HASP Student Payload Application for 2012

Payload Title: ARIES-GPS		
Payload Class: (check one) X Small ☐ Large	Institution: Inter-American University of Puerto Rico Bayamon Campus	Submit Date: December 15, 2011

Project Abstract

The UIPR is building a CubeSat. Thus each year we develop different sub-system and test them on the HASP platform to evaluate the performance of these sub-systems. This year the goal is to fly and compare the performance of two different dual frequency GPS receivers. The CASES (Connected Autonomous Space Environment Sensors) GPS receiver is a space weather monitor, while the Novatel GPS receiver is a COTS unit. Data collected from these GPS receivers will be used to characterize the line-integrated electron density between the receiver and GPS satellites. The GPS derived total electron content (TEC) will be compared to output from state of the art space environment models, such as the Thermosphere-Ionosphere-Mesosphere Energetics General Circulation Model along the HASP flight trajectory. In addition the data will be employed to observe gravity waves for the parameterization of momentum flux into the stratosphere. Proof of concept atmospheric profiling with GPS radio occultation will be performed. The project will involve 6 undergraduate students under the mentorship of Dr. Hien Vo. The space engineering program at UIPR is supported by a grant from Puerto Rico Space Grant and the government of Puerto Rico to train aerospace workforce for the island.

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Science Objectives

The goal of the ARIES-GPS experiment, proposed herein, is to provide the student team experience in systems engineering and scientific data analysis concepts. The flight opportunity on NASA HASP platform will help the students gain valuable experience in aerospace sciences in general, and particularly in CubeSat technology. An essential of a CubeSat is the GPS receiver because it allows to know where is positioned the payload when the scientific data is collected. The proposed experiment will help the student team to learn a critical skill in utilizing GPS signals to develop position solutions and the time of flight of the payload.

By other hand the GPS technology can be also employed to other scientific objectives such as derive the total electron contain (TEC) and to develop atmospheric profile through the radio occultation (RO) technique. Data acquired from the GPS receiver will be also used for characterization of line-integrated electron density between the receiver and the GPS satellite being tracked. The derived TEC values will then be compared with outputs from state of the art space environment models, such as the Thermosphere-Ionosphere-Mesosphere Energetic General Circulation Model. These types of comparisons are important to validate the model and they provide model developers critical benchmarks for testing their models. The ARIES-GPS experiments will also allow a demonstration of atmospheric profiling with GPS radio occultation profiles. The project will also increase the TRL (Technology Readiness Level) of the GPS receivers for future space application.

Payload Description

A general description for a system design of the ARIES-GPS payload is shown in **Figure 1**. The 30V and 0.5A from the HASP platform will be connected via the step down circuit on the power board that will supply the voltage and current required for the CASES and Novatel L1/L2 GPS receivers, dual frequency active GPS antenna, and the temperatures sensor. The data from the temperature sensor and the Novatel GPS receiver will be stored locally in the onboard SD card. The data from the CASES GPS receiver will be stored in its internal SD card.

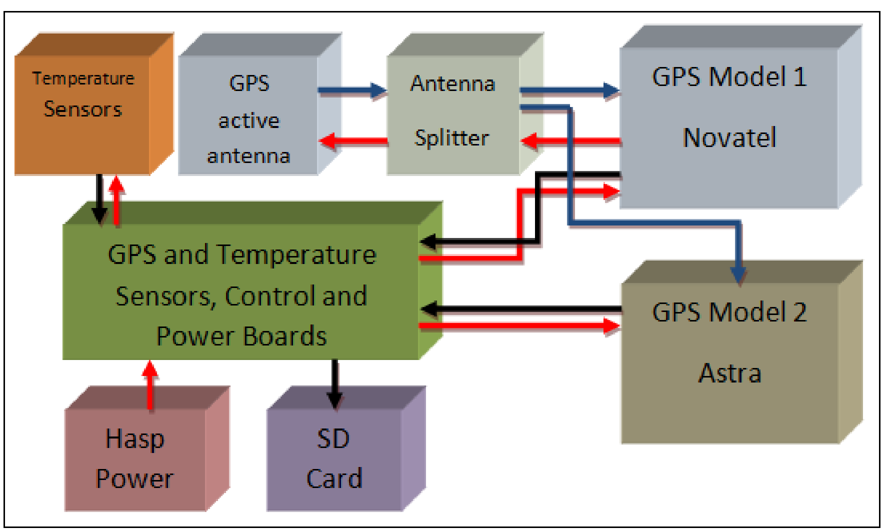

Figure1: System Diagram

Principles of operation

The ARIES-GPS experiment will compare the performance of two different dual frequency GPS receivers. Once the payload is turned-on , the CASES and Novatel L1/L2 GPS receivers will begin to collect data from the available GPS satellites. There will be several boards on the payload. A power board to convert the HASP power source to the respectively voltage range required to power up the CASES and Novatel L1/L2 GPS receivers ,a dual frequency active GPS antenna, temperatures sensor, microcontroller and SD card. The control board that has the microcontroller and SD card to run the payload task and store the data. The CASES receiver board will read data from the GPS satellites and store it in its internal SD card for post analysis. The Novatel receiver board will also take the data from the GPS satellites and store it in the control board SD card for post analysis. In addition to ensure proper operation environment on the ARIES GPS temperature sensors will be place in different areas of the payload to monitoring the internal temperature of the payload and stored in the SD card. The CASES receiver will be programmed to perform the TEC measurement, while the Novatel receiver will be programmed to perform the radio occultation (RO). In general, the overall objective is to collect data from two different GPS receivers. Data will be post-processed to obtain the line-integrated electron density between the receiver and the GPS satellites, and retrieve atmospheric profile.

