Power system: Experiment includes batteries? Yes		
	Type of batteries:	Li-$SOCl_2$ battery
	Number of batteries (and S x P):	6S
	Capacity (1 battery):	13.0 Ah

	Voltage (1 battery):	3.6 V

Table 6.13: Electrical interfaces applicable to BEXUS

6.1.4 Launch Site Requirements

We will need:

In Ground Station:

- An oscilloscope
- Multimeters
- Two power plugs, two multiplugs
- Office accommodation (tables and chairs)
- A toolbox
- Two power supplies able to output up to 30 V @ 1.5 A (to power our boxes during tests)

On the launch pad:

- A mattress to cushion the FTB during launch
- An external source of power on the launch pad for the FTB just before launch

6.1.5 Flight Requirements

A. The floating phase should last at least two hours in order to make sure we will record enough useful measures.
B. To cushion the Flight Train Box and especially the inlet during launch, we would need a mattress to be placed below the flight train were the FTB will be. The mattress can be placed the day before launch.
C. The team needs late access (1 hours before launch) to the flight train to attach the Flight Train Box and the 4 balloons. The placement of the balloons will have been previously marked out on the flight train (on day 2).
D. The thermal regulation system needs to be on while the FTB is outside waiting for launch, we will therefore need to use an external source of power for up to 20 minutes before launch, to avoid using our flight battery. 20 minutes before launch, the launch team will remove the external source of power and move the power switch to I (Internal). From Ground Station, the DESTINY team will confirm that the experiment is still running following the switch to internal power, before the launch team leaves the pad, we will therefore need to communicate with the launch team.

The external source of power we plan on using is another lithium battery that we used during our tests, along with any external source of power that could be provided at ESRANGE (> 21,6 V).

6.1.6 Accommodation Requirements

We will have to attach the upper box to the flight train so that the Flight Train Box can be easily accessible. The box will be attached 33m above the top of the gondola. We also wish to cushion the Flight Train Box by installing a blow-up mattress under the Flight Train Box for take-off.

6.2 Preparation and Test Activities at Esrange

Time/Day	Main Task	Responsible	Duration [h:m]	Comments
1	Unpack the experiment	Mechanical	3h	
	Set up ground station	Software	1h	
	Functional tests	Software	4h	Workbench tests to ensure the proper operation of sensors
2	E-Link communication test	Software	1h	
	Thermal tests	Thermal	2h	
	Mechanical compatibility test	Mechanical	2h	Ensure the flight train box, the balloons and the Ethernet cable can be properly attached to the flight train. Mark out the placement of the balloons on the flight train.
3	Gondola box setup	Mechanical	1h	
	Characterise acoustic signature of other experiments	Payload	2h	

Flight day	Flight train box setup	Mechanical	1h	
	Balloons attachment	Mechanical	1h	

The tests of the first day consist in the verification of the good state of all the equipment after traveling. The first thing to do is the settlement of the ground station which will then permit to control all the acquisitions. A table with power plugs and power supplies will be necessary (see 6.1.4)

When the ground station is settled, we will test the smooth operation of the components:

- The two boxes and the inlets: check their physical integrity after travelling.
- Electronics components: power the assembled boxes using the power supply and check their nominal behaviour.

During the second day the integration of the experiment into its environment is checked. First the E-link connection is verified, and the thermal management system is tested in ground conditions. Finally, the attachment mechanism of all the flight train components is checked.

The third day is used to install the gondola box in the gondola, after which the acoustic footprint of all the other experiments can be recorded. This may be delayed if other experiments need more time to be set up. The goal is to record the infrasound signals emitted during a nominal flight so that they can be removed from the signals acquired during the real flight.

Finally, all the flight train components are attached to the flight train on the flight day: the flight train box, the Ethernet cable and the balloons. Additionally, a blow-up mattress is installed to cushion the inlet during take-off.

6.3 Timeline for Countdown and Flight

Time [s]	**Signal**	**Function**
LAUNCH-1h	SETUP	Install the FTB on the flight train. Install the 4 balloons on the flight train
LAUNCH - 20m	SWITCH FLIGHT TRAIN BOX TO INTERNAL POWER	Change the power switch of the flight train box to internal and removes the external battery
LAUNCH-5m	ACQUIRE	Start data acquisition from ground control

LAUNCH	TAKEOFF	Start timer
CUT	CUTOFF	Updates timer
LANDING-20m	TOSECURE	Stops data storing
LANDING+10m	SHUTDOWN	Shutdown the experiment

Two blasts are organised in Mertainen (400 kg and 800 kg TNT equivalent) to occur just after the beginning of the floating phase and 1 hour after.

6.4 Post-Flight Activities

After the flight, the two boxes will be recovered and dismantled to prevent possible damages on the components.

The APPENDIX D describes the Flight Train Box detachment procedure.

The sensors will not be damaged and thus will be reusable. The batteries will be disposed of at ESRANGE.

The data from every sensor will be analysed and crossed according to the plan developed in part 7. In the case of the detection of an unknown signal, we will compare its occurrence to local data such as planes schedule or ground seismologic activities.

7 DATA ANALYSIS AND RESULTS

7.1 Data Analysis Plan

The data treatment must enable us to recognize and to characterize infrasound. It will have to eliminate the noise. The tasks in data treatment can be divided into two categories, which are the treatment of the inertial navigation data to reconstruct the motion of the gondola, and the treatment of the signals detected by our captors on board.

We have taken part in a similar experiment in *ISAE-Supaéro*, using the same sensors, which has yielded positive results proving the experiment concept.

7.1.1 Reconstruction of the gondola motion

In order to locate the origin of the perturbations, we studied the phase difference between the signals detected by the two barometers, as it is linked to the direction of the incoming wave. To do so, it is necessary to precisely know the absolute position and the inclination of the experiment, as well as the relative positions of the two boxes. We treated the data of the inertial unit with a Kalman filter.

A special attention needs to be paid to the study of the infrasound propagation in the stratosphere, as it is generally not in straight line. We will have to use reverse simulations to locate their origin.

We have realised a first version of the filter.

7.1.2 Pressure data

We continuously measure the external pressure to characterize the infrasound background and detect perturbations. Still, we expect very noisy signals; thus, we must recognise and eliminate this noise.

We analyse the evolution of the power spectral density function of the signal over the time in order to detect traces of specific events. To eliminate the background noise, wavelet filters were proved to be efficient in similar experiments.

We can already identify some of the noise sources, such as the wind, shocks of the gondola or other experiments. Therefore, we will cross the spectral data with the measurements of the anemometer, the inertial unit, and with other events linked to the other experiments.

We developed a simulation of infrasound propagation, which should enable us to locate the origin of a signal on a circle depending on its angle of incidence when it reaches the balloon. It considers wind, pressure variation and air density. Here are some figures computed with the simulation. We aim at perfecting this model and reversing it to find the origin of a perturbation.

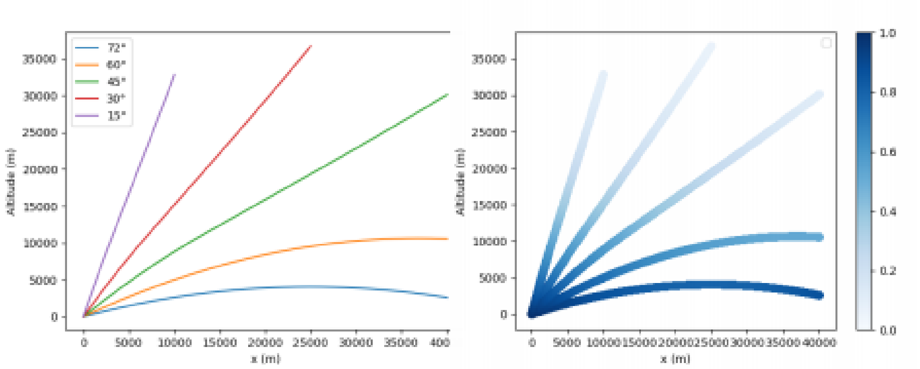


Fig 7.12.1 Bidimensional simulation of infrasound propagation, bending of the waves due to the temperature and air density profile (left) and decrease of the wave amplitude (right)

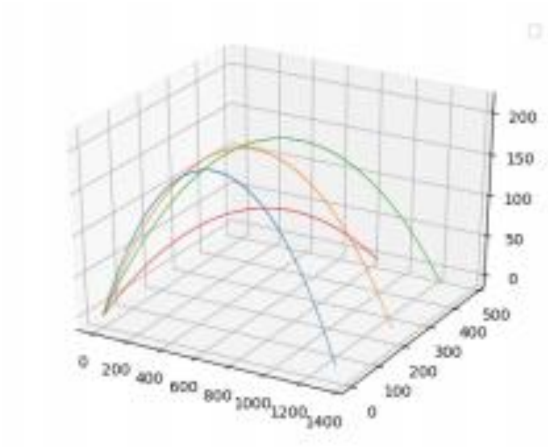


Fig 7.12.2: 3-dimensional propagation of infrasound with the influence of the wind

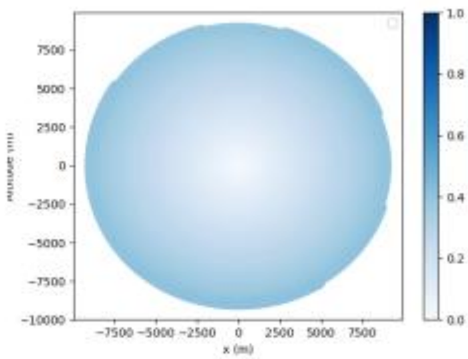


Fig 7.12.3: angle of incidence detected at 20km of altitude, for a source located at the centre of the circle

7.2 Launch Campaign

The Launch Campaign occurred from the 18th to the 28th of October 2019 and the flight happened on Friday the 25th of October. Our experiment went mostly according to plan and we collected the data we expected.

Here are a few drawbacks we were met with during the experiment:

- Due to the weather, the flight occurred early in the morning, before the time at which the LKAB company could perform the blasts. The winds also brought the balloon far from the Mertainen Mine, where the blast occurred, faster than we expected. In consequence, we could only perform one of the two initially planned blasts during the floating phase and the blast was performed with the balloon 240 km away from the Esrange launch pad, instead of less than 150 km away as we had initially planned. This might have affected the quality and the clarity of the blast data registered.
- We are missing 30 minutes of data on the FTB barometer. We do not understand what happened. Fortunately, the shutdown did not occur during the blast.

Despite these issues, we are happy with the way the experiment took place and we have collected 2h of data during the floating phase.

7.3 Data Analysis and Results

7.3.1 Pre-processing

The first step towards the analysis of our data collected during the flight was to pre-process it. During the flight, the experiment shut down a few times. Each time the experiment was turned on, the internal clock of the acquisition system of the two boxes was reset to zero, which created a loss of simultaneity between the two boxes. We needed this issue to be corrected in order to fulfil the objective SO2 of our experiment (see 1.3), which relies on precise measurements of the arrival time differences between the two boxes for a given signal. This problem was fixed with the time data provided by the two GPS we had in our experiment, one in each box. The GPS time was continuously synchronised during the experiment, so we used it as an absolute time reference issued at 1Hz to synchronise the two internal clocks which issues data at 180 Hz.

7.3.2 Preliminary data analysis

Once we collected the data and made it easily manipulable, the first step was to make preliminary analysis in order to handle the data and to check its consistency. Since we collected temperature and pressure information from the ground to an altitude of 27 km through the captors on board, our first analysis was to confirm that our data matched the atmospheric theoretical models that already exist.

Thus, we represented the temperature as a function of the altitude. The temperature of the atmosphere does not follow a precise pattern and depends a lot of climatic conditions, but an average model exists. The temperature evolves in the atmosphere according to different gradients depending of the section of the atmosphere. We can see in Figure 7.32.1 below the comparison between the empirical values of the gradients from the classical models and the value measured during the experiment.

We can see that it does not match exactly the theoretical model according to our linear regression but the behaviour remains the same: we can observe a linear diminution of the temperature in the troposphere then a stagnation in the stratosphere and finally an increase above 20km. More precisely, between 0 and 10 km of altitude we have a gradient of –5.85 °C/km against –6.5 °C/km in the literature. Between 10 and 20 km of altitude, we have a gradient of –1.1 °C/km against 0°C/km in the literature. Finally, between 20 and 27 km of altitude, we have a gradient of 4.3°C/km against 1°C/km in the literature.

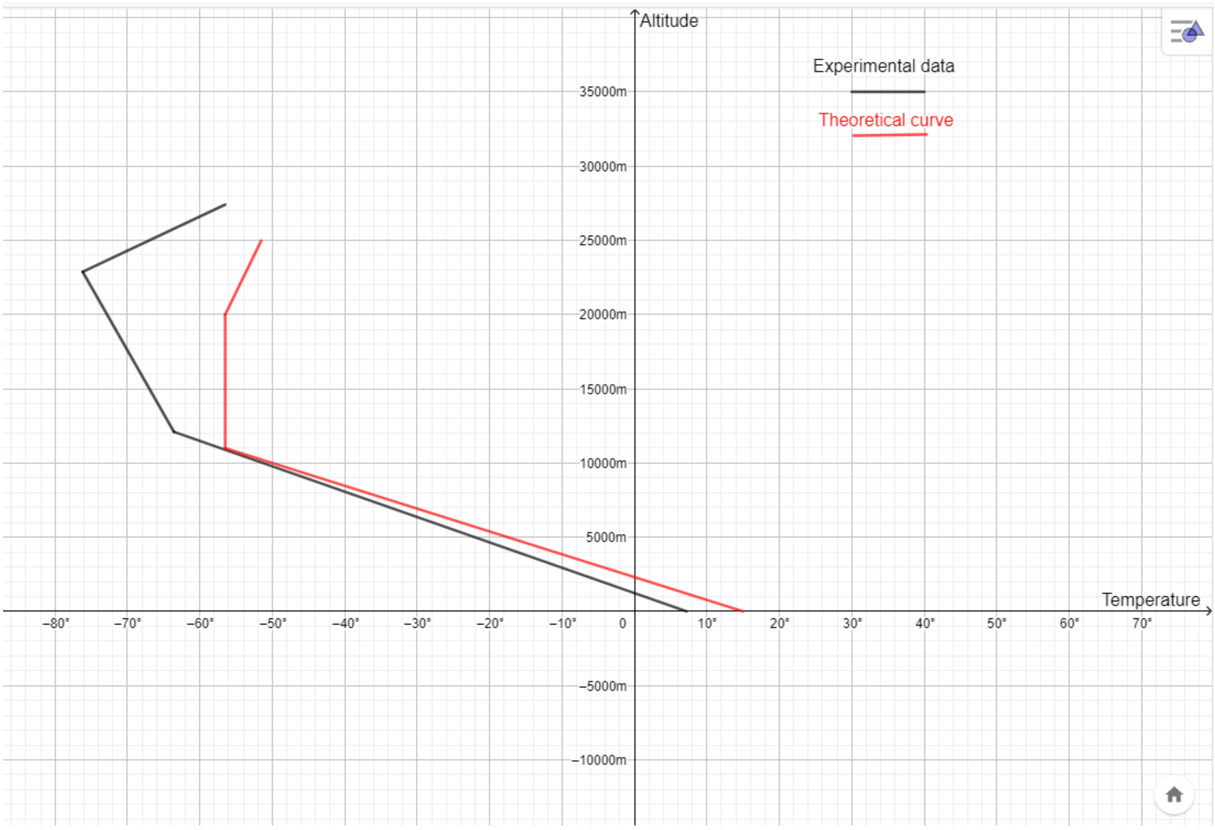


Fig 7.32.1: Vertical profile of the atmospheric pressure (Models and Measurements)

Then, the data needed to be compared with the pressure profile. In this case, the pressure can be directly related to the altitude in the troposphere (between 0 km and 10 km) with the relation:

$$p = p_0 \exp\left(-\frac{7g}{2C_pT_0}z\right)$$

Where Po=1013250 Pa, g=9.81 m/s**2, To the ground temperature (7°), and Cp=1006 J/kg/K. The coefficient in front of z the altitude is -0.00012.

By making an exponential modelling of our function pressure(time) we obtained a coefficient of correlation of 0.99975. We have indeed almost the same profile of pressure that what was expected according to the theory. Results are indicated right below.

Fitting for y = a * exp (r0 * x)

a	r0	r^2
101071.0	-1.403e-04	0.99905

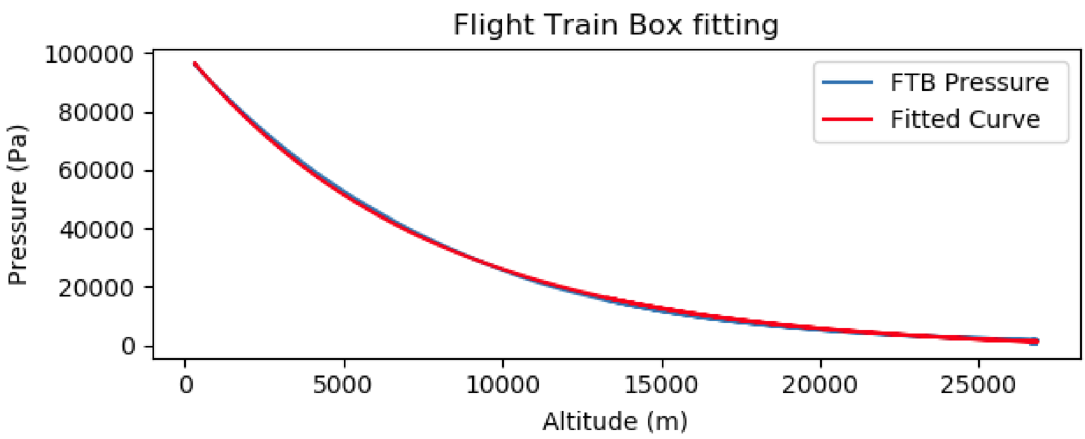


Fig 7.32.2: fitting of the pressure profile in the atmosphere measured by the FTB

Fitting for y = a * exp (r0 * x)

a	r0	r²
101021.0	-1.396e-04	0.99933

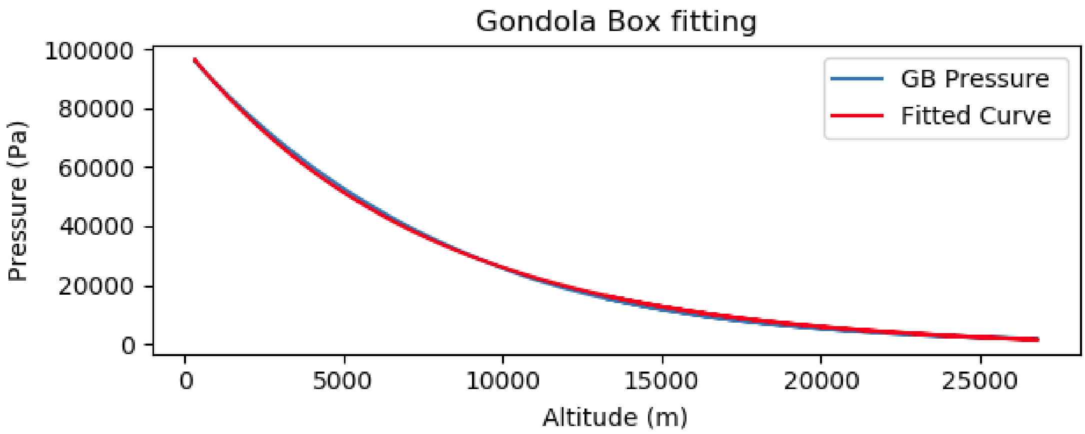


Fig 7.32.3: fitting of the pressure profile in the atmosphere measured by the GB

7.3.3 Blast analysis

The detonation occurred at 9:00 Swedish time, in Mertainen mine which is located 24km South the launching area in Esrange. Considering the delay due to the propagation of the signal in the atmosphere, we expected to detect the explosion between 9:12 am and 9:15 am approximately. The amplitude initially expected was about 0.3 Pa provided the explosion was detected with a ground distance less than 150 km from the source of the explosion. This amplitude should have been enough to clearly distinguish the shock wave from the background noise in the pressure data. Unfortunately, due to the weather conditions, the balloon was 240km away from the source at 9:12 am. Thus, the shock wave did not appear clearly in the data.

However, further analysis allowed us to identify the signal corresponding to the explosion. The signal is composed of three arrivals. The first signal, S1, is detected at 9:12:53 am (12 707s internal time), the second one, S2, is detected at 9:14:16 am (12 790 s internal time) and the third one, S3, is detected at 9:14:46 am (12 820 s internal time).

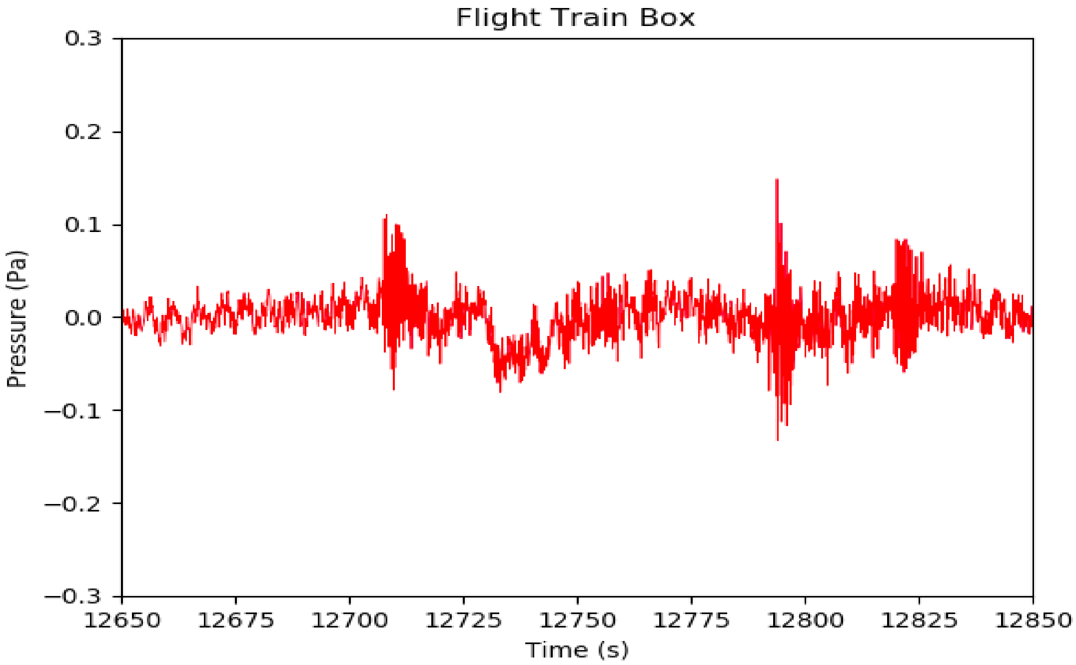


Fig 7.33.1: pressure profile of the FTB when the explosion was detected

It has been demonstrated in the literature (see [14]) that for a given event (ground explosion in our case), the stratospheric returns come in pairs consisting of a fast and slow arrival. The pair is created through competition between path length and propagation speed when the impulse is propagating in the stratosphere. Thus, we were expecting to detect two arrivals for our explosion, and the measurements are showing three arrivals.

It must be mentioned that for technical reasons that need to be investigated, nothing was detected in the measurements coming from the barometer of the Gondola Box. Only a small impulse associated to the second arrival can be noticed. Overall, the signal coming from the Gondola Box seems to be less noisy than the Flight Train Box. It could be explained by the shape of the gondola box, the position of the GB barometer and the angle of incidence of the wave. We think than given the incidence of the incoming shock wave, the gondola absorbed the wave and prevented the barometer from detecting the wave, which is not the case with the Flight Train Box.

