# HASP Student Payload Application for 2011

Payload Title: TIGRE SAT

| | | |
|---|---|---|
| Payload Class: (check one)<br>X Small ☐ Large | Institution:<br>Inter-American University of Puerto Rico Bayamon Campus | Submit Date:<br>Dec 17, 2010 |

Project Abstract

The goal of this project is to develop and test flight a 1U CubeSat prototype that consist of solar panels, an Electrical Power System (EPS), a Command and Data Handling system, an Attitude determination and control system (ADCS), and a camera payload. To keep the payload aimed at a certain reference frame, an attitude control system will maintain stabilization using a Proportional-Integral-Derivative PID control scheme. Ultimately, the technologies demonstrated by TIGRE SAT will make up the spacecraft bus for the SWIM (Space Weather Ion Measurement) CubeSat, designed to investigate the effects of space weather on the ionosphere.
The team currently consists of more than 15 undergraduate students from many disciplines across the university including computer science, mechanical, computer and electrical engineering.

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|---|---|
| Team Name:<br>TIGRE SAT | Team or Project Website:<br>https://sites.google.com/site/cubesatprojectinter/ |

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|---|---|---|
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# TIGRE SAT
# Proposal for the High Altitude Student Platform (HASP), 2011

## Advance Research and Innovative Experience for Students Laboratory
## ARIES Labs

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17 December 2011

# Contents

## Objectives

## Science Objectives

The following are several science objectives related to this experiment:

1. Increase the understanding of aerospace sciences specialized in CubeSat technology.
2. Gain knowledge and experience in attitude determination of a payload such that it can be applied for a CubeSat prototype.
3. Learn, test, and calibrate different sensors to measure the Earth's gravitational, and the Earth's magnetic field, the Sun intensity and the angular momentum of the payload for the attitude determination of the payload.
4. Measure the internal temperature during flight to determine the potential impact to the structure and the components.
5. Determine the position and the time of flight of the payload by using a global positioning system.
6. Collect images of the surrounding environment of the platform during flight to monitor behavior of the system and allow a system to detect the pointing direction of the cube.

## Technical Objectives

The technical objectives presented here are necessary to accomplish the science objectives. These objectives will be completed during the development of the ADCS Prototype:

1. Design and connect the sensors located in a PC104 board inside the body frame of 10cm cube to determine the attitude motion of the payload.
2. Use and program different attitude determination algorithms such as the Kalman Filter, QUEST and TRIAD to determine the attitude motion of the payload.
3. Develop graphs and charts related to show the output of the different sensors as well as the translational and orientation motion of the vehicle.
4. Obtain the platform's body frame orientation with respect to the body fixed reference frame
5. Reduce the attitude knowledge of the payload to less than 10 degrees of error.
6. Develop the circuit and case capable of acquiring the radiation measurements used to determine the orientation of the payload with respect to the Sun.
7. Develop a source code that will control the platform orientation by a closed loop system.
8. Implement a thermal system in the range of -10$^{o}$C to 60$^{o}$C to maintain the components in the nominal operating temperature range.

9. To develop efficient software to perform the attitude determination scheme depending on the sensor data.
10. Maintain the dimensions of the package within 15 x 15 x 30 cm area.
11. Include a CMOS camera with a resolution of .3Megapixel to collect images at a rate of 1second, to compare image by image (by using a star as a reference) and determine the difference in yaw and pitch.
12. Install the Solar Cell develop from the students at University of California (UC Berkeley).
13. Develop an efficient Electrical Power System (EPS).
14. Apply astrodynamics, engineering, and programming concepts to design software capable to interpret the data from the Attitude Determination System to stabilize the platform containing the scientific package.
15. Receive the light photons energy from the Sun to convert it to electricity with the use of photovoltaic device on the payload.

## Science Requirements

To accomplish the development of a robust TIGRE SAT prototype that would be used to determine the orientation of a satellite and control of a space simulator, it is necessary to define the requirements that are needed to obtain the orientation, position and heat characteristics of the payload and rotation in the yaw and pitch angles throughout the flight. These requirements are:

1. Determine the payload position within accuracy of 8m.
2. Determine the heat transfer rate into or out of the payload with an accuracy of 1 deg.
3. Verify the orientation of the payload by comparing an external reference magnetic field and the International Geomagnetic Reference Field (IGRF) model of the year 2011 with accuracy less than 10 degrees.
4. Use and verify the position accuracy of the Inertial Measurement Unit (IMU) with respect to the position GPS data with an accuracy of less than 10 degrees.
5. Use the obtained data to gather knowledge about the attitude motion of the payload and provide recommendations for future HASP and CubeSat projects.
6. To interpret the data given from the ADS, such as position, angular velocity, and the magnitude of the Earth's magnetic field, to calculate the desired orientation of the payload to allow a proper ACS positioning of the payload.
7. Develop a system which can use low cost Sun sensors without affecting the accuracy below 8 degrees.
8. Protect the Sun sensor and the electronic devices from the temperature that are exposed.
9. Complete CDR, FRR, Final Science report post flight.

## Technical Requirements

The requirements about the technology needed to accomplish them to determine the orientation, position, and control of the payload are:

General:

1. To develop a payload that requires less than 30V at 0.5Amps, provided by HASP, and as well to meet the CubeSat power requirements.
2. Develop a mechanical structure that can withstand all the stresses during the payload's flight such as 10g vertical and 5g horizontal.
3. Design and selected the proper elements to allow full operation and not exceed the 3kg weight limit.
4. Maintain the internal temperature in the range of $0^{o}$C to $60^{o}$C.
5. Obtain the data at a sampling rate of 4s.
6. Is necessary to implement an analog to digital converter (ADC) to translate the data into digital form that can be interpreted by the microcontroller.
7. Implement a Sun sensor system with an accuracy of $\pm$0.2 degrees.
8. Incorporate a microcontroller capable of performing all the required instruction and with enough digital input/output pins to be the flight control computer for the ADCS experiment.