The radio navigation systems such as GPS offer good opportunities for studying the ionosphere on a global scale. This is possible because GPS satellites transmit coherent dual-frequency signals in the L-band, which is low enough in frequency to measure the ionospheric contribution. Although the ionospheric first-order range error can be determined and removed using the GPS dual frequencies. Since the ionospheric contribution is proportional to TEC along the ray path between satellite and receiver. The GPS satellite continuously transmits on two different frequencies at the microwave L-band at f 1.5754 GHz (L_1) and f 1.2276 GHz (L_2) .However, when travelling through the Earth's atmosphere the signals are subject to modifications in amplitude, phase and polarization. Of particular relevance here are phase changes and propagation delays, to which several regions of the atmosphere contribute. Total electron content is a key parameter that describes the major impact of the ionization in the atmosphere on the propagation of radio waves and hence on precise navigation using GPS. Each of the operational GPS satellites broadcast information on two frequency carrier signals, and receivers provide two distances (known as pseudorange) and two phase measurements corresponding to the two signals. Based on the dispersive nature of the ionosphere, the two radio signals are delayed by different amounts, and their phases are advanced when they propagate from satellite to a receiver on the ground or on another space vehicle. Therefore the electron content along the GPS signal path between the receiver and satellite (known as slant TEC) can be obtained from the difference between the pseudoranges (P1 and P2), and the difference between the phases (L1 and L2) of the two signals.

In radio occultation the signal pass from GPS satellite to an LEO GPS receiver satellite. As this signal pass through the atmosphere is reflected; the magnitude of that reflection is affected for air density and atmosphere compositions. Tracking the refraction of the radio signal through subsets layers an almost instantaneous vertical profiling temperature, pressure, moisture and electron density through the earth atmosphere can be calculated. Previous experiment indicate that useful profile of refractivity can be derived from ~60km altitude to the surface with the exception of regions less than 250 m in vertical extend associated with high vertical humidity gradient. From the standpoint of the receiver, an occultation occurs whenever a GPS satellite raises or sets and the ray path from its transmitter traverses the Earth's atmospheric limb. GPS low earth orbit occultation observation are made in a limb- scanning mode, where vertical scanning is provided by the relative motion between the GPS transmitter and the LEO satellite GPS receiver. During an occultation as the ray path descend or ascends through the atmosphere the variation of the bending angle with the impact parameter depends primary on the vertical profile of the atmospheric refractive index. This profile can be retrieved from the measurement of bending angle as a function of impact parameter during the occultation. The time dependence of both bending angle and impact parameter during an occultation can be derived from the accurate measurement of the Doppler shifted frequency of the transmitter signal at the receiver. Doppler shift is determined by the projection of the spacecraft velocities onto the ray path at the transmitter and receiver, so that atmospheric bending contributes to the measured Doppler shift. Data from several GPS transmitter can be used to establish the precise position and velocities of the GPS transmitter and LEO GPS receiver satellites and to calculate the Doppler shift expected in the absence of bending. The atmospheric contribution to Doppler shift, can then be combined with satellite position and velocity knowledge to give an estimate of bending angle and impact parameter. Therefore the vertical profile can be retrieved from the occultation.

Besides of the fact that there exist ground-based GPS radio occultation measurements. The space based GPS radio occultation offers a more detailed and complete reference for to recover refractivity, density, pressure, temperature, and water vapor profiles. In the other hand the ground based radio occultation technique is more useful for estimating integrated water vapors. However the HASP platform is mainly used for simulating space environments for the GPS. With the HASP experiment we would check the GPS performance on these environments as a reference for future missions involving GPS receivers.

Power Budget

Sensor and Devices	Required Voltage	Current Consumption	Power Consumption	Power Source (after HASP)
Digital Temperature Sensor DS18B20	3.3 V	1.5 mA	4.95 mW	3.3 V Regulator
DSPIC33FJ256GP710 Microcontroller	3.3 V	100 mA	330 mW	3.3 V Regulator
SD card circuit	3.3 V	40 mA	132 mW	3.3 V Regulator
RS232	3.3 V	30 mA	100 mW	3.3 V Regulator
Real Time Clock DS1306	5 V	2 mA	10 mW	5V from DC/DC converter
GPS dual frequency receiver unit – CASES	5 V	1400 mA	7000 mW	5V from DC/DC converter
GPS Novatel OEMV-1DF	5 V	220 mA	1100 mW	5V from DC/DC converter
Novatel adaptor board – MBS-GPS-OEMV1-104	5 V	100 mA	500 mW	5V from DC/DC converter
GPS antenna – Antcom	5 V	50 mA	250 mW	5V from DC/DC converter
Total (Max Consumption based on 30V supplied by the	--	314 mA	9.42 W	--

HASP platform)				

Table 1: Power Budget

The current, voltage, power consumption and power source for each of the electronic sensors and devices on the ARIES SAT payload is shown in **Table 1**. The HASP platform provides power for small and large payloads. For small payloads (which is our case), the supplied voltage that HASP platform provides is 30 VDC @ 0.5 A. The payload total power consumption will be delivered entirely by the HASP platform at 30V and 0.5A giving a 15W source. This will be then down-converted by a DC to DC converter to 5V, and then from the DC/DC to a voltage regulator that will convert the 5V to 3.3V. The total power consumption by the **5V devices is 8.85W**. That let a maximum power consumption of 6.15W for the 3.3V components, which is no problem because the total power consumption by the **3.3V components is 0.567W**. The total power consumption by the components on the ARIES SAT is **9.42 W, or 62.8%** of the total power supplied by the HASP platform. The total current draw is **314 mA,** which is **37.2 %** less than the total current (500 mA) supplied by the HASP platform **at 30V**.

