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NPS Terahertz project: IR HAB flight testing and integration

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THESIS

NPS TERAHERTZ PROJECT: IR HAB FLIGHT TESTING AND INTEGRATION

by

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March 2018

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Terahertz (THz) technology has become very attractive for space purposes. In this context, Department of Defense (DoD)–Space recently started to sponsor the THz Project at NPS to develop this technology for future space applications. The goal of this project is to develop a prototype THz imager that could be flown in space. Given the proposed THz architectures, the infrared (IR) imager is an appropriate first step in that direction. Therefore, this study is a relevant starting point for the THz Project at NPS since it shows the results of experiments using an IR camera integrated on high-altitude balloon (HAB) flights. The objective of this thesis is to study the integration concerns in order to evaluate possibilities and suggest appropriate configurations. This study provided relevant knowledge about a Raspberry Pi–controlled command and data handling board with a radio and an Electrical Power System for the main bus, designed 3D printed pieces, developed interfaces between cameras and boards, assembled and disassembled structures, managed weight / power / data budgets, and accomplished the launch and recovery operations. The recommendations at the end of this thesis indicate that better configurations should be adopted for the next stages of the project.

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NPS TERAHERTZ PROJECT: IR HAB FLIGHT TESTING AND INTEGRATION

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requirements for the degree of

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ABSTRACT

Terahertz (THz) technology has become very attractive for space purposes. In this context, Department of Defense (DoD)–Space recently started to sponsor the THz Project at NPS to develop this technology for future space applications. The goal of this project is to develop a prototype THz imager that could be flown in space. Given the proposed THz architectures, the infrared (IR) imager is an appropriate first step in that direction. Therefore, this study is a relevant starting point for the THz Project at NPS since it shows the results of experiments using an IR camera integrated on high-altitude balloon (HAB) flights. The objective of this thesis is to study the integration concerns in order to evaluate possibilities and suggest appropriate configurations. This study provided relevant knowledge about a Raspberry Pi–controlled command and data handling board with a radio and an Electrical Power System for the main bus, designed 3D printed pieces, developed interfaces between cameras and boards, assembled and disassembled structures, managed weight / power / data budgets, and accomplished the launch and recovery operations. The recommendations at the end of this thesis indicate that better configurations should be adopted for the next stages of the project.

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LIST OF ACRONYMS AND ABBREVIATIONS

C&DH	Command & data handling
CAD	Computer-aided design and drafting
CMOS	complementary metal-oxide semiconductor
EPS	Electrical power system
FAA	Federal Aviation Administration
FPA	Focal plane array
FOV	Field of view
GPS	Global Position System
GS	Ground station
GSSAP	Geosynchronous Space Situational Awareness Program
HAB	High-altitude balloon
IR	Infrared
MEMS	Micro-electrical-mechanical systems
SSL	Small Satellite Laboratory
THz	Terahertz
TVAC	Temperature and Vacuum Chamber

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I really thank you all!!

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I. INTRODUCTION

A. HISTORICAL BACKGROUND

The terahertz (THz) radiation is a small window of the electromagnetic spectrum located between the microwaves and the infrared frequency ranges, as we can see in Figure 1. These waves are suited for many applications such as medical imaging, security screening, and the subject of this work, space science [1].

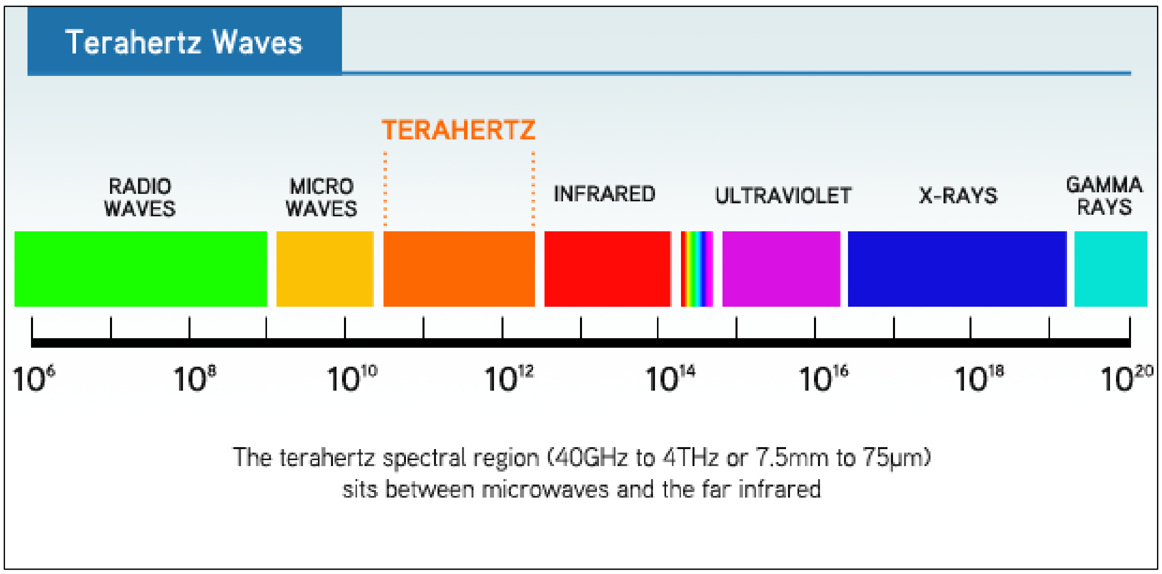

Figure 1. Cut on the electromagnetic spectrum showing THz window. Source: [2].

The number of orbiting fragments is increasing rapidly as a result of more than six decades of space exploration [3]. These fragments are called space debris. There is an effort from the space community to prevent the growth of this number, but it still increasing as more and more satellites are deployed.

Nowadays, space debris detection is based on ground radar networks and telescopes, which are very restrictive since only large objects can be detected. Besides, they are really expensive and require complex technologies to be developed. An example that corroborates this statement is the Lockheed Martin contract to develop a "space fence" based on a S-band radar ground network to detect low orbit objects. It was awarded in 2014 with nearly $1 billion and the company expects to spend over $1.6 billion until the end of 2018 when the system is supposed to reach initial operational capability.

The Geosynchronous Space Situational Awareness Program (GSSAP) indicates that every satellite should incorporate a device able to detect colder objects. This detection system can improve the knowledge about space objects orbiting Earth. This should be an efficient and cost-effective way to improve the information about new objects and check/ correct the trajectory of known objects comparing to ground systems, due to size and complexity. However, the detection of colder objects in space requires sensors using longer wavelengths than conventional infrared (IR). This task could be performed by sensors in the THz band, which have not been fully utilized due to the lack of sensitive detectors.

Driven by the current needs and sponsored by DoD-Space, researchers at the Naval Postgraduate School (NPS) started in 2015 to study the THz region and technologies associated. The objective in the beginning was to develop a highly sensitive and uncooled focal plane array (FPA). In 2016, using Micro-Electrical-Mechanical Systems (MEMS) technology and metamaterial absorbers, THz FPAs exhibiting nearly 100% absorption in two different frequencies, 3.8 and 4.7 THz, were fabricated [4]. This first design, as shown in Figure 2(a), was based on bi-material detectors, where a metamaterial structure is used to convert incoming THz radiation to heat that deforms bi-material legs [4]. The sensor's deformation [5], which is proportional to the absorbed THz radiation, is translated into an image by an optical readout (Figure 2(c)).

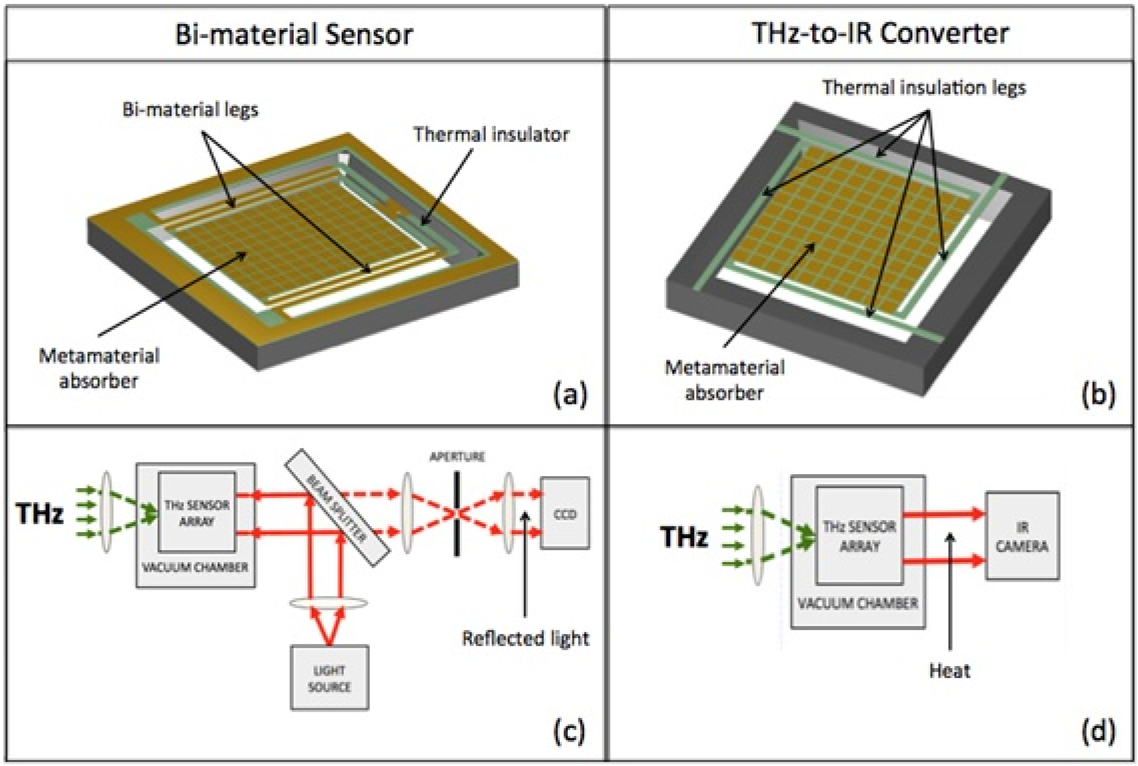

Figure 2. Schematic representation of bi-material sensor and THz-to-IR converter. Adapted from [4].

In 2017, a new configuration started to be investigated based on the expertise obtained to date. The alternative design involves a readout based on the heat generated by the THz absorption using an IR camera. When THz radiation is absorbed by the metamaterial, it is converted into heat [6], which is radiated by the back side of the sensor and collected by any commercial IR camera (Figure 2(d)). The THz-to-IR converter scheme (Figure 2(b)) is particularly interesting because it can be designed as a plug-in attachment to any IR camera already used in space applications.

As part of the ongoing project, a full THz-to-IR imaging system is under development to be integrated in a CubeSat for a potential space flight in 2019/2020. The initial task of the NPS THz Project is to understand the challenges of integrating an IR camera in a small spacecraft as well as to test the camera operation / limitations in near-space (region located over 25 km from Earth). In this context, High-Altitude Balloons

(HAB) experiment flights are the most attractive mean to start, since we can test parts of the THz imager using low-cost flights.

B. OBJECTIVE

Based on the macro objectives of the THz FPA project and applying deductive reasoning, the objective of this thesis work was to study the integration of an IR camera to a HAB payload, as well as to understand the camera operation / limitations during HAB experiment flights.

C. RESEARCH QUESTIONS AND HYPOTHESIS

The following questions were used to guide this research: How can we integrate an IR camera in a HAB payload in order to obtain images from near-space? What are the challenges to manage the interfaces between this device and the HAB payload?

The hypothesis that flagged this study was: It is possible to integrate an IR camera in a payload and obtain IR images during HAB flights. At the end of this work, this hypothesis should be revisited in order to validate the proposed statement.

D. METHODOLOGY

The research method used in this work was based on experimentation. Two different experiments (HAB experiment flights) with similar configurations were performed to obtain the results needed. Our strategy was to evaluate the results and propose appropriate solutions in order to improve the next steps in the development of the THz FPA for space applications.

E. ORGANIZATION OF STUDY

To provide a big picture of the experiment, Chapter II basically defines the HAB payload design to be used for both flights. The basic characteristics of the HAB payload components, the configuration chose, the operation steps and previous flights are described. Chapter III describes the components in details and their interactions. Chapter IV details the first HAB experiment flight, its problems and the proposed solutions to them. In Chapter V, the results and lessons learned from this flight are discussed.

Chapter VI describes the second HAB experiment flight in detail, problems and the proposed solutions to them. In Chapter VII the results and lessons learned from the second flight are presented and discussed. Chapter VIII highlights the most important aspects for the thesis and presents the suggestions for future HAB flights with this particular payload or a similar one.

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II. HAB EXPERIMENT DESIGN

A. HIGH ALTITUDE BALLOON

High-Altitude Balloons are basically weather balloons that can reach altitudes up to 120,000 ft. These balloons are usually made of a highly flexible latex material and filled with a gas like helium or hydrogen [7]. The buoyant force of the gas generates the required lift to carry on specific experiments. Therefore, they are used as a platform to perform all sort of experiments that need to be tested at the upper atmosphere where the conditions are very similar to space.

Gas balloons have been used as an efficient lift force since the 18th century. Today, just for weather measurements, people estimate that more than 75,000 balloons are launched per year in the United States [8]. Nowadays, due to the low cost, high-altitude ballooning has become a popular hobby and educational tool, and the estimated number is probably only part of the total number of launched balloons each year.

B. HAB EXPERIMENT FLIGHT

High-altitude balloon experimental flights, or only HAB flights as they will be called from now on, are a convenient way to replicate the satellite design process in a reduced scale and condensed timeline, resulting in a low-cost alternative for validating concepts and procedures to be used for larger spacecraft.

The balloon is used to carry a payload module, or only HAB payload as it will be called, and take it to the desired altitude. Almost all sub-systems are included in a small and simple structure (the HAB payload), usually a 2U or 3U (10x10x20 or 10x10x30 cm dimensions) based on the CubeSat form factor. The HAB payload can be divided in two distinct pieces: the bus, or main bus as it will be called from now on, and the experiment payload, or only main payload as it will be called from now on. They are designed with all the major sub-systems, including thermal control, power supply, telemetry, GPS, imaging and basic structures. The intention is to replicate the functionality of each sub-system in small scale and use the balloon to launch it into near-space, in order to validate proposed concepts. As flown previously in NPS's Small Satellite Laboratory (SSL), we chose the configuration described in Figure 3 to acquire the desired images.

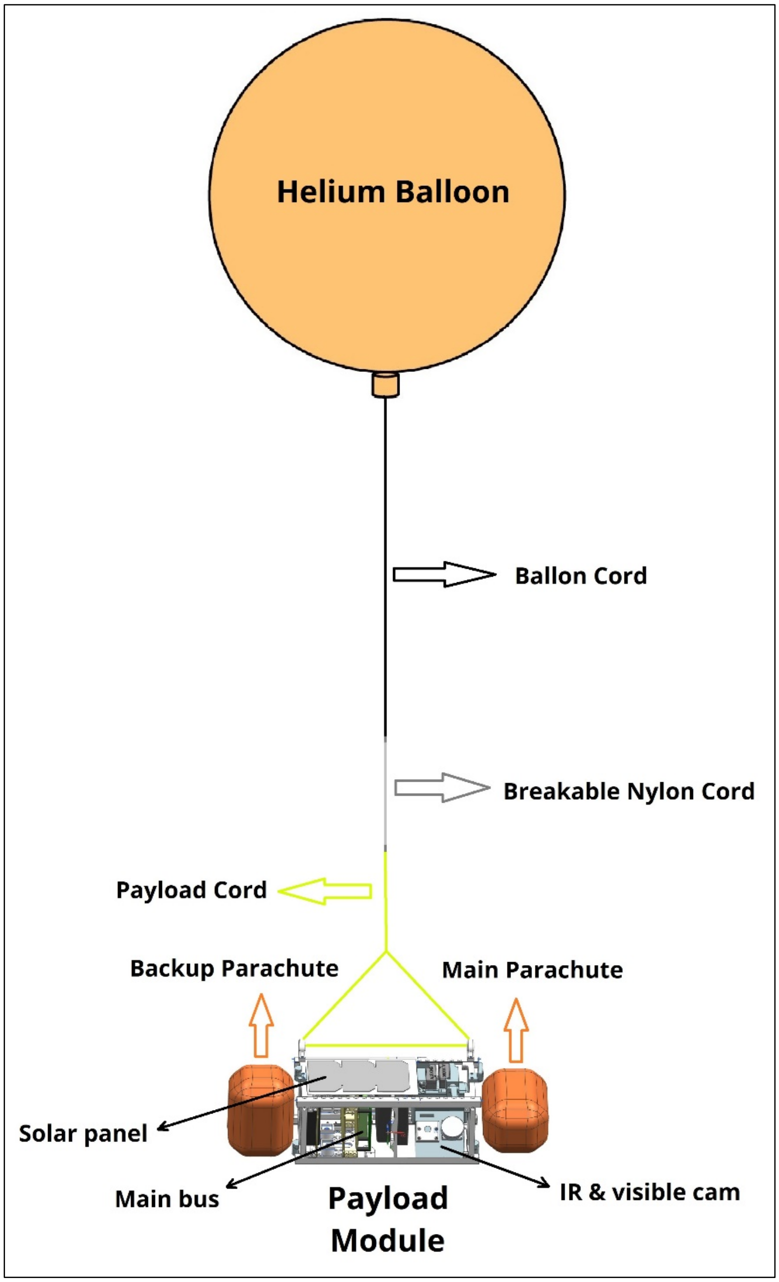

Figure 3. Configuration of the HAB flight for the THz Project

C. OPERATION

In order to perform a successful HAB flight, a complex operation needs to be planned. This operation is comprised of many steps sequenced in time as shown on Figure 4.

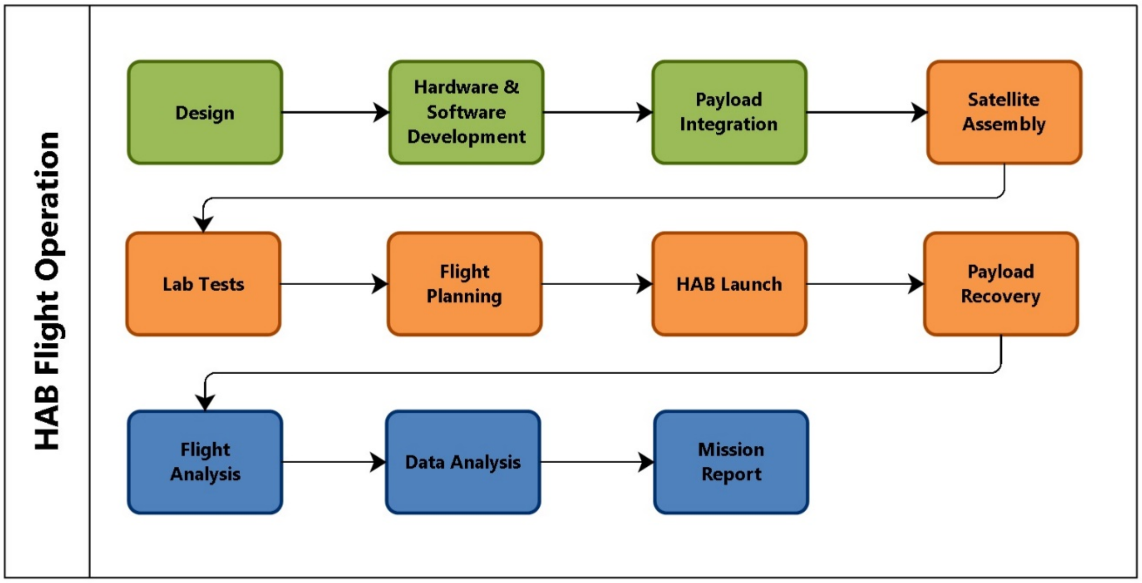

Figure 4. HAB flight operation block diagram

The design is the first phase, where the appropriate configuration for the mission is chosen. Hardware and software required for that configuration have to be listed, purchased, or developed. Next step is to integrate all components considering relevant parameters like power, weight and data storage available. Mounts, cables, connections, and all sort of components are often designed and customized at that phase. When the components are ready to be installed, the HAB payload can be assembled. Another important phase for the operation is the Lab Testing. The payload must be tested and approved on many tests to ensure the mission can be accomplished.

After establishing the basic parameters for the flight such as weight, target altitude, launch site, the predicted flight route can be determined. Based on the predicted route the field operations can be planned. Having the launching and landing sites defined, the HAB flight is ready to be launched. The HAB flight launch is performed from the planned point and the balloon will fly until the burst level or a desired level (commanded release). After the balloon detachment, the payload needs to be recovered for analysis. The chase and recover operation is performed by one or more groups that often have telemetry (GPS position) information and control of balloon and parachute release. Recovery Parachutes are used to avoid a hard landing and the destruction of the HAB payload.

The last few steps are devoted to the analysis. It is crucial to analyze the events that happened in the operation in order to point out the lessons learned and improve the following flights. The data analysis is the goal of the mission. We have to analyze all data obtained and generate our conclusions, which should be written as a mission report.

D. THE IR HAB FLIGHT

The main goal of the HAB flight for the NPS Terahertz (THz) Project is to obtain IR images from near-space to support future sensor development for space applications. In order to achieve this objective, it was proposed to launch a HAB payload equipped with two cameras with different capabilities. The first camera is a FLIR (forward looking infrared) Boson, which is a commercial IR camera looking at the horizon. The second is a pinhole CMOS (complementary metal-oxide semiconductor) camera that provides images of the IR scene, but in the visible range. This configuration allows a comparison between both types of images and simplifies the analysis after the flight. Another CMOS camera is looking at the balloon to record its behavior during the flight. Using a flight-proven main bus and the configuration described previously, a HAB flight mission was proposed to fly as a part of a Directed Study (SS3900) managed by NPS SSL and NPS Physics Department. This first flight happened on December 18, 2017, as shown in Figure 5.

In the context of the THz sensor for space applications development, it is important to understand the behavior of some components, such as the IR camera, to be integrated with the THz focal plane array. It was decided that the first flight would be dedicated to obtain data from the FLIR Boson camera, the key component of the proposed THz imager. We chose to work with a commercial low-cost IR camera due to the fact that more sophisticated ones would be very expensive to be exposed to a risk mission like HAB flights. Landing is probably the most sensitive step since a hard land can damage the whole HAB payload. Low-cost IR cameras have standard interfaces and are easy to replace.

Figure 5. December 18, 2017, IR HAB flight

E. PREVIOUS FLIGHTS

For this project, the NPS SSL experience was very relevant to obtain the expected results. Since 2011, the NPS SSL has performed several HAB flight projects and built expertise in this type of operation. The specialists and their skills were crucial to perform the adaptations required during the development process. Considering basically only few modifications, the main bus used for our project was very similar from the last two flights conducted by the Lab and it ended up being very reliable. Lessons from the flights performed by the summer interns in August 2017 and by the NPS space students in September 2017 were instrumental for the design and planning this project.

F. BASIC COMPONENTS

Based on the previous flights and the desired results, we were able to brainstorm the basic components required for the project (Figure 6). The main concept of the architecture chosen was to give preference to use flight-proven structures and electronic components in order to reduce the risk of failure during the flight. The basic components chosen were: Cameras (one IR and two visible ones), small single-board computers / electronics components (main bus), 3D printed structures, parachutes (main and backup ones), GPS and SPOT tracker, solar panels, and telemetry system (MHX920 radio and antenna). All main components will be deeper explored later on the next chapter.

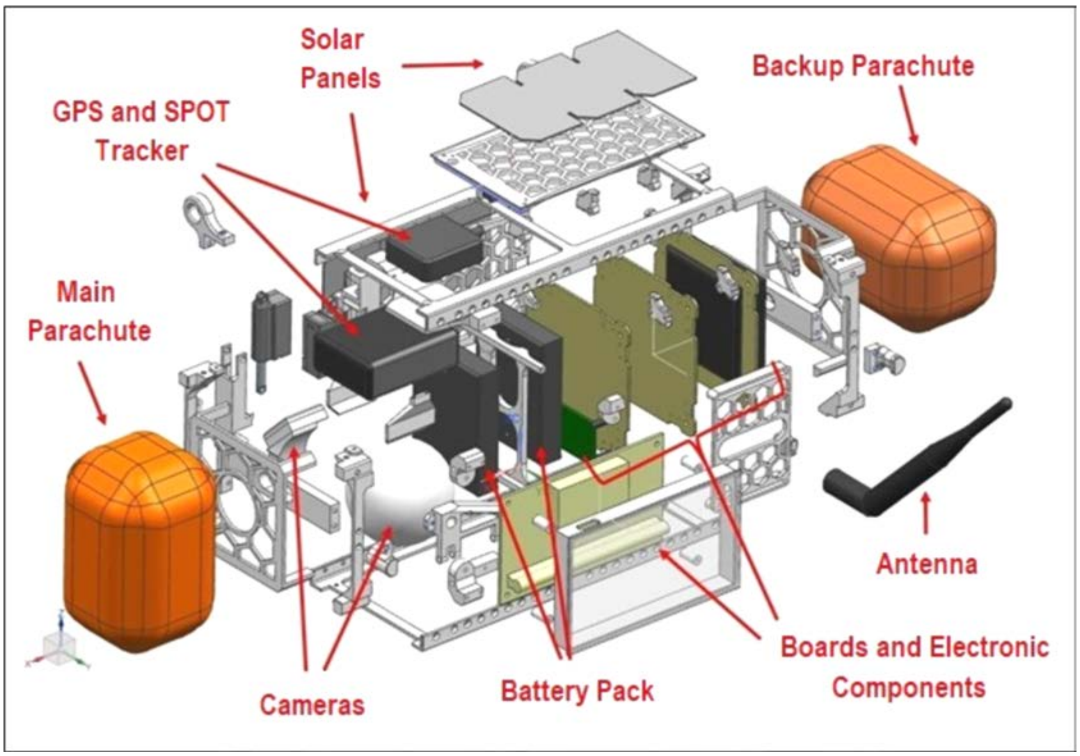

Figure 6. HAB payload basic components. Adapted from [9].

III. HAB FLIGHT COMPONENTS

A. IR CAMERA

The infrared camera is the sensor responsible for collecting IR images in all phases of the flight. Special attention will be given to the images at the near-space. In order to meet all the mission requirements, we had to select a camera that would comply with the requirements and limitations on dimensions, weight, thermal sensitivity, effective focal length, operation temperature range, resolution, power consumption, and cost. The FLIR Boson 320 18mm (Figure 7) was selected among many commercial IR cameras available on the market.

Figure 7. FLIR Boson 320 18mm. Adapted from [10].

Table 1. IR camera specifications. Adapted from [11].

Imaging	
Sensor technology	Uncooled VOx microbolometer
Array format	320x256
Effective frame rate	<9Hz
Thermal sensitivity	<40 mK
NUC	Factory calibrated
Field of view	12° HFOV
Solar protection	Integral
Electrical	
Input voltage	3.3V
Power dissipation	<580 mW
Video channels	CMOS or USB2
Control channels	UART or USB
Peripheral channels	I2C, SPI, SDIO
Mechanical	
Size	21 x 21 x 11 mm
Weight	7.5g
Environmental	
Operating temp.	-40C to 80C
Shock	1500g @ 0.4msec

Table 1 shows the key specifications of the FLIR Boson 320 18mm. It is a microbolometer camera that operates at room temperature with a thermal sensitivity less than 40mk. These characteristics in addition to the small size associate with low power consumption are very attractive for small sat operations. The camera was able to be interfaced with Raspberry Pi Zero boards as a webcam and a simple control routine was developed to assure the camera operation. The camera operated well during all the preparation phase and passed all initial integration tests (basic PYTHON commands).

In Table 2, we can see the configuration report generated by the FLIR Boson user interface application provided by the manufacturer (Boson APP), used to select the desired parameters for the IR camera. Through this APP, the configurations are loaded to the camera and saved. When the IR camera is connected to the stand-alone Raspberry Pi board, these configurations start to run automatically.

Table 2. IR camera configuration report

DDE	1.04999995231628	FFC Frames	8
Detail Headroom	12	SPNR State	FLR_ENABLE
Dampening Factor	85	Freeze State	FLR_DISABLE
Gamma	0.970000028610229	Telemetry Location	FLR_TELEMETRY_LOC_TOP
Linear Percent	20	TF State	FLR_ENABLE
Max Gain	1.37999999523163	Analog Video State	FLR_DISABLE
Outlier Cut	0	OverTemp Override State	FLR_DISABLE
Percent Per Bin	7	OverTemp Timer in Secs	10
Smoothing Factor	5000	SF Min	0.5
Entropy	FLR_ENABLE	SF Max	2.5
FFC Frame Threshold	1200	DF Min	0.800000011920929
FFC Mode	FLR_BOSON_AUTO_FFC	DF Max	1
SCNR	FLR_ENABLE	Norm Target	2.33999991416931
FFC Temp Delta	20	Delta NF	5
Gain Mode	FLR_BOSON_HIGH_GAIN	Delta Motion	300
High-To-Low Intensity Threshold	90	ThColSum	896
High-To-Low Population Threshold	20	ThPixel	64
Low-To-High Population Threshold	95	MaxCorr	60
BPR ENABLE	FLR_ENABLE	ThColSum Safe	896
Color LUT	FLR_COLORLUT_DEFAULT	ThPixel Safe	95
FFC State	FLR_ENABLE	MaxCorr Safe	90
Gain State	FLR_ENABLE		

B. RASPBERRY PI ZERO BOARD

The Raspberry Pi Zero is a small form factor single board computer and it was used for two distinct tasks on the flight. The first Pi Zero was used to control the main bus and the second to control the IR and CMOS cameras. The Pi Zero board (Figure 8) was able to communicate with numerous systems and control several parameters during flight. This device is low-cost, low power consumption, and it proved to be a powerful solution to keep all the systems working appropriately the entire flight.

