# PROBE-PLATFORM STRATOSPHERIC OF AUTONOMOUS FLIGHT

**Esperanza Camargo Casallas[1], Cesar Augusto Corones[2], Luis Alberto Jaime Hernández[3], Cristian Ancizar Bermúdez Bello[4]**

[1]Professor, Dept. of Telecommunications Engineering, Distrital Francisco Jose de Caldas University, Bogotá - Colombia
[2]Professor, Dept. of Engineering, SENA, Bogotá -Colombia
[3]Student, Dept. of Telecommunications Engineering, Distrital Francisco Jose de Caldas University, Bogotá - Colombia
[4]Student, Dept. of Telecommunications Engineering, Distrital Francisco Jose de Caldas University, Bogotá - Colombia

---***---

**Abstract -** *This article presents the design, development, and results of the launch of the autonomous flight probe Sabio Caldas. The project was carried out with a budget of the CIDC, developed by students of the Francisco José de Caldas District University of the Technological Faculty of the different careers related to the electronic technology curricular project. The research group that supported and directed the project was DIGITI (Intelligent Digital Systems) headed by the PhD Esperanza Camargo Casallas. The stratospheric probe Sabio Caldas had as objectives, to sense environmental variables, to generate an energy feeding system that satisfies the total flight consumption, to capture images of the Colombian stratosphere, to transmit the sensed data, video transmission, besides having GPS for to know the location in real time. An abstract summarizes, in one paragraph (usually), the major aspects of the entire paper in the following prescribed sequence.*

***Key Words***: probe, stratosphere, subproject, innovation, exploration, research, environment.

## 1. INTRODUCTION

The Project Probe- Platform Stratospheric of autonomous flight Sabio Caldas was launched into the stratosphere the 22 of September of 2016, to choose the launch date, 49 meteorology reports and flight projections were analysed, these reports were supplied by FAC, after the analysis of the reports, launching date was settled between the 21st and 23rd of September, with these dates in the projection, it was identified that the area in which the probe could be found was 5.6 km radius to the impact zone. After the launch time window was selected, the FAC restricted commercial and military airspace between 5 a.m. and 9:00 a.m. in the launch area at GAORI Base (Eastern Air Group), in the municipality of Marandúa, Vichada.

For the launching there was a staff of 17 people from the University, 15 people at GAORI in front of the project and 2 students supporting from CATAM and the campus of the Francisco Jose de Caldas Distrital University in Bogotá. The staff traveled on a FAC plane, where they received full support for the launch.

The probe's ascent lasted 2 hours and 20 minutes reaching 30,002 meters in the stratosphere as planned, during the ascent information was obtained from the sensors with the help of the telemetry system obtaining information on coordinates, pressure, humidity, altitude, ozone and UV up to 25,000 meters high. In terms of images, it is certain that the cameras were taking photos and recording, however, the video transmission failed at 2400 meters high.

The descent lasted 30 minutes, and the last coordinate obtained was 2,700 meters above sea level, the probe was 6 km from the launch point, very close to the swamp area next to the Tombo River, as simulated in the projections. For this reason, it is believed that the impact occurred in this area nevertheless recovery was impossible, despite the search that was carried out in helicopter and through an area of 3 km of perimeter with a 300 meters long lookout squad on foot.

Being this the first launch, the results are satisfactory, due to the height reached, the measured variables, the telemetry, the energy of the payload, the good operation of the navigation system, and the impact probe within the projection perimeter. With this launch, it is expected to develop new prototypes for space exploration in Colombia.

## 2. METODOLOGY

A system of control and integration was proposed by means of layers based on the OSI model. The last layers were not executed, since it was not remotely controlled, only the environmental data is acquired for later analysis.

Using previous calculations and investigations, it was necessary to guarantee the temperature and electrical current for the module's operation, in order for them to interact properly with each other through their respective communication protocols.

All the information acquired through the research process was physically and digitally documented in the DIGITI research group, hoping that this becomes the basis for the next prototypes of the vehicle. The required financial and human costs were contributed by the research group and its researchers.

The probe stratospheric Sabio Caldas project is segmented using modules that are physically, electronically, and digitally integrated. Additionally, flight projections must be done, so both the airspace required for the project and the place can be restricted, and to find the most suitable time for the launching.

For the development of this project, it was proposed to work by segments, a space segment made up of the payload, a remote base reception station and a monitoring station in Bogotá with the SPOT system were used.

