SED

Student Experiment Documentation

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Mission: BEXUS 28

Team Name: DESTINY

Experiment Title: Detection of Earthquakes through a STratospheric INfrasound studY

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CHANGE RECORD

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0	2018-12-09	New Version	
1		all	PDR
2			CDR
3			IPR
4			EAR, Pre-Campaign
5			Final report

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-SUPAERO.

ABSTRACT

The internal structure of terrestrial planets such as Mars, Earth and Venus contain key informations 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-Supaero 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, 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 the structure of Venus a key element in understanding the history of the solar system. In particular, 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 presents technical difficulties. Indeed, with ground temperatures reaching 400 °C and 90 atmospheres of pressure, 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 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, using balloon-borne pressure measurements.

These infrasounds are amplified during their propagation to 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: 1 atm pressure and 0 °C temperature. Furthermore, balloons have already been successfully used in the 1985 VEGA mission for short periods of time.

The researchers we are working with already conducted balloon-borne experiments to detect infrasounds [2], but at lower altitudes, and 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 to solve is how to probe a planet's structure without ground sensor. The solution we study consists in using atmospheric balloons to detect the infrasounds 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 experiment 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 embed a barometer and its acquisition hardware , using the arrival times difference between them, the inclination of incoming infrasound waves is measurement. This allows, after backward propagation simulation, to locate the source of these infrasound signals.

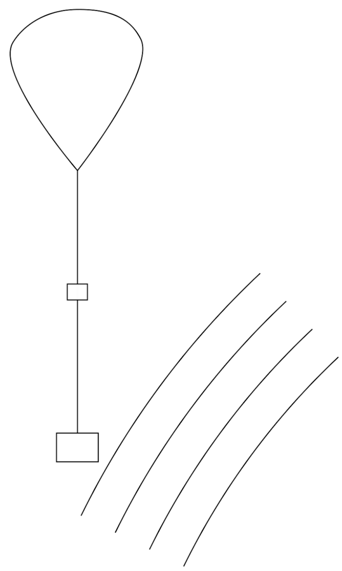

Figure 1.1: Measurement of incoming waves inclination

The primary goal of 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 to have the same time reference, but they operate independently of each other.

All of these data are stored locally, and send remotely to the ground station. In turn, the DESTINY team operates the experiment remotely, sending it 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 but switched to a manual mode.

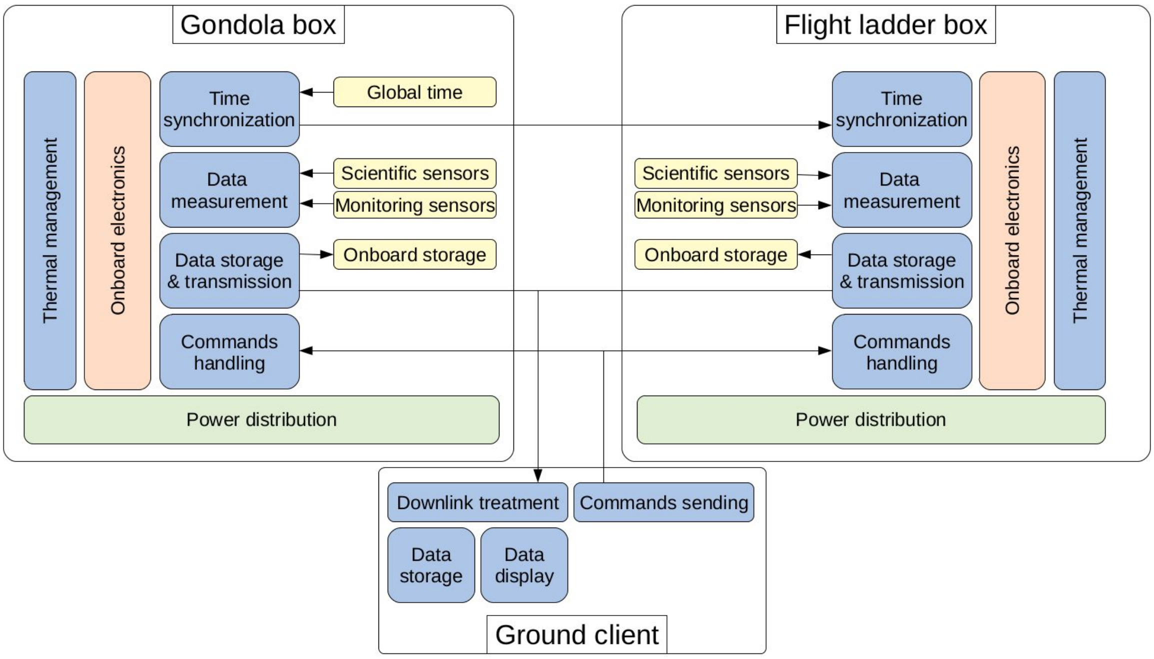

Figure 1.2: Block diagram of the DESTINY experiment

1.5 Team Details

The subject of the study was suggested by David Mimoun, endorsing professor of the project and research professor at ISAE-Supaero. The team consists in member from the french engineering universities ISAE-Supaero 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		
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Team Leader		Louis Dubois
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	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

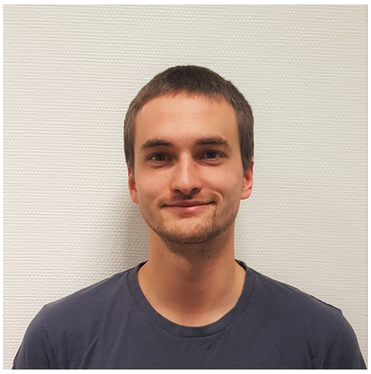
This section presents the members of the DESTINY team, including their respective role, educational background and field of work within the team. This project is done in the frame of a mandatory scientific project, and the members will be awarded at least 7 ECTS credits for work related to the experiment. The team consists mainly in student in their fourth year of study. Additional members will join the project in March and Mai.

Florian Abeillon
Thermal design, outreach

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

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

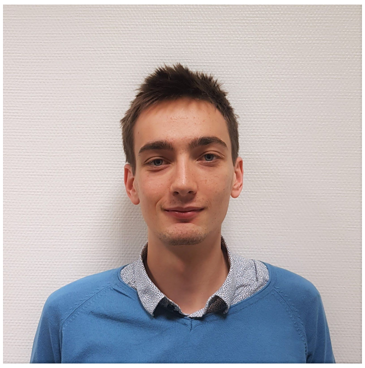
Second-year student at École Polytechnique, interested in Physics.

Krishan Bumma
Thermal design, payload

Second-year student at École polytechnique. Most interested in physics and material chemistry.

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.

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.

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 the wind turbulence speed.
F6	The experiment shall store measurements onboard.
F7	The experiment shall downlink measurements to the ground station.
F8	The experiment shall maintain an internal temperature suitable for its components.

2.2 Performance Requirements

P1	The pressure resolution shall be 0.01 Pa.
P2	The pressure measurement frequency shall be 200 kHz.
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 20 °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 internal temperature shall be kept in the range 0 °C to 60 °C.
P15	The internal temperature should be kept in the range 0 °C to 20 °C.
P16	The wind speed measurement rate should be 10Hz.
P17	The generated infrasound waves shall have an amplitude of 0.1 Pa when they reach the experiment.
P18	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 3D-printed 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.

2.4 Operational Requirements

O1	The DESTINY team shall be able to send commands from the ground station to the experiment from startup its shutdown.
O2	The DESTINY team shall be able to reset the experiment from the ground station.
O3	The DESTINY Team shall be able to start and stop data acquisition from the ground station.
O4	The DESTINY Team shall be able to select between an autonomous and a manual thermal management system from the ground station.
O5	The experiment shall enter a secure mode before landing.
O6	The experiment shall transmit telemetry during the flight.
O7	The experiment shall be able to handle network unavailability.
O8	The experiment shall be able to reset without any external intervention in the case of a loss of control.

2.5 Constraints

C1	The mass of the experiment shall not exceed 20 kg.
C2	The mass of the box attached to the flight train shall not exceed 4 kg.
C3	The mass of the box attached to the flight train should not exceed 2 kg.
C5	The telemetry bandwidth shall not exceed 200 kb/s.
C6	The budget of the experiment shall not exceed 4000 €.
C7	The endorsing professor and his team live in Toulouse.

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.

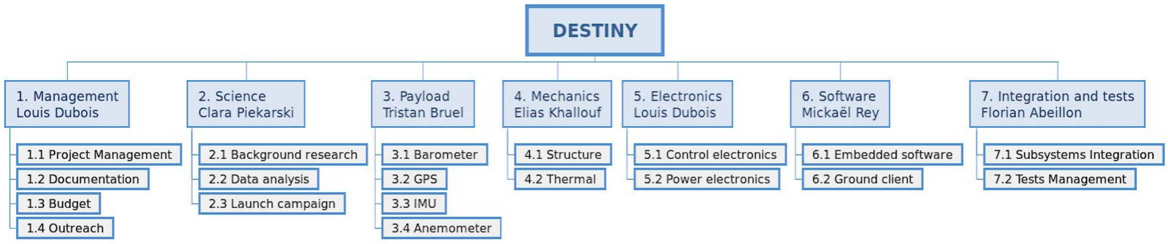


Figure 3.1 : WBS

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 take into account mishaps. A two-month margin of error is planned before launch.

