’LEPIC’ Balloon Project 2017-18

Master Space Technology and Instrumentation

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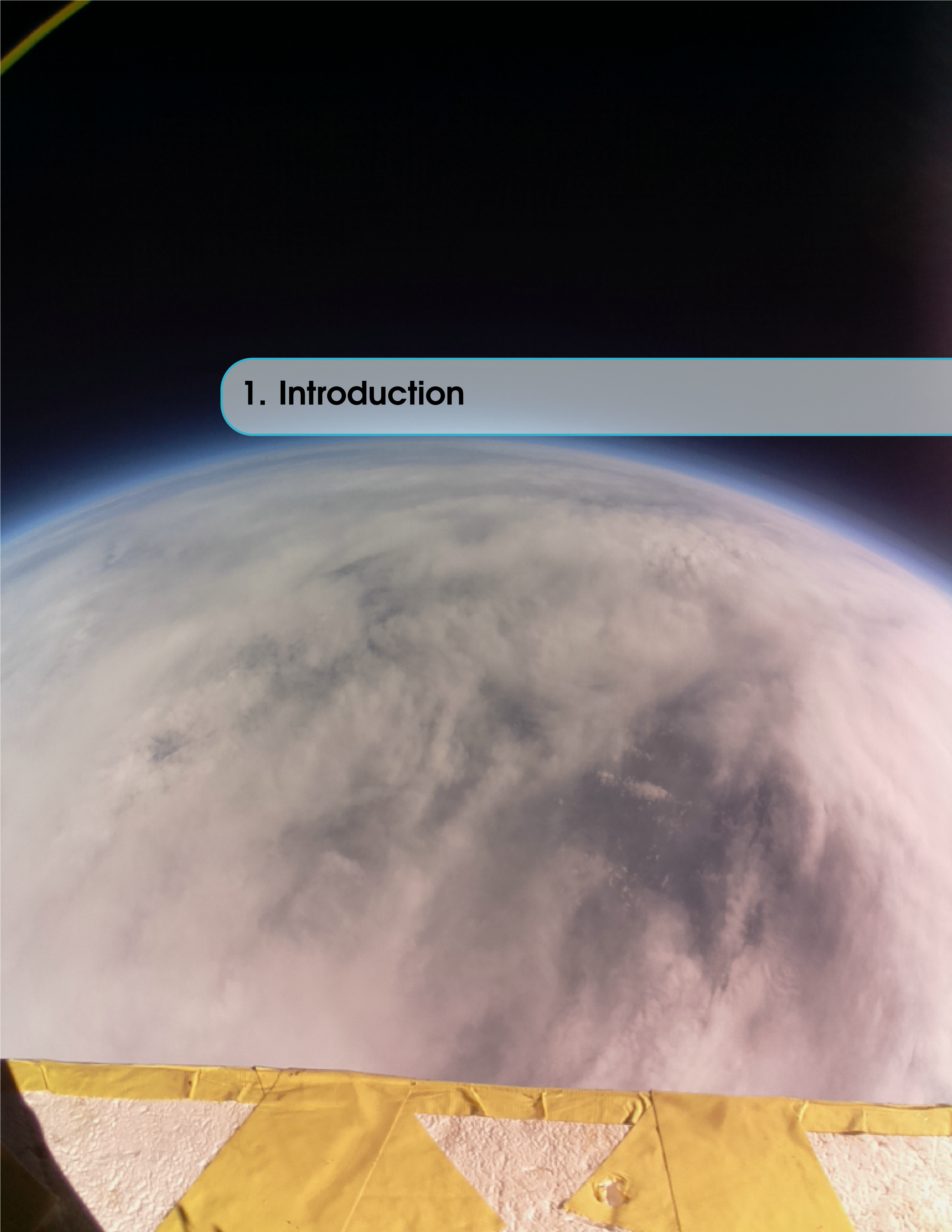
1. Introduction



1.1 Abstract

The atmosphere, especially the ozone layer protects us from a set of particles that bombard the Earth. Probably associated with star explosions or implosions, the composition of this radiation is now well known: 90% protons (hydrogen nuclei), 9% alpha particles (helium nuclei), 1% electrons and some others particles in very low quantity. By crossing, the atmosphere, successive collisions of particles produce multiple reactions and attenuate the flow. Earth's stratospheric layer hots UV rays absorption from Sun by ozone layer. This vertical stratification ensures that the stratosphere is dynamically stable: there is no regular convection or turbulence associated with this part of the atmosphere. The stratosphere is almost completely free of clouds or other forms of weather. Stratosphere is the home of electrical general circuit. In addition; Stratosphere is known to be passive with regards to transmission of electric fields coming from elsewhere. Unusual large electric fields have been reported from some observations.The electrical composition of the stratosphere, mainly concerns ozone coming from oxygen under the action of the Sun. Inside the stratosphere particles mixing takes a long time and could reach month's even years to be done. Though, measurements of electron density and electrical conductivity from a balloon platform are challenging because values are very low and difficult to obtain with this type of vehicle with regard to electron density. To find out more about the proportion of electrons and electrical conductivity in this layer, a probe can be placed to take measurements. The probe would be a Langmuir probe. Furthermore, from the take-off of the balloon from the ground to the stratosphere, we can try to make a panoramic video and take pictures of the landscape that we can see from the balloon platform. Hence, a suitable designed long duration balloon experiment capable of supporting such a payload instruments can provide us information to compare with former data and about the electron density. We present herein details of one such experiment EPIC (Langmuir Electromagnetic Pi Camera) carried out from a low-latitude site in France.The instruments package for this experiment is comprised of Go-pro cameras for taking pictures and videos. The experiment was conducted from CastelJaloux on March 1st.In spite of a few shortcomings, we report herein a noticeable feature of the fly which are photos, pressure and temperature profile get from this balloon experiment.

1.2 Project Overview and objectives

Nowadays, balloon holds a unique position among tools of scientific research. The balloon is an excellent tool for stratospheric exploration. Indeed, it is a vehicle halfway between space launchers and nano-satellites. Only it can evolve durably in the stratosphere, a region inaccessible to satellites and crossed too quickly by sounding rockets.

Therefore this is one of the reasons why they are used in Stratosphere exploration. Besides, another reason is that the balloon can be used for educational purposes. Hence, it is within the framework of our teaching unit: practical assignments that we had to realize the payload of a stratospheric balloon.

The subject of our research project concerns the measurement of physical characteristics of the Stratosphere, the flight environment, data acquisition, and the transmission of simple signals and transmission losses in the atmosphere and finally the exploitation of these data.

This will allow us in a first time to approach the planning and research phase in which are exposed the main ideas of which the Langmuir probe and the 360 degree camera are part.. With regard to the measurement of electron density and electrical conductivity, we will present the sources we consulted to propose our own experimentation for carrying out these measurements first in the laboratory and then in the Stratosphere. Besides, we will present an electrical architecture for Langmuir probe.

In a second stage, we will talk about the implementation phase. We will specify under what conditions we finally decided to not resort to the 360 degree camera and instead preferred to take pictures. In addition outline the criteria used to choice and establish the final setup for our report.

Thereafter, we will deal with tests phase and specify which were carried out in the room in order to get an idea of what the instruments will have to face once in altitude, on the platform of the balloon, essentially subjected to the rotation of the payload, pressure, temperature and above all the electromagnetic field coming up from others electronic components on the payload.

Afterwards, we will we will present the balloon flight by looking at the events before the flight and then describing the flight itself.

This will then lead us to the analysis of the results obtained in terms of temperature and pressure conditions, accelerometer and pictures get from cameras.

To sum this project up, we will present the future prospects for an experiment with nano-satellites, particularly with regard to measurements that can be carried out with the Langmuir probe. In addition, we will focus on possible future balloon projects for future promotions. At a later stage, we will also end up with revisions and suggestions that could have been made on our own project.

To complete our study, each of us will give his opinion on the approach followed for the realization of this project.

2. Initial Payload and architecture

2.1 Initial project

The whole project was divided into two aspects: 360 °camera and Langmuir probe. It was decided that the balloon payload will mainly consist of 360°camera. Since Langmuir probe is still being researched in most parts of the world, it was decided that a research report on Langmuir probe for stratospheric and tropospheric electric field measurements will be made. This report can then be taken by future students as a project. Also, an attempt can be made to make a prototype of the Langmuir probe and the associated electronics for data processing.

2.2 360°-camera

The initial plan in the project was to take 360°images from stratosphere. We planned to use eight Arducam cameras to cover an angle of 360 °along the axis of rotation of balloon i.e. all the cameras had to be separated from each other by an angle of approximately 45 °. Since the field of view of Arducam cameras is more than 45 °, it would have been ensured that there is no dead zone between the images taken by the different cameras on the payload. We planned to 3-D print a spherical casing in which all the eight cameras can be placed and mounted on the payload/balloon for the purpose of taking images. Since the balloon was expected to spin at a very fast rate during ascent/descent, we planned to merge accelerometer readings with the camera images in order to stabilize them. We also planned to extend the project to capturing videos once 360 °images are obtained and processed successfully. Since the storage of a video file takes up a lot of memory space, it was planned to use compression algorithms for storing data on SD card. Also, it wouldn't have been possible to take video for the whole duration of the flight due to limited memory size of the SD card. However, before starting the project, we had anticipated that the trickiest part would be to gather the images from all the cameras simultaneously and merge them into a single 360 °image. We planned to use two adapter boards with Raspberry Pi in order to get images from eight cameras (Each adapter board could support four cameras).

2.3 Langmuir probe

2.3.1 Measuring the Stratospheric Conductivity with a Langmuir Probe

The Earth's electrical environment is host to a giant electrical circuit which is often referred to as the global electric circuit (GEC). The GEC links various sources of electrical generators which are located in the lower atmosphere, the ionosphere and the magnetosphere. (Gurubaran, S. et al. 2017) The stratosphere is a region in the Earth's atmosphere where a number of interesting phenomena take place. Conductivity measurements can provide us with important clues pertaining to the nature of the phenomena taking place in the stratosphere.

Electrical conductivity increases exponentially with altitude in the stratosphere. It is proportional to the product of the ion concentration and the ion mobility. Variations in the cosmic ray flux can result in a change in the ion concentration and this will result in the variation of stratospheric conductivity. Stratospheric conductivity is an important parameter of the global electric circuit. (Gupta, S. P. and Thampi, S. V. 2015) It is believed that the horizontal electric fields present at stratospheric altitudes are of ionospheric origin.

The Indian Middle Atmospheric Program (IMAP) was one of the most important programs to study the variability of the middle atmospheric electrodynamics. Although the measurements of electric fields from a balloon platform are challenging due to their small magnitudes, a suitably designed long duration balloon experiment capable of detecting small fields can provide useful information on the evolution of stratospheric electric fields which would otherwise be only possible via in situ measurements by radar or satellite.

Balloon-borne measurements of the stratospheric conductivity were studied from near ground level to 35 km in conjunction with measurements of the ionization rate and the positive ion density. Using data from four flights, it was shown that conductivity values in the stratosphere are larger during periods of high solar activity compared to periods of low solar activity. It was suggested that heavy cluster ions dissociate into lighter ions during periods of high solar activity giving rise to enhanced conductivity over this region.

The IMAP measurements were based on a relaxation time technique. In this technique, one or more Langmuir Probes are driven to a potential different from the ground potential of the payload for a short period of time and then the potential difference is released and the potential of the Langmuir Probe is allowed to decay to a steady state value exponentially. For the relaxation time technique to work, the voltmeter that senses the potential difference between the driven Langmuir Probe and the payload ground must draw significantly less current than the current that flows from the Langmuir Probe to the medium. (Bering, E. A. et al. 2005)

The sensor used for the IMAP measurements was a hollow spherical copper sphere coated with aquadag of diameter 20 cm and mounted on a boom of one meter length on the balloon gondola. Aquadag was used to increase the surface work function, thereby suppressing the emission of photoelectrons which contaminate the measurements of the positive ion conductivity. Figure 2.1 below shows the setup of the IMAP measurements. A voltage pulse of ± 5 was applied for a duration of 1 sec with an interval of 50 sec. The decay time constant is then measured and the following equation is used to calculate the conductivity:

$$\sigma = \frac{\varepsilon}{\tau}$$

where, σ = Conductivity of air, ε = Permittivity of the medium, and τ = Relaxation time constant

In order to measure conductivity, the relaxation time constant of the Langmuir Probe voltage is measured with the aid of voltage decay curves obtained during in situ measurements. The shape of the voltage decay curve has been predicted to be near exponential by Chang and Kodera (1985). The best fitting exponential curves were used to obtain the decay time constant.