The space segment was made up of the modules listed below, Figure 1:

- Energy: It powers all the modules; it is in charge of controlling the intern temperature so that all the components work properly.
- Video: Captures images with the cameras, overlays the information from the sensors and sends them to the transmission module to be forwarded to the base reception station.
- Environment: Measures environmental variables such as Temperature, CO2, pressure, humidity, altitude, ozone and UV.
- Video transmission: Sends the video data using FPV (First Personal Vision) technology.
- Telemetry: Send the georeferencing data and measurements done.

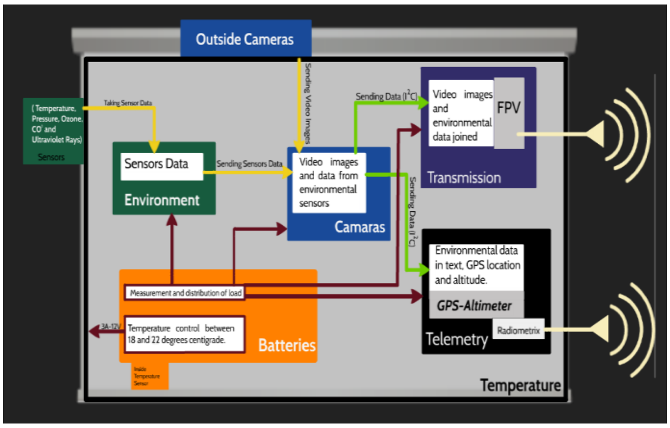



**Fig -1:** Space Probe Segment.

For telemetry, 2 internal GPS were used, one for referencing and another commercial SPOT system.

At the base reception station there were the telemetry and video reception modules with their respective required antennas, additionally in Bogotá at the CATAM facilities, the SPOT system was monitored, and the coordinates were being monitored during the flight at the University.

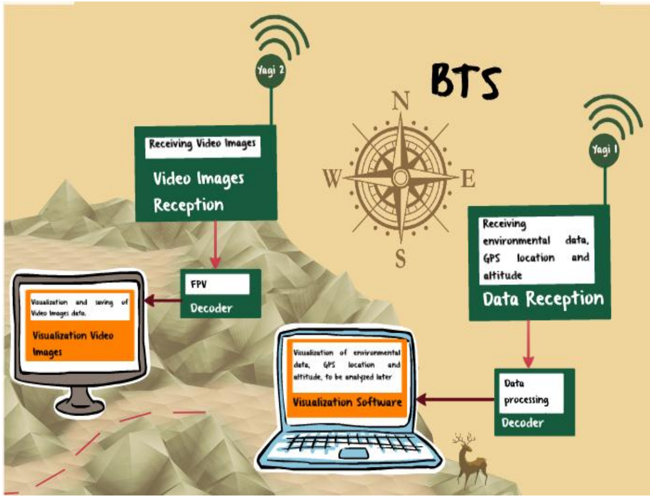



**Fig -2:** Base reception station

For the launching of the probe it was necessary to use a meteorological balloon as a transport vehicle with the capacity to carry a weight of 2 kilograms, the filling of this was done with helium, for which it was necessary to supply the UN codes for the transportation of the helium in an airplane.

The launch was carried out in an open field with sightline, due to this it was necessary to rent a power plant and binoculars to follow it up. The meteorological analysis begins so that the date for the flight can be narrowed, in this way a pattern could be established in space and time, afterwards the simulation system was selected, which was fed with the data provided by the Colombian Air Force, having information of winds, their magnitude and direction at different heights, humidity, temperature, time zone with UTC reference, sea level and latitude-longitude coordinates.

Due to the rotation and irregular reception of sun's rays on the Earth's surface, there are time differences between countries and continents all around the world. Earth's circumference has 360 meridians, every 15º of geographical length there is an hour of variation, so there are 24 time zones (360/15), the first of which has its axis on the Greenwich meridian, which hour is the equivalent to 00. "From here one hour is added (subtracted) every 15º of longitude towards the east (west). The eastern or oriental hemisphere has time more advanced than the western one" [1][2] as shown in Figure 3. It is considered that within each time zone there is the same time, but local needs impose modifications on the theoretical spindles and each country adopts their own official time to fit their convenience, but always trying to adjust as best as possible to the international time zone. International time is called Coordinated Universal Time, UTC, or Greenwich Mean Time, GMT, it is the time used for all meteorological observations.