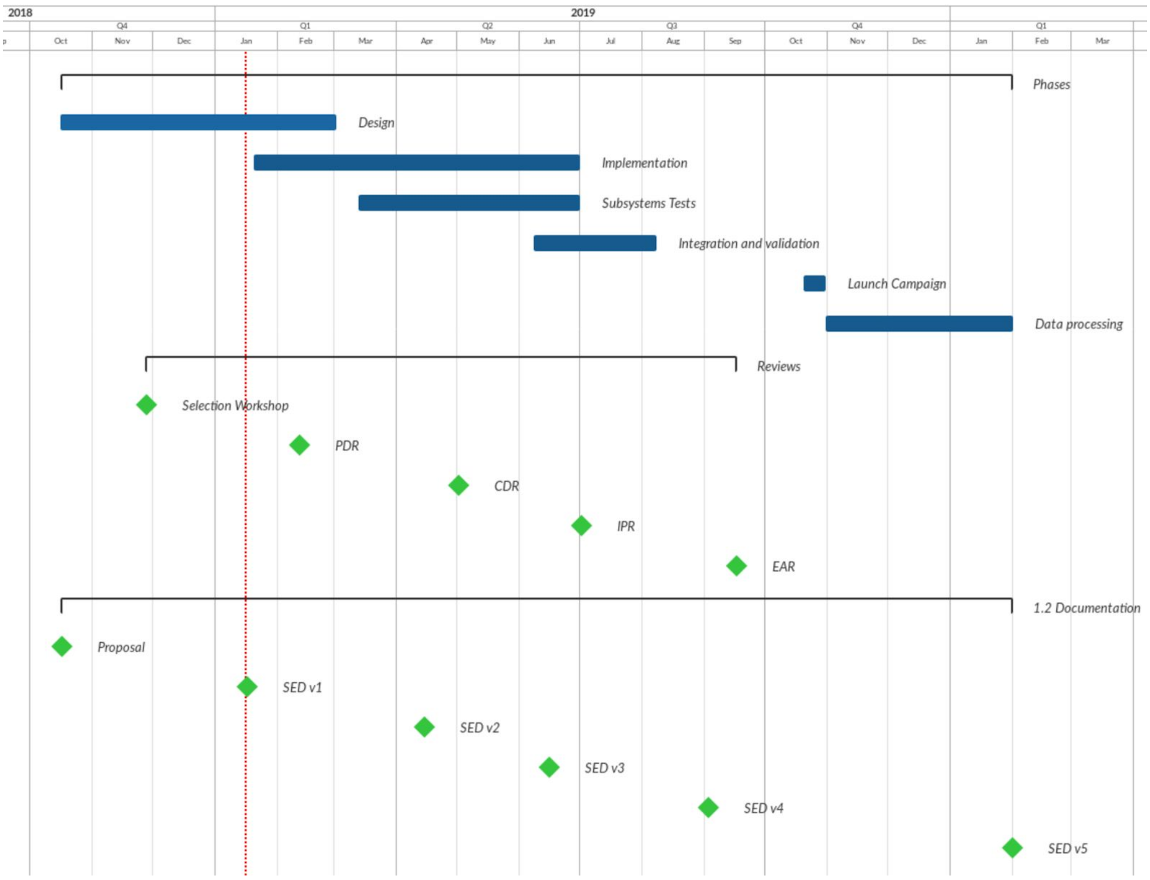


Figure 3.2: top level Gantt chart

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. The Table 3.3 sums up the members of these departments. 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.

Science	**Mechanics**	**Electronics**	**Software**	**Management**
Clara Piekarski Matthieu Jeannin Samuel Brasil	Elias Khallouf Tristant Bruel Florian Abeillon Krishan Bumma	Louis Dubois Louis-Arnaud Péchenart	Mickaël Rey Louis Dubois	Louis Dubois Clara Piekarski Florian Abeillon

Table 3.3: List of departments

Additionally, the team will recruit in March three students from ISAE-Supaero to work on the Electronics department, and four more École Polytechnique students will join the project in May, to reinforce the different departments for manufacturing and testing.

Except for the three ISAE-Supaero students that will be involved in the Electronics department, all the members of the team live in Paris. Yet, an important part of the electronic design and manufacturing will be conducted in Toulouse, which is also where we will find the best support for this task. However, the whole integration process will take place at École Polytechnique, in Paris.

3.3.2 Budget

ISAE-Supaero university is the main sponsor of the experiment, financing most of the instrumentation (in particular the barometers and the fiber optic gyrometer) and the electronics realisation. Then comes École Polytechnique which will cover other electrical and mechanical expenses. Finally, a crowdfunding campaign will be launched.

Table 3.4 displays a first estimate of 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-Supaero universities.

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 €
	Fiber optic gyrometer	12 000 €
	Anemometer	1 600 €
	Payload total	27 600 €
Other	Travel	600 €
	Experiment shipment	200 €
	Other total	800 €
	Total	29 280 €

Table 3.4: Budget

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 of fluid dynamics, and advises the team as well on project management.

David Mimoun, Associate Professor at ISAE-Supaero, 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-Supaero.

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 article 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, articles will be published on the website of *École polytechnique*, the first one should be released in February 2019. Presentations have been done to highschool students. The team will present its project to the university Space Week, on Thursday 30th January 2019.

3.5 Risk Register

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

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)					
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
	1	2	3	4	5
			Severity (S)		

Table 3-1: Risk Register

ID	Risk and non obvious consequences	P	S	P×S	Action
SF10	Fall of the upper box	A	4	Very low	Design the safest possible attach, with a security system
SF20	Fall of an inlet	B	2	Very low	Secure the fastening mechanism.
MS10	Fail to configure the sensors to detect the right infrasound signals	C	4	Medium	Study the signals we could detect through simulations and bibliography. Analyze the different measurement options of the sensors we have.
MS20	Absence or scarcity of infrasound signals to detect	C	4	Medium	Search for ways of creating infrasound perturbation. Contact the mines near Kiruna and SSC about the possibility of creating an explosion.
MS30	The infrasounds produced by the planned events are not powerful enough to be detected by the experiment	C	4	Medium	The barometers will be configured to detect very light pressure variations. Simulation will be done to assess the power of the detected wave according to the power of the source.
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	C	4	Medium	Manage temperature based on internal temperature. Implement safeguards to prevent overheating.
MT30	A sensor stops working because of unsuitable temperature	B	3	Low	Manage temperature based on internal temperature. Implement safeguards to prevent overheating.
VE10	Infrasound emitted by other experiment jam	C	4	Medium	Characterize the perturbation to reduce noise with data

	measurements				analysis. Get information about the time these perturbations made by other experiment occur.
PE10	A member of the team has to leave the project	B	3	Low	Find in advance potential new members. If the project is at an advanced state, redistribute the workload between other members.
PE20	Lack of manpower to fulfill all the tasks	B	4	Low	Find in advance potential new members, and recruit them if needed.

4 EXPERIMENT DESCRIPTION

4.1 Experiment Setup

The DESTINY experiment 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, though their clocks need to be synchronised. 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	
Fiber optic gyrometer	X	
IMU	X	X
Battery monitoring	X	X

Table 4.1: Content of the boxes

Each box embeds a thermal management system (TMS) which will be mainly used at low altitudes to heat the components. It consists of thermal pads driven by a PID controller based on temperature measurements made by sensors built in the different integrated components as well as additional ones. For safety reasons, the TMS can be switched to manual and safeguard modes.

The power supply of the gondola will be used to power the gondola box, and the flight train box will have 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,

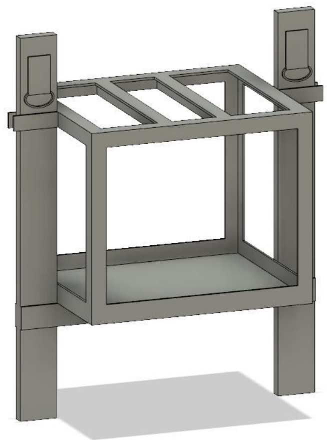
commands can be sent from the ground station. The TMS is turned on, operating in automatic mode.
- Before take off, the different sensors are tested to ensure that they are working properly.
- Shortly before take off, data gathering starts : sensors operate at their nominal measurement rate, store and transmit data to the ground.
- Shortly before landing, the systems enter secure mode : data stop 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.

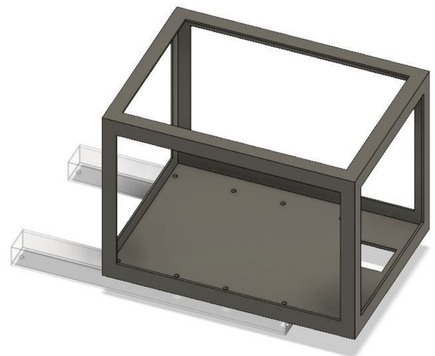
4.2 Experiment Interfaces

4.2.1 Mechanical

The upper box will be attached to the connecting “rungs” on the flight train. It will be bolted to the top of the rung. In addition, two bars attached to the boxe will serve as an additional attachment as an extra rung. And as a safety measure shackles will be placed above in order to attach a strap that will hold the box to the gondola in case of a structure breakdown.



Attachment system of the upper box



Attachment of the lower box

Figure 4.2: Attachments of the boxes

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 the picture above.

Type:	Size:	Amount:
Bolt	M6	24
Nut	M6	24
Washer	M6	24

Table 4.3: Estimated amount of bolts,screws, nuts and washers for both boxes

4.2.2 Electrical

E-Link

Both boxes are interfaced with the E-Link system using RJF21B connectors. Downlink is used for telemetry, through the UDP protocol 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 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 / 1 mA 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.

Protection

Additionally, a fuse will be used to prevent overcurrents.

Grounding

A distributed single-point grounding will be used.