Power System Block Diagram

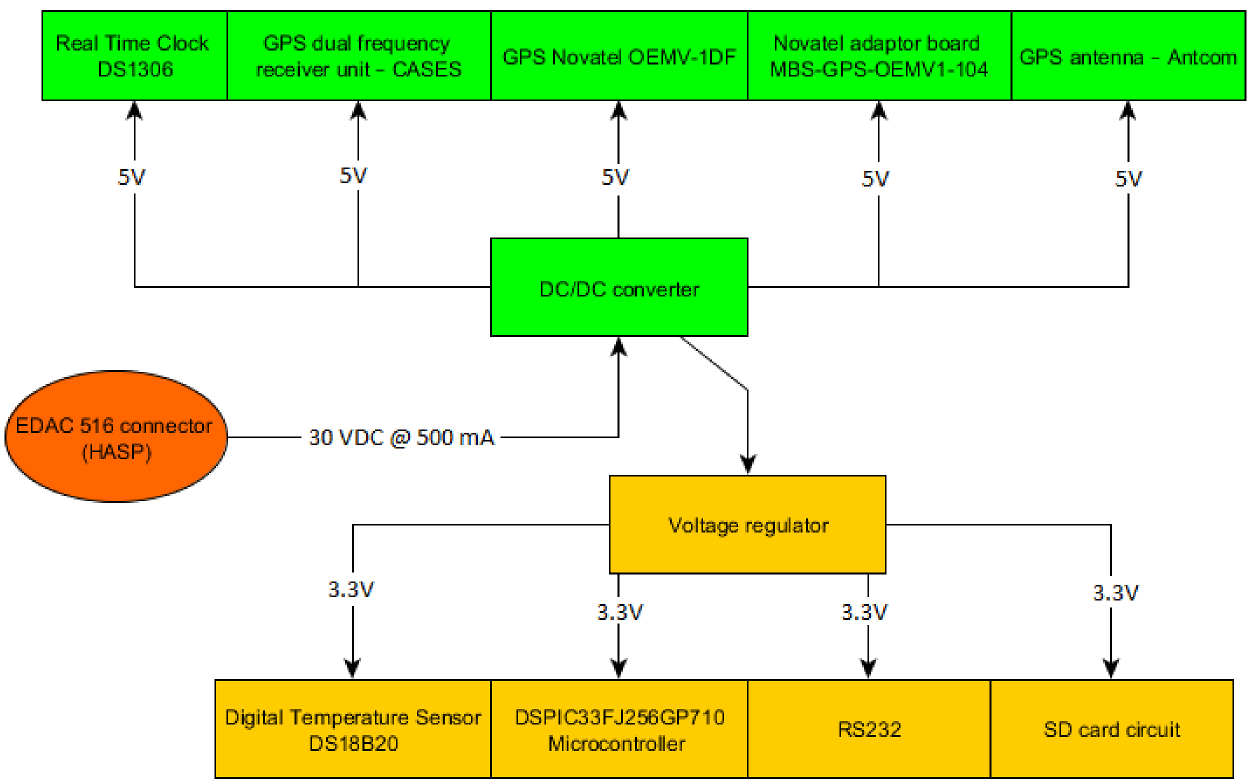

Figure 2: Power System Diagram

The power design for the payload is shown in **Figure 2**. The HASP platform will deliver 30 VDC at 0.5 A to the power boards on the ARISES SAT. The DC to DC converter on the power board will convert the 30 VDC from the HASP to 5 VDC, for each 5V components on the payload. A voltage regulator on the power board will convert the 5V from the DC to DC converter to 3.3 V for all the components that work at this level.

HASP Power Interface

The HASP mounting plate provides two connectors; one is a DB9 serial connector used for uplink and downlink of data, and the other is an EDAC 16 connector which provides connections for power, discrete commands to the HASP platform and analog outputs. **Figure 3** shows the platform and the location of both connectors.

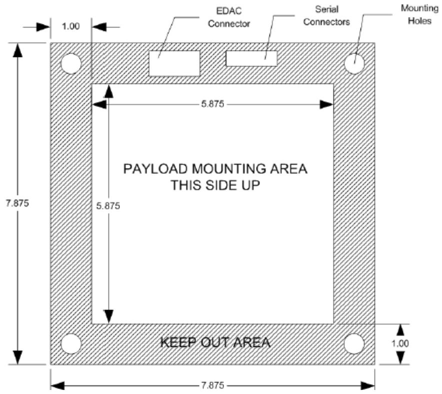

Figure 3 - HASP Mounting Area Layout

Function	EDAC Pins	Wire Color
+30 VDC	A,B,C,D	White with red stripe
Power Ground	W,T,U,X	White with black stripe
Analog 1	K	Blue
Analog 2	M	Red
Signal Return	L, R	Black
Discrete 1	F	Brown
Discrete 2	N	Green
Discrete 3	H	Red with white stripe
Discrete 4	P	Black with white stripe

Table 2 - EDAC 516-020 Pin Layou

Since the EDAC connector is the one that provides the 30V to our system, this is the one going to be discussed in this section. The EDAC is a 20 pin connector used to interface with the HASP power. The HASP already provide this connector in its platform each one is labeled with a specific color to identify its function. The **Table 2** describes its wire with its color label and its function (taken from HASP Interface Manual).