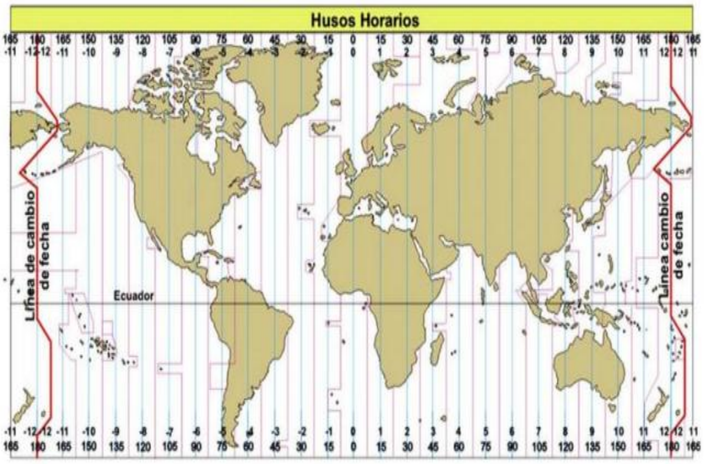
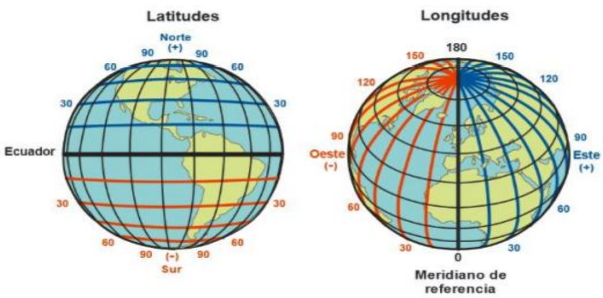



**Fig 1:** – Time zones [2].

The geographic coordinate system expresses all positions on Earth using the three coordinates of a spherical coordinate system that is aligned with Earth's axis of rotation. "This defines two angles measured from the center of the Earth, the longitude measures the angle in degrees, minutes and seconds between a point on the Earth's surface and the Greenwich meridian, also the latitude that measures the angle in degrees, minutes and seconds between a point on the earth's surface and the equator" [3]. As shown in Figure 4.

**Fig 2**: – Geographical coordinates [3].




Flight projections were made with the data obtained by the Colombian Air Force recorded in 49 meteorological bulletins supplied to the DIGITI research group, which helped to determine that the most suitable days with little precipitation for the flight were in September from the 19th to the 24th between At 1200Z-1800Z hours, in the territory of Marandúa Vichada at the Base Grupo Aéreo del Oriente (GAORI), with the help of the Colombian Air Force, the commercial and military airspace was restricted during the launch on September 22 in order to avoid any air accidents, this day was selected based on projections made on September the 21st from the base area with the previously mentioned meteorological reports officially issued, these indicated that the flight had to be made on the mentioned day at 5 AM.

## 2.1. Temperature Control and Power Supply Module for the Sabio Caldas Stratospheric vehicle

For the probes, waste and poor energy control have been a great problem for their proper operation. For this reason, a temperature control and power supply module was implemented, which has converters and voltage regulators to have 12V and 5V voltage outputs to power the navigation modules, video transmission, sensors, cameras and micro controllers throughout the flight of the vehicle. The electrical current consumption is constantly measured in all the modules of the Sabio Caldas vehicle, in addition to a heating system to maintain an optimum temperature in the vehicle and thus guarantee the correct operation of all the electronic components that make the probe what it is, finally all the data internally measured during the flight is stored on a removable device so that it can be watched after project execution.

In the stratosphere there are very low temperatures which affect the proper functioning of the probe's components, these temperatures can reach as low as -90 ° C in the mesopause, the layer that separates the stratosphere from the mesosphere and the minimum temperature required for classic electronic equipment's proper operation is -10 ºC.[4]

The electrical current consumption required by some devices like transmission modules, navigation and temperature regulation modules is approximately between 5 and 6 Amps. This high consumption causes that common voltage sources and batteries fail to supply for long periods of time. The temperature control and power supply module solve this problem, supplying the vehicle throughout its whole mission. With this module it is possible to maintain an optimal temperature greater than 8 ºC for the proper functioning of the electronic components inside the vehicle. The principal objective of the module is to control the temperature and supply energy to the Sabio Caldas Stratospheric Vehicle. This module consists of regulator and energy supplier, Vehicle thermal control and data collection about energy consumption.