Specific:

1. Employ a three axis accelerometer with an accuracy ± 2% to determine the position of the payload within 8 to 15 meters.
2. Determine the orientation by employing accelerometers with an accuracy of ± 2% and gyroscope with an accuracy of $0.01^{o}$/hr (angular velocity) to develop an Inertial Navigation System.
3. The rate of heat transfer is to be determined by using an internal temperature with a size of no bigger than 4 mm (because of space constraints) and an accuracy of ± 1 $^{o}$C.
4. Determine orientation with a 3 axis magnetometer with accuracy of 10o
1. Determine position from a three axis accelerometer that has an accuracy of ± 2% and a reference Global Positioning System sensor.
2. Develop an integrated system of sensor such as magnetometer ($10^{o}$ accuracy) accelerometer (±2% ) and gyroscope ($0.01^{o}$/hr.) at a sample rate of 10s.

## Principle of Operation

The ADCS experiment will take a variety of measurements, such as acceleration, temperature, position, radiation intensity, and magnetic field. A three axis accelerometer sensor will be use to obtain the acceleration which in the post analysis will be used to obtain velocity and position and will be compare to the GPS data. The magnetic field concentration will be determined by a three axis magnetometer to obtain the orientation of the payload. Also the orientation will be determined by a combination of the gyroscope and accelerometer to obtain robustness. The internal temperature data will be obtained by an internal temperature sensor used to monitor the payload's internal environment to maintain the temperature limits of the devices with a thermal system. The DSPIC33 will receive all the information provided by each one of the sensors from the ADS board and the GPS and will save this information to a micro SD to store the data. For the balloon payload, there are two primary angles to be controlled: yaw and pitch. In general, the overall objective is to keep the payload aimed at a certain reference frame, while maintaining its corresponding pointing direction

## Mission Justification

The TIGRESAT is a low cost, low medium-risk test flight to prove new technologies that are critical for the success of the SWIM satellite mission. Obtain a flight on the HASP environment allow a cost effective method of reducing risk factors the future CubeSat mission by permitting the development of new technology and proving prosperous operation in an environment similar to space. The TIGRESAT 2011 experiment is the next step in obtains a full attitude determination and control systems for a CubeSat Mission.

