Development of a Peruvian weather balloon for the Universidad Nacional de Ingenieria

A weather balloon for Peruvian academic projects
From 02/26/2018 to 08/11/2018

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Contents

Chapter 1

Abstract

The SmartMachines laboratory of the CTIC-UNI, in Peru, decided to develop its first weather balloon project. To do so, the laboratory proposed the direction of the project as an engineering internship. The aim is to create a weather balloon that could be useful for the Peruvian country and feasible with the means available to Peruvian students. First, two experiments have been selected. One to obtain a vertical profile of measurements related to the study of climate, and the other to study the evolution of UV light intensity with altitude. Then, dimensions were selected to reach the stratosphere while respecting Peruvian laws, thanks to a flight simulator software made for this project. What seemed the most adapted solutions for a Peruvian weather balloon in terms of sensors, telemetry, tracking and thermal insulation had been found and developed during this project. Eventually, the balloon has been launched in the desert of Ica in august 2018.

Le laboratoire SmartMachines du centre de recherche CTIC-UNI, au Pérou, a pris la décision de lancer son premier projet de ballon sonde. Dans ce but, le laboratoire a proposé la direction de ce projet en tant que stage ingénieur. L'objectif étant de créer un ballon sonde ayant un intérêt pour le Pérou tout en étant constructible avec les moyens à disposition des étudiants péruviens. Tout d'abord, deux expériences scientifiques ont été retenues en tant qu'exemples. Une concernant le climat, l'autre les rayons UV. Ensuite, la chaîne de vol a été dimensionnée de façon à respecter les lois péruviennes, et en utilisant un logiciel de simulation de vol réalisé pour ce projet. Des solutions adaptées pour le Pérou en termes de capteurs, suivi GPS et isolation thermique ont été recherchées et développées durant ce projet. Et pour finir, le ballon a été lancé en août 2018 depuis le désert de Ica.

Chapter 2

Introduction

This internship is about the development of an academic weather balloon for a Peruvian university. Therefore, before presenting the related mission, it is important to define what is a weather balloon, if they are required and used in Peru, and if so explaining why.

2.1 Presentation of weather balloons

A weather balloon is basically a balloon filled with a gas less dense than air, capable of carrying a scientific payload to probe the atmosphere thanks to the buoyancy force.

In its most simple design, it is a latex or chloroprene balloon filled with helium. Without control, the balloon will drift following the winds, and lift the payload up to 30 km, in the stratosphere. Its ascension ends because of the weakening pressure, which makes the balloon inflate and then burst. The payload is then retrieved with a parachute.

More complex designs exist, however they are less used because of their higher cost and complexity. And furthermore, some other designs are adapted to other types of flight, much longer or at different altitudes.

At student level, weather balloons are employed in many countries as a mean to discover science and experiment from primary school to the university. In France for instance, the space agency (CNES) helps students to launch their projects every year, with the help of the association Planète-Sciences.

Nearly a hundred balloons a year are launched, and the CNES pays for the balloon, the helium and the telemetry.

2.2 Weather balloons in Peru

According to the Integrated Global Radiosonde Archive, the first weather balloon launched in Peru was in 1957 from the Lima/Callao station. Since that day, the SeNaMHi (Servicio Nacional de Meteorologia y Hidrologia del Peru, the Peruvian weather agency) launched weather balloons from different stations : Iquitos, Morona, Talara, Piura, Chiclayo, Pucallpa, Lima/Callao, Las Palmas, Pisco and Arequipa.

However, in 2018 only the Lima/Callao station is still active, with nearly 15200 balloons launched since its opening. The data profiles are mainly used for aeronautical purposes.

But the concept of weather balloons is not declining in Peru. For instance, the CoNIDA (Comicion Nacional de Investigacion y Desarollo Aeroespacial, the Peruvian space agency) launched its own weather balloon in 2015, with telemetry and live video.

A few academic projects have been launched too, as the project of the Asociacion Peruana de Astrobiologia (ASPAST, association dedicated to astrobiology) in 2015. This will to launch new weather balloons projects is mainly motivated by some issues Peru faces, which require weather balloons to be solved.

2.3 Peruvian issues potentially requiring weather balloons

Since the end of the political instabilities and wars of the 1990s, the Peruvian industry is developing, and in 2018 the country is the 6th economy in America Latina, after Brazil, Mexico, Argentina and Colombia. However, this growing development is the cause of major issues.

For instance, according to a study from the World Health Organization in 2014, Lima (the capital of Peru) has the worst air quality in America Latina.

Then, the Andean region is the most affected by the UV radiations on the planet. This is mainly due to its proximity to the equator, and the extreme altitudes of the altiplano. However, there is another factor influencing the level of UV radiations there: the depletion of the ozone layer.

According to a study from the Instituto Geofisico del Peru, made by the observatory of Huancayo, as most of the stratospheric ozone on the planet is produced in equatorial regions (around 80 percent), and furthermore as the UV level are extreme in the Andean region, Peru is the ideal place to study the ozone layer.

Eventually, Peru is periodically facing the El Niño, a climate phenomenon changing the temperature of the Pacific ocean, causing violent climate events. In 2017, 65 people died in Peru due to floods.

Each year, the NOAA (National Oceanic and Atmospheric Administration, the American weather agency) publishes predictions of the phenomenon. Such predictions obviously rely on measurements and atmospheric models.

Weather balloons with the adequate sensors could help solving or predicting each one the Peruvian issues we presented. For this reason, weather balloons have a true potential in Peru.

2.4 The mission

The objective of this six months internship (february 26th to august 11th 2018) is to design a weather balloon project with embedded experiments related to issues previously presented, that could be developed and launched by Peruvian students. The aim of this project is to demonstrate the potential of stratospheric balloons in Peru, but also to develop tools and methods for future similar projects. This way, Peruvian students willing to send an experiment in the stratosphere could reproduce the work done during this internship. To achieve this mission, the balloon must be affordable for a Peruvian student, easy to make with all the tools ready, and must be able to safely bring a classical payload to the stratosphere.

A team of five students-researchers had to be selected, to work in the different domains of the project. The mission was to lead this team in the development of this weather balloon, and to select and provide them the tools and technologies they require to do so.

A secondary mission was the involvement in the laboratory SmartMachines. This means participating at the monthly meetings and at the communication events.

Chapter 3

Presentation of the context

Before presenting the problem to be solved by this internship, will be briefly presented the laboratory where this internship took place.

3.1 The National University of Engineering

The National University of Engineering (Universidad Nacional de Ingenieria) is a public university created in 1876, in Lima. With more than 12.000 students, this is the major Peruvian university of engineering.

The campus, located in the district of Rimac, is divided into 11 falculties. Each faculty is related to a sector of interest in Peru (Mechanical engineering, Petroleum engineering, Geological engineering and Electronic engineering for instance) (Figure 3.1).

The competition to enter the UNI is renowned as one of the most difficult in the country, and amongst its alumni the university has the current president of Peru Martin Vizcarra and three other members of the government. For those reasons, the UNI has a strong reputation in Peru.

The UNI has also several research centers, one of them being the CTIC-UNI.

3.2 The CTIC-UNI

The Center of Information and Communication Technologies (Centro de Tecnologias de Informacion y Communicaciones) is a research organization of the UNI. It was founded in 2008, thanks to the Korean International Cooperation Agency. One of its main objectives is the development of national and international technological projects.

Figure 3.1: Picture of the CTIC investigation center

The most famous of those projects is the cubesat Chasqui-I, a nanosatellite launched from the International Space Station in 2014. This cubesat was developed by students of the UNI as part of their studies.

After the success of this project, the CTIC-UNI decided to create a new laboratory for students willing to work on such research projects. This laboratory is called the Smart-Machines lab, and this is where this internship took place.

The CTIC-UNI is directed by Alonso Tenorio Trigoso, and the SmartMachines lab by Margarita Mondragon Hernandez.

This is not the first time that students from the ESTACA work in cooperation with this laboratory. The ESTACA rocketry club (ESTACA Space Odyssey) launched two projects in collaboration with the SmartMachines lab in 2016 and 2017. Then, in 2017 another student of the ESTACA went in Peru to work on experimental rockets for the laboratory, during an internship.

Chapter 4

Presentation of the problem

The first task of this project was the research of information about the issues in Peru and the history of weather balloons in the country, which have been presented in the introduction.

Then, it was the research of information concerning the conditions in the stratosphere, the Peruvian geography, the possible experiments and the aeronautic laws in Peru. For the last one, the project received the help of two experts.

All those fields are part of the problem that needs to be solved to complete the given mission.

4.1 The extreme conditions of the stratosphere

The stratosphere is the layer of the atmosphere which begins just after the troposphere, the layer where we all live. By definition it begins at the altitude where the temperature stops decreasing (around 12km of altitude), and ends where the temperature stops increasing (around 50km of altitude).

This layer of the atmosphere is renowned for its extremes conditions, which can be used as an environment to test space technologies and experiments. The temperature can decrease down to 215 K and the pressure at 30 km of altitude is only around 1000 Pa. The winds can also be very strong, up to 100 m/s relative to the ground.

Furthermore, two chemical layers of the atmosphere are present in the stratosphere. The first one is the Junge layer, where can be found sulfuric acid aerosols, which are the result of volcanic activity. Those chemicals can have effects on some sensors, and must be taken into account.

The second one is the ozone layer we previously mentioned, which is the result of the interaction of oxygen with UV light. The reaction of UV radiation with oxygen, producing ozone, absorbs nearly totally the UV-C and partially the UV-B. This is how the ozone layer protects life at the surface of the Earth.

Therefore, the payload of the weather balloon and its content must resist to those extreme conditions, and its trajectory must be predicted and then measured.

4.2 The Peruvian geography

The Peruvian geography is very peculiar, with a large diversity of landscapes, climates and altitudes. It can be divided into three main parts: the costa, the sierra and the selva (Figure 4.1).

The costa is a dry desert between the sea and the mountains, where Lima is located. It is more than 2000 km long but only 50 km large. This can be a problem knowing that a weather balloon can end up at 100 km from its launch site, depending on the wind. However it allows a good line of sight for telemetry, and the payload recovery would be easier than in the other regions.

The sierra represents the part of the Andes located in Peru. It is between the desert and the rainforest, and contains many valleys with cities and fields. A high altitude balloon launch in this area would be interesting, because of its peculiar climate. However the tracking and retrieval of the payload would be difficult if not impossible with the mountains.

And eventually, the selva represents the part of the Amazonian rainforest located in Peru. It is the largest of the three regions, and contains protected areas for native inhabitants. Recover a payload in the selva would be nearly impossible too.

For those reasons, it has been decided that the best option would be a launch from the costa. However, to really select a location, a software to simulate the flight of the balloon would be required.

4.3 The proposed experiments

As has been previously explained, the Peruvian climate is very peculiar. It varies a lot between winter and summer, between a year and another, and is completely different depending on the region (costa, sierra or selva). For this reason, predicting weather in Peru is a challenge, and requires data from many locations across the country. However, only a few stations use weather balloons on a regular basis in Peru.

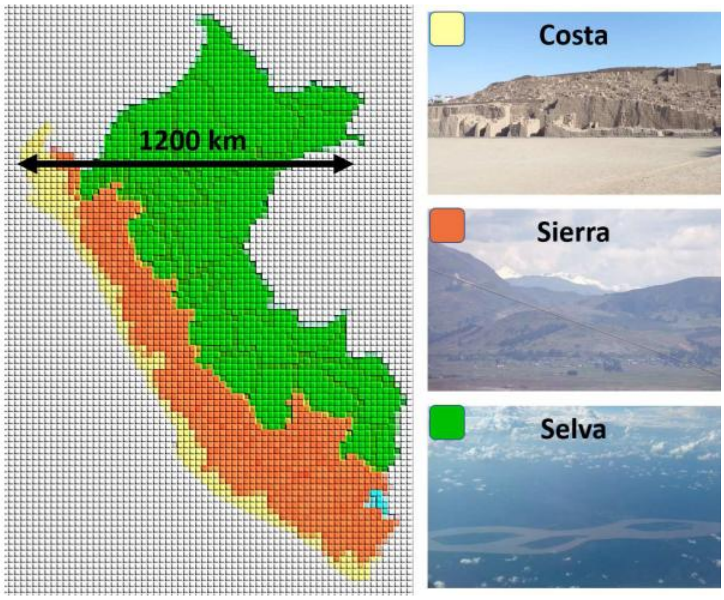

Figure 4.1: Map of the three natural Peruvian regions

The first and main experiment would be to test a small and cheap weather station inside the payload by comparing its measurements to the GFS numerical calculations. To do so, the project requires sensors capable of measuring temperature, pressure, winds and humidity.