The module is based on commuted sources, since it is an airspace device it should be as light as possible and save as much energy as possible as well, for this reason the project used 4-cell lipo batteries (16 volts) at 8 amps an hour, which means that if the device consumes 8 amps in an hour, it will drain the battery completely. This energy is sufficient to keep the vehicle flying during its 3-hour mission, since the average energy consumption of the vehicle is 3 amps per hour, the MP1584 switched source modules were implemented, as shown in Figure 5.


**Fig 3:** – MP1584 Module [5].

This device's main feature is converting voltages between 4.5 and 28v to lower voltages in a range of 0.8 and 18v, it also supports electrical currents of up to 3A and has an efficiency of up to 92%. The operating temperature is between -40 °C to +85° C. For the internal temperature sensing of the probe a PT100 was used, in case the temperature drops to a point that could affect the operation of the internal circuits, in such case the heating model is activated and the peltier cells start working with the heat sinks to increase the temperature.

## 2.2. Environmental Conditions Measurement Module for the Sabio Caldas Stratosphere Vehicle

This module collected data about the environmental variables measured by different tests carried out for each sensor and images were obtained between each one of the conditions and the times at which the respective sensor was exposed.

The creation of an environmental data acquisition system taken from the nearby Colombian atmosphere has been a little explored topic; Whether due to a lack of budget, a lack of electronic equipment or simply little interest on it, hence we find very little or no theoretical nor practical track record in terms of research done in Colombia. Despite this, several projects have been found in which measurements of different environmental variables have been made in the mentioned atmosphere. The objective of the module is to measure environmental conditions in the different layers of the Colombian atmosphere (Temperature, Pressure, Ozone, Co2 and Ultraviolet Rays), this in addition to inform the state of the atmosphere nearby Colombia, it will also be a pioneer investigation in the Colombian space exploration.

To obtain the temperature, pressure and altitude data, the BMP180 sensor was used, since it has small dimensions and the ability to measure all three variables mentioned above, thus providing a profit in terms of size and weight for the stratospheric vehicle. The characteristics that make this sensor the most suitable for the mission were its wide range of operation regarding the temperature (-40 ° to 85 °), its design allows a direct connection to a microcontroller through I2C and it also provides a measuring range from 300 to 1100 hPa (Hecto Pascal) with an absolute precision of up to 0.03 hPa. On top of that, an additional characteristic, which is that the operating voltage is 3.3V and consumes a maximum electrical current of 1mA [6].

The SI1145 is designed to measure light rays between 400nm -800nm wavelength, its supply voltage has a range that goes between 3V to 3.6V, in this case the power required was 3.3v, the temperatures at which the sensor is functional are between -40ºC and 85ºC [7]. To obtain the amount of carbon dioxide ($CO_2$) in the environment, it was decided to use one of the MQ series gas sensors, the MQ135 gas sensor is capable of recognizing gas changes such as: $NH_3$, alcohol, benzene, $CO_2$, among others. In this case we will only need to recognize changes in carbon dioxide ($CO_2$), for which it is necessary to perform a calibration of the variable resistance that the sensor brings as default and simultaneously determine an equation that correctly relates the resistance to the amount of $CO_2$ in ppm [8]. In the humidity measurement the sensor used was the DHT22, due to the precision and also to the large measurement range that it poses, going between 0% to 99% of Relative Humidity (RH), in addition to this the sensor is capable of measuring temperature in a range between -40ºC and 80ºC which allowed to make a comparison in terms of temperature measurements between the BMP180 sensor and the DHT22 [9].

## 2.3. OSD Video Processing Module for the Sabio Caldas Stratospheric Probe.

A video module was made for the stratospheric probe, serving this as informative visual aid, since it was hoped to present a combination of sensed data from the stratosphere and video images taken from the same probe with different perspectives, and therefore carrying a good amount of data regarding the electrical current state of the stratosphere.

The objective of this module is the processing of video OSD (On Screen Display) this will allow the recognition of the nearby Colombian atmosphere, observing its electrical current state and will also give a breakthrough in terms of research in the space field. When starting the capture of the video with a single camera OMXPLAYER was used to corroborate the storage of the video, this software is installed by default in Raspbian, so there is no need to install any additional package [10]. For the processing of the images captured by the hardware using OpenCV, the project provided an easy to use and highly efficient development environment implementing a solution of up to 4 cameras. This was achieved by programming on an extension of capabilities in Python, thanks to OpenCV's optimized C and C ++ code, taking advantage of the capabilities that this provides for solving computer vision problems through the use of libraries for mathematical operations. [11].