## Payload Design

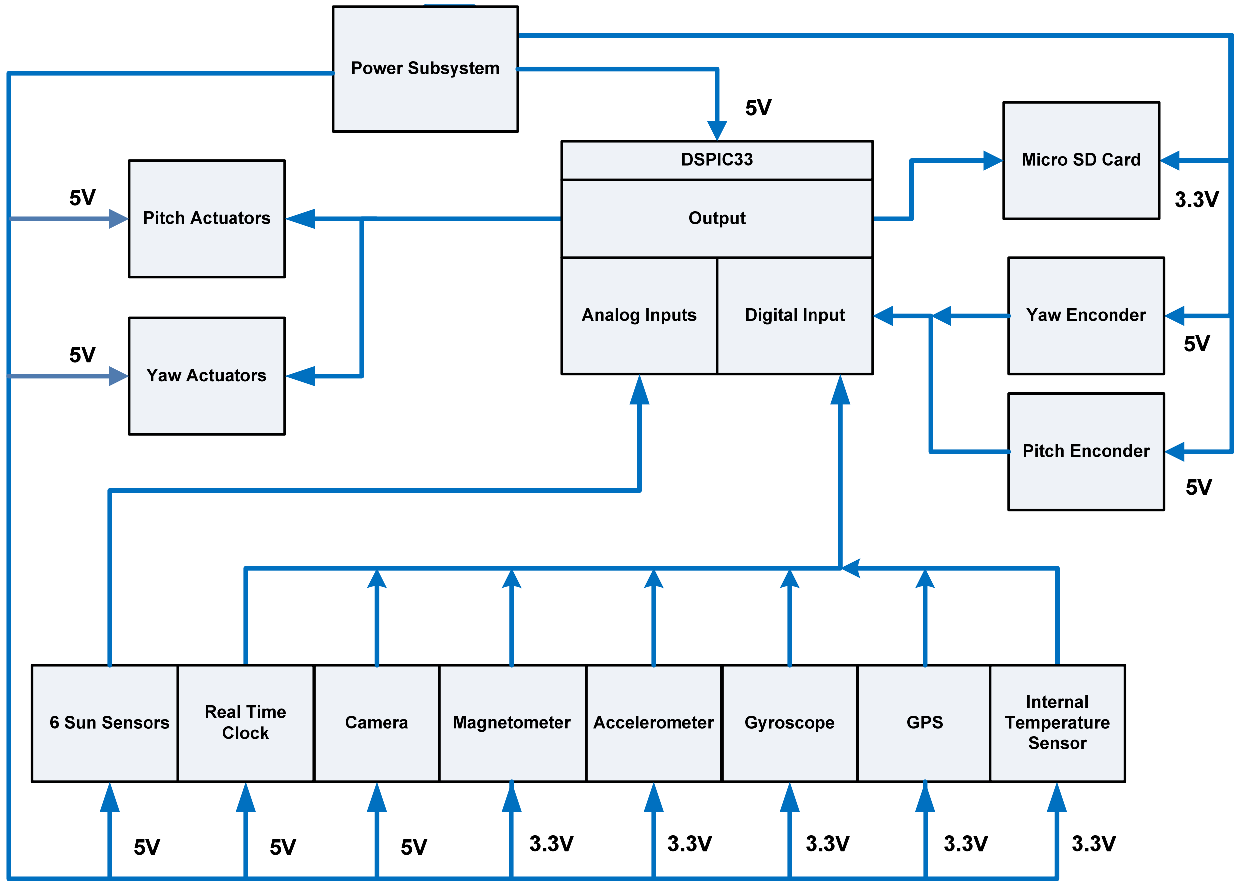

**Figure 1 Payload System Design**

A general description for a system design of an Attitude Determination and Control System Payload with image monitoring is shown in **Figure 1**. The sensor will be connected to a microcontroller to perform all the necessary actions. Different from a previous Attitude Determination System (ADS) design, now the following sensors will be included to allow better precision and robustness. The data obtained from the sensors and the camera will be used by the Microcontroller Unit (MCU) to determine how the Cube has moved away from a specific pointing direction. If it calculates a change the MCU will send the proper signal to the servo motors until the camera is aligned to its pointing direction (pitch and yaw) by receiving the movements it has performed from the rotational encoders. While at every sampling rate it will verify the temperature and turn on or off the heater to maintain an operating temperature higher than the most sensitive sensor to temperature. The power will be obtained the HASP platform and also from the solar panels on the exterior of the Cube.

## Success Criteria

## Comprehensive Success

1. The project shall determine the attitude and motion of the payload and save the data in the SD card and perform calculation to control the cube to maintain pointing in a specific direction.
2. Obtain energy from the photovoltaic power system and determine the performance and reliability of the panels
3. The project shall maintain the payload with a camera pointing in a specific direction during the complete flight duration to demonstrate the control system works properly.

## Minimum Success Criteria

1. The project shall calculate and return the attitude solution of the Space Weather using Ion spectrometers and Magnetometers CubeSat (SWIM) system in the form of Euler Parameter and the corresponding raw data every 1 second for a minimum of 4 hour during the float phase.
2. To implement a successful and a more robust and precise ADS in a PS104 format, since this a standard format for CubeSat experiments.

## Control Electronics

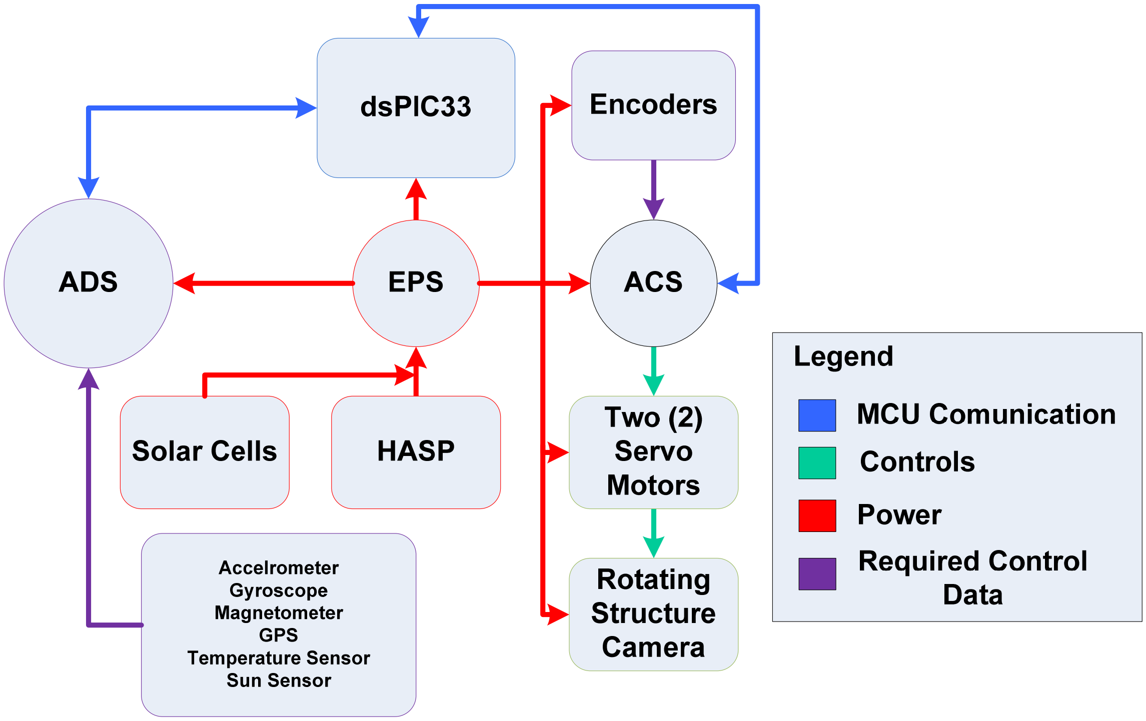

**Figure 2: Control System Diagram**

Control Electronics will be performed for this payload to allow development of an Attitude Control Program and to test various sensors and their combination of data for a future CubeSat project. In **Figure 2** demonstrate how the power will be obtain for the payload, the use of both HASP and Solar Panel will allow the experiment to have sufficient power to operate properly. It can be observed that the ADS are composed of the Attitude sensors and that the Attitude Control System ACS is mostly composed of software and two motors and encoders. These are necessary to determine the position of the pointing location and the control of adjusting back to the point direction.