4.2.3 Radio Frequencies

A GPS receiver is embedded in box B1, in the gondola. It listens to GPS and GLONASS signal, operating on the following UHF domain frequencies:

GPS	1575.42 MHz
GLONASS	1598 to 1605.5 MHz

Table 4.4: RF used

4.3 Experiment Components

The main components of the experiment are listed in Table 4.5, and the masse 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	7000€ (given by Supaero)	To be sent	Given by ISAE-Supaero
KVH DSP 1760 fiber	High accuracy and ISAE	1	Ø 8.89 H 2.48	0.6	? (given by	To be sent	Given by ISAE-Sup

optic gyrometer	wants to test it on a balloon-borne experiment				Supaero)		aero
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 high altitude	1	9×4×2	0.40	20 €	To be ordered	bangood. com
Vaisala WXT532 Ultrasonic anemometer	Ultrasonic anemometers seem to be the most appropriate considering flight conditions. The model might be subject to changes for budget issues	1	Ø 74 H 14	0.51	1593€	To be ordered	Vaisala
TI LM35H temperature sensor	wide range of temperatures	6	0.52*0.53*0 .43	0.005	10 €	To be ordered	Farnell
TDK NTC Thermistor	Resilient, small size factor reduces radiation perturbations	1	0.08*0.08*0 .14	0.003	6 €	Partially delivered	RS electronic s
BeagleBone Black		2	8.63 × 5.33 × 2	0.037	45 €	Partially delivered	Farnell
Ethernet 30m cable GSC-01-8347 1-00	Teflon-reinforc ed to support low temperatures	1	30m	1.5	250 €	To be ordered	Air cost control
Kingston 16 Go microSD UHSI	Waterproof	2	0.11 x 0.15 * x 0.01	0.0002 5	19 €	To be ordered	Kingston technolog y
Saft LSH20 lithium battery	Wire operating temperature range	4	Ø 3.34 H 6.16	0.1	20€	To be ordered	NKON

Minco polyimide thermofoil HK6907	Described as reliable by other experiments	2	2.5 × 5	0.027	40 €	To be ordered	Minco
Upper box casing	Aluminium	1	20 x 25 x 25	1.86	0 €	To be built	
Upper box isolation	Styrofoam	1	30 x 35 x 35	0.49		To be ordered	
Gondola box casing	Aluminium	1	35 x 25 x 25	2	0 €	To be built	
Gondola box isolation	Styrofoam	1	45 x 35 x 35	0.67		To be ordered	

Table 4.5: List of main components

Experiment mass (in kg):	4.53
Experiment dimensions (in m):	0.45 x 0.35 x 0.35
Experiment expected COG (centre of gravity) position:	0.25x0.08 m from the corner of the gondola (figure 4.3.1)

Table 4.6: Gondola box summary table

Experiment mass (in kg):	3.49
Experiment dimensions (in m):	0.30 x 0.35 x 0.35
Experiment expected COG (centre of gravity) position:	0.10x0.125 m from the corner of the box (at the center)

Table 4.7: Upper box summary table

Total mass (in kg):	9.52

4.4 Mechanical Design

The upper box will be attached to the gondolas flight train, while the other will be set inside the gondola as shown below.

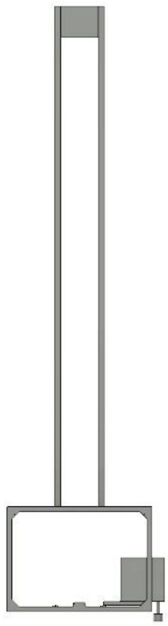


Figure 4.3: The complete mechanical setup (not to scale)

The bottom box will have to exceed the gondolas borders (15cm) in order to fix the inlet so that it won’t be shielded by the gondola, hence the hole in the box (seen in the mechanical interface).

Both boxes will be built from aluminum at École polytechnique, the material being light and available.

Preliminary mass calculations for the upper box can be seen in Table 4.8.

Component	Mass (kg)
Box	1.37
Barometer	0.43
Robotic Cape	0.013
BeagleBone	0.037
Batteries	0.4
Thermofoil	0.027
Fixation	0.22
Inlet	~0.5
Isolation	0.49
Total	3.49

Table 4.8: Mass of the upper box

The total mass is 3.49kg below our limit of 4kg. The inlet's mass is still not finalised, however, it is possible to reduce the mass of the box giving us margin for the inlet.

Two bars in T shape are added to the top of the box (seen in the previous section) in order to fix the inlet to the box.

The center of gravity of the upper box is expected to be at the center of the box. The center 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 4.4: The figure shows the 25cm position of the COG from the corner of the gondola.

4.5 Electronics Design

The two boxes of the experiment are similar in their organisation. Both of them 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, a custom PCB is used for power distribution, and to interface the sensors with the BeagleBone Black. Finally, an acquisition board is used to gather pressure measurements.

The global schematics of each boxes is displayed in Figures 4.4 and 4.5.

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

A distributed single-point grounding is used.

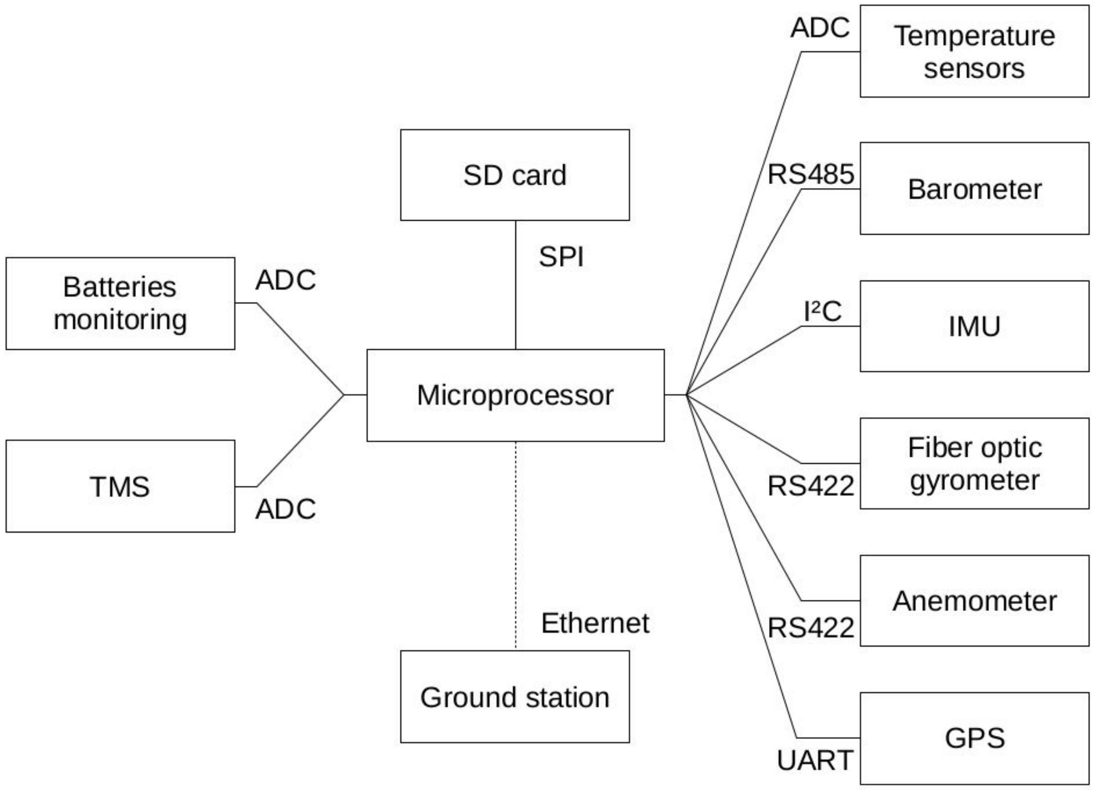


Figure 4.5: Gondola box global schematics

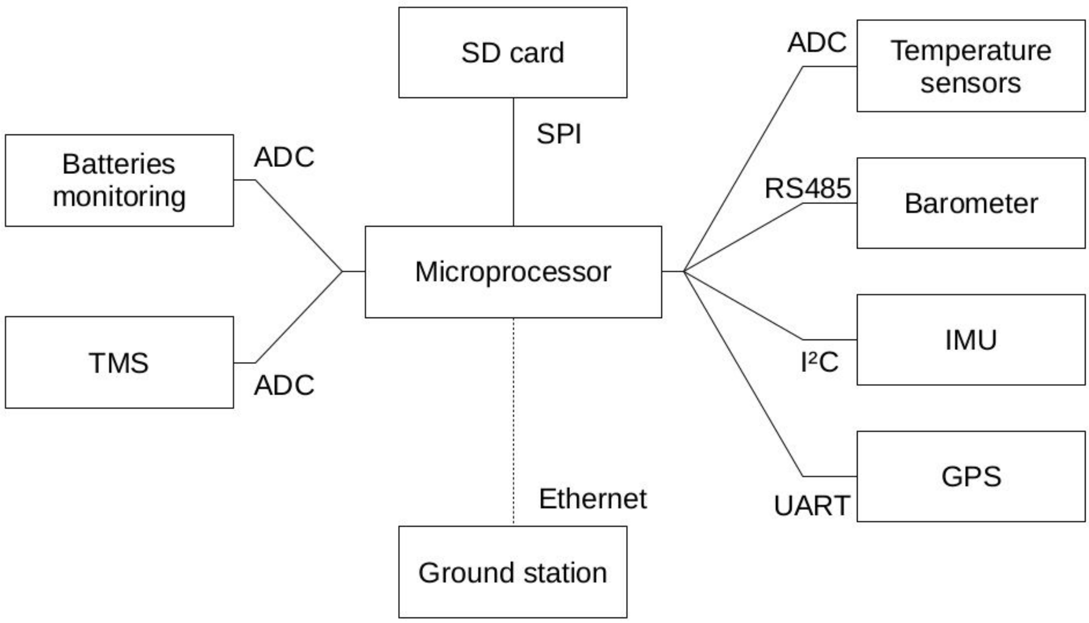


Figure 4.6: Upper box global schematics

4.6 Thermal Design

All the electrical components are 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 fiber 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 4.9: 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 insulation layer will be placed around the payload. Plus we plan to use a heating system with a Minco Polyimide Thermofoil heater placed next to the processor.

The TMS will have four operating modes. In the nominal mode, a PID control system is used, taking internal temperature measurements as inputs, and driving the heater. If, during the flight, it fails to keep the boxes in the required temperature range, due to a not adapted tuning, it is switched to a simple On/Off control. If it is still not sufficient, the team can control it in manual mode. Finally, to prevent damages due to overheating, a safeguard mode is implemented, stopping heating.

During the floating phase, the atmosphere is reduced and the main risk is the overheating of the components. The heaters will therefore be off most of the time. The critical components subject to overheating are the processor of the BeagleBone Black and the gyrometer. To regulate the temperature of the processor one way would be to dissipate the heat with a heat sink.
We are currently working on simulations on Ansys and Systema-Thermica to predict the thermal behavior of the payload both on ground and in high altitudes.

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 a pack of 8 of these same batteries, providing a total of 52 Wh. The LSH20 datasheet can be found in [5].

Table 4.10 and 4.12 show the estimated power budget of the experiment, providing details about main components' consumption, without taking into account heating, which is displayed in Tables 4.11 and 4.13. The total energy consumption of both boxes is summed up in table 4.15.