## 2.4. Telemetry Module for the Sabio Caldas Stratospheric Vehicle

This module allowed wireless communication and data transfer to the base reception station of some items such as positioning, smart charge and temperature, using a unidirectional communication protocol with Raspberry Pi card, radio frequency transmission and reception modules. The data detection was carried out at 50kbps in the available frequencies of 434.250MHz [12]. The transmission of digital data in radio frequency used a wavelength of 70cm and a frequency of 433MHz, this in order to go through the ionization that occurs in the upper layers of the stratosphere. The Raspberry Pi card configures the data transmission frequency, the transmission speed, the dimensions of the live images (taken at high and low altitude) and the height. The SDR software was used to convert the radio signal into an audible signal through the “virtual” audio cable, which consists of converting the resulting beeps and tones into real data (telemetry) [13]. On a computer, this work was carried out by a software called Dl-fldigi that can take the audio from the radio to be decoded and then sent.

## 2.5. Video Transmission for the Sabio Caldas Stratospheric Vehicle.

The OSD video module was in charge of acquiring the images in space and overlap the data provided by each one of the sensors of the environmental pollution module. Despite the fact that the navigation and video information could not be viewed from the base reception station in real time, a video transmission module was developed, which took the images and sent them using FPV technology [14]. For the vehicles' video transmitter, a cloverleaf antenna with 2.5 dBi input and 3 grams of weight and a Yagi antenna with an input of 12 dBi were used in the receiver of the base reception station, to improve the range in km of the FPV link [15]. For the radio frequency device, aspects such as: free-space path loss, receiver sensitivity, radio link calculation, and antenna characteristics (design, weight and gain) were kept in mind at all times.

## 3. RESULTS

The Sabio Caldas stratospheric probe reached a height of 30,002 meters, in which the environmental data obtained during the ascent was transmitted continuously and in real time; during the descent these were intermittent, and the last file of data received was at 2,700 meters of altitude.

## 3.1. Meteorology and Flight Projections

According to bulletin No. 509 for September the 22nd 2016, provided by third Technician Walter Martinez with a GFS model at coordinates 5.523889 - 68.686667 in Marandúa, Vichada, in the morning, stratocumulus-type cloudiness was expected in low and middle layers with a probability of drizzle in the zone between 12000z and 1400z.

In the meteorological projection carried out with the appropriate data, it was estimated that the optimal and appropriate day would be September the 22nd at 00:30 UTC, obtaining 5.8 km from the starting point to the impact point and a duration of 2 hours 45 minutes of flight. See figure 6.

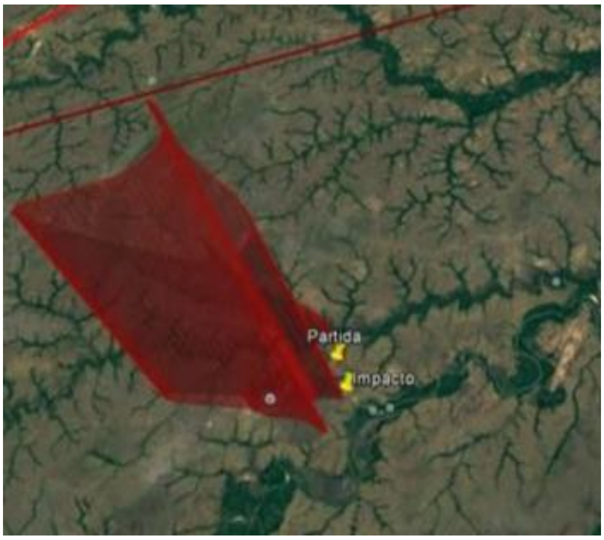



**Fig 6:** – Flight projection made with data provided by the FAC

## 3.2. Measurement of Environmental Variables

The temperature, pressure, altitude, ozone, CO2, UV and humidity measurement sensors were shown on the screen, thanks to the coupling made with the OSD video module and in the same way, transmitting to the base reception station by a module of video transference, on the other hand the data gathered was transmitted to the base reception station as flat data, by means of the telemetry module, comparing the values of each of its measurements regarding the height that the balloon was acquiring.