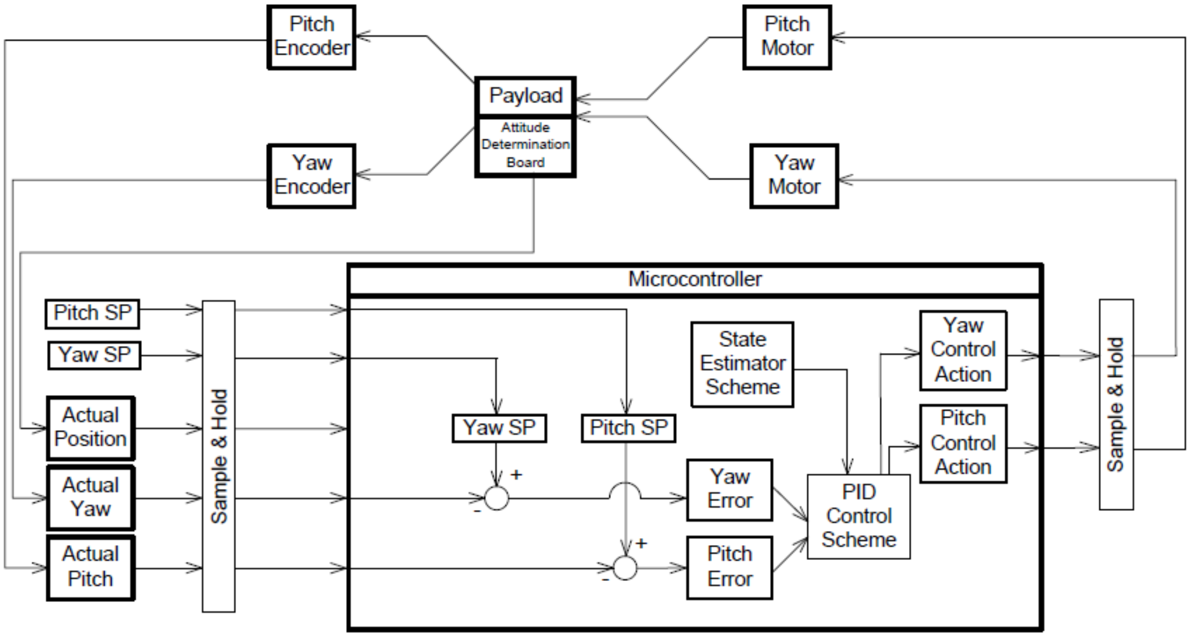

**Figure 3 Detail Control System Design**

In other words, the rotational table will keep its intended angle such that the payload's direction is sustained while the payload's view angle is fixed at a specific frame.

To be able to achieve the control objective, two servo motors will individually work on each of the two angles of interest. These two angles are sent to the microcontroller through two encoders. The microcontroller then receives the actual yaw and pitches angles and compares them to their respective set points in order to determine the error involved in each one of them. It's important to note that all signals coming into or out of the microcontroller will undergo a sample and hold to serve the control objective.

Once in the microcontroller, signals from the encoders and the ADS board will undergo a state estimation algorithm. Because a system's state is not always observable, state estimation takes all the information and measurements gathered so far and uses it to properly determine the underlying behavior of the system at any point in time. State estimation includes aspects such as fault detection and isolation, as well as continuous system parameter estimates. The key to achieve this is by using models and algorithms that allow the prediction of a system's behavior at a particular state. The predicted and actual behaviors are then compared in order to determine which state or states are most likely to produce the observed system behavior. State estimation plays a critical role by allowing the selection of better control actions and the detection of undesirable or unsafe conditions such that remedial actions can be taken.

The data from the state estimation algorithm, along with the measured errors in both pitch and yaw, are fed to a PID control scheme such that optimal control actions can be driven in the most efficient and stable manner, while taking up a minimum amount of time. A PID control divides its control action in three parts: a control action proportional to the error, a control action proportional to the accrued error over time, and a control action proportional to the error's rate of change. By properly modeling the dynamics of the overall system, a PID controller can be designed with the best performing set of controller gains such that all three control actions are optimally achieved.

In the final stage, the control actions determined by the PID control scheme are sent to their corresponding plants. As an example, if the current direction of the payload were far off from its desired set point, the control action would be more aggressive, demanding the corresponding amount of pulses to be sent to its respective motor such that its angular state may be corrected in a smooth, yet quick response, avoiding unnecessary overshoot and/or settling time.

## Electrical Power System

As every other satellite one of the most important components that it possess is the electronic power system (EPS). This EPS takes care of supplying and controlling the power flow on every other instrument that makes the satellite. It is the bridge between the power sources, solar panels and battery, and the rest of the satellite. It needs to provide different levels of voltage depending on the satellite's needs with the highest efficiency possible, wasting the least amount of power possible.

The EPS can be divided into 3 main parts, excluding the solar arrays and the battery board. These 3 parts are the battery charge regulators, power distribution module and the telemetry. These three parts are very essential for the satellite to operate and a well design EPS can guarantee a safe satellite operation. For this preliminary design each of these parts will be discussed in general, discussing the main functions of these parts and some requirements that might be designed to achieve it. A simple block diagram that describes the connections between each important part of the EPS is provided below:

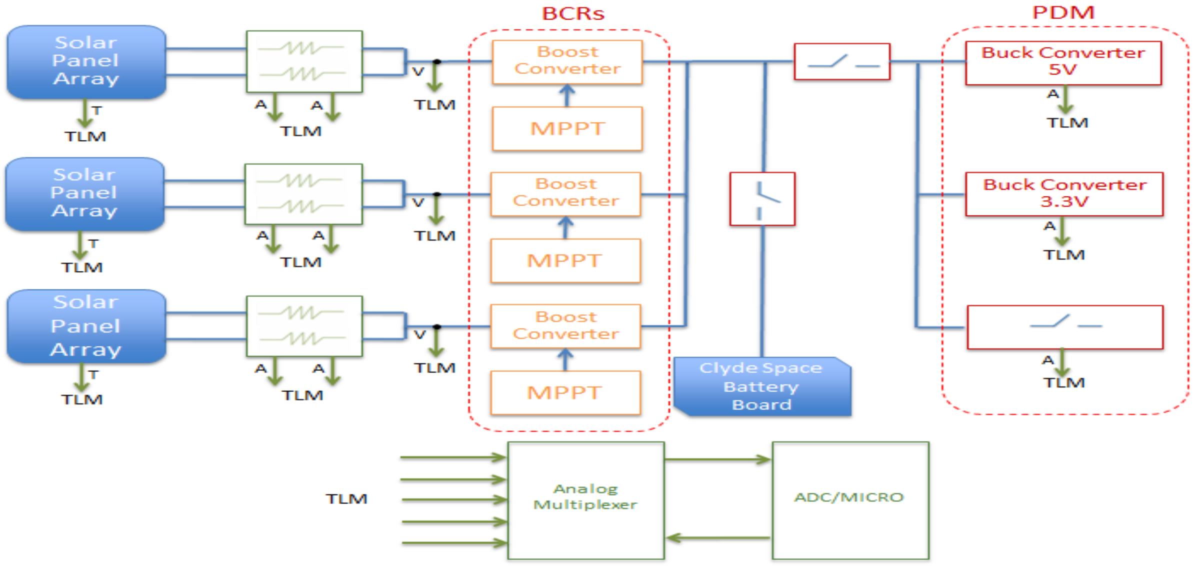

**Figure 4 Electical Power System (EPS) Diagram**

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## Solar Panels

The solar cell use are the SPECTRO Lab TASC cell  (triple junction) have an efficiency of 27%.This Solar Panel is designed to give an output voltage of 5.04V in open circuit and a current of up to 372mA in short circuit. Its typical results under sunlight will vary from 340-350mA and 4.8-4.9V due to the variation of intensity of the Sun’s rays on earth. Its max power point will be produced at 19.4Ω producing 4.56V and 234mA giving a total output power of 1.08W. The solar panels will be put in parallel. The approximate mass of each panel will be 35g and the panel size will be 8x8cm. The panels are bolted on to the CubeSat structure. The power requirement of the payload is distributed throughout the different systems sensors that will consume different voltage levels. It is important to emphasize that the solar panel will work only during the day. During the night the power will be obtained from HASP. As the solar panel and the EPS system are prototype, there will be a power system similar to that of the ADS board to obtain the power directly from the HASP platform. It is needed to the payload at the corner of HASP platform that face the sun.

The schematic in the **Figure 5** demonstrates the configuration of the TASC solar cell from SpectroLab. The solar panel will be connected to the EPS board for the proper energy distribution.

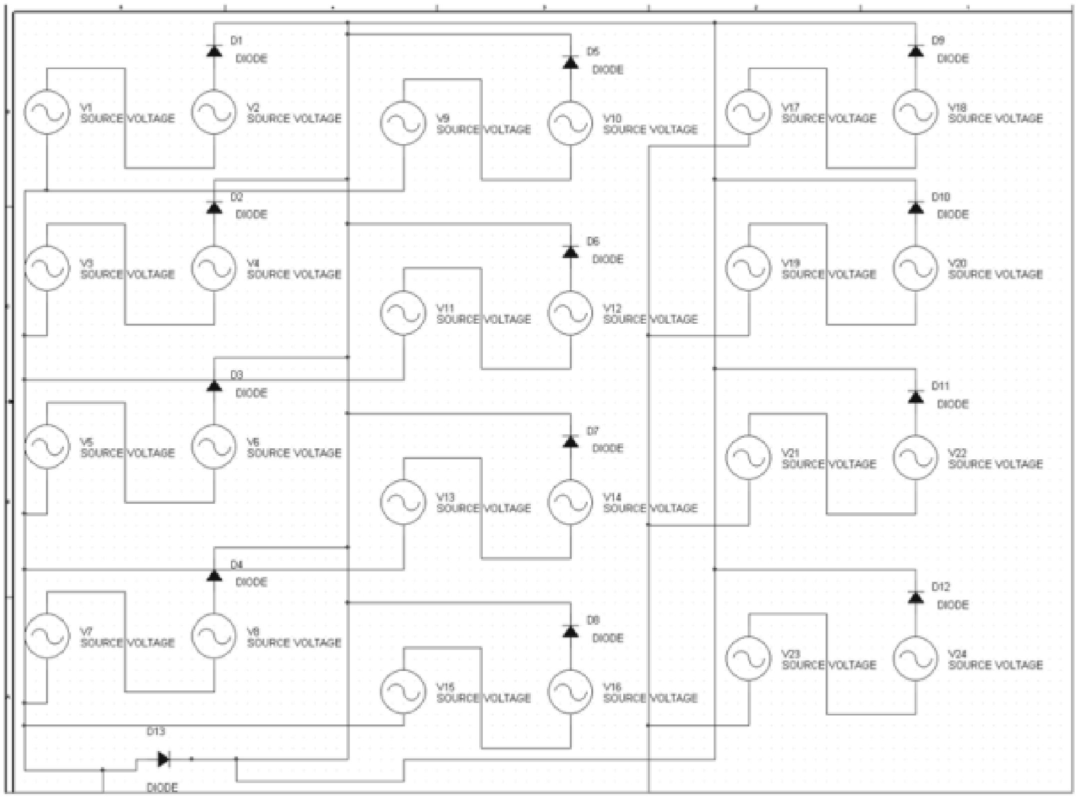

**Figure 5: Solar Panels Configuration**

## Payload’s Power Budget

| Sensor and Devices | Required Voltage (V) | Required Current Amperes (A) | Maximum Power Consumption Watts (W) | Power Source (after HASP) |
|---|---|---|---|---|
| Three Axis Gyroscope ITG3200 | 3.3 | 6.5mA | 21.45mW | TBD |
| Three Axis Accelerometer SCA3000 | 3.3 | .650uA | 2.145uW | TBD |
| Three Axis Magnetometer Micromag3 | 3.3 | .500uA | 1.65uW | TBD |
| Digital Temperature Sensor DS18B20 | 3.3 | 1.5mA | 4.95mW | TBD |
| DSPIC33F256MC710 DSPIC33 | 5 | 150mA | 750mW | TBD |
| Real Time Clock DS1306 | 5 | 1.28mA | 6.4mW | TBD |
| SD card circuit | 3.3 | 100mA(max)<br>38mA(Typical) | 125.4mW | TBD |
| GPS | 3.3V | 26mA | 85.80mW | TBD |
| Sun Sensor (6) | 5V | 0.0648mA (10.8uA each)<br>1.05mA (0.175mA each) | 0.324 mW<br>5.25mW | TBD |
| CMOS Camera (OV076) | 3V | 13.3mA | 40mW | TBD |
| Motors(2) | 5V | 200mA (100mAeach) | 1000mW | TBD |
| Encoders(2) | 5V | 2mA (1mAeach) | 10mW | TBD |
| Max consumption of sensors and devices | -- | ≈ 0.426A | ≈ 2W | -- |