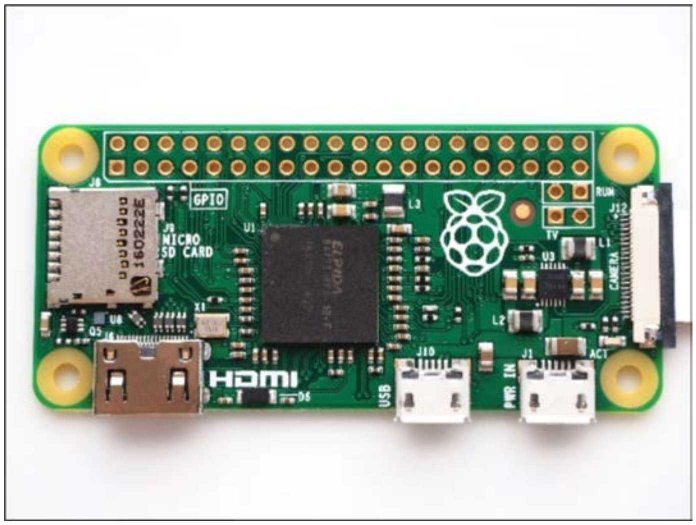

Figure 8. Raspberry Pi Zero board. Source: [12].

PYTHON was chosen as the software language used to control the Pi Zero. The Pi data storage is a micro SD card, where all the videos recorded during the mission were stored.

C. CHASSIS AND 3D PRINTED PARTS

The 2U design (two times the “1U” dimension— a CubeSat with dimensions of 10x10x10 cm) starts with a basic chassis with threated holes used to hook all components (Figure 9). This is a useful way to build the HAB payload and hold on it all pieces needed for the experiment. The chassis (frame) was 3D printed due to reliable and fast prototyping characteristics as well as light weight material.

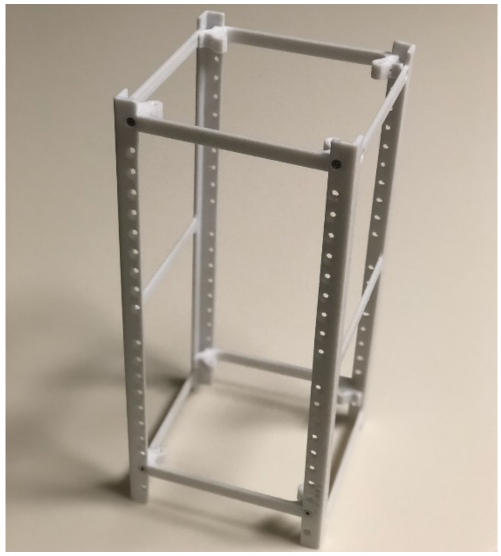

Figure 9. 2U design chassis

Although the chassis is the primary structure, several other pieces were designed and appropriately connected to the chassis. Among them, there were two pieces specially designed for this flight: the main payload mount and the stabilization fins. The first piece was used to mount the IR camera, the Raspberry Pi camera, and the Raspberry Pi Zero board (Figure 10 and 11).

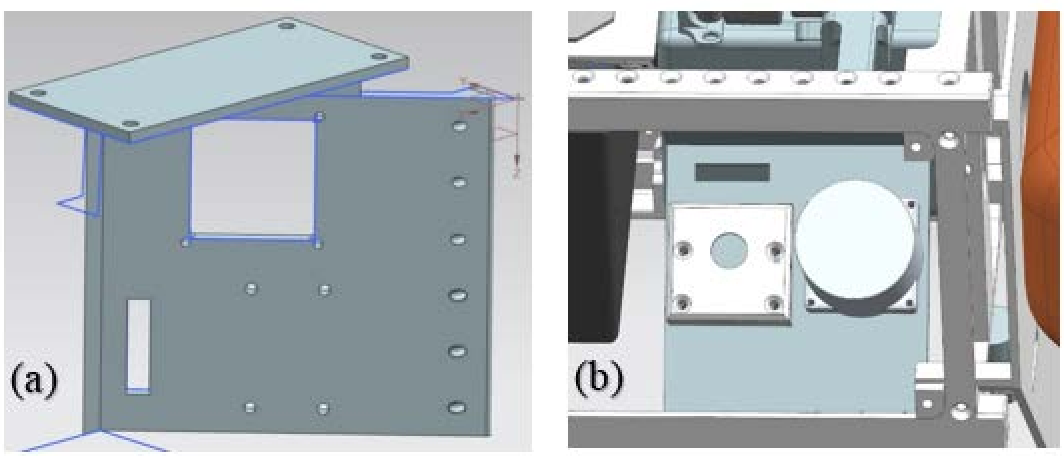

Figure 10. Two views of the main payload mount CAD model

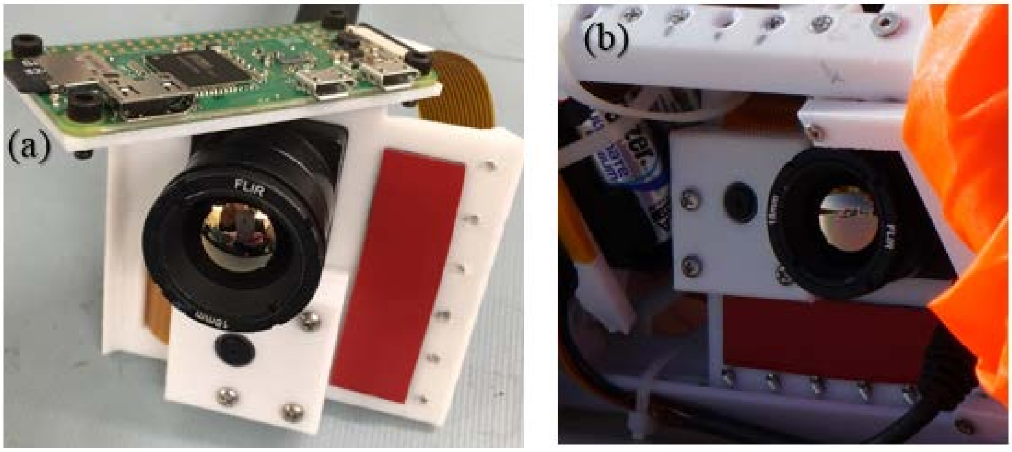

Figure 11. Two views of the main payload mount real version

The second piece was the device used to align the HAB payload with the wind during flight and provide stabilization: the body fins. The shapes of those pieces are shown in Figures 12 and 13. The selected shape was chosen among some options collected online from people that practice HAB activity as a hobby. The most successful shape was selected to be used on the experiment [13].

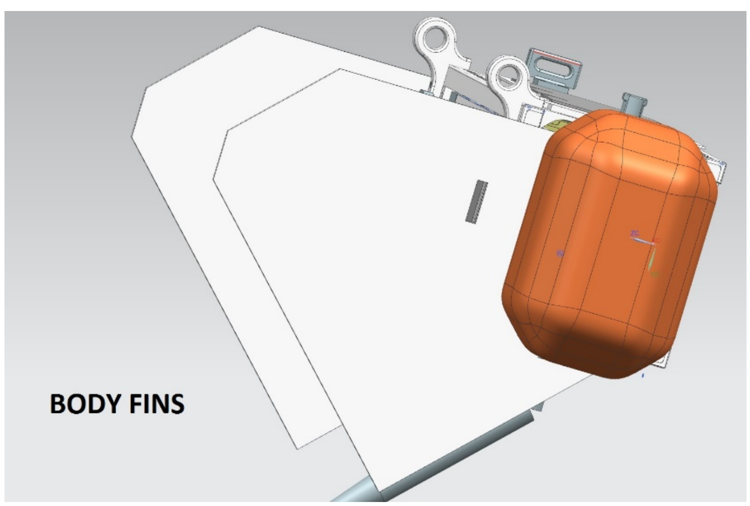

Figure 12. Body fins CAD model

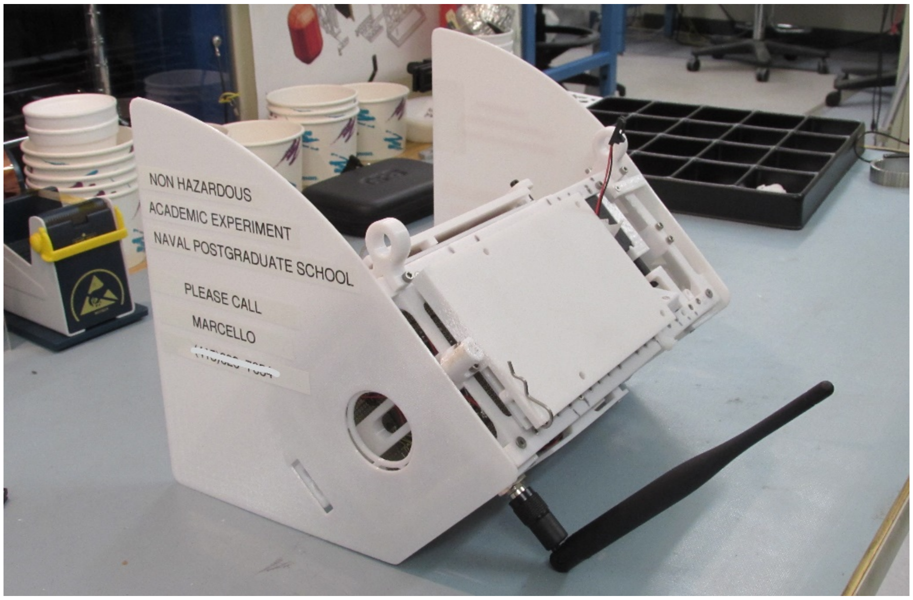

Figure 13. Body fins actual parts

D. PARACHUTES

The parachutes are responsible for decreasing the descent rate. They are also used to stabilize the HAB payload enabling better images during the descent. The parachute model used for the project was a Rocketman 4ft Standard made of rip-stop nylon that develops a descent rate of 17.83 ft/s for a generic 3.7 lbs. payload (closer to the payload designed for the experiment). The concept of operation includes a main parachute that can be released by a telemetry command and a backup parachute, automatically released at a preset altitude. They are installed at the sides of the HAB payload allowing both to deploy at distinct moments. Their positions are shown in Figures 14 and 15.

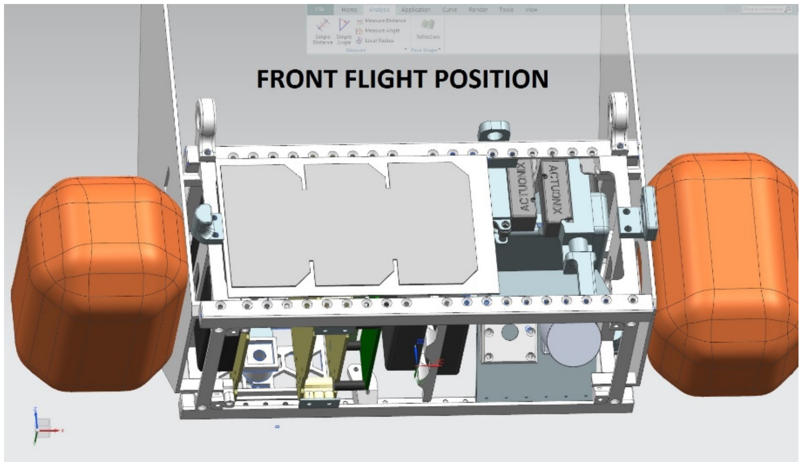

Figure 14. Parachute position CAD model

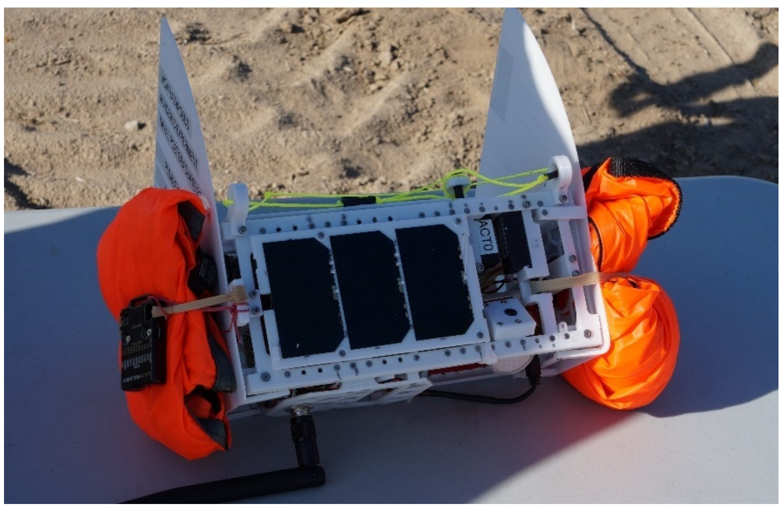

Figure 15. Parachute position actual devices

E. GPS

The GPS used on in this flight was the BYONICS GPS4 (Figure 16). It is powered by 5.0 V, 32 mA of current consumption, accuracy of 2.5 meters, RS-232 serial GPS designed for altitudes up to 84 thousand meters.

The position and altitude information are essential to the analysis of the images as well as flight monitoring and payload recovery. The main bus receives the GPS data and sends via radio to the Cosmos and Teraterm Ground System.

Figure 16. The GPS used on the HAB payload

F. SPOT TRACKER

The Spot Tracker is a commercial service comprised of a personal device attached to the HAB payload (Figure 17) that sends its location to a satellite network. To access the network, you need to register your device in order to receive a user name and password for your online account. You can access this account on the website or download a mobile APP. This system is often used as an emergency transponder for outdoor activities in areas without cellphone service. The device sends GPS coordinates to the satellite network as long it moves. The satellite relays the information to a web service that can be accessed by the mobile APP, then you have the updated position. This redundancy is very convenient, especially for the payload recovery.

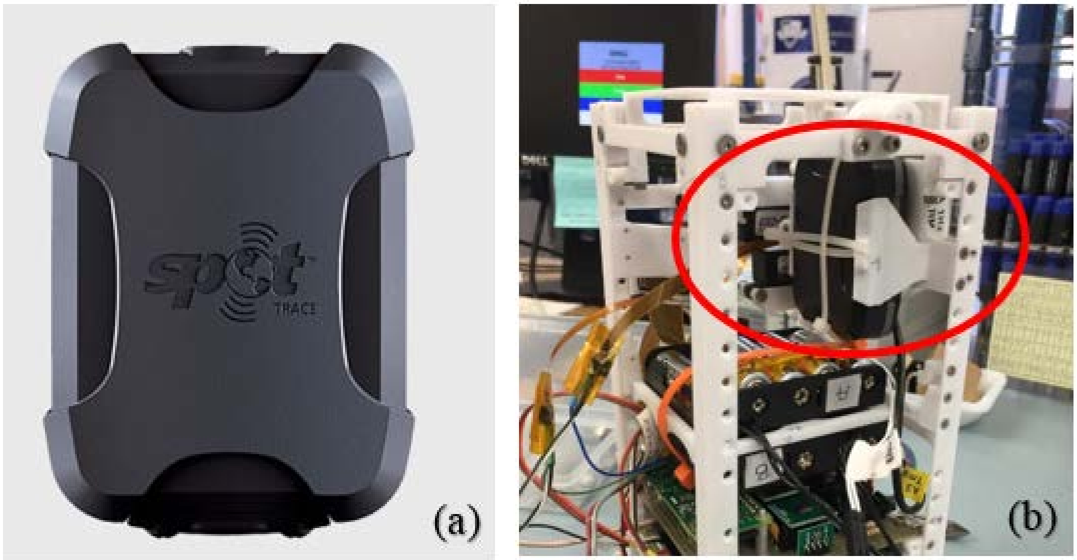

Figure 17. (a) SPOT Tracker device. Source: [14].
(b) SPOT Tracker installed on the HAB payload.

G. SOLAR PANELS

Solar panels (Figure 18) were designed for the experiment in order to help the batteries to provide the appropriate power to the HAB payload. The system is comprised of two panels with three solar cells in each one. The main bus uses both the batteries and solar cells during the flight. With this configuration we can have appropriate power supply during the flight. We used a triple-junction (InGaP / InGaAs / Ge) photovoltaic cell with monolithic diode from Emcore Corporation. Each cell has 26.6 cm^2, 28% average efficiency, 16.3 mA/ cm^2 of normalized current density, and voltage of 2.33V.

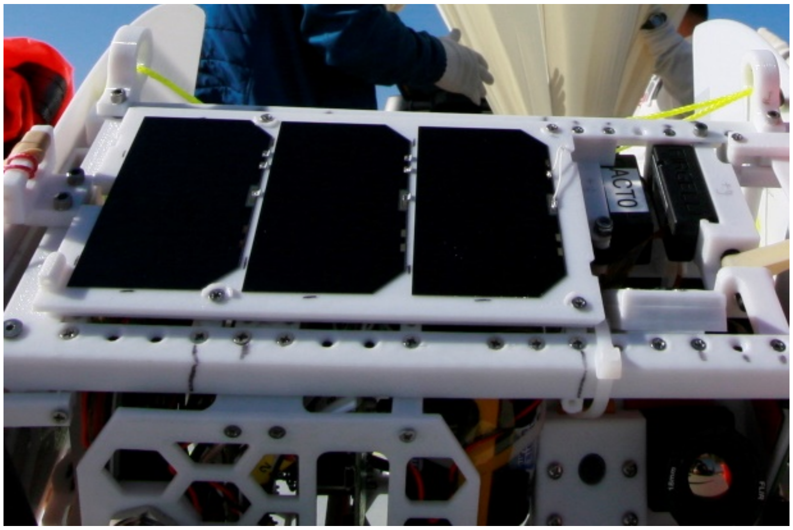

Figure 18. Solar panel on the HAB payload

H. TELEMETRY SYSTEM

This system is composed by the Spread Spectrum UHF Radio and an omnidirectional Antenna (Figure 19). The system is connected to the main bus and transmits data that can be acquired by a ground station (GS), controlled by two different applications: Cosmos and Teraterm Ground Systems. The hardware on the HAB payload and on the GS are both one Microhard System Nano n920 OEM Radio, which the specifications are shown in Figure 20. Provided by the system, several important information can be received by the GS operators remotely during flight. In addition, the telemetry system is responsible for receiving the control commands from the GS. The commands used on the flights are described on Appendix E. Information as GPS coordinates, altitude, battery temperature and voltage, solar panels voltage, CPU temperature, actuator's position (voltage), barometric pressure, remaining bytes on the main bus storage device and bus camera status (ON or OFF) are displayed by the system.

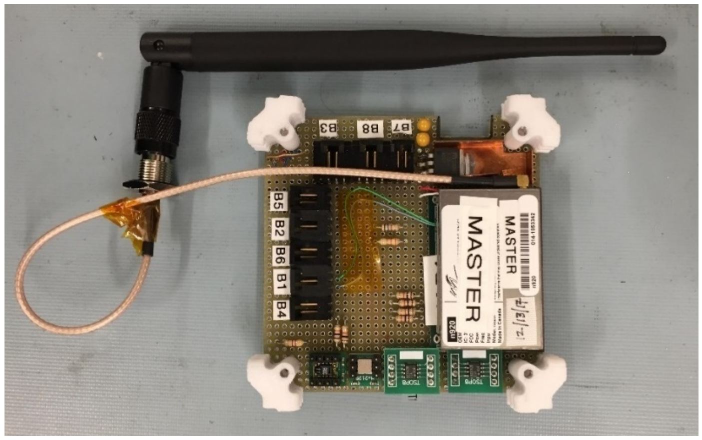

Figure 19. The telemetry antenna and the radio installed on C&DH board

Nano n920 Specifications

Frequency	902-928 MHz
Spreading Method	Frequency Hopping / DTS
Band Segments	Selectable via Freq Restriction
Forward Error Detection	Hamming BCH Golay Reed-Solomon
Error Detection	32 bits of CRC, ARQ
Encryption	Optional (see –AES option)
Range	60+ miles (100+ km)
Sensitivity n920T n920F	-100 dBm @ 10^{-4} -108 dBm @ 10^{-6}
Output Power	100mW - 1W (20-30dBm)
Serial Interface	TTL
Serial Baud Rate	- Up to 230.4 kbps asynchronous - Up to 3.2 Mbps synchronous
Link Rate	Up to 1.3824 Mbps (higher rates available, contact Microhard for details)
Operating Modes	Point-to-Point, Point-to-Multipoint, Store & Forward Repeater, Peer-to-Peer
Power Consumption (3.3V +/- 0.3V)	Sleep < 1mA Idle 20mA Rx: 140mA to 280mA Tx : 1000mA to 1500mA
(12V with Development board/Enclosed Unit)	Sleep < 1mA Rx: 50mA to 95mA Master Avg Tx/Rx: 140mA Slave Avg Tx/Rx: 110mA Tx : 300mA to 450mA
Connectors: **OEM** Antenna Data **Enclosed** Antenna Data	 MMCX 60 Pin OEM Header RP-SMA Female Bulkhead Female DB9 x2
Environmental	-40°C - +85°C (All units are fully tested over the entire temperature Range)
Weight OEM Enclosed	 Approx. 18 grams Approx. 210 grams
Dimensions OEM Enclosed	 Approx. 1.25" x 2.0" x .25" (32mm x 51mm x 6.35mm) Approx. 2.25" x 3.85" x 1.50" (57mm x 98mm x 38mm)
Approvals	FCC Part 15.247 IC RSS210

Figure 20. The specifications of the Radio Nano n920. Source: [17].

The GS is comprised of a laptop on which Cosmos and Teraterm are running, the radio, and an antenna (Figure 21). Two different applications are used, Cosmos and Teraterm Systems. The Cosmos System is more user friendly and presents the data in windows easy to interact with (Figure 22). The Teraterm System is the backup one and presents only raw data. You need to type the commands (Appendix E) in a command prompt window.

Figure 21. Radio and antenna used on the GS

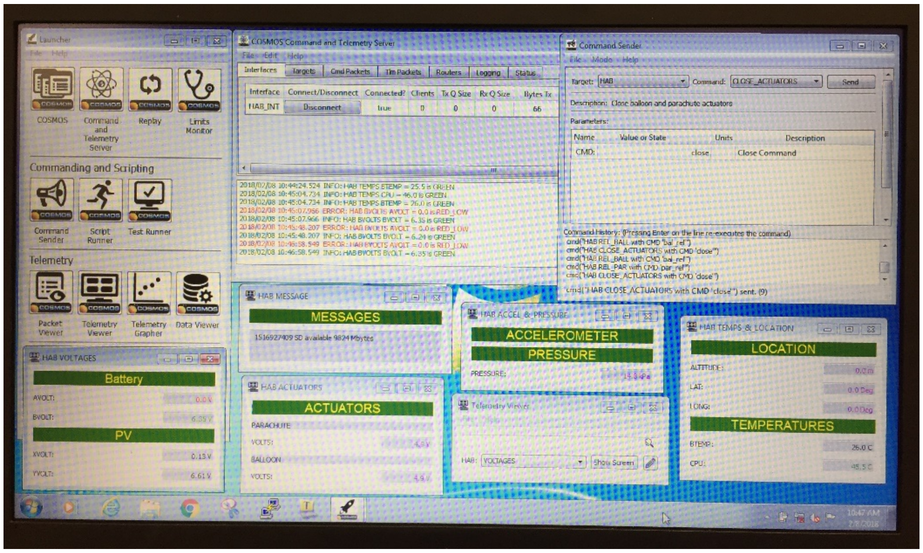

Figure 22. Photo of a Cosmos System screen

I. PRESSURE SENSOR

This sensor is located under the Command & Data Handling (C&DH) board and is responsible for the barometric pressure measure during the flight. The sensor is a MPX4115 (Figure 23) from NXP Semiconductors, with a pressure range from 1.45 to 16.75 psi and temperature range from -40 to 125ºC. The sensor sends the pressure information to the Raspberry Pi Zero board on the main bus. The telemetry system receives this information and sends to Cosmos using the downlink.

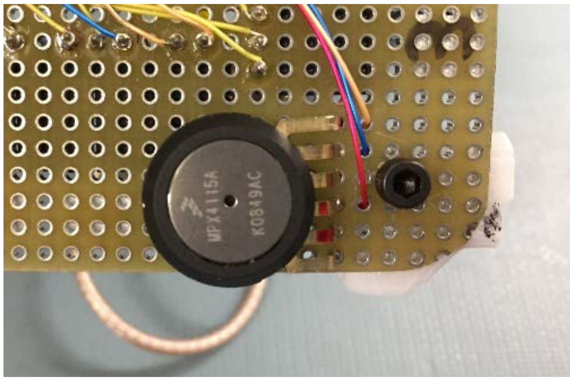

Figure 23. Pressure sensor installed under the C&DH board

J. COMPONENTS INTERACTION

A block diagram containing the interactions between the HAB payload components is shown in Figure 24. The diagram shows the HAB payload as a system and how the components are connected, how power supply is distributed, and how data is interchanged and transmitted to the environment.

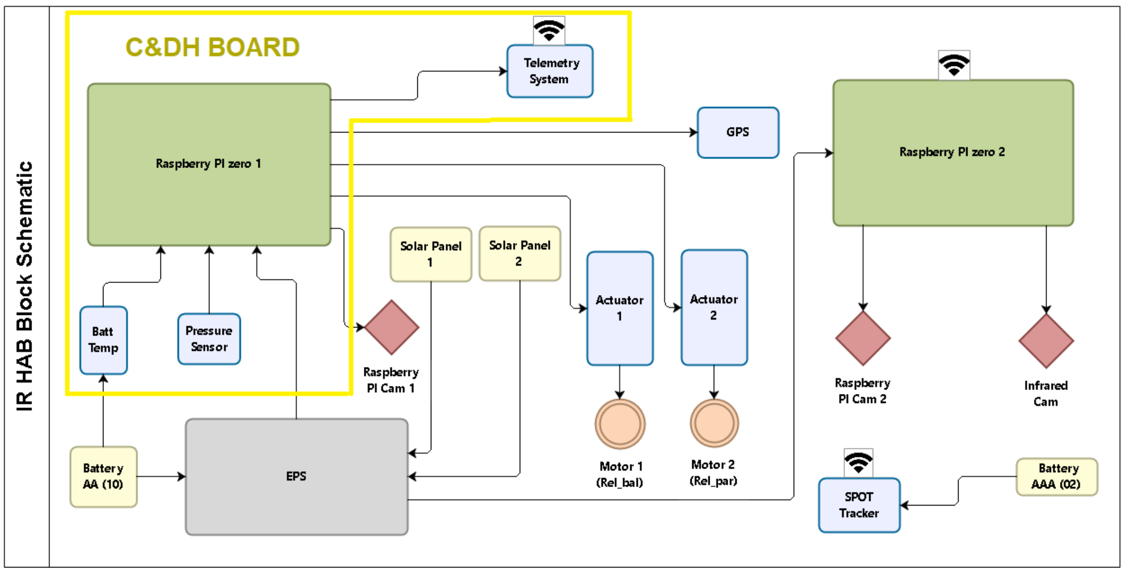

Figure 24. The IR HAB payload block diagram schematic

In the diagram, the three big boxes are the electronic boards. They are two Raspberry Pi Zero circuits (1 and 2) representing respectively the main bus and the main payload (stand-alone) connections. The third is the Electrical Power Supply (EPS), a board that is responsible of the power control management on the payload. The other components on the schematic were already described.

Figure 25 shows the inputs and outputs of the main components. As we can see from those diagrams, the Telemetry System is able to send some important information as GPS coordinates, altitude, battery temperature and voltage, solar panels voltage, CPU temperature, actuator's position (voltage), barometric pressure, remaining bytes on the main bus storage device and bus camera status (ON or OFF). That information is essential to appropriately conduct the HAB flight mission.