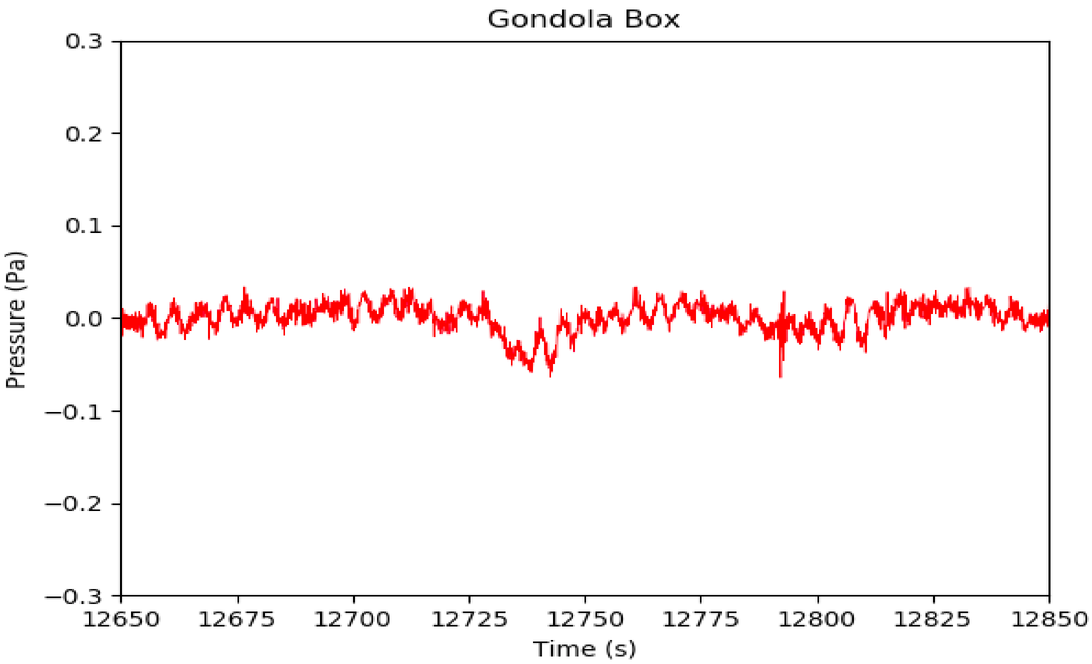


Fig 7.33.2: pressure profile of the GB when the explosion was detected

First, we proceeded to a spectrum analysis of the signal at the different times corresponding to the three signals but separately on the GB signal and on the FTB signal, on a scale of a few seconds. We also did three more measures: before, between and after the peaks. The different spectrums are represented down below.

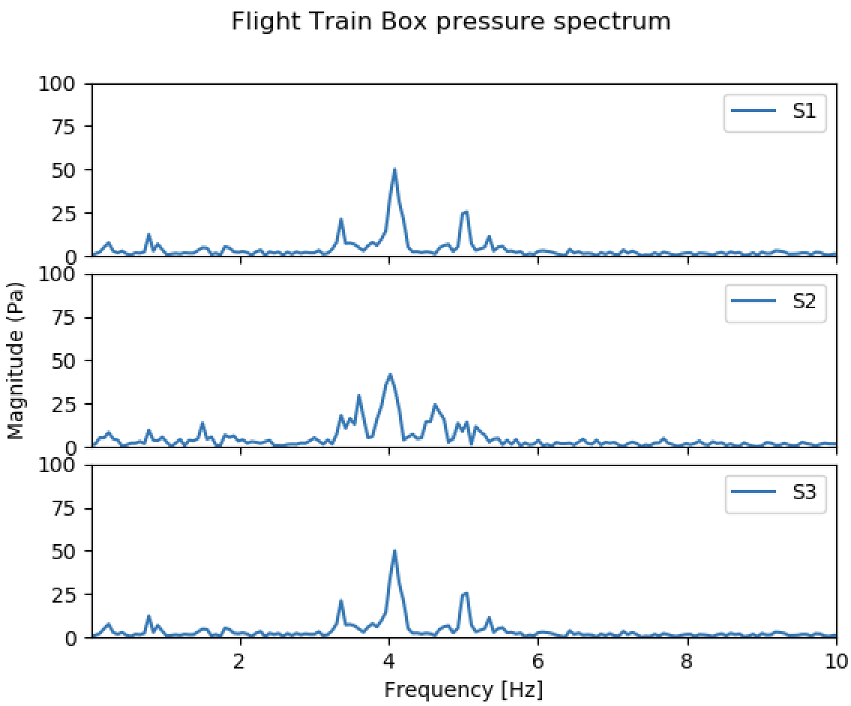


Fig 7.33.3: Spectrum analysis of the pressure measured by the FTB for S1, S2, S3

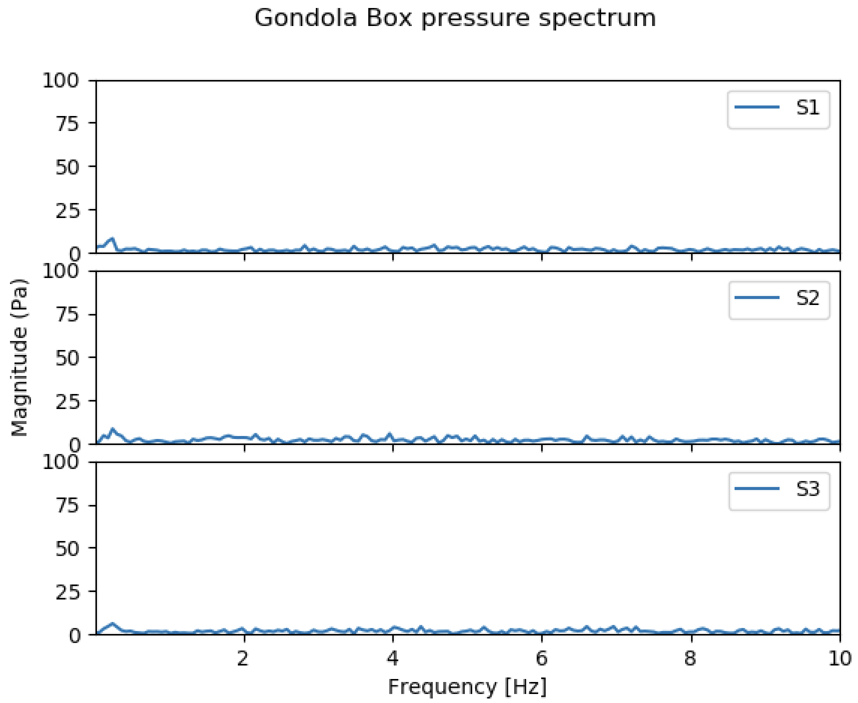


Fig 7.33.4: Spectrum analysis of the pressure measured by the GB for S1, S2, S3

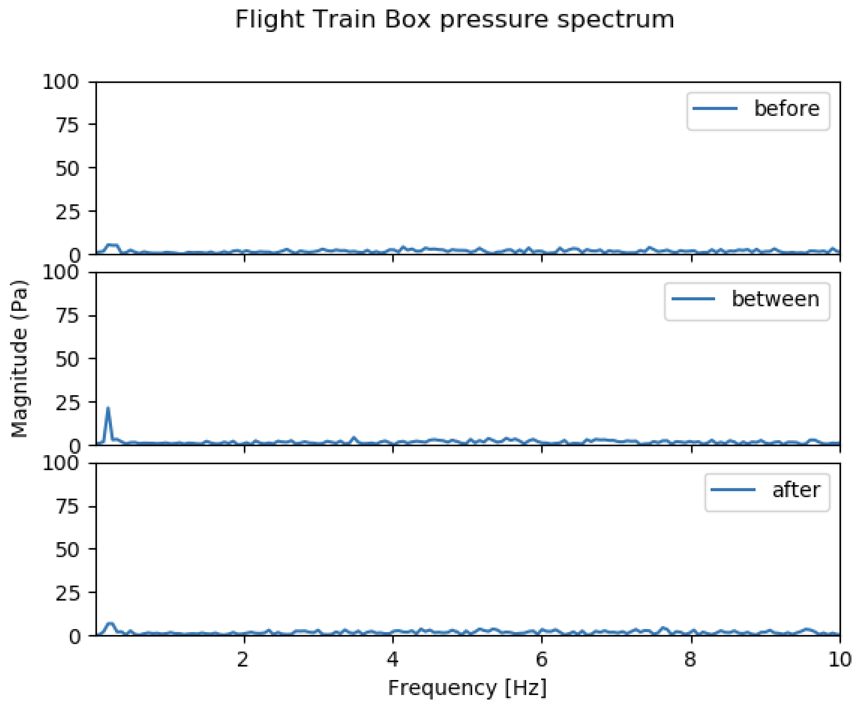


Fig 7.33.5: Spectrum analysis of the pressure measured by the FTB before, between and after the peaks

We then made the following observations:

- On the spectrums of the FTB we can see that there is a big contribution of a frequency of 4 Hz.

- The spectrum between and before the peaks do not contain any major frequential component and do not give any information on a potential signal received by the boxes.
- The different spectrums of the GB didn't provide any information on a possible signal received at the same dates with a frequency of 4 Hz.

Furthermore, in the literature (see [15]) we can read that explosions similar to ours generate waves with a frequency between 0.1 and 10 Hz. And the shape of these peaks can by compared to explosion signals and are very similar. It supports the hypothesis that S1, S2 and S3 correspond to the explosion.

These signals at 4 Hz are also visible when we observe the spectrograms of the pressure function of the time and it shows very clearly that these events are punctual and confirm that they come from the explosion.

We also studied the signals received by the accelerometers in the FTB and in the GB. We were surprised to see that S2 and S3 were also present in the signal from the FTB. Better, the accelerometer in the GB received a visible signal that corresponds to the signal S2. We used the same method than with the pressure data and the different spectrum are represented below.

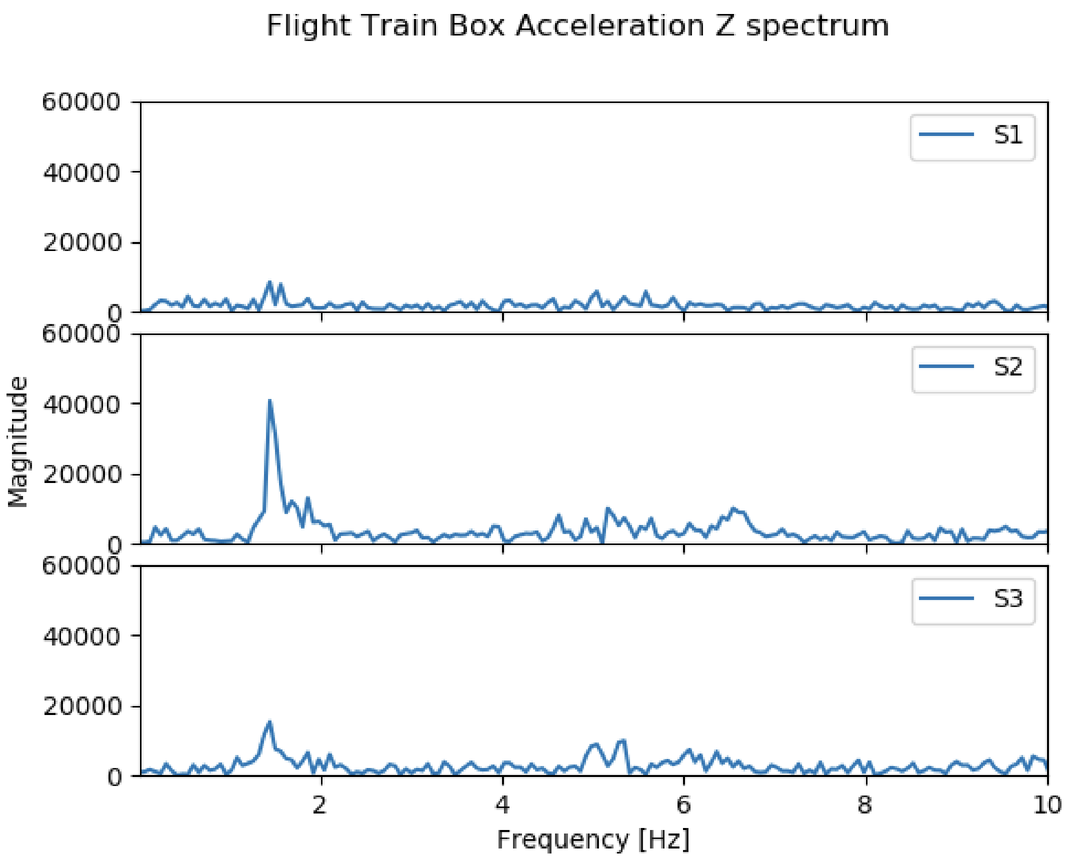


Fig 7.33.6: Spectrum analysis of the vertical acceleration of the FTB for S1, S2, S3

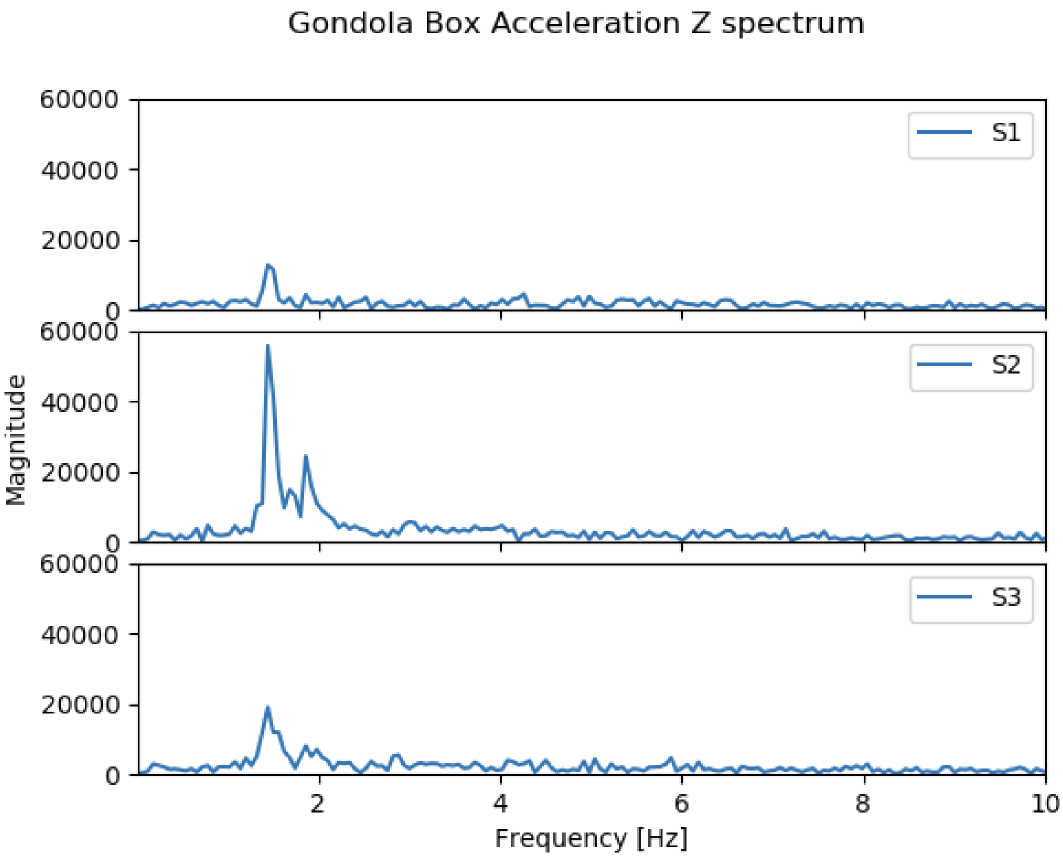


Fig 7.33.7: Spectrum analysis of the vertical acceleration of the GB for S1, S2, S3

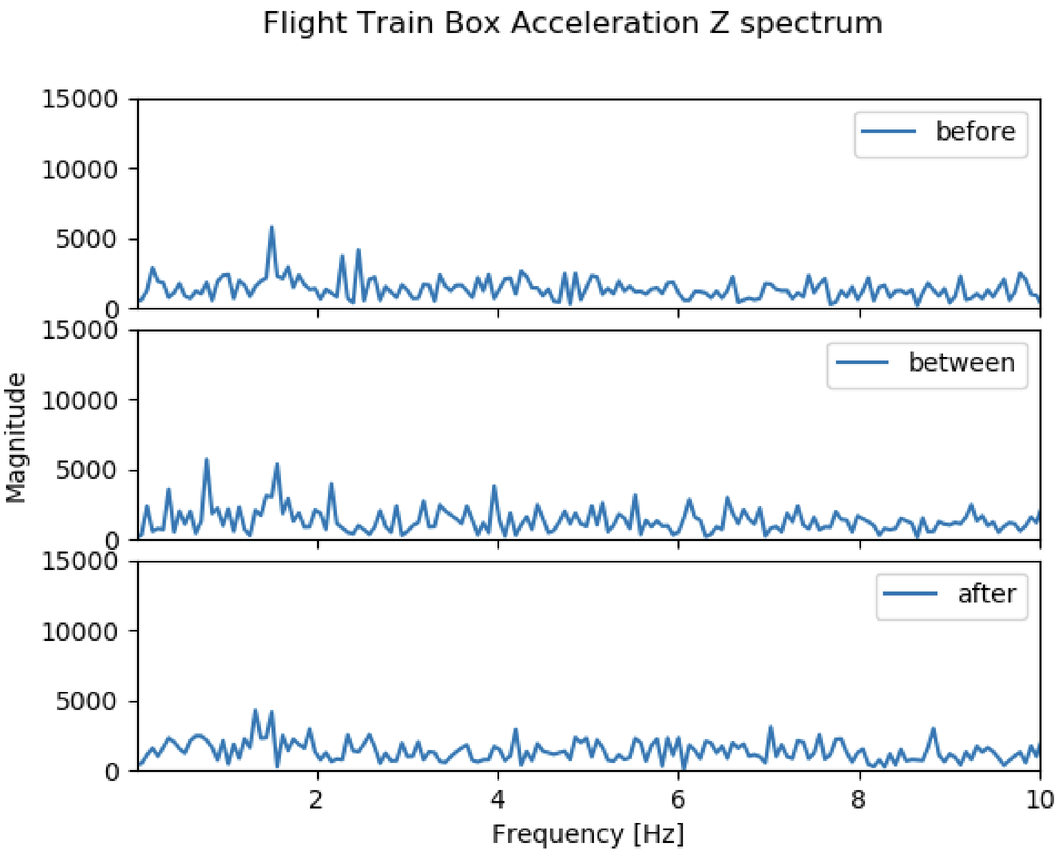


Fig 7.33.8: Spectrum analysis of the vertical acceleration of the FTB before, between and after the peaks of the explosion (not the same scale as 7.33.6)

We can observe that:

- On the spectrum of the FTB we can see a big contribution of a frequency of 1.4-1.5 Hz and no other major contribution.
- We can observe the same contribution for F-GB.
- We can observe the same contribution between the peaks but with a lower intensity. This contribution is also observed before the first peak.

From these results we made a hypothesis that could explain the difference of frequency detected by the barometers and by the accelerometers and that could also explain why we detected the component at 1.5 Hz between the peaks. Our supposition is that 1.5 Hz represent the resonance frequency of the boxes. This hypothesis will be deeper treated in 7.3.5.

The delay between the GB signal and the FTB signal allows us to calculate an angle of incidence for the wave from the explosion, knowing the relative position of the two boxes. We used S2-FTB and S2-GB because S1 and S3 were not detected by the accelerometer of the GB. With a delay of 0.05 s, and an angle of 2° between the vertical axis and the axis of the flight train, we obtained an angle of

27+-2° of incidence (considering the normal as the horizontal axis and so the sonic ray comes from above). That angle is very close to the theoretical angle calculated with our atmospheric model.

Another question is why do we have three signals instead of only one for the blast? The answer is further developed in 7.3.4 but, in fact, sound is necessarily deviated when it goes through the atmosphere and reach an altitude function of the angle of emission where the sonic ray rebounds and returns to the ground where it can be detected. So, our balloon can receive multiple signals coming from different angles and which have rebounded at different altitudes before being detected by our captors. This altitude of rebound can be calculated with the time the signal took to reach the balloon from the location of the explosion and the distance between the emission and the reception. Thus, an effective speed can be defined, and it is this effective speed that it linked to the altitude of the rebound. For the signals S1, S2 and S3 we obtained respectively 307 m/s, 277m/s and 267m/s. (The fact that these speeds that are very close to the speed of sound in the air supports once again the idea that the 3 signals were indeed produced by the explosion). This allows us to deduce that S1 has between a tropospheric and a stratospheric arrival, and S2 and S3 have a mesospheric arrival. The array for the classification is visible below .

Heights of ray turning, km	Type of arrival	Propagation speeds
0–1	Lamb waves	$c = r/T > 330$
1–20	Tropospheric	310–330
20–50	Stratospheric	280–310
50–85	Mesospheric	260–290
$z > 85$	Thermospheric	180–300

*Fig 7.33.9: Classification of infrasound arrivals (*Kulichkov et al.[17])

7.3.4 Localization of the blasts

To verify that the blast was indeed located in the Mertainen mine we chose to use GeoAc3D (see [18]) which is a numerical tool to simulate 3-dimensional propagation of acoustic waves through the earth with raytracing. To estimate the composition of the atmosphere and the wind at Kiruna we used the Mass Spectrometer – Incoherent Scatter (MSISE) model and the Horizontal Wind Model (HWM) model. As the GeoAc program can't detect the source of a wave knowing the point where we heard the wave, we had to do the opposite process: we launched multiple waves from Mertainen and saw which ones reached the balloon. However, the program doesn't give us an intersection at the good position. So, we changed the wind direction to a zonal wind since we could infer that this would work with the trajectory of the balloon.

With this rough model we checked that the times and the angles at which the blast reached the boxes are the same in the simulation and in reality.

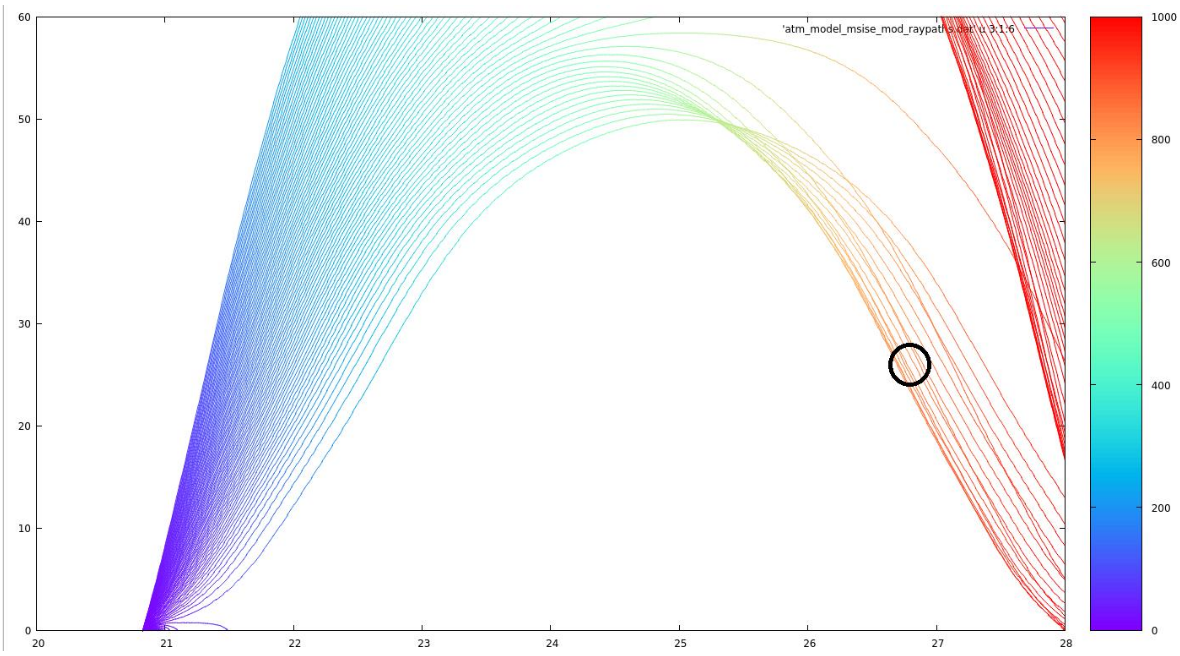


Fig 7.34: Simulation of the acoustic wave coming from Mertainen with a 90°

In the graph above, the abscise represents the longitude (in degree) and the altitude (in km). We detected the second blast at the position of 26.75° longitude 26.75km altitude and approximately 800 seconds after the blast occurred in Mertainen. We aren't using the latitude because it stayed approximatively the same during the flight. Graphically, we can see that the coordinates at which we detected the blast corresponds to where the sound waves come back down to earth after a reflection on the upper layers of the atmosphere. This means that our model shows that we were in the right place at the right moment to detect the blast when it occurred in Mertainen. However, the model we used to simulate the pathway of waves through the atmosphere is not very accurate, as we mostly had to infer it, since we couldn't find the necessary data.