Weight Budget

The ARIES-GPS payload has a weight limit of 3kg for the entire system. It is required to develop a weight budget in order to monitor the weight of the entire payload.The approximate weight of each one of the components for the payload is described in **Table 3**. Since this project is currently in the preliminary phases, there are several weights that are to be determined. Nevertheless, a more detailed weight will be present in the PDR and CDR document of this project and the final weight information of the components will be included in the FDR document.

Total Weight of HASP GPS Payload	
Weight (g)	*Instruments/Components*
146.4	**Power Board**
329.15	**Payload platform**
501.48	**4 – Walls**
95.16	**Top – Cap**
74	**1 – Antenna**
133	**1 RF Splitter**
200	**GPS Novatel receiver**
150	**Control Board**
907	**GPS CASES receiver**
2536.19	**Total**

Table 3 - Weight Budget

I order to reduce the ARIES SAT weight some changes were done. The power splitter will be located on the power board. The weight of the payload platform and walls were re-simulated. With this revision the payload weight **decreases** in **281 g** for a total weight of **2536.19 g,** which represent a **84.54 %** of the total weight allow for small payload (3kg). In addition the **GPS CASES receiver** will be re-designed (by the company) to reduce even more the ARIES SAT weight.

Payload Dimensions and Design

The ARIES-GPS experiment must comply with various requirements such as weight and power as mentioned previously. In addition, the AIRES-GPS experiment must also comply with the size requirement which states that the payload must not exceed the 15cm x15cm footprint, a height of 30cm, and the ability to survive the landing loads. For this weight, yield strength and size are taken into account in the design process. The ARIES-GPS payload design is shown in **Figure 4 and 5**.

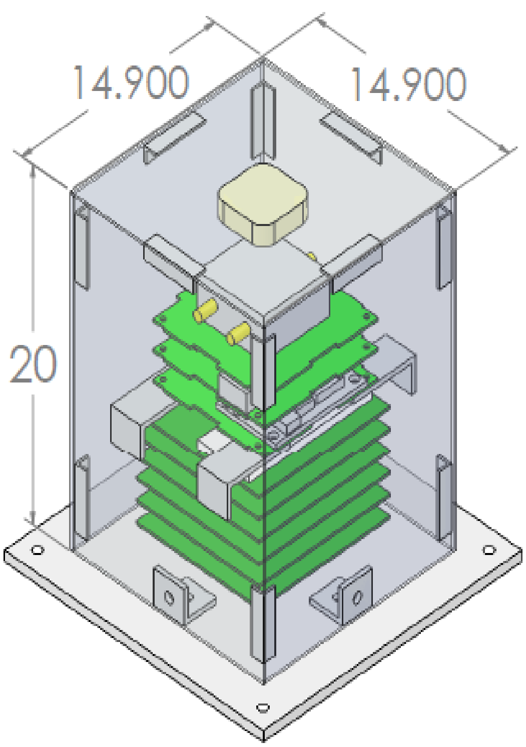

Figure 4: Mechanical Design

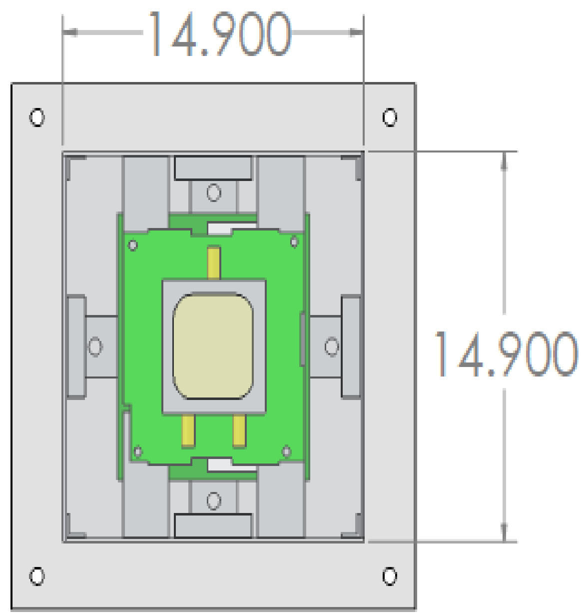

Figure 5: Payload top view dimension

Vector Analysis

Since the payload will be exposed to a vertical force of 10g vertical and 5g horizontal a vector analysis was perform on the areas that are considered critical and vulnerable for now, but this analysis will be performed to the complete structure. The preliminary results are show in the **Figures 6a,6b,7a and 7b**