Thanks to the transmission by the telemetry module, it was possible to recover temperature and pressure data up to approximately 23km, the information recovered related to height is the following:

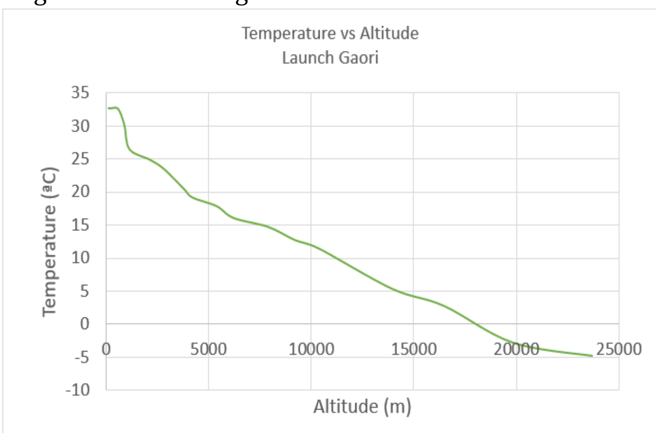



**Chart 1:** – Temperature vs altitude graph

The graphs are presented for each of the measured environmental factors, see figures 8 to 10.

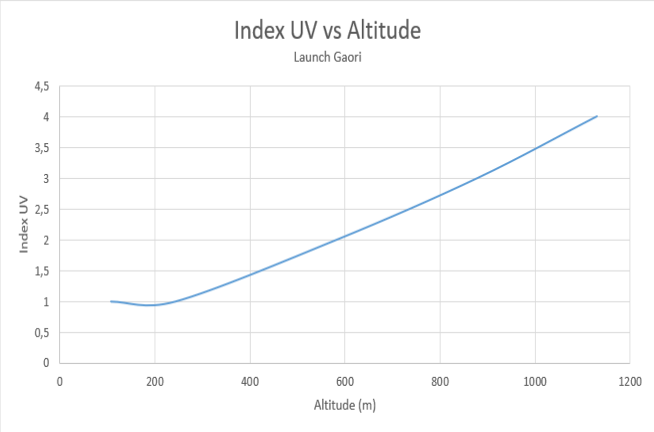



**Chart 2: -** Graph of UV index vs altitude

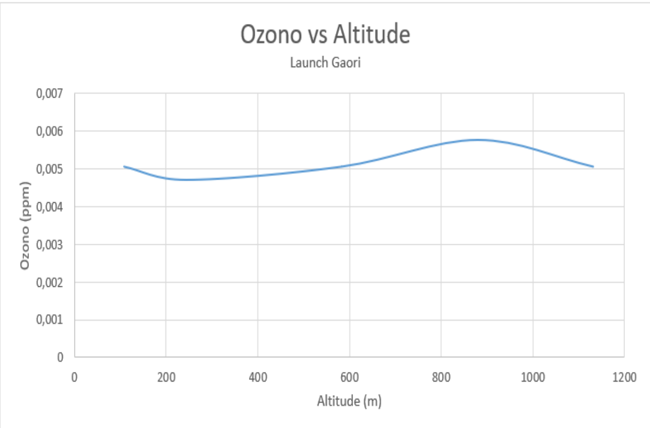



**Chart 3**: - Graph of UV ozone vs altitude

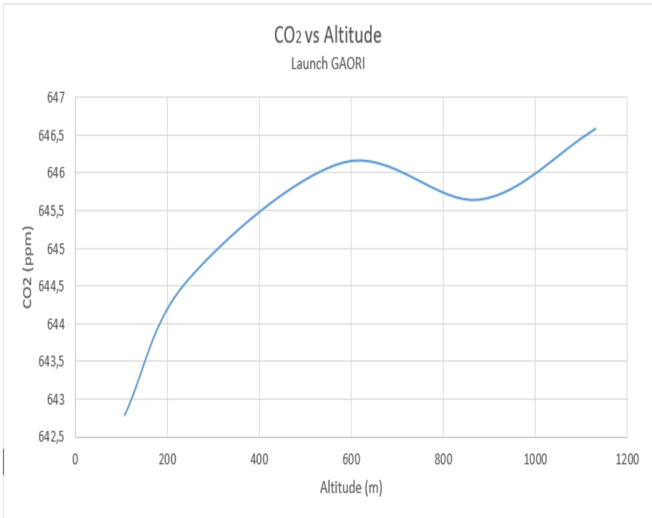



**Chart 4:** – Graph of carbon dioxide vs altitude.

### 3.3. OSD Video

Images of four cameras in different perspectives were obtained from the probe, the multiplexed display interface worked correctly with the four input signals, the data displayed from the environmental sensing module was correct as to the data sent in plain text. You can observe the images with the results of this module in figure 11.