7.3.5 Identification of background noise

In order to analyse the background noise, we chose to use spectrograms which allow us to have a visual representation of the data we collected. On a spectrogram, the data is broken down by frequency. We generated these spectrograms using a Python script (*see appendix I for code*).

Analysis of the pressure spectrograms

Before turning our pressure data into spectrograms, we sampled it to reduce its frequency from 180Hz to 10Hz, to make the processing less heavy. Also, for computational purposes, we did not take into account the ruptures of the internal time of the experiment caused by the few shutdowns discussed in paragraph 7.3.1. This means that the time shown by the spectrograms is **not the real experiment time**. We also applied a bandpass filter to select only the frequencies that were relevant to our analysis.

All the pressure spectrograms have these reoccurring vertical rays across the spectrum (at 2300sec for example). These rays happen when the experiment reboots itself and are not relevant to our analysis.

To begin with we applied a bandpass filter of 0.02Hz to 5Hz, because that is the frequency range in which we expect to detect the blast.

Flight Train Box

On the pressure spectrogram for the FTB we can see that during the ascent and the floating phase there are defined rays at the following frequencies: 0.2, 0.3, 0.8, 0.9, 1, 1.5, 2.5 and 4Hz. We also detect quite clearly the blast that occurred at 11 000s (time of the spectrograms) at approximately a 4Hz frequency. This result is coherent with the data we found in literature [15], as discussed in paragraph 7.3.3.

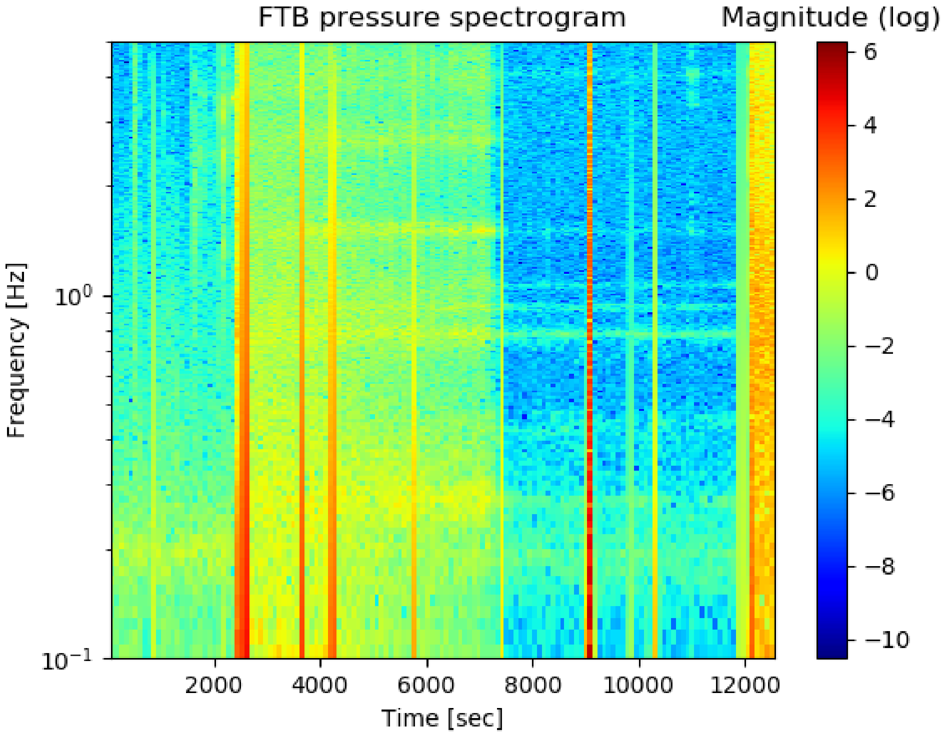


Fig 7.35.1: FTB pressure spectrogram with a 0.02 to 5Hz bandpass filter

Gondola Box

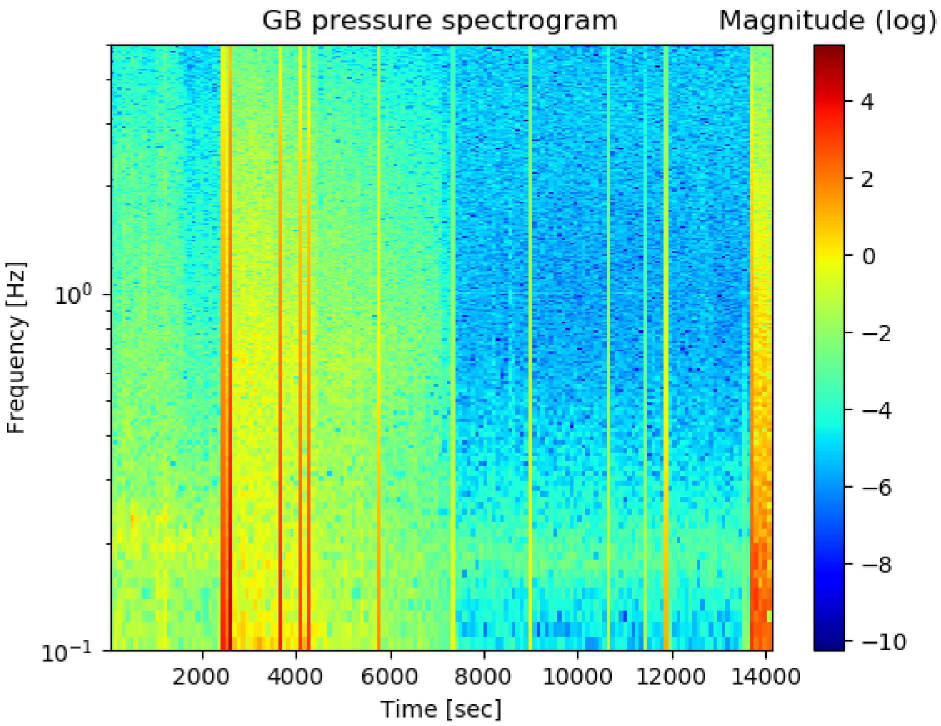


Fig 7.35.2: GB pressure spectrogram with a 0.02 to 5Hz bandpass filter

The pressure spectrogram yields little analysable information. The GB barometer has poorly registered the blast. The only visible ray is at 0.2Hz.

Analysis of the gyrometer spectrograms

Likewise, the time on the gyrometer spectrograms is not the real experiment time.

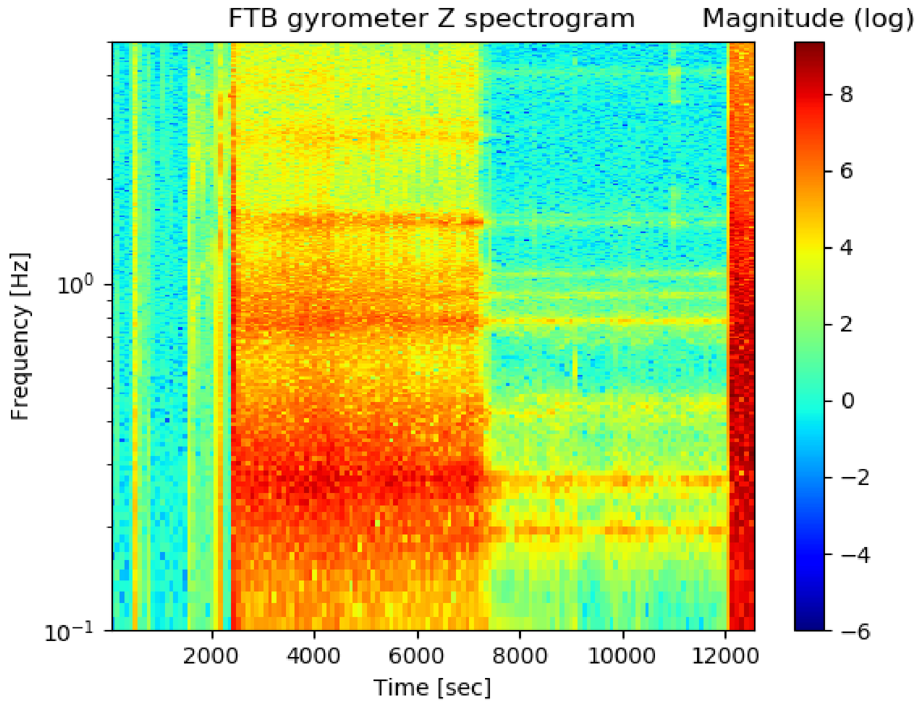


Fig 7.35.3: FTB vertical gyrometer spectrogram with a 0.02 to 5Hz bandpass filter

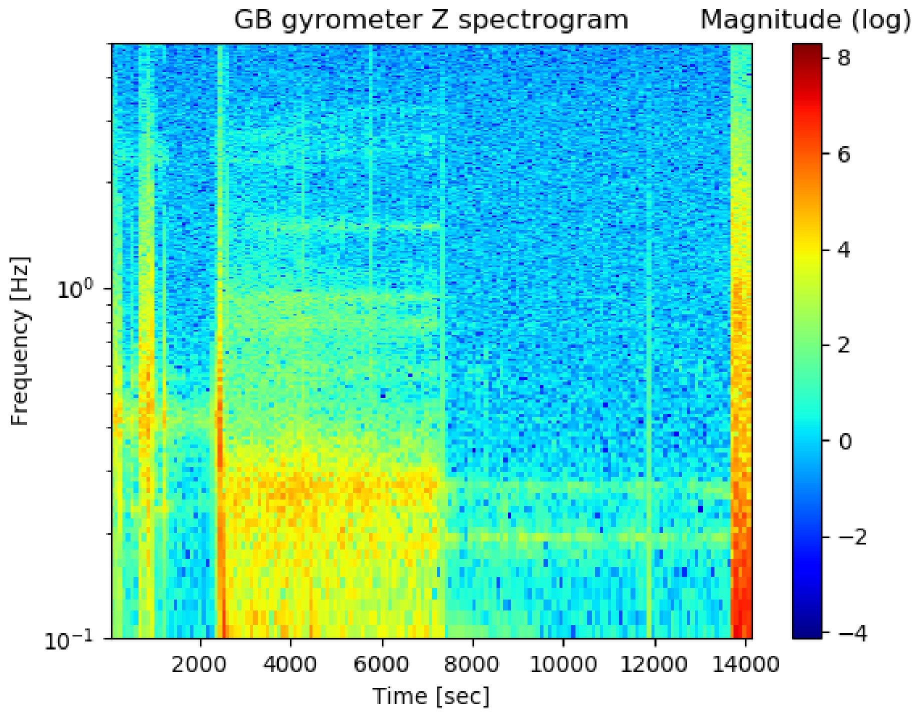


Fig 7.35.4: GB vertical gyrometer spectrogram with a 0.02 to 5Hz bandpass filter

We can see that the spectrograms of the barometers and of the gyrometers of both boxes are similar, in that the spectrograms for the FTB both have the same set of rays at given frequencies (0.2, 0.3, 0.8, 0.9, 1, 1.5, 2.5 and 4Hz) and the spectrograms for the GB both have the lower frequency rays (around 0.2 Hz).

In both cases, only the FTB detected the blast. However, the gyrometer's z axis detected the blast at two frequencies (as opposed to one for the barometer): 1,5 and 4Hz.

We can also notice that the information was better detected by the gyrometer and the accelerometer z axis. This comes from the fact that the flight train is vertical and elastic enough to act like a spring.

This led us to formulate the following hypothesis: <u>the rays that we detect at fixed frequencies throughout the flight are the eigen modes of the flight train</u>. Therefore, they are detected more easily by the devices in the FTB, which is placed directly on the flight train, than by the GB, who is shielded from the vibrations by the weight of the gondola. This theory also would explain why these specific frequencies were so well picked up by the gyrometer and the accelerometer of the FTB.

To test this out we determined the fundamental frequency of the flight train which using the usual formula:

$$\nu = \frac{1}{2L} \cdot \sqrt{\frac{T}{\mu}}$$

We have L = 55m the length of the flight train, T = 2500N because the gondola has a weight of 25kg and μ = 0.1 kg/m the linear mass of the flight train that we estimated. The result is that the fundamental frequency of the flight train is approximately 1 Hz. The results seem to corroborate our theory that some of the rays detected in the spectrograms are due to the eigen modes of the flight train.

A phenomenon we were hoping to register are microbaroms. Microbaroms are pulses of atmospheric infrasound emitted by ocean surface waves. They can be detected up to 150 km away from the ocean (see [16]) and the Esrange satellite station is 250km away from the coast. Their characteristic signature is a 0.2Hz signal at an amplitude of 0.1 Pa, that was registered in the paper mentioned above.

We registered a similar signal on both our barometers, with the same characteristics in frequency and amplitude. <u>This signal is visible throughout the whole flight after applying a low pass filter that blocks out the noise due to the movement of the balloon.</u> Without filter, we can clearly see the microbaroms signals when the balloon reaches local extremum of altitude during the floating phase, as shown in figures 7.35.5 and 7.35.6. In these instants, the variation of pressure caused by the movement is reduced and the microbaroms signals are clearly seen.

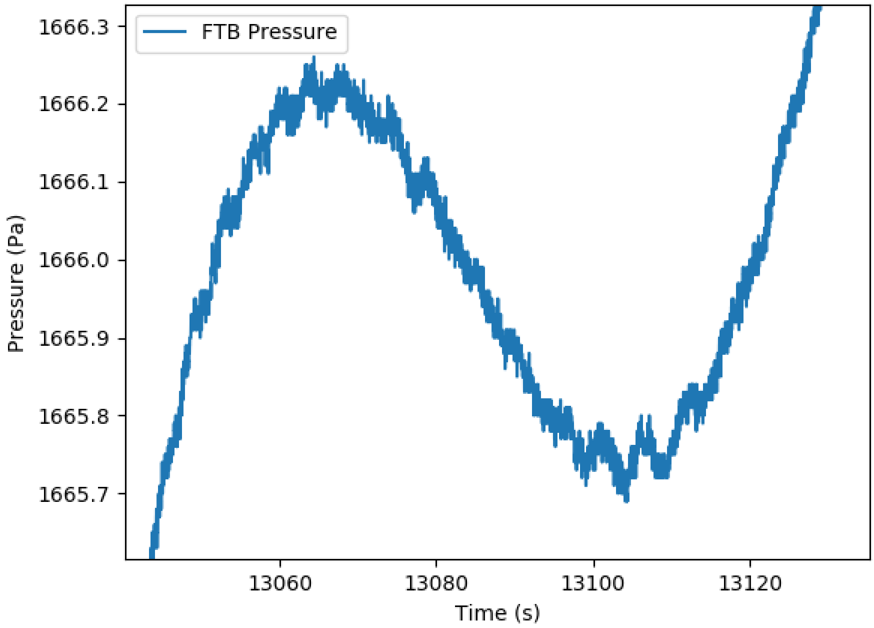


Fig 7.35.5: Pressure signal in the FTB during the ascent of the balloon showing microbaroms

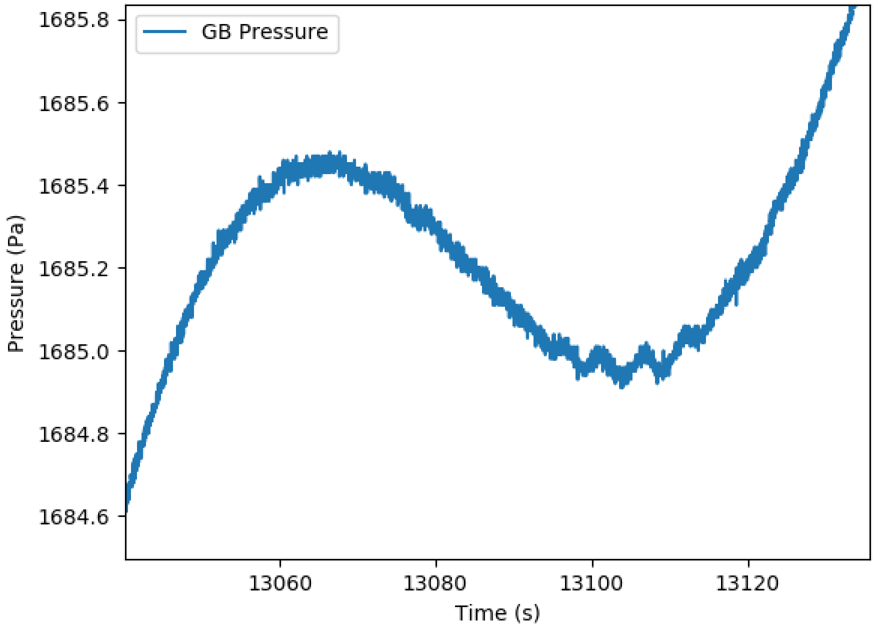


Fig 7.35.6: Pressure signal in the GB during the ascent of the balloon showing microbaroms

This leads us to believe that we registered the microbaroms effectively, and that they are the cause of the large ray centred around 0.2 Hz present in all pressure spectrograms.

7.4 Critical analysis of our experiment

This section is used to reflect on our design and protocol choices and explain how they could be improved by future experimenters.

One major issue with our experiment is that we failed to collect good data through the gondola box. We think this might be because of the position of the GB in the gondola: the bulk of the gondola possibly shielded the GB barometer from some of the infrasound. This could be avoided by finding a way of making the pressure port hang lower underneath the gondola, to clear its direct environment. Another possibility is to have both boxes on the flight train.

Furthermore, we did not make much use of the anemometer. It did not provide any useful information to study the background noise or to detect the signal from the blast. What is more, since the balloon in carried by the wind, the average value detected by the anemometer is close to 0 m/s. The only utility of this information would be to calculate the trajectory of sonic rays in the atmosphere but the wind information that is given by the anemometer at a given altitude is not enough to elaborate a theoretical model of atmosphere. We do not consider it to be a crucial part of any future experimentation.

On the other hand, the gyrometers and the accelerometers turned out to yield more information than we had expected. We had not planned on using the eigen modes of the flight train, but they helped us register the blast with the gyrometers and the accelerometers. Our initial plan was to better shield the barometers from any vibrations of the balloon, but the wired dampers were of little help when the whole flight train was oscillating.

The set up as we designed it allowed us to accomplish two of our three objectives. We were indeed able to use it to register the microbaroms in the stratosphere and characterize the infrasonic background noise during the floating phase as required by PO1 (see paragraph 1.3). We were also able to detect the occurrence of an infrasound event, which was our blast in this experiment, as required by SO1.

However, we were confronted to technical difficulties to accomplish the objective SO2. It was initially planned to rely mainly on linear geometry in order to localize the sources of the infrasound events detected with the two barometers. The fact that the data was missing in the Gondola Box was not the only issue. The propagation of infrasound in the stratosphere is a physical phenomenon which involves nontrivial nonlinear equations. The use of tools such as GeoAc (See Blom

[18]) is very helpful for these kinds of infrasound propagation analysis. We think that the localization of infrasound sources is possible with a setup more adapted to this task. Our setup could be improved by using several balloons all carrying a single barometer, as this has been done in other experiments that have demonstrated their capacity to accomplish tasks similar to our objective SO2.

7.5 Discussion and conclusions

The propagation of infrasound at high altitudes is a booming field that has promising outcomes in defence. The United States are currently developing experimentations in this field. This is partly why *ISAE-Supaéro* helped us to carry out this project and Leo Martire (see paragraph 3.3.3) presented our results at the Sandia High Altitude Infrasound Conference in February 2020. Our data will be added to a shared data base with scientists in this field from the US. We are glad that we could participate, however humbly, in a field that undergoes state-of-the-art research.

7.6 Lessons Learned

Our project has given us the opportunity to learn many lessons in various areas.

<u>Science</u>

- Planetology, previous missions on Venus
- Atmospheric science
- Infrasound, especially their propagation in the stratosphere
- To gather bibliography and extract useful information
- Data processing

<u>Mechanic and thermic</u>

- To discover new simulation software
- To apply theory to calculate the resistance of real structures
- To learn 3D-printing

<u>Management and organisation</u>

- Elementary work tools such as WBS and Gantt charts
- To organize the development of a project in an efficient way
- To document a project
- The difficulties that come with managing a team of ten people
- The importance of dividing the whole work in smaller work packages and assigning them to the appropriate person

<u>Outreach</u>

- To design a website

- To present our project to diverse audience, from high-school students to teachers

Organization:

- To insure a smooth transition between both teams

Manual work:

- To assure the transition between a model “on paper” and a reallife experiment

And finally, we learned that we were able to carry out a scientific experiment from start to finish, albeit with a lot of help.

8 ACKNOWLEDGEMENTS

This project is the result of a huge collaboration between students of different courses, and laboratories of the Ecole Polytechnique and Isae-Supaéro. We would like to thank all the people and organisations which have taken part in this project.

We thank David Mimoun, researcher at ISAE-Supaéro, as well as Marti Bassas-Portus for having followed us and helped us during the entire project.

We thank Jean-Claude Rubio and his team for having enabled us to test our experiment at the CNES center.

We thank Léo Martire, doctoral student in applied maths at ISAE-Supaero, as well as Daniel Bowman, for their help in the data analysis of the experience.

We thank the mining company LKAB for performing the blast during the flight.

We thank the Student Spatial Center of the Ecole Polytechnique, and all the researchers and other members of the university who permitted us to complete successfully our project.

We finally thank Maria Snäll, Stefan Krämer, and more generally all the members of Bexus program and Esrange, for having permitted us to conduct this wonderful project.

9 ABBREVIATIONS AND REFERENCES

9.1 Abbreviations

Add abbreviations to the list below, as appropriate and delete unused abbreviations.

AIT	Assembly, Integration and Test
ASAP	As Soon As Possible
CDR	Critical Design Review
COG	Centre of Gravity
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
EPM	Esrange Project Manager
ESA	European Space Agency
Esrange	Esrange Space Center
ESTEC	European Space Research and Technology Centre, ESA (NL)
ESW	Experiment Selection Workshop
FAR	Flight Acceptance Review
FST	Flight Simulation Test
FRP	Flight Requirement Plan
FRR	Flight Readiness Review
FTB	Flight Train Box
GSE	Ground Support Equipment
GB	Gondola Box
HK	House Keeping
H/W	Hardware
ICD	Interface Control Document

I/F	Interface
IMU	Inertial Measurement Unit
IPR	Integration Progress Review
LO	Lift Off
LT	Local Time
LOS	Line of Sight
MFH	Mission Flight Handbook
MORABA	Mobile Raketen Basis (DLR, EuroLaunch)
OP	Oberpfaffenhofen, DLR Center
PCB	Printed Circuit Board (electronic card)
PDR	Preliminary Design Review
PST	Payload System Test
RBF	Remove Before Flight
SED	Student Experiment Documentation
SNSB	Swedish National Space Board
SODS	Start of Data Storage
SOE	Start of Experiment
STW	Student Training Week
S/W	Software
T	Time before and after launch noted with + or -
TMS	Thermal Management System
TBC	To be confirmed
TBD	To be determined
WBS	Work Breakdown Structure
ZARM	Zentrum für Angewandte Raumfahrttechnologie und Mikrogravitation

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Appendix A EXPERIMENT REVIEWS

Preliminary Design Review – PDR

REXUS / BEXUS
Experiment Preliminary Design Review

Flight: BEXUS 28

Payload Manager: TBC

Experiment: DESTINY

Location: DLR MORABA, Oberpfaffenhofen **Date:** 14 Feb 2019

1. Review Board members

Michael Becker, DLR
Katharina Schüttauf, DLR MORABA
Markus Wittkamp, DLR MORABA
Alexander Kinnaird, ESA
Rodrigo Avila de Luis, ESA
Koen Debeule, ESA
Stefan Krämer, SSC
Simon Westerlund, SSC
Simon Mawn, ZARM
Dieter Bischoff, ZARM

2. Experiment Team members

Clara Piekarski
Krishan Bumma
Louis Dubois
Elias Khallouf

3. General Comments

- **PRESENTATION**
  - Exceeded the time given by few minutes.
  - Too much time dedicated to scientific objectives (science was already discussed at Selection Workshop)
- **STUDENT EXPERIMENT DOCUMENTATION**
  - Compact and quite complete for a first SED version.
  - Nevertheless, some important details were missing on mechanical and electrical design.
  - ACTION: The team shall address the following editorial remarks:
    - File name, should include version and issue number, e.g. v1-0.
    - Blank pages shall be avoided.
    - Bookmarks shall be included when printing the document to PDF.
    - University shall be indicated in the title page.