**Table 1 Power Budget**

## Software Design

The data will be retrieved from the sensors and thus the software will be designed to read the data, store the data in the SD card, perform all necessary calculations and perform all the necessary controls to allow stabilization. **Figure 6** shows the general flow char, following with the **Figure 7 and 8** with more in depth in the source structure.

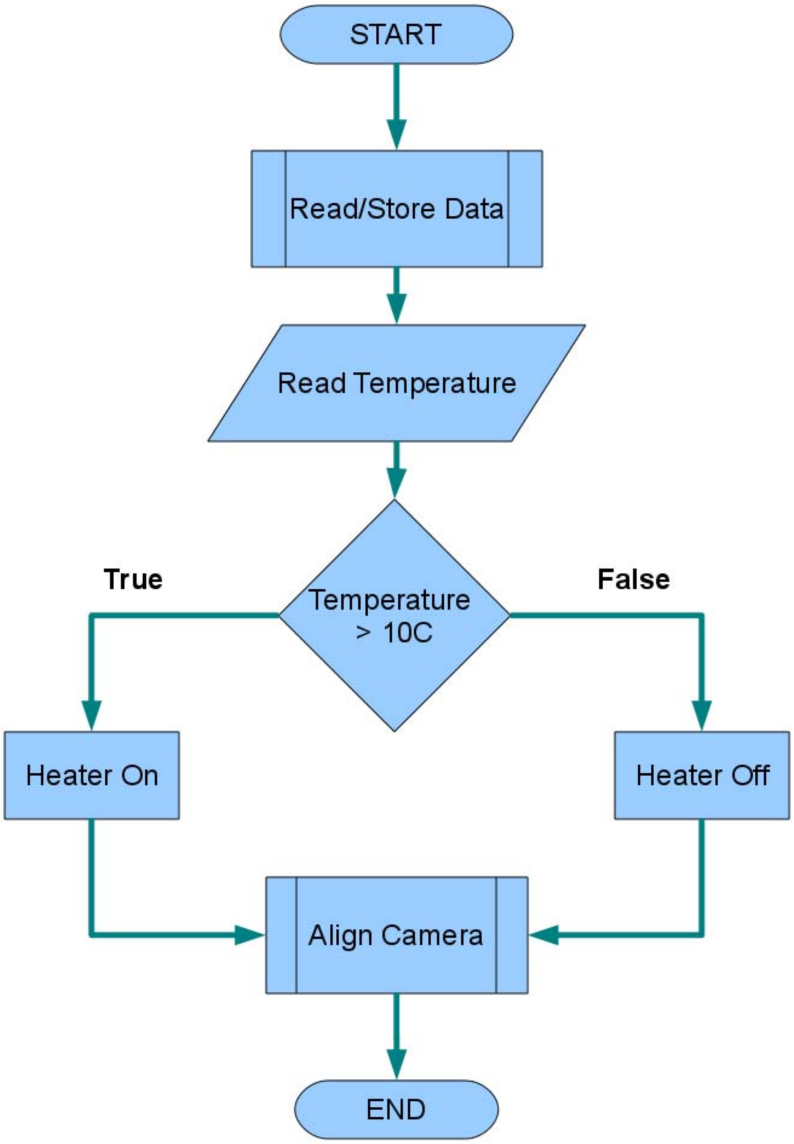

**Figure 6 General FlowChart for the ADCS experiment**

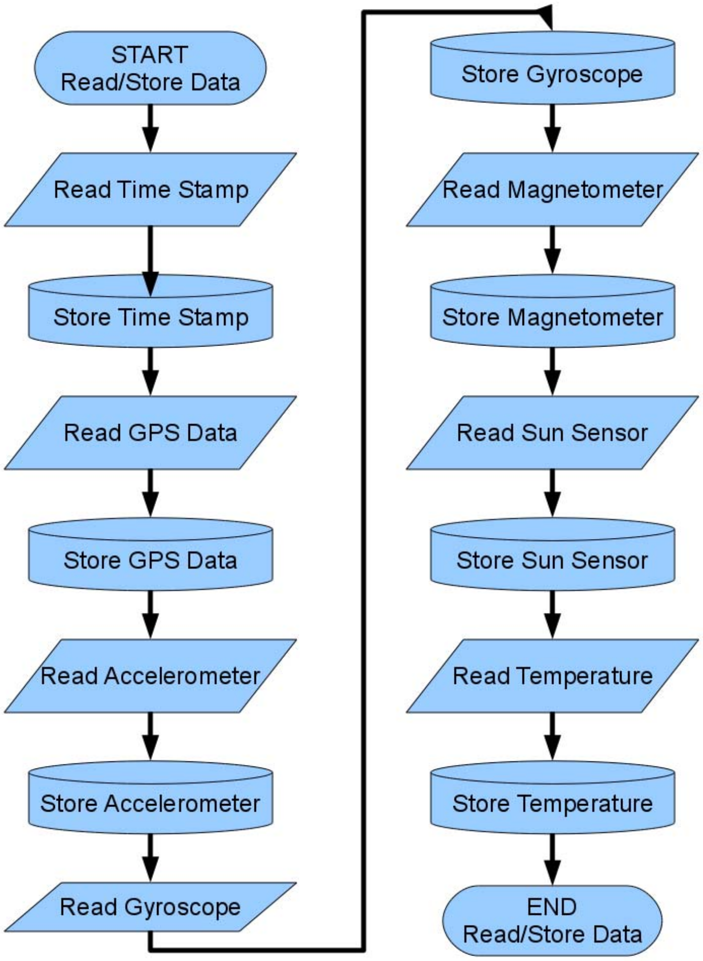

**Figure 7 FlowChart of the ADS Code**

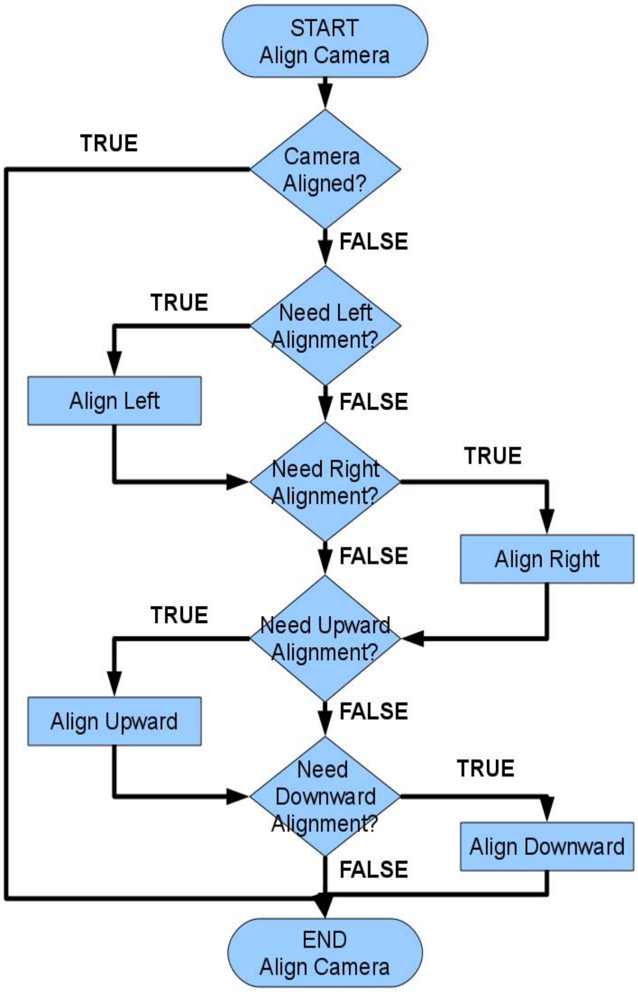

**Figure 8 FlowChart of the ACS Code**

# Mechanical Design

## Weight Budget

The TIGRE SAT payload has a weight limit of 3kg for the entire components; therefore, is required to develop a weight budget in order to monitor the weight of the entire ADCS payload to ensure the entire system will be within the weight limits mentioned in the technical requirements section. The approximate weight of each one of the components for the ADCS payload is described in the following table, which is **Table 2**. Since this project is currently in the preliminary phases, there are several weights that are in to be determine status. Nevertheless, a more detailed weight will be present in the CDR document of this project and the final weight information of the components will be included in the FRR document of the ADCS experiment. The values on the tables are estimate higher than expected to maintain a safe boundary.

| ***Devices for the ADCS Experiment*** | |
|---|---|
| ***Instruments/Components*** | ***Weight (g)*** |
| **ADCS Board** | 200g |
| **Power Board** | *150g* |
| **Rotational Structure** | *1404g* |
| **Cube Structure** | *1000g* |
| **Solar Panels** | 34 x 5 =175g |
| **ACS Motors** | 16g x 2 =32g |
| **Total Weight Approx.** | 2961g |

**Table 2: Weight Budget**

## Payload Dimensions and Design

The TIGRE SAT experiment must comply with various requirements such as weight and power as mention previously. But also a size requiremnet must be meet which is that are payload must not exced the 15x15cm footprint, a height of 30cm, and the ability to survive the landing laods. For this weight, yield streght and size are taking into acount in the design process. The TIGRE SAT payload will be mounted to the interface plate with four bolts from below. The design in **Figure 9** was develop to allow movements in two dimensions the yaw and pitch.