Has also been presented the problem of the UV radiation in Peru, probably related to a local weakening of the ozone layer. Nowadays, there is one station monitoring stratospheric ozone in Peru (marcapomacocha). Therefore, a cheap and easy way to monitor the state of the ozone layer could help a lot the understanding of the rising UV levels in Peru.

To achieve this goal, the second experiment needs sensors able to measure the UV radiation intensity and indicating the level of ozone in the air. The objective would be to detect the beginning of the ozone layer.

To retrieve the data during the flight, a LoRa is used. This mean of telemetry has been part of a few high altitude balloon projects, but it is quite new. Thus, the third experiment is to test this type of telemetry, which will be presented in detail later, with this project.

Eventually, as will be explained later, a weather balloon landing predictor has been developed for this project. The last experiment will be to compare the predicted position of the payload with the estimation given by a GPS.

Those experiments can easily be done by students, and can be useful for science in Peru too.

4.4 The Peruvian aeronautic laws

The project received the help of an aeronautical consultant to learn the Peruvian legal framework related to high altitude balloons. The Peruvian laws dealing with high altitude balloons are in the RAP-101 (Regulaciones Aeronauticas del Peru, the Peruvian Aeronautical Regulation). The couple of laws the project is concerned with could be translated as follows:

"Sub-section A: Generalities 101.1 Applicability (4) This regulation applies to every free-flying balloon which does not corresponds to the description in the section 101.7 or which does not: (i) Carries a payload heavier than 1.8 kg, or with an area density higher than 13g/cm2. (ii) Carries a payload heavier than 2.7 kg. (iii) Carries a payload divided with several parts higher than 5.5 kg. (iv) Uses a tether between the payload and the balloon unable to resist a mass higher than 22 kg. 101.7 Hazardous operations (a) Nobody is allowed to use a tethered balloon, a kite, a rocket or a high altitude balloon without passengers in ways that could harm people or properties. (b) Nobody is allowed to use a tethered balloon, a kite, a rocket or a high altitude balloon without passengers that could jettison an object in a way that could harm people or properties."

This means that if the payload has a mass lower than 1.8 kg and an area density lower than 13g/cm2, it is not due to respect the RAP-101. Therefore, it does not require any authorization.

However, it is necessary for security reasons to send a letter to the director of the Peruvian Civil Aviation Authority (DGAC), which will announce the launch at the Corporation of Commercial Airports and Aviation (CORPAC), which operates airports in Peru.

A letter was thus sent to the DGAC, which confirmed that an authorization is unnecessary, and gave us a NOTAM form to fill. A NOTAM (Notice to Airmen) is a notice alerting pilots and airports of hazards in a flight route. The process lasted three weeks, which means that a date and a location must be selected nearly a month in advance.

The major problem with the RAP-101, is the lack of definition of a "hazardous operation". To solve this problem, have been used the rules defined by the association in charge of high altitude balloons activities in France: Planete-Sciences.

For instance, the payload box is made with low-density materials, the parachute is designed to obtain a 5 m/s velocity at ground level, and the helium volume to take-off at 4 m/s. This way, the project is harmless and complies the section 101.7 of the RAP.

Chapter 5

Development of a solution

To achieve the mission and solve the previously described problem, a team had to be selected, and the tasks separated into different fields. The following description of the development of the solution is therefore divided into several part, each one corresponding to one of those fields.

5.1 Selection of the team and separation of tasks

A team of five students from the National University of Engineering has been selected amongst 20 candidates. The majority are specialized in mechatronics, and already members of the laboratory.

For a short project (only six months), it was important to have five members who already worked on similar projects in the laboratory. For instance, half of them also worked on an experimental rocket project.

The tasks were separated by theme, to take into account the different skills of each member of the project. The five parts are the following ones: the thermal insulation, the experiment electronics, the telemetry in emission, the telemetry in reception and the data processing.

As previously explained, during this internship, one of the missions was to select and prepare the materials, components, softwares, technologies and authorizations necessary for each part of the project. Another was to coordinate the work of the different members of the team, test what they did and organize the launch of the balloon.

5.2 First design of the chain of flight

To make the launch of the balloon as easy as possible, the weather balloon has been designed not to be affected by the RAP-101 laws. Thus, a maximum weight of 1.5 kg has been chosen for the payload, 1 kg for the actual payload and 0.5 kg for the rest of the chain of flight. It has been decided to abide by French laws if security limits do not exist in Peru.

For security reasons, a weather balloon in France is authorized to take-off if it has enough helium to achieve a 4 m/s speed. We therefore had to choose a type of balloon with a volume of helium allowing the payload to reach this speed at take-off (Figure 5.1). Weather balloons are usually classified by their weight, which is directly related to their maximum volume.

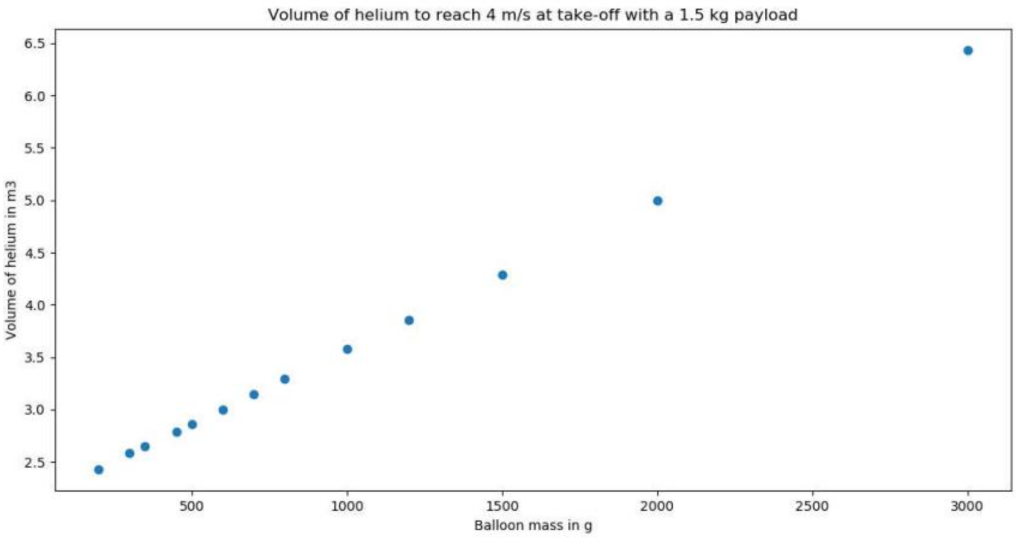

Figure 5.1: The required volume of helium to obtain a 4 m/s speed at launch

To carry 1.5 kg at 4 m/s, a 1000 grams latex balloon has been selected thanks to data given by the brand Kaymont. This way, the necessary volume of helium is affordable (150 dollars for 3.5 m3 in Peru).

A 1000 grams balloon is indeed able to carry the payload higher than 25 km (with a burst diameter of 6.4 m), which is high enough to reach the ozone layer. Furthermore, we can calculate that the maximum altitude of the balloon does not rise much for a balloon heavier than 1000 grams (Figure 5.2).

To reach the required altitude with a balloon of this weight, the minimum necessary volume of helium is, as previously mentioned, 3.5 m3. Using more helium would make the balloon faster, but would reduce its burst altitude

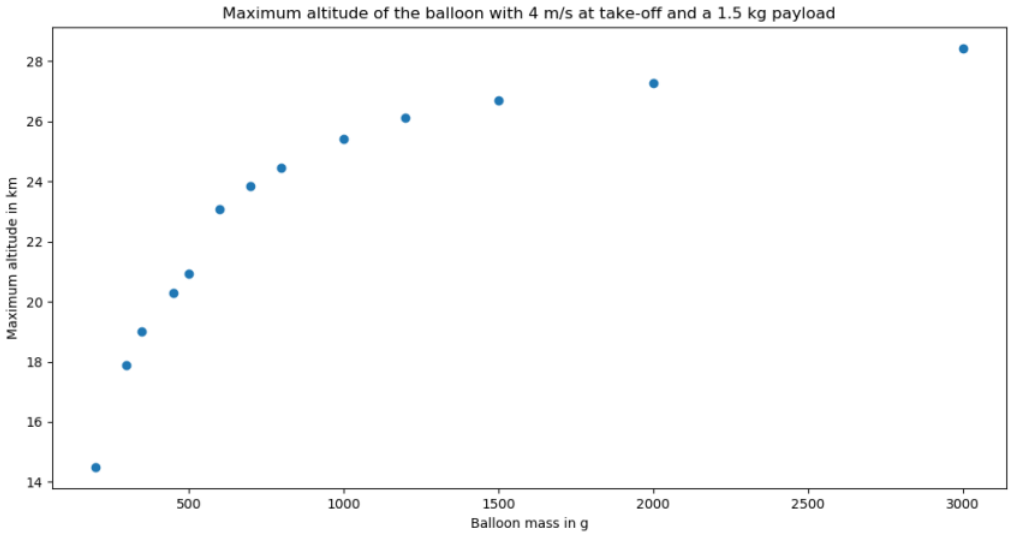

Figure 5.2: Evolution of altitude during the flight

because the volume of helium would reach the burst volume of the balloon faster.

Another security rule in France is a maximum landing velocity of 5 m/s for a weather balloon. To apply this rule to our balloon, a parachute with a diameter higher than 85cm is required (Figure 5.3).

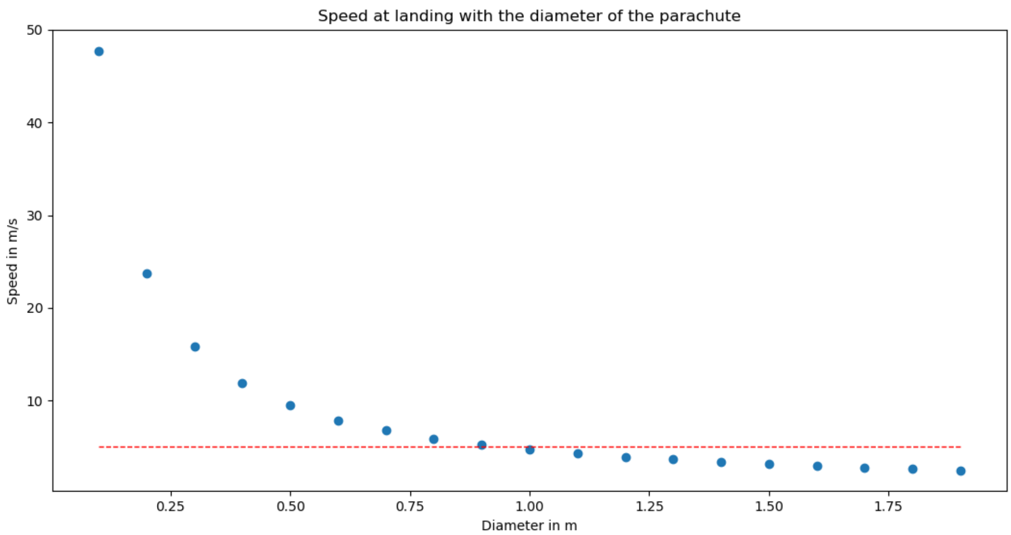

Figure 5.3: The speed at ground level with the diameter of the parachute

For safety reasons, it is also important to carry a radar reflector, so that the balloon may be detected by planes and airports. A simple combination of three 25cm aluminium foils is enough.