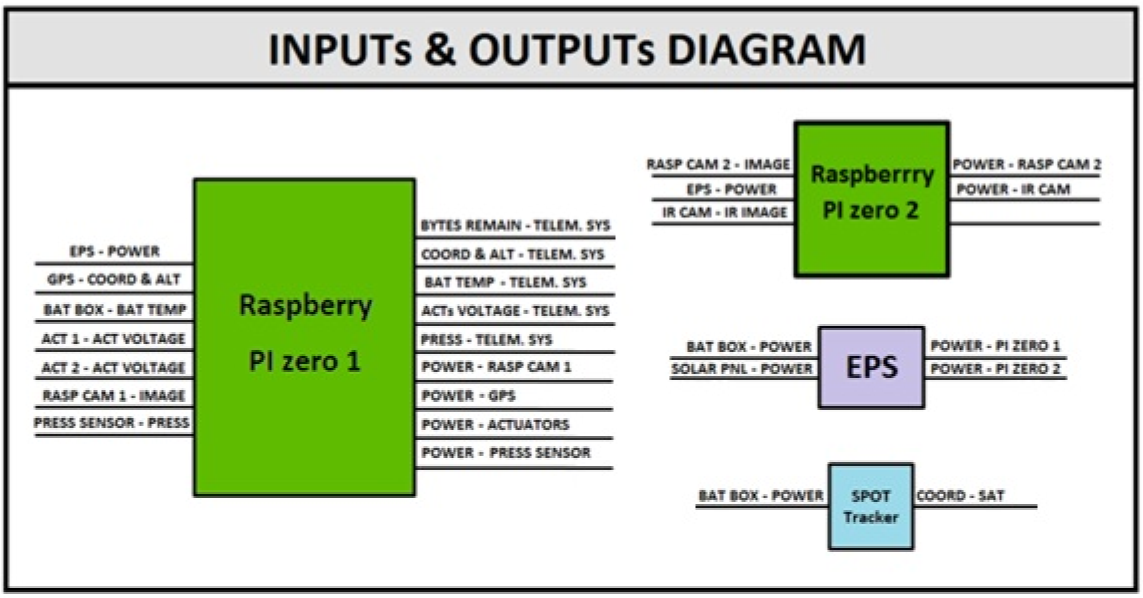

Figure 25. Inputs and outputs diagram of the HAB payload

IV. FIRST FLIGHT TIMELINE

A. FIRST WEEKS

After ordering the IR camera from a commercial company called OEM cameras, the searching phase about HAB flights started. The HAB and Rocket page from NPS Sakai Site was often the most reliable source in the early research, but a plenty of websites and online videos exploring the subject were found. Although all the information available, the real starting point of the whole planning was a team briefing including everyone involved from Physics Department and Space System Academic Group. At that moment, we proposed the architecture of the payload and the schedule for the flight. In the systems engineering point of view, we can say that this step brought the project to the railroad. The main decisions made on October 2nd (first meeting) are the following:

- Fly the same main bus used on the last HAB flight (September 8—Space Students) and similar components (structure was very well preserved);
- Use two parachutes to have a backup one and ensure a smooth descending;
- Use three cameras, two Raspberry Pi cameras on the visible range (pointing to the balloon and to the horizon) and another camera on the IR range (pointing to the horizon)—The first visible one would record the balloon behavior, the second visible would record the same IR image and allow a comparison for analysis, and the IR one would record the image from the upper atmosphere pointing to the horizon;
- Use 100,000 ft. as the aim altitude (in order to have a good information from near-space);
- Perform a Temperature and Vacuum Chamber (TVAC) test with the IR camera (to see the behavior of the IR camera in low temperature and high vacuum environment);
- Search for a stabilization mechanism to improve the quality of the images; and
- Launch the HAB flight at December 16th (having December 17th as an alternative day in case of bad weather conditions);

Among those decisions, the most challenging one for sure was the stabilization device, because there was no other device like this used on previous flights. The lead time for the IR camera order was also a problem, because initially the company were waiting for one camera component, but finally they could send the camera before the estimated time. The main payload mount was another component that should be carefully defined because the space available for it was not very large.

The first two or three weeks of work were dedicated to deal with those challenges. We were looking for all kinds of stabilization devices, most likely for HAB flights, and some good options were found. However, no one presented any warranty of success. We conclude that there were no easy solutions for the wind effect but we were able to find quite a few promising solutions that would be reasonable to test on flight. In order to get used to CAD (computer-aided design and drafting) models, especially to design the main payload mount and the stabilization device, that would have been 3D printed, a two-week training using NX 10 was very helpful. NX 10 is the CAD program often used by NPS SSL. The training was instrumental for the following steps of the project.

CAD drawings were created to show all pieces together and on the correct place. Those drawings helped the design process because we could rearrange the parts according to space available and estimate the shape of the HAB payload. Figures 26 to 28 show examples of the CAD drawings used to integrate the main payload and body fins to the HAB payload final design.

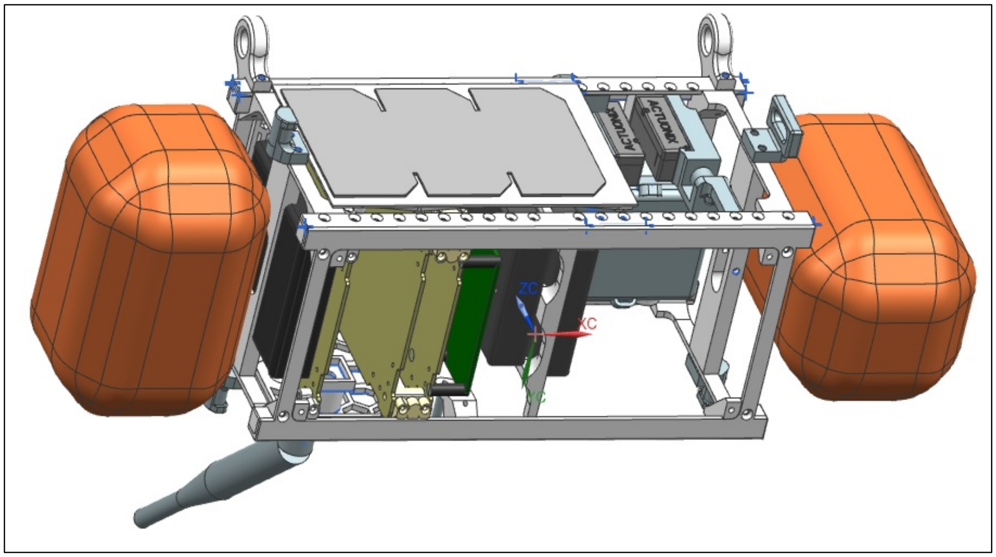

Figure 26. Main bus CAD drawing

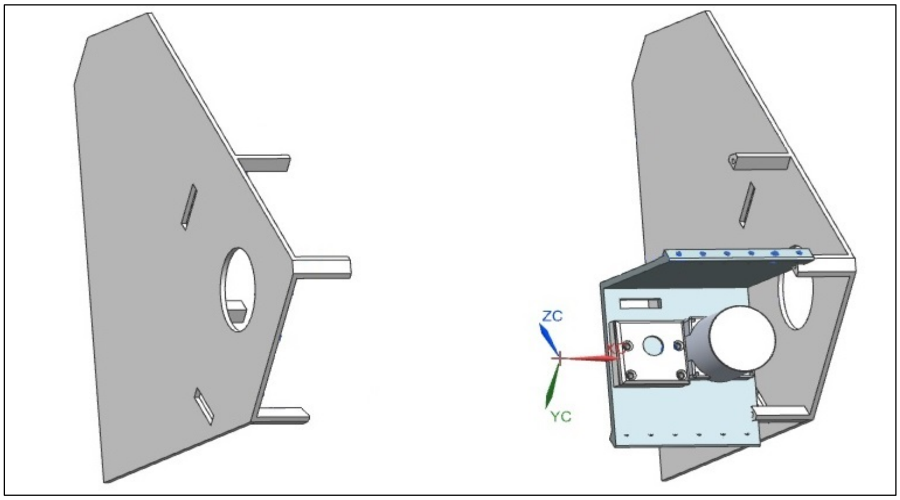

Figure 27. Main payload and body fins CAD drawing

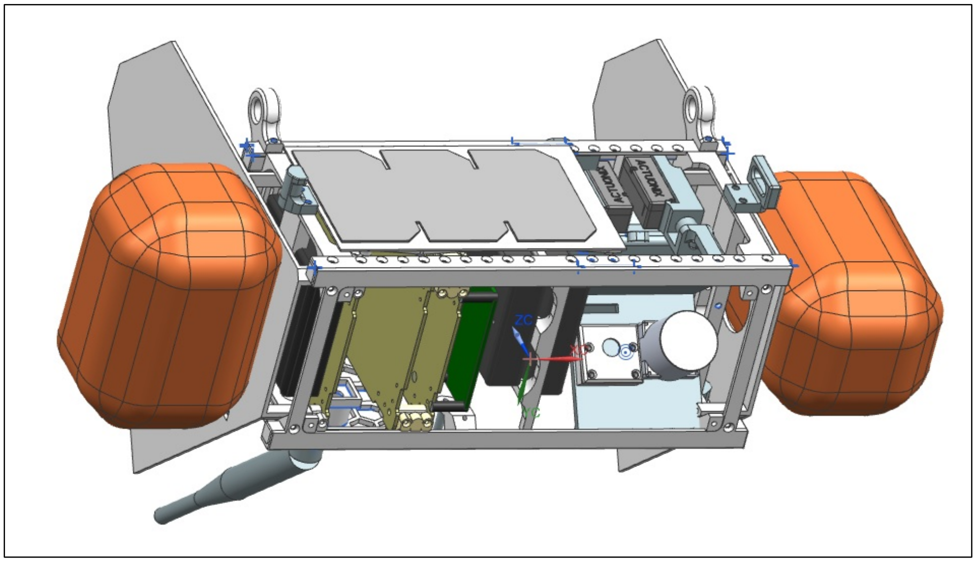

Figure 28. All components integrated on the same CAD drawing

Other tasks included the definition of budgets for the flight. The budget spreadsheets used, initially, were approximations to help guiding the HAB payload design. Substantial information, however, were obtained to lead relevant conclusions. Figures 29 to 31 show spreadsheet snapshots for power, weight and data budgets.

	A	B	C	D	E	F	G
1			**Current Drawn (mA)**	**Current over time (mAh)**	**Avg Power (mW)**	**Voltage (V)**	**Basic Conditions**
2	**Main Bus**	Chassis : 3D Printed	-		-	-	
3		(x6) Solar Cells	350			5	
4		Parachute	-		-	-	
5		Backup Parachute	-		-	-	
6		RaspBerry Pi 0	120	600	600	5	
7		RaspBerry Pi 0	120	600	600	5	Operation Time (hour)
8		Spot Tracker	-		-	-	5
9		GPS	32	160		3.3 or 5	
10		Radio	240	1200	792	3.3	
11		Battery/PowerSource					1800 mAh each
12		(10) NiMH AA					18000 mAh total
13							
14	**Sensors**	Temperature	0.0009	0.0045	0.03	3.3	
15							
16	**Camera**	IR camera	125	625		5	
17		Pi Camera 1	240	1200		5	
18		Pi Camera 2	240	1200		5	
19							
20			Total current drawn (mA)	has to be under 18000 (mAh)	Avg Power (mW)		
21	Total:		1467.0009	5585.0045	1992.03		

Figure 29. IR HAB payload power budget

	A	B	C	D	E	F	G	H
1		Name		Dimensions	Weight (g)	Not included in FAA (g)		
2	**Main Bus**	Chassis : 3D Printed		225 x 100 x 100 mm	//89.2			
3		(x6) Solar Cells	All 6		34.1			
4		Parachute	4ft #1	50 x 65 x 120 mm			110	
5		Backup Parachute	4ft #2	50 x 65 x 120 mm			110	
6		RaspBerry Pi 0		65 x 30 x 5 mm	9			
7		RaspBerry Pi 0		65 x 30 x 5 mm	9			
8		Spot Tracker		94 x 66 x 25 mm			150	
9		GPS	Byonics 5	42 x 36 x 15mm	45.5			
10		Radio	cable and antenna		120			
11		Battery	-	-	-			
12		10x Lithium AA	1.5 V nominal	14.5 x 13.7 x 50.5 mm	250			
13		EPS	mounting screws		65			
14		Copper Plate			26.8			
15								
16	**Sensors**	Temperature	Sensirion Thermistor	NA	15			
17								
18	**Camera**	IR Camera	OEM Camera 18mm	27.6 x 27.6 x 38.28 mm	36.28			
19		Pi Camera 1	1 per pi board	23.86 x 25 x 9 mm	3.4			
20		Pi Camera 2	1 per pi board	23.86 x 25 x 9 mm	3.4			
21								
22	**3D Printed**	Chassis and Mounts			544			
23								
24				**Total (g)**	1161.48	**Total (g)**	370	
25					**Required Neck Lift (g)**		1531.48	

Figure 30. IR HAB payload weight budget

	A	B	C	D	E	F
1	Category	Name	Data Feed	Operation Time	Transfer rate	Bytes of data (Mb)
2	**Payload**	Raspberry Pi 0		150	-	-
3		Raspberry Pi Camera		150	3Mb/min	450
4		IR Camera		150	40Mb/min	6000
5		SD card (32Gb)		150	-	-
6					**Remaining Bytes**	25550
7						
8	**Main Bus**	Temperature		150	-	-
9		Solar Panels (02)		150	-	-
10		Parachute (02)		150	-	-
11		Battery (10)		150	-	-
12		GPS		150	-	-
13		SPOT Tracker		150	-	-
14		Raspberry Pi 0		150	-	-
15		Raspberry Pi Camera		150	3Mb/min	450
16		SD card (8Gb)		150	-	
17					**Remaining Bytes**	7550

Figure 31. IR HAB payload data budget

Analyzing the spreadsheets, we could conclude that we had clearance in all parameters. We had appropriate power, weight, and storage data for the flight. Even though the precision of these calculations were not high, they were instrumental to obtain insights to tune the final configuration. Besides we noticed that we had room for changes during the pre-flight phase, which often happens.

We also performed initial calculations on balloon burst and estimated HAB flight route on this phase of the project. They were not precise at that moment, but as the launching time gets closer, the precision increased and we could take into consideration the predictions from the available tools. The calculators we used to obtain these predictions were the CUSF Balloon Burst Calculator and the CUSF Landing Predictor from HAB HUB website [16]. These tools use the HAB flight parameters and the forecasted wind data to calculate how the flight is going to be. But the concern is, they allow us to build the prediction for the flight date only if you are inside the previous 180 hours window before the flight. The calculations started to be more useful on the last week, when we were able to check the first real prediction for the flight time and date of the flight.

B. A COUPLE WEEKS BEFORE FLIGHT

Once the preparation phase was concluded, we felt ready to define the flight date. Trying to avoid any camera damage, we decided to perform the IR camera TVAC test after the flight, since we did not have a spare item for this one. We postponed the TVAC test to an after-flight date to be defined.

We choose December 18th as a first tentative day because it was the first day that all important participants were available. The before-flight weeks were intense and many tasks were performed. We disassembled the 2017 Directed Study Summer's HAB flight following the procedure described on their report and checked the general condition of the components. The listed procedures turned very useful for this task, even though we found some steps that could be improved. The full description of these procedures with our inclusions is on Appendix A.

Since the components were well preserved, we started the assembling procedure. Due to the limited space to work on the HAB payload, careful movements are required to avoid damage on electronic components or cables, causing extended times to accomplish small tasks. Once we had the main bus assembled, we performed basic tests to determine if all components were working well. Many pieces were not ready to install at that time like the main payload, solar panels, cables, and the stabilization fins, but most components were put together on the HAB payload without any problem.

The first problem detected in the main bus was a terminal on the EPS board (power distribution board) we noticed that was not wired. This terminal was empty (without any connection) since the 2017 Summer Intern's HAB flight. We intended to use this terminal to power on the stand-alone Raspberry Pi Zero, which was used to manage the main payload. We had to disassemble the HAB payload for the second time and fix the EPS to provide the power connection we needed.

The EPS was done very quickly and we could start the second assembling process. The process of assembling and disassembling the HAB payload was a good training and provided confidence to move forward. The most significant improvement on this procedure due to multiple interactions was the decision to use tape to hold all the exceeded cable length, bending carefully the cable to avoid broken wires. We noticed improvement on the radio signal by observing that more packages were received on the receiver radio from the HAB payload. In addition, it was easier to access the main bus components (more space to work), which helped with the assembling of the other components and decreased the risk of damage. We can easily see the difference in Figure 32, where the right image is the improvement described.

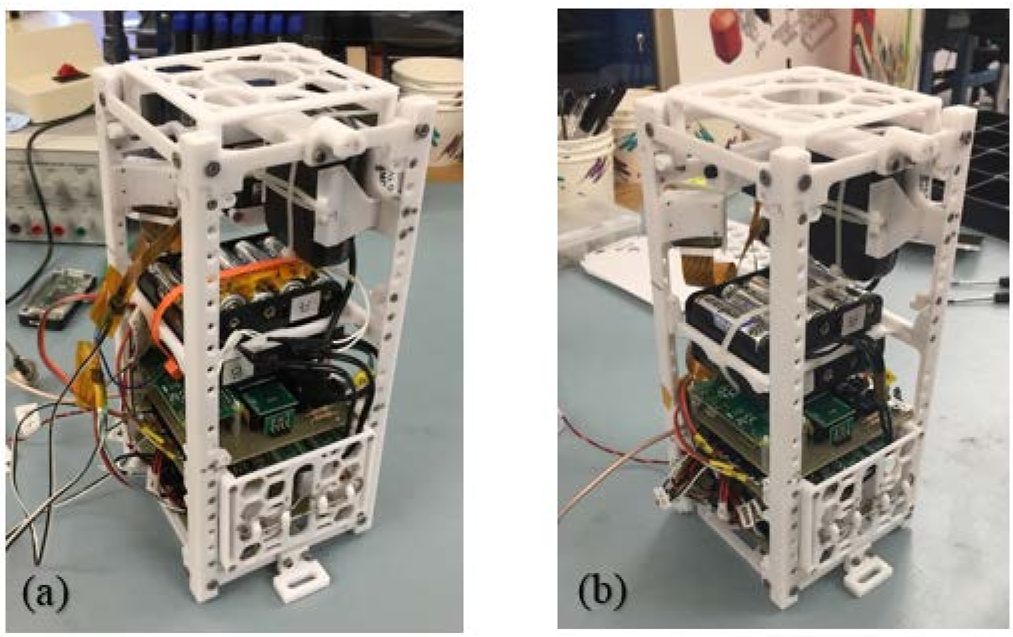

Figure 32. Difference after taping the wires

With all main bus ready for flight, the next step was work on the main payload and the other components not installed yet. The main payload, as the heart of the experiment, was our focal point at that time. We finished the preparation of the stand-alone Raspberry Pi Zero (mount and cables) and placed it on the HAB payload. To make sure all covers would fit we tried to install them and the stabilization fins. The idea was to have all components together and start to test the HAB payload as fast as we could. However, when we were installing the antenna's face cover, we realized that the antenna's cable was coming out of the wrong place. The cable was installed inside the C&DH board (main bus data board) and should come out of a different face to be bent and then come out of the antenna's face. It was coming out of the antenna's face causing a problem with the cover installation. Due to this problem, the whole HAB payload was disassembled and reassembled again. The repetitive assembling/disassembling processes consumed crucial time, causing schedule delays.

C. THE LAST WEEK

On the beginning of the last week before flight, we were worried about the remaining time and a possible flight delay. After the first complete assembly (no solar panels yet) we performed (Figure 33), the test with the cameras could start.

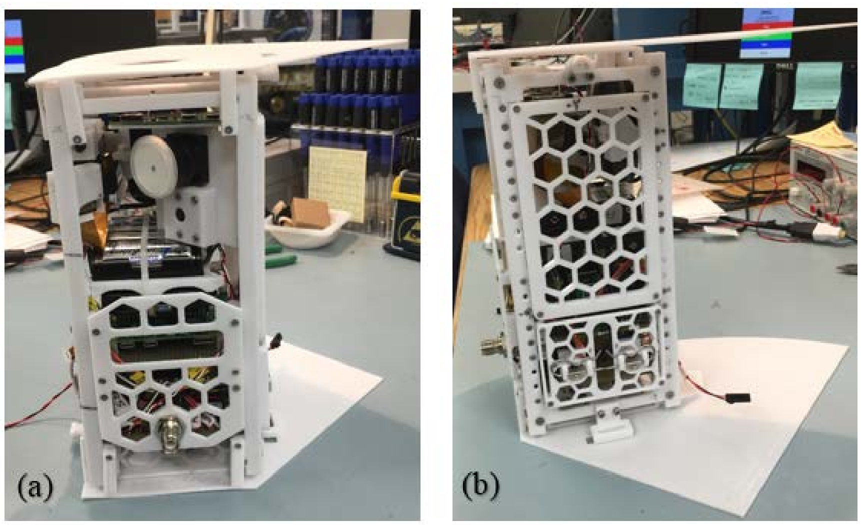

Figure 33. The HAB payload after the first complete assembling process

At the same time, in order to provide an appropriated planning overview for the team involved with the flight, we started to set up a briefing to define procedures and show the timeline for all participants. We have been checking during the whole week the estimated route and burst calculations about the flight to present on this briefing and to confirm the early predictions. The briefing was performed on Thursday December 14th, four days before the flight.

The cameras' test was schedule to be done on Tuesday December 12th. Even though the IR camera has been tested on a stand-alone fashion, it had never been tested controlled by the Raspberry Pi Zero board mounted on the HAB payload. The language used to program the Raspberry was PYTHON. Since for us it was an unknown language, the help from the SSL staff was essential in order to accomplish all required interfacing and tests.

We started the proposed test as scheduled with the all cameras and surprisingly the three cameras were not working. We started debugging the IR camera. After performing some changes in software with no success, we decided to ask help from FLIR Company, the IR camera's manufacturer. A FLIR software specialist was able to help us recommending several libraries to be installed and this procedure was enough to fix the software problem. This problem was caused by the replacement of the micro SD card for one with more capacity (32Gb) when we assembled the new Raspberry Pi Zero board and the new card did not have those libraries yet.

Next step was discovering the problem with the Raspberry Pi camera installed on the main bus. As we knew, the hardware (the camera itself) was not changed from the last two HAB flights, and that was our guess about the problem. We replaced the camera for a new one and luckily this procedure solved the problem. From that moment, the new camera never malfunctioned again.

The last camera's problem was the most challenging one to find out and also the most time consuming. After a couple hours trying different approaches, we finally decided to change the stand-alone Raspberry Pi Zero board based on a possible problem with the camera's cable connection. We have detected that the cable connection was not tight enough and the replace was the only way fix it. Once the board have been changed, the problem was no longer in place.

On Wednesday December 13th, we performed more tests to make sure the cameras were working well. Despite the fact we did only short duration tests, we had no more problems with the cameras on those ones and we considered the cameras ready for flight at that moment.

As the launch was scheduled on Monday December 18th and considering only business days, the briefing on Thursday December 14th could be treated as the previous 48 hours before the flight. On this briefing we reviewed the check lists for 72 and 48 hours and discussed some aspects of the calculations and about the day of launch check list. This meeting generated very productive discussions and the main conclusions reached are listed:

- We defined the whole timeline for the launch day including a timeline for the Cosmos System (primary telemetry system) commands in case of telemetry failure (balloon release and parachute release)—Appendix B;
- For the chase operation, we divided the group in 3 cars—car 1 (principal) with Cosmos System (primary telemetry system) and Teraterm System (secondary telemetry system), car 2 (secondary) with Cosmos System and Teraterm System, and car 3 (spare) with Teraterm System;
- We decided that we would not do the test with the actuators on the launch site, since we did this several times before - Appendix B;
- We agreed to start the balloon fill procedure only after finish all other tests with the HAB payload (to avoid any risks of a blow-up with a sensitive full balloon waiting for HAB payload tests);
- We decided to perform an altitude mapping test during the launch day test on campus taking the HAB payload to top of Spanagel Building;
- We agreed to perform a long duration test with the HAB payload before the flight to increase its reliability;
- We decided to add an "erase all data" procedure on the 24-hour check list (make sure we will have enough space on the SD card for the flight) - Appendix B; and
- We decided to put a tape (a highlight color tape) on the micro SD card or on the IR camera mount to protect and easy find in case of a hard land and a total loss of the HAB payload.

Following the suggestion about the long duration test, we started with this test on Thursday afternoon hoping that all components would have worked well. But unfortunately, we discovered a considerable problem with the HAB payload after less than 2 hours of test. For some reason, suddenly the current value of the current inside the main bus increased and reached 2.00 amp for a few seconds. This behavior was repeated after some minutes and was observed several times during the test. We observed that after the current peak the telemetry system, based on the radio installed, also stopped working for a few minutes. We discussed the problem with all SSL staff and concluded that this problem had potential to ruin the whole flight.

We agreed that we could not tolerate that problem and all efforts were focused on to find out what could be the cause of the malfunction. The most logical possibility was a radio problem since in the past, a similar problem was observed. The decision was to disassemble the entire HAB payload and start a flat test (put all the disassembled components to work over the test bench and see what we can conclude about the problem). We disassembled the HAB payload and left the components ready to be tested on Friday.

Unfortunately, on the last business day before the flight, we had the HAB payload all disassembled, not working well, and we did not know the reason for that. As planned, we performed the flat test in the early morning, but the test has shown the same behavior as the previous day. Since we were planning to check the radio components, we began with the cable test. We noticed that the cable was transmitting less than 60% of the signal through it. Whereas we suspected that this problem wouldn't cause the described current surge, the cable and the radio were replaced and the tests with these devices were found in acceptable parameters.

Once the current surge problem was fixed, the only concern was the fact that the long duration test was not completely done and we did not have time to start it again because, despite having the entire HAB payload working well, we still had an entire final assembling process to perform (Figures 34 and 35). Besides that, this one should have been very careful, with no chance of any mistake. This procedure was done in about 3 hours.

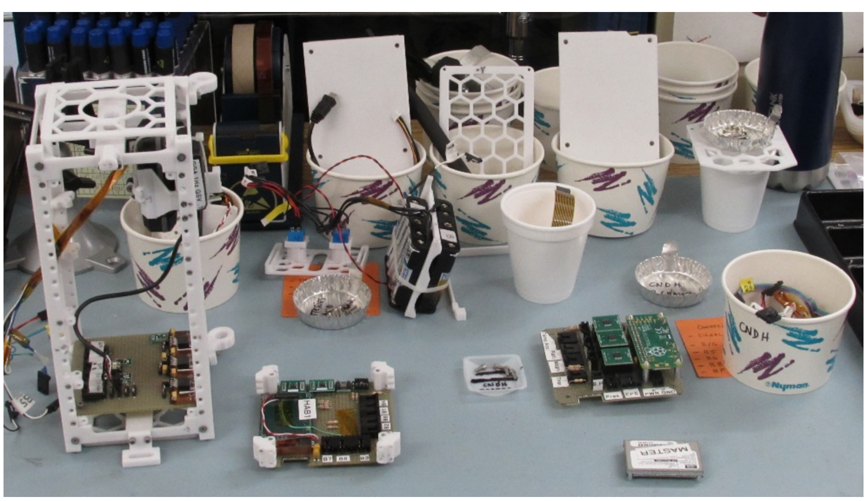

Figure 34. HAB payload disassembled on the last business day before flight

Figure 35. HAB payload assembled after the assembling procedure

D. THE LAUNCH DAY

On the day of flight, radio and cameras were tested again and no problem was presented. They were working as expected. The data from the video recordings were checked, however, the images were not verified during this test. They were found to present no problem when accessed after flight. These tests and other technicalities, such as printers not working, as well as the parachute installation that took more time than expected, caused a 30 minutes delay on the Launch Day Briefing. This delay propagated throughout the operation day. The launch time was 30 minutes after the scheduled time, however, this was not a cause of route change. Despite the delay, we decided do not rush with the procedures and risk skipping relevant information. We did all day-of-launch check list (Appendix B) as planned, packed all equipment required and went to the launching site.

We arrived at the launching site with the same delay and started all the procedures as agreed. The only hiccup on the checking sequence was the GPS system. During the first initializing process, the GPS did not work. Even though it is expected about 10 minutes to connect, it was taking too long and we decided to restart the HAB payload. The procedure worked well. After finishing the last items, the balloon filling process was started, which happened without problems. Finally, we were able to connect the balloon to the HAB payload and perform the launching (Figure 36), which happened at 11:31a.m.

Figure 36.   The launching moment

E. CHASING AND RECOVERING TIME

In order to recover the data inside the HAB payload it is necessary to perform an effective chasing activity. Support material and dedicated personnel are necessary to execute this mission. First of all, the chase mission was planned and updated daily to increase the chance of a successful recovery. The CUSF Balloon Burst Calculator was used to predict the balloon burst time. This tool calculates the time of flight, the gas volume, and the neck lift if you give it the desired altitude or the ascent rate, the balloon mass, and the HAB payload mass. Figure 37 shows a screen where the information is given. This was the last calculation using the precise HAB payload mass just before the Launch Day Briefing.

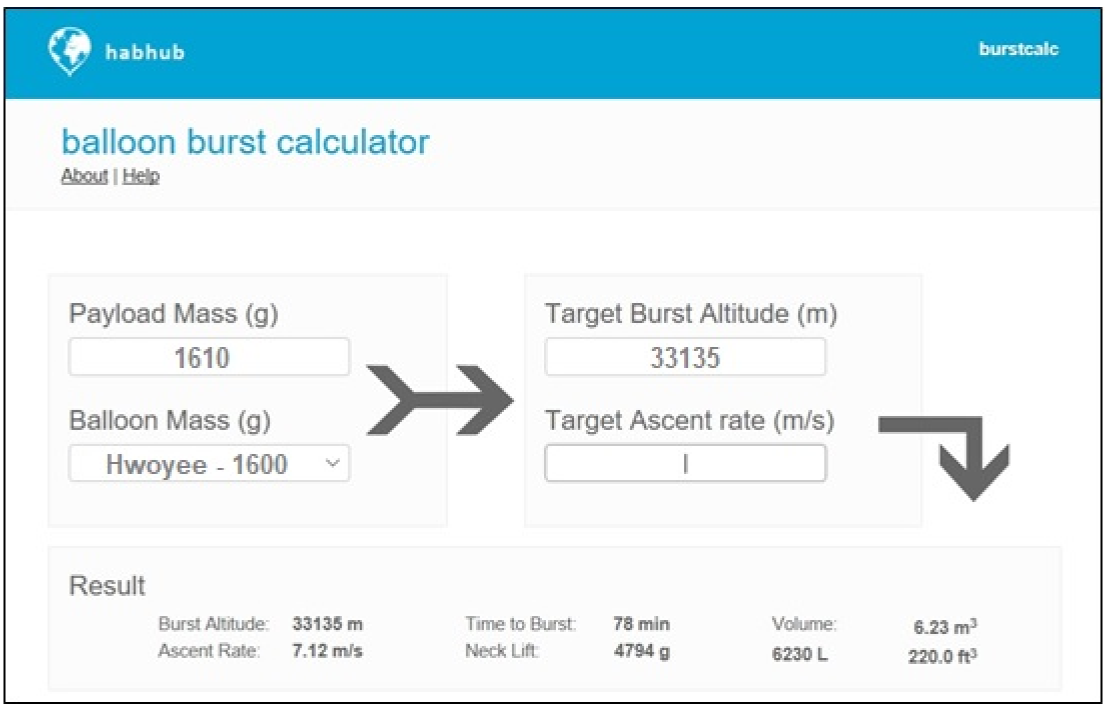

Figure 37. The final balloon burst calculation

Having the burst calculation, the CUSF Landing Predictor was used to calculate the predicted route based on the launching site selected. We have to enter the ascent rate, burst altitude, descent rate (this one depends on the type of parachute and the desired release altitude), and the launching site information (place, time and altitude). We choose to launch the HAB flight from the Central Valley because it is a large plane area located between two mountain-chains not so far from NPS. The area is flat and filled with orchards to cushion the land. In our planning we preferred to start selecting the landing area and then refining the launching site due to the fact that FAA rules are more restrictive for the landing site. These restrictions are: five miles away from any city or town, major highway, private land, Wildlife Refuge area, and difficult to navigate terrain.