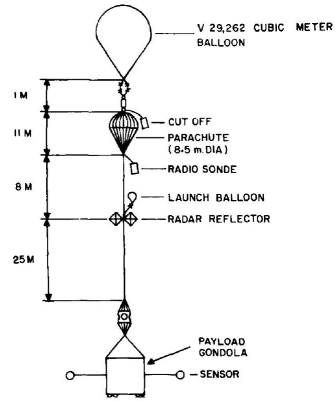


Figure 2.1: IMAP Balloon Payload (Division, R. S. 1984)

2.3.2 Design of LEPIC Langmuir Probe

There is a growing trend towards miniaturization in space instrumentation. Micro Electro Mechanical Systems (MEMS) is a field which is rapidly developing and covers many areas and products. The attraction of MEMS is their massively reduced resource requirements (lower mass and power requirements, smaller size). For the LEPIC mission, we aim to employ MEMS in order to miniaturize the experiment conducted by IMAP. Although there are performance limitations and constraints imposed by the MEMS approach, we believe that our proposed design of the Langmuir Probe could at least match the overall performance of the IMAP mission.

2.3.3 Langmuir Probe Geometry

We considered three possible design configurations of the Langmuir Probe geometry. These were planar, spherical and cylindrical geometries. Figure 2.2 below shows these three different geometries.

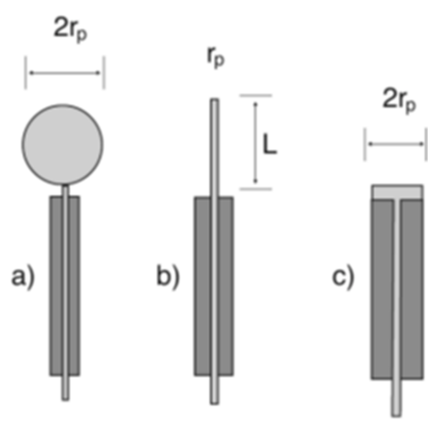


Figure 2.2: Collecting Langmuir Probes with radius r_p and a) spherical, b) cylindrical and c) planar geometries

The representative current-voltage curves for the three different probe geometries is shown in Figure 2.3 below. It can be seen that the spherical geometry provides the best performance and this is why it was chosen as the preferred geometry for the LEPIC mission.

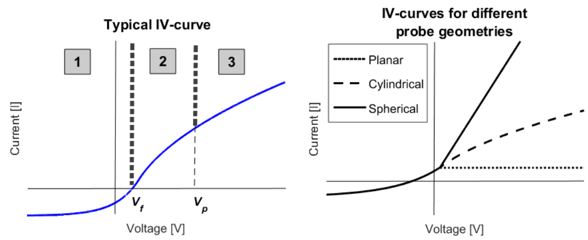


Figure 2.3: IV - curves for different probe geometries

2.3.4 Langmuir Probe Material

We considered copper and silver as possible materials for the probe tip due to their high electrical conductivities and low cost compared to gold. Copper ($\sigma = 5.96 \times 10^7 s/m$) was chosen over silver ($\sigma = 6.30 \times 10^7 s/m$) as the preferred material for the LEPIC mission due to its lower cost despite the slightly higher conductivity of silver.

2.3.5 The OML Approach

A complete general theory which describes the collection of charged particles by a Langmuir Probe does not exist. The appropriate theory depends on the parameters of the plasma and the size and shape of the probe. The Orbital Motion Limited (OML) approach is often applied for spherical objects in low density plasmas. For this approach to be applicable the following condition has to be satisfied:

$$r_p << \lambda_D$$

where, r_p = Probe radius, λ_D = Debye Length

The OML approach allows us to predict the plasma potential and it also provides us with a plasma analysis model. The following equation is used to calculate the plasma current with the OML approach:

$$I_p = q{r_p}^2 n_e [\frac{8\pi k T_e}{m}]^{\frac{1}{2}}$$

where I_p = Plasma Current, r_p = Probe radius, ε_o = Permittivity of free space $(8.854 \times 10^{-12} F m^{-1})$, k = Boltzmann's Constant $(1.380 \times 10^{-23} J K^{-1})$, q = Charge $(1.602 \times 10^{-19} C)$, n_e = Electron density, T_e = Electron Temperature, m = Mass of an electron $(9.109 \times 10^{-31} kg)$

2.3.6 The Space Potential Method

The electrostatic probe method is often used to measure the electric conductivity of atmospheric ions. There are three different techniques and they can be classified as follows: (1) attracting potential method, (2) transient response method and (3) space potential method. The theoretical model for all these methods are based on the "equivalent RC- electric circuit model." This analysis also satisfies the OML condition:

$$r_p << \lambda_D$$

For $\frac{R_p}{\lambda_D} \leq 0.1$ the space potential method is the most suitable method to obtain conductivity. The method requires the use of currents I_1 and I_2 at potentials V_{1f} and V_{2f} relative to floating potential V_f. These potentials are arranged so that V_1 and V_2 are large and positive (or negative for σ). The following equation is used to calculate conductivity:

$$\sigma = \frac{I_1{}^{\frac{1}{\beta}}}{V_{1f} + V_\Gamma}\left(\frac{kT}{e}\right)\frac{\varepsilon_o}{C_p}$$

See Chang and Kodera (1985) for nomenclature.

2.3.7 Langmuir Probe Operating Regimes

The analysis of the different operating regimes of the Langmuir Probe allowed us to decide on a suitable design concept to pursue. For this we have to consider the conditions in which the Langmuir Probe will operate in. A key plasma parameter we consider first in the stratosphere is the electron density. Due to the varying nature of the electron density, we consider three different values of the electron density which represent the best case scenario, the average scenario and the worst case scenario for the LEPIC Langmuir Probe experiment. Table 2.1 below displays these three different regimes.

Another important plasma parameter we consider is the Debye Length. The Debye Length is the distance over which a charge q is shielded by the ions in a plasma. The following formula is applied to calculate the Debye Length:

$$\lambda_D = \sqrt{\frac{\varepsilon_o kT}{q^2 n_e}}$$

where λ_D = Debye Length, ε_o = Permittivity of free space $(8.854 \times 10^{-12} Fm^{-1})$, k = Boltzmann's Constant $(1.380 \times 10^{-23} JK^{-1})$, q = Charge $(1.602 \times 10^{-19} C)$, n_e = Electron density, T = Temperature $(T_{stratosphere} = 273K)$

As the principle of MEMS is miniaturization, we set a maximum probe radius of 5 cm. Smaller radii can be considered depending on the electron density of the stratosphere at the time of measurement. The following table summarizes the three different regimes with the expected values of electron density, Debye Length and electric current.

Table 2.1

Regime	n_e	λ_D	I_p	$\frac{R_p}{\lambda_D}$
Best Case Scenario	$10^{12} m^{-3}$	$1.14 \times 10^{-3} m$	$1.291 \times 10^{-4} A$	43.86
Average Scenario	$10^{7} m^{-3}$	$0.3605 m$	$1.291 \times 10^{-9} A$	0.139
Worst Case Scenario	$10^{2} m^{-3}$	$114.006 m$	$1.291 \times 10^{-14} A$	4.386×10^{-4}

Our proposed spherical copper Langmuir Probe of radius 5 cm is capable of measuring currents in a low density plasma. Expected plasma densities in the stratosphere between $10^7 m^{-3}$ and $10^2 m^{-3}$ obey the OML approach and this could be used as a governing theory to determine the operation of the Langmuir Probe in such low density plasmas. In addition, this range of plasma densities satisfies the condition of the space potential method which allows us to calculate the electrical conductivity. We propose further analysis of the model of Chang and Kodera (1985) in order to establish a relationship between the calculated values of conductivity and the impact on the parameters of the electrical subsystem.

2.3.8 Electrical Architecture for Langmuir Probe

The most commonly used electrical architecture for measuring the Langmuir probe potential is illustrated in the following figure. However, the above block diagram is valid in the case Langmuir probe potential needs

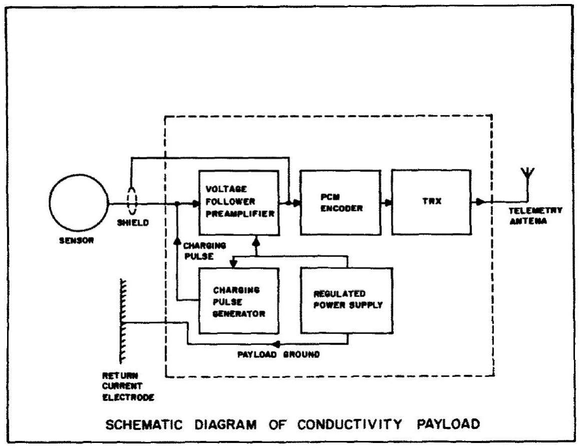


Fig. 1. Block diagram of the conductivity payload.

to be transmitted to a ground station. For our case, we do not need to use PCM encoder and TRX. Instead, we can directly connect the voltage follower preamplifier output to the ADC of Raspberry Pi. However, care needs to be taken because the ADC pin can only measure a maximum voltage of 3.3 V. Therefore, if the output voltage from voltage follower preamplifier is expected to be more than 3.3 V, then it would become essential to design a voltage divider circuit in order to measure Langmuir probe potential. We intend to use AA batteries in the project. These batteries provide a regulated power supply. The charging pulse needs to provide a voltage spike to the Langmuir probe. This will allow the Langmuir probe to be charged. The voltage spike should have a maximum in the range of 5 V to 9 V. The spike can be provided to Langmuir probe with the help of a relay switch. The relay switch can be programmed to turn ON as soon as the voltage on the Langmuir probe discharges to 10% of the value with which it was charged. Relay switch can be kept ON for some estimated time so that the probe is charged again and then it can be toggled to the OFF state.

A voltage follower preamplifier is required to process the potential developed on Langmuir probe. Typically, the input resistance and the input capacitance to the electrical circuit is of the order $10^{12}\Omega$ and 1.5 pF respectively. We can measure the probe current by observing the charging and discharging cycle of the probe potential. However, the charging and discharging of the Langmuir probe is dependent on the capacitance and resistance of the probe. While observing the charging and discharging cycles, we might not get a true estimate of the probe current due to the stray capacitance introduced by the wires and other electronics in the circuit. In order to minimize the effect of the stray capacitance, we should insert a high value of resistance (around 10 kΩ) in series with the input and as physically close to the input pin as possible. However, the value of the resistance to be used is dependent on the frequency response of the circuit. For lower frequency applications, we need to use a higher value of resistance in order to preserve the frequency response of the overall circuit.

For measuring currents of the order of femto-Amperes, we can use Ultra-Low Input Current Amplifier IC LMC6001 Ultra. This is a low cost IC developed by Texas Instruments. The supply input voltage to the IC ($V^+ - V^-$) is recommended to be in the range 4.5 V to 15.5 V. Therefore, it is possible to use this IC by using a combination of AA batteries. It has ultra-low bias current (typically less than 10 fA) and high input impedance (>1 TΩ) which makes it suitable to be used as a preamplifier.

When high input impedances are required, it is suggested to guard the input lines in order to reduce leakage and stray capacitance. For amplifiers with ultra-low input current, it is often desirable to use high values of feedback resistances in order to have a measurable voltage or a voltage gain. An input capacitance may occur between wires and the ground and this might adversely affect the performance of the circuit. For cancelling the effect of input capacitance, we can add a capacitor C_f around the feedback resistor as shown in Figure 2.4.

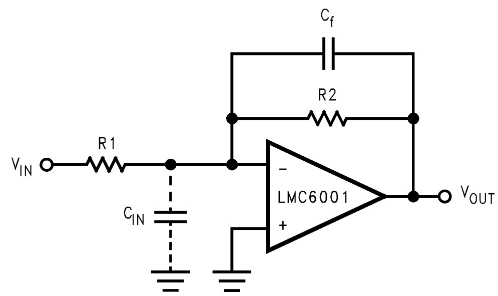


Figure 2.4: Cancelling the effect of input capacitance

The value of C_f should satisfy the condition:

$$\frac{1}{2\pi R_1 C_{IN}} \geq \frac{1}{2\pi R_2 C_f} \implies R_1 C_{IN} \leq R_2 C_f$$

C_{IN} is generally less than 10 pF. Therefore, optimum design parameters can be $R_1 = R_2 = 10k\Omega$ (for unity gain) and $C_f = 0.01\mu F$

As the balloon gains height, electric potential on the electrical lines in the circuit changes gradually. Therefore, it becomes necessary to measure the probe potential against a reference potential . That is why, most of the Langmuir probe circuits have a return current electrode. However, since there is no provision of return current electrode on our balloon, therefore it becomes inevitable to search for an alternate solution. One of the solutions that we propose is to use an instrumentation amplifier as a preamplifier. This can ensure that our measurements of the probe potential is independent of the drift in electric potential with height. However, the proposed solution is heavily based on the assumption that the drift in potentials is almost same on all the electrical lines in the circuit.