Component	**Voltage (V)**	**Current (A)**	**Power (W)**
Fiber optic gyrometer	12	0.4	5
BeagleBone Black	5	0.4	2
Ultrasonic anemometer	12	0.0035	0.042

GPS	3.3	0.02	0.06
IMU	3.3	0.004	0.013
Barometer	6	0.001	0.008
		Total	7.081

Table 4.10: 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	14	14
Ascent		1.5	0.25	7	10.5
Float		3	0	0	0
Descent		0.6	0.25	7	10.5
				Total	24.5

Table 4.11: Gondola box heating power consumption

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

Table 4.12: 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	18	18
Ascent		1.5	0.31	9	13.5
Float		2.5	0	0	0
Descent		0.6	0.31	9	5.4

Total	35.5

Table 4.13: Upper box heating power consumption

	Max input current (A)	Total consumption (Wh)
Gondola box	1	31.5
Upper box	0.7	37.5

Table 4.14: Summary of experiment consumption

The different components needs different input tensions, provided by different DC-DC regulators. They are summed up in Table 4.16.

	Input (V)	Output (V)	Power (W)
Gondola box	28.8	5	2
		6	0.0078
		28	21
Upper box	14.4	5	2
		6	0.0078
		28	12

Table 4.15: 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 informations 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 start 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 4.16.

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 are 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 4.16: 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, heaters are driven by a PID or On/Off controller run by each of the BeagleBone Black. It uses 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 PID inadequate settings or to temperature sensors errors, the TMS sets the heaters power according to commands from the ground client. Finally, if the connection with the ground client is broken and housekeeping measurements yield extreme data, the experiment goes in *fail-safe TMS mode*. Then, all the heaters are shut down, and the experiment waits for the recovery of the connection with 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
Fail-safe TMS mode	Heaters are shut down

Table 4.17: 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 4.18 and 4.19, 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. The telemetry protocol and the UDP overhead will induce an estimated 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
Fiber 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 4.18: 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 4.19: 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 4.20 for their list.

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

	Command	**0**
General mode commands	`ACK`	Reset the TCP watchdog timer. Used as an acknowledgement signal.
	`INIT`	Put the experiment in Initialisation mode. Used in case a reinitialisation of the devices is needed.
	`ACQUIRE`	Put the experiment in Acquisition mode. Used shortly before take off, or after a successful reinitialisation.
	`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 as been sent, if the DESTINY team think that the automatic mode is now appropriate.

Table 4.20: Ground client commands

4.8.5 Safety measures

To recover measurements in case of a loss of E-Link connexion and stored data corruption, each box duplicates measurements on an internal flash memory and on a SD card. In addition, data storage is stopped shortly before landing, which mitigate 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 Boxes synchronisation

Data acquisition must be precisely timed, which imposes the clocks of both boxes to be synchronized. The GPS provides the primary time reference, and is polled by the GPS receiver hosted by the gondola box. Then, this box acts as the master clock of the experiment, and the flight ladder box synchronizes its clock to it using the PTP protocol.

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:

- Receive telemetry through E-Link, and store it locally.
- Allow the DESTINY team to send commands to the experiment through E-Link.t
- 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 similar to the provided BEXUS power supply 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 ®

ID	Requirement text	Method	Reference	Status	Verification Result
P14	The internal temperature shall be kept in the range 0 °C to 60 °C.	A, T	Test 1.1 Test 1.2 Analysis 1.1	To be done	
P16	The generated infrasound waves shall have an amplitude of 0.1 Pa when they reach the experiment	A	Analysis 2	To be done	
P18	All measurements shall be made with the same time reference	T	Test 2	To be done	
D7	The 3D-printed inlets should be as efficient to reduce the noise as the original metal inlets	T	Test 3	To be done	
P4	Incoming waves direction should be known with a 20° margin of error.	A	Analysis 3	To be done	
D1	The experiment shall operate in the temperature profile of the BEXUS	A, T	Test 1.1 Test 1.2 Test 1.3 Analysis 1	To be done	

	vehicle flight and launch				
D2	The experiment shall operate in the vibration profile of the BEXUS vehicle flight and launch	A	Test 5 Test 6	To be done	
D4	The experiment batteries shall be qualified for use on a BEXUS balloon.	R, S		To be done	
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.	R, T		To be done	
D6	The batteries in the gondola-mounted experiment shall be accessible from the outside within 1 minute.	I	Inspection 1	To be done	
D3	The experiment shall not disturb or harm the launch vehicle	R, A	Test 4 Test 4.1 Test 6	To be done	
D8	The data transmission between the two boxes shall not suffer from the length of the cable.	T	Test 6	To be done	

5.2 Verification Plan

Test number	Test 1.1
Test type	Thermal
Test facility	École polytechnique
Tested item	The whole boxes
Model	Qualification model
Procedure, Test level and duration	Low pressure conditions Vacuum chamber test to ensure the electrical circuit does not overheat
Test campaign duration	1 day
Test campaign date	June
Test completed	No
Requirements verified	(P14)

Test number	Test 1.2
Test type	Thermal
Test facility	École polytechnique
Tested item	Insulation
Model	Qualification model
Procedure, Test level and duration	Low temperature insulation tests.
Test campaign duration	1 day
Test campaign date	May
Test completed	No
Requirements verified	(P14)

Test number	Analysis 1.1
Test type	Thermal
Test facility	École polytechnique
Tested item	The whole system
Model	Qualification model
Procedure, Test level and duration	Low pressure conditions Crossing the results of analysis on AnSys and Thermica to predict the thermal behavior of the experiment
Test campaign duration	1 week
Test campaign date	May
Test completed	No
Requirements verified	(P14)

Test number	Test 2
Test type	Software
Test facility	Ecole Polytechnique
Tested item	All software
Model	Qualification model
Procedure, Test level and duration	Connect both boxes to a router similar to E-Link, start data acquisition. Measure the same event with both boxes, and compare the measurement times.
Test campaign duration	2 days
Test campaign date	July
Test completed	No
Requirements verified	

Test number	Test 3
Test type	Acoustic
Test facility	École Polytechnique
Tested item	3D-printed inlet
Model	Proto-flight model
Procedure, Test level and duration	Wind tunnel test Objective: check that the new inlet efficiency for noise reduction Procedure: Measure various infrasound signals with the same barometer, with and without an inlet, for different wind speeds.
Test campaign duration	1 week
Test campaign date	May
Test completed	
Requirements verified	

Test number	Test 4
Test type	Mechanical
Test facility	École Polytechnique
Tested item	Boxes and attachments
Model	Proto-flight model
Procedure, Test level and duration	Static load Objective: 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	June

date	
Test completed	No
Requirements verified	

Test number	Test 4.1
Test type	Mechanical
Test facility	École Polytechnique
Tested item	Boxes and fixation
Model	Proto-flight model
Procedure, Test level and duration	Dynamique test: 10g and 3m fall Objective: 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 3-4m high.
Test campaign duration	1 day
Test campaign date	June
Test completed	No
Requirements verified	

Test number	Test 5
Test type	Mechanical
Test facility	École Polytechnique

Tested item	Electronics
Model	Flight model
Procedure, Test level and duration	Objective: check that the 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	2 days
Test campaign date	July
Test completed	No
Requirements verified	

Test number	Test 6
Test type	Mechanical analysis
Test facility	École Polytechnique
Tested item	Whole system: boxes and fixations
Model	Flight model
Procedure,Test level and duration	Objective: Make sure the device can endure the flight. Procedure: Simulation of the flight and the landing.
Test campaign duration	1 month
Test campaign date	June
Test completed	No
Requirements verified	

Test number	Analysis 2

Test type	Physics
Test facility	École polytechnique
Tested item	
Model	
Procedure, Test level and duration	Objective: check which infrasounds sources will be powerful enough to be detected when they reach the gondola Procedure: 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	No
Requirements verified	(P14)

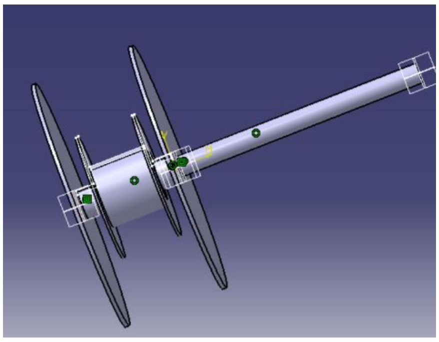
5.3 Verification Results

6 LAUNCH CAMPAIGN PREPARATION

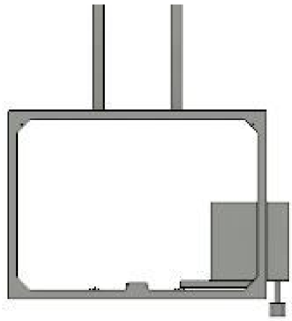
6.1 Input for the Campaign / Flight Requirement Plans

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 reinforced with teflon.

Two inlets come out of the boxes, they are pointed 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.



An inlet



The lower box in the gondola

6.1.1 Dimensions and Mass

Table 6-1: Experiment mass and volume

	Upper box	Lower box (in the gondola)	Cable linking the boxes	Total
Experiment mass (in kg):	3,49	4,53	1,5	9,52
Experiment dimensions or module size	0.30x0.35x 0.35	0.35x0.35x 0.45	3 m	
Experiment expected COG (centre	0.1x0.125 (m)	0.25x0.08 (m)	X	X

of gravity) position:	From the corner of the upper box	From the corner of the gondola		

6.1.2 Safety Risks

Table 6-2 Experiment safety risks

Risk	Key Characteristics	Mitigation
The inlets break away	Dimensions: Mass:	Safe attachment, tests
The upper box breaks away	Dimension: 0.3x0.35x0.35 Mass: 3.49 kg	Safe attachment (reinforced) Backup strap and shackles.

6.1.3 Electrical Interfaces

Table 6-3: Electrical interfaces applicable to BEXUS

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):	20 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):	4S
	Capacity (1 battery):	13.0 Ah
	Voltage (1 battery):	3.6 V

6.1.4 Launch Site Requirements

We will need:

- An oscilloscope
- Multimeters
- Two power plugs, two multiplugs
- Office accomodation (tables and chairs)
- A toolbox
- A long measuring tape (20m if possible)

6.1.5 Flight Requirements

The Kiruna LKAB mines perform explosions everyday between 01:15 and 01:30 AM. As we would like to be able to detect these explosions, the balloon should be in its stationary flight phase at this time. We also contacted the Boliden area mine and are waiting for an answer.