Route predictions using the day of launch data are only allowed if you are less than the previous 180 hours to the launching time, but the accuracy increases when you enter the information even closer to this time. We performed the last calculation, shown in Figure 38, less than 12 hours before the launching time.

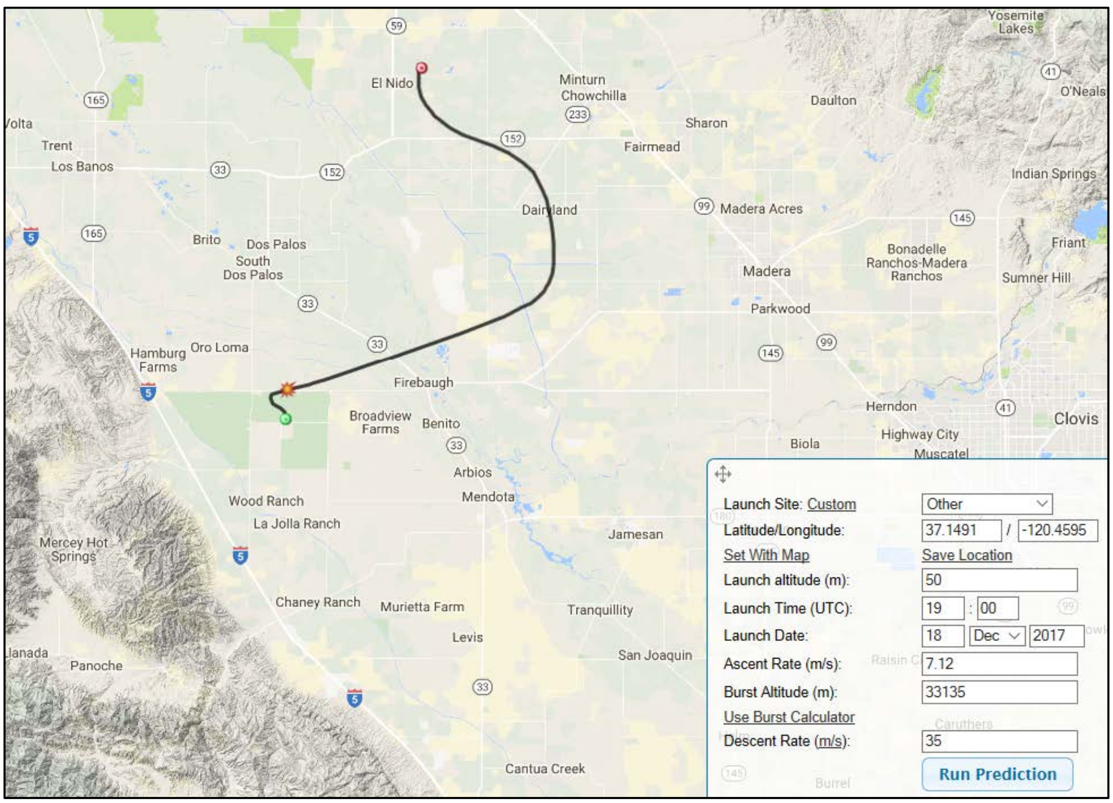

Figure 38. The final route calculation

The landing site in Figure 38 (green dot) was selected because this place meets all required characteristics (see Figure 39). Besides that, we checked this calculation just before the last briefing (less than 4 hours before the launching time) and the changes were negligible.

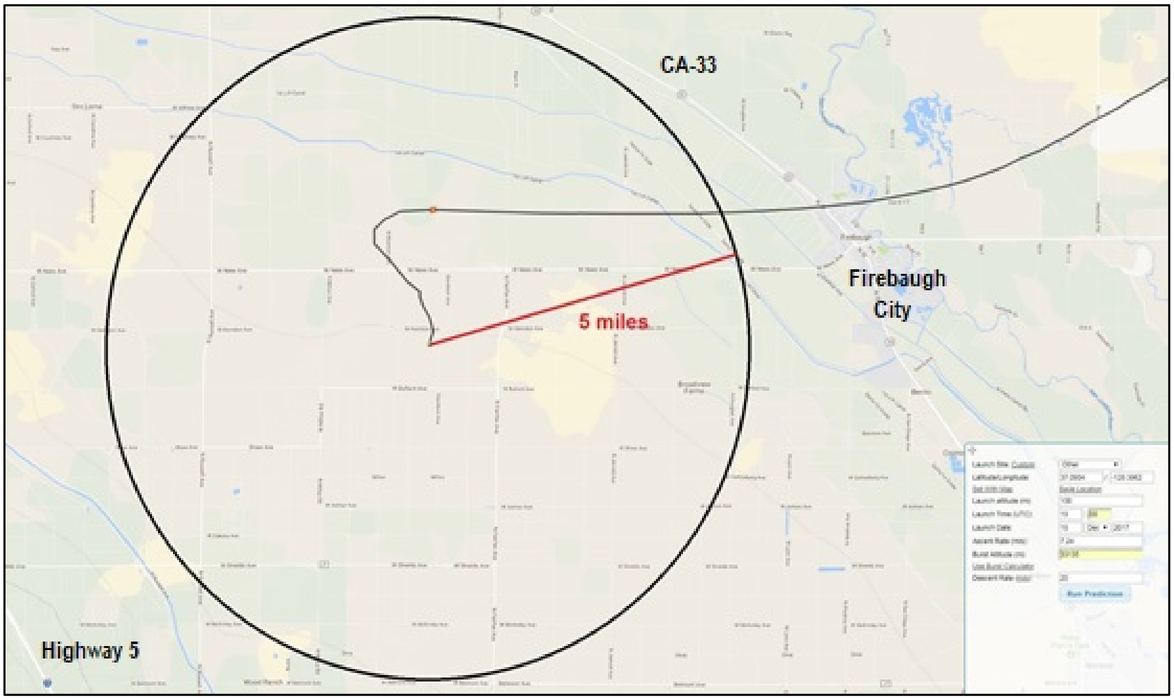

Figure 39. The landing site

Immediately after the HAB flight launching, the chasing operation started. We had the HAB flight GPS coordinates all the time and we were able to follow the HAB flight position along the real path. The primary chasing car (car 1) decided to follow the directions to the landing site using a low speed avoiding to be distant to the HAB flight trajectory. We expected a HAB flight similar to the simulated one and, be at landing site little early, seemed to be helpful because we had a chance to identify the HAB payload in flight (both red parachutes opened) before the vegetation hides it during the landing. The other chasing cars decided to wait sometime before starts chasing the balloon directions in order to be close to it at the final part of the flight.

The balloon was doing basically the same route as predicted. But after it crossed 18,000 meters of altitude, it started to descend. First, we tried to confirm this information. We called the other cars and they confirmed the descent. The balloon was about 20 miles behind us. We made a “U” turn to follow the new route described by it. From that point, we presumed that for some reason the HAB payload was not connect to the balloon. The predicted route wouldn’t help anymore since the HAB payload wouldn’t be affected by the same wind (different altitude).

We noticed that, in order be closer to the HAB payload, we could use the main parachute to reduce the descent rate. The only concern was, we could not release the main parachute without make sure the balloon remains were released before. Otherwise, we could affect the parachute aperture. The Cosmos Operator on car 1 was instructed to command the balloon release and he did, but he did not receive the complete action confirmation (0.00 V on the actuator). The altitude was something about 11,500 metros. He sent several times the balloon release command, more than 20 times, but the balloon release confirmation was received only 3 minutes before the landing. We also asked the other cars to command the balloon release and the answer was the same, no change at the actuator voltage.

Without a confirmation if the balloon remains were released or not and the altitude going down fast, we decided to command the parachute release because the altitude was less than 5,500 metros and we were concerned that a HAB payload free fall could be worse than a possible fail during the parachute aperture. Again, we did not receive confirmation from the telemetry about the parachute released and we commanded several times. We discovered after recovering the HAB payload that the rubber band used to hold the parachute was grabbed by the actuator pin (Figure 40). That was the reason why the actuator never went to zero.

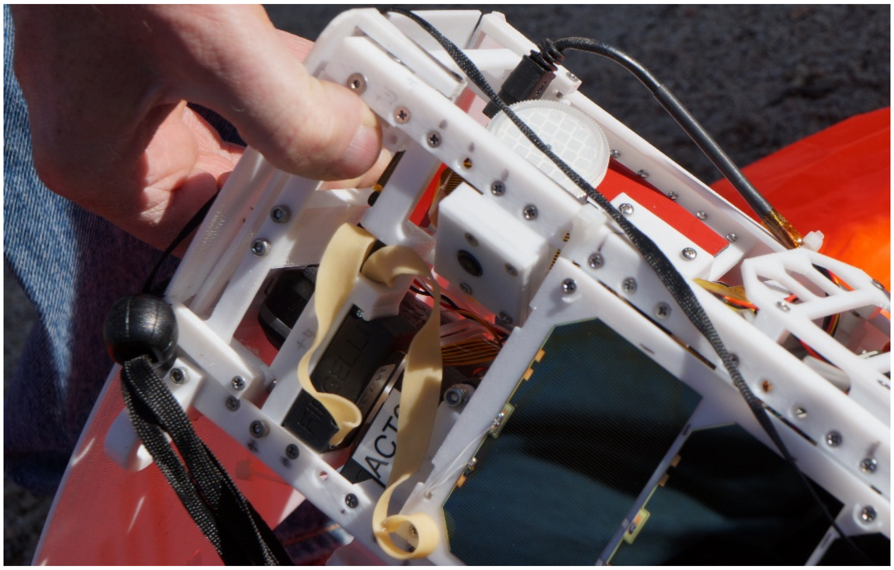

Figure 40. The rubber band grabbed on the actuator

Given the fact we did not receive parachute release confirmation, we were afraid that both parachutes did not open. The descent rate seemed to be the same during the whole descent time. Once we arrived at the land site, we notice that the parachutes were opened but tangled and the efficiency of them were probably reduced, but they were able to avoid a crash on the ground. The payload components were almost intact, as we can see in Figure 41. The landing was in a hard surface close to a secondary road.

Figure 41. The HAB payload after landing

To provide a useful material for analysis, we took pictures from the HAB payload landed at the site, and then folded the parachutes and put it into the case to return to campus. On the following day at SSL we downloaded the videos and the after-flight check list (procedure introduced on this flight) was performed as described on Appendix B. The damages were not severe and we could get the data produced by the sensors.

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V. FIRST FLIGHT ANALYSIS

A. STRUCTURAL ANALYSIS

The damages found on the HAB payload were minor and basically on the plastic components. The most relevant damage was some cracks on one solar panel, probably caused by the balloon remains (a cord with a metal swivel at the end that connects the balloon to the HAB payload) colliding during the descent. These cracks are shown in Figure 42.

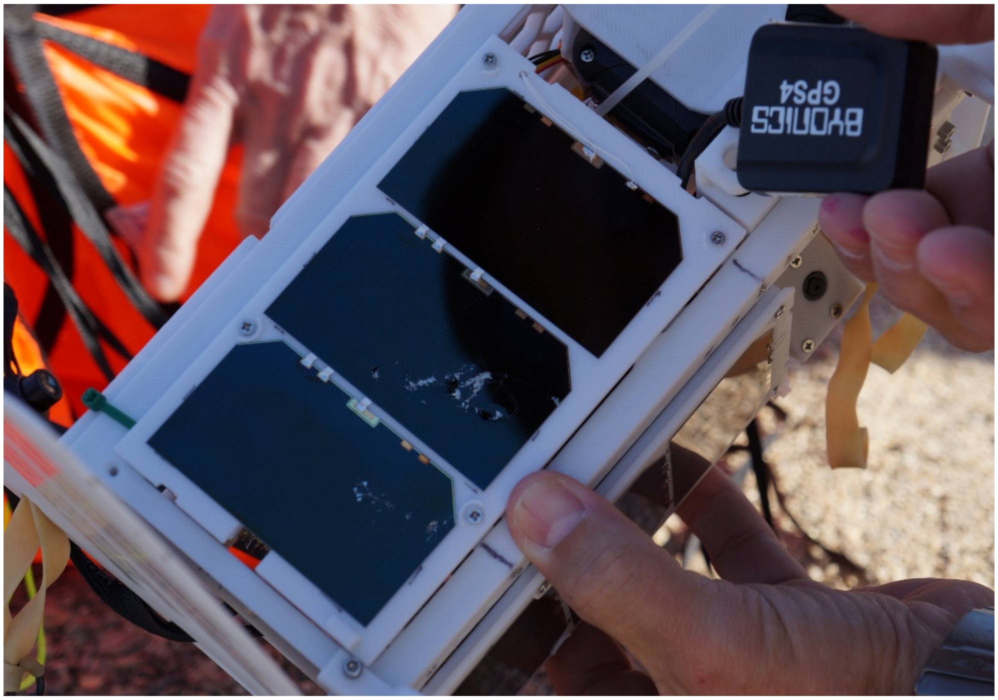

Figure 42. The solar panel damages

Other minor damages were found on the frame structure but no electronic component was affected by the hard landing. The broken components are displayed in Figure 43.

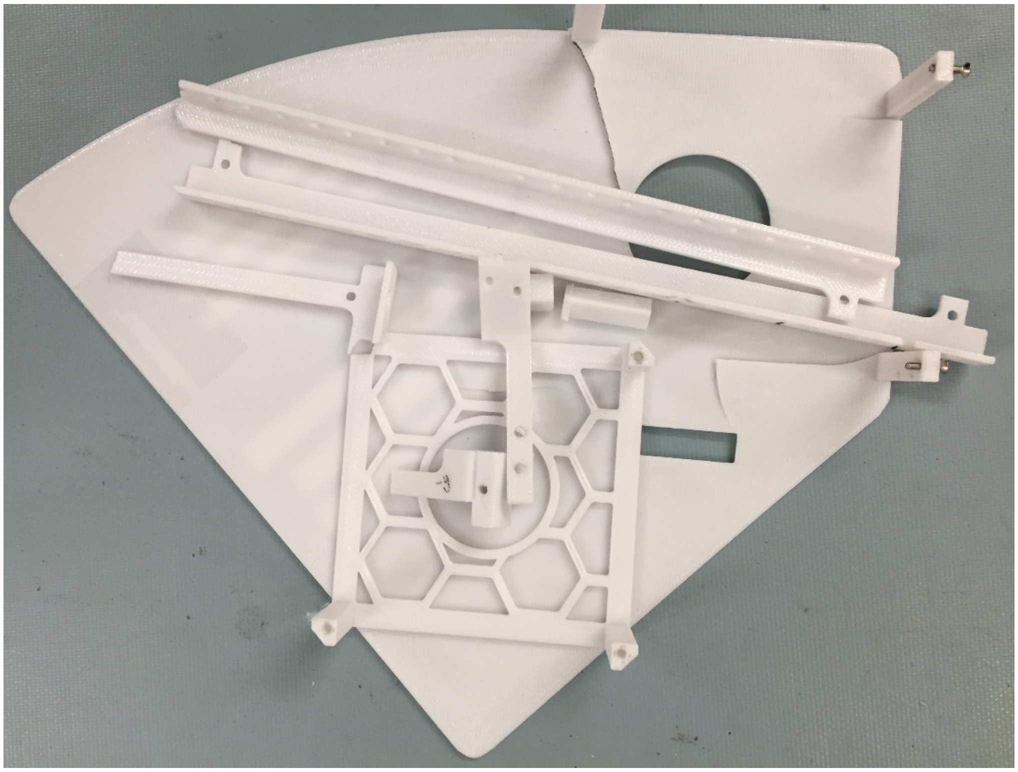

Figure 43. Structural damages

B. ROUTE ANALYSIS

The HAB flight did not reach the planned altitude, however, we could compare the predicted flight and the actual flight in order to obtain insightful information about the discrepancies. The predicted flight was uploaded on the Google Earth program just before we left the SSL towards the launch site. The same program was used to record the actual position of the HAB payload during the flight. These GPS coordinates were received from the telemetry system and displayed on the Cosmos System during the operation. The result is showed in Figure 44.

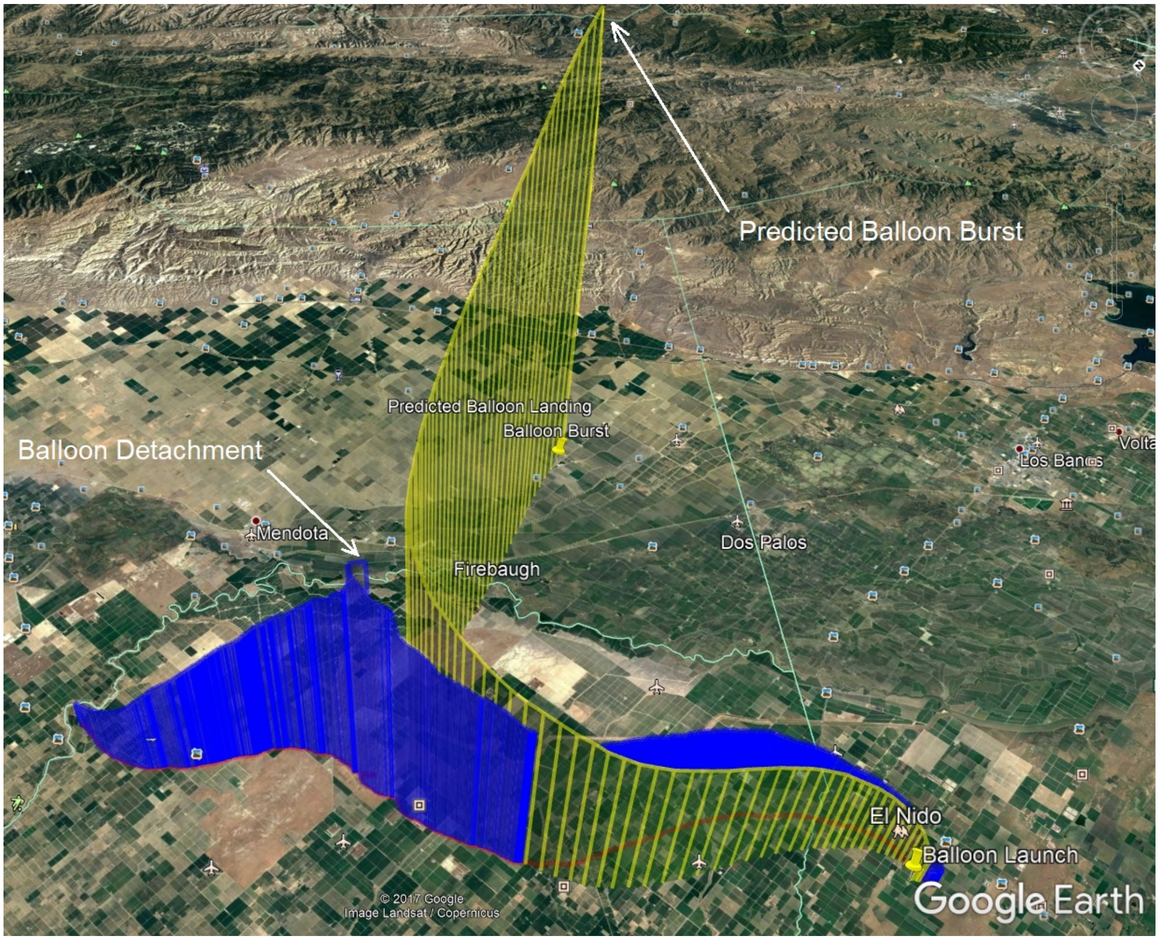

Figure 44. Google Earth predicted route x actual route

As we can see, the actual route (blue route on the graph) was close to the predicted one (yellow route on the graph) until the balloon detachment, indicated in the route by a white marker. The predictor tool takes into consideration the wind chart based on the flight levels, therefore makes sense the difference after the balloon detachment since the HAB payload levels of flight were uncorrelated with the previous prediction. Actually, the wind direction on the actual flight levels flew by the HAB payload without the balloon were almost opposite comparing by the prediction, so it went to east instead of going to west as predicted. This extreme change in the wind direction caused a significant delay in the recovering operation. The first chase car (car 3) arrived at the landing site about 20 minutes after the actual landing. Car 1 arrived few minutes after the first car because there was an attempt to be at the landing site a little earlier in order to identify the HAB payload by the parachutes on the last minutes of flight. The HAB flight change in direction required a navigation replanning, causing the delay.

The landing area was a remote site between grape and orange orchards and no people were circulating around the area. We could state that no one touched the HAB payload before the recovery team.

Using the data recorded on the main bus, the log file, we could recover the HAB payload trajectory during the flight based on the latitude and longitude coordinates, as shown in Figure 45.

Figure 45. Actual HAB payload flight route

The log file downloaded from the main bus was allowed for recovery of another relevant information of the flight, the time and altitude. This graph shown in Figure 46 is a good representation of the vertical path drawn by the HAB payload during its flight.

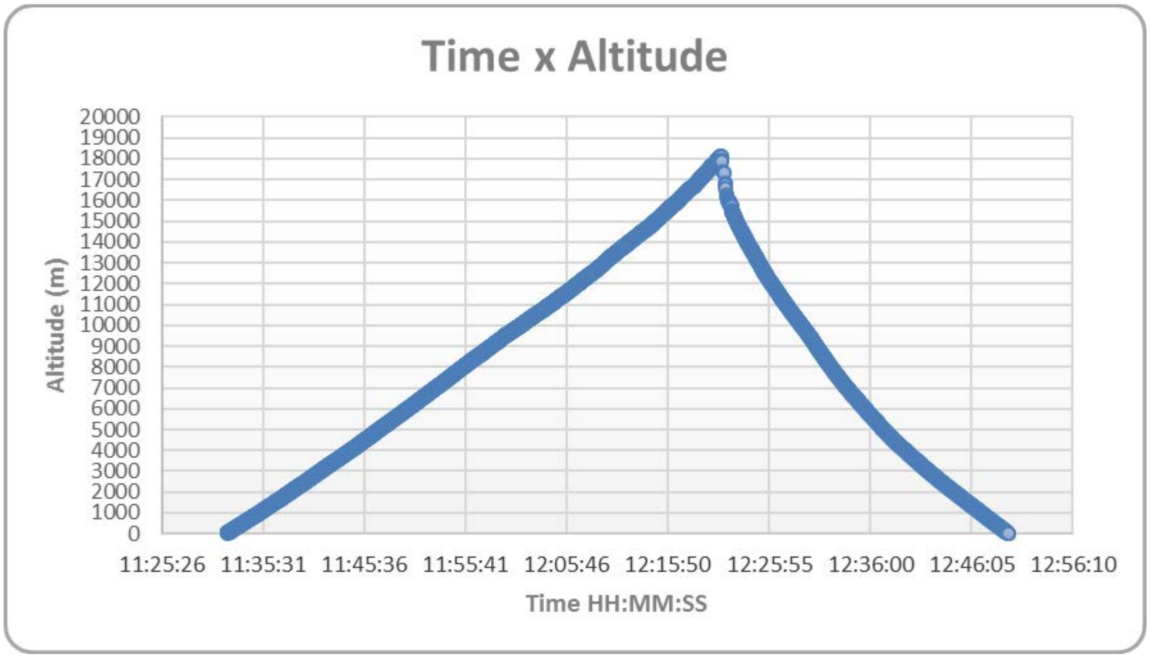

Figure 46. HAB Payload Graph (Time vs Altitude)

As shown in Figure 46, the descent starts to be a little less steep only after 5000 meters, when the first parachute opened. The backup parachuted was deployed at 1000 meters, but we can't notice the change in descent rate on the graph because the parachutes were tangled and the efficiency was reduced. Despite the problem that happened during the deployment, the parachutes were able to protect the HAB payload as expected.

C. VIDEO ANALYSIS

The video analysis allowed important conclusions that can be used to improve future flights. We programed the cameras to perform 5 minutes clips and record all the flight. The storage devices were appropriately dimensioned to provide enough space for the flight time.

1. Raspberry Pi Camera 1—Main Bus

The first camera, a Raspberry Pi camera controlled by the main bus, was pointed to the balloon and was able to record all balloon behavior during the flight. It was a powerful tool because it could show us the early balloon detachment.

During the chasing operation, we did not know yet what happened to the balloon and why it started to descent earlier than expected. The initial assumption was that the balloon has exploded earlier for some reason. Watching the videos from this camera, we discovered that the balloon was detached and went up undamaged. The 15 second video (Video 1) showing the balloon detachment is available on YouTube (https://youtu.be/VAXoRkVRljM). Four frames of the most critical moment are shown in Figure 47.

Video available on YouTube at https://youtu.be/VAXoRkVRljM.

Video 1. Detachment moment

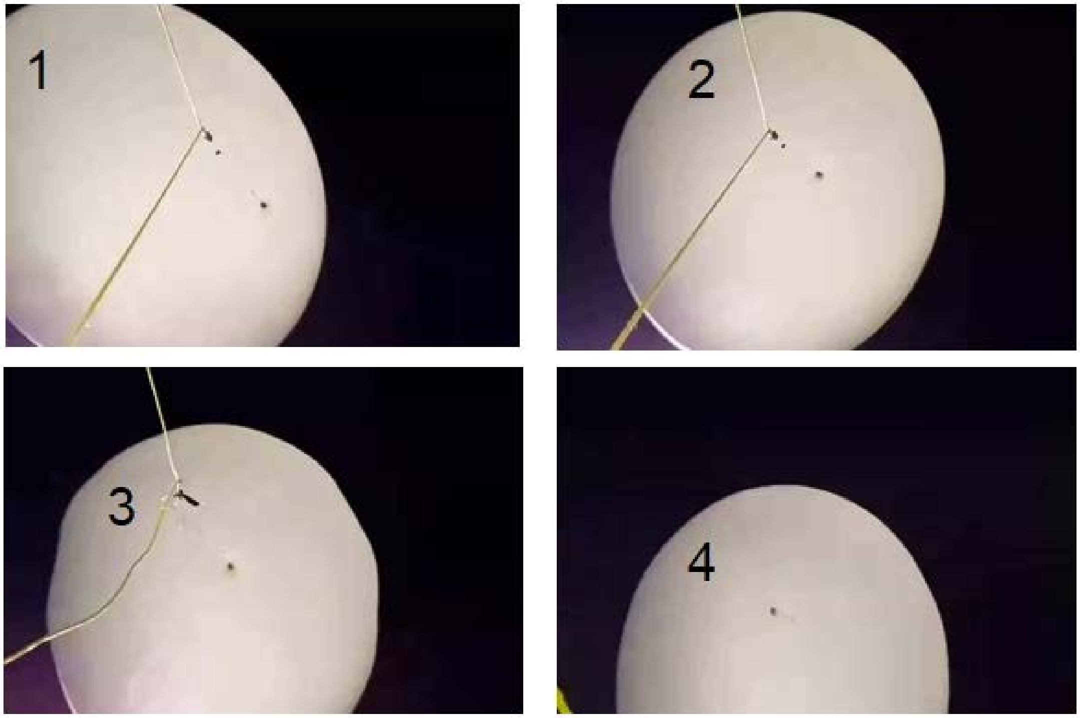

Figure 47. Four snapshots (1 to 4) the balloon detachment moment

As it can be noticed from the video and the images, forces during a rotational movement have broken the hard connection between the balloon and its payload. The most probable explanation is the severity of the jet stream (a narrow belt of high-altitude winds) at the level where the detachment happened. When the HAB flight was exposed to considerable high forces due to the jet stream acceleration, the nylon line broke. According the FAA rules for the HAB flight activity we are not allowed to: “Uses a rope or other device for suspension of the payload that requires an impact force of more than 50 pounds to separate the suspended payload from the balloon” [15]. It is proved to be not strong enough to resist such high accelerations.

2. Raspberry Pi Camera 2—Off Bus

The second Raspberry Pi camera was used to obtain the same scene recorded by the infrared camera, to make the IR scene easier to interpret. The videos recorded by this device were perfectly acquired and provided comparable images in the visible range of the spectrum. An excellent example of this device capability was the launch moment (Video 2), available on YouTube (https://youtu.be/1UJMhnO-VVc). The camera showed all the scenario around the launching site and would help to identify features seen by the IR camera.

