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 16, 2011

Project Abstract

As part of UIPR's effort to develop its CubeSat program, 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 simulations 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 8 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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1. Payload description

Introduction

As our society becomes more dependent upon technology in space, there is a growing awareness that we require accurate knowledge of the ionospheric environment to understand and predict its impacts on vital space-based systems, including communications, navigation, and surveillance systems. Traditional ground-based ionospheric monitoring systems have been expensive, bulky, and power intensive and have not permitted coverage of large ocean areas or on-demand theater coverage. What is needed is an inexpensive, lightweight, low-power, and robust ionospheric monitoring system that can fill these gaps in coverage. A GPS autonomous micro-monitor fulfills these needs. It is a passive receiver, relying on existing GPS broadcast signals available everywhere on earth, and therefore can be made to operate at low power with minimal electromagnetic emissions. A GPS autonomous micro-monitor can detect phase and amplitude scintillation on its received signals that indicate the presence of ionospheric electron density irregularities. In dual-frequency operation, it can estimate the total electron content (TEC) along each of its multiple lines of sight to the GPS satellites, thus characterizing the line-integrated electron density for assimilation into global ionospheric models and for predicting the local propagation environment.

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. The proposed experiment will also help the student team learn critical skills in utilizing GPS signal to develop position solutions and the time of flight of the payload. Data acquired from the GPS receiver will be 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 predictions from state of the art space environment models, such as the Thermosphere-Ionosphere-Mesosphere Energetics 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 GPS data will provide data related to gravity waves for the parameterization of momentum flux into the stratosphere. The project will also increase the TRL (Technology Readiness Level) of the GPS receivers for future space application.

Payload system

The proposed Advance Research and Innovative Experience for Students (ARIES) experiment will consist of two payloads, a powered antenna, a power control board, and a telemetry sub-system. The two payloads selected for this experiment are: (i) ASTRA's CASES GPS ionospheric scintillation monitor and (ii) the Novatel GPS OEMV-1DF receiver. ASTRA's CASES GPS receiver is a smart, dual-frequency GPS software receiver with robust dual-frequency tracking performance, stand-alone capability, and complete software upgradability. CASES system consists of a real-time GPS software receiver for the L1 C/A and L2C codes, as well as a custom hardware platform on which to run this receiver. This receiver was developed as a low-cost space weather instrument for monitoring ionospheric scintillation and total electron content. The Novatel OEMV-1DF is a dual frequency GPS receiver capable of receiving and tracking the GPS L2C and L2 P(Y). It has a Patented Pulse Aperture (PAC) with multipath mitigation technologies, and a 32 bit processor. This allows the OEMV-1DF receiver to offer multipath-resistance processing at a high data rate.

Figure 1 shows the general description for the system design of the ARIES-GPS payload. A 30V/0.5A signal source from the HASP platform will be connected via a step down circuit to the Attitude Determination (AD) 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 sent through the telemetry and also stored locally on the onboard SD card. The data from the CASES GPS receiver will be stored on its internal SD card.

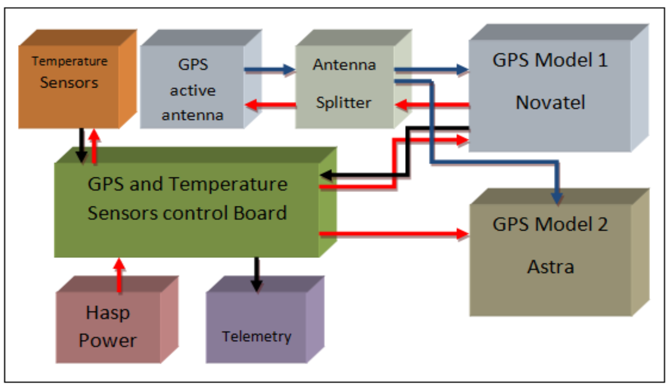

Figure1: System Diagram

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 the data from the available GPS satellites. There will be several boards on the payload; a control board for monitoring external and internal temperatures of the payload which will be stored in the SD card. HASP power source will be down-converted to the required voltage for the CASES and Novatel L1/L2 GPS receivers, a dual frequency active GPS antenna, and the temperatures sensor. The CASES receiver board will be powered from the control board and it will read data from the GPS satellites and store in its internal SD card for post analysis.