The ropes must be selected for their resistance, and a ring must be used to assure that the parachute will open during the fall (Figure 5.4).

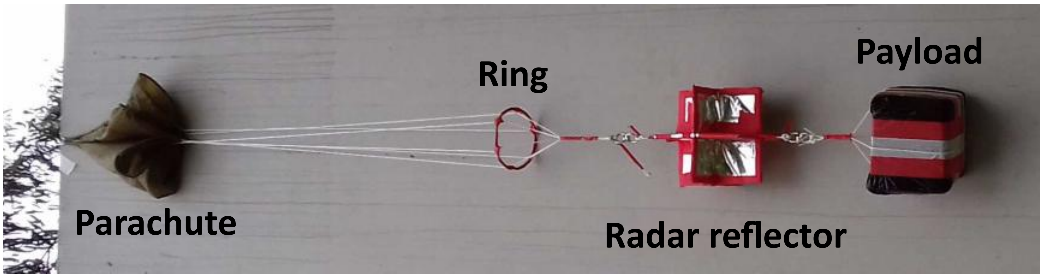

Figure 5.4: Picture of the chain of flight

5.3 Development of a trajectory simulation software

To choose a location for the launch of the balloon, and to help the recovery of the payload if the communication with the balloon fails, a trajectory simulation software is required.

This type of software is quite common and many can be found for free on the internet. For instance, the CUSF landing predictor from the university of Cambridge is used by many high altitude balloon projects. However, to understand how such a software works and not to rely on the work of another university, a software has been developed during this internship.

The software has been coded in Python, and uses three main libraries: siphon to obtain weather predictions, Tkinter to display a user interface, and simpleklm to create a KLM file that can be opened with Google Earth.

The entries of the program are the volume of helium, the mass of the payload, the mass of the balloon, the altitude and the coordinates of the launch site, the temperature at ground level, the burst diameter of the balloon and the diameter of the parachute.

The software then uses the GFS databank to simulate the flight of the balloon. First, the variation of the altitude of the balloon is estimated by calculating the value of the main vertical forces: weight and buoyancy. Only the last one will change during ascension, because of the inflation of the balloon with the variation of pressure. During the second phase of the flight, after the burst of the balloon, buoyancy is replaced by the drag force applied

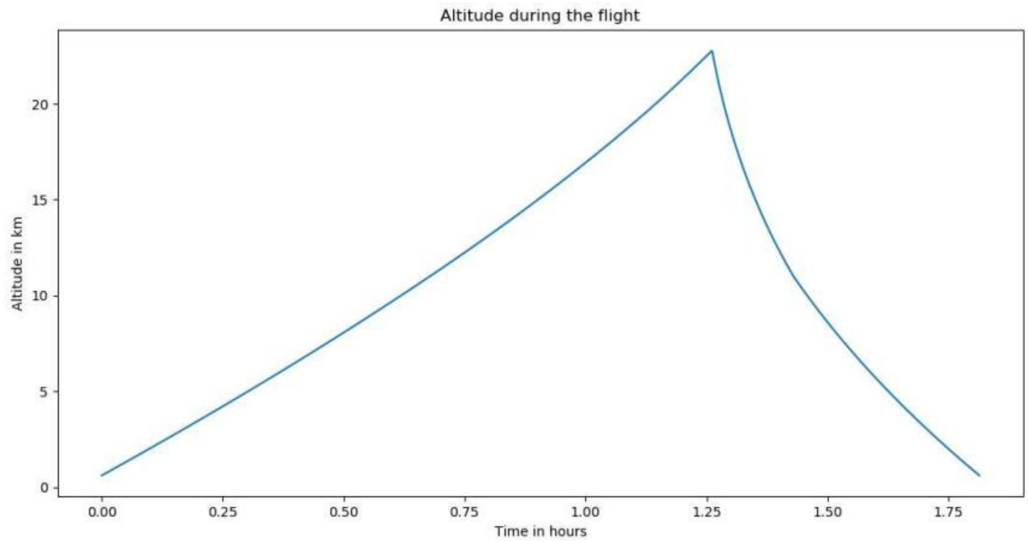

Figure 5.5: Example of simulated vertical trajectory

to the parachute. The speed of the balloon is calculated with a 0.1 second step (Figure 5.5).

Then, the drift of the balloon is calculated using the speed of wind around it. As the horizontal speed of the balloon quickly follows the speed of the wind, they are considered by most of the simulation softwares as equal. Thus, only predictions of the speed of the wind at different altitudes are required. This is why we use the GFS.

The Global Forecasting System is a numerical model developed by the NOAA to simulate the properties of the atmosphere up to the stratosphere, at every 0.5 degree of latitude and longitude on Earth for 15 days in the future. The model takes into account the mountains, which is necessary to make a reliable weather forecast in Peru.

At the end of the simulation, the calculated trajectory is displayed using Google Earth (Figure 5.6).

The software has been tested and compared to other softwares from other universities. The results are nearly the same, because the only difference between the softwares is the time step.

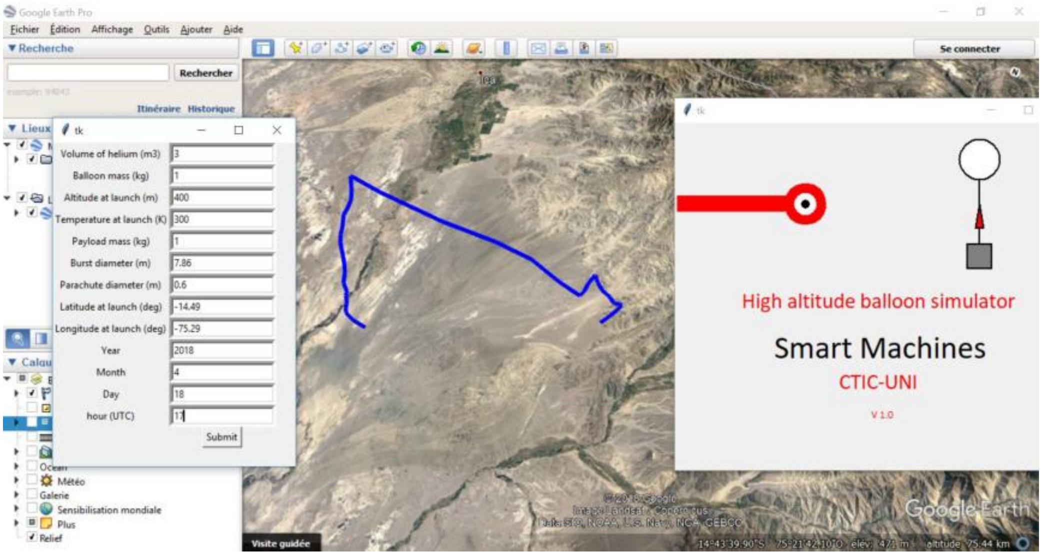

Figure 5.6: The developed trajectory simulator software

5.4 Selection of the components

5.4.1 Sensors

To achieve the objectives of making a vertical profile of measurements related to climate, and trying to detect the beginning of the ozone layer, several sensors were selected with six criteria. The first one is the weight, the second is the power consumption, the third is its measurement range, the fourth is its functioning temperature, the fifth is its availability in Peru and the sixth is the ability of a student to use it.

Temperature sensor

The first sensor to be selected is the temperature sensor.

In Peru, there are two main types of temperature sensors available. The first one is the thermistor, and the second the thermocouple. The thermistor, hence its name, is a resistor with an electrical resistance varying with temperature. To measure this resistance, a current must be applied to the component (Ohm's law). In Peru, thermistors available are LM35, PT100 and those embedded in other sensors. Their weight is lower than 10 grams, but they consume power and the measurement range of the LM35 is not enough for a weather balloon. The thermocouple has been chosen because of its numerous qualities.

A thermocouple is a mere twisting of a couple of wires of two different metals. At the end of the sensor, the tension between the two cables in open circuit varies with temperature because of the Seedback effect. Therefore, this sensor is light because it is only a wire, it does not require a power input, it is easy to use and one type is available in Peru.

The thermocouple type K can read temperatures as low as 73 K, and is available in Peru. With an amplifier MAX6675 it can be read by an Arduino board.

Pressure sensor

There are many pressure sensors available in Peru. However, to be easy to use for a student, the sensor must be an absolute calibrated one. This means that the sensor must contain a bubble at known pressure and compare this pressure to the atmospheric pressure. A sensor of another type would require a vacuum chamber to calibrate it. The only absolute pressure sensor available in Peru is the BMP180.

The only problem with this sensor is that the manufacturer tested it only up to 9000 m of equivalent altitude. It has been used by many high altitude balloon projects in the past, including the one developed by the ESTACA Space Odyssey (a student rocketry club of the ESTACA), and it seems to be working at more than 20 km of altitude as the results are perfectly logical. But, the only way to be sure of this would be to test this sensor in a vacuum chamber. This was not possible during the internship, because the vacuum chamber of the laboratory needs to be fixed. But once this done, no calibration would be required for future projects.

Humidity sensor

Two air humidity sensors are available in Peru. The DHT11 and the DHT22 are a combination of a thermistor and a humidity sensor, used to obtain the relative humidity of the surrounding atmosphere. The only difference between the two sensors is that the DHT11 can measure humidity between 10 and 90 percent, while the DHT22 can measure humidity from 0 to 100 percent.

A weather balloon can go through a cloud during its flight, thus a DHT22 is more appropriate.

UV light intensity sensor

As previously described, as the ozone layer is the result of UV light being absorbed by the atmosphere, it can be detected through the variation of UV light intensity. The UV light being absorbed in the ozone layer is mostly

UV-B and UV-C. Therefore, a sensor able to detect the intensity of at least UV-B is necessary.

The elected sensor is the ML8511, which is sensible to light between 280 and 390 nm (UV-B corresponds to light between 280 and 315 nm). This a calibrated analog sensor, which gives a tension directly proportional to UV light intensity.

This is the only sensor of this type available to students in Peru.

5.4.2 GPS and telemetry

GPS tracker

To receive the trajectory of the balloon during its flight with telemetry, a GPS module must be added to the sensors.

But this tracking system relies on the telemetry. This means that if the telemetry fails during the flight, we would be unable to locate precisely the payload. For this reason, a second tracking system has to be chosen for security.

For this system to be as reliable as possible, the same GPS beacon as the one used in the high altitude balloon of the E.S.O. (ESTACA Space Odyssey) last year had been considered. The TK102 GPS beacon uses the GSM network to send an SMS with to its owner with its GPS coordinates. This system worked perfectly last year, however a good GSM network is required to make it reliable.

One of the many Peruvian phone companies allows its users to check a map of its network on its website. The following map of the region of Ica has been downloaded from this website (Figure 5.7).

It shows that nearly two third of the region is connected to the GSM network. This is enough to justify the use of the GPS beacon, but might not be enough to retrieve the payload.

The association ASPAST, which launched various high altitude balloons in the past few years, agreed to be a sponsor of the project, giving us a satellital GPS beacon.

The Spot GPS beacon does not use the GSM network, but communication with the Spot satellite network. This method is much more reliable and works in every location of the Peruvian country.

With batteries able to resist at very low temperatures, the beacon was placed on the top of the payload, to be sure that it would connect with the satellites (Figure 5.8).