Video available on YouTube at https://youtu.be/1UJMhnO-VVc.

Video 2. Launch moment

3. IR Camera—Off Bus

Unfortunately, despite all efforts, we were not able to recover any IR video from the flight. The IR camera stopped working after the last test on SSL before flight, on the launch day. We still do not know yet the reason why the camera stopped working, however it is suspected that a software problem caused the failure. The camera was for sure the most tested component and it operated under expected parameters in all tests.

4. Lessons Learned from the Images

Despite the fact that the cause of the failure was not identified, the IR camera software needs to be improved to assure the camera will work on the next flights. The plan is to install some scripts inside the program to prevent it to stop running during the restarting process.

Another important action to be taken is to ensure the cameras are working well just before the launch. Until now, we were only able to check the camera's off bus functioning at SSL. But if we use a stand-alone Raspberry Pi with a wireless connection it would be possible to check the cameras just at the last minutes before flight. I believe this solution might be very efficient to increase the probability of success.

Another detail, related to the Raspberry Pi camera off bus, is the color configuration. I believe some colors were not seeing as real colors. As we can see at the video, the black tends to a dark green. I recommend a new adjustment to provide better colors and this action could help the process of identifying the IR scenario.

D. FINAL THOUGHTS

Although we had so many problems during the preparation and the operation itself, I believe the results of the flight were very positive for the project. Besides, we could learn a lot with all problems and we can leave a good legacy for the next flights sponsored by the SSL. As an experiment, this HAB flight was relevant because many lessons learned were accumulated during the process. The main aspects of the learning process can be highlighted as follow.

The ability to work on CAD programs was extremely useful during all the design and preparation phase. Since the changes and modifications to the structure happened often, a good skill of CAD work was necessary. We have printed out more than 20 versions of different components. The body fins were a good example of that, we had to design some previous versions to finally find one that fits on the payload. Unfortunately, they ended up being less efficient than expected and we do not recommend to use these surfaces again without performing some dynamic tests to check their efficiency before flight.

The planning tools, provided by HUB HAB website, can be considered very powerful to provide precise calculations, but the closer to the launch time the better. Any calculations more than 12 hours can only be used just as an estimation for planning purposes. Less than this will be a good parameter to plan our operation. The budgets calculation was also essential for the preparation and planning phases.

We have learned to be prudent with tests and avoid go to the limits of the electronic components. The decision of postpone the TVAC test with the IR camera was important because it could cause an unrepairable damage to the camera, risking the entire experiment. The skills developed in assembling and disassembling the payload was another positive result due to the experience and ability which helped a lot at the final phase of the flight preparation. Besides that, we could improve ways to do this task and update previous established procedures (check list).

The Cosmos commands sent by telemetry system could be considered a weak part of the experiment. We had to send several times the same command to have the confirmation of the action on the HAB payload. The same problem was observed on the last flight with the NPS space students in September 2017. This problem needs to be carefully investigated and the uplink deficiency resolved. Since the behavior of the uplink during the Lab tests was within the expected parameters, power of the radios and gain of the antennas should be put to a check.

Another weak aspect of this experiment was the long duration test. Due to the problems that happened during the last week before the flight, we were not able to perform the long duration test. This test might have revealed the software failure of the IR camera control, allowing for correction or flight cancelation.

Taking into consideration that the acquisition of IR videos, and their interpretation, is the main objective of this experiment, we believe some improvements can be made to help this task. We believe it will be beneficial to have the correct time synchronization on the videos from the main payload as for the main bus videos. The main bus has GPS time information connected, but the stand-alone Raspberry Pi Zero on the main payload does not, making difficult to correlate the videos. This could be a good improvement for the next flight.

The early balloon detachment needs to be discussed with caution. The HAB flight will be subjected to the jet stream area every flight we plan if we are trying reach the upper atmosphere. The rules from FAA are clear, no one can use more than 50 lbs. of resistance on the nylon line. We should ensure the maximum allowable lashing resistance, but if the HAB flight was subjected to forces with more intensity than this value, the nylon will probably break again. Flying during seasons with less severe jet stream would be an option.

On the parachute problem, even though they were tangled in some way, they accomplished their role. The problem with the rubber band grabbed by the actuator was critical because it can prevent the parachute release, but the solution is not complicated to achieve. The best way to avoid this problem is a simple sleeve covering the actuator pin.

VI. SECOND FLIGHT TIMELINE

A. FIRST WEEKS

Since we had some problems on the first flight, we asked the SSL staff for another flight to cover gaps and apply the lessons learned in order to obtain the desired data. The main concern from the first flight was for sure the IR camera failure. All efforts were concentrated in to find out the best solution for that. We started the work focused on to discover the cause of the IR camera malfunction, since we did not know that reason yet. We tried many times to replicate the failure during short and long duration tests after flight, that we could say it was not a hardware problem. Something on the software installed on the Raspberry Pi might be the cause.

Assuming the software used to control the camera should be improved, we worked on the first weeks to find out ways to robust it for the second flight. One of the SSL staff, a PYTHON specialist named James Horning, wrote some scripts trying to create a procedure to look for inconsistencies and reboot the program if necessary. With this procedure running on the Pi board, if the failure was only related to the software, the hardware would be able to operate again after the reboot. This seemed like an efficient solution but we still needed to have a way to check if the system is actually running well just before the launching.

In order to address this matter, a way to check the IR camera on the field, we concluded that the best solution would be to provide a wireless capability to the stand-alone Raspberry Pi Zero. This was necessary due to the fact the IR camera was connected to the Pi board by the unique USB port and there was no other option to have a wired access to the board. The way to solve this problem was to acquire a Raspberry Pi with wireless capability (Figure 48).

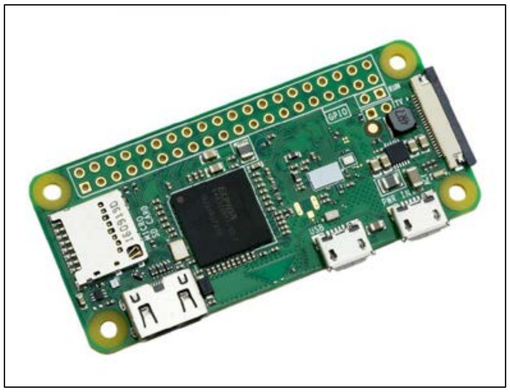

Figure 48. Raspberry Pi Zero W. Source: [18]

We knew that the second flight must happen as soon as possible since our project schedule was tight. However, we had two lead times: to receive the wireless Raspberry Pi boards ordered and to have the Helium cylinders refilled for the flight. After have all the administrative measures for the acquisitions done, we could define the date for the second flight: Friday January 19, having the following day as a weather alternative.

The objectives considered for the second flight were the same for the first flight. Considering the problem with the early balloon detachment a difficult variable to control due to the limitations imposed by the FAA rules (50 pounds breakable nylon line), we decided to keep the same configuration and just test the lashing resistance before flight. We also address very easily the problem with the rubber band and the parachute actuator. We designed a 3D printed sleeve for the mobile axis that is able to prevent any contact between the rubber band and the actuator, as shown in Figure 49.

Next, it was decided to not use stabilization fins. This topic will be revisited in future flights after further studies.

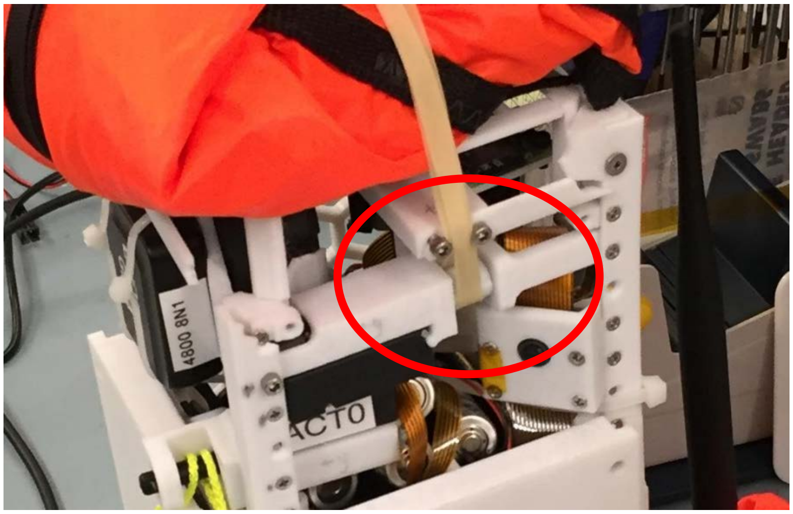

Figure 49. 3D printed sleeve for the actuator axis

We reviewed the budgets for the flight and concluded that no change had to be done on the spreadsheets calculated for the first flight. We assumed that the change in weight caused by not to use the body fins was negligible for planning purposes.

After the new Pi board arrival, we changed the board and the components broken on the first flight. We could say “ready for flight” at that moment, but we actually knew that several tests had to be done yet. We had to decide about the TVAC test again. The risk to expose the IR camera close to its limits would not be recommended since we did not have a spare camera to use in cause of a significant damage. We decided to perform this test after flight in order to preserve the crucial component for the project.

We started the tests as soon as we could after having the wireless connection configured on the Raspberry Pi. This task was concluded just one week before the flight date, on Friday January 12, 2018. The last week was planned to be dedicated to the required tests and the group briefing, which was planned in order to show the participants the estimated conditions of the flight.

B. THE LAST WEEK

We used the weekend before the flight date to recruit the team required for the flight since we probably would need to qualify some participants to use systems they were not familiar with (Cosmos and Teraterm). On January 17, we performed the group briefing as planned.

The beginning of the week was used to test the cameras and the wireless connection. Initially, we could have the wireless capability and the cameras worked without any relevant problem. But we noticed that, on long-term tests, some problems were detected. Sometimes the wireless connection was not available and at the same time the IR camera was not working properly. Sometimes bad files were produced by the camera, sometimes it just stopped and videos were no produced anymore. Although the software protection was able to reboot the system in some cases, it was not all the time as expected.

The first assumption was the voltage regulators located on the EPS board not been able to provide the minimum necessary current to the IR camera and to the stand-alone Raspberry Pi. We could not confirm that even if using appropriated instruments.

It was decided to disassembly the HAB payload to check the condition of all cables and connections first and then check the regulators on the EPS. The overall conditions of the electronic components were classified as well preserved and it led us to the regulator option. We were close to change the regulator responsible for the power line that connects the Pi board, when someone noticed that the voltage selected on the external power supply was incorrect. We were using 5.6 V on that, however, the minimum required during the flight was about 6.6 V.

After we selected the correct value (6.6 V) on the external power supply, we did a long-term and instrumented test on the HAB payload disassembled, as we can see in Figure 50, and no more problems were detected. We still had the bad files made by the IR camera sometimes, but no more stops were noticed. Despite the time spent on those investigations, we noticed that it was the first time we could replicate the failure happened on the first flight.

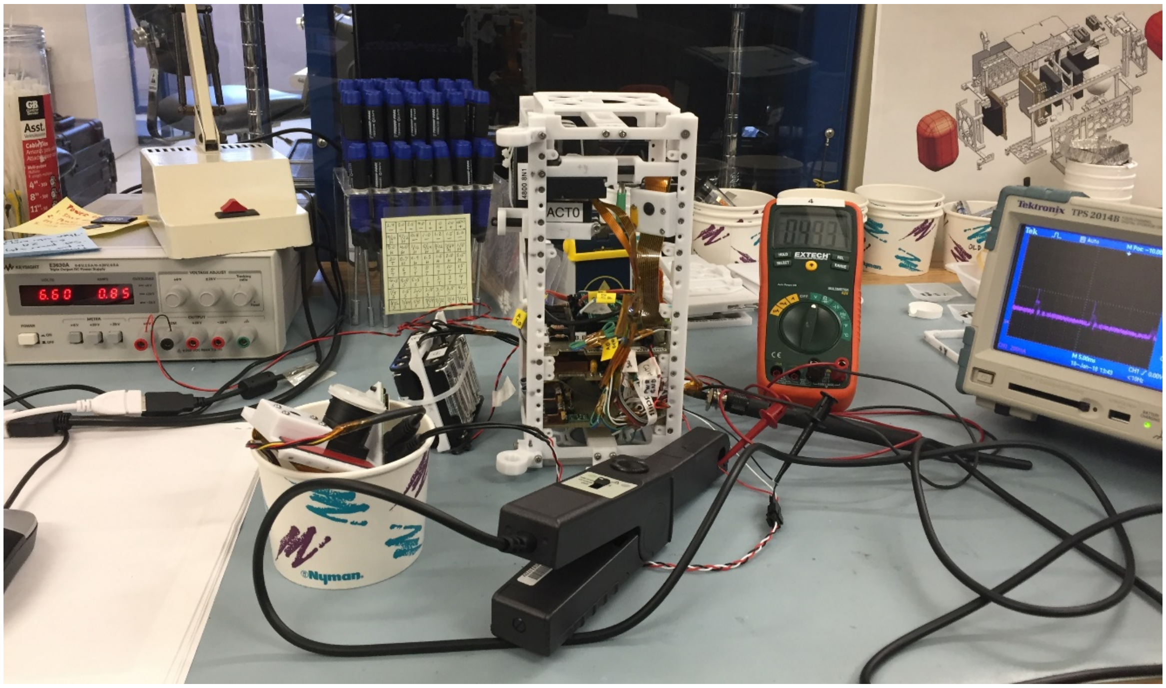

Figure 50. Power supply instrumented test on the HAB payload

On January 17, the plan overview was shown to the selected team on the group briefing. The main decisions arising from the meeting:

- We defined the launch day timeline including a timeline for the Cosmos System commands in case of GPS failure (balloon and parachute release)—Appendix B;
- For the chase operation, we divided the team in three groups—car 1 (Cosmos System and Teraterm System), car 2 (Cosmos System and Teraterm System), and car 3 (Teraterm System);
- We agreed that we would send the telemetry commands at the same time all groups when the decision for it was made, trying to avoid the problem caused by bad line of sight between the cars and the HAB payload;
- We decided that we would not perform the test with the actuators on the launch site, since it was done several times before the flight.—Appendix B;
- We decided to start the balloon filling procedure only after finished all other tests with the HAB payload;
- We decided to perform an altitude mapping test during the launch day test on campus taking the HAB payload to the top of Spanagel Building as last flight;

The weather forecast for the flight was oscillating during the flight week. During the briefing we agreed that on Thursday someone would evaluate the predictions and make a final decision about the flight date. Due to this instability on the forecast for Friday, we decided to change the flight to Saturday since the weather forecast was much better. Due to administrative problems (the potential government shutdown and bad weather), the launch had to be rescheduled for Thursday, January 25. We did again the check list procedures for 48 and 24 hours before the flight and the HAB payload was finally ready for the second flight, as we can see in Figure 51.

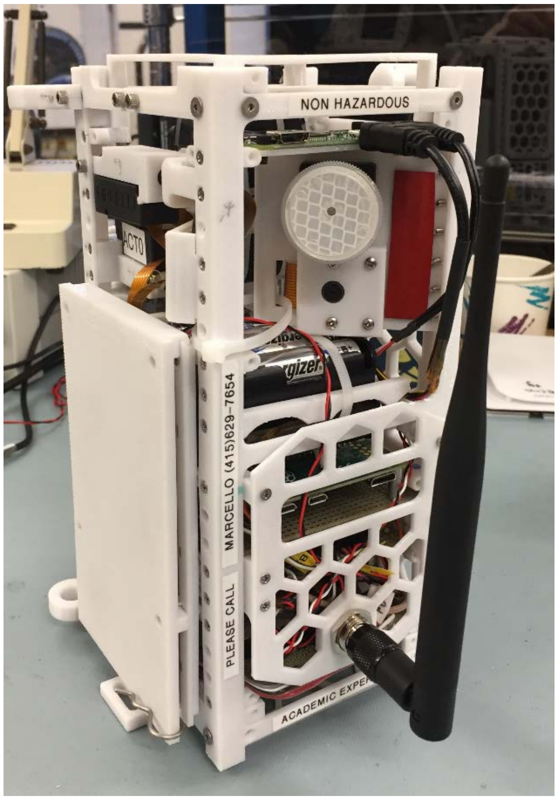

Figure 51. HAB payload ready for the second flight

C. THE LAUNCH DAY

We started the day reviewing the route predictor to have the final planning for the flight. We checked the tool late on the previous night and no significant changes were noticed in the morning (Figure 52). We presented the entire planning on the Launch Day

Briefing with all required information to provide situation awareness for all participants. Only one point was objected by some senior participants, with more experience on the field, about the launching site. They suggested a small change on the selected point to another one very close but with more wind protection in order to reduce the risk during the balloon filling process.

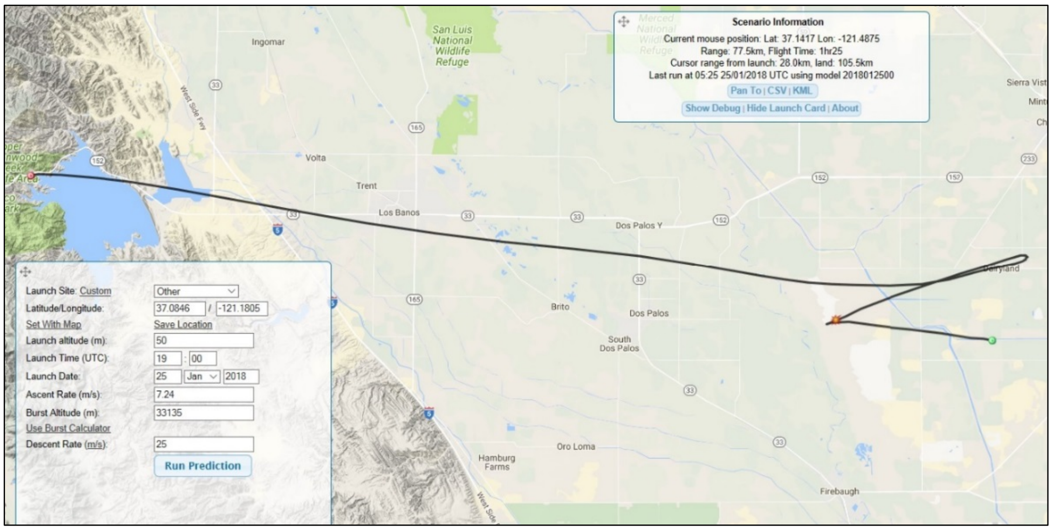

Figure 52. The predicted route for the second flight

Following the check list for the launch day, we started the procedures after the briefing as expected. However, during the GPS check in the Lab, it was taking so long to synchronize with the satellites, therefore it was decided to reboot the HAB payload to solve the problem. This was exactly what happened with the first HAB payload on the launching site. After rebooting the HAB payload, the GPS worked well.

The other procedures were accomplished as well and no other unusual detail was detected during the tests on campus. The cameras were tested without any problems. We were a little late on the timeline at the end of the check list on campus (about 20 minutes) due to the time spent on waiting for the GPS be synchronized, but nothing that could cause any problem on the plan. Everything less than one hour would not affect significantly the planned route. We finished all day-of-launch check list (Appendix B) as planned, packed all equipment required and went to the launching site.

We arrived at the launching site at 10:30 a.m. and we noticed that the place was very appropriate to perform the balloon launching. It was a spacious parking lot, a good support structure (bathroom and tables), and a great open area attached which was suitable for the filling and releasing process (Figure 53).

Figure 53. Launching site

We perform all check list procedures on the field without any problem, including the last-minute wireless camera check, which was planned to make sure the cameras on the main payload were working before launching.

The only concern about the procedures before launch was the GPS test. Although we had GPS information on both telemetry systems (Cosmos and Teraterm) during the last few minutes before launching, we lost the GPS synchronization and no one could note the problem in time. If we were able to reset the GPS before releasing the HAB flight, we could avoid the "blind" part of the flight. A simple reboot on the payload would help, but unfortunately, it did not happen. We released the balloon at 11:18 a.m. (Figure 54) without any suspicion that an important system was not working appropriately. We noticed the GPS problem just few minutes after the launching moment.

Figure 54. The launching moment for the second flight

D. CHASING AND RECOVERING TIME

The chasing operation started without any GPS information. We only had the planned route and the hope for receiving the SPOT information about the HAB payload position for recovering. We knew that SPOT Tracker wouldn't send information in flight, however, we predicted a stop message at the landing site after landing, but it did not happen. The planned flight time for the second flight was a little different from the first one due to the weight difference (no body fins), as defined by the burst calculator in Figure 55.

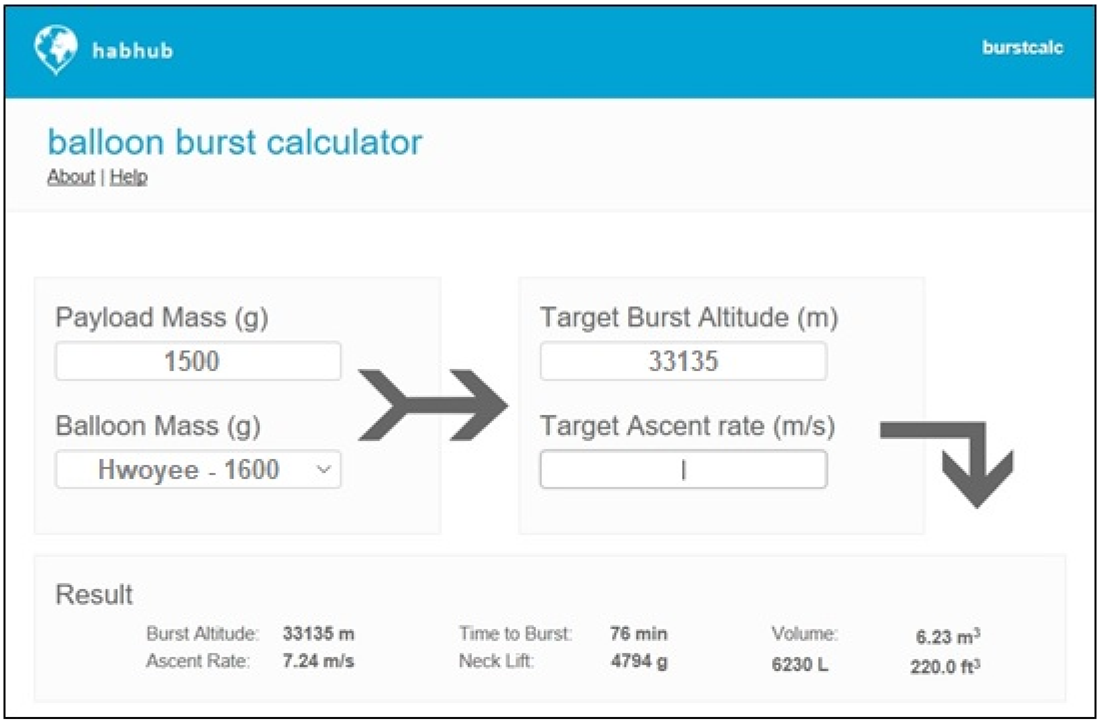

Figure 55. Second flight burst calculation

Following the planned route without GPS information was challenging. We tried to find the atmospheric pressure information on Cosmos, but no one could find. Having that information, we were able to estimate the actual altitude of the HAB payload. We only had the timeline for balloon release and parachute release commands. But this calculation presumes the flight being accomplished as planned, and we did not know if it was the case. Assuming it was, we followed the predicted route during the "blind" part of the chasing.

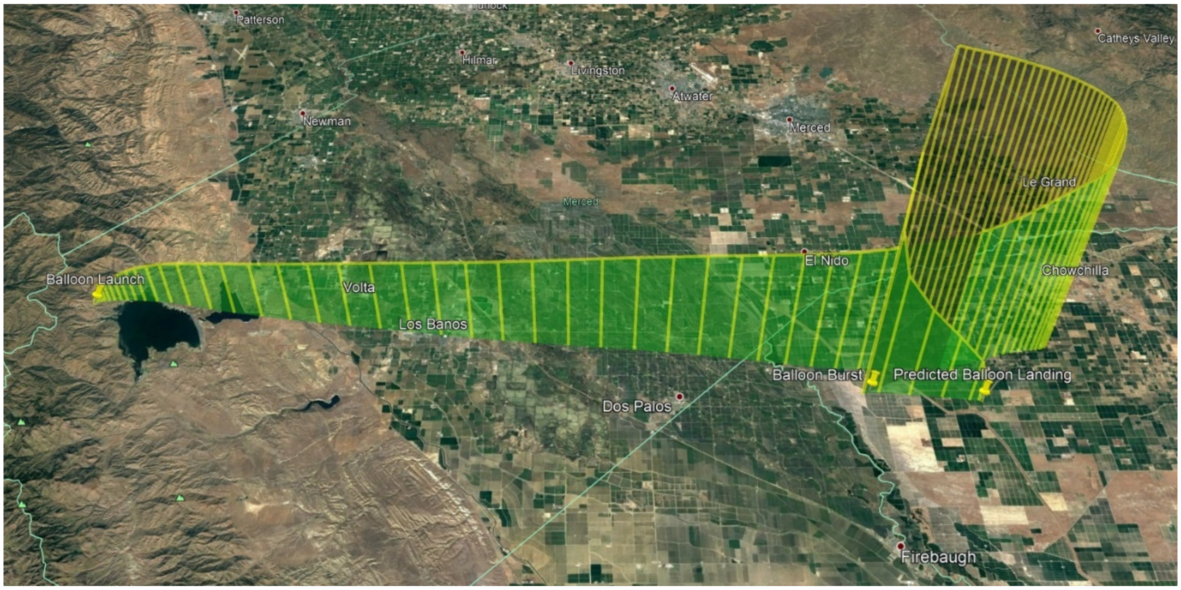

Figure 56. Second flight 3D predicted route on Google Earth

As we can see on the 3D route in Figure 56, the wind direction was almost constant during the ascension. After the jet stream area, the wind direction would become the opposite and would tend to push the balloon closer to the previous trajectory. Since it was the expected movement, there were not a problem if the balloon was a little ahead, because it would change its movement after the jet stream effect. However, because of the jet stream turbulence, the balloon was disconnected earlier and it never crossed the altitude where the wind direction supposed to reverse.

After almost one hour of “blind” chasing, we started to receive GPS information. When we received the first data, we noticed that the altitude was not appropriate for that GPS position. Something wrong with the flight should happened. The first altitude received was 6,300 meters in descent trajectory, very far away from the altitude expected for that time of flight, something around 26,500 meters in ascent trajectory.

The first reaction taken was to send the balloon release command in order to be ready for the main parachute release. Nevertheless, we noticed that we were far away from the HAB payload position. The GPS indicated a position way over the predicted landing point. Despite the large distance, we ordered all Cosmos operator to send the balloon release command, but it did not work. We did the same for the parachute release command

and it was also an unsuccessful action. We tried to send each command at least 30 times from each car and none was able to reach the HAB payload.

Because of the flight altitude changes, the predicted landing site was not a useful point for the chasing operation anymore. Since the balloon never crossed the jet stream altitude, it did not reverse its trajectory. It continued going on the same direction all the flight, causing an actual landing point really far away from the predicted one (Figure 57). Moreover, we noticed that the descent rate was less than the predicted one. We discover after the flight that the backup parachute opened inadvertently at the same time the balloon was disconnected. That was the reason for the small descent rate and the long descent trajectory.

Figure 57. Second flight predicted vs. actual landing site

After a long trip we could arrive at the landing area, but not at the landing point, since the payload landed inside a private property and we were not allowed to enter. We stopped at a gate locked (Figure 58) on the closest road we could find. We received a good last GPS coordinate at 900 meters of altitude before we lost telemetry connection with the payload. We knew it was not a precise one for the landing point, but probably it would be very useful to find the payload. One Cosmos Operator left the System in operation even after no connection with the payload during the drive and he was able to receive one more GPS information, which was the refined coordinate for the landing point, as confirmed by the recovery team on the following day.

Figure 58. The private property gate

We tried to find someone at the gate or close to ask permission to enter but seemed like there was no house inside the property. The owners live in a different place. We knew that we were very close to the HAB payload (about 1.5 miles) as shown in Figure 59, but without permission we could not enter there. We called the Cal Fire to help us to identify the owners. They dropped by after a while and tried to help us, however, they did not have phone numbers on the land registration. Going around the area, we could find some people that gave us a contact number, but only on the following day. We went back to NPS without the HAB payload.

Figure 59. Balloon landing and locked gate position

On the following morning (Friday, January 26) we were able to contact the property owner and he allowed us to enter and recover the HAB payload. A small team was designated to recover the HAB payload and they found it easily and very well preserved. They could see only small damage on the plastic structure. They noticed that the balloon and parachute release mechanism did not work, but the backup parachute was opened as shown in Figure 60. On Monday at SSL the videos were downloaded and the after-flight check list, as described on Appendix B, was done. The damages were small and only on the structure. None of electronic component was affected by the landing with only one parachute.

Figure 60. The HAB payload at the landing site

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VII. SECOND FLIGHT ANALYSIS

A. STRUCTURAL ANALYSIS

The damages on the HAB payload were small and affected only the plastic structure (Figure 61). It landed on a grassy area. Probably it hit the ground with the upper part of the chassis (solar panel face +y) and it caused some broken pieces and cracks on this area. Some batteries were displaced but no electronic damage could be found. Considering the fact that the payload landed with only one parachute released and out of the predicted area, the results of the landing were better than expected.