The CASES GPS receiver is capable of onboard calculations of the receiver position and TEC measurements. The code range navigation solution is obtained by determining the CASES GPS location in latitude, longitude, and altitude at a specific time. By the code range we mean the pseudo-range obtained by transmitting the C/A code at a known time, which is then received by a GPS receiver and tagged with the receiver time. The navigation solution is determined in the ECEF coordinate frame. Then, from the ECEF frame, the navigation solution is transformed into a frame that represents the Earth as an ellipsoid: the WGS-84 ellipsoid model.

The pseudo-range from satellite *j* to the receiver measured at time *t* is $P^j(t)$. The actual range is $\rho^j(t)$. Recall that there is also a satellite clock offset δ^j, which is known and transmitted in the navigation message, yielding a pseud-orange correction $c\delta^j$. In addition, there is an unknown receiver clock offset, yielding a pseudo-range correction of $c\delta_R$. Using these definitions, the pseudo-range becomes

$$P^j(t) = \rho^j(t) + c\delta^j(t) - c\delta_R(t) \quad (1)$$

The time dependence of the various components of equation 7.1 has been stated explicitly. For the remainder of this laboratory, the time dependence will be assumed and not stated explicitly. If *X*, *Y*, *Z* represent the ECEF coordinate of the GPS receiver antenna and X^j, Y^j, Z^j represent the ECEF coordinates of the j^{th} satellite, then

$$\rho^j(t) = \sqrt{(X^j - X)^2 + (Y^j - Y)^2 + (Z^j - Z)^2} \quad (2)$$

where the time dependence is in the satellite and receiver motion but is not of concern since we will only consider one point in time for this laboratory. In terms of the GPS receiver coordinates the pseudo-range becomes

$$P^j - c\delta^j = \sqrt{(X^j - X)^2 + (Y^j - Y)^2 + (Z^j - Z)^2} - c\delta_R \quad (3)$$

This equation has four unknowns on the right: *X*, *Y*, *Z*, and δ_R. On the left-hand side of 7.3 are the measured pseudo-range and the satellite clock offset calculated from coefficients in the navigation message. If four pseudo-range measurements to four GPS satellites have been acquired, then four equations exist and a solution can be found for the four unknowns.

CASES GPS receiver uses dual-frequency code-delay observations to obtain ionospheric observables related to the (TECs) along the satellite-receiver line of sight (LOS). The CASES GPS receiver measures the difference in ionospheric delays between the L1 and L2C signals with the assumption that each signal travels along the same path through the ionosphere. Thus, the group delay can be obtained as:

$$P_1 - P_2 = 40.3TEC(1/f_2^2 - 1/f_1^2) \quad (4)$$

Where P1 and P2 are the group path lengths corresponding to the high GPS frequency

(f1=1575.42 MHz) and the low GPS frequency (f2 =1227.6 MHz), respectively.

The TEC can also be obtained by writing Eq. (4) as

$$TEC = 1/40.3TEC(f_1 f_2 /(f_1 - f_2))(P_2 - P_1) \quad (5)$$

If dual frequency receiver measurements are available; where (P1 and P2) are the pseudo-ranges measured in L1 and L2, respectively.

The Novatel GPS receiver board will be placed on top of the CASES receiver. The Novatel will also collect the data from the GPS satellites and store it in the control board SD card. In general, the overall objective of the experiments 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 GPS satellites and to retrieve atmospheric temperature profile below the balloon height. To ensure proper operational environment on the ARIES GPS temperature sensors will be placed in different areas of the payload. These temperature sensors will be used in specific location to monitor and maintain the temperature with the heater, if needed.

2. Payload specifications

Team Structure

This project will be performed at the Inter American University of Puerto Rico (UIPR), Bayamon Campus. The laboratory at the UIRP, where majority of the work will be carried out, is managed and lead by a core group of students under its Director, Dr. Hien B. Vo. The primary focus of the lab 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.

The HASP program will enrich 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. Figure 2 shows the organizational chart for the ARIES project and lists key personnel and their areas of responsibilities.