The floating phase should be as long as possible, at least two hours.

6.1.6 Accommodation Requirements

We will have to attach the upper box to the flight train so the flight train should be easily accessible. The box will be attached about 30m above the gondola.

6.2 Preparation and Test Activities at Esrange

Time/Day	Main Task	Responsible	Duration [h:m]	Comments
1	Set up ground station	Software	1h	
	Check the good state and functionement of all the components	Payload	1h	
	Attach the upper box to the flight train	Mechanical	2h	
2	Test the barometer, the anemometer,	Payload, Thermal		Test the sensor and the

	the GPS, the accelerometer, the gyrometer, the thermometer			data storage
	Test the thermal control	Thermal		
	Test the whole content of a box	Software, payload		Data storage
3	Test the E-link	Software		
	Test the communication between the two boxes	Software		Time synchro nization
	Test the attachment of the upper box to the flight train	Mechanic		
	Install the lower box inside the gondola	Mechanic		

6.3 Timeline for Countdown and Flight

Time [s]	**Signal**	**Function**
T-1h	Manual start of the experiment	Manually power up the experiment
T-5m	ACQUIRE	Start data acquisition
T	TAKEOFF	Start timer
T+3h40m	CUTOFF	Updates timer
T+4h30m	TOSECURE	Stops data storing
T+4h40	SHUTDOWN	Shutdown the experiment

6.4 Post-Flight Activities

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

The data from all the sensors will be analyzed and crossed according to the plan developed in part 7. In the case of the detection of an unknown signal, we will compare its occurance to local data such as planes schedule, data from ground seismologic station.

7 DATA ANALYSIS AND RESULTS

7.1 Data Analysis Plan

The data treatment must enable us to recognize and characterize infrasounds. 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 pressure data.

7.1.1 Reconstruction of the gondola motion

In order to locate the origin of the perturbations, we will study 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 and the relative positions of the two boxes. We will treat the data of the inertial unit with a Kalman filter.

A special attention is paid to the study of the propagation of infrasounds in the stratosphere, as it is generally not in straight line. We will have to use reverse simulation of such propagation to locate the origins of the infrasounds.

7.2.2 Pressure data

We continuously measure the external pressure to characterize the infrasound background and detect perturbation. But we expect very noisy signals, thus we have to recognise and eliminate this noise.

We will analyse the evolution of the power spectral density function of the signal over the time in order to detect fingerprint 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 in the flight train, other experiments. Therefore we will cross the spectral data with the measurements of the anemometer, the inertial unit, and with events linked to the other experiments.

7.2 Launch Campaign

7.3 Results

7.4 Lessons Learned

Although this is only the beginning of our project, it has already given us the opportunity to learn many lessons in various areas.

Science

- Planetology, previous missions on Venus
- Atmospheric science
- Infrasounds, especially their propagation in the stratosphere
- Gather bibliography and extract useful information

Mechanic and thermic

- Discover new simulation softwares
- Apply theory to calculate the resistance of real structures
- Learn 3D-printing

Management and organisation

- Elementary work tools such as WBS and Gantt charts
- Organize the development of a project in an efficient way
- Documenting a project
- The difficulties that come with managing a team of ten people
- The importance to divide the work in work packages and assign them to the appropriate person

Outreach

- Design a website
- Present our project to diverse audience, from high-school students to professors

8 ABBREVIATIONS AND REFERENCES

8.1 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
GSE	Ground Support Equipment
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

Mbps	Mega Bits per second
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

8.2 References

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APPENDIX A EXPERIMENT REVIEWS

Preliminary Design Review – PDR

Critical Design Review – CDR

Integration Progress Review – IPR

Experiment Acceptance Review – EAR

Appendix B Outreach and Media Coverage

Online presence:

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

Media coverage:

- Articles to be published to www.polytechnique.edu/en/news

Exhibitions:

- The team will set up an exhibition stand at *École Polytechnique* Space Week, on the 31th of January 2019.

Presentations:

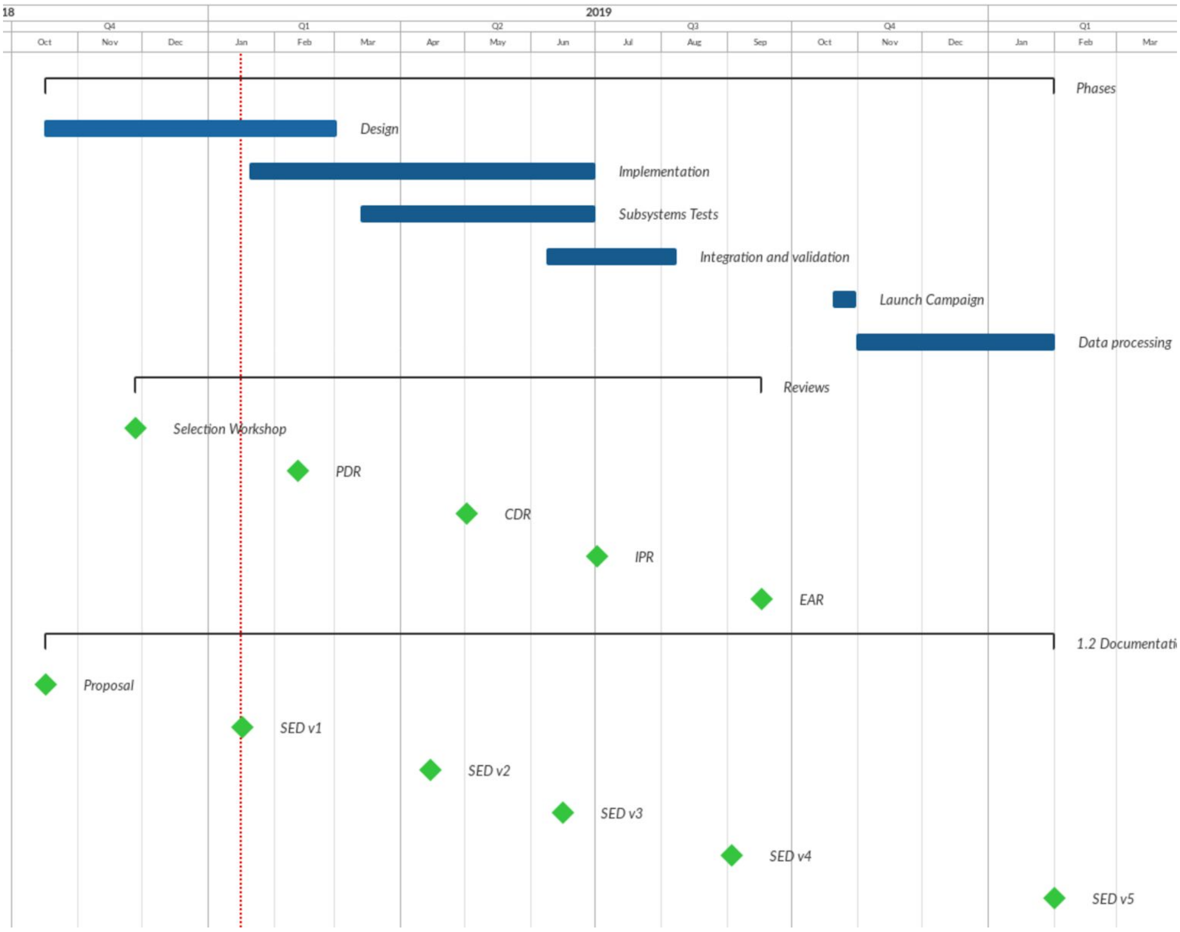
- Presentations have been made to highschool students about the study of the solar system planets and DESTINY project.

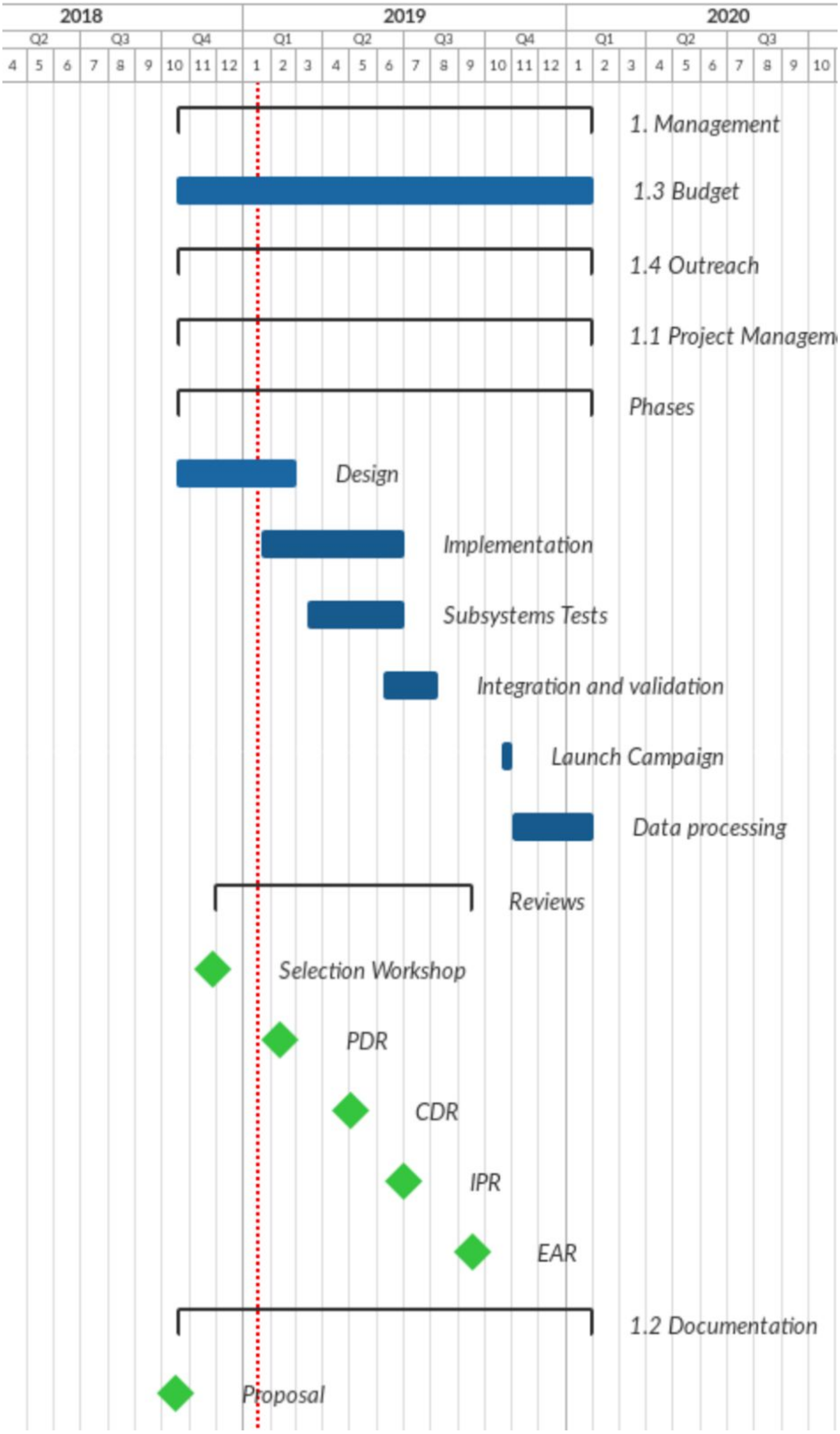
Logo:

Appendix C Additional Technical Information

APPENDIX D CHECKLISTS

APPENDIX E PROJECT PLANNING

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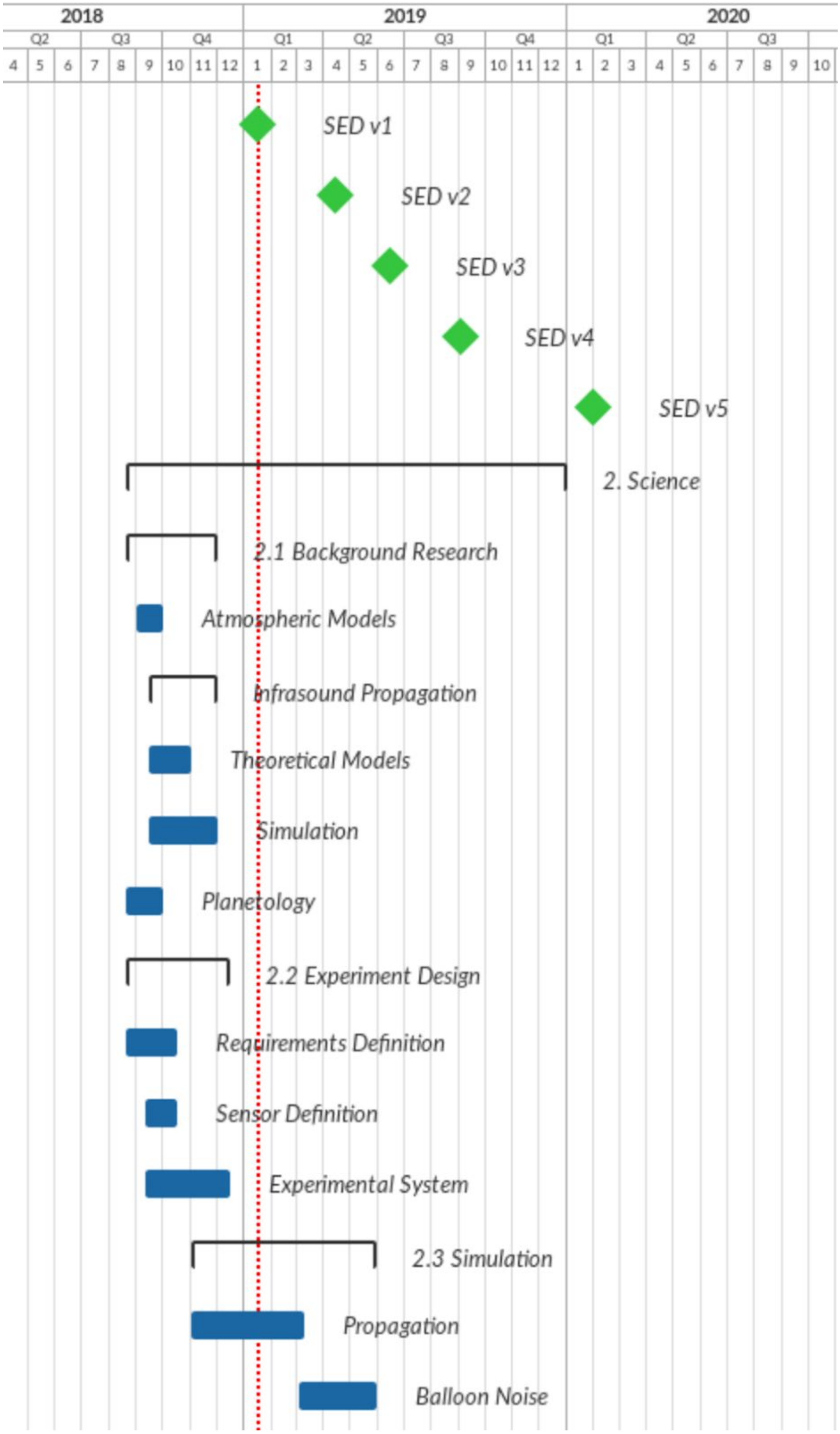
1. Management
1.3 Budget
1.4 Outreach
1.1 Project Managem
Phases
Design
Implementation
Subsystems Tests
Integration and validation
Launch Campaign
Data processing
Reviews
Selection Workshop
PDR
CDR
IPR
EAR
1.2 Documentation
Proposal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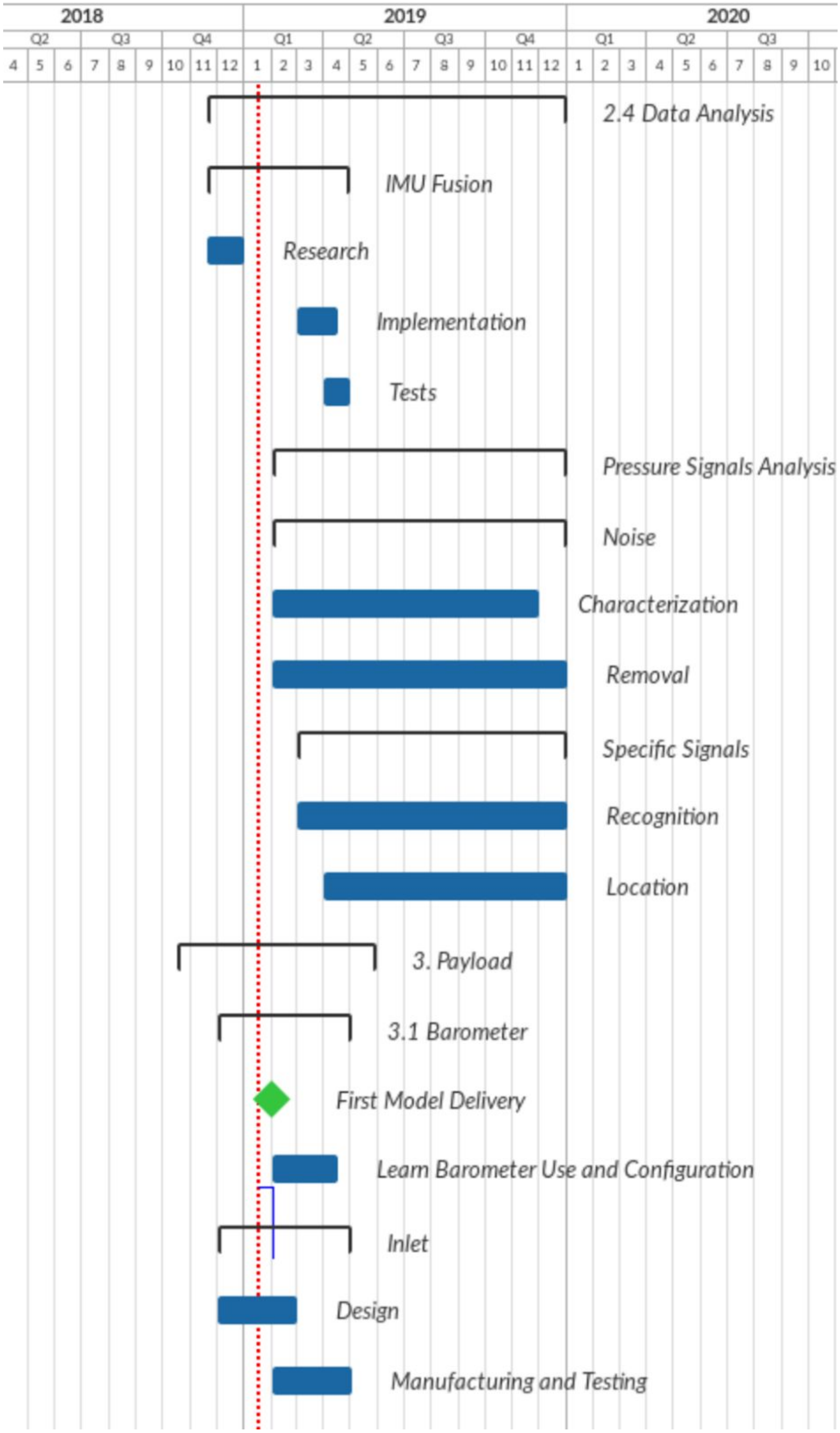
SED v1
SED v2
SED v3
SED v4
SED v5
2. Science
2.1 Background Research
Atmospheric Models
Infrasound Propagation
Theoretical Models
Simulation
Planetology
2.2 Experiment Design
Requirements Definition
Sensor Definition
Experimental System
2.3 Simulation
Propagation
Balloon Noise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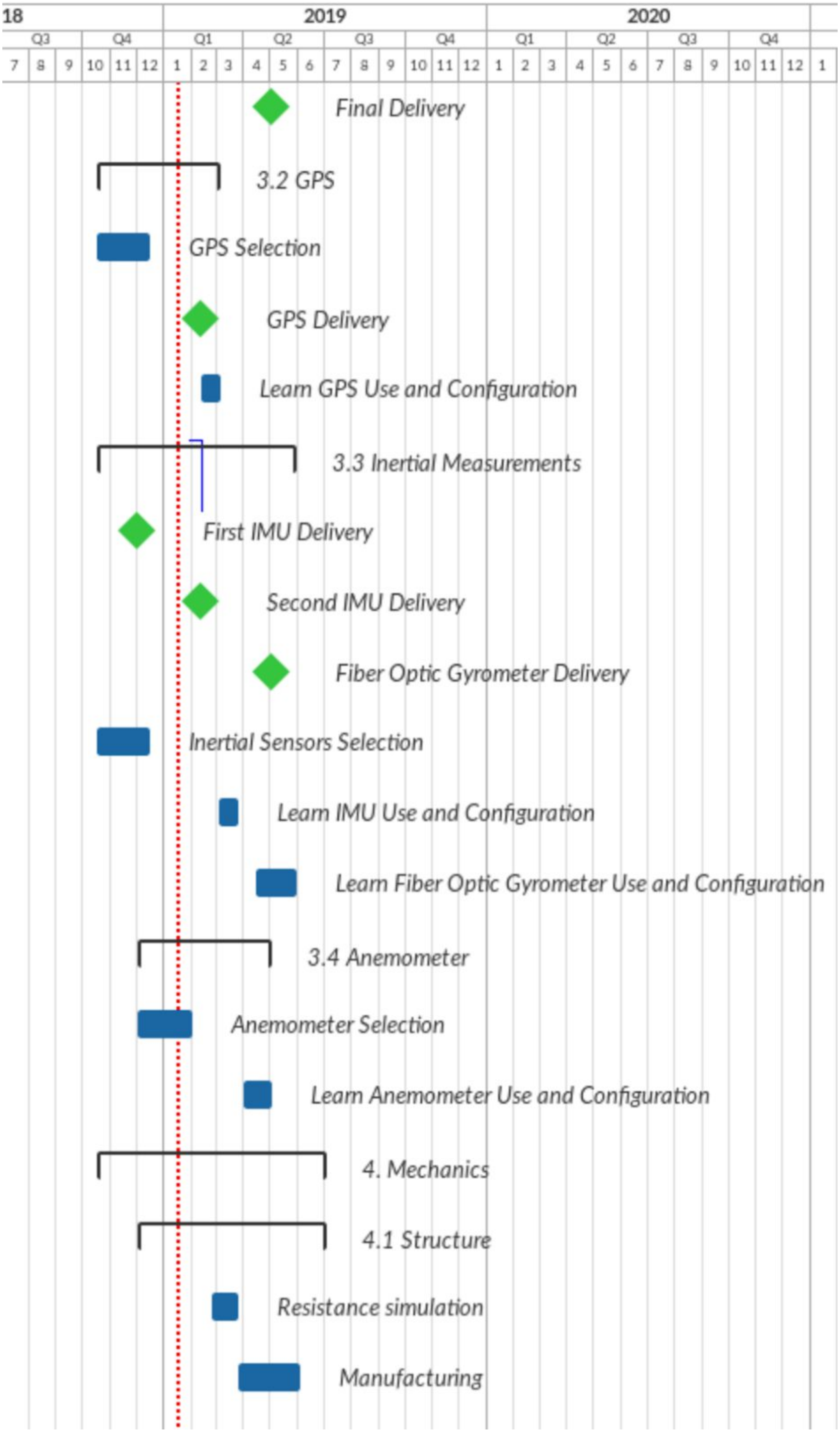
2.4 Data Analysis
IMU Fusion
Research
Implementation