**Fig 7**: - Photo number 1406, maximum height of the test.

### 3.4. Video streaming

The video images could not be viewed in real time on the base reception station, the module had flaws in the reception area, video images were generated throughout the trajectory, additionally it generated the transmission to the base receiver station but it was only viewed up to 2.4 km high, after this point the signal was lost and it was not possible to obtain any further results from this module.

### 3.5. Telemetry

The measurement of positioning, smart charge and temperature, using a unidirectional communication protocol was successful and the data acquired is shown in figure 12.


**Fig 8: -** Probe flight graph.

### 3.6. Energy

The module worked efficiently, it supplied 6 hours of power for all the probe modules and assisted the telemetry module in the data transmission, it was also verified that the internal temperature of the probe was in an optimal range of between 18 and 36 degrees centigrade.

The data storage about energy consumption was successfully obtained on the removable device by creating different Excel files every 30 minutes, without losing information. As shown in Table 1 and Figure 13.

**Table 1 -** Energy module temperature data.

| *Hour* | *Altitude(m)* | *Temperature(°c)* |
|---|---|---|
| *05:55* | *3917* | *36,9* |
| *06:30* | *10000* | *29,64* |
| *06:41* | *14000* | *27,05* |
| *06:51* | *16000* | *26,02* |
| *06:59* | *17000* | *25,5* |
| *07:10* | *20000* | *22,9* |
| *07:19* | *23700* | *20,9* |
| *07:27* | *27800* | *18* |
| *07:43* | *30002* | *18,9* |

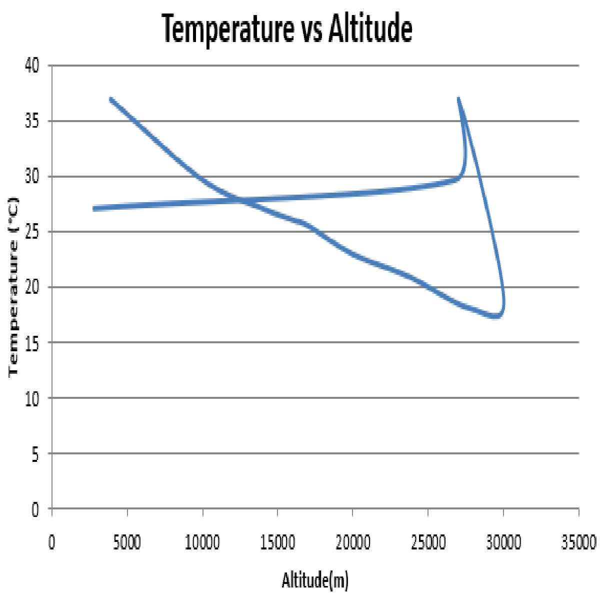



**Chart 5: -** Graphing in continuous time of the data measured in the energy module

### 4. CONCLUSIONS

It is necessary to implement a navigation system, since it is possible that there are bodies of water in the impact zone and the stratospheric vehicle could not be recovered.

The commercial geo-referencing system SPOT maintained communication until 6,800 meters, since then communication was lost. Therefore, it is necessary to implement a reset of the height value to continue with the latitude transmission.

The sensors must be isolated from each other, because there are internal and external factors that influence the data measured by each one of the devices and a greater error range could be achieved in each measurement if this is not done.

Field effect sensors should be used because they have a greater operational range and their precision is greater than doing them with 1Ω resistors, since they do not present heating or power wasting, and it is better to implement commercial buck-type switching sources. Since they present better weight and size conditions for aerospace projects.

Data transmission through communication with i2c was executed in a simpler way because the devices that used this communication were connected to the same clock (scl) and data (sda) lines.

It is advisable to use OpenCV and other necessary libraries within a virtual environment, the last mentioned within the operative system, in this virtual environment you can install all the required files without affecting other utility programs in the operative system, otherwise, make sure to install all the files necessary for the application, before compiling and launching the project.

A good power supply is necessary, so that the Raspberry Pi does not restart due to a lack of electrical current, it is recommended to use a 5 volt and 1- or 2-amp adapter for a proper operation.