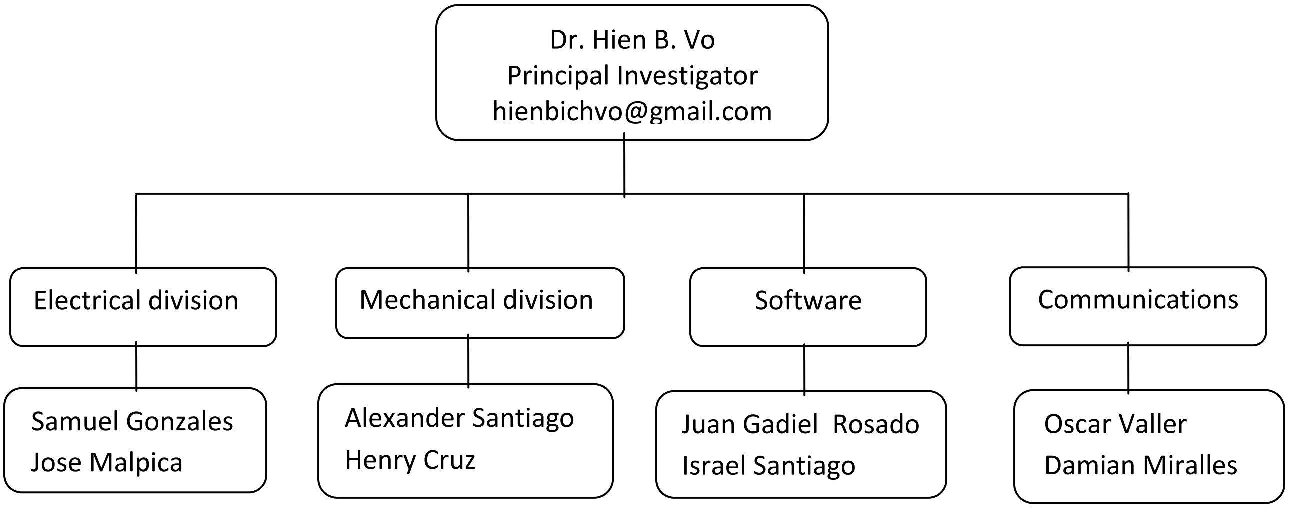

Figure 2: Team Management

Figure 3 shows the schedule for all major tasks to be completed by AIRES-SAT team. The schedule and work plan will be rigorously designed at the start of the project. The project will be supported by bi-weekly meetings to check on the progress and exchange of ideas.