Tests
Pressure Signals Analysis
Noise
Characterization
Removal
Specific Signals
Recognition
Location
3. Payload
3.1 Barometer
First Model Delivery
Learn Barometer Use and Configuration
Inlet
Design
Manufacturing and Testing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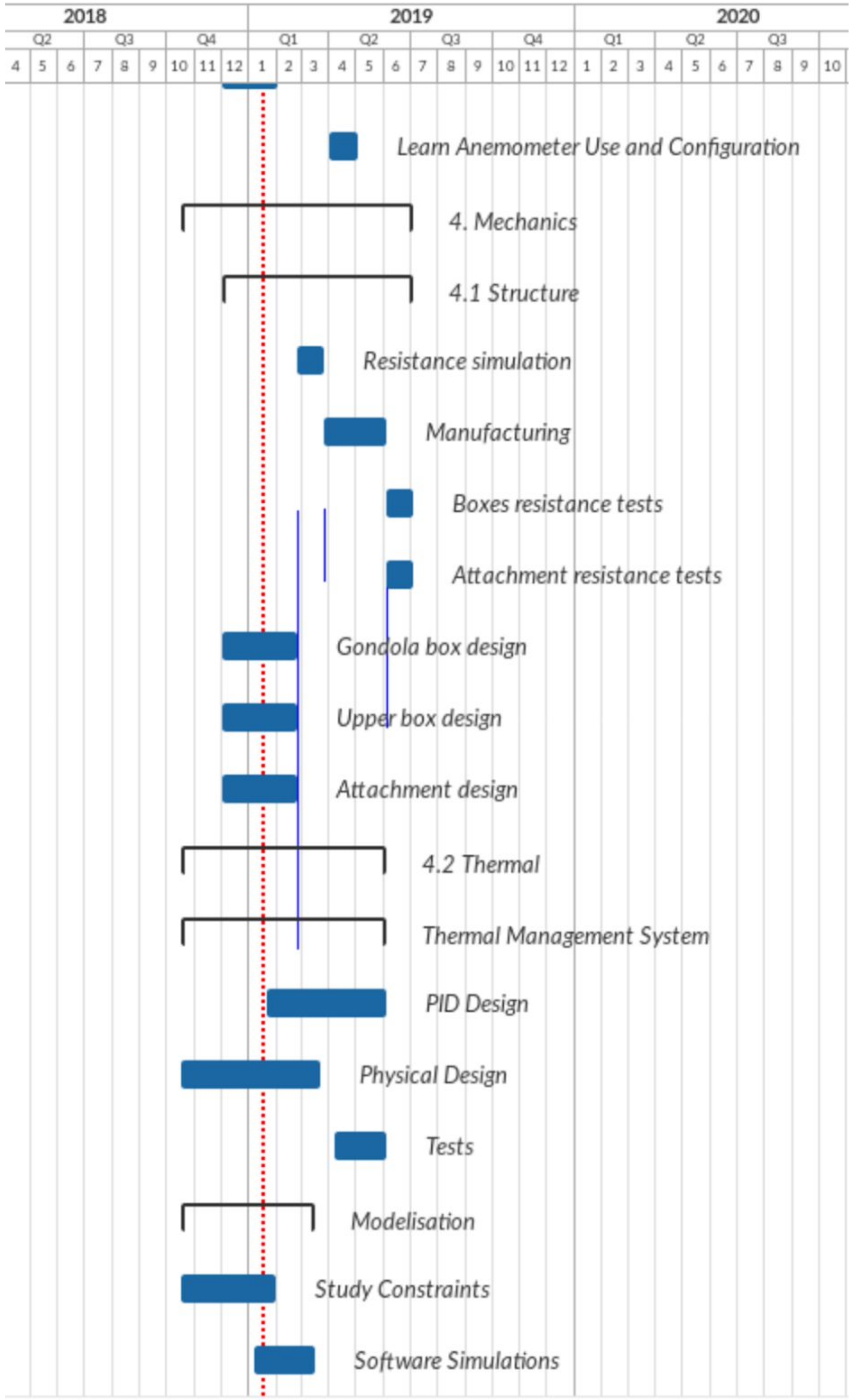
Final Delivery
3.2 GPS
GPS Selection
GPS Delivery
Learn GPS Use and Configuration
3.3 Inertial Measurements
First IMU Delivery
Second IMU Delivery
Fiber Optic Gyrometer Delivery
Inertial Sensors Selection
Learn IMU Use and Configuration
Learn Fiber Optic Gyrometer Use and Configuration
3.4 Anemometer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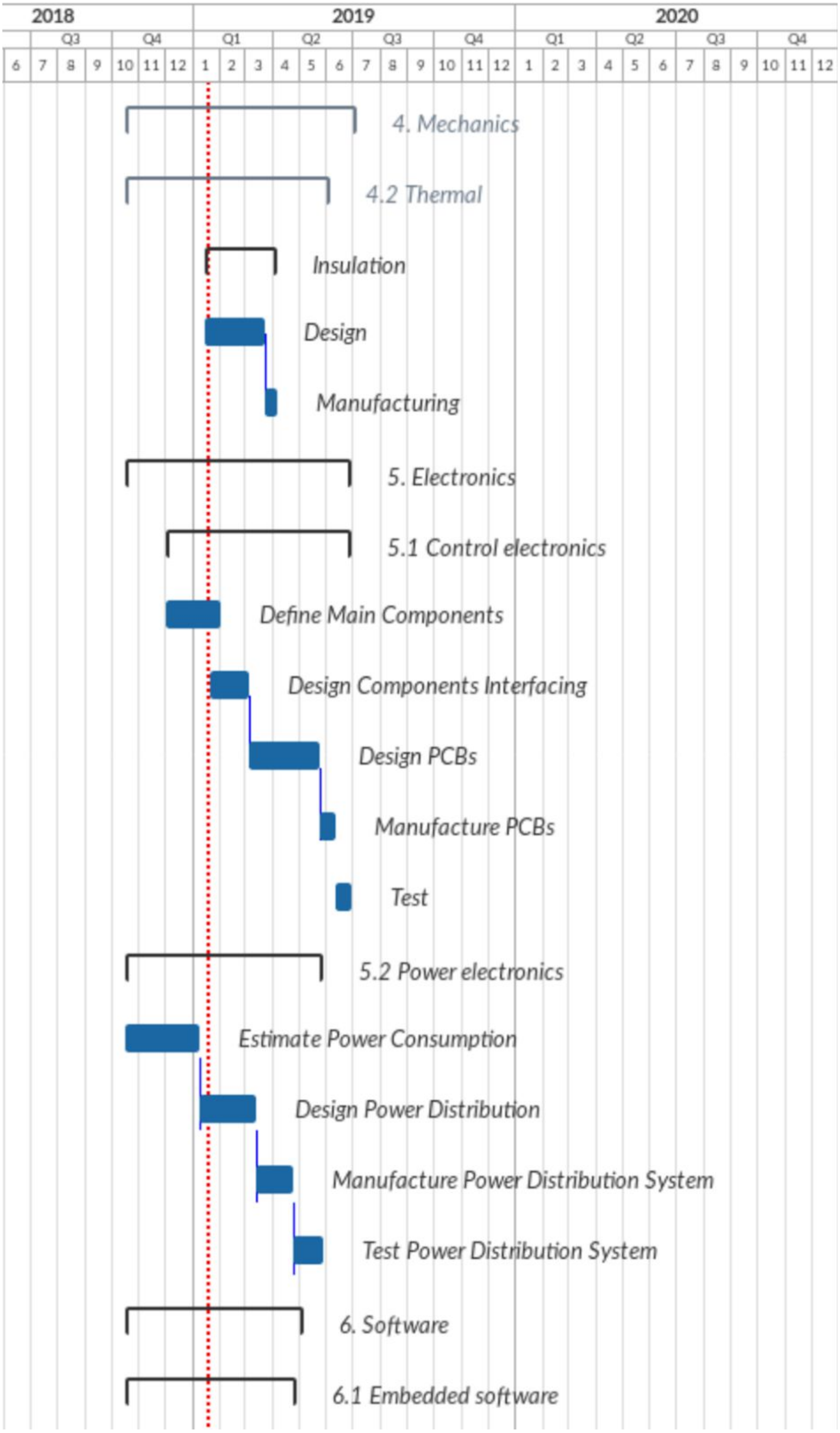
Learn Anemometer Use and Configuration
4. Mechanics
4.1 Structure
Resistance simulation
Manufacturing
Boxes resistance tests
Attachment resistance tests
Gondola box design
Upper box design
Attachment design
4.2 Thermal