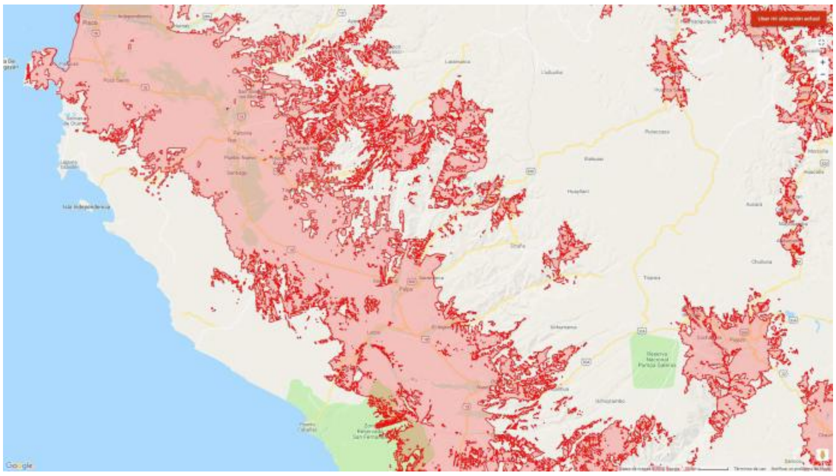

Figure 5.7: The mobile network of a Peruvian phone company

Figure 5.8: The Spot GPS beacon and the sponsoring

Telemetry components

The telemetry we used had to be chosen following precise criteria. First the telemetry has to work in a frequency authorized for radioamateurs in Peru. Then, the range of the telemetry has to be enough to receive data from the balloon in the worst flight case (the balloon landing at 100 km from the launch site). And finally the mass and power consumption of the telemetry are important criteria knowing that the mass of the payload and therefore the mass of the power source are limited.

The most common way of sending data from a weather balloon is using Automatic Position Reporting System. The APRS is a communication protocol allowing a radio beacon to easily send its GPS position in Ultra High Frequency. The problem is that a system using APRS necessitates a radio amateur license as well as expensive equipements in reception. The solution in Europe and the USA is to use a network of radio amateur stations, sending the received data through an internet website. However, such a network does not exist in Peru.

Another mean of communication could have been the XBee. Those Ultra High Frequency modules from the Digi company are commonly used in student telemetry projects because of they can reach powers up to a watt with less than 10 grams of mass. However, the XBee SX868 works in the 860-870 MHz frequency range, which is forbidden in Peru because it is already used by some mobile phone operators.

The telemetry that has finally been selected for the project is the LoRa technology. The LoRa ("Long Range"), is a RF communication technology developed by the French company Cycleo, now part of the American company Semtech. It has been created to improve communications between real world objects, also known as Internet Of Things. For this reason, the LoRa modules are light, cheap and achieve very long ranges with 10 mW of power.

To achieve tens of kilometers of range, LoRa uses a modulation technique called Chirp Spread Spectrum (Figure 5.9).

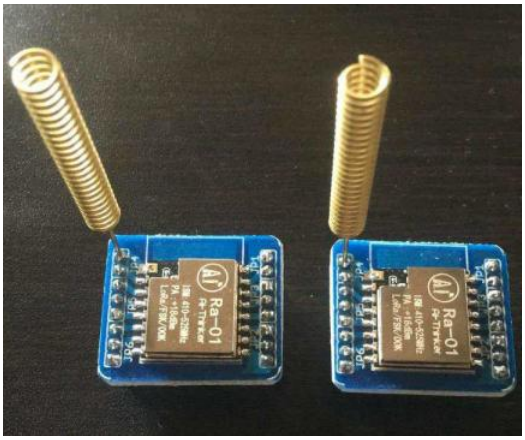

Figure 5.9: The LoRa modules

The antenna

A link budget calculation has been done to design an antenna in reception.

First, the worst distance between the payload and its taking-off location is around 100 km. With this distance, the path loss is -125.17 dB. With a frequency of 433 MHz, a transmitter with a power of 18 dBm and antennas with a gain of 2.5 dBi for the transmitter and the receiver, the received power is -102.17 dBm.

The receiver has in theory a sensibility of -141 dBm. But such a sensibility can only be achieved under ideal conditions with a bitrate of 18 bits per second. For instance, some real-world tests only measure a sensitivity of -100 dBm. And this result is without taking into account the losses caused by the connections with coaxial cables (Figure 5.10).

To be sure to have a margin over the practical sensitivity of the LoRa module, a high-gain antenna has been made.

The Yagi antenna is a natural choice because of its low cost and easy making. Furthermore, a lot of free softwares exist to calculate a design for a Yagi antenna. This type of antenna contains three types of elements. First, the directors guide the electromagnetic field, then the reflector assure that the electromagnetic field will mostly be in the direction of the antenna, and eventually a dipole will retrieve the signal and transmit it to the LoRa module.

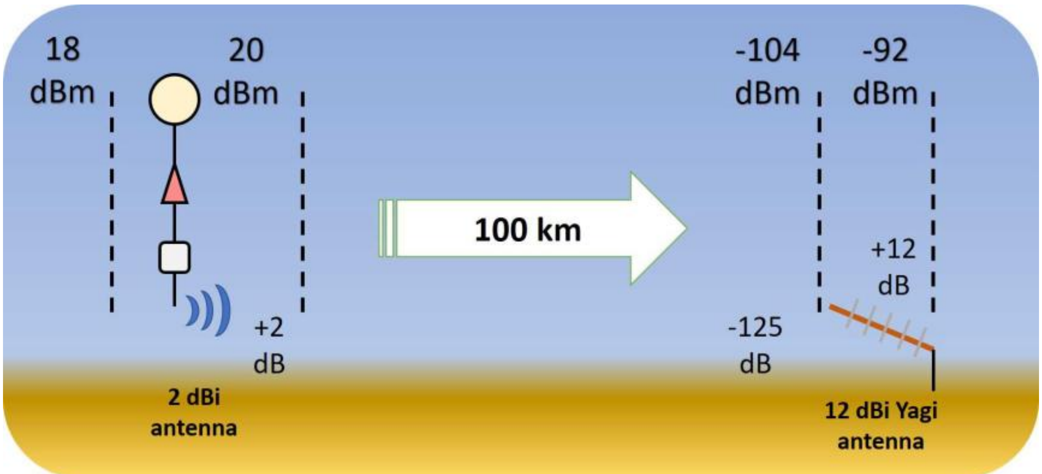

Figure 5.10: The link budget of the telemetry

The antenna made for this project has been designed with the Rothammel DL6WU code, which focus on maximizing the gain of the antenna. To obtain a 12.3 dBi antenna (which is a classical gain for a Yagi), eleven elements are required. The length of the antenna is then 1.77 meters (Figure 5.11).

A support had to be bought for the antenna to be stable. A tripod has been chosen.

To connect the antenna to the LoRa module, a 50 ohms coaxial cable had to be chosen too. The cable was not difficult to find in Lima, and the LoRa

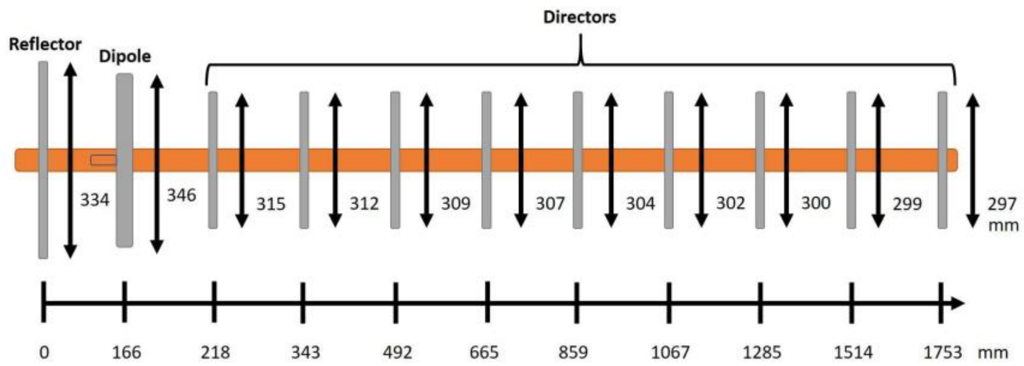

Figure 5.11: The dimensions of the Yagi antenna

was put into a 3D printed box on a PCB.

This antenna can easily be used. Once the USB cable is connected to the box, a Python program on the computer displays the received data (Figure 5.12).

Figure 5.12: Pictures of the Yagi antenna

It has also been calculated that a classical 9V battery is enough to power the telemetry and the other systems during the flight. The brand was the one recommended by Planète-Sciences and the CNES.

5.5 Thermal simulation of the payload and insulation

5.5.1 Thermal simulation

The payload of a high altitude balloon is embedded in a box made of a material with thermal insulation properties. The most common is the extruded polystyrene, which has a low density as well as a very low thermal conductivity for a large range of temperatures.

The most important properties of an insulating material are indeed density, conductivity and heat capacity. Density (ρ) is obviously important because the total mass of the payload must be under 1kg. The thermal conductivity (λ) is the ability of a material to let the heat pass through it, and must be minimized. And the specific heat capacity (c) is the heat required to raise the temperature of 1kg of material by 1K. It must be maximized. All those parameters are used to calculate the thermal diffusivity (D), which represents the rate of heat transferred through a material.

$$D = \frac{\lambda}{c\rho}$$

Here is a selection of insulating materials with their conductivity, specific heat capacity and density at ground level.

Material	ρ (kg/m^3)	λ (W/m.K)	c (J/kg.K)
Extruded polystyrene	30	0.032	1450
Expanded polystyrene	30	0.036	980
Mineral wool	85	0.045	820
Polyurethane foam	35	0.03	1450
Oak wood	740	0.17	2000

Comparing those classical insulating materials, it would seem that the best compromise is the extruded polystyrene. For this reason, it is the most common material to make a high altitude balloon payload.

A classical mistake is using expanded polystyrene instead of extruded polystyrene. However, the expanded polystyrene containing larger air bubbles than the extruded one, its shape and thermal properties change a lot when pressure decreases.

To really choose a material, and a thickness for the walls of our box, we need a thermal analysis with the variation of temperature during the flight. For this reason, with the properties of our balloon, has been simulated the temperature around it for a two hours flight (Figure 5.13).

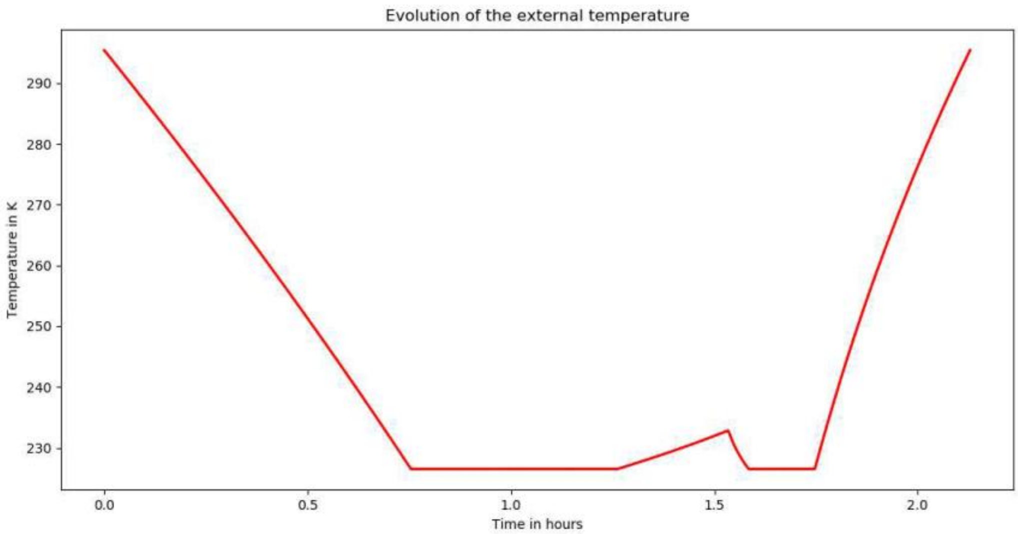

Figure 5.13: Evolution of temperature during the flight

The main problem is that extruded polystyrene is nearly impossible to find in Peru, and is very expensive when imported (70 USD for one insulation panel). For this reason, another material has been selected.