Figure 2.5 depicts an instrumentation amplifier with the following features:

- High-differential and common-mode input resistance (>$10^{14}\Omega$)
- 0.01% gain accuracy at $A_V = 1000$
- excellent CMRR with $1-M\Omega$ imbalance in source resistance
- Input current less than 20 fA
- Offset drift < $2.5\mu V/°C$

With the help of R_2, we can adjust the gain without degrading CMRR. R_7 is an initial trim used to maximize CMRR without using super precision matched resistors. For good CMRR over temperature, low-drift resistors should be used.

If $R_1 = R_5, R_3 = R_6, R_4 = R_7$,

$$\implies \frac{V_{OUT}}{V_{IN}} = \frac{R_2 + 2R_1}{R_2} \times \frac{R_4}{R_3}$$

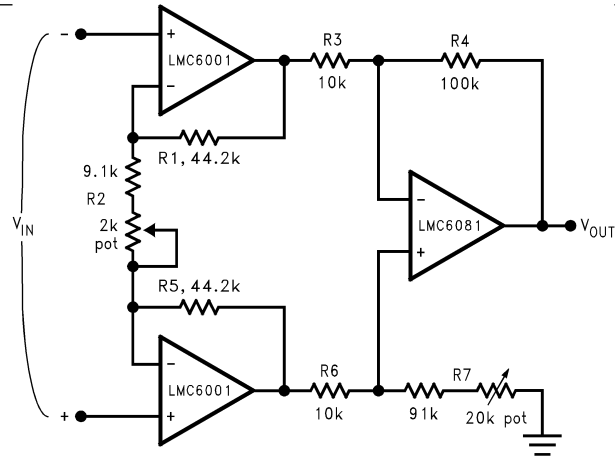
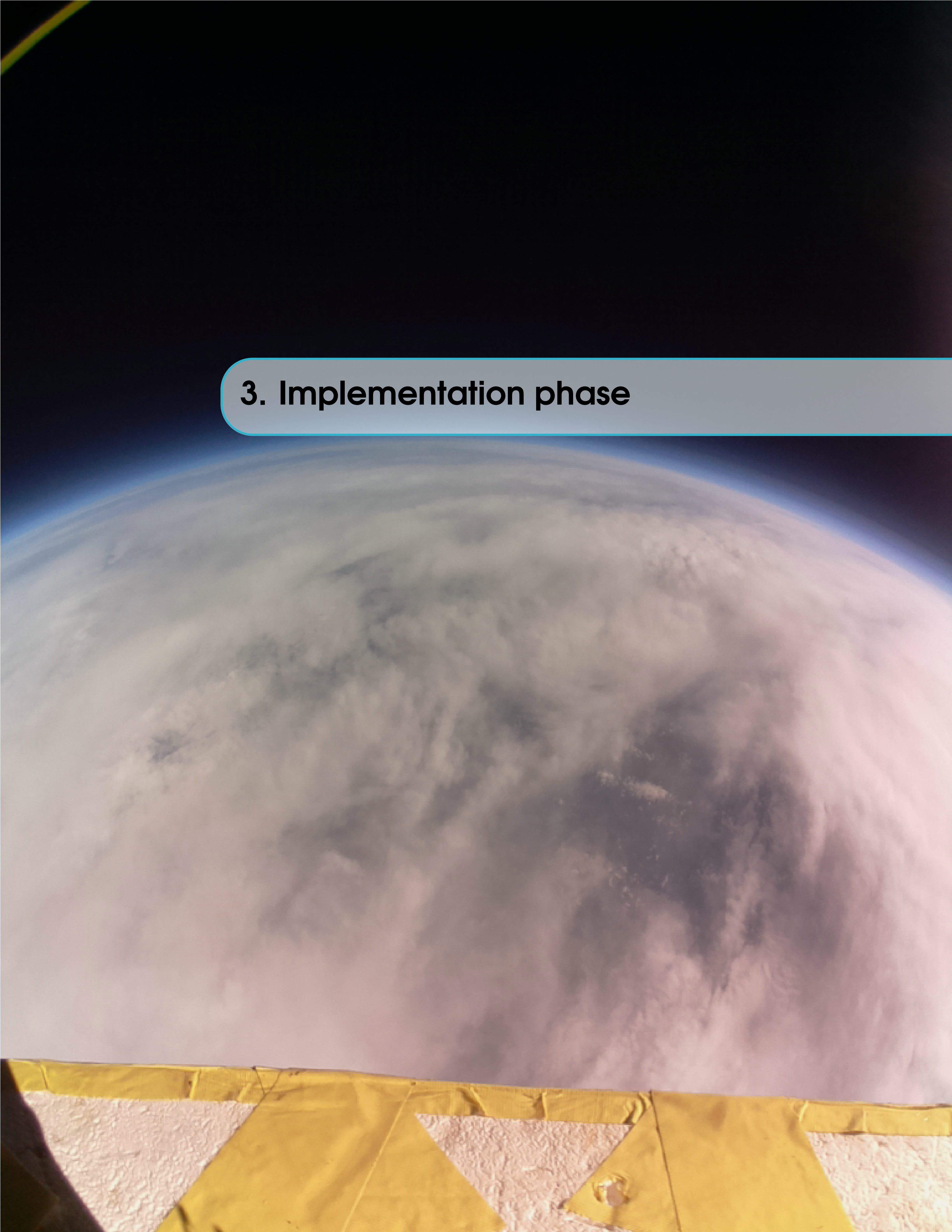


Figure 2.5: Instrumentation Amplifier

If the potentiometer resistance of R_7 is $9k\Omega$ and the potentiometer resistance of R_2 is $0.75k\Omega$, then A_V is approximately 100. If the preamplifier has to be used as a unity gain amplifier, then we can use the configuration $R_1 = 250\Omega$ and $R_3 = R_4 = 10K\Omega$.

3. Implementation phase



3.1 Finally no 360°camera

As explained on the previous chapter, the first idea of this project was to create a 2 π camera to capture images from the stratosphere. In addition to imagery we also wanted to put together a video of the whole flight. So we ordered from the roboshop website a multi camera adapter for Raspberry. This module was first designed for connecting more than one camera to a single CSI camera port on Raspberry Pi board. One adapter board can connect 4 cameras. A maximum of 4 adapter boards could have been stacked, which means having up to 16 cameras on a single Raspberry Pi board.

Figure 3.1: Multi camera adapter for Raspberry

We followed the pin configuration. First of all we only used one multi camera adapter board. The switches 1 and 5 has been switched to ON position. It was at this moment that difficulties appeared. We tried the script that was given on the website (Link in at the end). By control the GPIOs according to the given configuration tables, this device was designed to for taking photos or videos by switching between different cameras.
So we understood at this moment that the cameras couldn't work at the same time. We thought to an another solution. Taking at a certain frequency pictures from all cameras by switching them on and off. The result should have been panoramic pictures, considering that the payload wont spin too quickly, or having a image post-processing.
Unfortunately, the luck wasn't on our side. Taking picture from a single camera was easy, however, it wasn't possible to read images from different cameras simultaneously by using this adapter board i.e. the device will not start reading an image from another camera until and unless it has finished reading the image from the current camera. The time between reading images from different cameras was too big in order to produce a decent quality 360 °image. Today the problem isn't solve. Some other projects encountered the same problem. We also tried to remove resistance on the camera as counseled in forums. The final answer to that was given by a previous study. This module wasn't made to work on with raspberry but with Arduino and the correct shield. The correct shield was found after few month but it was too late. This is IVPort V2, the first Raspberry Pi (It is compatible with all models of Raspberry Pi 1, 2 and 3) 8MP Camera Module V2

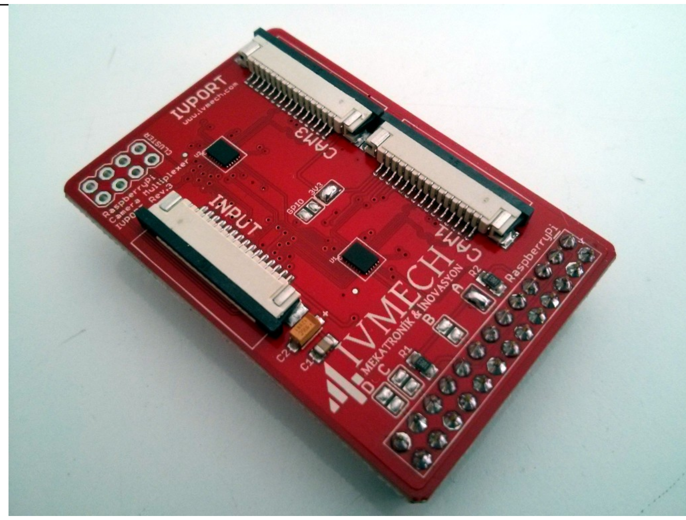


Figure 3.2: IVPort Raspberry Pi Camera Module Multiplexer

Multiplexer designed to connect more than one Camera Module V2 to Raspberry Pi. It has 1 CSI connectors for the input and 4 CSI connectors for outputs to the camera modules (as the previous one) with using flex cables. Also it has stacking headers for the GPIO connection and self stacking up to 4 Ivport. Ivport is a real and functioning product already. The PCB has been prototyped and works great. It can switch camera input even while video is streaming over RTSP.

3.2 Final setup

We were running out of time, the launching date was approaching and we had nothing to launch. Finally we decided to launch the payload with 2 cameras. The first one plugged in the raspberry pi (ArduCam) fixed on a side of the box. The second was a GoPro Hero 5 placed under the payload to record the lauching.Two SD cards have been used. One for the payload and the other for the GoPro camera. They present the same caracteristics: 16 Go (Verbatim)

Setup

The electronical box (Raspberry Pi + GrovePi)is around 13*7.3*7.78 cm. The entire mass with the aeronef and the CNES's devices was around 1.3 kg.
The entire system was composed of a Raspberry Pi 3 model b+, a Grove Shield to plug the different sensors, two 9 V batteries. The DOD was calculated to not going down 20% to protect the system from a rupture. We estimated a 5 hours of full operation.
A set of tests have been made for checking the integrity of the system. Three sensors have been plugged to the payload. The first one is the accelerometer on one I2C port on the Grove shield. The second one was the temperature sensor plugged on A0 port and the last one the Barometer & Temperature sensors plugged on one I2C port.

ArduCam

Figure 3.3: Camera for Raspberry

On this camera a fisheye lens has been mounted in order to obtain with a short focal distance a great aperture. On the horizontal field, the aperture is 185 °. The working temperature varied from -20°to +80°.

Grove Kit

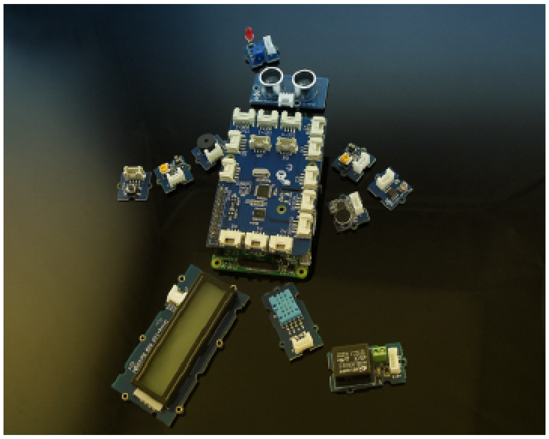


Figure 3.4: The Grove kit used for this project

Accelerometer

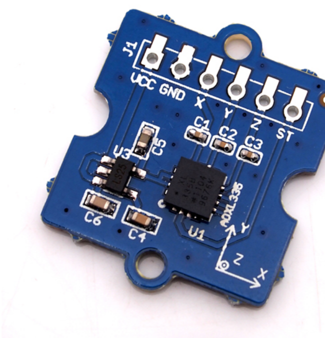


Figure 3.5: Accelerometer from Grove Kit

Is a cost-effective Grove interfaced and integrated sensor combination of 3-axis digital accelerometer and 3-axis digital gyroscope, but we only used the accelerometer.

Grove-Barometer Sensor

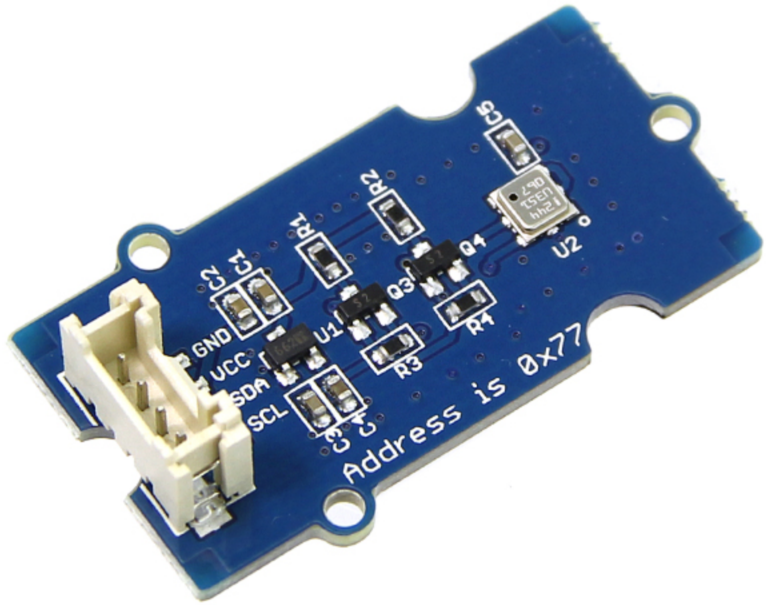


Figure 3.6: Grove-Barometer & Temperature sensor

It can widely measure pressure ranging from 300hPa to 1100hPa, i.e. +9000m to -500m above sea level, with a super high accuracy of 0.03hPa(0.25m) in ultra-high resolution mode. The chip only accepts 1.8V to 3.6V input voltage.