4. Panel Comments and Recommendations

- **REQUIREMENTS AND CONSTRAINTS** (SED chapter 2)
  - Requirement P5 could consider different performances for altitude and position.
  - Requirement P11 poses a quite low limitation in the upper limit for temperature measurement. ACTION: This requirement shall be revised; the team is encouraged to increase the range.
  - Requirement P14 has been miscategorized, should be a design requirement.

BX28_PDR Report_DESTINY_V1-0_14Feb19

- Requirement P15 has been miscategorized, should be a design requirement.
- Requirement O2 has been miscategorized, should be a design requirement.
- Requirement O3 has been miscategorized, should be a design requirement.
- Requirement O6 is evident, the team should consider disregarding it.
- Requirement O7 has been miscategorized, should be a design requirement.
- Requirement O8 has been miscategorized, should be a design requirement.
- Requirement F5 is unclear, the team shall clarify what does “turbulence speed” means.
- Requirement F6 is evident, the team should consider disregarding it.
- Requirement F7 is evident, the team should consider disregarding it.
- Requirement F8 has been miscategorised, should be a design requirement.
- Constraint C5 has been miscategorized, should be a design requirement
- Constraint C6 has been miscategorized, should be a design requirement
- Constraint C7 should not be consider as such.
- Requirements regarding the pressure profile are missing.
- Requirements regarding static loads (10g vertical, +/-5g horizontal) are missing.
- Requirements regarding distance between boxes are missing.
- Requirements regarding attachment of boxes are missing.
- Requirements regarding mass and dimensioning are missing (they have been included as constraints C1, C2 and C3, but this is not the recommended approach).
- The team should reconsider including complex functionality requirements, such as stop of data collection. This could add an undesired risk for the mission.

▪ **MECHANICS**

- The proposed attachment system of the upper box to the flight train via clamping is discouraged, as the belt might weaken. An attachment system sew on the belt will be offered to the team to install the box.
  ACTION: The team shall contact SSC personnel (Stefan Kramer) to ask for the details regarding the attachment system.
  ACTION: The team shall propose an design for the upper box that ensures an easy detachment for recovery purposes.
- For safety reasons the upper box needs to be secured by an additional safety cable or flexible rope to prevent free falling parts from the flight train.
- When attaching masses to the flight train, low frequency vibrations could be expected.
  ACTION: The team should investigate carefully where to locate the mass of the box in order to avoid resonance effects.
- The team proposes to mount the sensor aboard the Gondola out of the structure. The team shall assume the risks of the sensor being destroyed when landing.
- The team shall consider using a maximum of 6 bolts when attaching structures to the Gondola.
- **ACTION:** The team shall propose an assembly procedure of the sensor on the Gondola.
- The team should provide more details on the design of the boxes (final dimensions, materials, assembly, manufacturing process, etc.) and how are the electronic components fixated inside.

▪ **ELECTRONICS AND DATA MANAGEMENT** (SED chapter 4.2.2, 4.2.3, 4.5, 4.7, 4.9)

- **ACTION:** The team shall provide insight on the number of PCBs that they are going to use and how are they going to interface them.
- The team should consider that the upper box might be attached to the flight train for long times. There will be no possibility of delivering power during the separation procedure.
  ACTION: The team should investigate the dimensioning of the battery of the upper box.
  ACTION: The team shall provide more detailed information about the batteries.
- Regarding fuses, the team should be careful on when to use them: for testing could be a good idea, but for the flight they might add an extra risk preventing the instruments to work.
- The team should make sure the total mass of the cable connecting the upper box adds only 1.5 kg to the mass of the system, as stated (experience tells this value is usually 2 to 3 times higher).
- The team shall ensure the GPS/GLONASS system will operate at float altitude.

▪ **THERMAL** (SED chapter 4.2.4 & 4.6)

- **ACTION:** The team shall include in the report the calculations of the internal heat (electronic heat dissipation) and the loss of heat through the insulation cover to prove their thermal design proposal is adequate.
- The team shall consider that polystyrene might expand in low pressure conditions, not recovering its original shape leading to damage or destruction of the insulation cover.

- **ACTION:** The team shall provide more details on how the heater will be implemented (need to be conducted on heat sinks with appropriate thermal capacity, otherwise they will burn) and their control loop.
- **ACTION:** The team shall specify which method will be implemented in the design to keep temperature critical components such as the BeagleBone Black safe.
- **ACTION:** The team shall provide information about the temperature sensor(s) to be used.

▪ **SOFTWARE** (SED chapter 4.8)
- **ACTION:** The team shall investigate and clarify in the report about the sensitivity of the system to the relative position between the two boxes (explain why the angular rotation of the boxes is not a very important factor but the alignment of the flight train is, for example).
- **ACTION:** The team shall investigate and clarify in the report about the sensitivity of the system to time synchronization (explain why expected delays of 1 ms are tolerable).
- The team shall consider redundancy in the data storage system.
- The team is encouraged to opt for GPS time synchronization rather than through PDP protocol.

▪ **VERIFICATION AND TESTING** (SED chapter 5)
- Some of the requirements proposed are not linked to a verification plan
  ACTION: The team shall provide verification plans for all the requirements.
  ACTION: The team shall rework and complete chapter 5.
- Requirement D2 could be tested, for example, by driving the experiment in your car over a bumpy terrain.
- Requirement D4 verification plan by similarity is unclear/unfeasible.
- Requirement D6 verification plan should be consider testing.
- The team is encouraged to perform a vacuum test.
- The team should think about the different level of verification tests (acceptance, qualification, etc.) regarding different experiment models (qualification, flight, etc.).

▪ **SAFETY AND RISK ANALYSIS** (SED chapter 3.5)
- **ACTION:** Risk 10 shall be better formulated.
- **ACTION:** Risk 20 shall be associated with a deadline.
- **ACTION:** Risk SF10 could be categorized as class 5.
- Risks regarding science output and usefulness of the data are missing.
- Risks regarding funding of the project are missing.
- Risks regarding campaign operations are missing.

▪ **LAUNCH AND OPERATIONS** (SED chapter 6)
- The team shall accept that a night flight won't be provided.
- The team shall keep in mind that the blast of the mine (200 m depth), could be not recognizable at ESRANGE anymore.
- The team shall consider the possibility of capturing super-sonic shocks. For discussing this possibility, the team could contact: *https://www.facebook.com/ftjugoett/*
- The team is encouraged to think about operations early in time.
- It could be possible to have two e-links, each one dedicated to each one of the boxes. The team shall indicate this request on chapter 6 of the SED if desired.
- Proposed data rates of 170 kb/s seem fine.
- The team shall consider covering the inlets.
- **ACTION:** The team shall rework the information regarding campaign planning and timeline for countdown and flight. It is recommended to use CUT – X mins for events related to cut.
- The team shall take into consideration that could be SSC who will attach box to the flight train.
- If required, the team shall ask for special careful recovery of the upper box in chapter 6.

▪ **ORGANISATION, PROJECT PLANNING & OUTREACH** (SED chapters 3.1, 3.2, 3.3 & 3.4)
- When incorporating new members on the team it is important to ensure a good knowledge transfer for them to understand the steps and decisions taken in the past.
- In terms of skill set of the team, electronics seem to be the weaker one at the moment.
  ACTION: The team shall look into recruiting experienced members in electronics or ask for advice.
- The team shall specify the specific skills (specialization) of each team member on the SED.
- The team proposed a very detailed WBS and Gantt, with a good use of milestones.
  ACTION: The team shall upload the project file (WBS/Gantt) on the TeamSite for further review.
- The team is encouraged to investigate the Critical Path of the project.
- The team is encouraged to think about work package duration sensitivity, especially with work packages regarding learning or acquiring new skills.

BX28_PDR Report_DESTINY_V1-0_14Feb19

- The team shall not underestimate the challenges of having a spitted site (and dual-stakeholders) ACTION: Capture this in the risk register and lessons learned.
- ACTION: The team shall look at the budget as it does not match with the proposed constraints.
- ACTION: The team shall take a deeper look into travel and shipping costs as they seem to be underestimated.
- ACTION: The team shall consider including traditional media in their outreach plan.
- ACTION: The team shall make sure the website works properly (URL not working).
- ACTION: The team shall provide the URLs for the social media sites and blog in the SED.
- The team is encouraged to capture online articles about their project as they might be removed from the Internet at some point.
- The team is encouraged to include a link to the website from the Facebook page (and vice-versa).

5. Internal Panel Discussion

- Summary of main actions for the experiment team
  - **The team shall include more details on the electronics, including schematics, focussing in the connection of the sensors to the Raspberry Pi and the data time synchronization.**
  - **The team shall provide insight on the sensitivity of the system to time synchronization when computing the origin of the sound wave.**
  - **The team shall rework chapter 5.**
- PDR Result: **CONDITIONAL PASS**
- Next SED version due: v1-1, 16th March 2019

Critical Design Review – CDR

REXUS/BEXUS CDRs

EXPERIMENT CRITICAL DESIGN REVIEW

FLIGHT: BEXUS 28
EXPERIMENT: DESTINY
LOCATION: ESA/ESTEC Noordwijk, The Netherlands **DATE:** 16 May 2019 15:30

1. REVIEW BOARD MEMBERS

DLR	Michael Becker	SSC	Stefan Kramer
ESA	Alexander Kinnaird	SSC	Maria Snäll
ESA	Rodrigo Avila de Luis	ZARM	Simon Mawn
ESA	Koen Debeule	ZARM	Dieter Bischoff
ESA	Paolo Concari	DLR-MORABA	Katharina Schüttauf

2. EXPERIMENT TEAM MEMBERS

Florian Abeillon
Louis Dubois
Elias Khallouf

3. GENERAL COMMENTS

PRESENTATION

- The presentation was very well received by the panel members.

STUDENT EXPERIMENT DOCUMENTATION

- The document in general has greatly improved since the CDR review.
- ACTION CDR-01: The team shall remove unused blank pages (84, 104, 105, 123, 124).
- ACTION CDR-02: The team shall include bookmarks from Appendix F onwards.
- ACTION CDR-03: The team shall avoid splitting tables across pages (Table 4.10, 6.2).
- ACTION CDR-04: The team shall correct the typo in Page 30 where a 28.8 V / 1 mA battery pack is mentioned, the current is only relevant when considering total capacity.

4. PANEL COMMENTS AND RECOMMENDATIONS

REQUIREMENTS AND CONSTRAINTS (SED chapter 2)

- Requirements regarding the maximum dimension of the experiments are missing. The team might consider including these requirements if needed.
- The team shall consider splitting requirement F5 concerning wind speed and direction in two different requirements (one for speed and one for direction).
- Requirement D9 is not very well defined, as it does not specify how the distance between boxes are measured (from centre of mass to centre of mass?, from top surface to bottom surface?,...)
  ACTION CDR-05: The team shall reformulate requirement D9.
- Requirement D12 mentioning that the experiments shall maintain an internal temperature suitable for the components is not specific enough (bad requirement). The team might consider mentioning a temperature range in which the experiment components shall be kept, such as indicated in requirement D13.
  ACTION CDR-06: The team shall consider deleting requirement D12.

MECHANICS

- The mechanical design chapter left some open questions and some important details which are expected for a critical design review level document.
  - Although it could be found in the appendix, it would be practical to include in Chapter 4.4 information of the materials to be used (type of aluminium).
  - Also, in chapter 4.4 it is stated that "The bars will be soldered together to form the box's structure" but there is no information on the profile of these bars. Moreover, from the appendix it could be inferred that the box structure is constructed using aluminium plates soldered together by the edges. It seems to be contradictory and confusing.
  - Furthermore there is no information on how the internal components will be fixed. Once again from the appendix (see Figure 1) some idea on mounting holes could be inferred by looking at the technical drawings, but is rather confusing and no descriptions are provided.

  ACTION CDR-07: The team shall include clear information on the aforementioned aspects in Chapter 4.4.

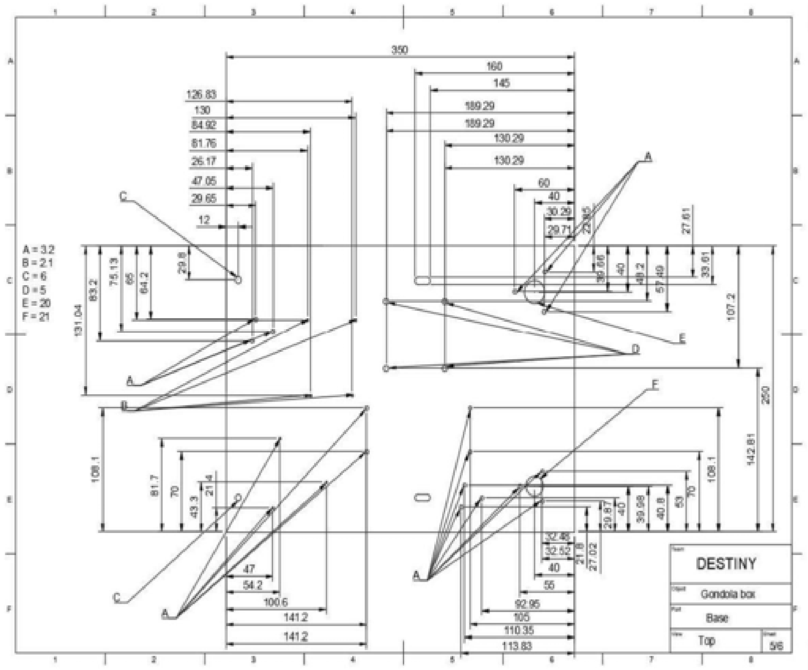


Figure 1. Technical drawing extracted from DESTINY SED.

- The team shall keep in mind that, for safety reasons, the upper box needs to be secured by an additional safety cable or flexible rope to prevent free falling parts from the flight train.
  ACTION CDR-08: The team shall mention these additional lines in the design in Chapter 4.2 and include the design of the corresponding attachment points.
- ACTION CDR-09: The team shall clearly specify the position of the lower box relative to the Gondola in Chapter 4.2 'Experiment Interfaces'.
- The team shall consider sealing the box against water and snow. Water by melting snow can flow into the narrowest gaps (see BX24_EXIST).
  ACTION CDR-10: The team shall provide leak protection for the experiment, based on the IP44 standard (recommended) or even IP67 standard (bath or shower).
  The flight train is a flexible structure which could stretch causing the Ethernet cable to break or get disconnected if it's too tight.
- ACTION CDR-11: The team shall leave some use a cable slightly longer than the distance between connectors (boxes to e-link).
- The team shall consider including some protection for the cable connectors to the boxes in order to avoid accidental disconnection derived from shocks, impacts or manhandling.
- The proposed design for the attachment of the main box to the Gondola is not convenient, as it requires screws to be inserted from the inside of the box. The team shall consider an alternative design for attaching the box which avoids the need of opening it to get it fixed to the Gondola.

- The consideration that the 'impact to the lower box comes from below' is not correct, as it strongly depends on ground winds (so the resulting impact will most probably not occur exactly in vertical direction).
    - The team shall expect non-standard launch environment conditions defined by uncharacterised shocks and vibrations (even 'rubbing' against the top of the Hercules launch vehicle).
    - The team is encouraged to take a look at the following video to get an idea of the loads which could be expected on the upper (flight train) box: https://www.youtube.com/watch?v=slAUpTryk0I

  ACTION CDR-12: The team shall consider stiffening the tube connecting the sensors to the boxes (see Figure 2) to prevent them from breaking during launch. Another solution could be making them flexible so they do not break when subjected to loads but plastically deform instead.

  ACTION CDR-13: The team shall consider manufacturing the disks in polycarbonate rather than Plexiglas, as it is less susceptible to damage.

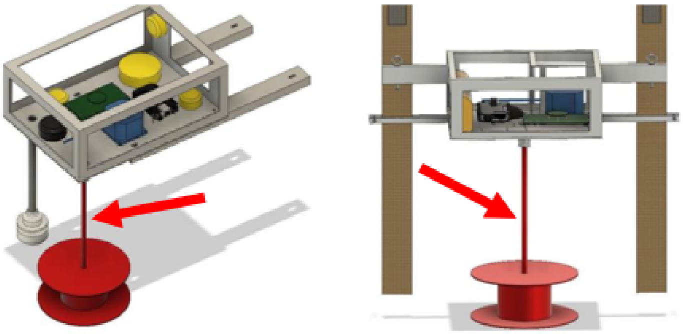


Figure 2. Tubes connecting the sensors to the boxes, extracted from DESTINY SED.

- ACTION CDR-14: The team shall include the vibration analysis in the annex.

ELECTRONICS AND DATA MANAGEMENT (SED chapter 4.2.2, 4.2.3, 4.5, 4.7, 4.9)

- ACTION CDR-15: The team shall clarify if a GPS/GLONASS receiver is included in one or the two boxes (Table 4.4 suggest only one whether Table 4.1 suggest two).
- ACTION CDR-16: The team shall clarify that two e-link connections will be used in the electrical interface Chapter 4.2.2.
- ACTION CDR-17: The team shall include the PCB layouts.
- The team shall strongly consider using a good quality Ethernet cable, with a good shielding, allocating if necessary, more budget for the cable.

THERMAL (SED chapter 4.2.4 & 4.6)

- ACTION CDR-18: The team shall analyse the heat dissipated by the electronic components before proposing a thermal control solution.
- ACTION CDR-19: As well, the team shall include into their thermal calculations the heat transferred through the box support (attachment bars) which will act as heat bridges. The team shall try to avoid these heat paths.
- ACTION CDR-20: The team shall provide an estimation of the heat transfer through the thermal insulation.
- ACTION CDR-21: The team shall ensure the 50 mm XPS material is suitable for vacuum environment as extruded polystyrenes expand when in vacuum and usually do not restore completely when back in ambient pressure, which might ruin the thermal cover.
- The team could consider attaching the heatsink with thermal silicone, which is thermally conducting but electrically isolating, if this would be a better solution than the proposed thermal paste or tape.
- ACTION CDR-22: Some information regarding the thermal management system could be found in the software section, although the team shall provide some of it in the thermal section, like for example, which are the conditions to be maintained inside the box (temperature ranges).
- In the thermal section it is stated that more information could be found in Appendix E, but this appendix has project planning information. No appendix with thermal control information was found.

  ACTION CDR-23: The team shall fix the error regarding missing appendices.

SOFTWARE (SED chapter 4.8)

- If the connection is lost during manual mode, then fail-safe TMS seems to suggest that the experiment is left to freeze.

  ACTION CDR-24: The team shall think logically about likely failure modes, the experiment objectives and recovery options.

- In general, the team seems to be using good methods for the software: the communication protocol, the modes, the way of using the Ethernet, the data rates, the commands for sending, the client server architecture, the solution for box synchronization, etc. Nevertheless the way it is written in the report might make it difficult to be translated into software.
  ACTION CDR-25: The team shall define in the SED which is the activity of each module.
- ACTION CDR-26: The team shall be precise when using the terms 'time synchronization' and/or 'time correlation' for the sake of clarity.

VERIFICATION AND TESTING (SED chapter 5)

- ACTION CDR-27: The team shall propose verification methods for their functional requirements. In the end, all the requirements, functional and non-functional shall be verified.
- ACTION CDR-28: The team shall describe all tests, as some of them seem to be missing from the document (Test 2.1, 3.2, 4.1, 5.2, 5.3).
- Some of the test procedures are vague making it difficult to discern whether or not they can verify the requirements.
  ACTION CDR-29: The team shall be specific and complete when describing their tests.
- The team shall take into account that test is rarely a standalone verification method, and is often proceeded by review and/or analysis. In particular, testing accuracy and range requirements via test is expensive, difficult and sometimes not necessary.
  ACTION CDR-30: The team shall consider whether these may be verified by review and whether that is acceptable for your experiment's primary objectives. (E.g. is it is that important to test the accuracy of the temperature sensor?)
- ACTION CDR-31: The team shall reconsider the following verification methods:
  - Requirement D3 shall be verified first by review and then by test (not by inspection).
  - Requirement D9 shall be verified by test, not by inspection.
  - Requirements D16, D17 and D18 have to be verified by test, not by review.
- Some test should have been completed already according to the proposed schedule.
  ACTION CDR-32: The team shall follow the test schedule.
- ACTION CDR-33: The team shall consider testing the sensitivity of the barometers to infrasound sources experimentally rather than computationally, if possible (Test 3.1).

SAFETY AND RISK ANALYSIS (SED chapter 3.5)

- ACTION CDR-34: The team shall consider using an additional safety line which could be a steel cable or a flexible rope (Dyneema) as a countermeasure for lowering risk SF10 and the risks in Table 6-2.
- ACTION CDR-35: The team shall be more precise when describing the risk of falling parts (SF10, SF20): which is the reason why this parts might fall?
- ACTION CDR-36: The team shall not renumber risks or create new risks with old risk IDs in future SED versions, as it makes it very difficult to track risk evolution.
- ACTION CDR-37: Risks related to thermal failure should be mitigated through analysis and test.
- ACTION CDR-38: The team shall consider barometer damage as a risk for the project, due the high cost of these devices.
- Project risks related to testing, manufacturing and transport are missing.
  ACTION CDR-39: The team shall consider including this risks in the risk register.
- Probability of risk MG20 is stated to be low but in the presentation you are presenting this risk as probable.
  ACTION CDR-40: Update this information and take the appropriate countermeasures.
- ACTION CDR-41: Split requirements MS10 and MS20, as they require actions for mitigation which might be completely different.
- ACTION CDR-42: The challenges presented in the last slide of the CDR presentation should be reflected in the risk register.

LAUNCH AND OPERATIONS (SED chapter 6)

- ACTION CDR-43: The team shall consider including 'remove before flight' protection for the sensors.
- ACTION CDR-44: The team shall update Chapter 6 to include the idea of using exploding balloons as infrasound sources.

ORGANISATION, PROJECT PLANNING & OUTREACH (SED chapters 3.1, 3.2, 3.3 & 3.4)

- There are no updates in the WBS, Gantt Chart, etc. This makes it difficult to get an idea on the progress of the project.
  ACTION CDR-45: The team shall update Figure 3.2 (top level Gantt chart) on page 21 as the progress line sits still at PDR. Same for the detailed Gantt chart in the appendix.
- As new team members are joining the project a proper knowledge transfer shall be ensured, with special attention on how the REXUS/BEXUS program is structured and its deadlines, emphasizing that no major design changes could be implemented after passing the CDR.

- ACTION CDR-46: The team shall double check the budget, there seem to be some errors when adding numbers up (Table 1).

Payload	Barometers	14 000 €
	Fibre optic gyrometer	12 000 €
	Anemometer	400 €
	Payload total	15 600 €

Table 1. Extract from Table 3.4 of DESTINY SED.

- Major components seem to be covered by sponsorships but is yet unclear where the funds to get all the rest of the minor components will come from.
  ACTION CDR-47: The team shall clarify where how this funds will be obtained.

- The outreach section is general good.
- ACTION CDR-48: The team shall include the Facebook, and website URLs in Chapter 3.
- The team developed a good website with nice level of detail and approachable. The team shall consider including dates, schedules, countdown clocks, etc. to make it even more attractive.
- On the other hand, the approach in Facebook is weak, with little content and updates.
- ACTION CDR-49: The team shall use the 'standard programme sentences' for their outreach, like the one presented below. All the details could be found in the Outreach Guidelines available on the TeamSite.

"The REXUS/BEXUS programme is realised under a bilateral Agency Agreement between the German Aerospace Center (DLR) and the Swedish National Space Agency (SNSA). The Swedish share of the payload has been made available to students from other European countries through the collaboration with the European Space Agency (ESA).