The polyurethane foam has very interesting properties: nearly the same thermal conductivity and capacity as extruded polystyrene, and a very low density. Furthermore, this material is very easy to find in Peru, in spray, for only 5 USD the bottle (300 mL). It was thus used to build the box of the payload.

A first thermal analysis of the material during the flight has been done using the heat equation in 1D with finite differences for walls of polyurethane foam with different thicknesses.

For each thickness, the wall is considered homogeneous, and is divided into spatial intervals of length Δx. The heat equation applied to this material is then

$$\frac{\partial T}{\partial t} = D\frac{\partial^2 T}{\partial x^2}$$

The simulation is done for the duration of the flight, with time intervals of Δt. According to the Von Neumann stability criteria, the simulation can only be stable if

$$\frac{D\Delta t}{\Delta x^2} < \frac{1}{2}$$

For instance, as the temperature is calculated every 0.1 seconds, with Δx

= 0.05 cm the simulation is stable for a 2cm thickness. Only the variation of temperature through the wall with conduction has been taken into account, and the surface temperatures of the walls are considered as equal to the air temperatures, the conduction phenomena being much slower than convection in this case (Figure 5.14).

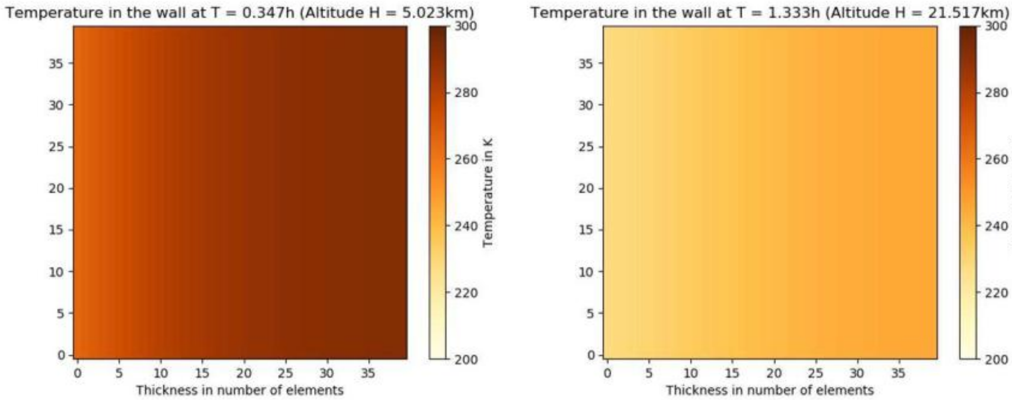

Figure 5.14: Temperature simulation at two different times

The simulations with different thicknesses of polyurethane foam (PU) give the following results for the temperatures given by the trajectory simulation software for a two hours flight (Figure 5.15).

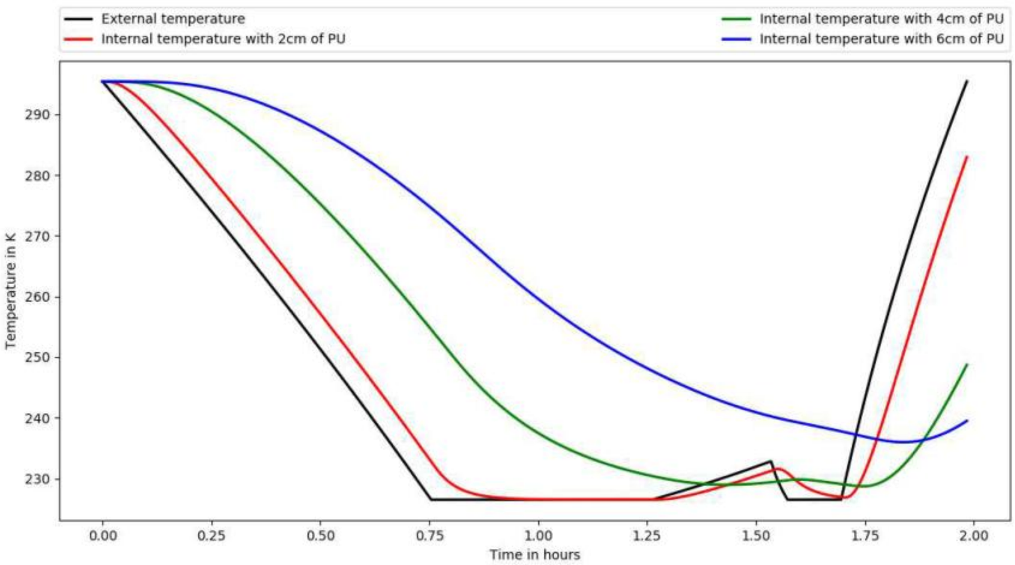

Figure 5.15: Evolution of the internal temperature with different thicknesses

According to this study, a 6 cm thickness of material is necessary to get a minimum temperature always above 233K on the interior face of the wall during the flight. This temperature corresponds to the minimum temperature for the less resistant components (Figure 5.16).

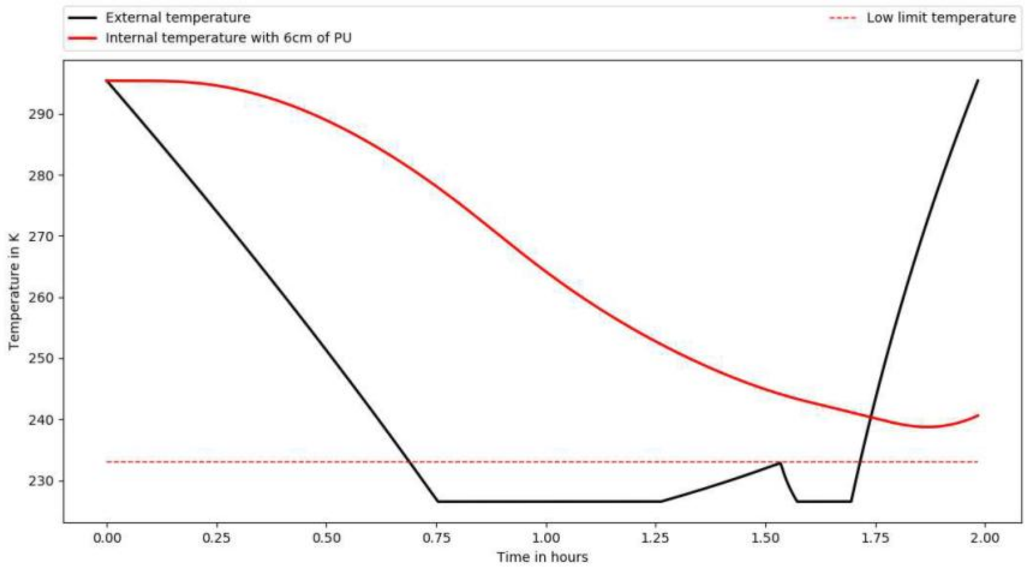

Figure 5.16: Evolution of the internal temperature with a 6 cm thickness

5.5.2 Insulation of the payload.

As explained previously, polyurethane foam has been selected as the insulating material of the payload. It can be found in spray in Peruvian shops. The only difficulty is that we need to make a mould of the box and fill it with polyurethane.

The first tried method was to use a wooden box as a mould and fill it with spray foam. To release easily the insulation box from the mould, the walls were covered with tape. However, this method did not give good results, as most of the foam remained on the walls, even though we used tape (Figure 5.17).

It was then tried to use transparent plastic foils, which seemed to be naturally smoother than the tape we used. The method gave better results, the insulation box being very easy to remove from the mould (Figure 5.18).

However, as can be seen with the images, there are a lot of air bubbles in the walls of the insulation box. Having imprisoned air in the walls is normal, and even a good thing because this is the air which gives a very low

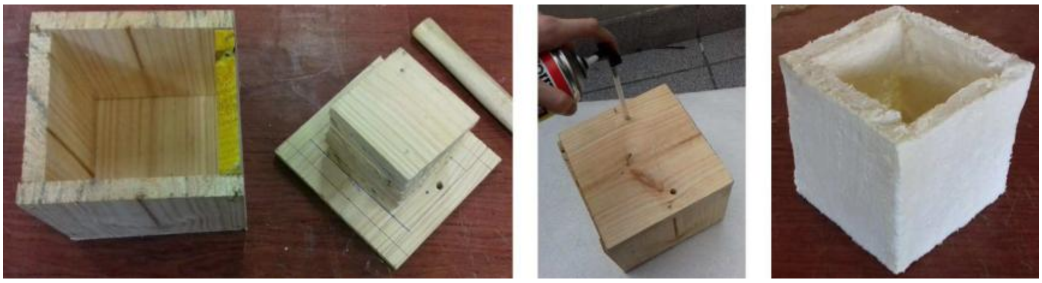

Figure 5.17: Moulding method with a mould in wood and PU in spray

Figure 5.18: Moulding method with a mould in PVC and PU in spray

conductivity to the polyurethane foam. But it could be a problem if a hole exists between the inside and the outside of the box. The bubbles are too big. For this reason, another way to obtain polyurethane foam had to be found (Figure 5.19).

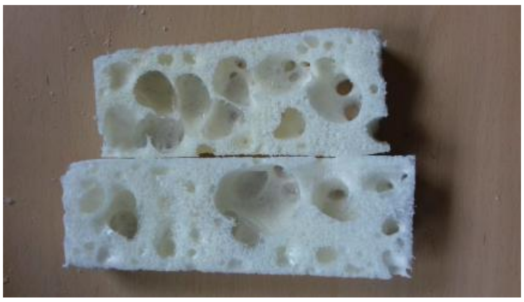

Figure 5.19: Internal structure of the PU in spray

To make polyurethane foam, two components A and B are required. When those elements are melted, two reactions occur. First, isocyanate monomer reacts with polyol to produce a polymer. Then, isocyanate reacts with water to produce carbon dioxide. The polymer and the gas create together the polyurethane foam.

To obtain a better result, the two components have been bought from a shop specialized in foams and silicon located near the Avenida Universitaria in Lima. The price of 1kg is 37 soles (around 11 dollars).

To determine the required proportion of each component, a test has been done with different mass proportions, for the same total mass. This way was determined the proportions to obtain a hard material, with small air bubbles and a low density (Figure 5.20).

Figure 5.20: PU synthesis tests with different proportions

The first one, made with a proportion of 50 percent A and 50 percent B, is good in terms of hardness, density, and bubbles size.

The second one, with a proportion of 75 percent A and 25 percent B, is not hard and seems like a sponge. As the component A is responsible for the creation of air bubbles and the component B for the creation of the structure, this is normal.

The third one, with a proportion of 25 percent A and 75 percent B, is hard and has small air bubbles. However, its density is too high and our insulation box would be too heavy.

The fourth one, with a proportion of 10 percent A and 90 percent B, is mostly plastic without air bubbles.

The fifth one, with a proportion of 90 percent A and 10 percent B, is creamy as if the reaction did not happen.

The sixth one, with a proportion of 50 percent A and 50 percent B, adding 10cl of water, gives a result similar to the fifth one.

Thus, a new box with a similar mould has been made, melting 250g of component A with 250g of component B (a total mass of 500g being the maximum acceptable for our insulating box).

The expansion occurs less than a minute after melting the components, and precautions must be taken as the reaction releases gas and heat. The roof has been made apart, with the hole for the camera. Its weight is 100g, and therefore the total weight of the box is 600g (Figure 5.21).