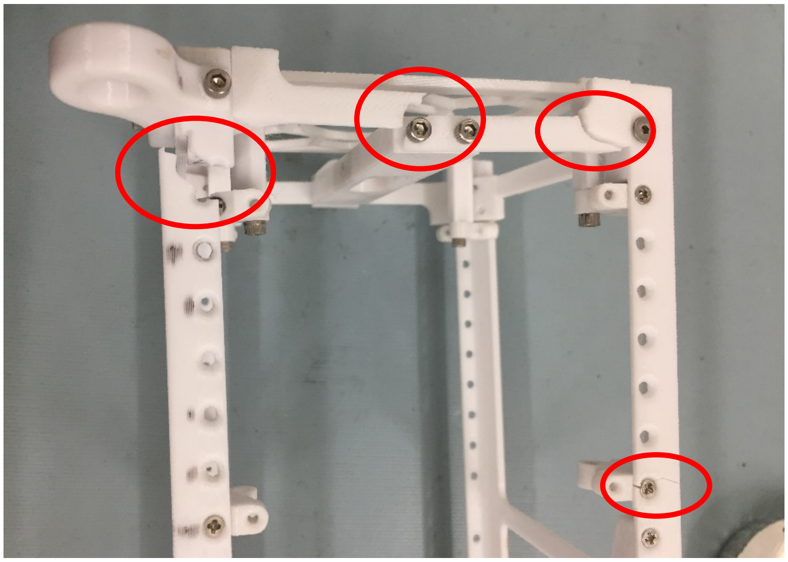


Figure 61. The chassis damage

Besides the chassis, only one more broken piece was detected, the antenna's face cover, as shown in Figure 62.

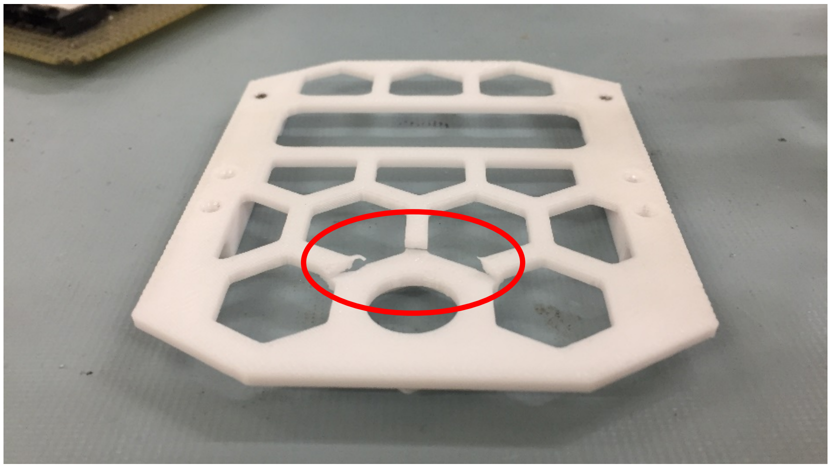


Figure 62. Antenna’s face cover damage

B. ROUTE ANALYSIS

We planned the route based on the predictor tool and we noticed that the wind was blowing in a constant direction, basically west-east, below the jet stream level and in the opposite direction over it. If the HAB payload could not cross this level it could be directed towards the end of the central valley. However, this wouldn’t be a problem because with the planned descent rate the HAB payload wouldn’t be able to reach the mountains. Nonetheless, we did not expect a low descent rate caused by the backup parachute early opening and it was close to happen (Figure 63). The actual landing area is not a flat area, as we most likely see at the Central Valley, but it did not compromise the recover.

Figure 63. Second flight predicted route and actual landing point

Based on the barometric information, downloaded from the main bus, we were able to generate the time vs altitude graph of the flight. It was important because this data was the only way to infer the altitude of the images we could obtain, since the GPS was not available most part of the flight. The barometric pressure information is a relevant redundancy that allows the altitude registration in case of GPS failure, as it happened in this flight. Unfortunately, all Cosmos Operators could not find the barometric pressure information window, but it wouldn't be easy to use during the operation without the proper conversion table.

The Atmospheric Pressure Calculator [19] from CASIO was used to transform the barometric data into altitude to build the time vs altitude graph. The results are shown in Figure 64.

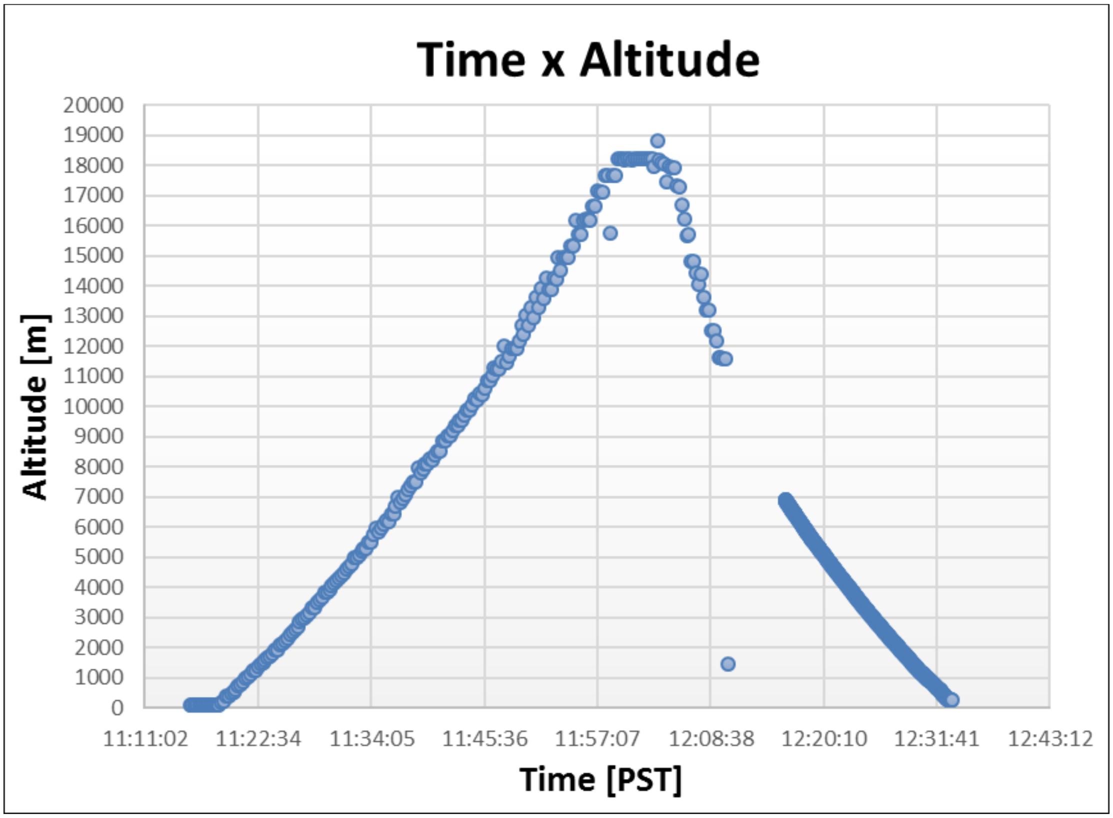


Figure 64. 2nd Flight HAB Payload Graph (Time vs. Altitude)

Those data in Figure 64 shows that the HAB payload went up until almost 19000 meters before be affected by the jet stream, condition very similar to the first flight. The main bus was subjected to an automatic reboot before the GPS information was reestablished, as we can easily notice by the area on the graph without any point. The reboot procedure took approximately 6 minutes (from 12:10 to 12:16) and we do not know the reason for that. After analyzing the case, the most probable reason seems to be a low battery temperature that could cause a great voltage drop and consequently a system shutdown. When the batteries temperature returned to an acceptable value, the system started again, like a computer reboot procedure.

Figure 65 shows the battery (blue) and CPU (orange) temperatures that explains in numbers this behavior.

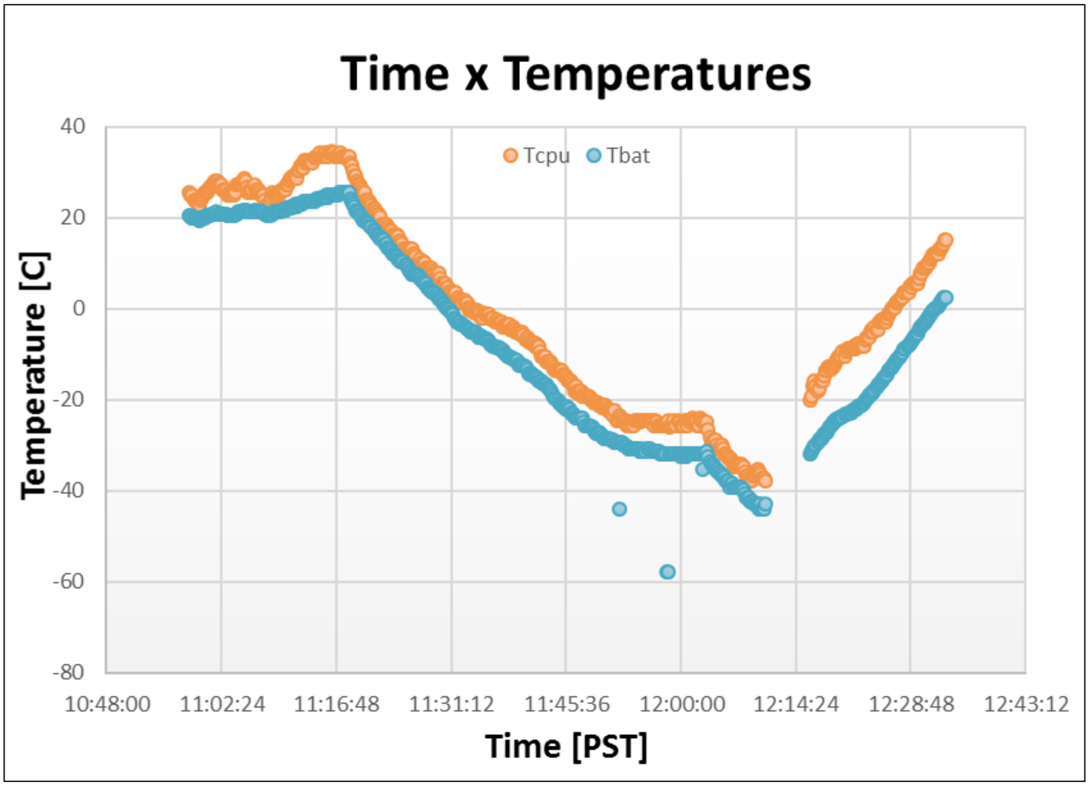


Figure 65. 2nd Flight HAB Payload Graph (Temperatures)

Not considering the outlier data points, we can infer the minimum temperature as -44ºC just before the system shutdown. The operating temperature for normal alkaline batteries is from -30ºC to 55ºC, it means way further this range. This could be very harmful for the system, as we could verify on the battery voltages graph (Figure 66), a significant voltage decay. The voltage generated on both sides of the battery box (A and B) were less than 4V, not enough to provide the power required by the system.

Moreover, the solar panels were not able to sustain the correct voltage for the whole system. The photovoltaic voltage graph (Figure 67) seems to be the same curve compared to the battery graph.

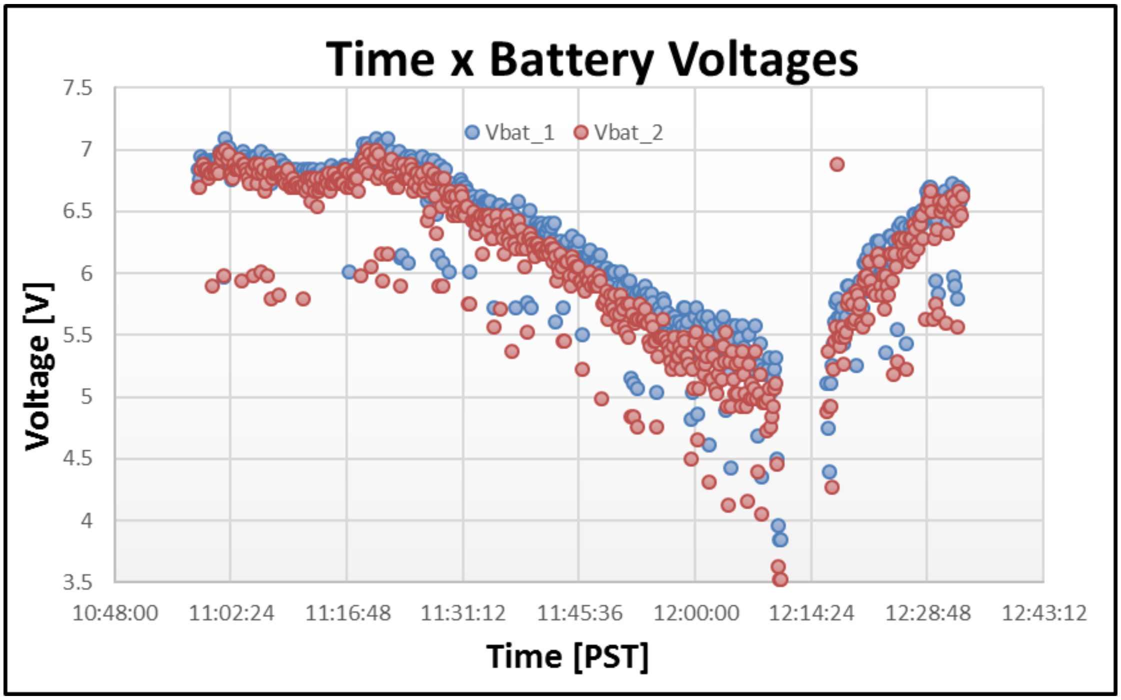


Figure 66. 2nd Flight HAB Payload Graph (Time x Battery Voltages)

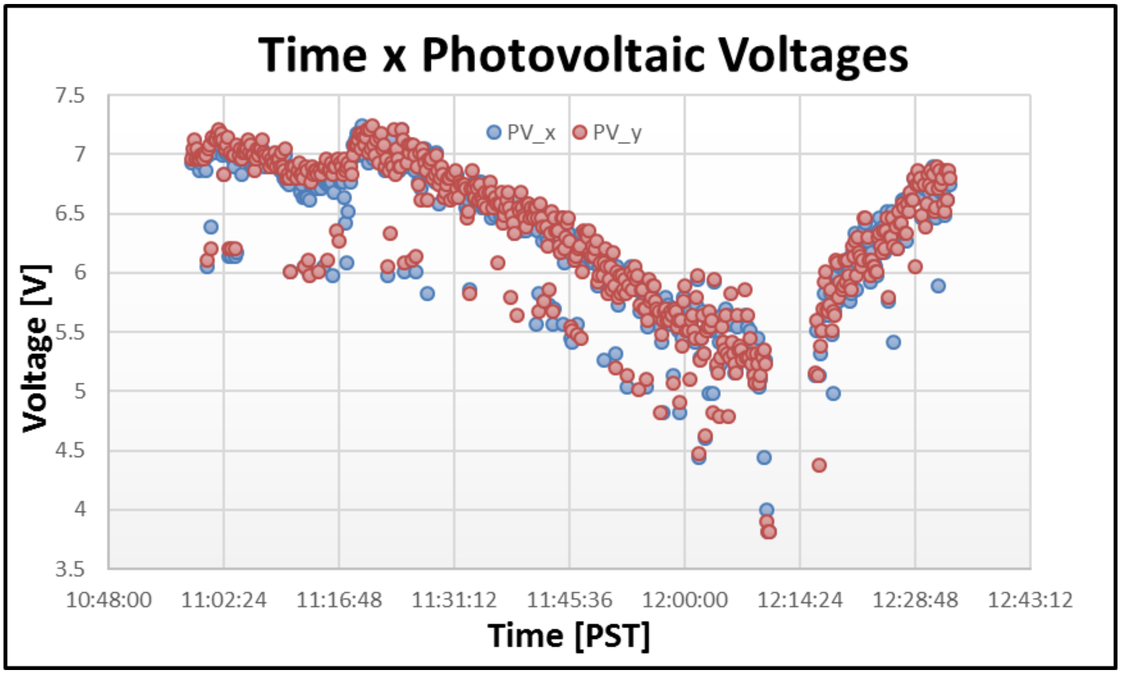


Figure 67. 2nd Flight HAB Payload Graph (Time x Photovoltaic Voltages)

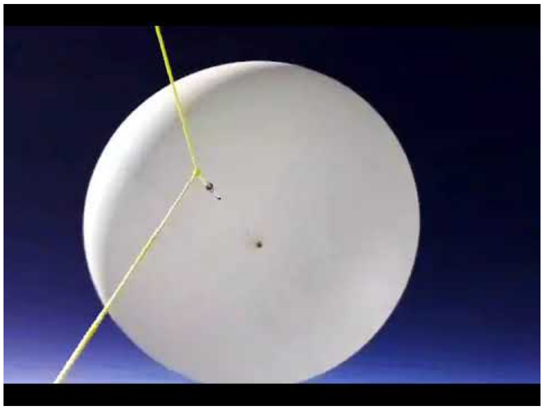
C. VIDEO ANALYSIS

The same camera configuration was used on the second flight. All cameras were programed to record 5 minutes clips during the entire flight. The results from each one was analyzed and could provide the required acknowledge for the Terahertz project.

1. Raspberry Pi Camera 1—Main Bus

As the first flight, this camera was looking to the balloon and was crucial to clarify how the balloon was disconnected during the flight. We concluded that the same fact as the first flight happened again, a very strong turbulence force probably was the reason for the precocious balloon detachment. The jet stream forces were so strong that caused rotational movements and unexpected tensions on the breakable nylon cord. The result was a nylon cord broken and a balloon early detachment that increased in complexity the chasing operation, since we did not have GPS information most part of flight.

On the video of that moment, downloaded from this camera, we could clearly see the nylon cord breaking and the balloon going up faster not carrying the payload as it supposed to be. Besides that, the same video showed the inadvertent backup parachute opening, most likely caused by the same forces. During the after-flight check, we concluded that just the barometric mechanism connection of the parachute was detached and no rubber band broken as we could presume. That means the parachute was removed from its place and the mechanism was open only at the preset altitude (1000 meters). We did a 15 second clip of this moment and posted on YouTube (https://youtu.be/BC-B-F-Kmxg) (Video 3). Four frames snapshots of the moment were also taken and showed in Figure 68.



Video available on YouTube at https://youtu.be/BC-B-F-Kmxg.

Video 3. Second flight detachment moment.

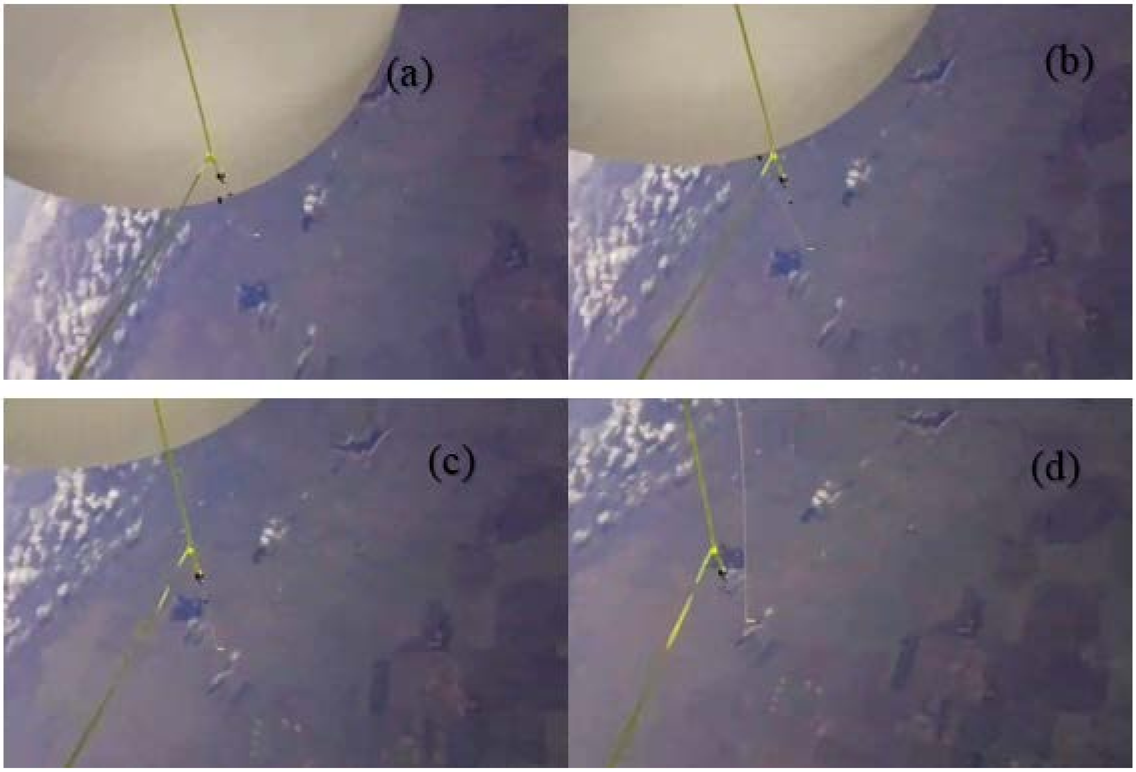


Figure 68. Four snapshots of the 2nd Flight Balloon detachment

Another reasonable explanation for the early detachment is related to the backup parachute opening. There is a possibility that the problem with the backup parachute had been the cause for it. The parachute opened would increase instantaneously the drag on the system and thus the tension on the nylon cord, causing it to break.

This camera was not able to restart after the system shutdown. Only videos before 12:10 were recorded by the camera. Considering the fact this camera was designed to look to the balloon, its function was not necessary after the detachment. Therefore, this condition did not affect the results of the mission.

2. Raspberry Pi Camera 2—Off Bus

The goal of this camera was to obtain the same scene of that of the IR camera to help the image analysis. Without the visible images sometimes would be difficult to identify different elements on the scene. The CMOS camera was able to accomplish its task, since it provided the videos as expected and during the whole flight. On the launch moment, as an example of its capability, the camera was able to record the launching site and help the interpretation of the IR image. This video is available on YouTube: https://youtu.be/9oZnaacFOQ0 (Video 4).

Video available on YouTube at https://youtu.be/9oZnaacFOQ0.
Video 4. Second flight launch moment

3. IR Camera—Off Bus

IR videos were recorded as expected during the ascent part of the flight, but it stopped about four minutes before the detachment. The probable explanation for that was the insufficient power supply, fact to be explained in details on section 4. The other problem found was related to the saturation of the sensor. This problem affected the camera several times during the flight, when were created a type of highlighted path on the screen caused by a sensor direct exposure to the sun light. This degraded significantly the image, since the pixels affected were not useful for the following images until a new self-calibration was performed by the camera.

Other problem observed were related to the stability of the payload. Since it was not possible to cross the jet stream levels, and ascend to levels where we would have a stable flight, most of the images were blurred due to the high dynamic of the camera. Despite of this, we were able to register useful images for the project.

In order to present the scenes registered by both sensor, infrared and visible ones, we performed two snapshots at the exactly same time as we can see in Figure 69. Due to the different field of view (FOV), the scales of the images are different. Without the time information available, the correlation task would be very hard to accomplish.

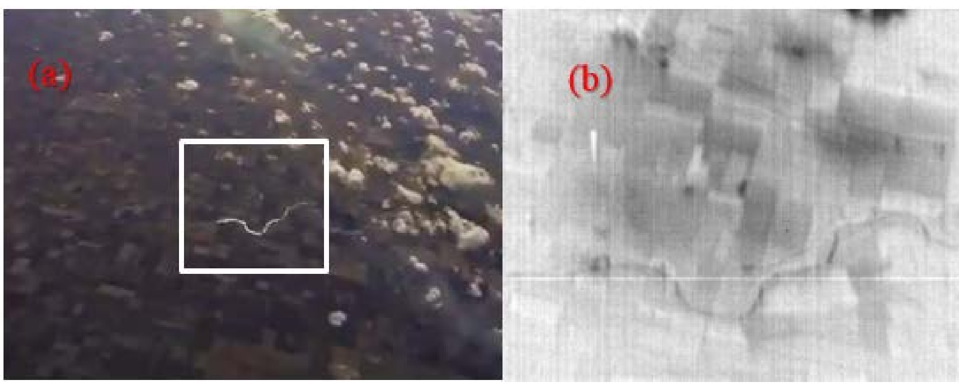


Figure 69. The visible and IR scenario at 11:52:52 in flight

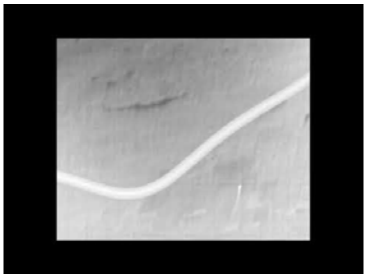
These images were obtained at 11:57:52, in an altitude about 17,400 meters. For this snapshot, it was easy to perform the correlation between the images because we can easily recognize the river (bright line on the visible image and dark line on the IR image). However, it was not that easy most of the time.

Given the fact the IR camera was not able to capture a high-resolution image from the scenario, all details were relevant to build the scene. The sun was very harmful to the sensor as we can see in Video 5, which is available on YouTube: https://youtu.be/je9rZdY33HM). The problem happened always when the sun was perfectly on the center of the cameras FOV. It is easy to note the sun just at the image center on the CMOS camera, as shown in Video 6—available on YouTube at https://youtu.be/WqyfSC2WIew. The videos were slowed down in order to show more details about the problem.

Video available on YouTube at https://youtu.be/je9rZdY33HM.
Video 5. Second flight, first sun mark IR camera

Video available on YouTube at https://youtu.be/WqyfSC2WIew.
Video 6. Second flight first sun mark CMOS camera

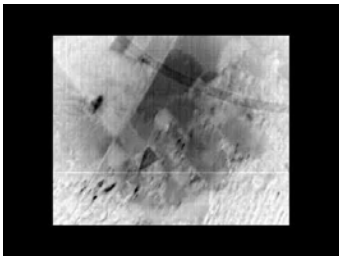
As shown on Videos 5 and 6, only at the second time when the sun appeared on the camera's FOV, a line was created on the IR video. This happened because only at the second time the sun was at the center of both cameras' FOV. We performed another clip presenting the same problem but at different time. In Video 7 (YouTube from https://youtu.be/ m_ET7iq7MWE) there are two saturation lines registered.



Video available on YouTube at from https://youtu.be/ m_ET7iq7MWE.
Video 7. Second flight second sun mark IR camera

The IR camera did automatic calibration few times during the flight. This was helpful whenever happened and is shown in the beginning of Video 9 (YouTube https://youtu.be/ V5raZKDmnOs). This video basically shows the performance of the IR camera on the last minute of working, from 11:57:33 to 11:58:33, and from 17,100 to 17,700 meters of altitude. Video 8 (YouTube https://youtu.be/FMRhaLWpCvM) was provided as a comparison parameter, due to the fact both are synchronized and slowed down to increase the details that can be seeing by the viewer.

Video available on YouTube at https://youtu.be/FMRhaLWpCvM.
Video 8. Second flight from 11:57:33 to 11:58:33 CMOS camera



Video available on YouTube at from https://youtu.be/ V5raZKDmnOs.
Video 9. Second flight from 11:57:33 to 11:58:33 IR camera

4. Lessons Learned from the Images

In order to provide a graphical timeline and help to explain the basic components behavior of the HAB payload, we built a Timeline Scale in Figure 70 indicating the main events and times as happened in flight.

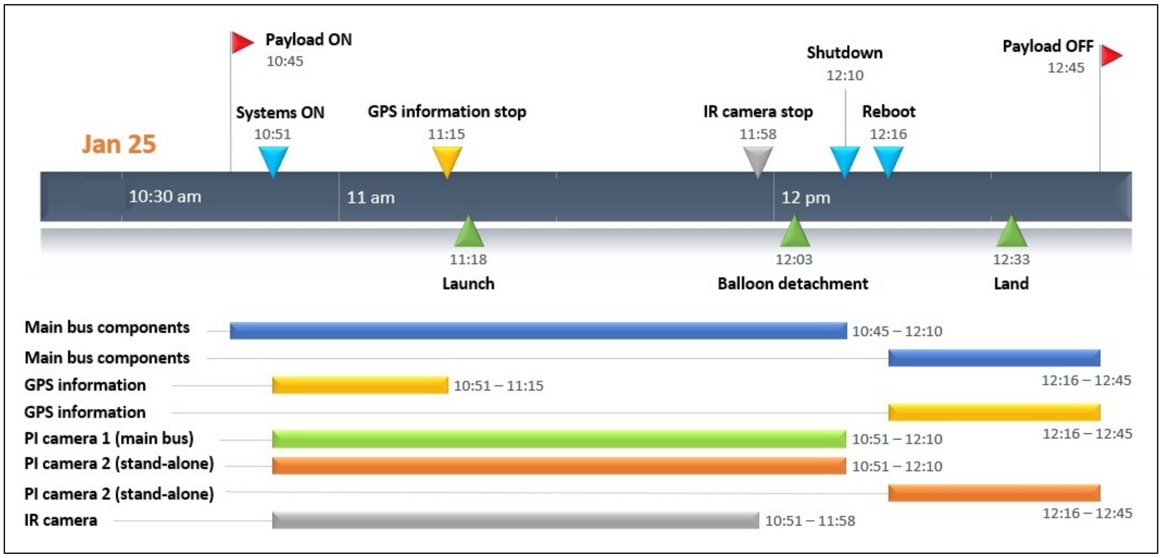


Figure 70. The Timeline Scale for the events in second flight

Both Raspberry Pi cameras worked well and were able to comply with the needs of the project. Despite the fact the bus camera stopped after 12:10, it was irrelevant because we registered all images we expected from that camera. Without the balloon, this camera was not useful. About the IR camera, we can say it functioned well, but not as expected. Even if the HAB payload was able to reach the aimed altitude (33,000 meters), the IR camera would not be able to record, given the fact it stopped when the payload was about to cross 18,000 meters of altitude.