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

ADDITIONAL COMMENTS ON THE SCIENCE

- ACTION CDR-50: It is fundamental to test the main function of your experiment and characterize the instrument on ground, discerning between infrasound sources and noise. After the flight your system might be destroyed and characterization could not be possible anymore.

5. INTERNAL PANEL DISCUSSION

Summary of main actions for the experiment team:

- The team shall prove their experiment concept: this means calibrate and characterize the instrument, process the signals obtained, evaluate the signal to noise ratio, test the functionality on ground, etc.
- The team shall provide more detail on the mechanical design (attachments, disposition of internal components, clear structure of the boxes).
- The team shall provide more detail on the electronics design (PCB layouts).
- The team shall provide a complete thermal analysis of the experiment.
- The team shall provide a complete and updated project planning.

CDR RESULT: CONDITIONAL PASS
Next SED version due: v2-1, 1st July 2019

Integration Progress Review – IPR

BEXUS

Experiment Integration Progress Review

Page 1

1. REVIEW

Flight: BEXUS 28

Experiment: DESTINY

Review location: Polytechnic University Paris / France

Date: 17-18 July 2019

Review Board Members

Stefan Krämer (SSC)

Experiment Team Members

Théo Boyer	Gatien Fonmartin
Nathan Vaneberg	Sariah Al Saati
Louis Dubois	

1. GENERAL COMMENT

The team has exchanged members during the past two months with the exception of the team leader. This transition translates into a risk of knowledge loss. Design decisions which have been taken by the former team cannot easily be comprehended by the new team. Implementation and manufacturing of its design is more difficult if not all aspects are fully understood. The team is advised to question certain design aspects and discuss them with the old team regarding any occurring problem during manufacturing as well as during implementation and testing. The old team still has the responsibility of a full knowledge transfer.

A major part of the new team was present during IPR and showed strong interest and understanding of the program and a high motivation to keep on working on the DESTINY Project.

The stakeholders criticise the general responsiveness of the team in terms of deadlines and direct email contact. A successful and fruitful collaboration between the organisers and the team is highly depending on the correct flow of information in both directions. This also includes the flow of official information towards the whole team. Establish regular team meetings which are used to discuss the status, problems and to plan the next project steps as well spread important information internally.

1.2 Presentation

- The presentation was clear and detailed.

2. SED

- The team shall add more data about the sensors to be used in the specific chapters and add the datasheet in the Appendix.
- The team shall enable bookmark navigation when producing the pdf document.
- Thermal analysis is supposed to be in Appendix E, but there is no such thing. The document jumps from Appendix D to F. The team shall fix this problem.
- The hyperlinks are not working thought the document. The team shall fix this problem.

BEXUS

Experiment Integration Progress Review

Page 2

3. Hardware

- Following components were presented:
  - Anemometer.
  - 1 Barometer 800-1100 mBar. For flight the team will get 2 models with the range of 0-1000mbar.
  - Beaglebones as OBC.
  - 2 Set of Flight Batteries.
  - Prototype of inlet.
  - GPS.

2. FOLLOW UP ON CDR ACTION ITEMS

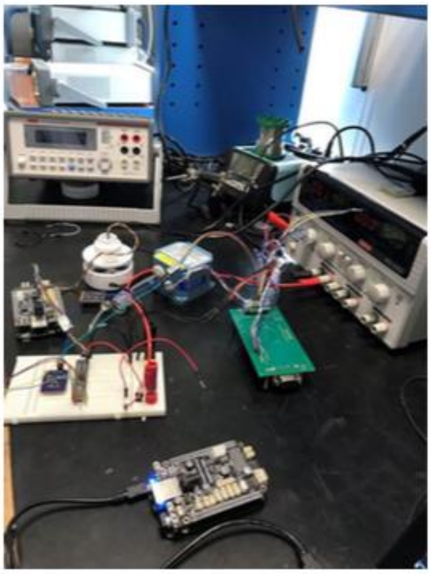
- The CDR action item list was discussed. Most actions were updated in the current SED but not in very deep detail.

3. PHOTOGRAPHS

	Beagle Bone, Sensor interfaces and anemometer.
	Anemometer.

BEXUS

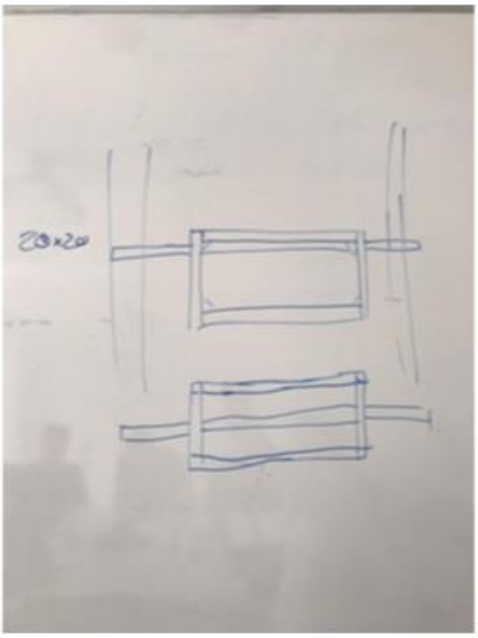
Experiment Integration Progress Review

	Test setup with barometer, anemometer, OBC and sensor interfaces.
	Sponsored SAFT Batteries for the upper box in the flight train. Two batteries are ready.

BEXUS

Experiment Integration Progress Review

Page 4

	Prototype of the inlet.
	Sketch for new profile based upper box in flight train.

4. REVIEW BOARD COMMENTS AND RECOMMENDATIONS

1. Science

- The inlet is a copy of the existing design. The team shall ensure that the flight model is correctly manufactured regarding the most important parameters (e.g. parallelism and alignment of disks to each other).
- The team shall design a test setup for the calibration of the barometric sensors with respect to one another:
    - Set the inlets at the same distance from a sound source.
    - Set a sound source in the same frequency range than the infrasound which is trying to be measured during flight.
    - Consider performing tests and calibration with a sound source inside a vacuum chamber.
- The team shall build the inlets as accurate and similar to each other to avoid influences due to differences in the signal path.
- The signal paths (tubes and hoses) have to be exactly the same for the main box and the secondary box in the flight train.

2. Requirements and constraints (SED chapter 2)

- No further comments.

3. Mechanics (SED chapter 4.2.1 & 4.4)

- The team recognised that the manufacturing of the boxes by welding is not convenient.
- The team shall consider using Item or Bosch Rexroth profiles. The team could get into contact with their local distributer to ask for the presentation and help with the design.
    - The team shall consider using a 20x20mm frame and close the sides with 1mm aluminium sheet.
    - The team shall fit check the new design inside the gondola 3D model (stp). The team shall use the CDR interface discussion presentation available on the Teamsite as a reference.
- The team shall use appropriate connectors for the pressure signal path to guarantee a reproducible length after connecting/disconnecting. Paroscientific uses PARKER components. The team can consider using PARKER or Swagelok.
  The team shall update the description of the new structural design in the SED_v4-0.
- The team shall analyse the structural strength of the new design.
- Currently the box has to be screwed to the Gondola rails from the inside. The team shall consider implementing the CDR recommendation on modifying the attachment system for the box located in the Gondola.

4. Electronics and data management (SED chapter 4.2.2, 4.2.3, 4.5 & 4.7)

- The team shall test the PCBs before connecting them to the any expensive sensor.
- The team shall check the set values for the sample frequency of the standalone devices and verify the data.
- PCBs are ordered and in production:
    - Power Interface Board.
    - Sensor Interface Board.
- Bread board with functions of Sensor Interface was presented and proven functional.
- The team shall start mounting and implementing the electronics as soon as they get the PCBs

- The team shall be careful when routing the cables. The team shall:
  - Avoid tension on the cables.
  - Use strain relief / cable pads.
  - Bundle cables if possible and necessary.
  - Use twisted pairs on power cables for heaters.
  - Use Teflon insulated cables.
- The team shall fixate the MOLEX connectors with glue before flight.
- The team shall fixate the Ethernet cable to the Beaglebone with a drop of silicone.
- The team shall order the male counterparts for the Ethernet MIL connector to "upgrade" the long Ethernet cable. These connectors enable the strain relief of the interface.

5. Thermal (SED chapter 4.2.4 & 4.6)

- The thermal simulation might need to be updated. The team shall verify the results by comparing them with a very simple model.
- During thermal and vacuum testing the team shall monitor the temperature of critical components.
- The team shall properly attach the temperature sensors with glue.
- The new structural design might show different thermal behaviour. The team shall reiterate the analysis taking the thermal mass and conductivity of the profiles into account.

6. Software (SED chapter 4.8)

- On board Software:
  - Read out of sensor:
    - Anemometer 1/512ms
    - Barometer 200Hz
    - GPS 1Hz
  - Test via USB – Ethernet not yet activated.
- Ground Station Software:
  - Almost ready.
  - Presentation of dummy data functional.

7. Verification and testing (SED chapter 5)

- The team shall be prepared for the vacuum test at CNES/Toulouse on the 16-20th September.
  - The team shall have a test plan based on the expected results.
  - The team shall compare the test data with the thermal analysis.
  - The team shall monitor the temperatures while testing.
- The team shall test the full setup inside the vacuum chamber. The team shall:
  - Perform full end-to-end test by using a signal source inside the chamber.
  - Verify the function of the experiment by:
    - Testing the signal path and comparing the two experiment parts.
    - Analysing the data.
  - The data shall be comparable regarding:
    - Signal to noise ratio.
    - Offset.
    - Timing (Very Important).
- The Thermal Chamber at campus in Paris can be used without previous booking.
- The team shall start scheduling the rest of the tests more in detail (specifying in which week each test is planned to be performed).
- The team shall propose a verification plan for the functional requirements.
- The team shall implement action CDR-31, proposing proper verification methods for requirements D3, D9, D16, D17, D18.

BEXUS

Experiment Integration Progress Review

Page 7

8.	Safety and risk analysis (SED chapter 3.4)

- No comments at this point.

9.	Launch and operations (SED chapter 6)

- The launch campaign was discussed based on the CDR Presentation.
- The team shall plan the tests to be done on battery (FCT) and on external power.
- The team shall provide a standard power interface and specify when they will need external power on the balloon pad and for which tests. Request it in chapter 6 of your SED.

10.	Organisation, project planning & outreach (SED chapters 3.1, 3.2 & 3.3)

- The Team has changed drastically after CDR. New team members which have not attended any other RXBX event until now were recruited and took over the major work on the project. The Team Leader Louis keeps the position and leads the new team.
- The new team members were introduced to the RXBX program, the structure and project flow as well as the stakeholders.
- The stakeholders criticise the general responsiveness of the team in terms of deadlines and direct email contact. It has to be mentioned that a successful and fruitful collaboration between the organisers and the team is highly depending on the correct flow of information in both directions. This also includes the flow of official information towards the whole team.
- The team shall consider regular team meetings to discuss the status, problems and the next project steps as well spread important information internally.
- The status line in the Gantt Chart is existing but not really representing the actual status. The team shall add either a progress bar or percentage completed on each task or adapt the status line to each task.
- The team shall include updates on the crowdfunding campaign.
- Last article on the website is dated April 2019, this is even before CDR. The team shall update the website.
- The team shall keep the Facebook page active.

11.	End-to-end Test

- The sensor readings of the barometer and anemometer were verified with the help of the OBC and the OBC software via USB connection.

5. FINAL REMARKS

1.	Summary of main actions for the experiment team

- The team shall verify with SUPAERO that the required barometers in the range 0-1000 mbar are available.
- ***Condition***: The team shall redesign the mechanical structure and provide a first CAD design latest on the 25th July. Discussion and decision on Telecon latest 26th July.
- ***Condition***: The team shall provide a short video of the main functions of the experiment as soon as the PCBs arrive and have been tested. Please upload the video on the TeamSite and inform ESA Education Office (Alexander Kinnaird, Rodrigo Ávila) and SSC PM (Stefan Krämer).

2.	Summary of main actions for the organisers

- Finding contact to F21 Team Luleå.
- Review mechanical redesign.

3. IPR Result: pass / conditional pass / fail

- Conditional pass.

4. Next SED version due

- 1 week prior to EAR. Date to be determined.

6. INTEGRATION PROGRESS REVIEW – IPR

Experiment documentation must be submitted at least five working days (the exact date will be announced) before the review (SED version 3). The input for the Campaign / Flight Requirement Plans should be updated if applicable. The IPR will generally take place at the location of the students' university, normally with the visit of one expert.

The experiment should have reached a certain status before performing the IPR:

- The experiment design should be completely frozen
- The majority of the hardware should have been fabricated
- Flight models of any PCB should have been produced or should be in production
- The majority of the software should be functional
- The majority of the verification and testing phase should have been completed

The experiment should be ready for service system simulator testing (requiring experiment hardware, electronics, software and ground segment to be at development level as minimum)

Content of IPR:

- General assessment of experiment status
- Photographic documentation of experiment integration status, with comments were necessary
- Discussion of any open design decisions if applicable
- Discussion of review items still to be closed
- Discussion of potential or newly identified review item discrepancies
- Discussion of components or material still to be ordered or received by the team
- Clarification of any technical queries directed towards the visiting expert
- Communication and functional testing (Service system simulator testing and E-link testing for REXUS and BEXUS respectively).

Experiment Acceptance Review – EAR

BEXUS

Experiment Acceptance Review

Page 1

1. REVIEW

Flight: BEXUS 28

Experiment: DESTINY

Review location: Ecole Polytechnique Paris / France

Date: 30 September 2019

Review Board Members

Stefan Krämer (SSC, Science Services, Payloads)

Experiment Team Members

Louis Dubois	Elsa Deville
Nathan Vaneberg	Sariah Al Saati
Gatien Fonmartin	Théo Boyer

2. GENERAL COMMENTS

2.1. Review Summary

The team presented a functioning and fully integrated experiment. All requirements were discussed and verified. The Implementation in general is good and only minor updates necessary.

The team shall now focus on the operation and reconsider the late access procedure

2.2. Mechanics

Net Mass (measured)	n/a	kg
Gross Mass (measured) GB	5.10	kg
Gross Mass (measured) FTB	5.92	kg

2.3. Electronics

Low Battery Voltage	24	0.52A
Average Battery Voltage	28.9V	0.46A
High Battery Voltage	30.9V	0.42A

- Measurement only GB which is running on BEXUS batteries.
- FTB is running on own battery – not included in measurement.

2.4. Software

Uplink	28kBit/s
Downlink GB	53kBit/s
Downlink FTB	51kBit/s

- Ground Station
  - Ground station GUI is clear and functional.
  - All data can be read out and displayed.
  - Ethernet connection is re-established after interruption.
- Experiment
  - Experiment software is finalised and all sensors are read out.

2.5. Verification and testing

- Testing Schedule is far developed.
- Extensive testing has been performed at CNES in Toulouse.

2.6. End-to-end Test

- End to end test was performed
  - All functions were verified.
  - Barometers.
  - Temperature sensors.
  - GPS (not functioning during test).
  - Current measurement.
  - Anemometer.

2.7. Launch Site requirements

- Clarify the late access as discussed:
  1. Mount experiment box to flight train
  2. Mount balloons to flight train
  3. Mount extra battery for pre heating
- Prepare a LATE ACCESS checklist and instruction for the launch crew and estimate a realistic time frame.

3. PHOTOGRAPHS

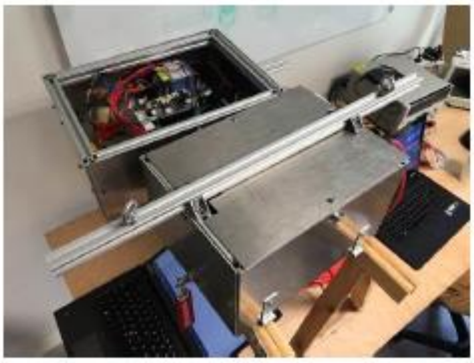
Gondola Box interior (GB)

Flight Train Box interior (FTB)

Inlet of FTB

Thermocouple and interface for Inlet of GB

Ground Station GUI



Flight Train Box

Insulation of FTB

Insulation for GB

4. REVIEW BOARD COMMENTS AND RECOMMENDATIONS

4.1. Science

- The experiment setup measures very small pressure changes – walking on the soft floor, opening of doors or windows.

4.2. Requirements and constraints (SED chapter 2)

- All verifiable requirements for this stage of the project are verified.

4.3. Mechanics (SED chapter 4.2.1 & 4.4)

- Mechanics looks fine.
- The team had changed the design to extruded aluminium profiles which simplified the manufacturing.
- The structure seems sturdy and safe.
- Safe attachment to the flight train.
- Remove sharp edges.

4.4. Electronics and data management (SED chapter 4.2.2, 4.2.3, 4.5 & 4.7)

- Provide an Amphenol female/female adapter to connect the FTB to the E-Link.
- The GPS stopped working under testing. This failure occurred before and need to be fixed. New GPS modules are ordered.

4.5. Thermal (SED chapter 4.2.4 & 4.6)

- Heater circuit verified.

4.6. Software (SED chapter 4.8)

- Ground Station
  - Software finalised and in testing.
  - No further comments.
- Experiment
  - Software finalised.
  - No further comments.

4.7. Verification and testing (SED chapter 5)

- Good testing progress. The team got support by CNES and could use the T-vac chamber.
- Even the test to qualify the inlets and compare the sound path was performed.

4.8. Safety and risk analysis (SED chapter 3.4)

- **No comments.**

4.9. Organisation, project planning & outreach (SED chapters 3.1, 3.2 & 3.3)

- Implementation and testing progress in time.
- Shipping 04th October.

4.10. End-to-end Test

- Was successfully performed.

5. FINAL REMARKS

5.1. Summary of main actions for the experiment team

- Fix the GPS Problem.
- Check E-Link interface Amphenol.
- Update Late Access Procedure and deliver new SED.

5.2. Summary of main actions for the organisers

- **Organise LKAB Blast**
- **Check E-Link latency**

5.3. EAR Result: pass / conditional pass / fail

- Pass.

5.4. Next SED version due

- SED v4-1 14th October 2019.

6. EXPERIMENT ACCEPTANCE REVIEW – EAR

Experiment documentation must be submitted at least five working days (the exact date will be announced) before the review (SED version 4) This will take place upon delivery of the completed experiment to EuroLaunch. The review may take place at either the location of the students' university, or a DLR, SSC or ESA institute.

Content of EAR:

- Team presentation of project status
- Follow-up of IPR action items
- Review of schedule status with respect to REXUS program timeline and upcoming activities
- Demonstration of the fully integrated experiment
- Experiment mass properties determination/discussion
- Mechanical and electrical interface checkout
- Electrical Interface Test (REXUS service system simulator test or BEXUS E-link functionality test)
- Flight Simulation Test (FST) – including a full end to end system demonstration
- Experiment acceptance decision: Passed/conditional pass/failed. If a conditional pass is elected, the immediate action items should be discussed, along with an appropriate deadline(s)

Appendix B OUTREACH AND MEDIA COVERAGE

Online presence:

- Website (destiny.binets.fr)
- Facebook page: facebook.com/Destiny-Project-254660291873036/

Traditional media coverage:

- An article was on the *École Polytechnique* website. Other articles are to be published in local magazines.

Exhibitions:

On January 31st 2019, the team has set up an exhibition stand for the *École Polytechnique* Space Week, an event gathering students and professionals of the space sector.

In December of 2019, a science fair was organised at the Ecole Polytechnique. We had the opportunity of showing our experiment and our results to high schools students that came for the event.

Logo:

Presentations:

Presentations have been made to high school students about the DESTINY project and planets study.

Appendix C ADDITIONAL TECHNICAL INFORMATION

1. SENSITIVITY OF THE SYSTEM

Consider the two barometers, $B_{Gondola}$ and $B_{Flight\ train}$, and an incoming infrasound wave with speed $\vec{c}$. Since the distance between the barometers h is about 30 meters, and the source of infrasound is located on the ground approximately 30 km below the balloon, we can consider that the wave is plane. Then, the time delay between the reception of the same signal by the two barometers is $T = \frac{h}{c\ cos(\alpha)}$, where α is the angle between the wave direction and the line between the two barometers.

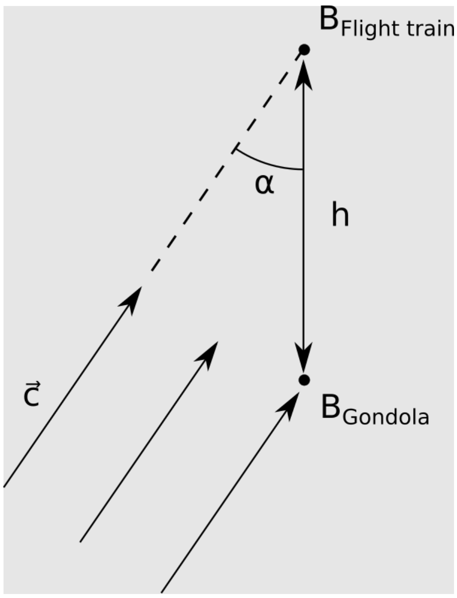


Figure C.1.1: Infrasound wave coming to the barometers

Taking the derivative, the error on the measurement of Tpropagates to α according to $\Delta\alpha \simeq \frac{c}{h}\Delta T$, with $c/h \simeq 600°/s$. Then, with a $1\ ms$ error on the reception delay, the error on α is less than 1°.

Now, let's analyse the sensitivity of the experiment to the position of the boxes. The system presented in the figure C.1.1 only measures the angle between the flight train and the incoming wave. However, what matters is the angle between the direction of the wave and a vertical axis, so the inclination of the flight train must be determined. This is done by accurately measuring the relative position between the two boxes (the angular rotation of the boxes is not a very important factor). The error on the alignment of the flight train then adds the error on α for the direction of the incoming wave. With a 5° error, requirement P8 is thus satisfied.

2. THERMAL CALCULATIONS

The model assumes uniform temperatures outside and inside the box, as well as a view factor of ½. The convective heat transfer coefficient used for our calculations is $h = 0.6W.K^{-1}.m^{-2}$.

We consider that the styrofoam insulation only conducts heat through a surface equal to the internal area of the insulation layer. However, to simplify the calculations, the box radiates with the maximum area. The values taken for the estimations below are those of the flight train box, the gondola box is in very similar conditions. The calculations are a worst-case scenario, with an outside temperature of $210K$ and convection.

Styrofoam surface emissivity	$\epsilon = 0.9$
Styrofoam surface solar absorption coefficient	$\alpha = 0.3$
Styrofoam heat conductivity	$\lambda = 0.033W.K^{-1}.m^{-1}$
Styrofoam insulation thickness	$L = 0.05m$
External area	$A = 0.20 \times 0.30 \times 4 + 0.30 \times 0.30 \times 2 = 0.42m^2$
Internal area	$A_{in} = 0.16m^2$
Solar absorption	$Q_{sun} = 30W$
Earth albedo	$Q_{eal} = 9W$
Earth IR radiation	$Q_{IR} = 11W$
Heat dissipation	$Q_{dis} = 2W(withoutgyrometer)$
Convection	$Q_{conv} = Ah(T_{ext} - T_{air}) = 0.252(T_{ext} - 210)$
Radiative heat transfer	$Q_{rad} = \epsilon A \sigma T_{ext}^4 = 2.06 \times 10^{-8} T_{ext}^4$

$$Q_{sun} + Q_{eal} + Q_{IR} + Q_{dis} + Q_{heat} - Q_{rad} - Q_{conv} = 0$$
$$T_{in} = T_{ext} + \frac{(Q_{dis} + Q_{heat})L}{(A_{in}\lambda)}$$

Using the fsolve python function, we reach $T_{in} = 292K$ with a heating power**.** The actual heating power should be weaker, as the only component we need to keep warm is the BeagleBone Black with a heating power of $Q_{heat} = 5W$.