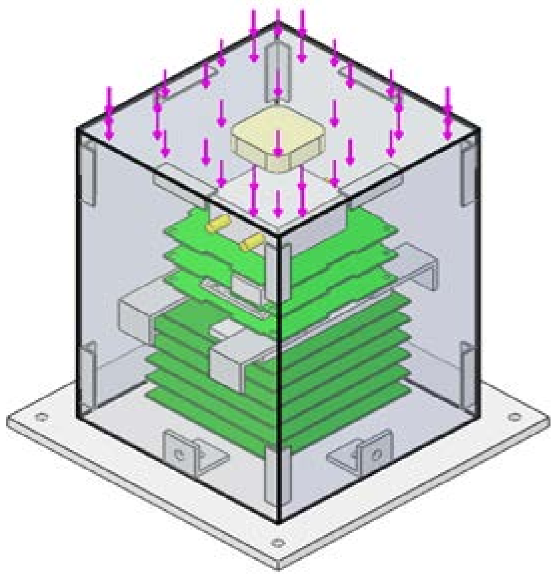

Figure 6a: 10g vertical force

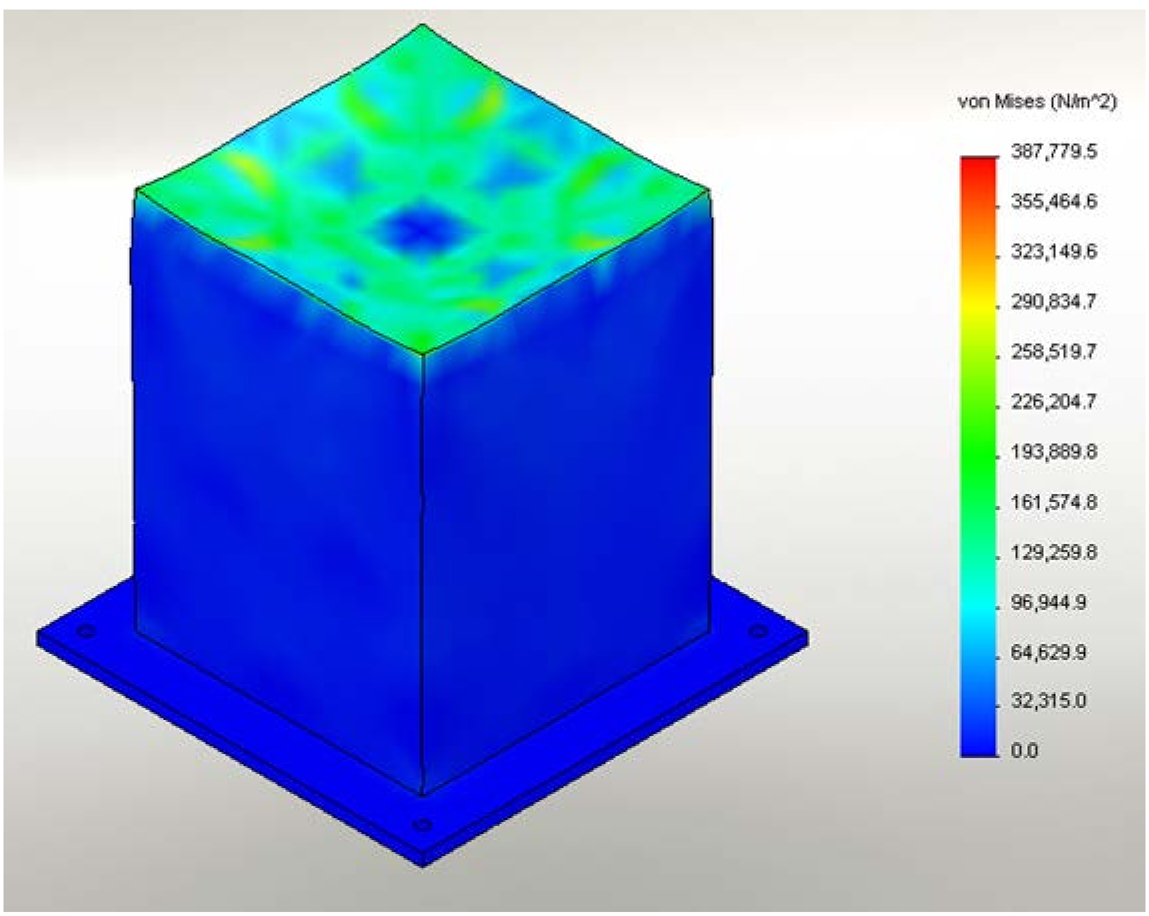

Figure 6: 10g vertical force

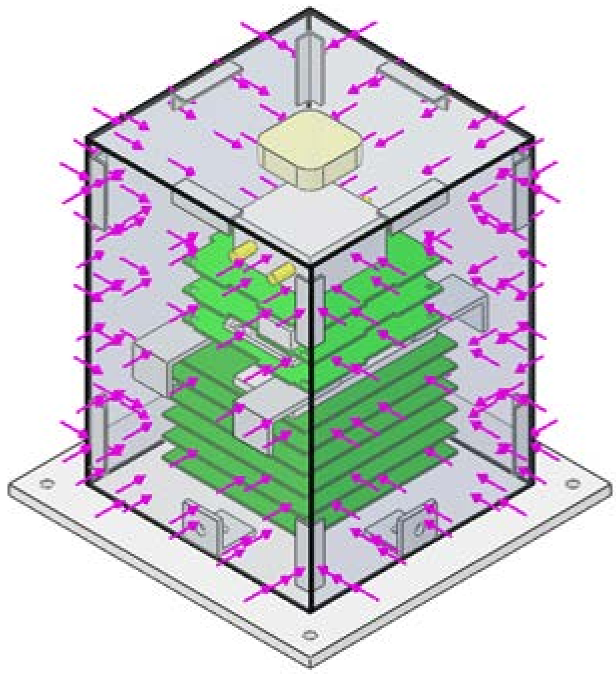

Figure 7a: 5g horizontal force

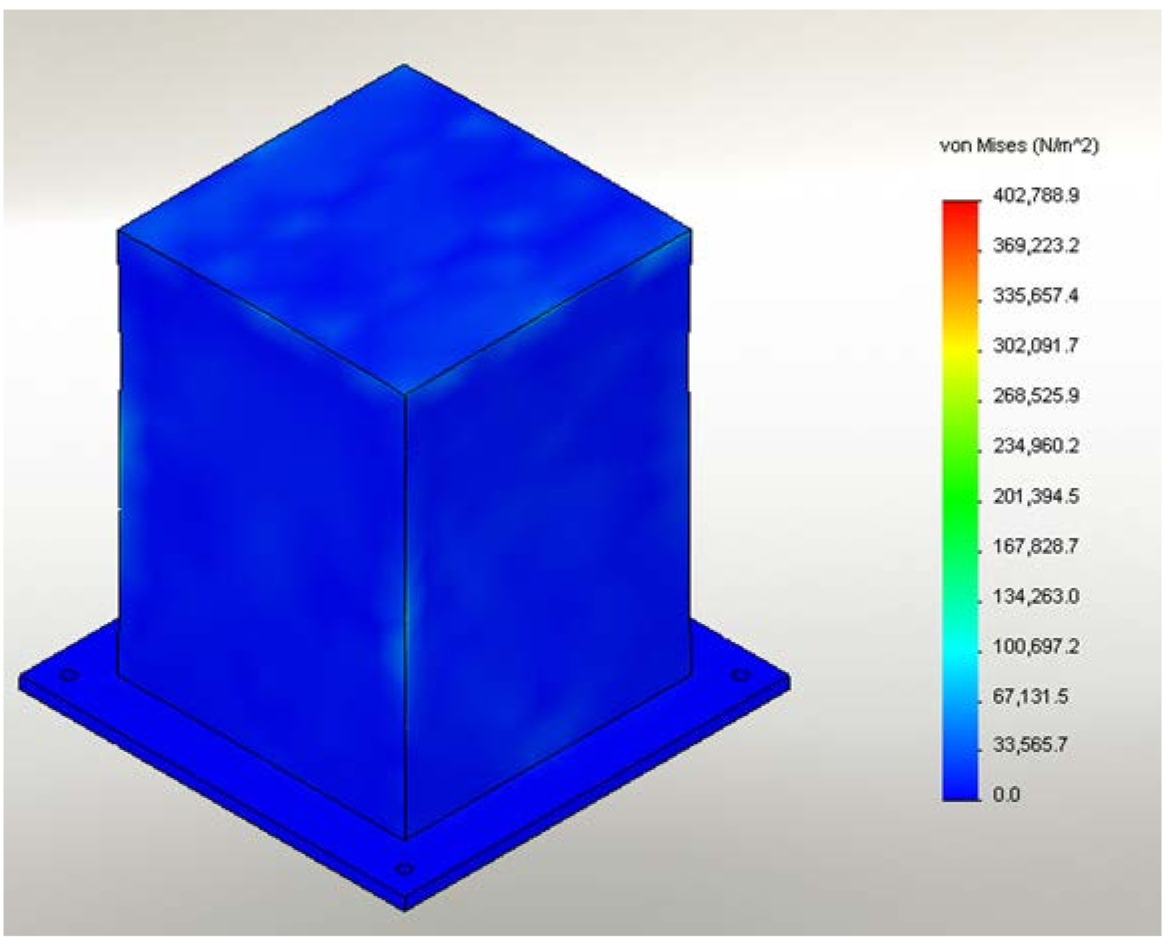

Figure 7: 5g horizontal force

Thermal Analysis

For the thermal issue, the structural aluminum payload needs to be insulated with kapton and MLI (multi-layer insulation) material due to this high conductivity. The use of kapton and MLI is useful in this due to this thickness in less space consuming and it low conductivity for electrical component protection from temperatures about -80 Celsius to 60 Celsius degrees , data obtained from previous projects. To design how many kapton of layers and thickness of MLI are going to be used, the analysis will be considering external temperature vs. internal temperature produced by the electrical components power. For that reason, in this project will be used Heat Transfer Analysis in FEA software as Ansys and Comsol Multiphysics to validate the data. Finally, to generate more internal heat in cold case at temperature of -80 Celsius degrees is necessary increase the taking of samples in the microcontroller to increase the temperature and in hot case samples need to be decrease or be standby in critical event.

Downlink and Uplink