Grove -Temperature Sensor V1.2

Figure 3.7: Grove-Temperature Sensor V1.2

The range varied from -40°to +125°.
The accuracy is 1.25°.

Decoupling power supply

This Power Module is a small size 5A 350KHz 25V Buck DC to DC Converter.It can convert any DC voltage between 3.6V-25V to a selectable voltage from 3.3V to 25V. We could choose 5V direct output voltage with the switch or adjust the output voltage by the blue&white resistor.

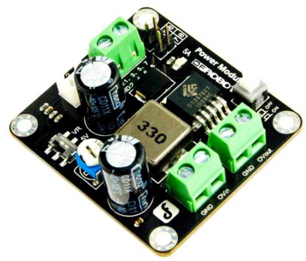


Figure 3.8: Decoupling power supply

Finally

The CNES devices were the transponder, their own sensors (next figure)and a tracking device.

CNES devices

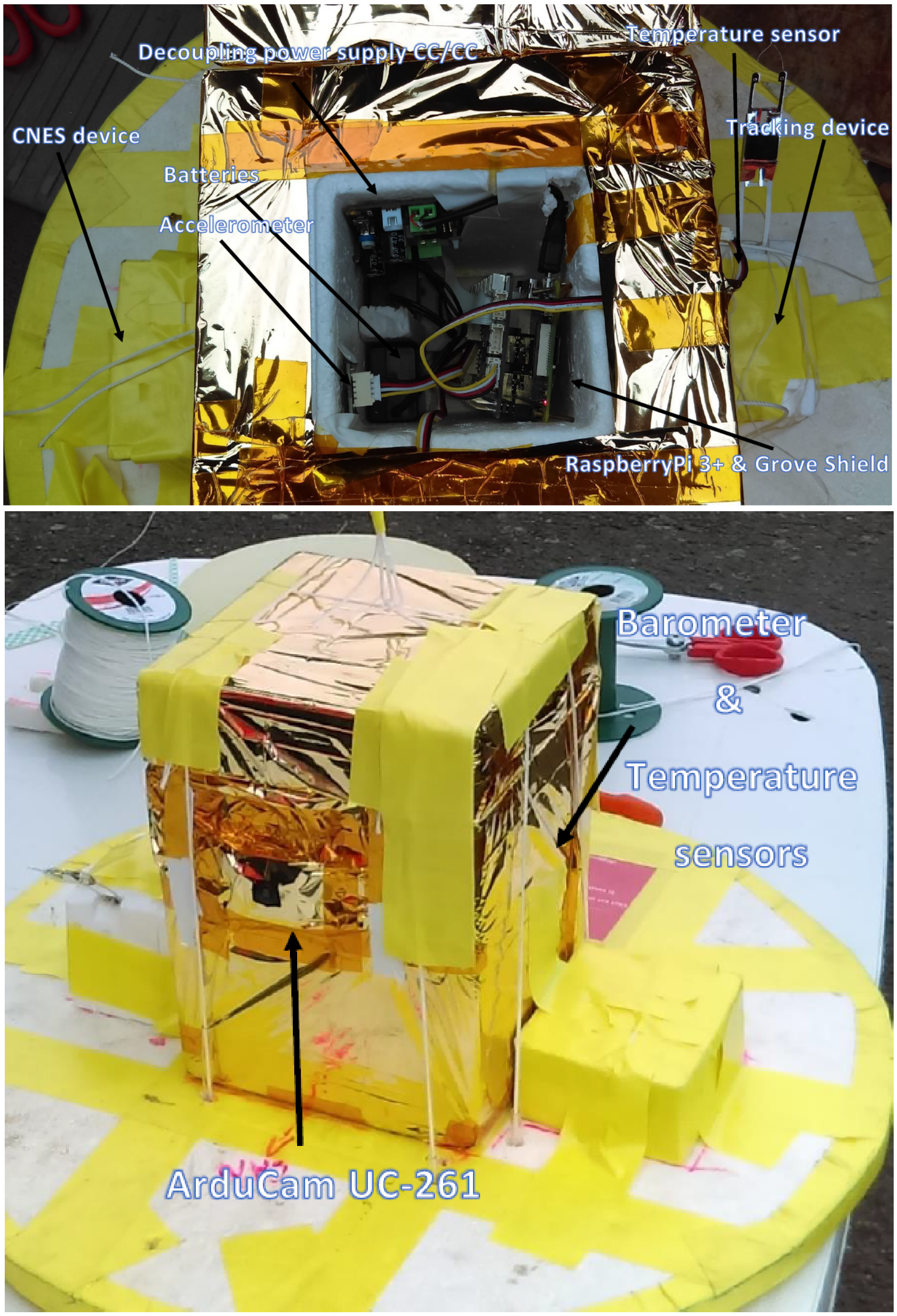
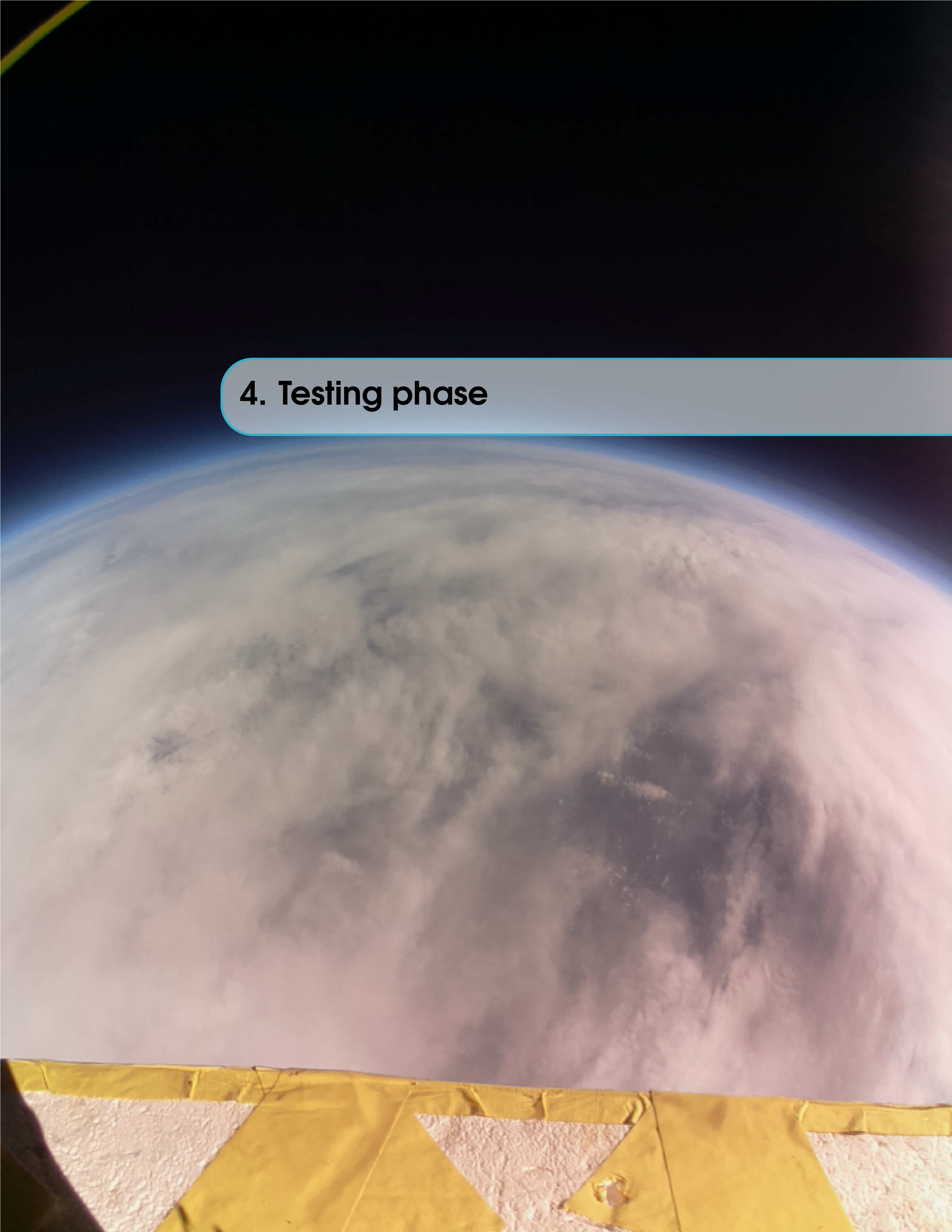
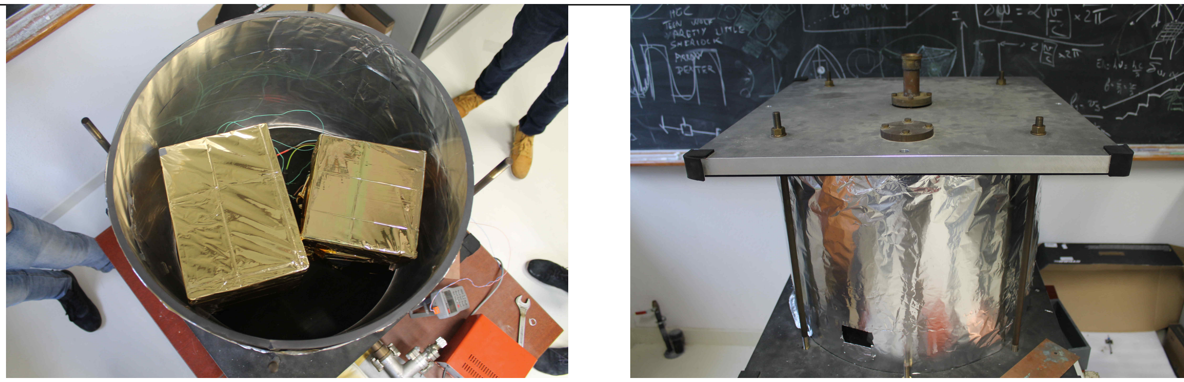


Figure 3.9: Description of the payload from different sides

Figure 3.10: CNES devices

4. Testing phase





(a) Payloads inside of the chamber (b) Sealed testing chamber

Figure 4.1: Thermal-vacuum test chamber

During the balloon flight the payload is exposed to extreme conditions. These include temperatures down to -70 °C and pressure down to a few kPa. On top of that our payload would be exposed to electromagnetic radiation from the transmitting instruments provided by CNES. In order to ensure that all systems will work stably nonetheless, we tested these conditions in the lab, before the actual launch.

4.1 Low pressure and temperature testing

Using a simplified thermal vacuum chamber, which was built by the TSI students of the previous year, we could test the low temperature and vacuum conditions in the lab. The test chamber was built from an insulated plexiglas cylinder with a height of approx. 60 cm and a radius of roughly 30 cm. These dimensions allowed to place both our payload and the payload of the other group into the chamber at the same time and perform the testing together. The cylinder was sealed from both ends by pressing two aluminum plates on it using four metal rounds that connected the two plates. The chamber with the two payloads is shown in Figure 4.1.

During the whole testing process the system of the payload was set to run precisely like in the actual flight. This means the temperature, the pressure and the acceleration were measured and pictures were taken every 10 seconds. The GoPro-camera that was used for the final flight was not included in theses tests, since it constituted an independent system, which have not built ourselves. Liquid Nitrogen was used to cool down the test chamber. Figure 4.2 shows the process of pouring the Nitrogen on the chamber.

Figures 4.3 and 4.4 show the temperature and pressure measurements for the testing. Before the testing the box was covered in pieces of a space blanket for thermal insulation. This foil serves the purpose of reducing thermal radiation and convection. Two sensors were placed on the outside of the box. There was one pressure/temperature sensor under the thermal insulation foil and one temperature sensor on the outside of the foil. This allowed to draw conclusions about the insulation capability of the foil. The data clearly shows the temperature difference between inside and outside of the foil. While the temperature on the inside only drops by 5°C, the outside temperature drops more than 40°C down to -22°C. It is safe to assume however, that the big temperature difference between the sensors can be accounted to a slight heat production in the inside sensor. Since the inside sensor is surrounded by styrofoam and insulation foil, the heat can not escape very well.