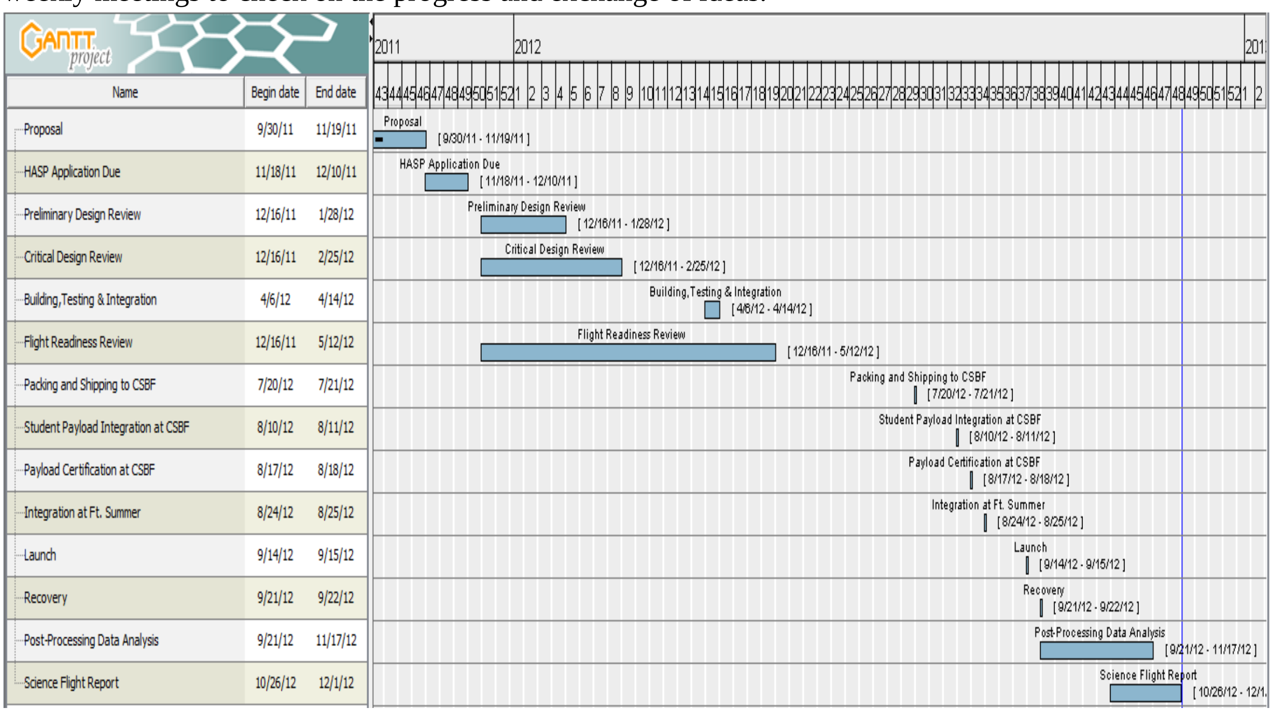

Figure 3: Preliminary Gantt Chart

Power Budget

These devices will run with HASP Power				
Sensors	Voltage (V)	Current (A)	Power (W)	Power Source
Digital Temperature Sensor DS18B20	3.3	0.01	0.02	HASP
DSPIC33F256MC710 Microcontroller	3.3	0.05	0.17	HASP
Real Time Clock DS1306	5	0.00	0.01	HASP
SD card circuit	3.3	0.04	0.13	HASP
RS232	3.3	0.03	0.10	HASP
Heater	30	0.15	4.50	HASP
GPS dual frequency receiver unit - CASES	5	1.40	7.00	HASP
GPS Novatel OEMV-DF1	5	0.22	1.1	HASP
Novatel adaptor board - MBS-GPS-OEMV1-104	5	0.1	0.5	HASP
GPS antenna - Antcom	5	0.05	0.25	HASP
	Total	2.05	13.7656	

Table 1 – Power consumption for the ARIES-GPS

The payload total power consumption will be delivered entirely by the HASP platform at 30V/0.5A giving a 15W source. This will be then down-converted by a DC to DC converter to the appropriate voltage depending on the load. **Table 1** describes the power distribution for the payload. The heater is included in the payload to provide thermal protection, if needed.

Weight Budget

The ARIES-GPS payload has a weight limit of 3kg for the entire system. A detailed weight budget is mandated in order to monitor the weight of the entire payload to ensure that the entire system will be within the weight limits specified in the technical requirements section. The approximate weight of each of the components for the payload is given in **Table 2**. Since this project is currently in the preliminary phases, there are several weights that are to be determined. Nevertheless, more detailed weight information will be available in the PDR and CDR document for this project and the final weight information of the components will be included in the FRR document.

Total Weight of HASP Components	
Weight (g)	*Instruments/Components*
146.4	ADS Board
550	Payload platform
505.48	4 - Walls
95.16	Top - Cap
74	1 - Antenna
189	1 RF Splitter+ Empty Board
200	GPS Novatel receiver
150	**MBS-GPS-OEMV1-104**
907	GPS CASES receiver
2817.04	Total

Table 2 - Weight Budget

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 3 and 4**.