For occultation applications, we may consider the radio signals arriving at the payload from a GPS satellite as being a pair of spherical monochromatic waves from a distant point source at frequencies of 1575 MHz and 1228 MHz, respectively, plus Doppler shifts from kinematics and refraction of up to a few tens of kilohertz. Therefore, our telemetry data contents will store the data generated by the dual frequency GPS receiver in the Carrier Frequency mode of operation. We will be storing all the data generated by the payload in our own SD-card. Like there is no need to process data in real time we can store it and later at our laboratory process it and obtain the meteorological data from the radio occultation technique.

On the other hand, the payload will **not download** data to the HASP flight computer at all, our SD cards will have plenty of space for storing all the incoming data during the flight; but our main issue with the HASP flight computers is the serial baud rate that is **1200 bps** for small payloads. That baud rate is too low for our mission requirements. The amount of data generated by our payload needs a high speed serial baud rate for processing and storing. The OEMV-1DF GPS have a serial baud rate by one of its communication ports of **300 to 921,600 bps**, using TTL voltage levels. Our flight computer will be using a dspic33fj256gp710 that can process the data with baud rate ranging from **38 bps up to10 Mbps** at 40 MIPS. The serial rate offered by the HASP flight computer is too low for our mission objectives and requirements, for that reason our systems will not downlink the received data from the GPS systems.