The lowest pressure that was reached were approximately 6 hPa.

The accelerometer data from the test is shown in Figure 4.5. Interestingly the horizontal accelerometer measurements show a correlation with the pressure drop. While the pressure dropped about 1000 hPa, the

Figure 4.2: Cooling the test chamber

acceleration along the Z-axis increased by about 0.06 g. However the X-axes didn't seem to be affected and neither the Y-axis showed a very strong correlation. From this we concluded that the measured accelerations were caused by the dynamics of the vacuum chamber and the airflow that was caused by the pump.

All in all the system seemed to withstand the low pressure and temperatures for the tested amount of time. Since we already knew that the flight would not take longer than three hours, we had an indication that our payload would also be resistant to the real flight conditions for the whole duration of the actual flight.

4.2 Electromagnetic compatability testing

Having learned from the launch of the previous year, we conducted a testing of the electromagnetic compatability with the transmission box that is provided by CNES to locate the payload after the flight. To test this, we simply set up an antenna next to our payload that was transmitting with the same frequency as the CNES system. We then turned our system on and took the recordings like in the real flight conditions. The transmitted signal did not show any effect on the recording of the data or any other system performance. All the readings were successfully taken and saved.

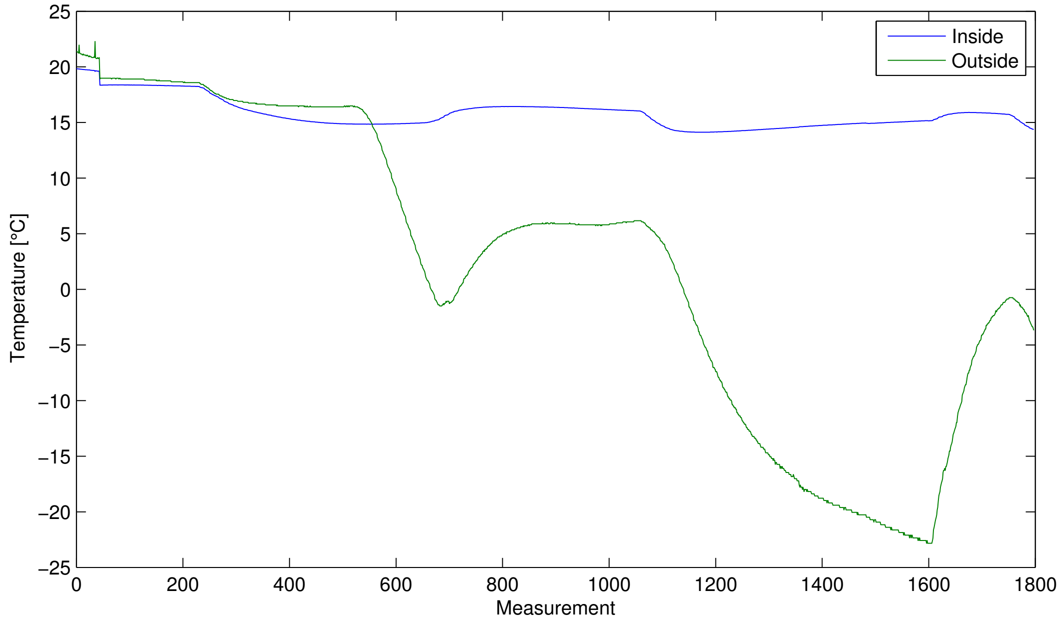


Figure 4.3: Temperature data from two sensors from thermal-vacuum test

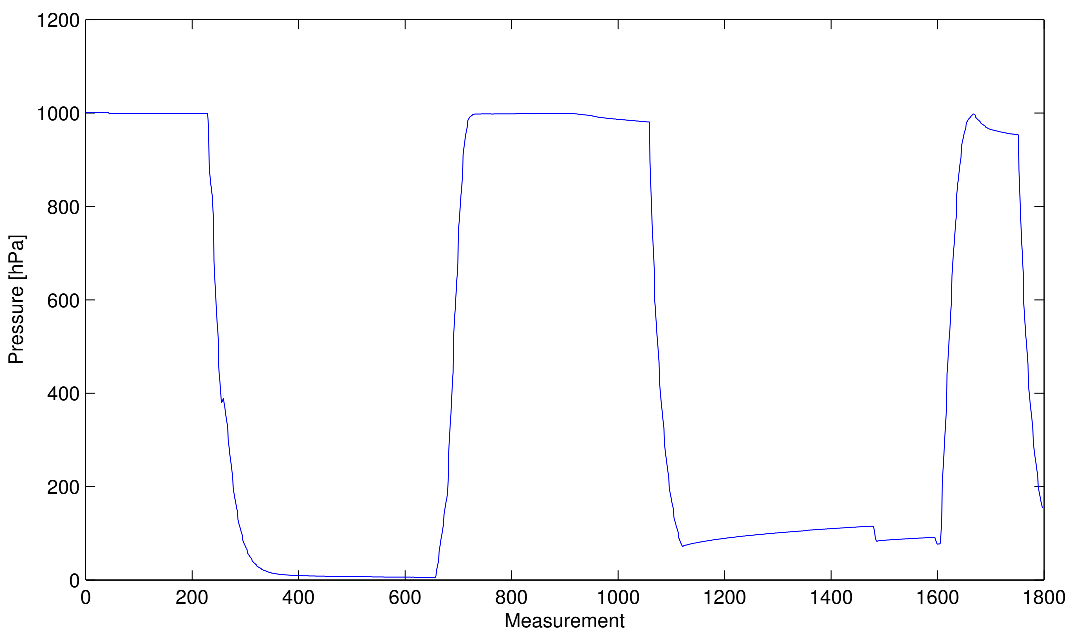


Figure 4.4: Pressure data from thermal-vacuum test

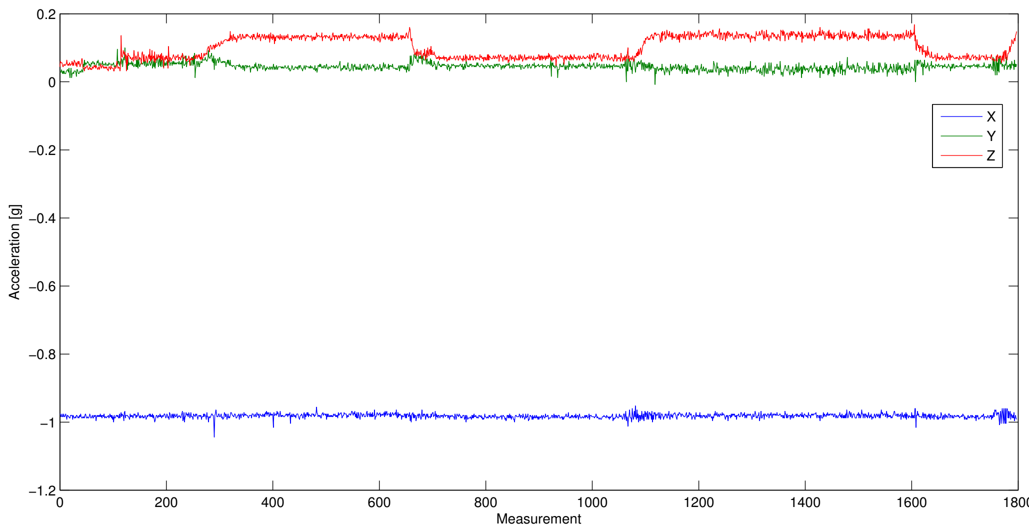
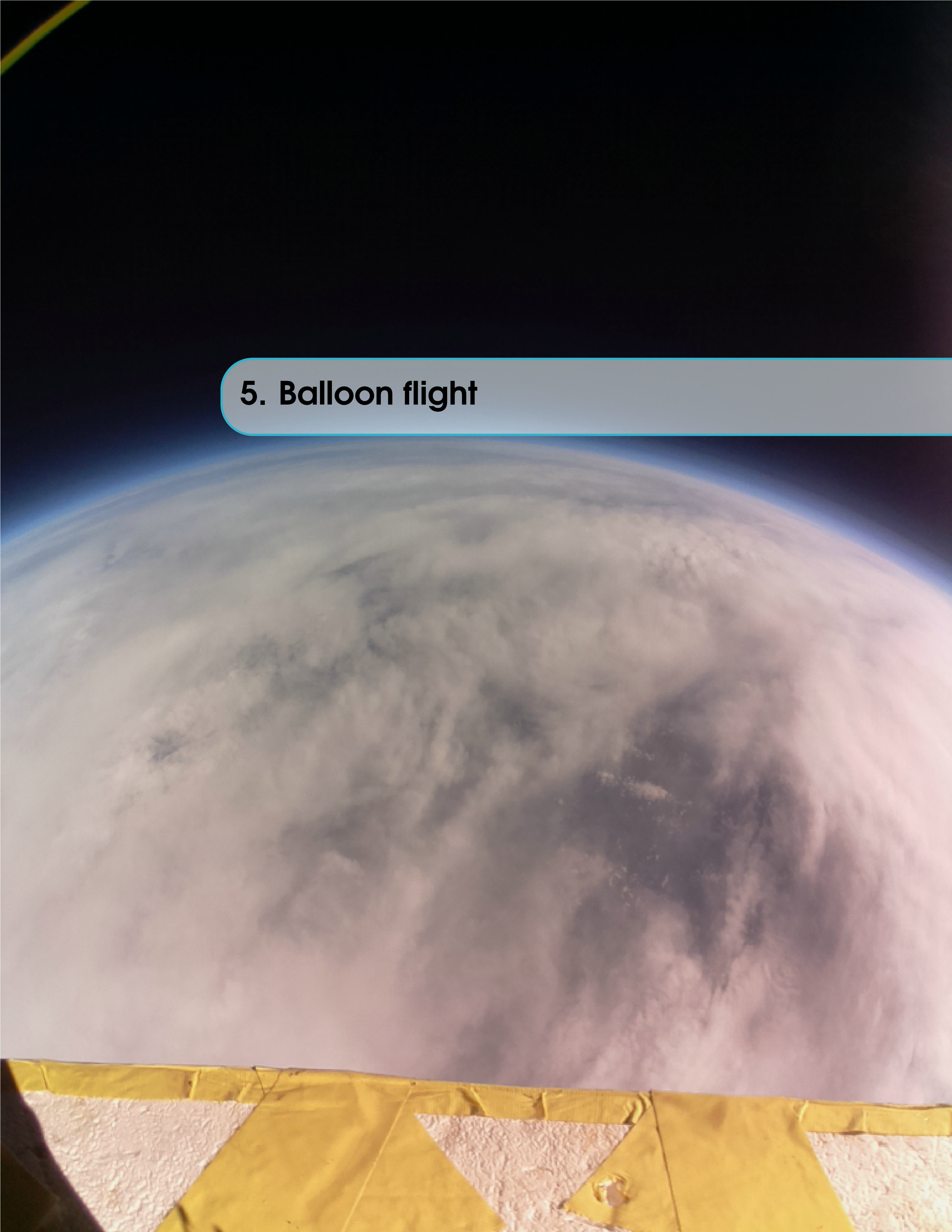


Figure 4.5: Accelerometer data from thermal-vacuum test

5. Balloon flight



The launch of the balloon was planned for March 1st at 11 AM from the CNES Centre de Lancement de Ballons Aire-sur-l'Adour (CLBA). The conduction of the balloon launch was kindly conducted by the employees of the CLBA. Our responsibility was to prepare our payload according to the requirements of the balloon.

5.1 Pre-flight setup

We arrived one day in advance to conduct the final setup and preparation for the launch. This consisted mostly of fixing all the parts of the payload tightly to the box and running one last test of the system.

In the morning, right before the launch, the integration of our payload to the balloon was done by the CLBA employees. The payload box with the instruments was mounted on a styrofoam disk of 1 m in diameter and about 5 cm in thickness. The purpose of this disk was to keep the strings, that connected the payload to the balloon, apart from each other to provide structural integrity and stability. In order to insure that the payload was horizontal at most of the time during the flight, our box had to be precisely balanced on the disk during the integration.

Before the integration with the balloon, the total mass of the payload had to be measured in order to adjust the inflation of the balloon pre-start. The total mass of the payload was found to be 1.081 kg. The scale that was used is shown in Figure 5.1.