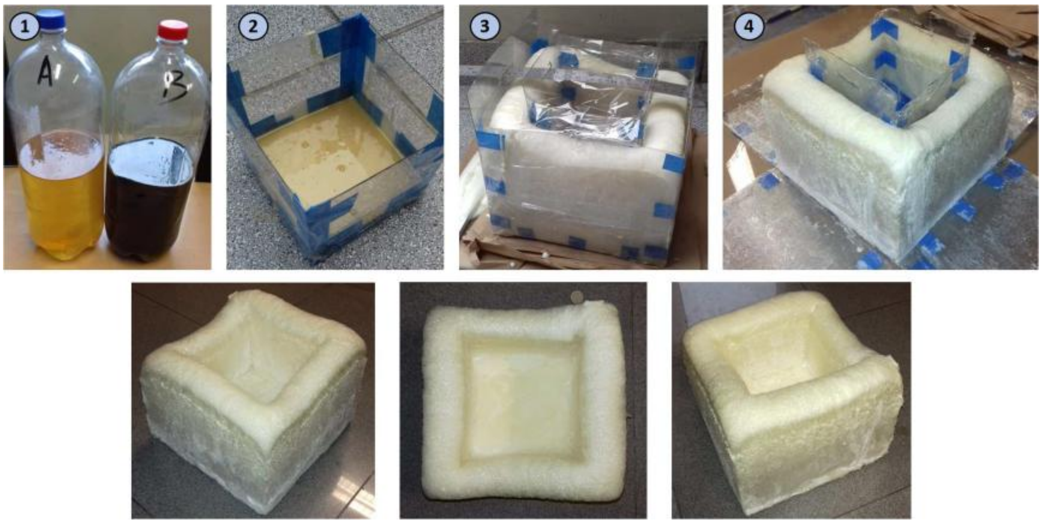

Figure 5.21: Moulding method with a mould in PVC and synthesized PU

This method gives excellent results, with a resistant material, containing only little air bubbles (diameters shorter than 1mm). However, a thermal test is necessary to confirm the insulating efficiency of the material. A test in a vacuum chamber would also be required in theory to check if the material can resist the low pressures of the stratosphere (Figure 5.22).

Figure 5.22: Internal structure of the synthesized PU

The final result of the insulating box is the following one, weighting 600g and costing only 22 soles of material (6.7 dollars)(Figure 5.23).

Figure 5.23: Final result of the insulating box

5.5.3 Test of the thermal insulation

To be sure that the polyurethane foam box is able to insulate the payload during a nearly two hours flight (a classical duration for a weather balloon flight), a thermal test has been done.

The box was put in a freezer for 4 hours to be sure that the temperature of the material was nearly homogeneous. Then, the box was taken out of the freezer and the DHT22 sensor put inside. The results were compared to simulation made with the same initial conditions, the same thickness of material and different thermal conductivity.

The density of the material has been deduced from the weight of the box (Figure 5.24).

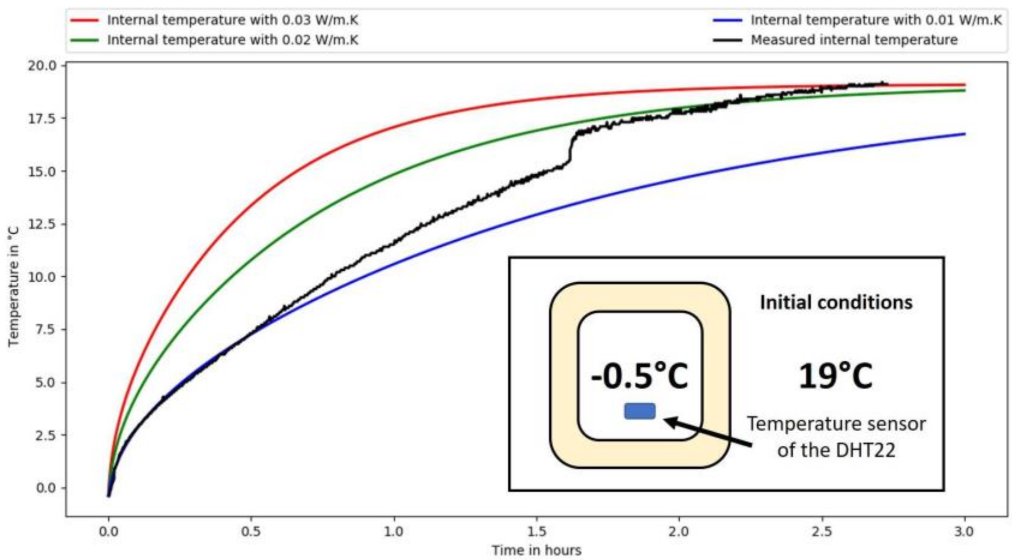

Figure 5.24: Evolution of temperature inside the box compared to simulations

The result of this test is that the temperature inside the box remains lower than what it should be with a conductivity of 0.03 W/m.K. The consequence is that the insulating box is as good as it was designed to be.

When analysing the result of this test, one must be aware that for the simulations the internal temperature is considered equal to the temperature of the internal walls, and that the precision of the sensor is between one and two degrees Celsius.

A time flight of two hours for the simulations has been chosen as a classical duration in Peru, to have a payload adapted to most of the Peruvian weather balloon projects.

Chapter 6

Test of the sensors and telemetry

6.1 The sensors

The selected sensors were tested on a breadboard during 5 hours on the roof of the laboratory, as if it was a weather station.

The measurements were stored in a SD card, and read with a Python program. This test gave the following results (Figure 6.1).

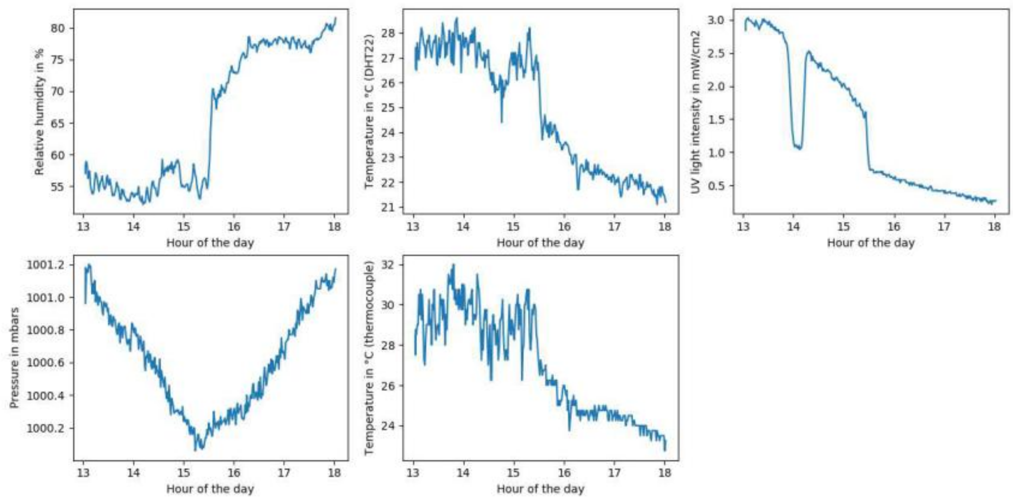

Figure 6.1: Results of the test of the sensors

The first observation we can make is that the general variation of each measurement seems logical. The temperature and the intensity of UV light is decreasing, while the humidity is increasing. It seems that a huge changing is occurring at 3:00 pm leading to the night. This is normal, as the timezone in Lima is the cause of an early sunset (between 5:30 pm and 6:00pm), and as the city is between huge hills and the sea.

It is difficult to analyse the results of pressure measurements. The pressure seems fine, but to be sure of its reliability the sensor would need to be tested in a vacuum chamber.

The two temperature measurements (one with a thermocouple and one with the DHT22 humidity sensor) seems to give nearly the same results but with an off-set. For this reason, further tests would have to be done to determine which sensor has an off-set, with a reference temperature measurement.

After testing all the modules, a PCB has been developed and printed in an electronics shop. This PCB has been made with plugs, so that the components could be changed in case a problem occurs. It had to be tested too, and it worked as expected (Figure 6.2).

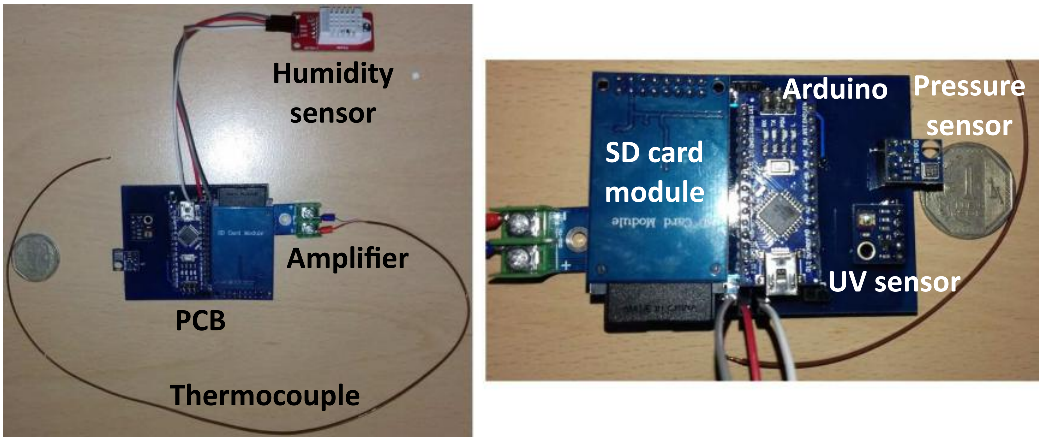

Figure 6.2: Picture of the sensors PCB

6.2 The telemetry

For the telemetry, a PCB has been designed too, with the GPS module. The two PCB communicate with a serial connection (Figure 6.3).

The PCB of the sensors saves the measurements in a SD card, and then sends the data to the PCB of the telemetry. Then, the PCB of the telemetry reads this data, the data from the GPS module and sends the lot to the LoRa module.

An Arduino Mega, bigger than the controller of the PCB of the sensors (an Arduino Nano), has been selected for this PCB. This is because were required two serial ports.

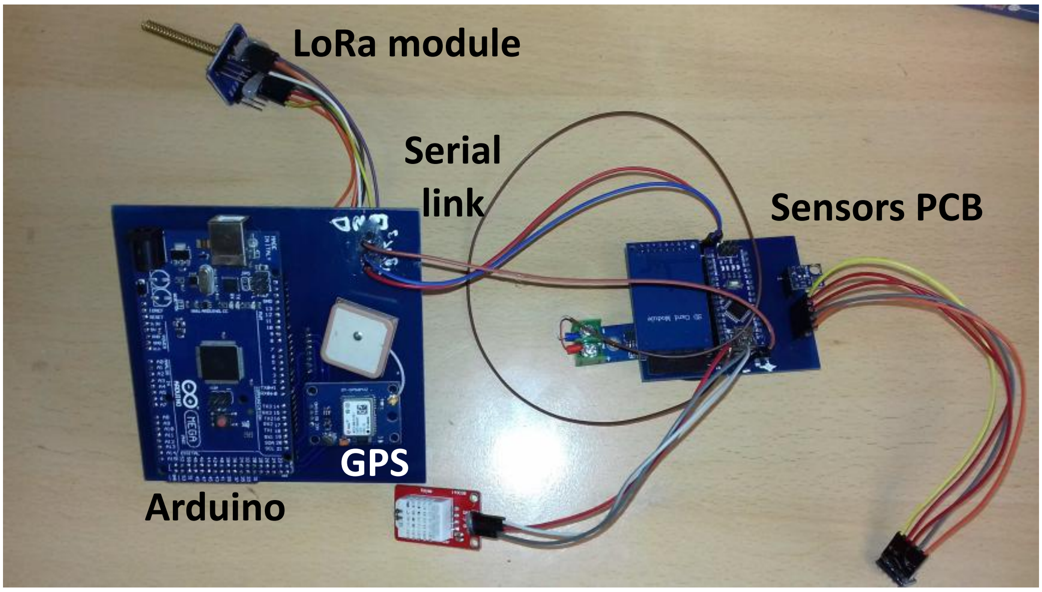

Figure 6.3: Picture of the sensors and the telemetry PCBs

The telemetry has been successfully tested in the university campus, but a test with long distances was not possible because the only free field in Lima would be between two points on the seashore, and some of those locations can be dangerous.