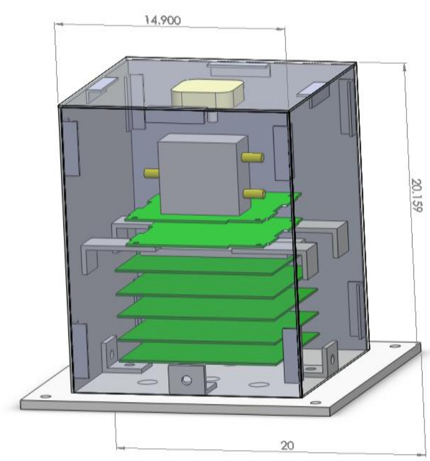

Figure 3: Mechanical Design

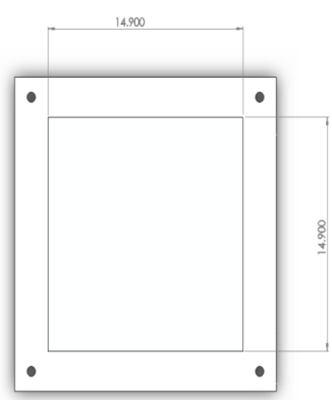

Figure 4: Payload top view dimension

Vector Analysis

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

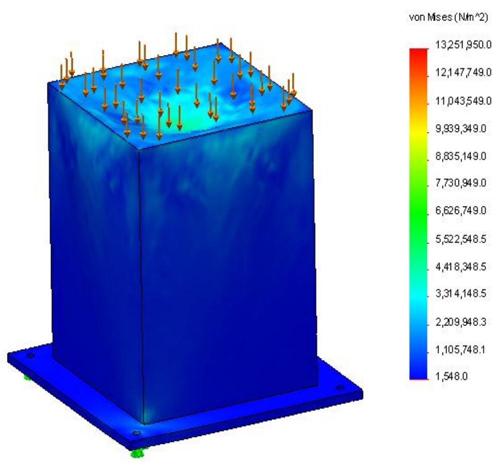

Figure 5: 10g vertical force

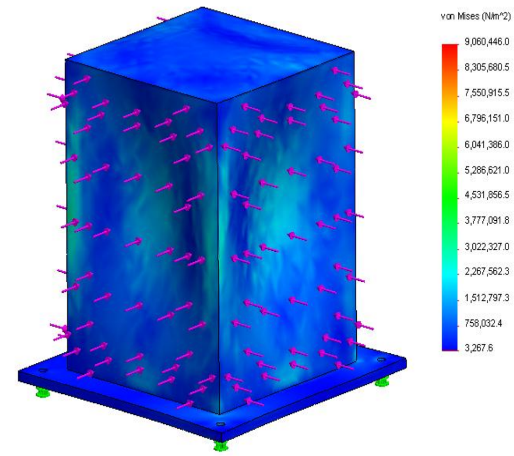

Figure 6: 5g horizontal force

Thermal Analysis

For the thermal issue, the aluminum structure of the payload needs to be insulated with kapton and MLI (multi-layer insulation) material due to its high conductivity. The use of kapton and MLI is useful in this regard due to its compactness and it low conductivity for electrical component protection from temperatures about -80° Celsius to 60° Celsius. To estimate how many layers of kapton and thickness of MLI will be needed, the thermal analysis will take into account temperature gradients across the structure produced by the electrical components. We will perform thermal analysis of the payload using finite element analysis (FEA) software such as Ansys and Comsol Multiphysics.

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 7** shows the platform and the location of both connectors.

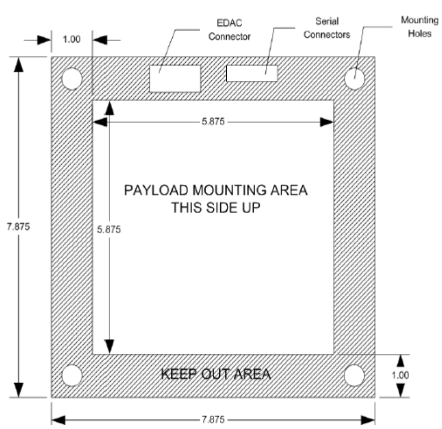

Figure 7 - HASP Mounting Area Layout

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 3 - EDAC 516-020 Pin Layout

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 3** describes its wire with its color label and its function (taken from HASP Interface Manual).

Downlink and Uplink

The ARIES-GPS payload will use the serial telemetry downlink at a baud rate of 1200 for the data. Critical data, such as the payload health and attitude data will be down linked using the telemetry link. This data will be downlinked, (with the provided RS232 connector from the HASP platform), every minute according to the Interface manual. Discrete command will be used to change the state of the payload during the flight. During the flight the commands that will be required are:

- OFF- to turn off the payload in case of a problem (will reply with an accept command).
- ON- to turn the payload on in case it was turned off (will reply with an accept command).

Desired Position and Orientation

No specific position is requested so long as there is a clear view of the sky. The GPS antenna requires a clear line of sight to the sky above it so as to lock on to the surrounding GPS satellites.

Integration Procedures

Integration of ARIES-GPS payload to HASP will consist of fastening the mounting plate to the HASP and connecting the power and data cable to the provided connections. The power on command will be sent and the payload will reply with the accept command to verify that was turned on correctly.