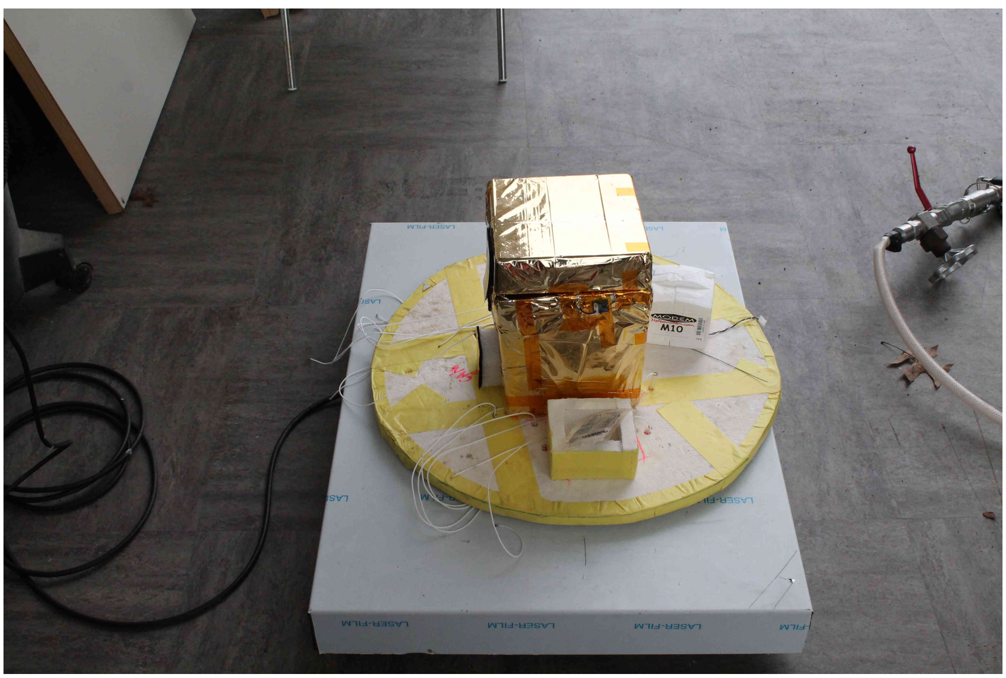


Figure 5.1: Measuring the weight of the payload

The final setup is shown in Figure 5.2.

5.2 Flight description

The launch of the balloon was conducted by hand by the CLBA staff. A string of about 20 m length connected the payload and the balloon. One person was holding the balloon while a second person stood downwind with

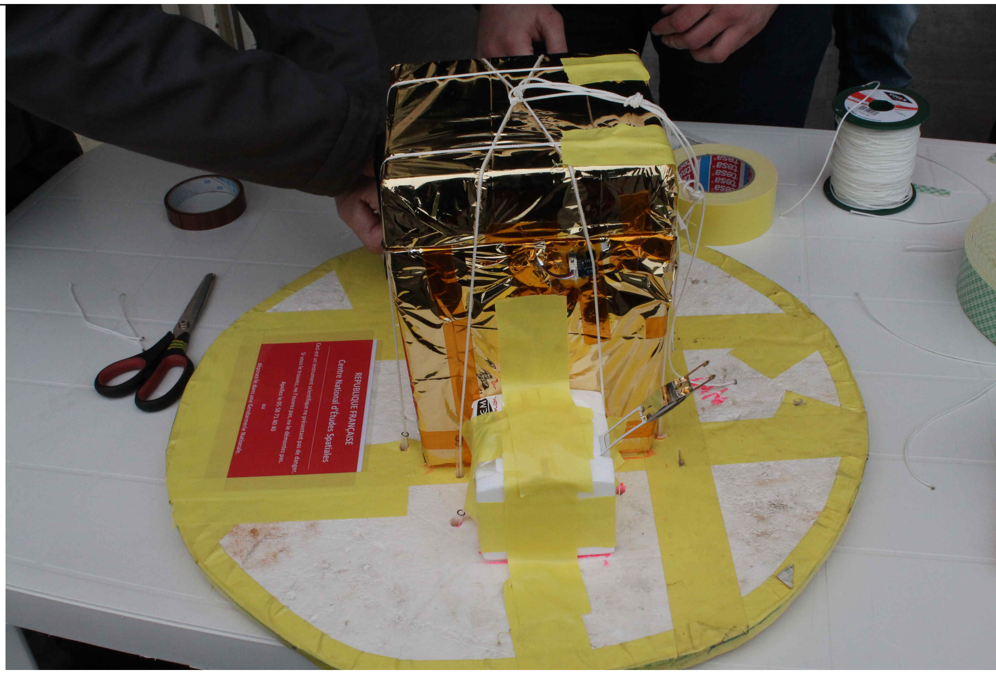


Figure 5.2: Final setup of the payload

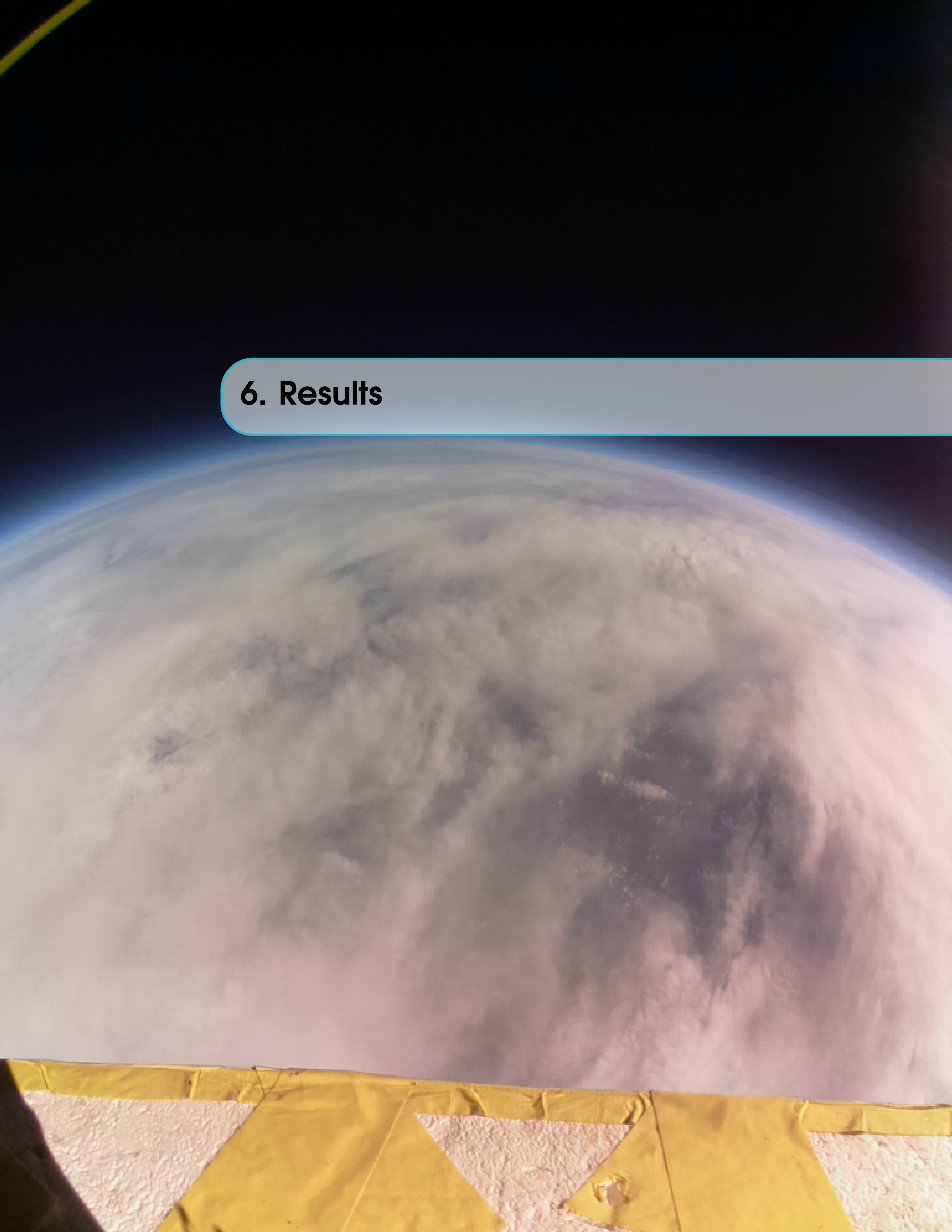
the payload. The person holding the balloon then let go of it and as soon as the connecting string was about to be stretched, the second person let go of the payload as well. This way the risk of the payload touching the ground was minimized.

The duration of the flight was about 2 hours. There was a south wind on ground at the time of the launch, so the balloon drifted northward as it ascended.

The altitude at which the balloon explodes is hard to be predicted. According to the barometer measurements, the maximum altitude was at about 33 km. Using the GPS-tracker which was attached to the payload by the CLBA staff, we were able to find the landing location. The payload reached the ground 17 km west of the village Casteljaloux, which around 80 km north and 20 km east of the launch site.

The payload was found in the top of a tree, beyond reach. With the permission and the help of the owner of the area the tree was cut down and the payload was recovered intact.

6. Results



This chapter will presents the results and the data collected during the flight. The results were pre-processed on Excel and processed on MATLAB.

6.1 Measurements

The code running on the embedded Raspberry Pi and controlling the several sensors and the camera has been developed in order to save all the measurements in a *Coma Separated Values* file (.csv). The temperatures, pressures and accelerations measurements were saved in one *string* value as shown below.

$$13.651562148843004, 983.7824831145714, 14.308703620473977, -0.984, 0.04, 0.064 \quad (6.1)$$

The first term is the temperature measured by the barometer, the second one is the pressure by the later, the third one is the temperature measured by the temperature sensor and the last three components are respectively the acceleration on the X, Y and Z axis.

The code ensured that a measurement request was sent to each sensor plus the camera every second. The data were then stored ten by ten (forming a packet) and every packets were separated by a space from each others in the .csv file. This has a double objective: first to ensure that even if an unwanted failure would have occurred during the flight, only the current packet of data was lost and not all the previously measured data. The second objective was to ease the visualization of the data on spreadsheets. In order to have a set of data properly separated (one column per parameter and no space between packets), the raw set of data was pre-processed on Excel with the Import Text tool available on the later.

The pre-processed file was then imported in MATLAB and the following section will present the results.

6.1.1 Temperature

The temperature measurements have been done thanks to two sensors as previously said. The figure 6.1 shows the results given by the two sensors during the stratospheric flight.

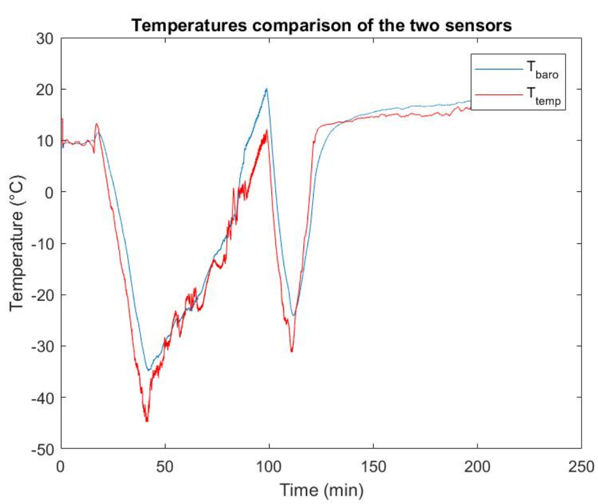


Figure 6.1: Temperature measurements done during the flight

On the graph 6.1, the temperatures is expressed versus the time of the flight. The time dimension was simply computed as each measurement done represents a second elapsed. In total, 3,64 hours of measurements were recorded.

In the temperature graph, the data from the two sensors are similar. As the time goes, the temperature indicated by the two sensors is decreasing more and more until the 42th minute. At that time, the payload is presumed to be at the altitude of approximately 9000 meters (see section *Altitude*). The minimum temperature measured is -33,7C for the barometer sensor (which is located under the MLI) and -43,8C for the temperature sensor (outside the MLI). This sudden behavior is probably due to the fact that we were out of the range of the good functioning of the sensors which minimal accepted temperature if -40C.

The temperature is decreasing again when the measurements are above -35C after the balloon has exploded at its maximum altitude and the payload was falling back to Earth. The temperature is then rising up until reaching a stable temperature around 15C.

6.1.2 Pressure

Thanks to the embedded barometer, pressure measurements have also been done as shown on the figure 6.2.

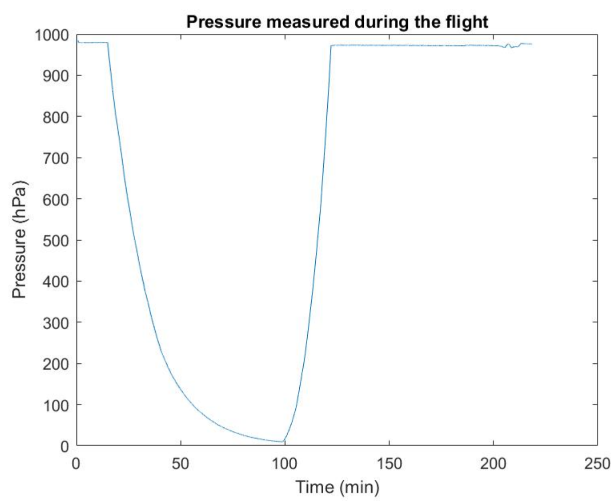


Figure 6.2: Pressure measurements done during the flight

The pressure graph is clearly showing the decrease of pressure during the rise of the balloon, the moment of explosion of the balloon and the stall of the payload (98th minute) and then the increase of pressure as the payload is falling back to Earth. It is worth to note the clear difference between the slope during the rise of the balloon and during its fall, showing the difference in vertical speed between the two.