Thermal Management System
PID Design
Physical Design
Tests
Modelisation
Study Constraints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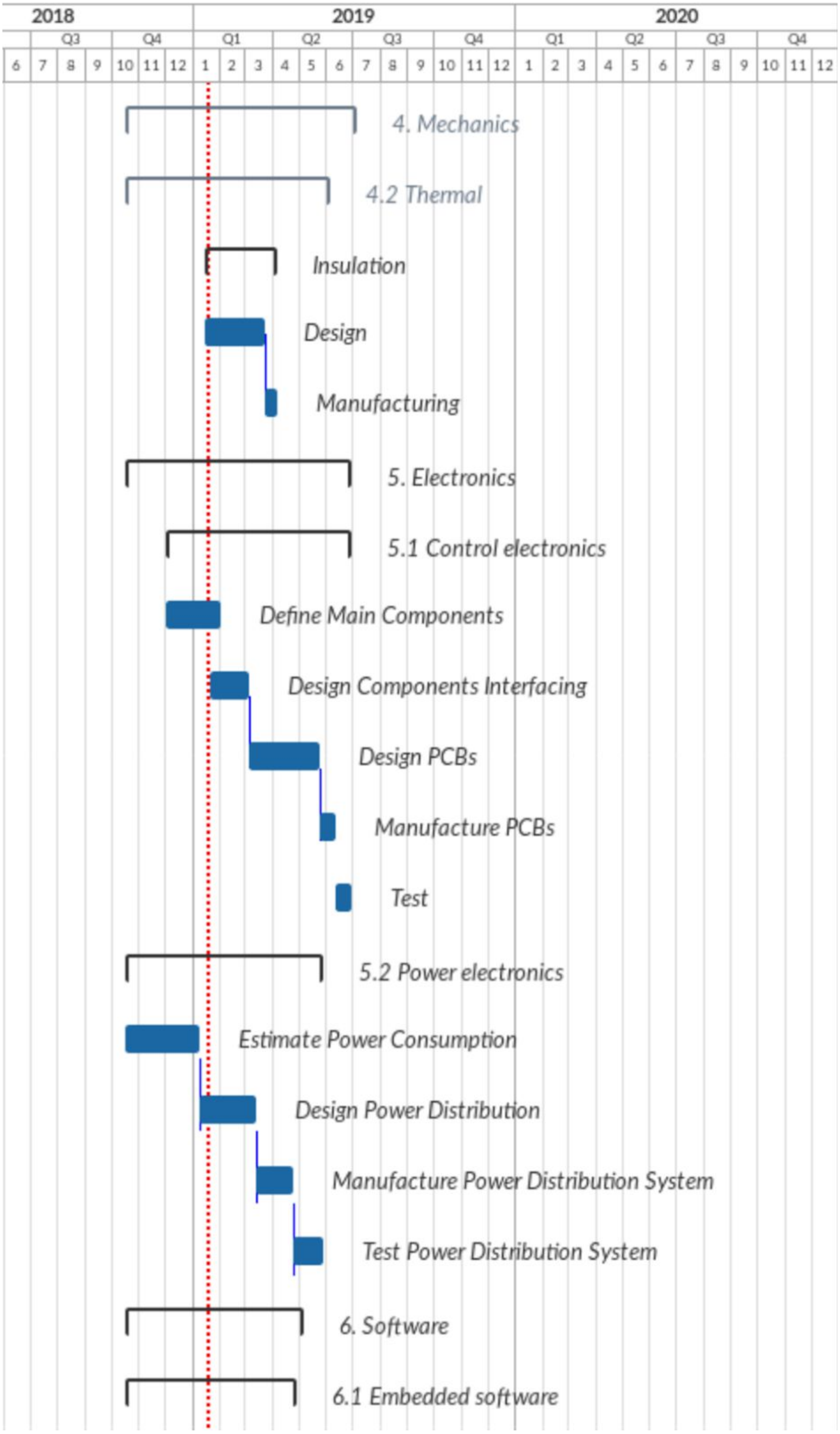
4. Mechanics
4.2 Thermal
Insulation
Design
Manufacturing
5. Electronics
5.1 Control electronics
Define Main Components
Design Components Interfacing
Design PCBs
Manufacture PCBs
Test
5.2 Power electronics
Estimate Power Consumption
Design Power Distribution
Manufacture Power Distribution System
Test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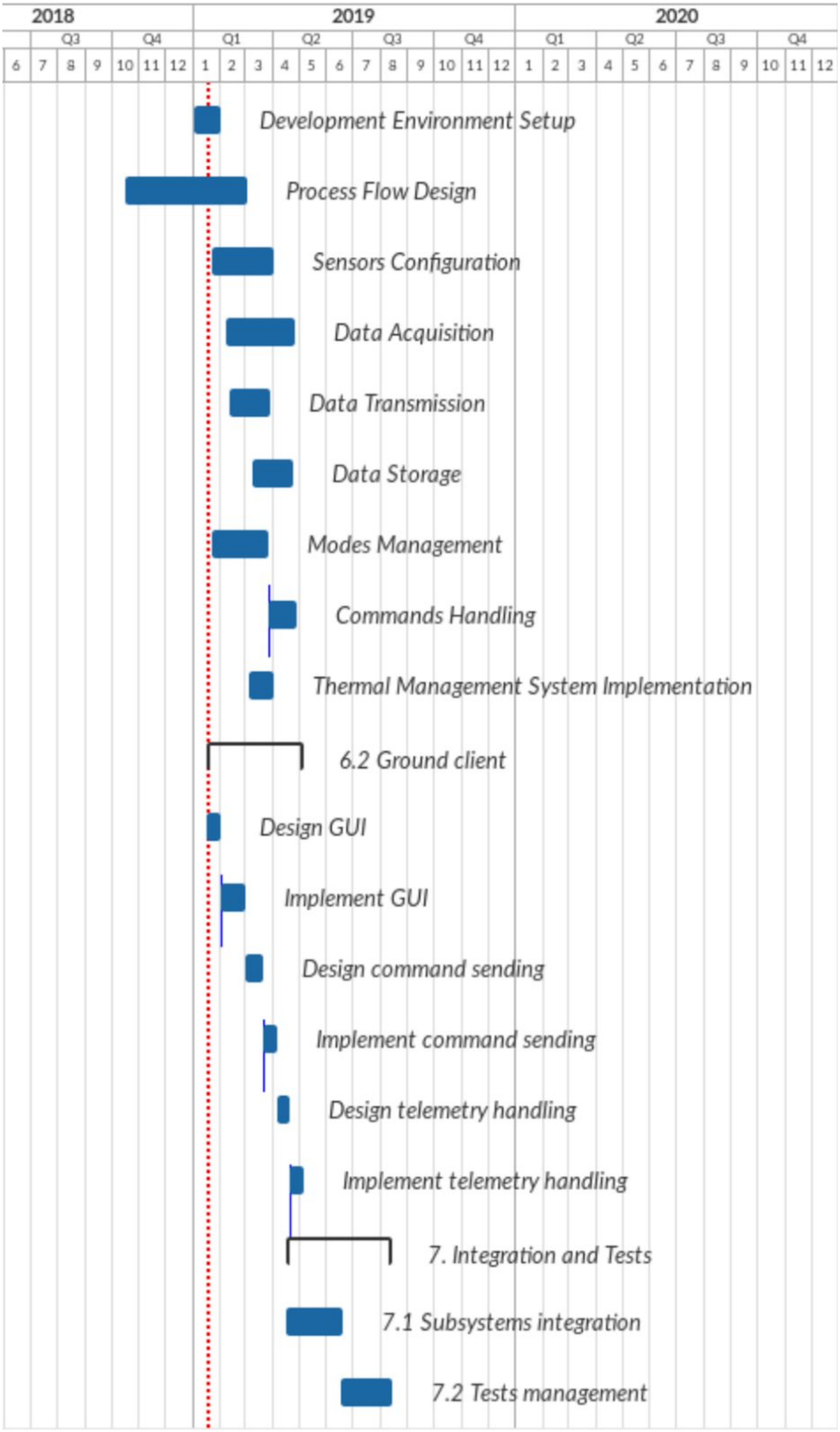
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Development Environment Setup
Process Flow Design
Sensors Configuration
Data Acquisition
Data Transmission
Data Storage
Modes Management
Commands Handling
Thermal Management System Implementation
6.2 Ground client
Design GUI
Implement GUI
Design command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