Discrete command will be used to change the state of the payload during the flight. During the flight the commands that could be required are:

- OFF- to turn of the payload in case of a problem
- ON- to turn the payload ON in case it was turned off
- RESET- to change the pointing direction of the payload in case of an error
- PAUSE- To stop for a period of time the storage of data due to avoid any unnecessary data stored.

Team Structure

This project will operate under the auspices of the Inter American University of Puerto Rico (UIPR), Bayamon Campus. The laboratory is managed and lead by a core group of students under its Director, Dr. Hien B. Vo. The primary focus of the laboratory is the integration of real-world space-systems project work with the traditional curriculum to better educate students and prepare them for careers in space science and engineering. HASP projects at UIPR provide senior capstone projects, independent study projects, undergraduate honors theses, and graduate theses.

HASP enriches the students' experience by introducing them to the resources, faculty, projects, opportunities, and other students that they otherwise might never meet. By participating in, and often leading in some way, the lifecycle of a complex project, students are better prepared for the challenges ahead, whatever field they may pursue. By creating an environment where creativity and independence is encouraged, and by giving students access to other experienced students and exciting projects to work on, the students can grow faster than in any classroom.
Based on IUPR past projects' experience with travel costs and student schedules, it is likely that 2 students will support the integration personally at CSBF, and eventual launch of HASP in person. In addition, the rest of the students will likely support the integration and launch operations remotely from UIPR. The team management chart is show in **Figure 8** and the preliminary Gantt chart in **Figure 9**.