6.1.3 Altitude

Thanks to the altitude measurements, we computed the altitude of the payload with two different models given by the *National Weather Service* and NXP semiconductors which produces the used chip on the barometer. The first model is describing the evolution of altitude in function of pressure for altitude between the sea level and 11000 meters.

$$alt(m) = 44330.77 * (1 - (p(hPa) * \frac{100}{101326})^{0.1902632}) \tag{6.2}$$

An offset was also added at the previous equation to obtain the right altitude where the balloon was launched. Such an offset is advised by NXP Semiconductors.

The second model gives the altitude in function of the pressure above 11000 meters and is describes as the following.

$$alt(m) = -log(\frac{p(hPa)}{226.32}) * 216.65 * \frac{287.04}{9.80665} + 11000; \tag{6.3}$$

Thanks to these two models, the altitude of the balloon during the flight was computed on MATLAB and is given in the figure 6.3.

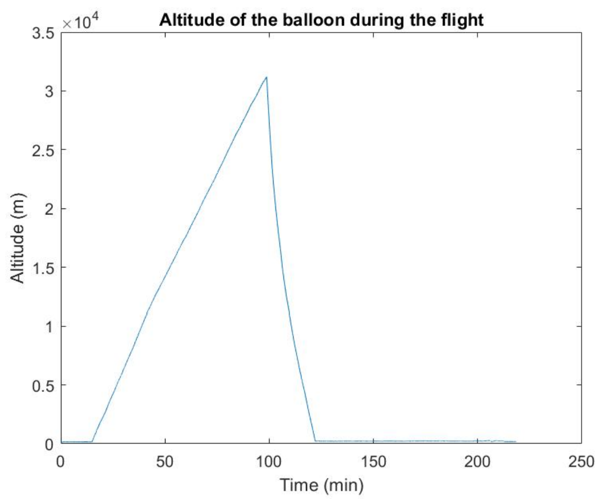


Figure 6.3: Altitude of the balloon during the flight

The maximum altitude measured is 31203 meters reached by the payload at the 98,72th minute of the flight.

The rising speed has been computed with the slope of the rising part of the graph whereas the falling speed with the the decreasing part of the graph. It gives a rising speed of 6,15 m/s and a falling speed of 19,86 m/s, reached thanks to the parachute. The payload took 98,72 minute to rise up and 23,3 minute to fall back to Earth.

6.1.4 Accelerometer

The acceleration has been measured in the X,Y and Z dimensions of the payload as shown on the figure 6.4. It is interesting to note that the three set of data seems to be correlated. Whenever there is a high signal on one dimension, the same signal is found on the two others.

It is interesting to see that these data are correlated with the previous graph giving the altitude of the payload (6.5). The moment when the payload felt down back to Earth and when it touched the ground can clearly be seen respectively at the 98th minute and the 115th minute (6916 seconds).

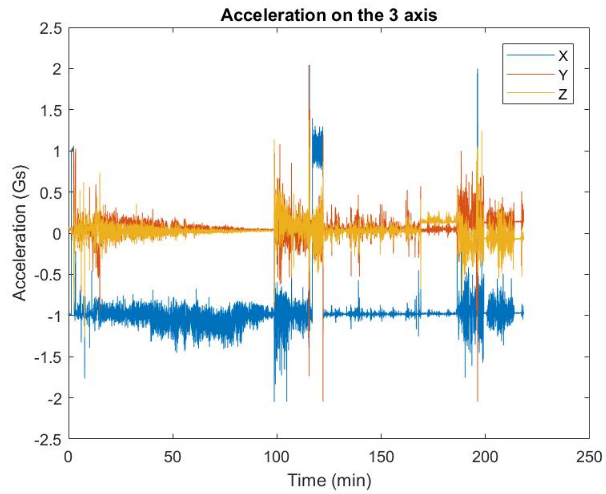


Figure 6.4: Accelerations of the balloon during the flight

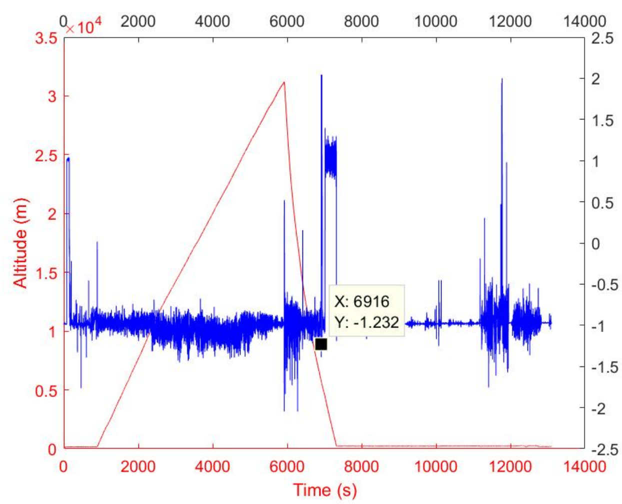


Figure 6.5: Correlation of the information given by the accelerometer and the altitude of the balloon during the flight

Such correlation can also be seen when plotting the altitude and the temperature given by one of the two sensor on the same graph (6.6).

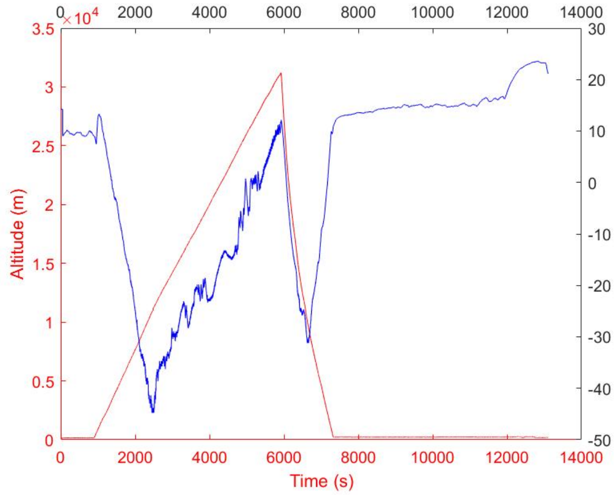


Figure 6.6: Correlation of the information given on the temperature and the altitude of the balloon during the flight

6.1.5 Cameras

In total, more than 1200 pictures have been taken by the embedded camera. Even in very harsh conditions, the camera still took very good pictures, which is definitely a great success for this mission. The objective being to prove that such cameras could be used for 360 degrees imaging in the stratosphere, we concluded that such equipment would perfectly do the job.

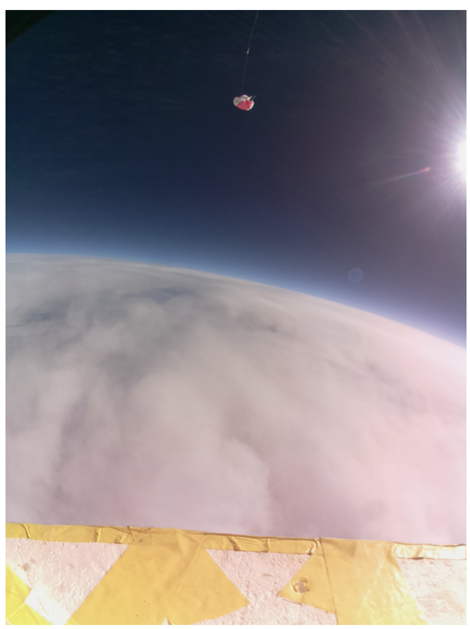


Figure 6.7: A picture taken by the payload just after the balloon exploded

6.1.6 Discussion

These results are showing the great success of the mission. Besides the temperatures measurements which were out of range above 9000 meters, the data have been collected properly and are showing correlated results and coherent observation with the scientific literature.

It proves that such an equipment is suitable for such a stratospheric mission. Particularly regarding the embedded camera, a 360 degree camera could be done in the future based on the same material.

7. Outlook and future projects

7.1 Future Balloon projects

Even if the proof of concept of the implementation of a Langmuir probe in a stratospheric balloon has not been taken in place for this launch, extensive studies has been conducted on the feasibility of such project. In particular, with extensibility studied the feasibility to use a Langmuir Problem on a balloon platform. Thanks to our work, the future TSI's students will be able to implement this probe on their balloon.

We can also use the upward facing camera which will used to determine the diameter of the balloon at different altitudes to know more about environmental effects.

7.2 Outlook for a nano-satellite project

We saw through this project that even with a basic and low cost equipment we can fulfill great things. On the chapter 3 we saw the range of working for each components and in the real life those limits have been exceeded. We thought then on a possible creation of a nano-satellite based on the same requirements.
A standard Cube-Sat defines the physical properties of the satellite structure, in which a standard structure is designated a "1U"(Unity). A 1U structure is shaped as a cube with each side measuring 12cm. This gives the 1U a total volume equal to 1000 cm^3 with a weight requirement of no more than 1.33kg. The Cube sat standard allows for the satellite team to expand the size of their project by combining several 1U's into a 2U or 3U structure, doubling or tripling the length of the satellite.
There is a lot of kind of organization to set this kind of project. Jean-Loup is currently working for his internship on the Cube-Sat 'EyeSat' which have two objectives. One of them is to take a 360°picture of the Milky Way. The entire project is realized by students so this kind of dream is not utopic. We can easily imagine in a near future low cost cube-sat launched by students.
But at this stage those kind of project takes time. It came through several phases (0,A,B,C,D,E) each phase takes one year. We can easily imagine this type of organization.