Through the investigation, two fundamental devices for reception were found, such as receiving radios and scanner receivers, capable of receiving in SSB, AM, and FM. The effective radio modulation for this type of transmission is SSB.

With the Linux operating system, it is concluded that this system is a great integrator to work with Python and C, essential for coding, obtaining and transmitting data.

The synchronization time for the GPS depends on where it is placed, because it needs at least three linked satellites to provide the information that sends the coordinates, concluding that it has between 2 and 5 minutes for its respective link.

It was found that even though it is transmitted on a specific frequency of 434.250MHz. The reception has a small margin of error of 1% when receiving in a frequency of 434.261MHz.


## Acknowledgements

We thank the DIGITI research group and the Francisco Jose de Caldas District University for allowing us to develop this project with them, where we learned a lot and had great experiences for the future, we would also like to thank the CIDC of the university and the OTRI Bogotá for supporting us in the development and financing of this project, to the FAC for lending us their facilities to carry out tests and to the follow-up of them as well, for providing us with their support in carrying out this investigation. And finally, to our coworkers Lina Uyasaba, Daniel Roa, Carlos Rodríguez, Víctor Carvajal, Carlos Hernández, Jonathan Cubides, Andrea Giraldo, Yamit Ruiz, Giovanni Ramírez, Hans Montañez, Brigette Torres and Yuliana Ruiz, who worked with arduous passion and dedication in this project.

## REFERENCES

1. M. C. C. Castillo and M. A. Jordán, Meteorología y clima. 1999.
2. J. C. Inzunza Bustos, Meteorologia descriptiva., 1st ed. Santiago de Chile: Universitaria, 2019.
3. B. Malavé R, "FORO CLIMÁTICO NACIONAL NAPO-TENA," 2014.
4. M. jose Rivas Martinez, Gestión térmica de sistemas espaciales. Madrid: Fundacion Madrid Para el Conocimiento, 2008.
5. Sunrom Electronics / Technologies, "DC-DC Step Down 3A [4498]," 2004. https://www.sunrom.com/p/dc-dc-step-down-3a (accessed Jul. 25, 2020).
6. Bosh Sensortec, "BMP180 digital pressure sensor," no. April. p. 28, 2013, [Online]. Available: https://www.sparkfun.com/datasheets/Components/General/BST-BMP085-DS000-05.pdf.
7. Silicon Laboratories, "Si1145/46/47 PROXIMITY/UV/AMBIENT LIGHT SENSOR IC WITH I2C INTERFACE," Communication. 2014.
8. Huanwei Electronics, "MQ-135 Gas Sensor," vol. 1. pp. 1–3, 2014.
9. Aosong(Guangzhou) Electronics, "Digital relative humidity & temerature sensor AM2302/DHT22." pp. 1–5.
10. R. Velasco, "Cómo usar Omxplayer para ver películas en alta definición (HD)," Mar. 28, 2014. https://www.redeszone.net/raspberry-pi/como-usar-omxplayer-para-ver-peliculas-en-alta-definicion-hd/ (accessed Jul. 25, 2020).
11. OpenCV, "OpenCV," 2013. https://docs.opencv.org/master/d0/de3/tutorial_py_intro.html (accessed Jul. 25, 2020).
12. M. R. Garcia Patiño and D. A. Suárez Fajardo, "MÓDULO DE TELEMETRÍA INALÁMBRICO PARA EL MONITOREO DE SEÑALES DE PRESIÓN, TEMPERATURA Y NIVEL," UNIVERSIDAD PONTIFICIA BOLIVARIANA, 2008.
13. J. M. Nocedal de la Garza, "RF Jamming, capítulo 1. Conceptos de Radiofrecuencia," Universidad de las Americas de puebla, 2006.
14. S. Landeros Ayala and S. Chávez Cárdenas, "Análisis de la eficiencia de los estándares de transmisión de televisión digital por satélite en las bandas Ku y Ka," Ing. Investig. y Tecnol., vol. 14, no. 3, pp. 335–353, 2013.
15. J. Gómez Paredes, L. Barrero Páez, and R. Celelita, "Diseño de Antenas Yagi Uda Usando Algoritmos Genéticos," Ciencia, Investig. Acad. y Desarro., vol. 8, no. 2, pp. 19–24, 2003, doi: 10.14483/23448393.2687. https://docs.opencv.org/master/d0/de3/tutorial_py_intro.html