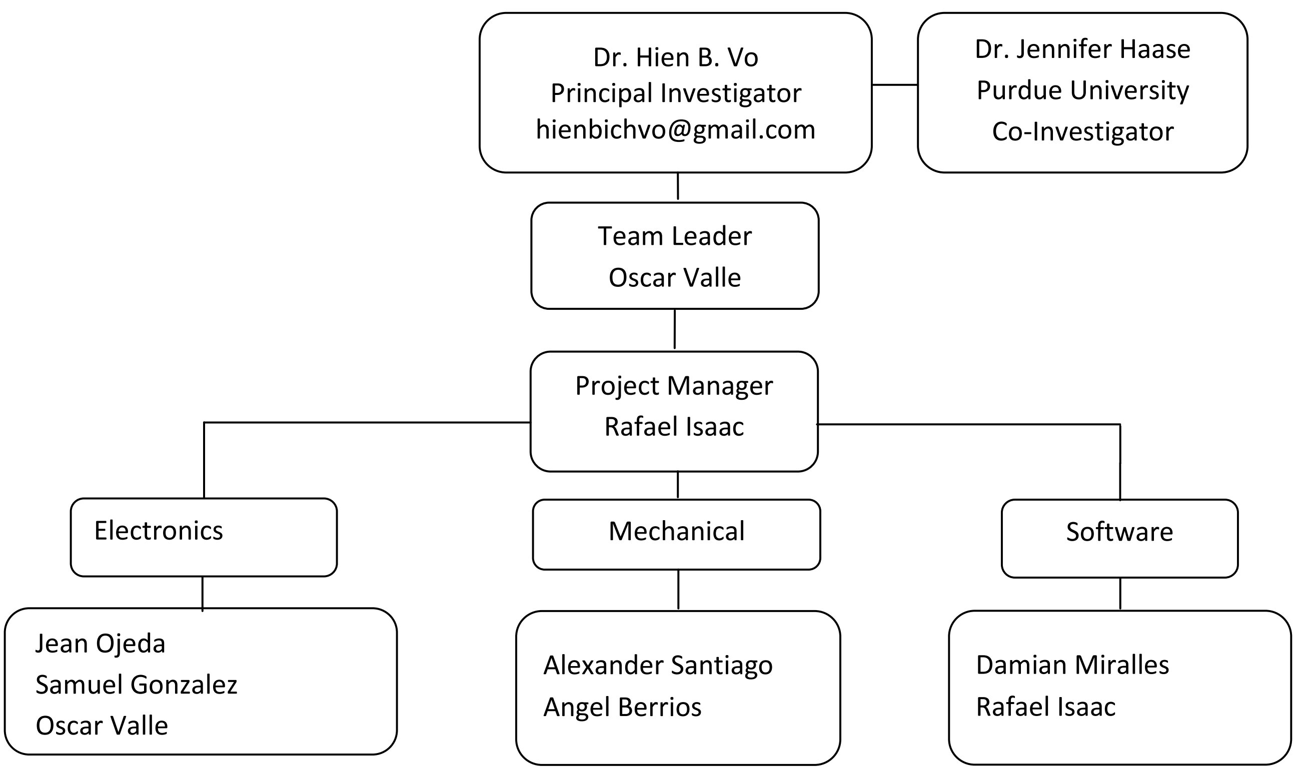

Figure 8: Team Management

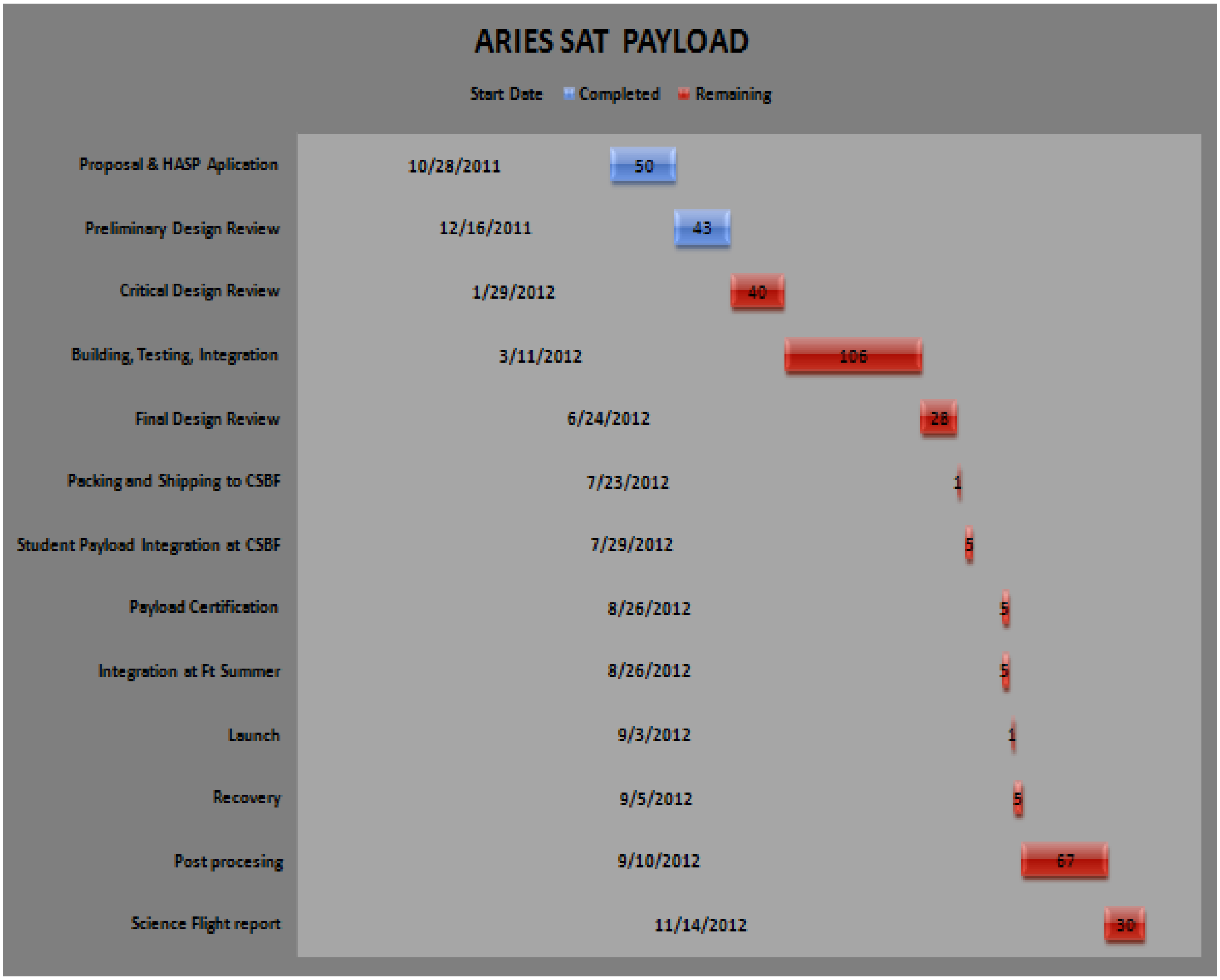

Figure 9: Preliminary Gantt Chart

Desired Position and Orientation

No specific position is requested so long a clear view of the sky without obstruction. The GPS antenna should have a clear line of sight to the sky above to be able to lock in the GPS satellites.

Integration Procedures.

The personnel that might be traveling to the integration for the HASP payload at July 29(one day before the integration starting date) will be Oscar Valle and Damian Miralles. This could be changed at any time. In case of change the personnel will be replace with someone with the proper knowledge to deal with the payload.

Oscar Valle
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A successful integration for the ARIES SAT payload will be achieved when we obtain a scientific GPS (a GPS system able of give position, perform radio occultation and atmospheric TEC) system that meet the thermal, vacuum, power, weight and size require for a small Hasp payload. In order to the ARIES SAT accomplish the small payload specifications several HASP requirement has to be fulfill.

The ARIES SAT payload will require environmental testing for flight system validation. This project will be tested in extreme temperatures to ensure that the payload will perform successfully throughout the flight. According to the temperature profile of previous payloads EQUIS and TigreSAT it is necessary to perform tests in a temperature range of -80^{o}C to + 60^{o}C for a 8hr period. A physical prototype of the experiment will be developed and tested in a thermal-vacuum, chamber at the Inter American University of Puerto Rico. The test will perform a simulation of cold/hot environments, thus allowing us to perform any adjustments with time if were necessary.

In addition to complete the integration the ARIES SAT payload has to weight less than 3kg including the payload plate. Also its dimensions including the mounting structure cannot excess 15cm X 15cm X30cm.While its measured current at 30 VDC has to be less than 500 mA. In addition the payload has to be able of receive discrete command from the HASP platform. The ARIES SAT payload will not do downlink to HASP platform, its data will be stored on the payload internal SD card (for the reasons that was explained before on the Downlink and Uplink section, pages 9 and10).

Another fundamental part on the integration process is the documentation of the ARIES SAT. A project manager will be on charge to do that and also of the project logistic in order to be able to meet with the HASP schedule. In addition the project manager has to control and review the mechanical, electrical software and design review documents; to make sure that these documents fulfill with the HASP requirements. Doing this we will be prepared to pass and complete the integration process efficiently as efficient as possible at the Columbia Scientific Balloon Facility.