3. POWER INTERFACE BOARD SCHEMATICS

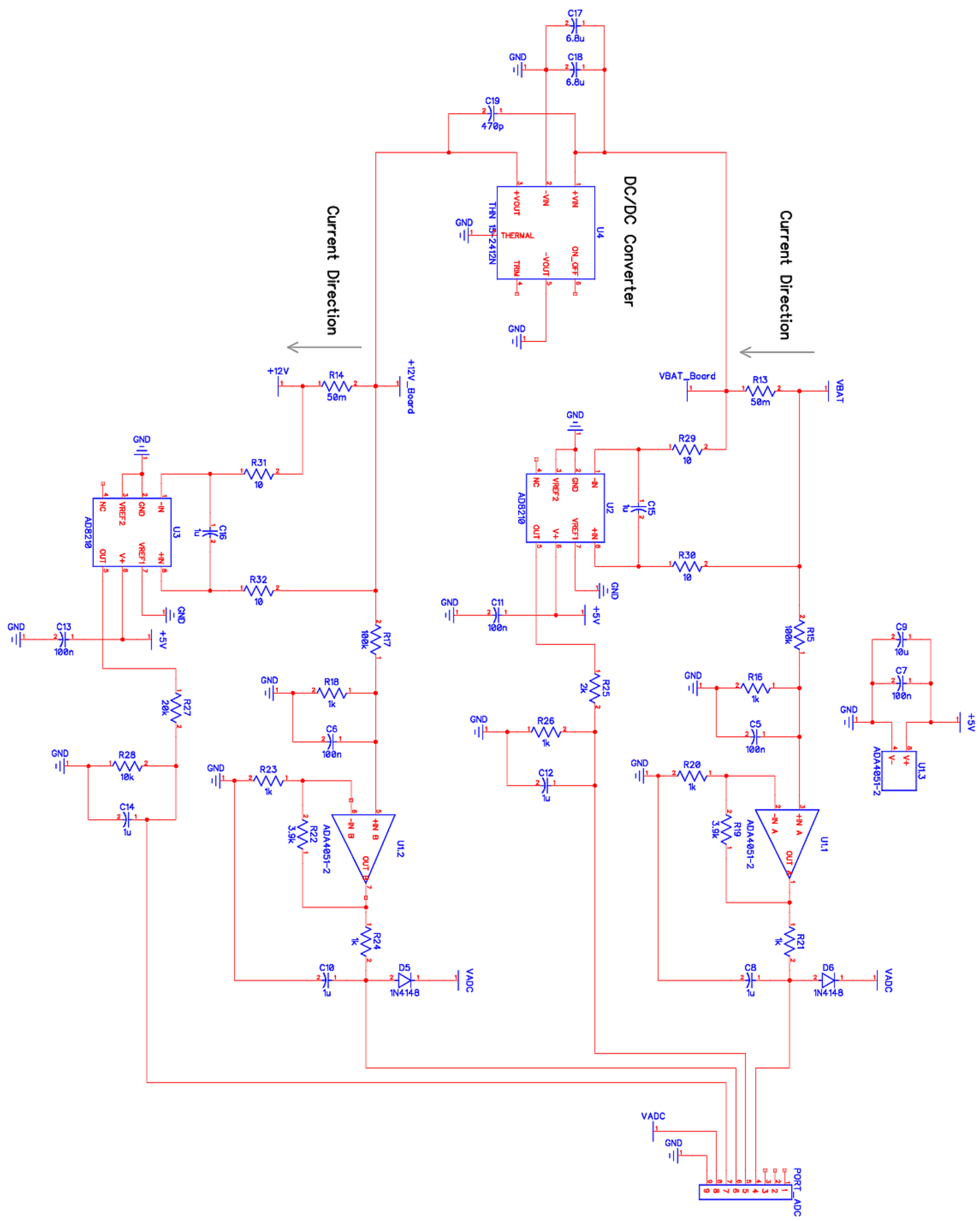


Figure C.3.1: Voltage regulation and monitoring

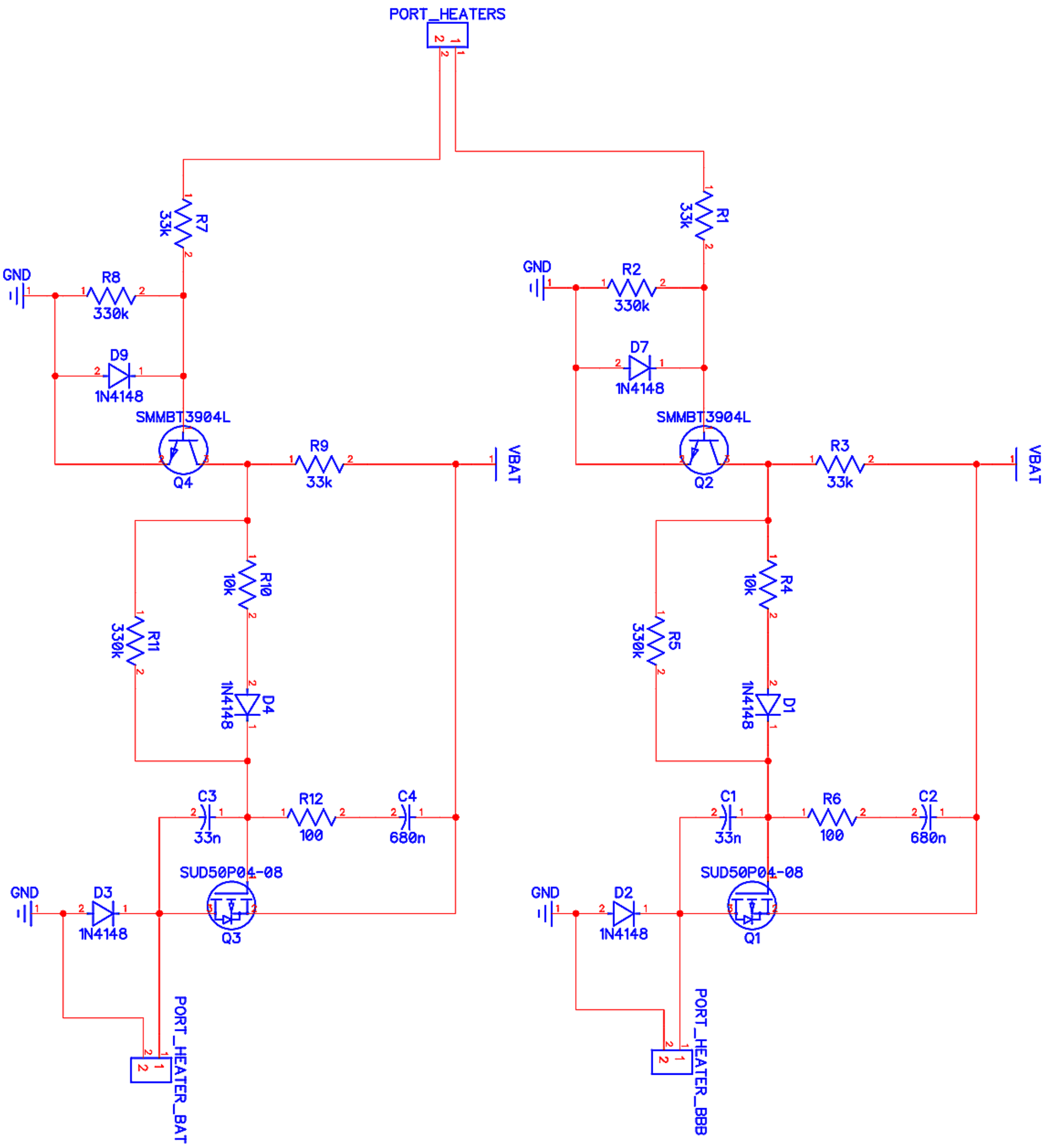


Figure C.3.2: Heaters driving

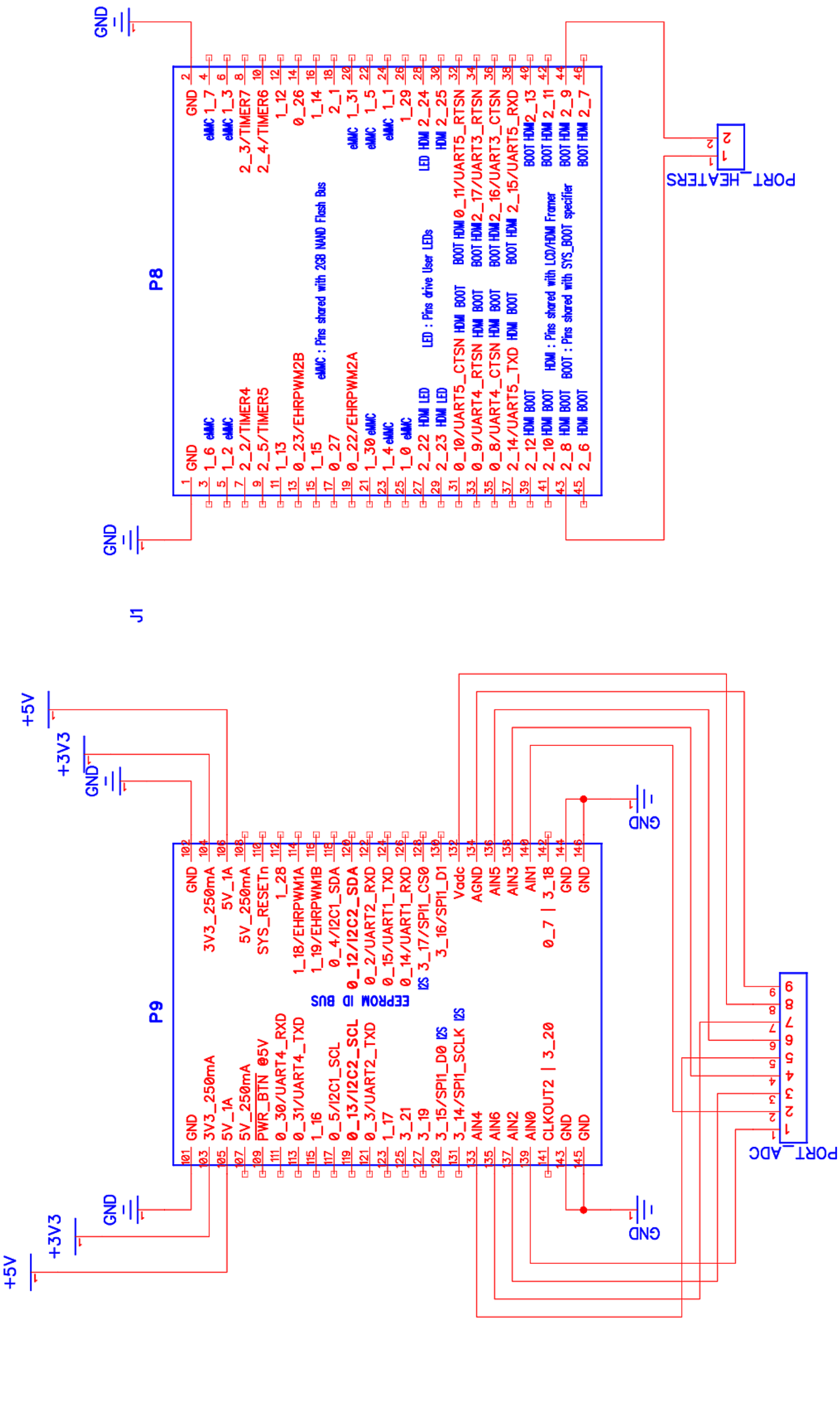


Figure C.3.3: Headers connections

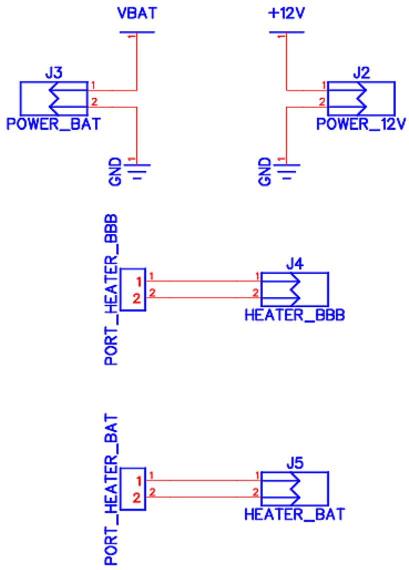


Figure C.3.4: External connections

4. SENSORS INTERFACE BOARD SCHEMATICS

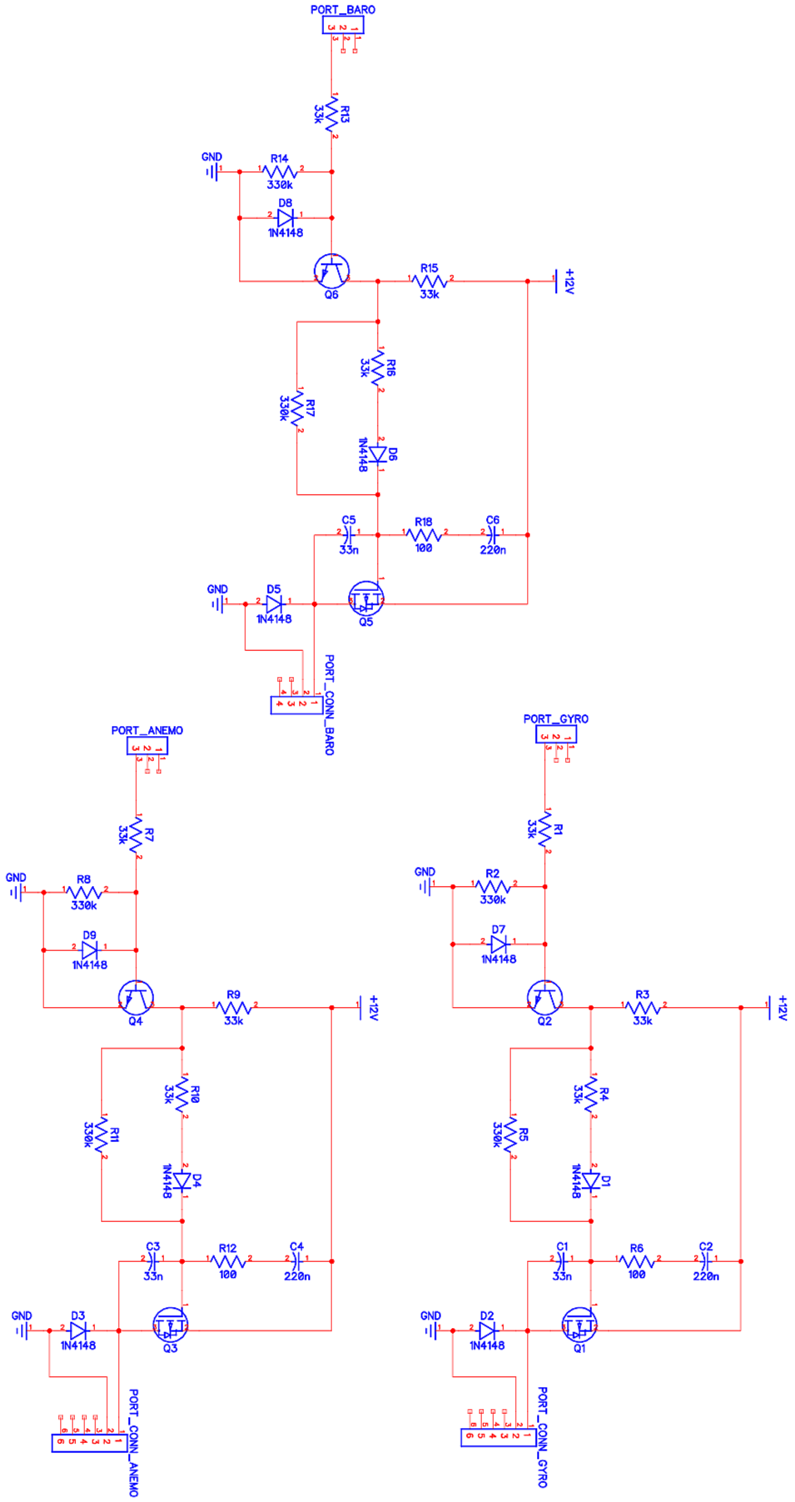


Figure C.4.1: Sensors powering

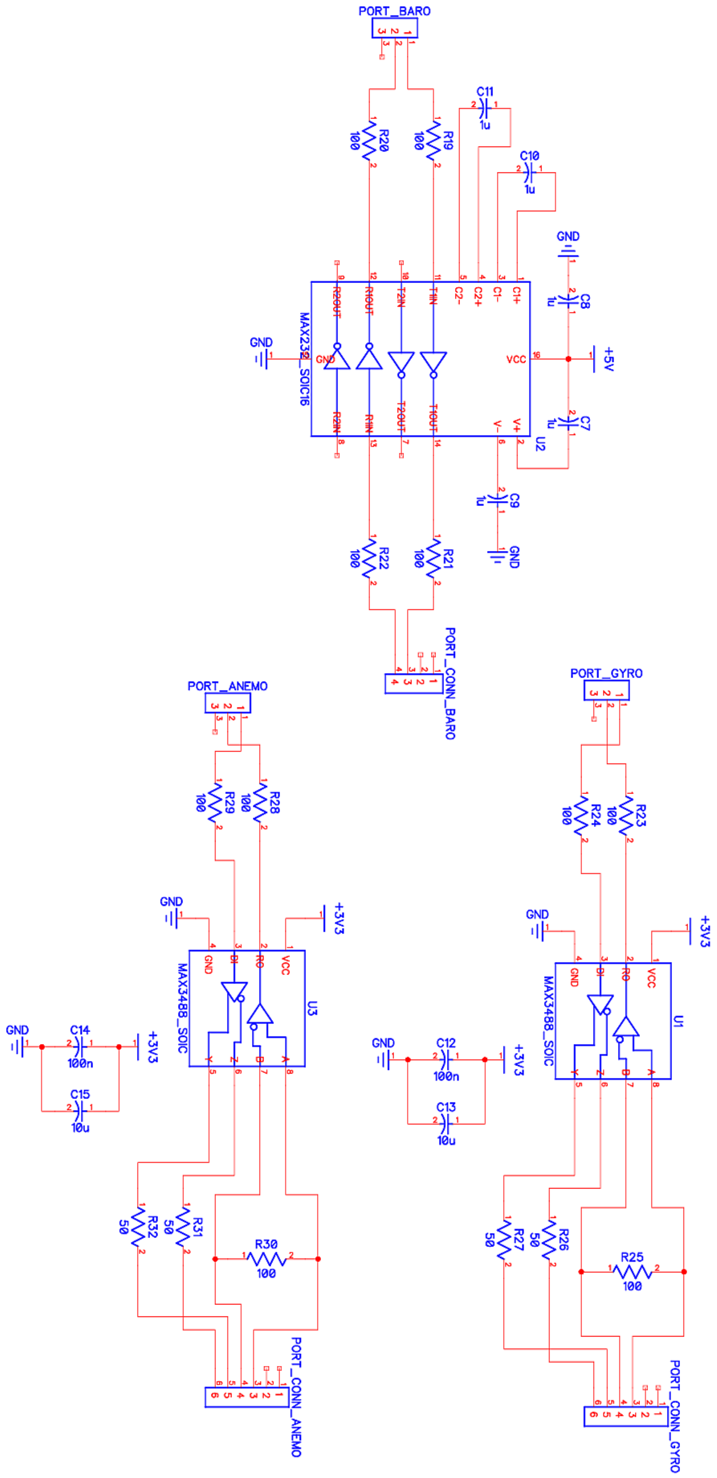


Figure C.4.2: Sensors logic level adaptation

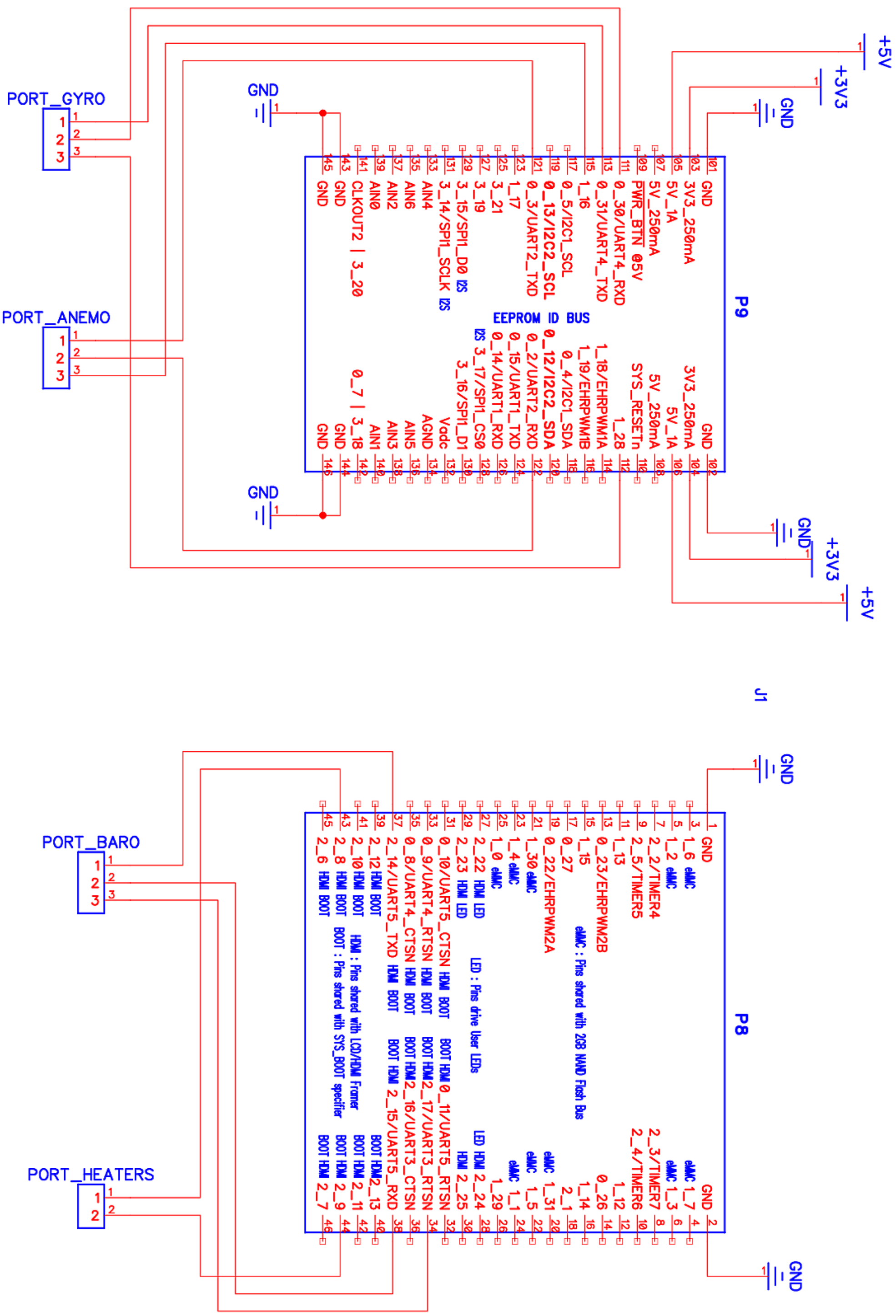


Figure C.4.3: Headers connections

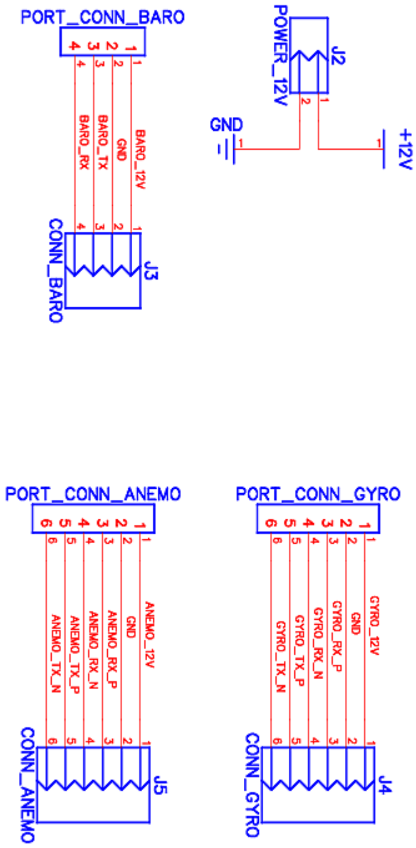


Figure C.4.4: External connections

5. SENSORS DATASHEET

Mesure de la vitesse du vent	0.25-40 m/s (0.5 – 80 knots)
Résolution de la mesure de vitesse du vent	0.1 m/s (0.1 knots)
Sensibilité de la mesure de vitesse du vent	0.13 m/s (0.25 knots) Independent of weather conditions
Mesure de la direction du vent	0-359 °
Résolution de la mesure de la direction du vent	1°
Sensibilité de la mesure de la direction du vent	+/- 1 °
Alimentation nécessaire	8 V to 33 V DC
Consommation électrique	9 mA
Dimensions du capteur	4 s
Délai de démarrage	Cylinder Ø 64 mm - height 61 mm
Câble	35 cm standard delivery 4x0.22 mm².
Bras support	16 mm de diamètre
Poids du câble	100 gr
Température opérationnelle	-15°C to +55°C
Environnement	Sensor IP67
Marque CE	EN 55022 EN 55024