For a distance of 2 km in the campus, a power in reception around -60 dBm has been measured, which is quite good according to our link budget calculation (-58.4 dBm predicted for such a distance).

Chapter 7

Analysis of the results

7.1 Difficulties encountered

As the known difficulties for the development of a high altitude balloon in Peru have been explained during the presentation of the problem, this section will only focus on the unexpected difficulties encountered during this internship.

The main difficulty in Peru is to find the elements to make a weather balloon. As the project lasted only six months, buying all the components or materials on the internet is impossible because of the shipping time, which is one month from the USA and two months from China.

To find electronic components in Lima, the easiest is to go to El Paruro. El Paruro is a street located in the Chinese neighbourhood of Lima, in which are the majority of Peruvian electronics stores. The problem of this near-monopoly is that if a component cannot be found in El Paruro, it is nearly impossible to find in Peru.

It has been explained that extruded polystyrene is usually used to make the box containing the payload of weather balloon projects. However, this material is very difficult to find in Peru, while its expanded counterpart can be easily found in every market. The reason to this difference is that extruded polystyrene is used for house insulation, and expanded polystyrene for food insulation. As the insulation of buildings is nearly non-existent in Peru, the few companies selling this material import it from Mexico. The price of an extruded polystyrene board is nearly 230 soles (70 dollars), which represents a lot for a project willing to demonstrate the feasibility of student weather balloons in Peru. Thus another material has been found to make the box.

Furthermore, the most critical part of the project, the balloon, cannot be found in Peru. The only way to get a latex weather balloon in Peru is to import it from the United States or China. This is very expensive for a Peruvian student, nearly 150 dollars with shipping (more than 500 soles).

Eventually, the main problem encountered is the road traffic in Lima. As it is necessary to go to different districts of the city to buy the components and materials needed for the project, hours can be lost in a week just going from one shop to another. For instance, to build the Yagi antenna of the project, it was necessary to go to five different districts, to buy the aluminium, the wood, the tripod support, the LoRa module and the coaxial cable. Thus, it took a week to buy everything to make the antenna.

7.2 Launch

The weather balloon was launched in the desert of Ica (-14.073643, -75.822579) at 14:45, in attendance of an agent of the regional government of Ica (Figure 7.1 and 7.2).

Figure 7.1: The payload as it was on launch day

The contact by telemetry was lost at 15:00, five minutes after losing the visual contact with the balloon.

Thanks to the GPS beacon, the trajectory of the payload was known up to the landing point (-14.09019,-75.09491). However, to this day the payload has not been retrieved.

The payload fell in a zone with small mountains, at the beginning of the Sierra, at three hours walking from the nearest town. This is what had to be avoided, but the strength of the wind changed a lot between the publishing date of the NOTAM and the day of the launch. It caused an important change in our trajectory simulation. The sponsor ASPAST has a team in Ica, and sent someone to seek it, without success. It might have fallen in

Figure 7.2: Picture of the launch

a pit next to the last coordinates, or more probably someone retrieved the payload before.

For this reason, the laboratory contacted authorities of the nearest town, to ask villagers if they had found or seen something.

7.3 Experimental results

The measurements from the different sensors have not been retrieved to this date. However, are available 15 minutes of telemetry, and a trajectory of the balloon to compare with the forecast given by the simulation software.

7.3.1 Trajectory of the balloon

With the Spot GPS beacon, 18 coordinates of the payload during its flight were obtained. The only problem is that the GPS beacon does not send its altitude. Therefore, only the horizontal trajectory can be compared to the simulation (Figure 7.3).

Figure 7.3: GPS coordinates given by the beacon

It can be seen that the real trajectory matches the simulated one for the first phase of the flight. The distance between the real ultimate point of the first phase and the simulated one is only 2 km. This is quite good knowing that the total distance between the launch and the fall is 78.5 km. However, it is clear that the second phase (the fall with the parachute) is very different from the simulated one. The payload fell closer than expected (Figure 7.4).

There are two possible explanations to this difference. First, it is possible that the parachute did not open and thus that the payload went to the ground in free-fall. Second, it is also possible that the model of the fall with a parachute does not match reality.

To know which explaination is the right one, it is necessary to compare the expected duration of the fall with the real one (Figure 7.5).

The expected fall duration is 27 minutes, which is very close to the measured 25 minutes. It is thus very likely that the parachute opened, meaning that our model of the falling parachute is wrong.

It was assumed that the speed of the payload was the same as the speed of wind. This seemed to be true for the first phase of the flight, but not for the second.

7.3.2 Range of the telemetry

The last message from the telemetry was received at 15:00, with a power of -99 dBm in reception. At that time, the balloon was at 7 km from the antenna.

In theory, at this distance, the power in reception should be -69 dBm. There are different explanations to this difference.

It is possible that the advertised power in emission is not the real one. It is also likely that the gain of our antenna is not exactly 12.3 dBi. However, to explain a 30 dBm difference, the best explaination is that the antenna was

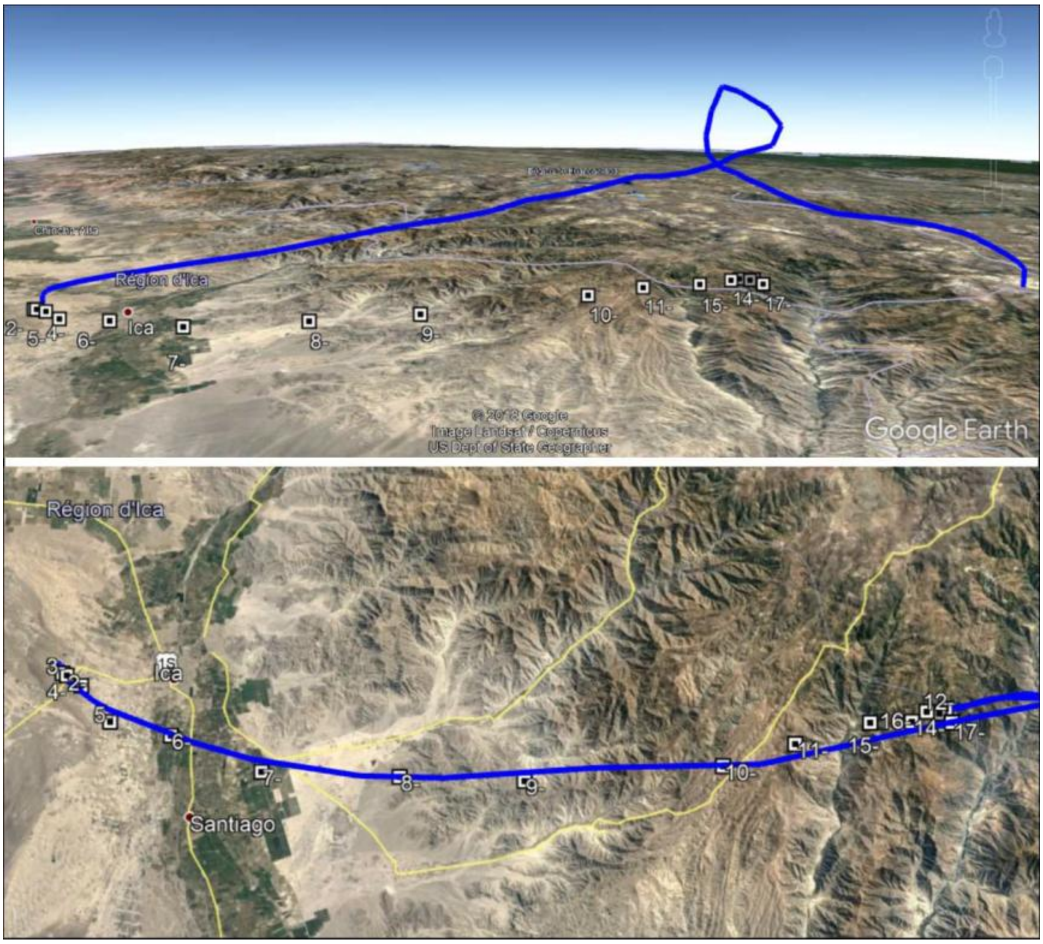

Figure 7.4: GPS coordinates (white squares) compared to the simulated trajectory (blue line)

not in the direction of the balloon when the telemetry was lost.

This is for instance what happens in most of the losses of telemetry for students weather balloons projects in France. As the time of the loss corresponds to the moments when the visual contact with the balloon was lost too, it is very likely that the direction of the antenna was the main cause of the loss (Figure 7.6).

As can be seen, the direction of the balloon from the antenna did change at that time of the flight.

To counteract this effect, there are only two solutions. Increasing the emission power is possible, but would require more energy and therefore heavier batteries. Using the GPS data to change the direction of the antenna is possible too.

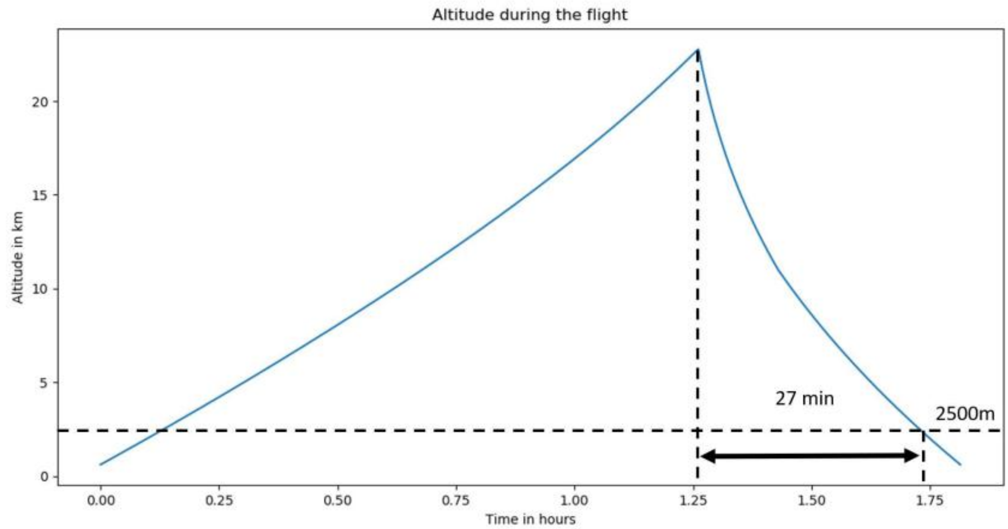

Figure 7.5: Vertical trajectory simulation and fall duration

Figure 7.6: Direction of the antenna (red line) and direction of the balloon (blue line) when the telemetry was lost

7.4 Gains for the laboratory

7.4.1 Experience for future projects

The main objective of this weather balloon project was to create a prototype which could be made by any Peruvian student. It is therefore important to write down the experience acquired during this internship. For this reason, a document in Spanish has been written, explaining in details how to design, build and launch a high altitude balloon in Peru.

This document was given to the laboratory, and will be used for a new weather balloon project next year.

This is to transmit the experience acquired on the preparation of a weather balloon project, but there is also the experience acquired on the launch of the balloon itself.

The payload of this weather balloon project was lost. This is not something unusual and half of the weather balloons launched by students in France are lost every year. However, after this project, we can propose different solutions to reduce the chances to lose future payloads.

First, as it takes three weeks for the ministry of transports to contact authorities and prepare the NOTAM, it is necessary to give a date and a location three weeks in advance. In the case of this project, winds changed a lot in intensity and the balloon went up to the mountainous Sierra region, while it would not have a few days before or after. For this reason, it would be important next year to ask the ministry if the publication of a NOTAM for an entire week is possible. This way, students could choose the best day of that week to launch the balloon, and it would fall in a location where it can easily be retrieved.

Another solution would be, with the data of flight simulations, to contact local authorities near the predicted landing point. They could be waiting for the payload to fall and seek it just after the landing.