Moreover, the IR images were affected by the lack of stabilization. When the payload performed quick movements in flight, the images were blurred and indicating that the camera settings must be adjusted for high dynamic sequence of events (higher frames per second). Also, image averaging, self-calibration and other parameters must be investigated in order to improve the images. Despite these problems, we could verify that the software protection worked well, since the camera operated more than one hour without any problem. The IR camera stopped at 11:58, as we can see on the Timeline, and this problem was probably caused by the power supply and not specifically by the camera. The voltage registered at 11:58, as we can see in Figure 61 and 62, was around 5.6V for batteries and solar panels, and this was exactly the value that the camera stopped on the tests.

D. FINAL THOUGHTS

The second flight results were a little more substantial than the ones obtained on the first flight. From the problems observed we could obtain many valuable lessons learned described as follows.

The preparation phase was short and dedicated to implement the possible changes to improve the results obtained on the first flight. The problem with the parachute release mechanism was addressed with a new 3D printed component. A new wireless Raspberry Pi board was used in order to allow the access of information from the main payload about the cameras on the launching site. This solution was very efficient and could be considered the most considerable improvement for this flight. Important changes on the IR camera software were performed to increase its robustness. It was proved on the tests that it was effective. The tests were very conclusive and increased the understand on the power supply limitations.

The planning phase was satisfactory. The operation itself was not as expected due to the early balloon detachment, the GPS failure and the uplink commands that never reached the main bus. The jet stream turbulence is believed to be the cause of the balloon detachment, which lead to the conclusion that the HAB flights should be scheduled during seasons when the jet stream is less severe.

The GPS behavior should be better investigated. The malfunction on the test performed hours before the launching could be an indication of potential future failures. We believe the best option is to replace the device, nevertheless, if it is not an option, we should at least investigate the reasons for the recurrent loss of connection. The GPS information is the most important telemetry data, not only for the recovery operation, but also for data analysis. Without GPS, the backup option was the SPOT Tracker, however, it did not work well. We were waiting for a stop message at the landing site that never came. The SPOT sometimes did not send the stop message and that was the case. If the payload did not move, we were not able to localize the payload using SPOT information.

We had the opportunity to use two different approaches trying to overcome the command uplink problems. On the first flight we had only one Cosmos Operator sending the commands at a time, whereas on the second flight we decided to have all operators sending at the same time. This was planned because one Cosmos Operator should have better line of sight than other. This measure was adopted to increase the chance of a successful uplink. Both approaches were not totally ineffective, since we could command the parachute release on the first flight, but the system is not reliable at all. The downlink seems to work much better than the uplink. More outside tests and range measurements should be performed in order to decide how to improve or replace this system.

The most impacting problem that happened on the second flight was the power supply malfunction. The low temperatures at higher levels of altitude were the cause of the low voltage observed on the payload. This voltage was not high enough to sustain the payload and it caused the system shut down during the flight. From 12:10 to 12:16 all systems were not available. The IR camera was affected earlier than the others, because it would not work below 5.6V as demonstrated on tests. It also did not reboot as expected, given the fact the voltage was still below at the reboot time. The solar panels were not able to provide the required amount of energy to back up the batteries at that level. To prevent that problem to happen again, the power supply system (batteries and solar panels) should be redimensioned.

The cameras behavior in flight was another point to mention. The Raspberry Pi camera controlled by the main bus, even though it was able to accomplish its mission, it should be able to reboot as the other electronic components after the shutdown. A software protection should be implement to address this problem. The Raspberry Pi camera stand-alone presented a better operation result, since it worked well during the flight and was able to reboot as expected following the system procedure.

As it can be notice from the IR videos presented on this work, the sensor saturation is a considerable problem faced by the IR camera. This feature needs to be tested and adjusted in order to prevent to happen again in future flights. The sensor gain is the first parameter to be changed, but it would be better if a direct exposure to the sun was prevented.

VIII. CONCLUSIONS AND RECOMMENDATIONS

The previous seven chapters were used to report information collected from two HAB flight experiments performed as part of the THz Project effort at NPS. Chapter I showed the connection between this work and the THz Project sponsored by DoD-Space. In Chapter II, the HAB flight design was described and the explanation about the configuration selected was provided. In Chapter III, the components of the selected configuration were described in detail. Chapter IV was used to describe the first HAB flight sequence of events, and Chapter V analyzed the results obtained from this flight. Chapter VI and Chapter VII were used as well to describe the events and results from the second flight. Given the fact that the objective of this work was to study the integration of to a HAB payload, as well as to understand the camera operation / limitations during HAB flights, we can say that it was accomplished as proposed.

The last step of this work is dedicated to review the results and to recommend improvements that are necessary to increase the efficiency and reliability of the testing platform.

From the lessons learned on the first flight we could apply three relevant modifications for the second flight, which we could obtain positive results. The first and more considerable was the wireless connection with the Raspberry Pi stand-alone. The second was the time synchronization that was only possible because of the wireless connection. This improvement was essential for the images interpretation. The third was the sleeve designed as a protection for the parachute actuator, preventing the contact between the rubber band and the actuator axis. Our suggestion is to apply those modifications as standard components.

From the problems experienced on the second flight, some considerations can be made. About the power supply problem, the best way to address it is to protect the battery box from low temperatures. A sealed box or a temperature protected one (based on multi-layer insulation) might be the most efficient way to prevent the voltage decay at high altitude. Another possible solution is the use of heaters to increase the temperature when needed. In this case a compromise between power and weight should be considered.

Another crucial improvement necessary is related to the telemetry system. Our suggestion is to focus on a long session of tests on the ground at different distances and then a short flight test performed by a drone carrying on a reduced payload in order to test the uplink efficiency and the commands execution, since the telemetry control system was not efficient enough during the experiments. Analysis of new and more powerful radios / ground stations also should be performed in order to verify if the current system needs to be replaced.

For instance, another drone, probably a special one, should also help in the recovery operation. In cases where the payload landed in a private property, like it happened on the second flight, a drone can recover it if the area is not inhabited or just fly over it to take pictures in order to reduce the time spent on the recovery operation. This idea can also be used in areas with restricted access, like mountains or swampy regions.

This thesis also recommends a deep research on stabilization devices. The lack of stability during flight increased considerably the difficult to correlate and interpret the IR images. The proposed body fins were not as efficient as expected, but they should be used as a starting point. It is clear that is not possible to prevent the wind effect in flight, but the objective should be the reduction of this effect to an acceptable value, allowing better results.

This study definitely recommend that the flights should be scheduled in more appropriate seasons of the year when the jet stream is not very intense. It is necessary to increase the probability of success when the aimed altitude is above 20,000 meters. On another note, for navigation purposes, an application should be implemented to indicate the best route on the ground during the chasing operation. In this context, the received GPS coordinates could be used directly by this application, that would provide the best route for chasing the payload. This capability reduces to only two people the minimum crew on each chasing car.

The Cosmos System also should be able to transform the barometric pressure information in altitude in order to have a secondary information of altitude, which would be very useful in case of GPS failure. Those changes are not hard to implement; there might be some software for that purpose already available on market. The SPOT Tracker is another possibility of improvement, since the stop message sometimes are not received. My suggestion is to use in the future flights the new model (SPOT Gen3) which is available at the SSL. The shape is a little different and the mount should be customized, but it probably works well and might increase the reliability of the system.

The IR camera, being the most sensitive device of this project, should be the focus of attention. The configuration used for the second flight was just a starting point and should be tested and proved before establish a standard for this type of flight. All items listed in Table 2 should be better understood and well-tested to define the optimum configuration. Besides that, there are some modes of operation like the Averager Mode (mode that uses the average value of the pixels for consecutive frames) that should be also tested. The sun mark on the screen is another problem to be studied very carefully. We suggest a deep investigation about all possibilities this camera is able to provide as a very first step for the next flight.

All things considered, even though the experiments were not able to cross the jet stream level in both flights, we evaluate the experiment as a concrete success. The hypothesis could be validated since efficient ways to integrate an IR camera in a HAB payload were successful tested. Several lessons were learned as well as many steps forward on the integration of a new functionality to the HAB payload. All aspects of designing, assembling, planning, executing and leading the flight operation were instrumental for the improvement of the future similar endeavors at the SSL and the future of the THz sensor development for space applications.

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APPENDIX A. ASSEMBLY / DISASSEMBLY PROCEDURES

A. DISASSEMBLY PROCEDURE

Considering a HAB payload after flight, the procedure starts from the external components to the basic structure passing through all electronic components and 3D printed parts. First, we need to have places labelled to put the small components to avoid missing these parts. The large pieces were already labelled (+/- x, y, z) and we did the same with new parts that were designed for this flight. It is important to constantly check if surfaces and components are labelled and are being grouped on the same location to be easier to perform the assembling procedure. Additionally, ever wire connection should be labelled too to ensure a clear process of reconnection. The disassembling process was carefully described in the following sections:

1. Remove Parachutes

It is just to detach the parachute cords from the actuator connection point because the rubber band is already disconnected after the main parachute release command / automatically release of the backup parachute during flight (Figure 71).

Figure 71. Removing parachutes

2. Remove Body Fins, Antenna, and Solar Panels

To remove the body fins is just unscrew the surface from the HAB payload. They are just six external connections. The antenna is very easy to disconnect from its connection point and the solar panels is just unscrew as well from the holding points (Figure 72).

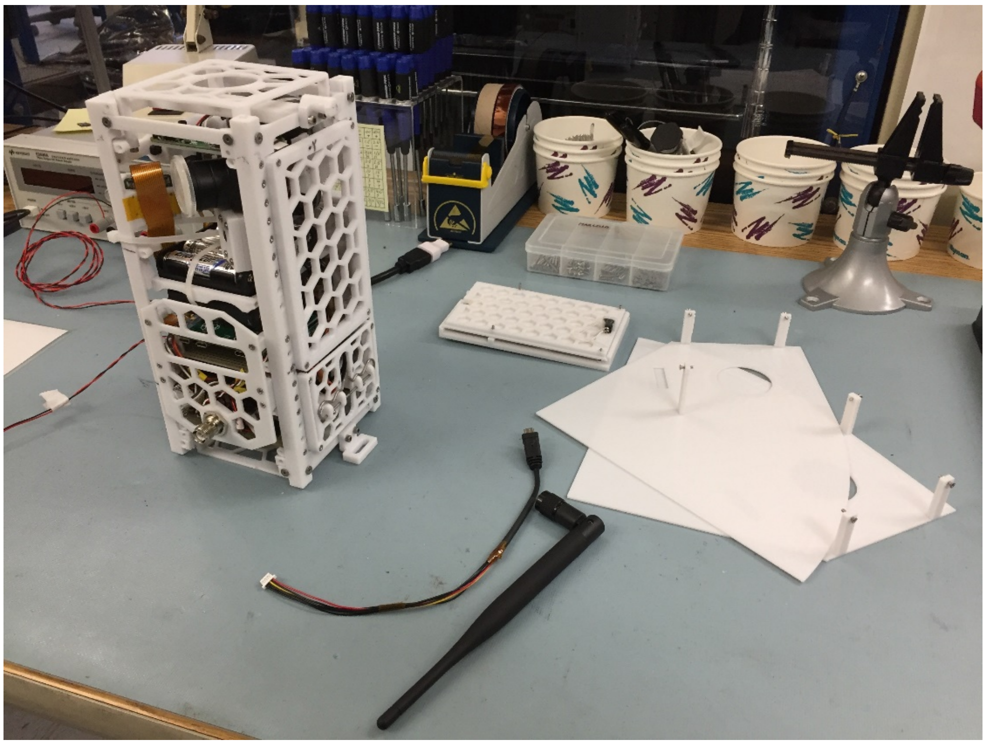

Figure 72. Removing body fins, antenna, and solar panels

3. Remove Side Panels

This is the next step in order to have access to the electronic components inside the HAB payload. It is just to unscrew the side panels holding points as well (Figure 73).

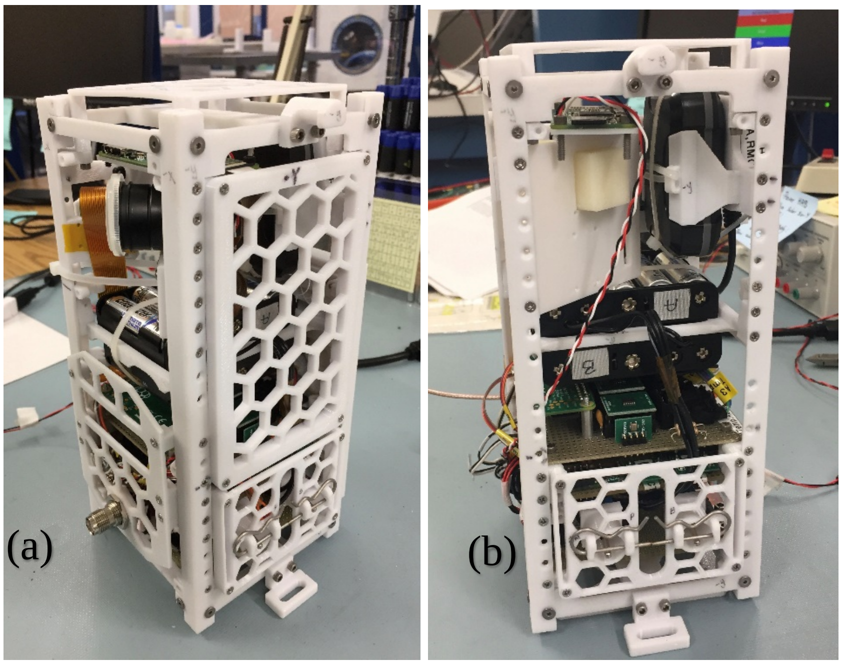

Figure 73. Removing side panels

4. Remove Main Payload, Power Switch Plate, and Battery Pack

This step is basically a starting point for the electronic parts of the HAB payload. The main payload is hooked to the chassis in six points and have the most important devices attached on it. The designed connection is simple (six screws) and uses a 45 degrees angle to point to the horizon during flight. The power switch plate is almost like a side panel but it has several cables to connect the panel to the power sources on the HAB payload. Besides unscrew the panel, we need to disconnect all cables to remove this part. The battery pack is connected to the chassis in three points and has cables for other connections. The connection with the power switch plate does not have a terminal to disconnect. To remove it is just unscrew the holding points and disconnect the cables (Figure 74).

Figure 74. Removing battery and power switch plate

5. Remove Main Bus Raspberry Pi Camera and Board Cables

The main bus Raspberry Pi camera is attached to the chassis in two holding points and its cable is connected to the Raspberry Pi Zero board, the heart of the main bus. The camera’s cable is the hard part of this step because the connection inside the board is very fragile. We need to be very careful during the disconnection to avoid any damage. All cables are correctly labelled and can be remove without worried about where we should group them. The only concern is about the terminals because they are also fragile and have to be carefully manipulated (Figure 75).

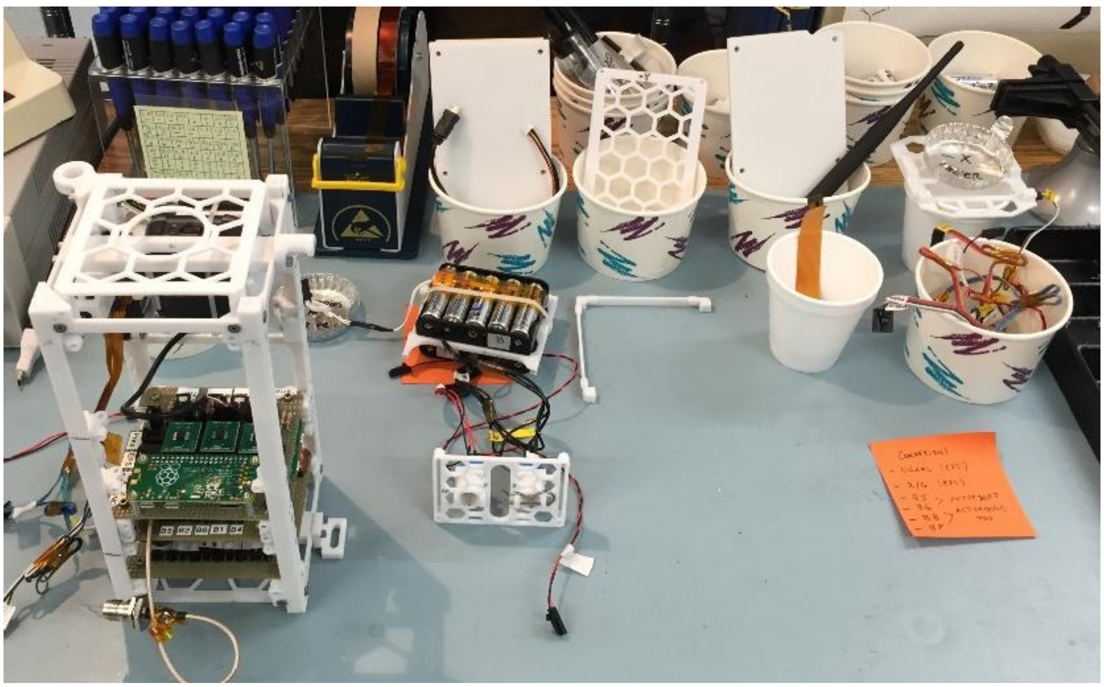

Figure 75. Removing Raspberry Pi camera and board cables

The C&DH is the electronic board where the main bus Raspberry Pi board is installed. This device is like a sandwich of two plates where we have many electronic components connected to. It is connected to the chassis by four corners and the plates are connected between each other by four 3D pieces used to determine the distance between them. Those four 3D pieces are also attached to the chassis. To remove it is just unscrew the corners and the 3D pieces from the chassis. In Figure 76 (c), we can see the upper part with the Raspberry Pi Zero on the right and the lower part with the 3D pieces on the left.

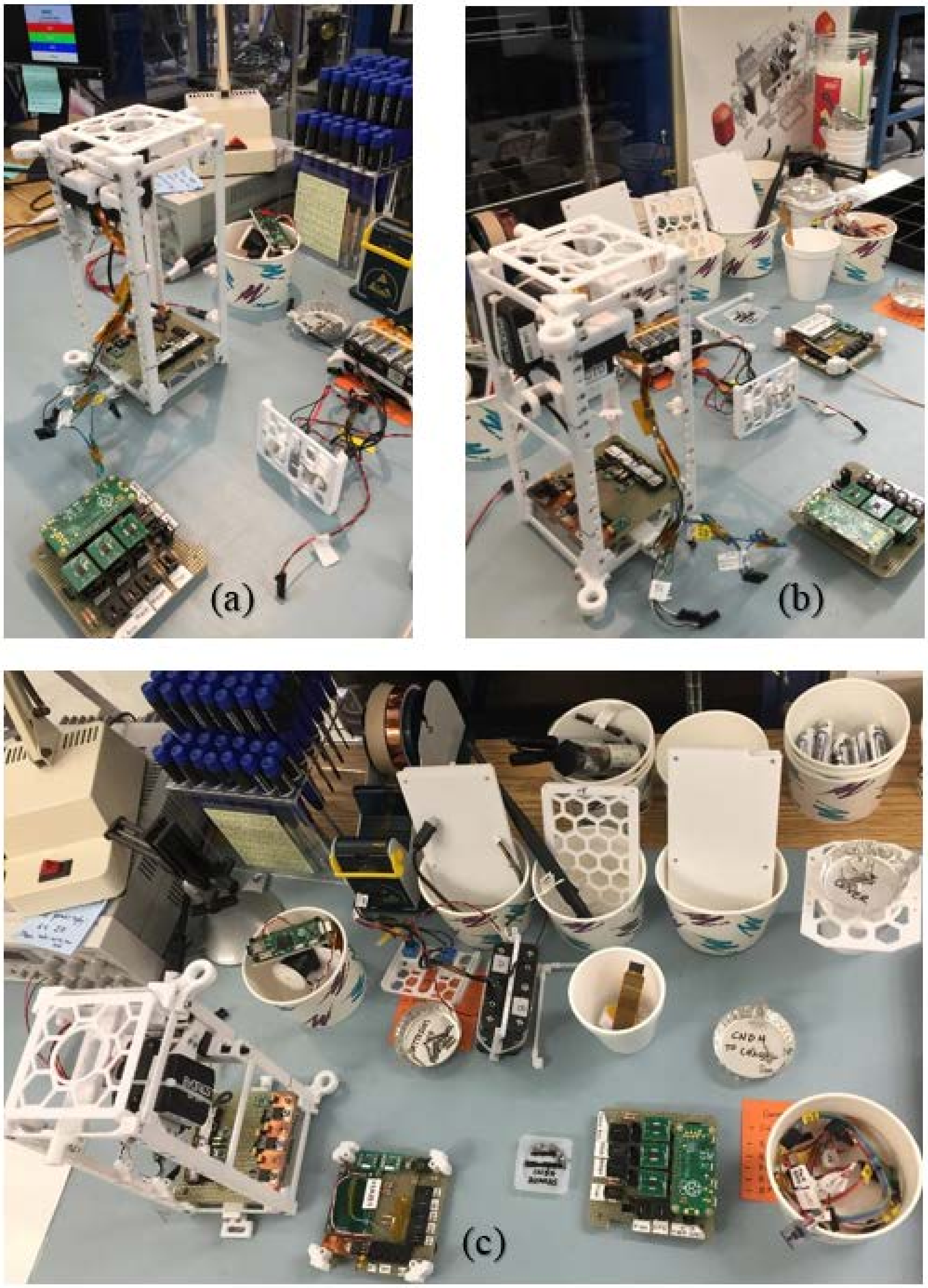

Figure 76. Removing C&DH board

6. Remove Actuators, GPS, and EPS Board

After removing these components, the only parts of the HAB payload structure left were the four supporting frames. To remove the actuators and the GPS is just unscrew the holding points. The EPS board requires a little more working time because it is connected to the lower cover (like a table) used to attach the parachute. We need to remove this structure before remove the corners to release this board (Figure 77).

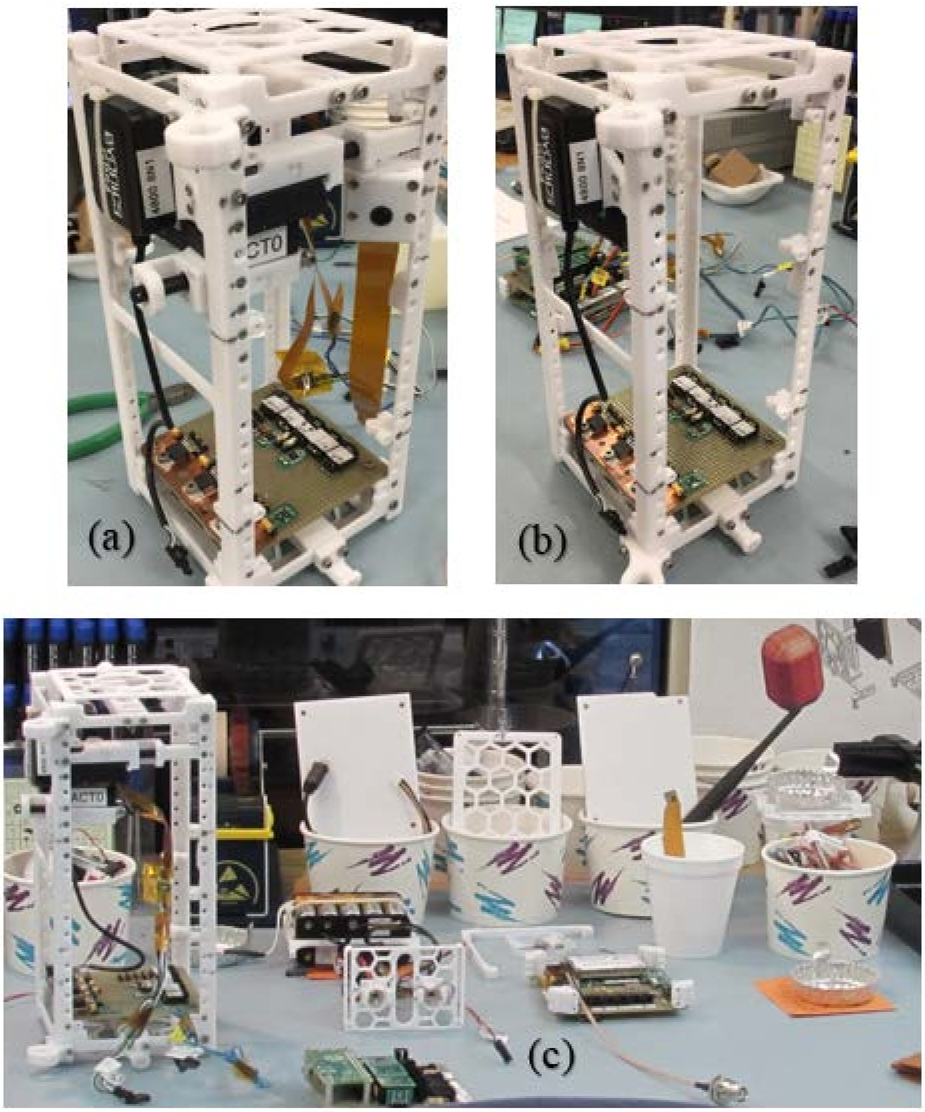

Figure 77. Removing actuators, GPS, and EPS board

B. ASSEMBLY PROCEDURE

With all components grouped and organized on the bench table, we can easily start the assembly procedure. The sequence is just the disassembly process in reverse and we can see below the pictures of the last assembly process we did before the first flight (Figures 78 to 86). We also registered all procedures executed into Video 10 (YouTube: https://youtu.be/gEfDP7qOgZ4) and 11 (YouTube: https://youtu.be/L1EAmb8XPfw).