Figure C.5.1: Anemometer datasheet

TCXO or Crystal	GNSS	GPS & GLONASS
Max navigation update rate	NEO-M8N NEO-M8M/Q	5 Hz 10 Hz
Velocity accuracy [7]		0.05 m/s
Heading accuracy [7]		0.3 degrees
Horizontal position accuracy [8]	Autonomous SBAS	2.5 m 2.0 m
Accuracy of time pulse signal	RMS 99%	30 ns 60 ns
Frequency of time pulse signal		0.25 Hz…10 MHz
Operational limits [9]	Dynamics Altitude Velocity	≤ 4 g 50,000 m 500 m/s

Figure C.5.2: GPS datasheet

Absolute and Gauge Pressure Transducers Series 2000

Series 2000 Absolute Pressure Transducer

Series 2000 Gauge Pressure Transducer

RANGES
10 Absolute Ranges
0-15 psia to 0-500 psia
7 Gauge Ranges
0-2 psig to 0-200 psig

APPLICATION AREAS
Metrology
Hydrology
Aerospace
Meteorology
Oceanography
Laboratory Standards

FEATURES
0.01% Accuracy
0.0001% Resolution
Frequency Outputs
Low Power Consumption
NIST Traceable Calibration
High Stability and Reliability
On-Board Application Memory
ISO 9001:2000 Quality System
Fully Calibrated and Characterized
On-Board Coefficient Storage (DDS)

Figure C.5.3: Barometers datasheet

Appendix D FLIGHT TRAIN BOX DETACHMENT PROCEDURE

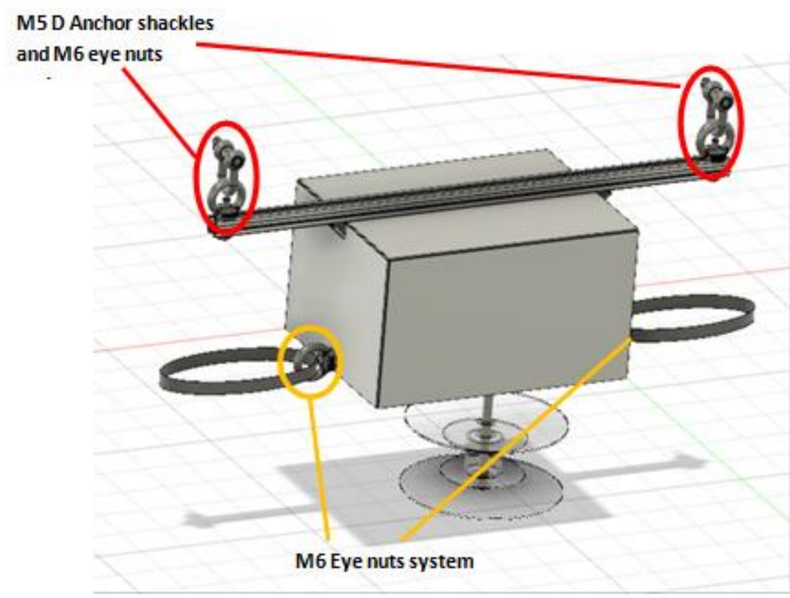


Figure D.1: The fixation system of the flight train box to the flight train.

Figure D.2: The M6 eye bolts connected to M5 D anchor shackles sewed on the flight train.

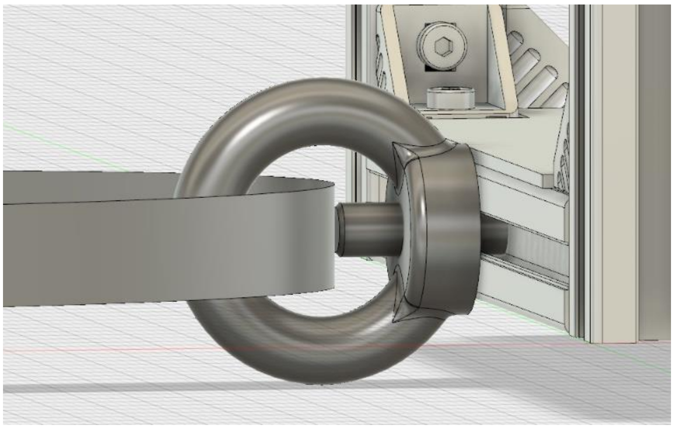


Figure D.3: Attachment of the straps that wrap round the flight train to the bottom of the box, to prevent the rotation of the box

STEP 1:

- **DETACH THE SECURITY STRAPS ATTACHED TO THE FLIGHT TRAIN AND TO THE BOTTOM OF THE BOX ON EITHER SIDE**

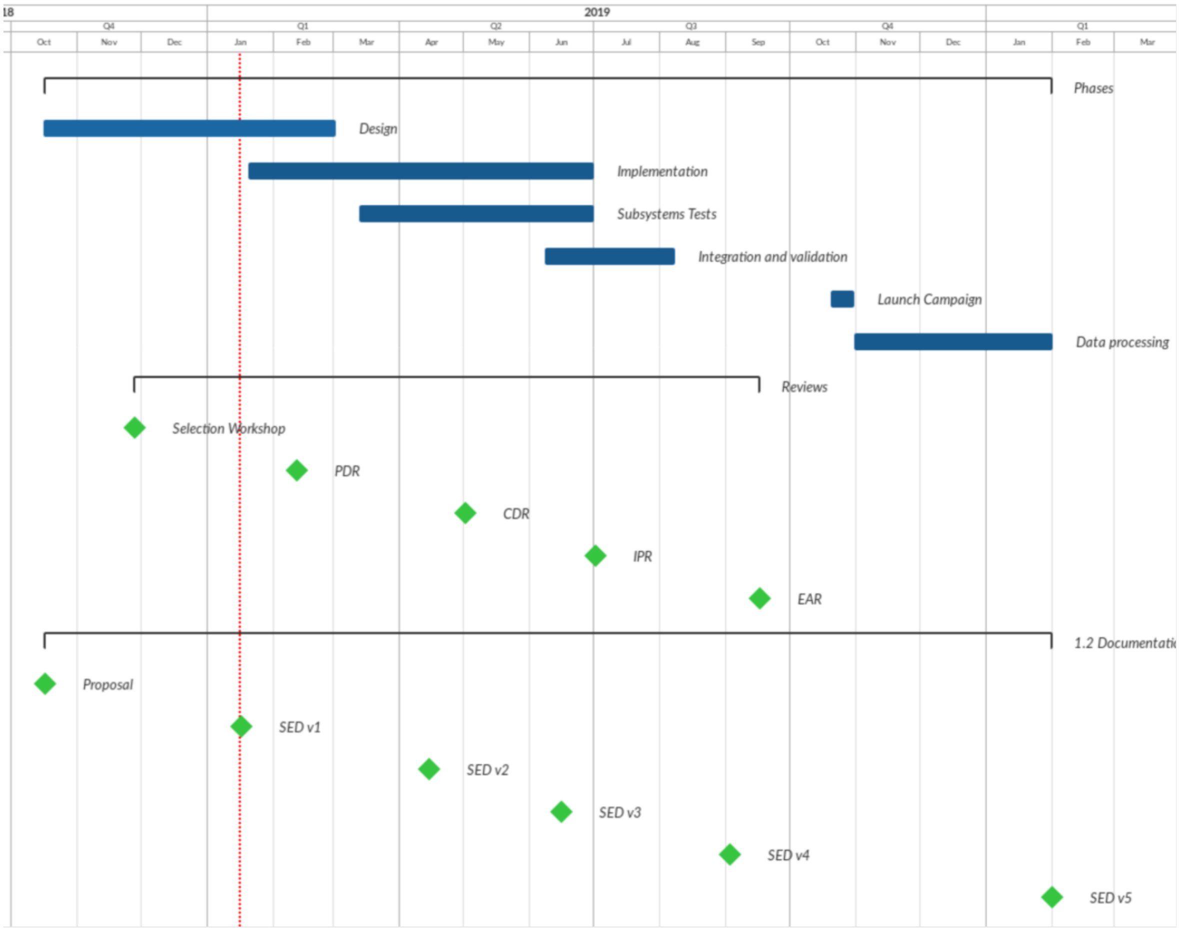
STEP 2:

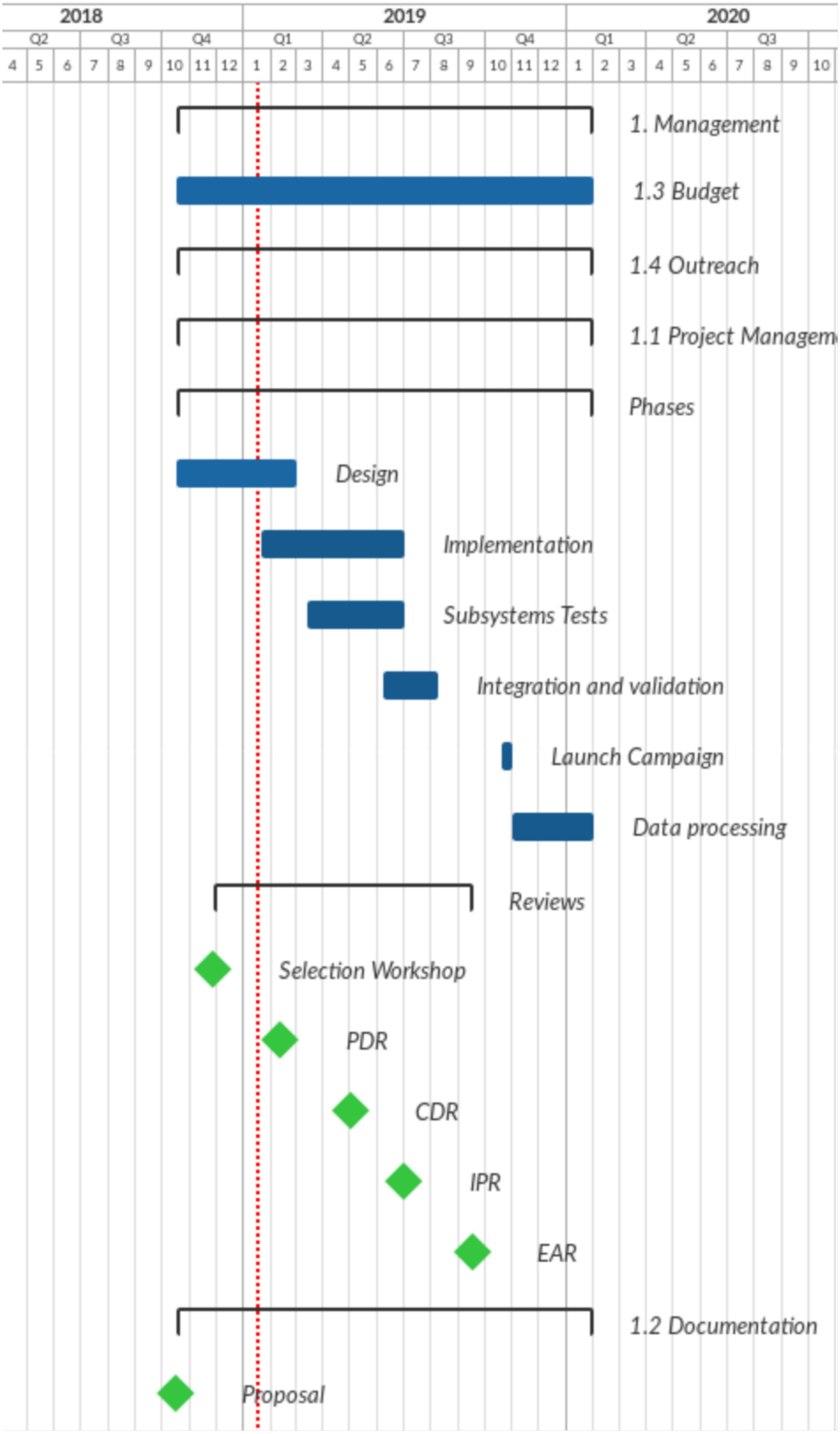
- **LOOSEN THE M5 D ANCHORS FROM THE SHACKLES AND DETACH THE SHACKLES FROM THE EYE BOLTS.**
- **RECOVER THE BOX**

STEP 3:

- **REMOVE THE ISOLATION BY REMOVING THE TAPE THAT HOLDS IT TO THE BOX.**
- **TO ACCESS THE BATTERY, OPEN THE SIDE OF THE BOX FIXED WITH HINGES BY UNLATCHING THE SECURITY. UNPLUG IT, REMOVE IT AND THEN, STORE IT IN A NON-FLAMMABLE BOX**