The telemetry has to be improved too. The solution would be increasing the power of emission, although it would mean increasing the weight of batteries, our building an automatic tracking system for the antenna.

7.4.2 External communication

A high altitude balloon project is often a way to promote a school, a company, a laboratory or science in general. Communication on the project was therefore necessary to promote the CTIC-UNI and the use of weather balloons by students in Peru.

First, the SmartMachines laboratory has a Facebook page where were published pictures of the project.

Then, the project was presented during several events. The SmartMachines laboratory participated to the day of astronomy in the Los Olivos district, where the high altitude balloon trajectory software was presented.

The laboratory received an invitation to a radio show called Encuentro con la ciencia (Meeting science), broadcasted by RBC every sunday. During this show, two projects of the laboratory were presented, one being the weather balloon (Figure 7.7).

Figure 7.7: Radio interview about the project

The work done for this project was eventually presented during the Encuentro Cientifico Internacional (International Scientific Meeting) in Lima (Figure 7.8).

Figure 7.8: Presentation of the project at the ECI

For communication purposes, it has been decided to give a name to the project. The tradition in the laboratory is to give a name in Quechua (an indigenous language spoken in some regions of Peru) to the projects. For a light flying payload, it seemed logical to give him the name of the smallest Peruvian bird, the colibri: Q'inti.

7.5 Gains for the intern

This internship allowed as an intern to lead an academic scientific project, requiring knowledge and research in a wide variety of fields (electronics, mechanics, thermal insulation, radio communications). Many techniques and technologies had to be tested, and the required information to be found. It was also the occasion to communicate about the work in process and the objectives of the project.

The aim was not only to develop a project, but also to develop it in a way that it could be easily repeated in the future.

The internship also took place in Peru, in a different cultural environment. This means adapting to another language, other ways and working environment.

This experience is therefore part of a professional project, as the objective is to continue in doctorate as soon as october 2018 (accepted for a thesis in the French laboratory LATMOS). Adaptation to other cultures, work in various fields with various technologies and communication skills will be necessary.

7.6 Proposition of a potential alternative to latex balloons

One possible improvement of weather balloons in Peru could be the use of solar balloons.

Solar balloons are made of black coloured neoprene, to absorb solar energy and heat the gas inside (air or a mix of air and helium), therefore reducing its density.

Those balloons are much bigger than latex balloons for the same payload, and they do not explode in flight, meaning that they will stabilize in the stratosphere until nightfall, but they are much cheaper. With the help of the CNES and Planete-Sciences, French students succeeded in 2008 to launch a 2 kg payload up to 9 km of altitude with a solar balloon only made out of trashbags.

The only problem is that sunlight is strong only half of the year in the Costa region in Peru. The other half of the year, it is so cloudy that a launch would be impossible (it has been tested several times with a small 10 m3 prototype during this internship and it did not work).

However, the study of this type of balloon could be the subject of another project for the laboratory, and would reduce the cost of future projects.

Chapter 8

Conclusion

During this six months internship, a protoype of student weather balloon has been developed in Peru, and launched for a first flight.

The price of the launch, 2500 soles (760 dollars) with the experiment, is affordable for a Peruvian high school or university, and the selected launch site is close to Lima. A project report in Spanish has been written, and other weather balloons projects are planned for next year in Peru.

The project has been advertised in many different ways. Nearly 40.000 people have seen the pictures of the launch in social networks, and the project has been presented to the Ecuentro Cientifico Internacional, the major scientific event in Peru.

This way, there is hope that other students will be motivated to launch their weather balloon projects in Peru. For instance, the sponsor ASPAST plans to launch a balloon in december 2018, and the CTIC-UNI wants to launch other weather balloons projects in 2019.

Therefore, Peruvian students weather balloons projects have a promising future, and should further be encouraged as there are a plenty of feasible experiments that could be related to Peruvian issues.

The next steps now would be to improve the communication with the DGAC and the local authorities, to increase the power of the telemetry and maybe to test another type of balloon.

A launch in another location, with interesting issues that could be investigated, and institutions that would be interested in a weather balloon launch should be done. Huancayo, for instance, would be a good place. The city suffers from strong UV levels related to the depletion of the ozone layer in the region, and scientific authorities seemed interested in a launch.

List of Figures

Chapter 9

Appendix

9.1 Pictures of the launch

Figure 9.1: Pictures of the launch

9.2 References

9.2.1 Publications

Gettelman, A. (2001). "El Nino as natural experiment for studying the tropical tropopause region"

Sherwood Rowland, F. (2006). "Stratospheric ozone depletion"

BING, Federation of European Rigid Polyurethane Foam Associations, (2006). Talon, A., Lalique, E. (2008). "Phaeton the solar balloon".

Planète-Sciences, CNES (2016). "Cahier des charges pour ballons expérimentaux V11".

Robinson, S. (2016). "Long distance tracking and monitoring with LoRa".

"Thermal insulation materials made of rigid polyurethane foam".

Thaheer, A., Ismail, N. (2017). "Mission design and analysis of USM high-altitude balloon".

Renegar, L. (2017). "A survey of current balloon trajectory prediction technology".

Manatsa, D. (2017). "A connection from stratospheric ozone to El Niño-Southern oscillation".

9.2.2 Laws and regulations

RAP-101, Regulaciones Aeronauticas del Peru, "Globos cautivos, cometas, cohetes no tripulados y globos libres no tripulados".

"Registro nacional de frecuencias"

9.2.3 Other references

Websites of the World Health Organization, the Peruvian Ministry of Tranports and Communications, the NOAA, the Global Radiosonde Archive, Instituto Geofisico del Peru, Senamhi, Planète-Sciences, the CNES and the ASPAST.

Credits for the pictures : Nicolas Oudart and Williams Kevin Solis Quispe.

9.3 Evaluation of the internship and updated resume

ESTACA
ÉCOLE D'INGÉNIEURS

ASSESSMENT FORM

To be filled in by the tutor or direct manager only and returned by email to:
evaluation.stage@estaca.fr

SURNAME OF THE STUDENT :	OUDART
FIRST NAME OF THE STUDENT :	NICOLAS
YEAR OF STUDY AT ESTACA :	2018
COMPANY :	CTIC - UNI
TOPIC OF THE INTERNSHIP :	DESIGN OF A PERUVIAN WEATHER BALLOON
TUTOR NAME :	TENORIO TRIGOSO
TUTOR FIRST NAME :	ALONSO
POSITION :	DIRECTOR OF THE CTIC-UNI

CRITERIA

	EXCELLENT	SATISFACTORY	AVERAGE	UNSATISFACTORY
GENERAL ATTITUDE				
Adaptation to company rules	☒	☐	☐	☐
Punctuality	☒	☐	☐	☐
Discipline	☒	☐	☐	☐
Attitude towards managers	☒	☐	☐	☐
Integration into the company	☒	☐	☐	☐
Team spirit	☒	☐	☐	☐
Knowledge of industrial sector	☐	☒	☐	☐
INTELLECTUAL & PROFESSIONAL SKILLS				
Scientific & technical skills	☐	☒	☐	☐
Ability to be creative, take initiative	☒	☐	☐	☐
Dynamis, natural authority	☐	☒	☐	☐
Communication skills (written & spoken)	☒	☐	☐	☐
Listening skills, diplomacy	☒	☐	☐	☐
Organisation skills and rigor	☒	☐	☐	☐
Autonomy	☒	☐	☐	☐
OVERALL VIEW				
Carried out tasks, met objectives	☒	☐	☐	☐
Interest and determination to fullfil work for the company	☒	☐	☐	☐
Presentation of internship (when necessary)	☒	☐	☐	☐
SYNTHESIS	☒	☐	☐	☐

EVALUATIONS OF THE CAPACITIES OF THE STUDENT

Your comments please

Areas of strengths

. Skills on weather balloons
. Skills on leadership for working in a multidisciplinary team
. Good spanish knowledge : writing, speaking, reading.

Needs improvement on...

· Geography restrictions in the Peruvian Andes.
(His weather balloon felt down in an abyss area in a 100 Km from the launch site)

Having seen the student work in a professional environment, what advice would you give him/her ?

• Get advice from Geographers concerning the working area of the project.
. Visit the site, talk with local people, authorities, before the launch for improving the knowledge of the site and evaluate the risks of loosing the payload.

DATE : August 12th, 2018

SIGNATURE : Margarita D. Mondragón.

MARGARITA D. MONDRAGON
Chief Smart Machines Lab.

ASSESSMENT FORM

To be filled in by the tutor or direct manager only and returned by email to:
evaluation.stage@estaca.fr

SURNAME OF THE STUDENT :	
FIRST NAME OF THE STUDENT :	
YEAR OF STUDY AT ESTACA :	
COMPANY :	
TOPIC OF THE INTERNSHIP	
TUTOR NAME	
TUTOR FIRST NAME	
POSITION	

CRITERIA

	EXCELLENT	SATISFACTORY	AVERAGE	UNSATISFACTORY
GENERAL ATTITUDE				
Adaptation to company rules	☐	☐	☐	☐
Punctuality	☐	☐	☐	☐
Discipline	☐	☐	☐	☐
Attitute towards managers	☐	☐	☐	☐
Integration into the company	☐	☐	☐	☐
Team spirit	☐	☐	☐	☐
Knowledge of industrial sector	☐	☐	☐	☐
INTELLECTUAL & PROFESSIONAL SKILLS				
Scientific & technical skills	☐	☐	☐	☐
Ability to be creative, take initiative	☐	☐	☐	☐
Dynamic, natural authority	☐	☐	☐	☐
Communication skills (written & spoken)	☐	☐	☐	☐
Listening skills, diplomacy	☐	☐	☐	☐
Organisation skills and rigor	☐	☐	☐	☐
Autonomy	☐	☐	☐	☐
OVERALL VIEW				
Carried out tasks, met objectives	☐	☐	☐	☐
Interest and determination to fullfil work for the company	☐	☐	☐	☐
Presentation of internship (when necessary)	☐	☐	☐	☐

SYNTHESIS	☐	☐	☐	☐

EVALUATIONS OF THE CAPACITIES OF THE STUDENT

Your comments please

Areas of strengths

Needs improvement on….

Having seen the student work in a professional environment, what advice would you give him/her ?

DATE :

SIGNATURE :

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french, english (TOEIC 930/990), spanish

ESTACA
ECOLE D'INGENIEURS

GROUPE ISAE

Experiences

2018 6 months — **Internship at CTIC-UNI** — Rimac, Lima, PERU

Responsible of the development of the first student weather balloon of the peruvian National University of Engineering (UNI), in the CTIC laboratory. The balloon was launched in august 2018, and lifted a payload containing experiments dealing with climate and UV radiations.

2017 4 months — **Internship at LATMOS** — Guyancourt, Yvelines, FRANCE

Development of an interpretation chain for the data of the ground penetrating radar WISDOM of the EXOMARS (ESA) mission, to automate the analysis of its radargrams.

2016 1 month — **Tutor at TechCamp UK** — Sparsholt, Hampshire, UNITED KINGDOM

Teaching quadcopter drone engineering, and automation for teenagers at TechCamp UK vacation camp. Participated at the organization of the camp.

Studies

2016 2018 — **ESTACA** — Montigny-le-Bretonneux, Yvelines, FRANCE

Aerospace engineering studies at the ESTACA, *grande école* part of the ISAE group (Master academic degree).

2014 2015 — **CPGE MPSI-PSI** — Orléans, Loiret, FRANCE

Physics and engineering preparatory classes at the lycée Pothier, in Orléans (licence academic degree).

Student projects

2016 2018 — **Member of the administration council of the ESO association**

Responsible of a high altitude balloon project and electronics courses at the ESTACA Space Odyssey, an association dedicated to the development of student projects related to space industry.

2018 — **Member of the Roamer 4 lunar rover project**

Working on the odometry of the Roamer 4 lunar rover, a student project of the french space agency CNES. Development of image processing and interpretation softwares.