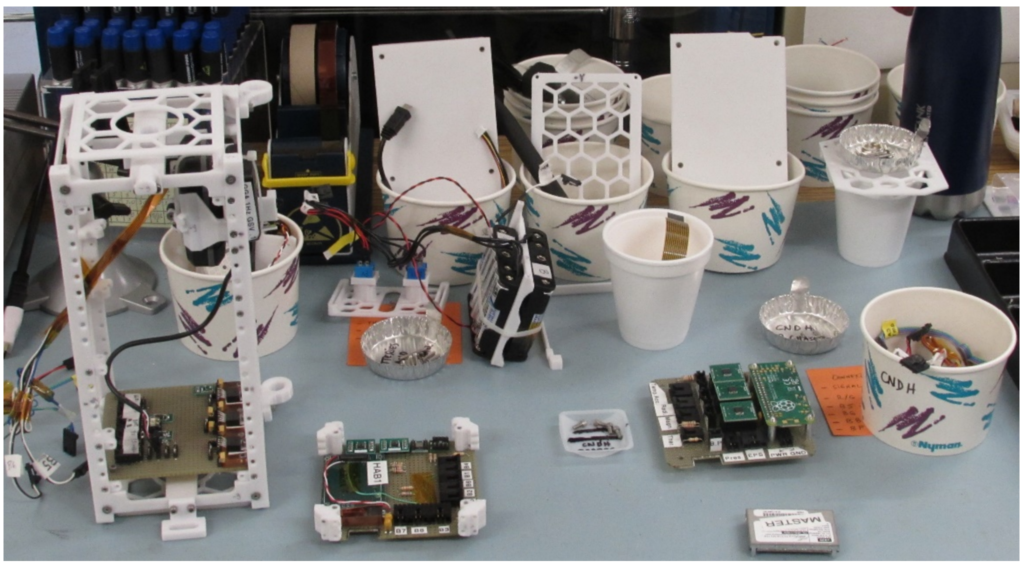

Figure 78. Assembling actuators, GPS, and EPS board

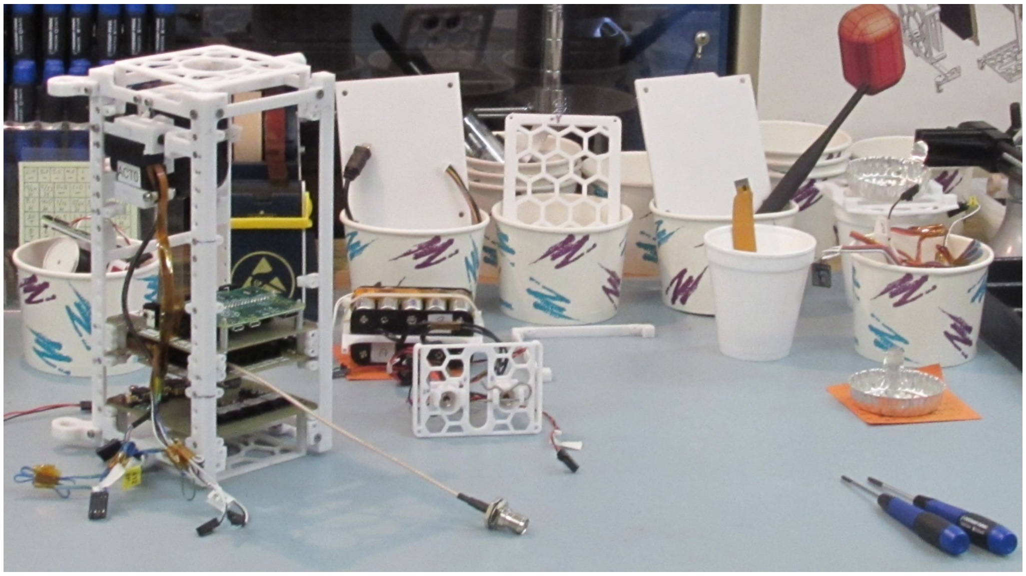

Figure 79. Assembling C&DH board

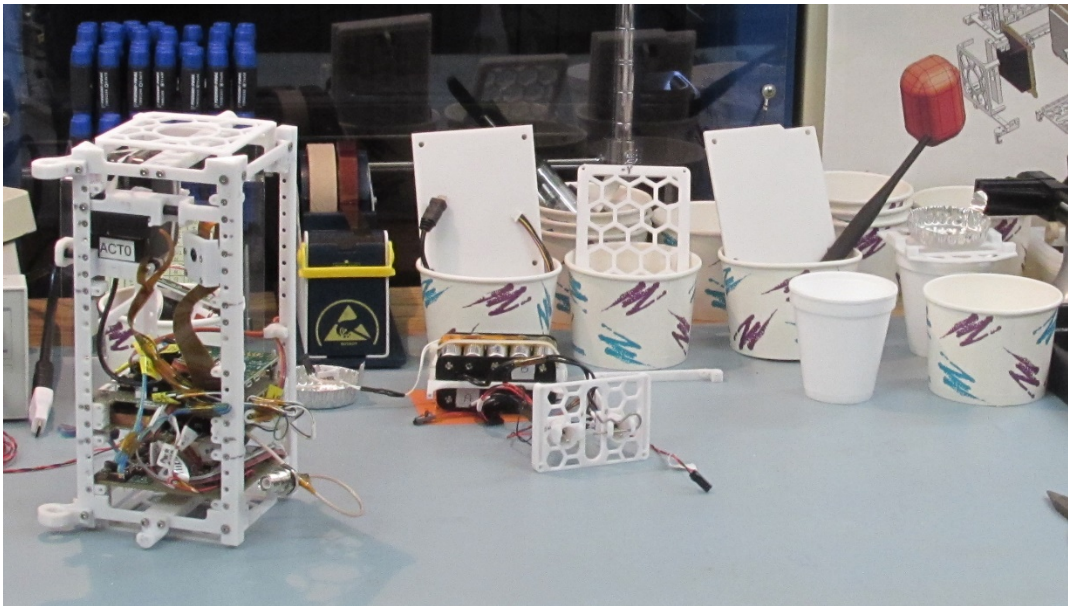

Figure 80. Assembling the Raspberry Pi camera and board cables

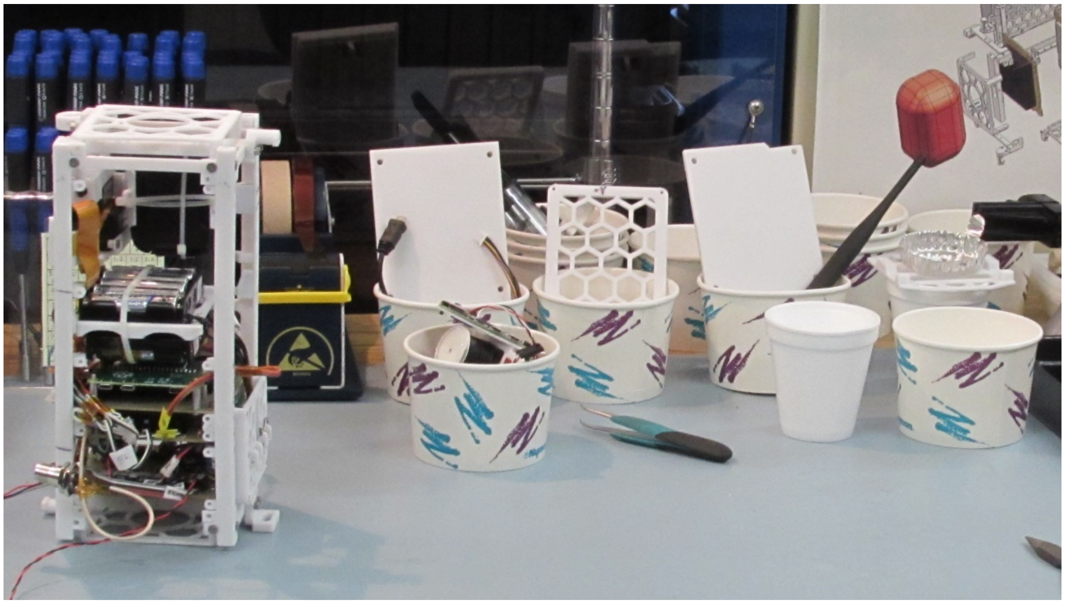

Figure 81. Assembling the battery pack and power switch plate

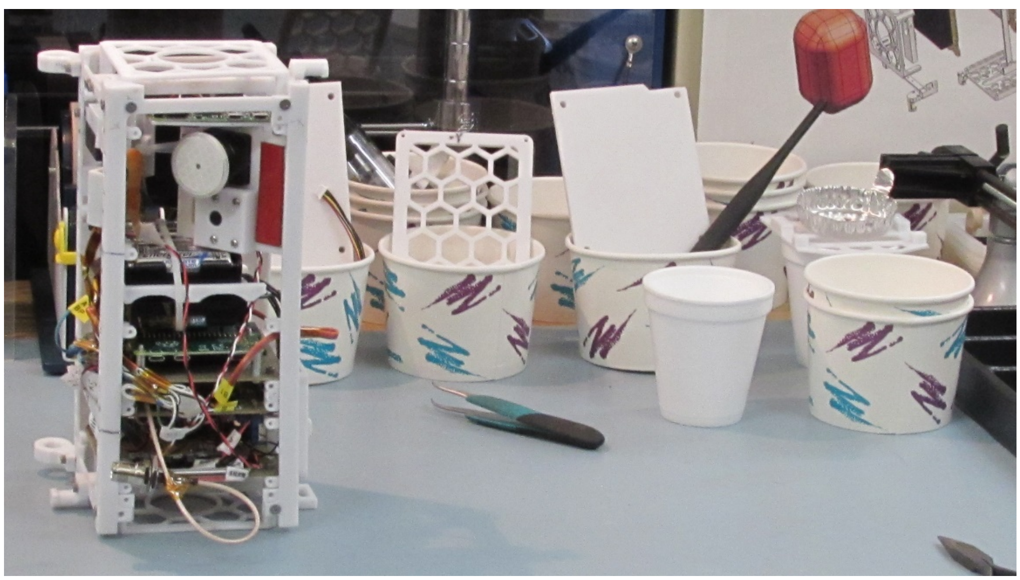

Figure 82. Assembling the main payload

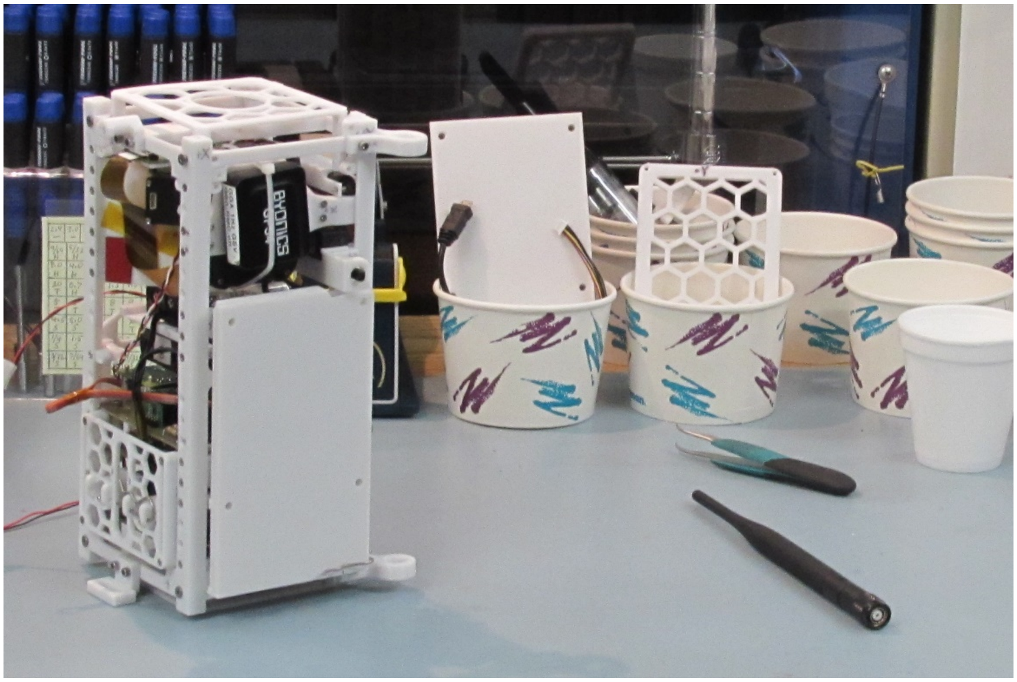

Figure 83. Assembling solar panels

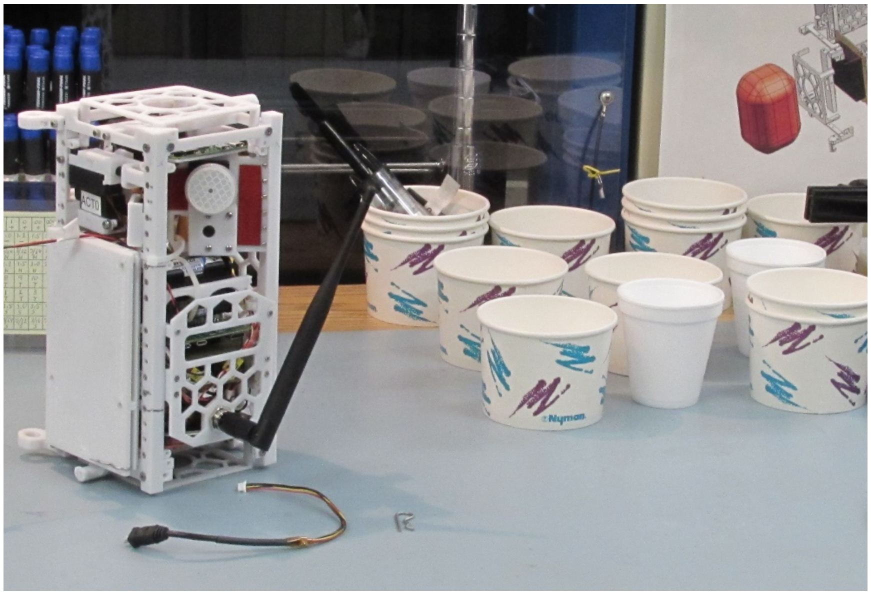

Figure 84. Assembling side panels and antenna

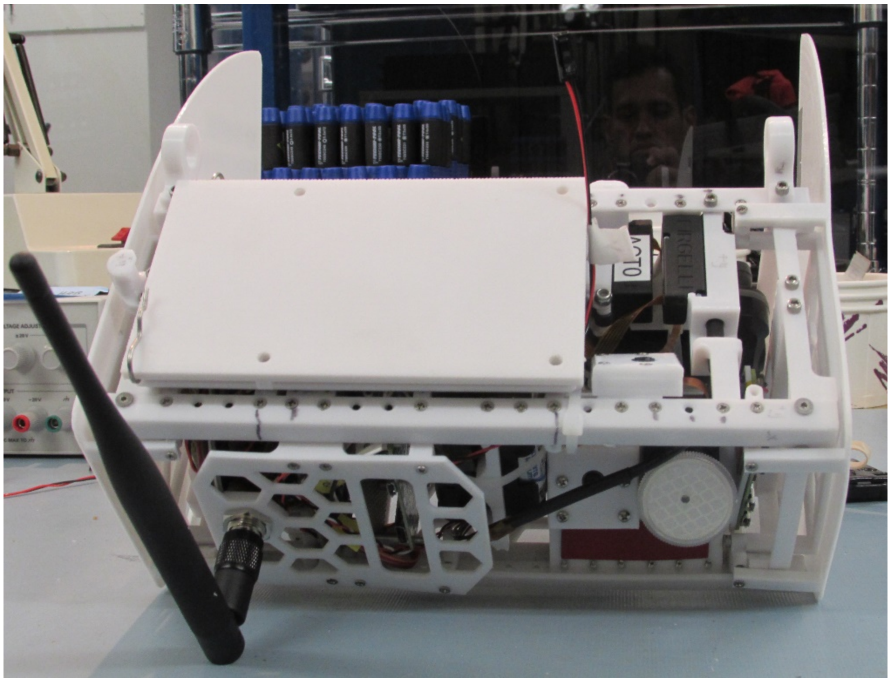

Figure 85. Assembling the body fins

Figure 86. Assembling parachutes and removing solar panels protection

Video available on YouTube at https://youtu.be/gEfDP7qOgZ4.

Video 10. Assembling process

Video available on YouTube at https://youtu.be/L1EAmb8XPfw.

Video 11. Assembling process accelerated

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APPENDIX B. CHECKLIST

A. BEFORE LAUNCH CHECKLIST

1. T-72 hours

Task During Briefing (72h before flight):	POC	Initial When Complete, Date/Time
Determine for launch day: ☐ Car assignments ☐ Master Check List Manager w/ clipboard ☐ Coffee/Donut grabber ☐ Packing listed items ☐ Program Manager ☐ Time Keeper ☐ Create recall roster / text group		
Review HAB HUB analysis (launch/land sites)		
Ensure power inverters work in chase vehicles		
After Briefing:		
Conduct rehearsal on campus ☐ Practice balloon fill ☐ Knot tying for 50 lbs. test ☐ Practice setting up a ground station by setting up a pelican case in a car		
Review launch day procedures		
Email out Flight Readiness Review Timeline/ Location		

2. T-48 hours

Task	POC	Initial When Complete, Date/Time
Prepare for Flight Readiness Review		
Review launch day procedures		
Conduct HAB HUB analysis, continue to keep eye on tentative launch site		

3. T-24 hours

Task	POC	Initial When Complete, Date/Time
Conduct testing on HAB payload ☐ Turn on battery power ☐ Turn on PV power (only if conducting outside testing with solar panels; if indoor testing and solar panel are covered, no need to turn on PV power) ☐ Watch for radios to lock (three green lights) ☐ Ensure data packets received at ground station o Verify actuator voltages close to 4.9V o Verify battery voltages close to 7.2V ☐ Test balloon release mechanism o Send command from COSMOS ☐ Test parachute release mechanism o Send command from COSMOS ☐ Test main bus camera o Video on command function on COSMOS o Verify message on COSMOS shows available bytes decreasing o Video off command function on COSMOS ☐ Test other cameras ☐ Turn SPOT trace on o Verify on phone apps the SPOT is sending data and the app is receiving ☐ Verify GPS locks (sometimes takes a few min) ☐ Check backup parachute batteries		
Thread nylon cord into HAB payload ears/holes		
Put new batteries in battery pack		
Re-test with new batteries o Turn HAB payload battery power switch on o Verify voltage of batteries (7.2V) using COSMOS o Power source off and lock for transportation		
Review launch day procedures and assigned roles		
Conduct Flight Readiness Review		
Conduct HAB HUB analysis of launch sites		
Document final weight of HAB payload ☐ Weight:___________		
Verify COSMOS and Teraterm running on both laptops for chase vehicles		
Pack pelican cases		

Fill chase vehicles with gas		
Attach tag to HAB payload with contact information in case of poor landing location		

B. LAUNCH DAY CHECKLIST

Time	Task	Initial complete w/ time
T-4:00	Get final HAB HUB prediction / launch site confirmation ☐ Print copies for chase vehicles	ROUTE TEAM
T-4:00 (00:30)	Cameras final Test on campus ☐ Erase all data	PAYLOAD TEAM
T-3:45	Turn SPOT Tracker ON	MAIN BUS TEAM
T-3:45 (00:30)	Properly attach parachutes	BALLOON TEAM
T-3:15	Meet at NPS (quick donuts and coffee)	ALL
T-3:00 (00:15)	Last Minute Briefing	ALL
T-2:45 (00:15)	Grab Pelican Cases (check items) go to chase vehicles Power up ground station: ☐ Run TERATERM ☐ Run COSMOS ☐ Open applicable windows: o Command and Telemetry Server o Command Sender o Telemetry Viewer	GROUND STATION TEAM
T-2:30 (00:30)	Test COMMS between HAB payload and the laptops: ☐ Turn on HAB payload with battery switch ☐ Ensure packets are received on COSMOS laptops ☐ Go to top Spanagel Hall to do altitude test ☐ Shut down HAB payload with command on COSMOS ☐ Lock power switch in off position on HAB payload	GROUND STATION TEAM
T-2:30	Ensure all balloon equipment on board	BALLOON TEAM
T-2:00	Finish packing cars, depart (for approx. 2 h drive): ☐ See PACKING LIST	ALL
T	Arrive at launch site	ALL
T	Turn on Go-Pro for launch time-lapse	PHOTOGRAFER
T T	Unload equipment Set up table	PAYLOAD TEAM

T	Set up helium tanks	BALLOON TEAM
T	Power up ground stations	GROUND STATION TEAM
H-0:40 (00:15)	Power up HAB payload: ☐ Take off solar panel covers ☐ Take off camera's cover ☐ Turn on battery power ☐ Turn on PV power ☐ Lock power switches in on position ☐ Watch for radios to lock (three green lights) ☐ Ensure data packets received at ground station: o Verify actuator voltages close to 4.9V o Verify battery and PV voltages close to 7.2V ☐ Verify GPS locks (sometimes takes a few minutes): o Verify GPS time synch, ensured by message on COSMOS ☐ Confirm position received on SPOT APP	MAIN BUS TEAM / GROUND STATION TEAM /
H-0:25 (00:05)	☐ Turn on Auto Mechanism on backup parachute ☐ Tether balloon to HAB payload	BALLOON TEAM
H-0:20 (00:10)	Cameras final Test off campus: ☐ Verify cameras working (remaining bytes decreasing)	GROUND STATION TEAM
H-0:10 (00:10)	Fill balloon with the helium tank: ☐ Fill time/Pressure: _________/________ ☐ Tape balloon closed (ensure no leaks)	BALLOON TEAM
H	Go/No go for launch: ☐ Program Manager gives final decision, confirms with master checklist manager	PROGRAM MANAGER
H	Launch ☐ Time: __________ ☐ Lat/Long: ________________________	CK LIST MANAGER
TBD	Pack-up launch site and go mobile	ALL
TBD	Watch COSMOS and track HAB payload's progress	CHASE VEHICLES
TBD	For retrieval ☐ Send command via COSMOS to release balloon o Time: __________ ☐ Release confirmation (0.00 V on the actuator) o Time: __________ ☐ Send command via COSMOS to release parachute o Time: __________ ☐ Release confirmation (0.00 V on the actuator) o Time: __________	COSMOS OPERATOR

TBD	If COSMOS commands are not going through: ☐ Ensure communication is clear between cars about the command failures ☐ Send commands via Tera Term ☐ Take note about the times ☐ Turn on Log o File/Log, save to Desktop with current date	COSMOS OPERATOR
TBD	Land ☐ Time: ___________ ☐ Lat/Long: ______________________	CK LIST MANAGER

C. AFTER-FLIGHT CHECKLIST

1. After Land on Site

Time	Task	Initial complete w/ time
TBD	Arrive at land site: ☐ Time: ___________	ALL
TBD	Take photos from all angles	PHOTOGRAFER
TBD	Body Damage Check (look for damages on the structure) Turn power switches OFF (battery and PV)	MAIN BUS TEAM
TBD	Put camera's covers on Put solar panel's covers on	PAYLOAD TEAM
TBD	Remove parachutes	BALLOON TEAM
TBD	Put payload on the Pelican case	PAYLOAD TEAM
TBD	Return to NPS	ALL

2. After Land on Campus

Time	Task	Initial complete w/ time
TBD	Debriefing at SSL	ALL
TBD	Measure batteries remaining charge: ☐ Main batteries: _______________ ☐ SPOT batteries: ______________ ☐ Backup parachute batteries: _____________ Measure Solar Panels efficiency	MAIN BUS TEAM
TBD	Download the data Disassemble the payload (if required)	PAYLOAD TEAM

TBD	Disassemble the main bus (if required)	MAIN BUS TEAM
TBD	Upload data and photos on the Sakai site	PAYLOAD TEAM

APPENDIX C. LAUNCH DAY TIMELINE

A. FIRST FLIGHT

TIME	EVENT
07:28	SSL Launch Day Briefing
08:32	GPS Test from Spanagel Rooftop
08:39	NPS Departure
10:29	Team Arrival at Launch Site
10:35	Tables Setup
10:45	Clear Video / Video On commands
10:55	HAB Payload Shutdown (No GPS connection)
10:57	HAB Payload Turn On
11:05	GPS signal after HAB Payload Reset
11:13	HAB Payload Video ON from Cosmos (Manual Command worked)
11:13	Helium Fill Start
11:31	Launch Time
12:22	Start of Unplanned Descent
12:26	11,500m First Release Balloon Command Sent
12:36	5,200m First Parachute Command Sent
12:45	Balloon Released (0.00 Volts on Actuator)
12:49	Last GPS Update (probable land site)
13:05	First team arrival at Land Site

B. SECOND FLIGHT

TIME	EVENT
07:15	SSL Launch Day Briefing
08:30	GPS Test from Spanagel Rooftop
09:06	NPS Departure
10:26	Team Arrival at Launch Site
10:32	Tables Setup
10:45	HAB Payload Turn ON
11:01	Helium Fill Start
11:15	GPS loss of signal
11:18	Launch Time
11:58	IR Camera Stop
12:03	Balloon Detachment
12:10	Payload Shutdown
12:16	Payload Reboot
12:33	Land site
13:14	First team arrival at the Gate Locked

APPENDIX D. REMARKABLE PARAMETERS

A. FIRST FLIGHT

<table>
<tr><th>TIME</th><th>PARAMETER</th></tr>
<tr><td>07:05</td><td>Document final weight of HAB payload. Weight: <u>3.40 + 0.25 = 3.65 lbs.</u>



</td></tr>
<tr><td>11:31</td><td>Launch site
Lat/Long: <u>37.1491 / -120.4589</u> <u>(40m)</u>
<table>
<tr><td>11:31:55</td><td>1.51E+09</td><td>37.1491</td><td>-120.459</td><td>40</td><td></td><td></td><td></td><td></td></tr>
<tr><td>11:31:56</td><td>1.51E+09</td><td>37.1491</td><td>-120.459</td><td>40</td><td>+7.02 +6.9</td><td>6.96</td><td>+7.08 +7.1</td><td>7.15</td></tr>
<tr><td>11:31:57</td><td>1.51E+09</td><td>37.1491</td><td>-120.459</td><td>40</td><td></td><td></td><td></td><td></td></tr>
<tr><td>11:31:58</td><td>1.51E+09</td><td>37.149</td><td>-120.459</td><td>45</td><td></td><td></td><td></td><td></td></tr>
<tr><td>11:31:59</td><td>1.51E+09</td><td>37.149</td><td>-120.459</td><td>46</td><td></td><td></td><td></td><td></td></tr>
<tr><td>11:32:00</td><td>1.51E+09</td><td>37.1491</td><td>-120.459</td><td>49</td><td></td><td></td><td></td><td></td></tr>
<tr><td>11:32:01</td><td>1.51E+09</td><td>37.1491</td><td>-120.459</td><td>52</td><td></td><td></td><td></td><td></td></tr>
</table>
</td></tr>
</table>

12:21

Maximum Altitude: **18,130m** (log file)

12:21:05	1.51E+09	36.9209	-120.284	18091					
12:21:08	1.51E+09	36.9207	-120.284	18120					
12:21:09	1.51E+09	36.9206	-120.284	18130					
12:21:13	1.51E+09	36.9206	-120.284	17910					-29.9
12:21:14	1.51E+09	36.9206	-120.284	17855	+5.47 +5.2	5.26	+5.42 +5.4	5.42	

After Launch

Retrieval

- ☐ Send command via COSMOS to release balloon
  - o Time: **12:26**
- ☐ Received command from log file
  - o Time: **12:32**

12:32:45	2E+09	36.85	-120.2	7578														
12:32:46	2E+09	36.85	-120.2	7568														
12:32:47	2E+09	36.85	-120.2	7557										command <[illegible]barel> received.				
12:32:48	2E+09	36.85	-120.2	7548	+5.18	4.95	+5.20	5.2	-20.2	-33.5								
12:32:49	2E+09	36.85	-120.2	7538														

- ☐ Release confirmation (0.00 V on the actuator)
  - o Time: **12:46**
- ☐ Send command via COSMOS to release parachute
  - o Time: **12:36**
- ☐ Received command from log file
  - o Time: **12:40**

12:40:22	2E+09	36.81	-120.2	3617													
12:40:23	2E+09	36.81	-120.2	3610													
12:40:24	2E+09	36.81	-120.2	3602										command <bal_re_[illegible]jpar_rel> received.			
12:40:25	2E+09	36.81	-120.2	3595													
12:40:26	2E+09	36.81	-120.2	3588													

- ☐ Release confirmation (0.00 V on the actuator)
  - o Time: **12:45**

12:45:50	1.51E+09	36.793	-120.19	1457								4.3		command <bal_rel> received.		
12:45:51	1.51E+09	36.793	-120.19	1452								4.4				
12:45:52	1.51E+09	36.793	-120.19	1445					19.1	4.2		4.4				
12:45:53	1.51E+09	36.793	-120.19	1439								0				
12:45:54	1.51E+09	36.793	-120.19	1433	+6.62	6.54	+6.64	6.58				0		command <bal_rel> received.		
12:45:55	1.51E+09	36.793	-120.19	1426								0				

12:49

Land site

- ☐ Lat/Long: **36.7979 / -120.1911** (43m after stabilization)

\

After Flight

Measure batteries remaining charge:

- ☐ Main batteries: **1.703 V**
- ☐ SPOT batteries: **1.694 V**
- ☐ Backup parachute batteries: **half life**

B. SECOND FLIGHT

<table>
<tr><th>TIME</th><th>PARAMETER</th></tr>
<tr><td>08:15</td><td>Document final weight of HAB payload
Weight: 3.30 lbs.

</td></tr>
<tr><td>11:18</td><td>Launch site
☐ Lat/Long: 37.0749 / -121.0719 (96m)—few minutes before (No GPS)</td></tr>
<tr><td>12:03</td><td>Maximum Altitude: 18,830m (barometric pressure info)</td></tr>
<tr><td>After Launch</td><td>Retrieval
☐ Send command via COSMOS to release balloon
o Time: 12:20
☐ Send command via COSMOS to release parachute
o Time: 12:25</td></tr>
<tr><td>12:33</td><td>Land site
☐ Lat/Long: 36.9496 / -119.5447 (265 m after stabilization)
<table>
<tr><td>12:32:57</td><td>1516912377</td><td>36.9497</td><td>-119.5448</td><td>261</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>12:32:58</td><td>1516912378</td><td>36.9496</td><td>-119.5448</td><td>261</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>12:32:59</td><td>1516912379</td><td>36.9496</td><td>-119.5448</td><td>261</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>12:33:00</td><td>1516912380</td><td>36.9496</td><td>-119.5448</td><td>261</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>12:33:02</td><td>1516912382</td><td>36.9496</td><td>-119.5447</td><td>260</td><td>6.66</td><td>6.47</td><td>6.8</td><td>6.86</td><td>15.3</td><td>2.6</td><td></td></tr>
<tr><td>12:33:03</td><td>1516912383</td><td>36.9496</td><td>-119.5447</td><td>262</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>12:33:04</td><td>1516912384</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>14.3</td></tr>
<tr><td>12:33:05</td><td>1516912385</td><td>36.9496</td><td>-119.5447</td><td>264</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
</table>
</td></tr>
<tr><td>After Flight</td><td>Measure batteries remaining charge:
☐ Main batteries: 1.496 V
☐ SPOT batteries: 1.708 V
☐ Backup parachute batteries: half life</td></tr>
</table>

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APPENDIX E. TELEMETRY COMMANDS FOR TERATERM

act_status obtain actuator status

bal_rel release balloon (open the release mechanism)

close close both balloon and parachute release mechanisms

par_rel release parachute (open the release mechanism)

use_rmc synch system time to GPS time (if no GPS Fix is available)

video_clear clear all video files (must do this when NOT recording video)

video_off turn video on (main bus)

video_on turn video off (main bus)

REBOOT reboot main bus (must send this twice within 30 seconds)

SHUT_DOWN shutdown payload (must send this twice within 30 seconds)

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SUPPLEMENTALS

A. EXCEL CHART DATA MATRIX OF FLIGHT 1 AND 2

Two excel files were provided that contains all data collected on the main bus about the payload during Flight 1 and 2. These data include time, position (lat/long), altitude, battery voltage, solar panel voltage, battery temperature, CPU temperature, and telemetry commands.

In case of interest in obtaining those files, please contact the NPS Library for more information about the procedure.

B. PYTHON SCRIPTS CREATED FOR THE IR CAMERA INTEGRATION

In order to integrate the IR Camera on the HAB Payload, some computer codes were designed in PYTHON language and installed on the Raspberry Pi board stand alone to appropriately control the IR camera. These files were provided to allow any desired replication of this architecture. Part of these files were also used as a software protection to increase the robustness of the system.

In case of interest in obtaining those files, please contact the NPS Library for more information about the procedure.

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