Appendix E PROJECT PLANNING

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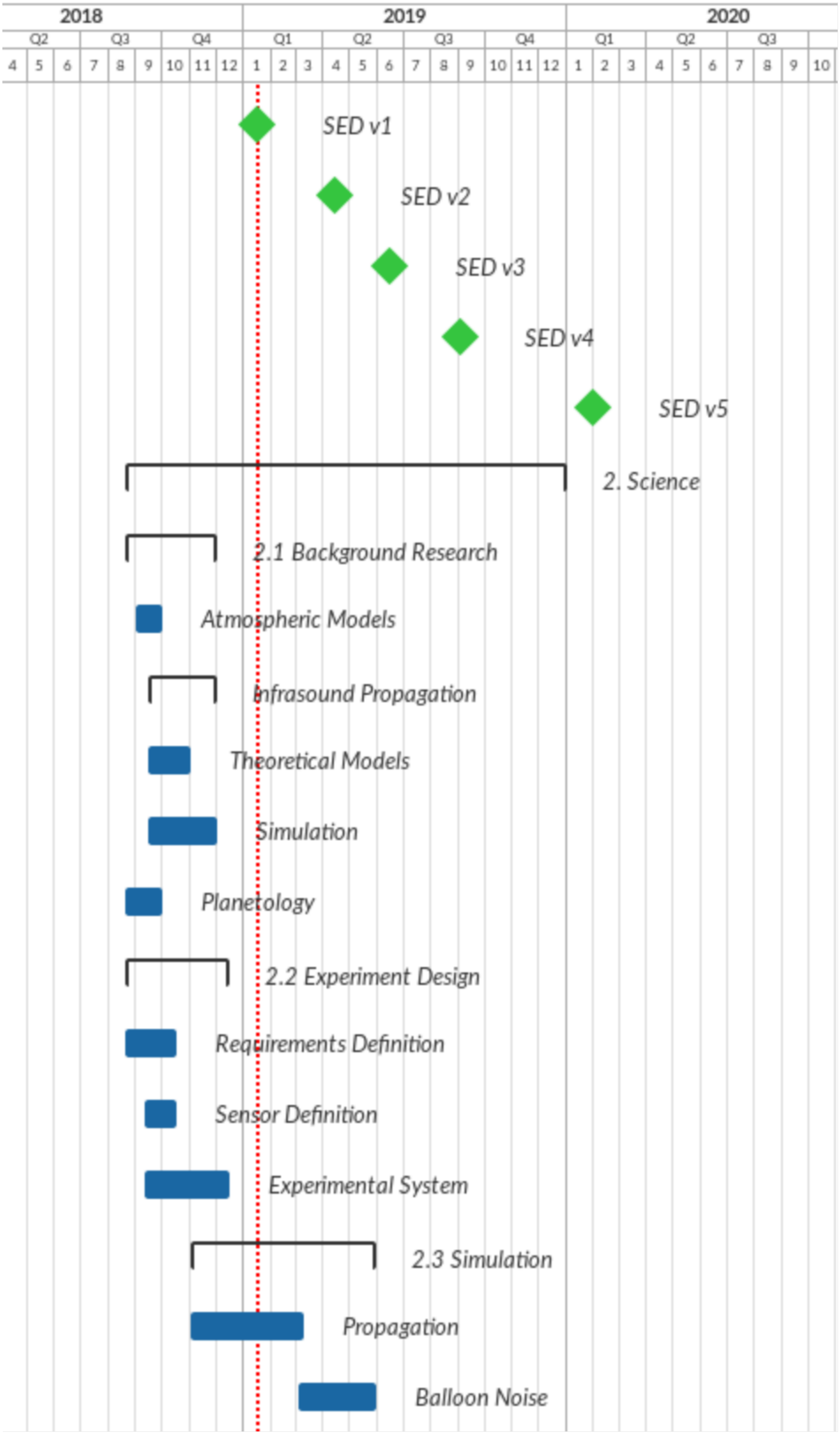
1. Management
1.3 Budget
1.4 Outreach
Phases
Design
Implementation
Subsystems Tests
Integration and validation
Launch Campaign
Data processing
Reviews
Selection Workshop
PDR
CDR
IPR
EAR
1.2 Documentation
Proposal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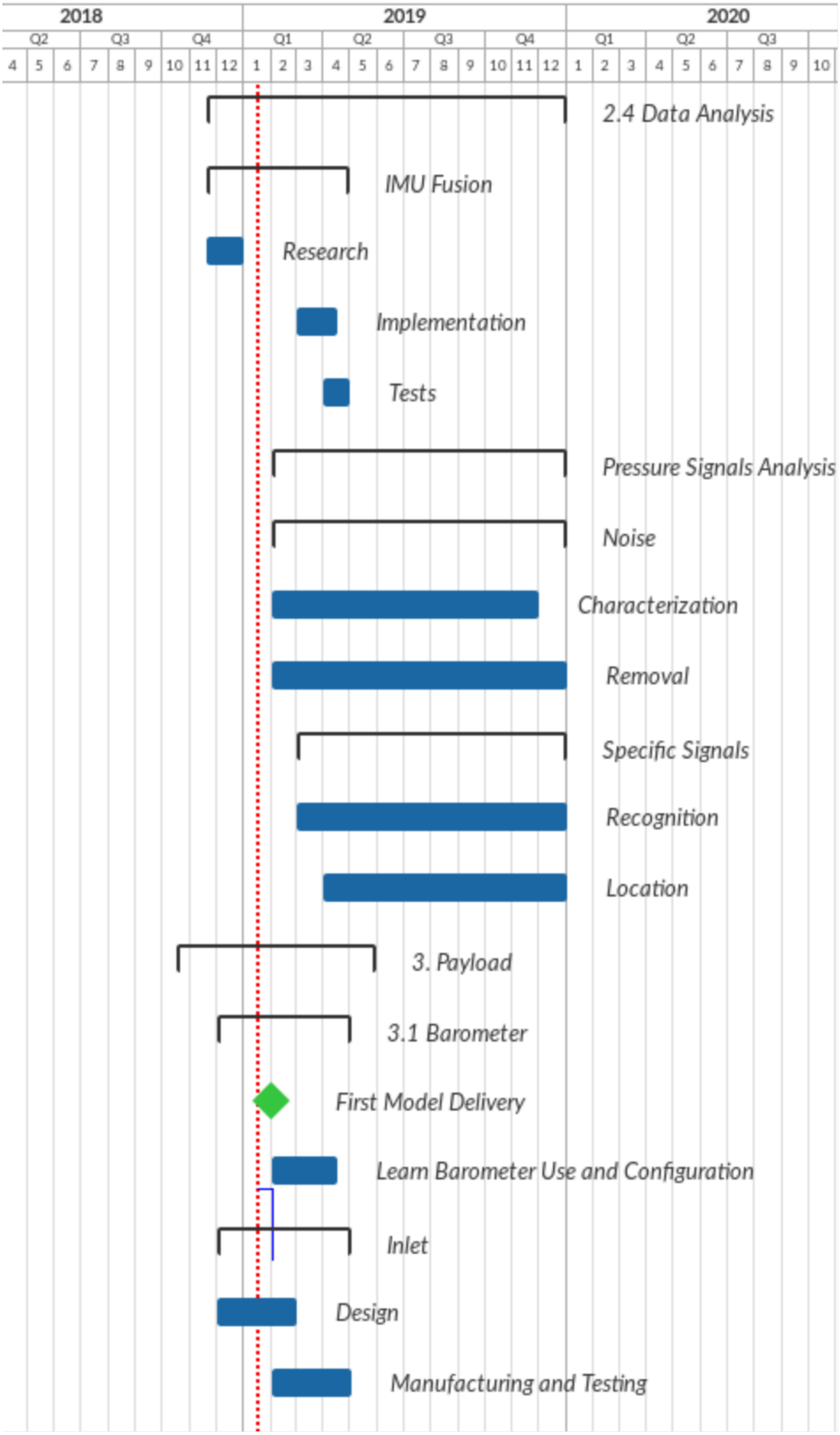
SED v1
SED v2
SED v3
SED v4
SED v5
2. Science
2.1 Background Research
Atmospheric Models
Infrasound Propagation
Theoretical Models
Simulation
Planetology
2.2 Experiment Design
Requirements Definition
Sensor Definition
Experimental System
2.3 Simulation
Propagation
Balloon Noise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2.4 Data Analysis
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Noise
Characterization
Removal
Specific Signals
Recognition
Location
3. Payload
3.1 Barometer
First Model Delivery
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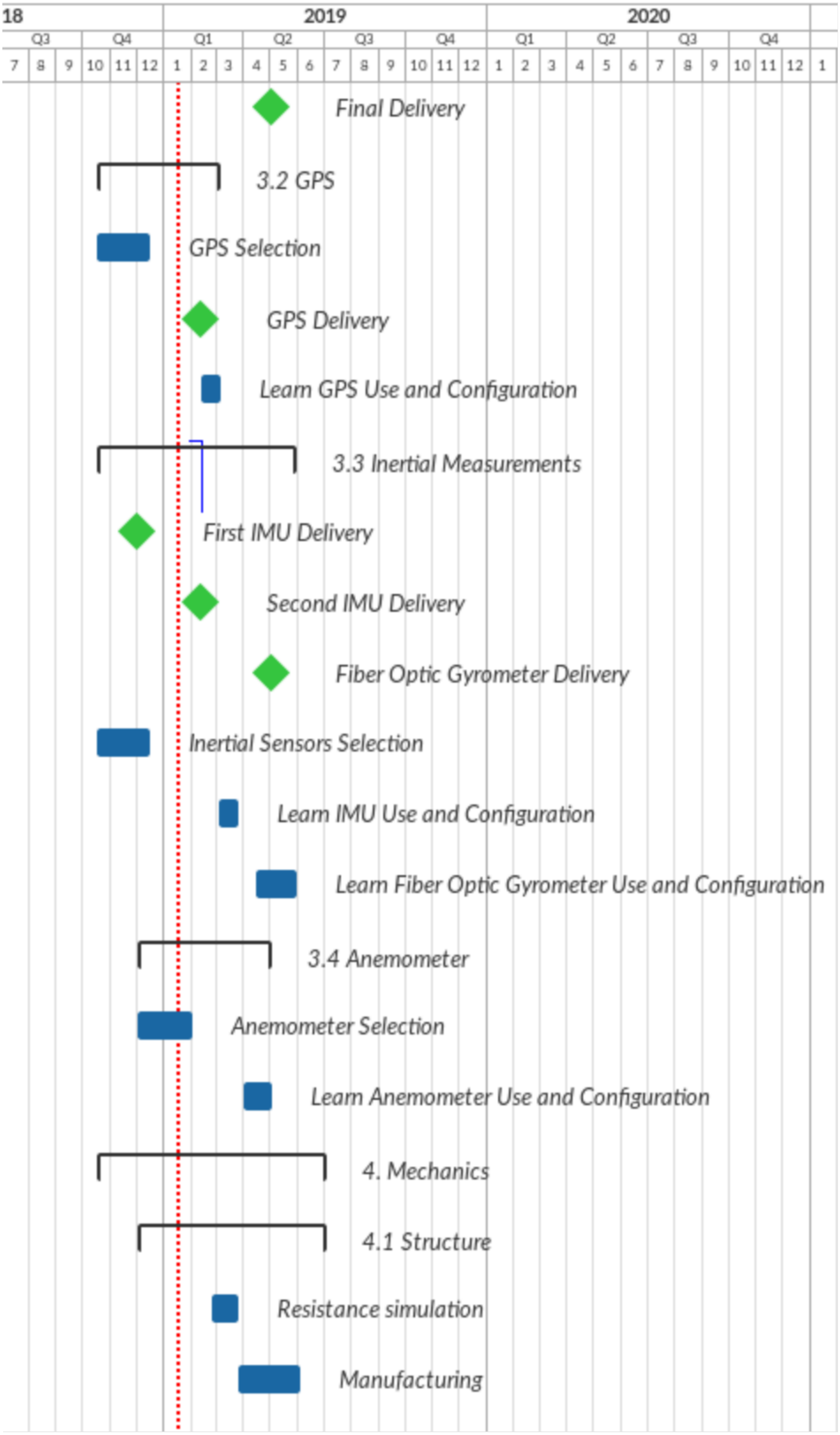
Inlet
Design
Manufacturing and Testing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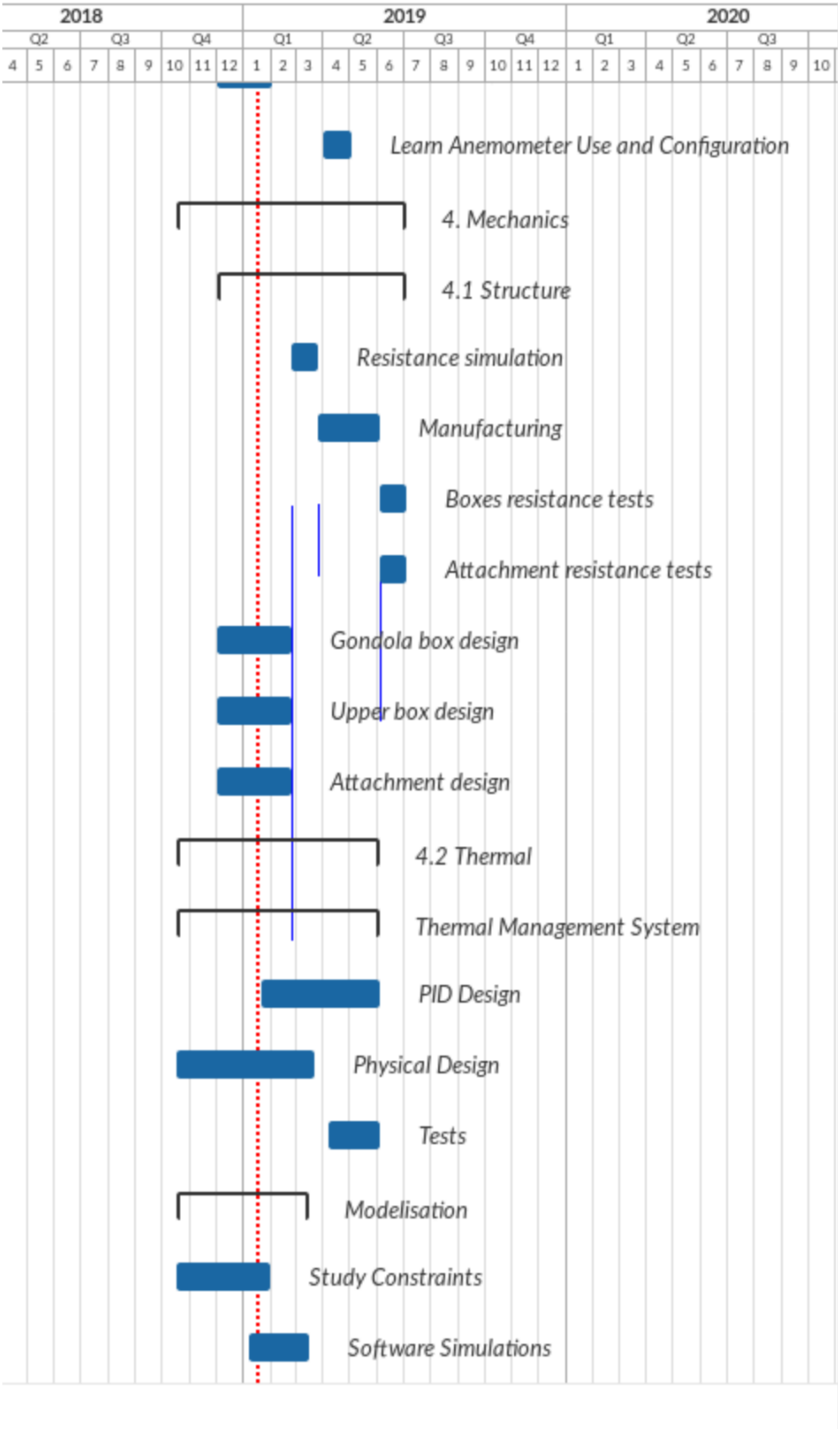
Final Delivery
3.2 GPS
GPS Selection
GPS Delivery
Learn GPS Use and Configuration
3.3 Inertial Measurements
First IMU Delivery
Second IMU Delivery
Fiber Optic Gyrometer Delivery
Inertial Sensors Selection
Learn IMU Use and Configuration
Learn Fiber Optic Gyrometer Use and Configuration
3.4 Anemometer
Anemometer Selection
Learn Anemometer Use and Configuration
4. Mechanics
4.1 Structure
Resistance simulation
Manufacturing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Learn Anemometer Use and Configuration
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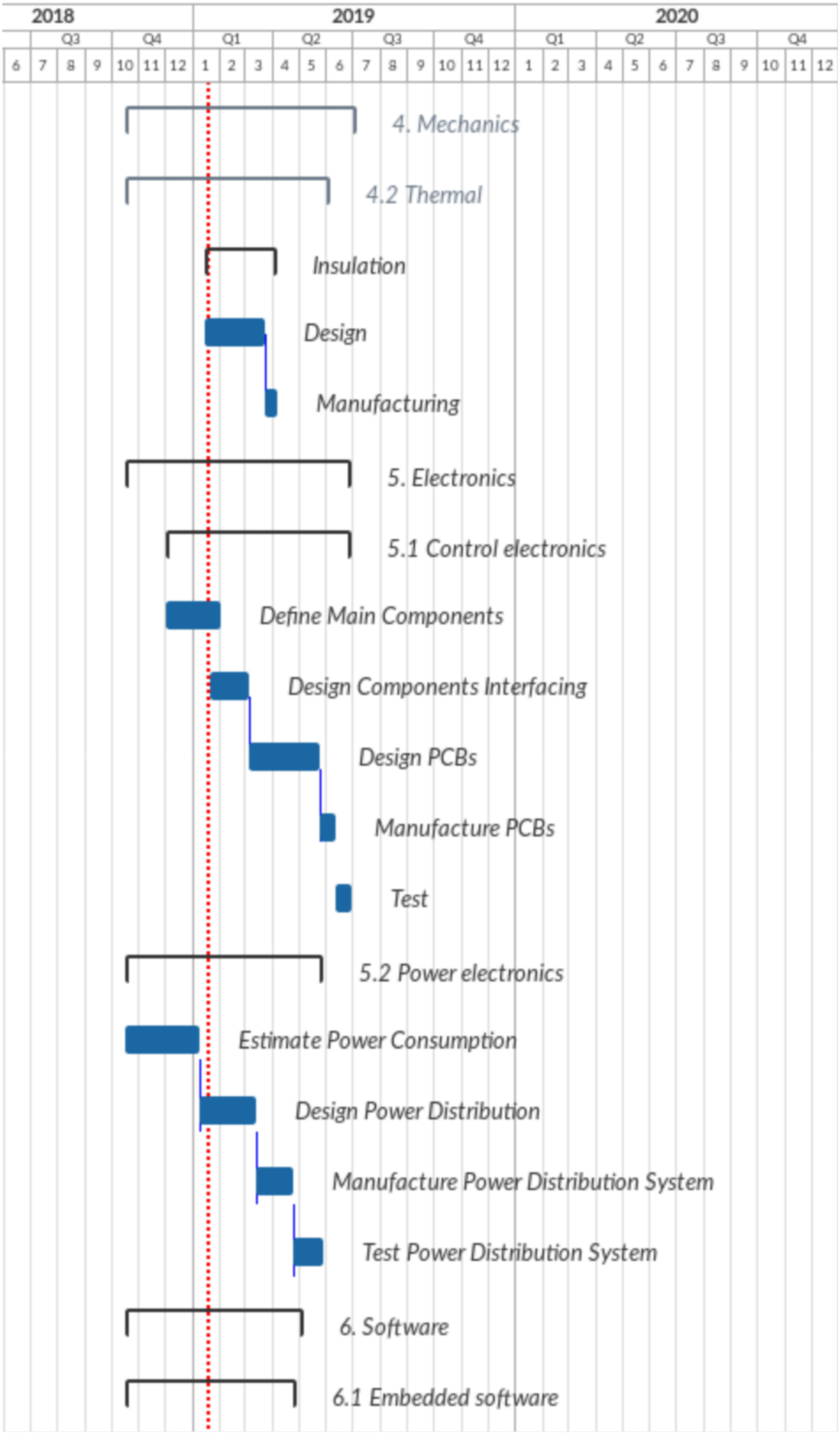
4.1 Structure
Resistance simulation
Manufacturing
Boxes resistance tests
Attachment resistance tests
Gondola box design
Upper box design
Attachment design
4.2 Thermal
Thermal Management System
PID Design
Physical Design
Tests
Modelisation
Study Constraints
Software Simulations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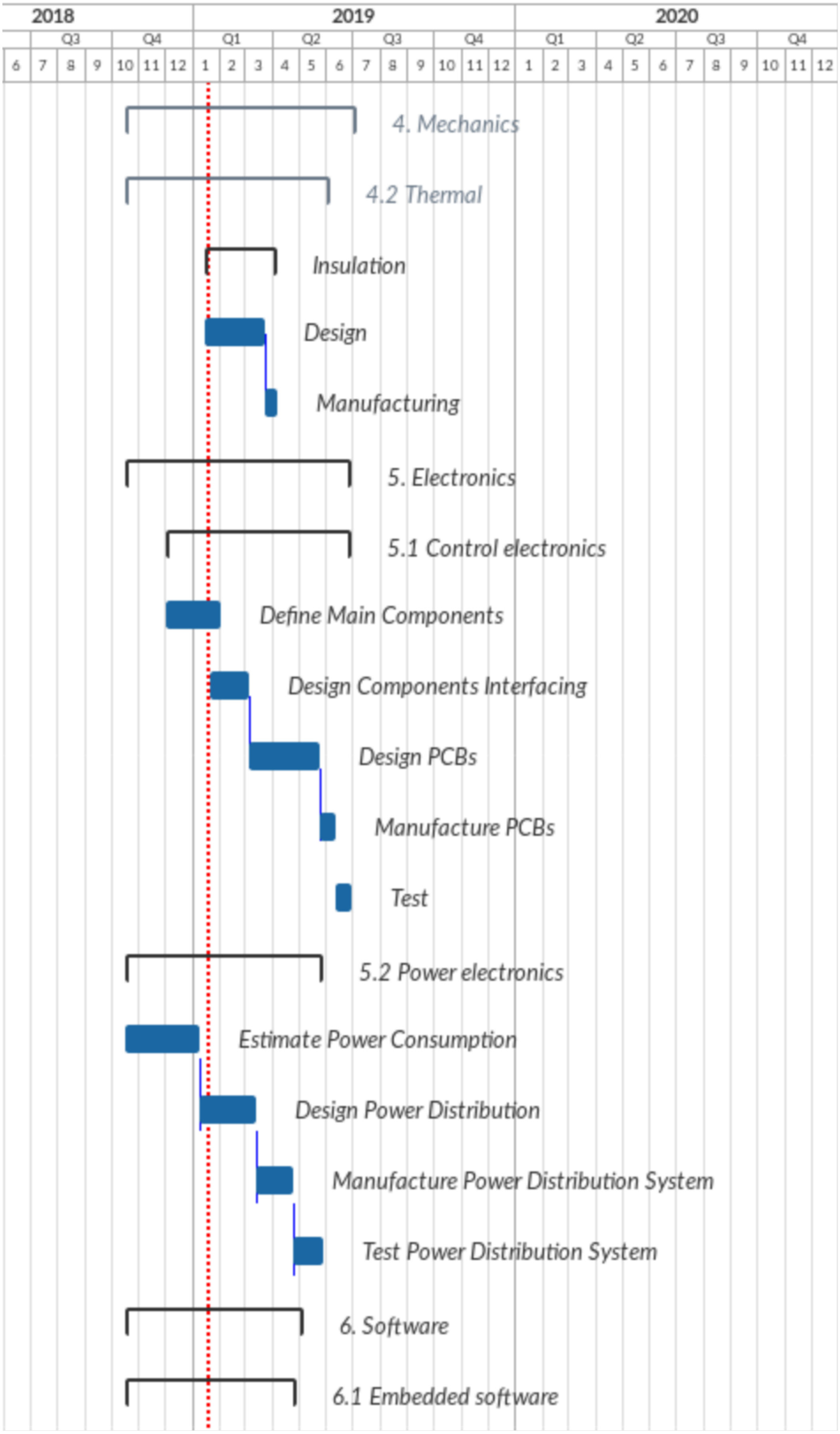
4. Mechanics
4.2 Thermal
Insulation
Design
Manufacturing
5. Electronics
5.1 Control electronics
Define Main Components
Design Components Interfacing
Design PCBs
Manufacture PCBs
Test
5.2 Power electronics
Estimate Power Consumption
Design Power Distribution
Manufacture Power Distribution System
Test Power Distribution System
6. Software
6.1 Embedded software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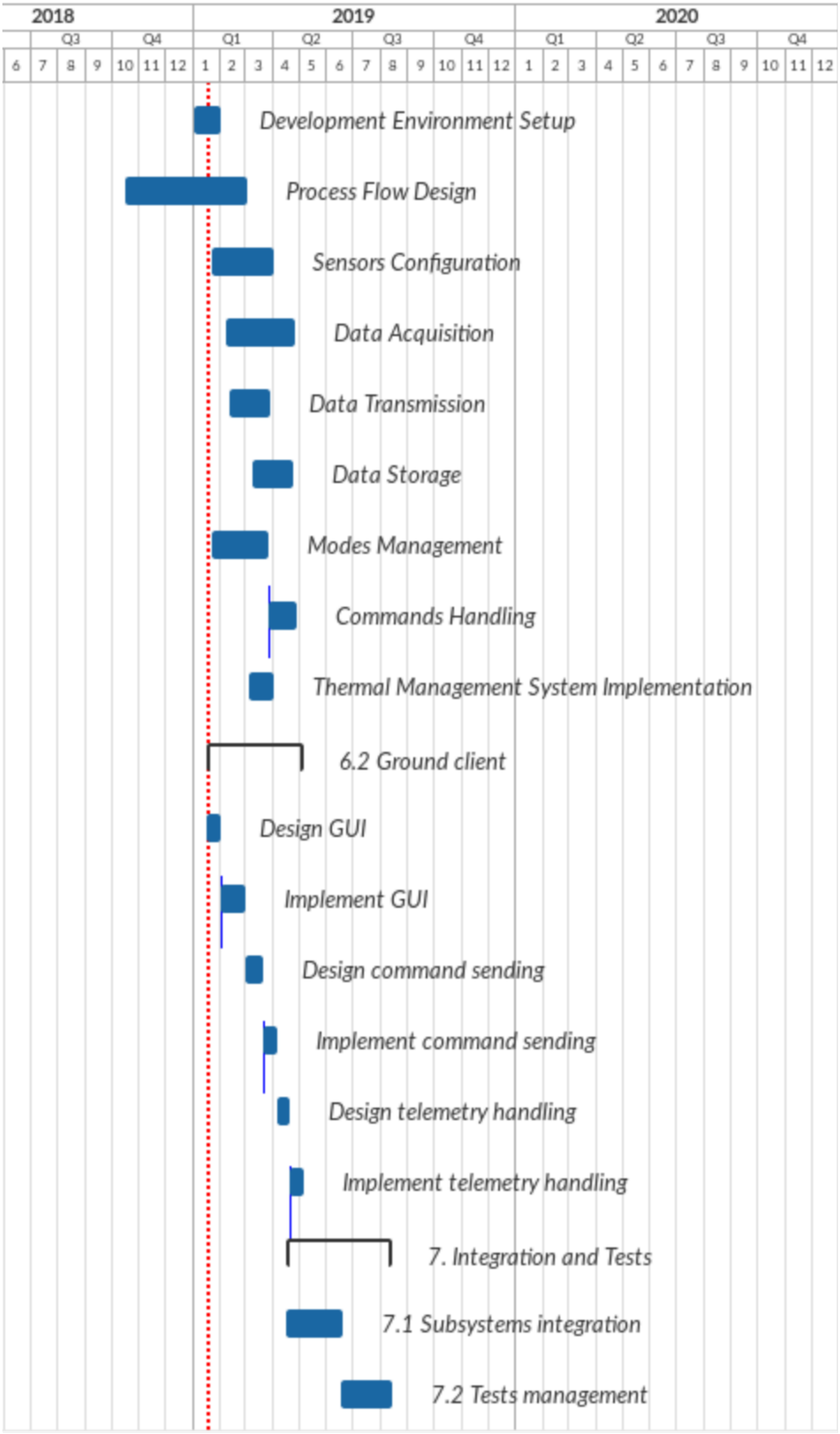
4. Mechanics
4.2 Thermal
Insulation
Design
Manufacturing
5. Electronics
5.1 Control electronics
Define Main Components
Design Components Interfacing
Design PCBs
Manufacture PCBs
Test
5.2 Power electronics
Estimate Power Consumption
Design Power Distribution
Manufacture Power Distribution System
Test Power Distribution System
6. Software
6.1 Embedded software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Development Environment Setup
Process Flow Design
Sensors Configuration
Data Acquisition
Data Transmission
Data Storage
Modes Management
Commands Handling
Thermal Management System Implementation
6.2 Ground client
Design GUI
Implement GUI
Design command sending
Implement command sending
Design telemetry handling
Implement telemetry handling
7. Integration and Tests
7.1 Subsystems integration
7.2 Tests management

Appendix F BALLOONS

We consider a balloon which move from the ground to an altitude A in the troposphere (altitude between 0 m and 10000 m). The balloon is closed so the quantity of air inside is constant: we can call it n0.

We used a model of evolution of the pressure in the troposphere depending on the altitude z:

$$p(z) = p0 * e^{\frac{-7*g}{2*Cp*T0}*z}$$

Where p0 is the pressure on the ground (101 325 Pa), g is the acceleration of the gravity 9,81 m.s^-2, Cp is the thermal capacity at constant pressure of the air and T0 is the temperature on the ground (293K).

We supposed that the balloons are perfectly elastic which means that the pressure inside and outside the balloons are equal.

So now we can use the ideal gas law:

$$Psol - Palt = n0 * R * (\frac{Tsol}{Vsol} - \frac{Talt}{Valt})$$

$$p0 * (1 - e^{\frac{-7g}{2*Cp*T0}*zalt}) = n0 * R * (\frac{Tsol}{Vsol} - \frac{Talt}{Valt})$$

To determine Talt for every altitude we used a model of temperature in the atmosphere available at the end. T0 will be measured before the launch.

By dividing by p0 we have:

$$(1 - e^{\frac{-7g}{2*Cp*T0}*zalt}) = \frac{n0 * R}{p0} * (\frac{Tsol}{Vsol} - \frac{Talt}{Valt})$$

And $n0 * \frac{R}{p0} = \frac{Tsol}{Vsol}$

So: $$1 - e^{\left(-7*\frac{g}{2*Cp*T0}*zalt\right)} = 1 - Talt * \frac{Vsol}{(Valt * Tsol)}$$

$$\frac{Vsol}{Valt} = \frac{Tsol}{Talt} * e^{\left(-7*\frac{g}{2*Cp*T0}*zalt\right)}$$

Finally, to know how to fill our balloons to make them explode at the designated altitudes we have to measure their volumes on the ground. Valt will be the maximum volume a balloon can reach. We suppose that our balloons have approximatively the same maximum volume which we will measure on our sample of balloon.

The results for balloons with a maximum volume of 50000 cm^3 are:

Altitude (km)	Vsol (cm^3)	Radius if the balloons were spherical (cm)
5	31450	19,6
10	15975	15,6
15	5000	10,6
20	2750	8,70

Appendix G EXPLOSIONS REQUIREMENTS

We plan to perform two blasts, the first one a 400 kg TNT equivalent surface blast and the second one a 800kg TNT equivalent surface blast, at the mines of Mertainen (located nearly 30 km south of Esrange) in order to produce well characterized infrasound signals. This signal will propagate in the atmosphere at a frequency of 3 Hz.

We will ask for the first blast to be delivered 10 minutes after the balloon has reached buoyancy altitude. The balloon is expected to be located, in the worst-case scenario, less than 70 km from the location of the blast. At this range, considering that the deflagration will propagate in the atmosphere spherically, and thanks to the data provided by *Bowman and Albert [13]*, we expect to detect amplitudes of perturbation between 0,3 Pa and 0,8 Pa.

The second blast will be delivered one hour after the first blast. According to the data displayed in the Bexus user manual, the ballon is expected to be less than 130km distant from the mines. The amplitudes expected to be detected are between 0.25 Pa and 0.8 Pa.

Appendix H TESTS PROCEDURES AT CNES

Test 1: Calculation of the constants of temperature:

Goal: Test of the barometer + analysis of the comportment of the experiment with a low temperature and pressure.

Thermal environment:

Time(h)	Temperature(°C)	Pressure(mBar)	Indications
10h22	20	1000	/
11h08	-15	0.005	/
12h30	-15	0.005	Return to ambient condition

Procedure:

11h28-11h35: Generation of sounds with the loudspeaker

11h56: Heaters GB on

12h07: Heaters FTB on

12h14: Heaters GB off

12h30: end of the test

Test 2: Cold test:

Goal: Simulate the launch of the experiment à Esrange and see if none of the components are too cold.

Thermal environment:

Time(min)	Temperature(°C)	Pressure(mBar)	Indications
15h06	20	1000	/
16h04	-70	500	/
16h20	-70	100	/
16h38	-70	100	Return to ambient conditions

Procedure:

16h00: Heaters FTB on

16h23: Heaters FTB and GB on

16h26: Heaters off

16h38: Heaters 50% on and thermal vacuum chamber turned off

-The goal of this step is to see if the heaters can perturbate the acquisition of the data of the barometer.

-The thermal vacuum chamber is turned off to stop to noise caused by her.

Test 3: Hot test:

Goal: Put the chamber at vacuum condition to verify that none of the components will overheat during the fly

Thermal environment:

Time(min)	Temperature(°C)	Pressure(mBar)	Indications
8h49	20	1000	/
8h58	20	10	/
11h33	20	10	Return to ambient conditions’’’

Procedure:

-Heaters off during all the experiment

Appendix I SPECTROGRAMS GENERATION CODE

```
from scipy import signal
import pandas as pd
import matplotlib.pyplot as plt
import numpy as np


#cd /home/user/Documents/Destiny/newData
#
# ftb = pd.read_csv(r"FTB.csv", sep = ',')
#
# gb = pd.read_csv(r"GB.csv", sep = ',')


b,a = signal.butter(2,[0.02,5],'bandpass', fs = 180)


y = gb["barometer"].to_numpy()
y_filtered = signal.filtfilt(b,a,y)

y_filtered_reduced = []
for i in range(len(y_filtered)):
    if i%18 == 0:
        y_filtered_reduced.append(y_filtered[i])
y_filtered_reduced = np.array(y_filtered_reduced)


f,t,Sxx = signal.spectrogram(y_filtered_reduced, 10, nperseg = 1000, nfft = 1000 )
Sxx = np.log10(np.abs(Sxx))



plt.figure()
plt.pcolormesh(t, f, Sxx, cmap = 'jet')
plt.ylabel('Frequency [Hz]')
plt.xlabel('Time [sec]')
plt.title("GB pressure spectrogram")
plt.yscale('log')
plt.ylim((0.1,5))
plt.colorbar()
plt.show()
```