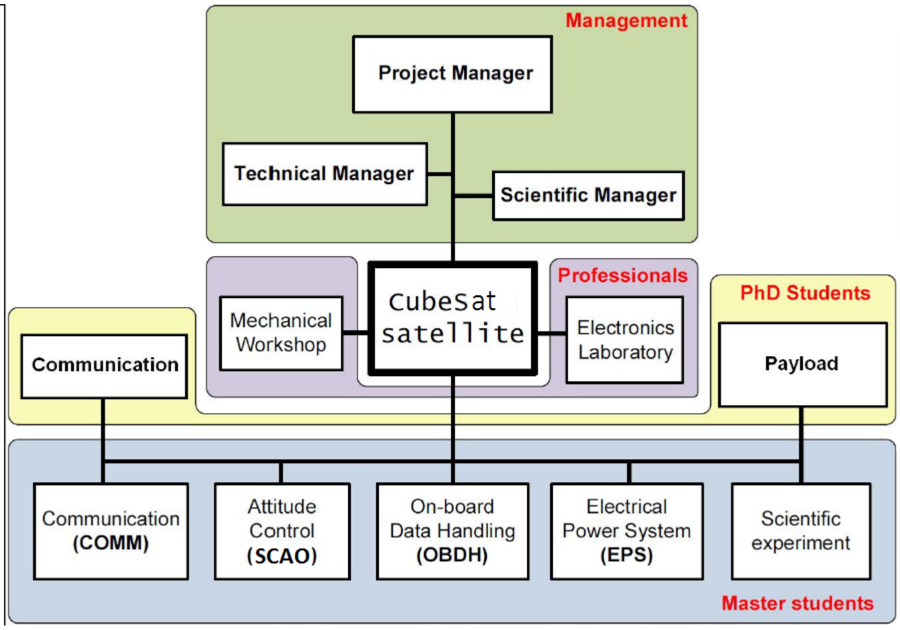


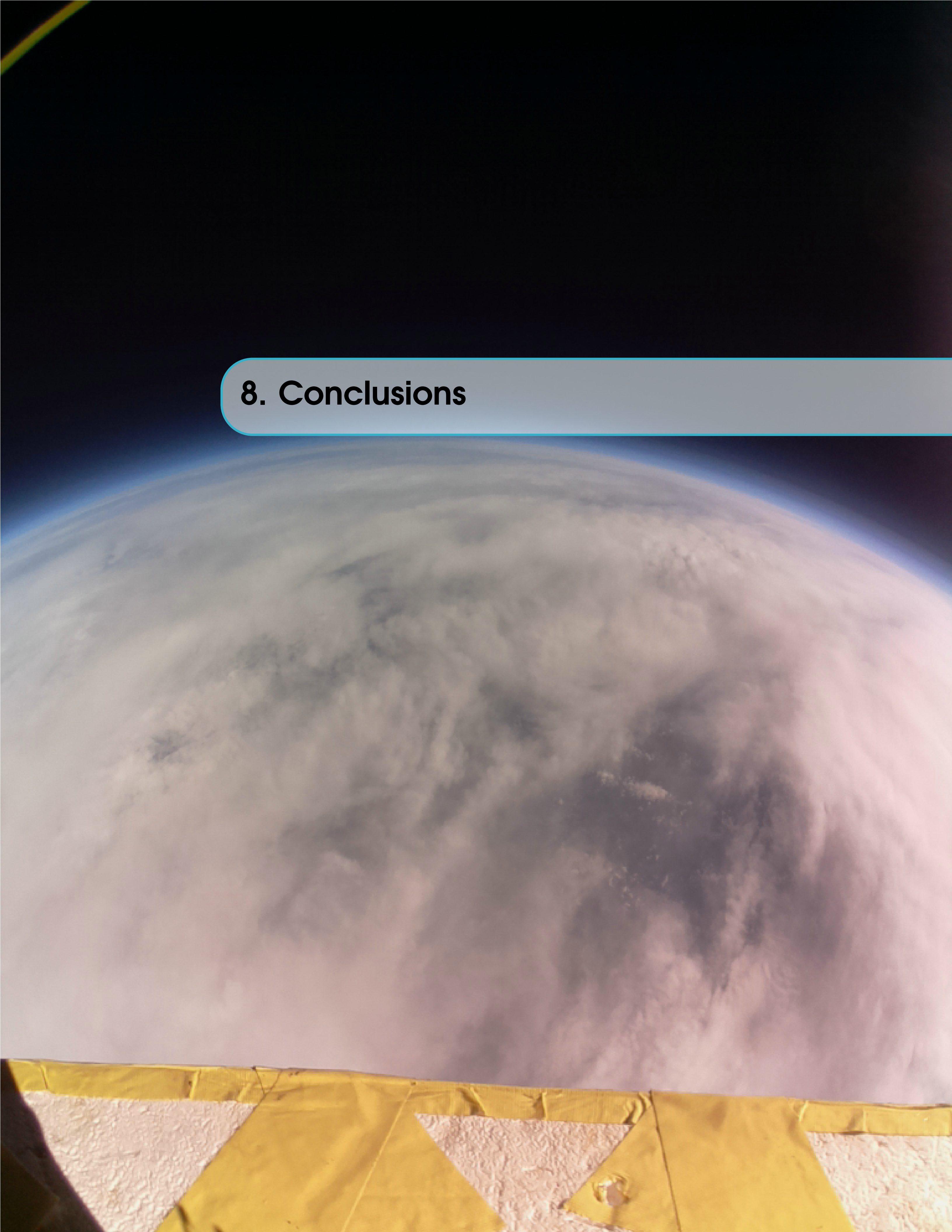
Figure 7.1: Type of CubSat organization

7.3 Project review and suggestions

A suggestion we all have on the organization of the project is that the timing was tight. Indeed, we had the project introduction in the first weeks of September and started working later on the project. 5 months isn't enough time to define a balloon architecture and implement it, for the very reason that order and receive the components take up to 2 months.

A suggestion we have for the balloon project is to make half of the glass working on the definition and implementation of an experiment that will effectively fly the year after. For instance, the 2019 class can work on the prototyping and testing of the Langmuir probe, and the 2020 class could fly it. This way, students don't start from scratch every year.

8. Conclusions



Jean-Loup

For me this project allowed me to determine which kind of life I want in the future. Between research and manipulation it's a way I can truly see myself in. This project allowed me to work in team and to be multitask. Even if we encountered a lot of issues, be able to bounce back and forth for new solutions enthrilled me. Even though, the scheduled plan were too high, we had to aim high ! At the end it was for me more than an adventure, but also a watershed in my life. The end of the student life and the beginning of my scientific life. Thank you for this gift. And we also proved one thing: Life exists on Earth :)

Figure 8.1: A strange life exists on Earth

Solange

First of all, the realization of the payload of a stratospheric balloon is an excellent idea for Master's students. This allowed me to realize the relationship which links the world of work and our studies. We had to address the questions that we will find in our future professions such as time management, the division of tasks (research, testing and writing) and communication between the different actors of the project. I am thus aware that time management is a decisive element. That's why when you receive a project you have to get busy, get to work immediately and get fully involved. As for the distribution of work, I am quite satisfied because it has been done taking into account everyone's skills, however small and different they may be. However, we have had to deal with different opinions. We therefore had to override this by finding compromises in order to ensure that the project was completed within the allotted time. We have been at the heart of the system engineering module, the practical work received during semester 1 and the theoretical knowledge received since we entered university. We are learning how to use what we have learned and I believe that direct and concrete application has been the most interesting part for me. This is a good way to mature in the professional world. Because we also had to communicate with professionals from the outside world.This was particularly the case when we went to the Plasma Physics laboratory. Thereafter I think that it is an excellent compromise for the universities which do not have or little means. Especially for university students in the field of space, we had an overview of the development of more complex projects such as those using satellites and rockets. We became aware of everything that was really behind a space vehicle launch project, particularly with regard to the realization of the payload, which requires a certain compatibility of the components and instruments used. I can say that this project has brought me a lot in the field of relationships and has in fact been an opportunity to acquire new knowledge through exchanges with other students and professionals from the outside world.

Gwendal Hénaff

The outcomes of this project were good, and we ended up with a model that flew and saved data. I personally learned about the testing operations of a flying model, were we have to reach low temperatures and check if the system is effectively resistant enough. Looking back, it might have been good to implement time management tools such as Gantt diagrams which would have avoided few members of the group to finish the prototype during their week-ends.

Vanshika Kansal

This project was important to our team in all aspects of ownership such as formulating research question, planning for that, designing and executing the project and after that analysing the final data. Of course we encountered with many challenges but we worked together to prepare for the launch. In my view, personal ownership of any project led us to learn more and become more knowledgeable in that research topic. For me, this project wasn't only good experience but it was the opportunity to learn about more science in stratosphere because the conditions of the stratosphere are unlike as on the ground. Ballooning is the new vehicle to learn new concepts, more about our atmosphere and also applying our theorical knowledge in the real-world.

Felix Grigat

This project was a valuable experience for future work on science and engineering projects. While there are a few things that should be improved regarding the structure of the project, exactly those process management mistakes that we did where representative of the same problems engineers face in real projects. When we started out our project, we had barely any constraints and a lot of freedom in our actions. On the one hand this was great because we could choose a project that we were all interested in, however it also resulted in quickly coming up with way too ambitious ideas and not realistically planning the whole project. At the end I believe that this was the downfall our project. Often I think it would be more proficient to restrict the students more and enforce a tougher planning. Nevertheless the possibility to design a payload for a stratospheric balloon is a very special opportunity that I strongly appreciated and that will also be valuable to future generations of students.

Mini Gupta

Classroom learning is enriched when we get a hands-on experience on the current technologies. This project work presented an opportunity to not only read about the ongoing research stratospheric projects but also to try to build one. Everything from the conception of idea to selecting the components and finally to build a payload provided an insight on how a project is realized in organizations. I sincerely believe that this project has a lot to convey to the people who might want to work on similar topics. We tried to attempt something which hasn't been done before in the balloon launches. Our work might provide a foundation to other people who might want to create 360 $^{\circ}$images in stratosphere or use a Langmuir probe without heavy electronics in balloon flights and provide them an opportunity to learn from our mistakes. Personally I consider this project a huge success in the field of science and technology. It has the potential to save a lot of time and money in the future projects.

Peter Chingaipe

This project was able to give us an insight into how we can approach a space mission when we begin our professional careers. From the conceptual phase, through to the design and implementation, we were exposed to various challenges which only serves us well for the future as we'll be able to use the methods and techniques we have acquired during this process. Our supervisor Hassan Sabbah gave us complete control over our objectives and I found this to bode well with the creative process as there were no limits as to what we could do. Finally, it was a really exciting process to try to envisage a Langmuir Probe as part of a future mission. The support provided to us by Freddy Gaboriau and Laurent Liard from the Laplace Laboratory was invaluable and they input motivated us to try to realize our objectives.

Pierrick Loyers

This project has been a great opportunity for me to work on a space instrumentation problematic. The instrumentation part of it was the most interesting to me but I also liked the fact that we faced several undesired situation during the year. Even if these situation were not all the time easy to handle, we manage to overpassed them with success. This project was also a good opportunity to experience all the challenges that a team work has to offer. At the end, this project has been very rewarding and instructive. Seeing the pictures took by our payload of the Earth once it was launched gave me a really nice satisfying feeling. I learned a lot about Raspberry Pi as well, which I did not know before, and this is definitely a positive point for me.

Issmail Batou

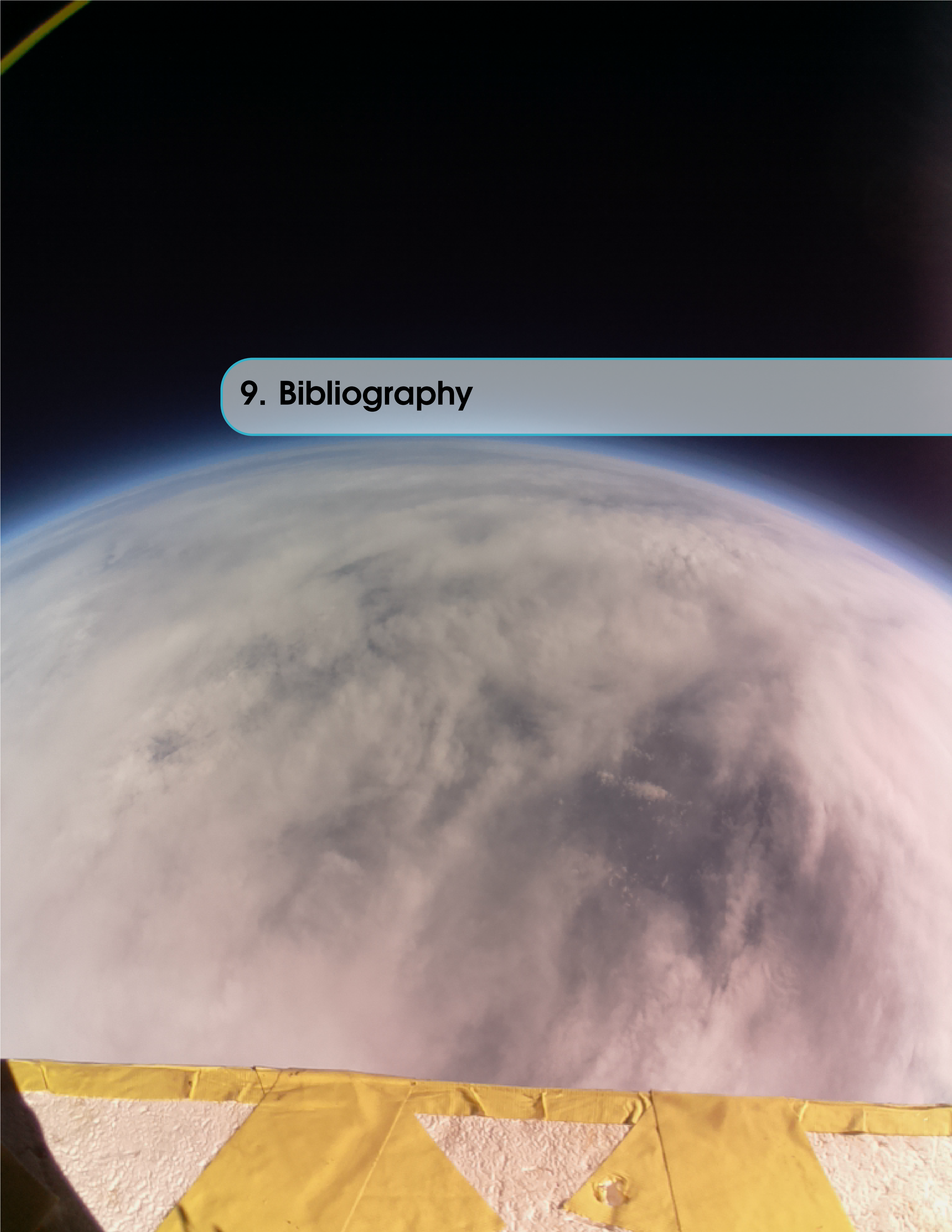
With the funding from Paul Sabatier University, our group has been able to make incredible strides in our understanding of payload design. We learned how to manage power resources to payload components and how to cope with stabilization, weight limitations and encountered issues. We ran crucial tests to not redo the same mistakes as previous project, even though we made new ones. Overall, this project has expanded all our horizons. We started with drafts and ideas, but now we have the resources for a fully operational near space program. What we have learned from this project will lay the foundation for more advanced research, collaboration and dream realization.

Acknowledgements

First-of-all, we would like to thank Hassan Sabbah, without whom, this project would never have got off the ground. With is patience especially for the equipment and the store deliveries. We also got to know him better during the launches and it was great moments.

We also thank the CNES team, for their kindness and their professionalism. Finally, we thank Josué Delgado for its help during our implementation tests and we hope he is feeling better.

9. Bibliography



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