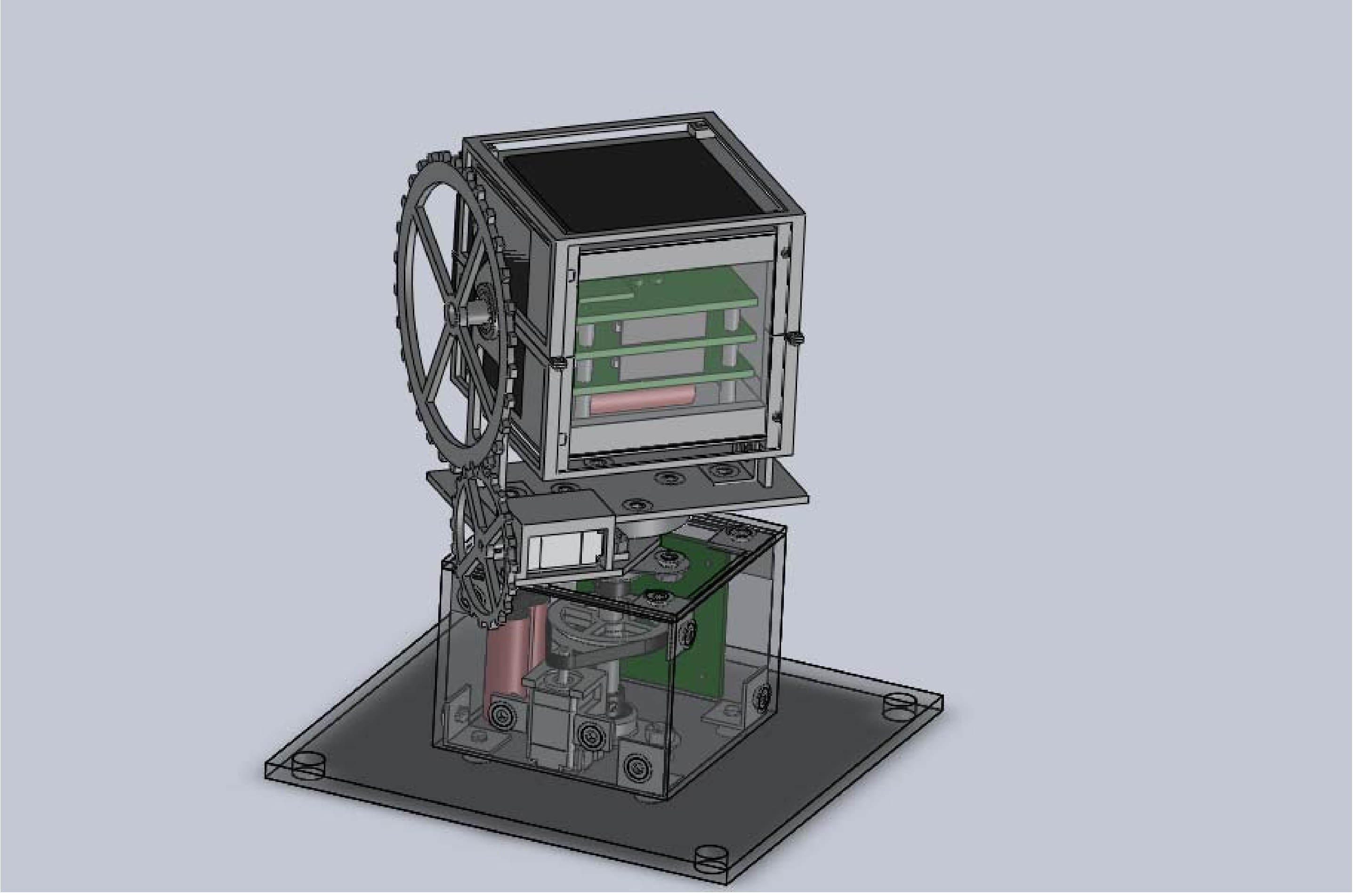

**Figure 9: Mechanical Design**

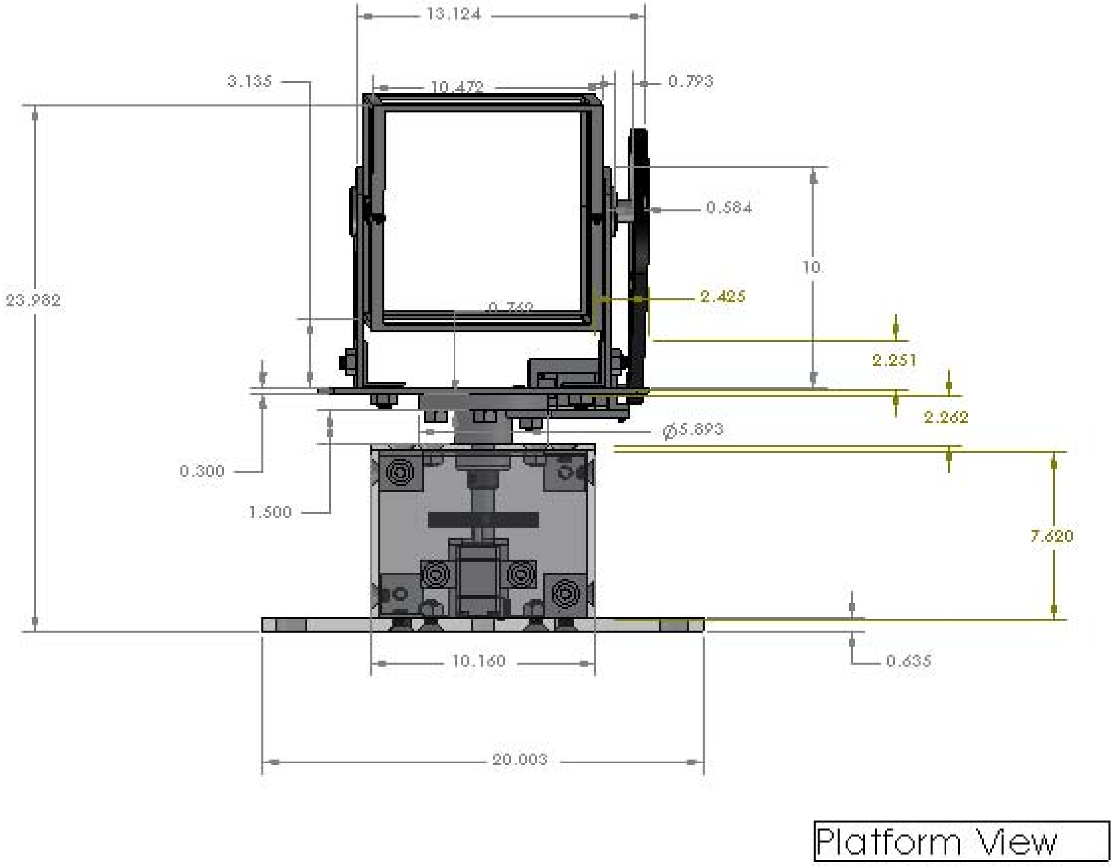

**Figure 10 Payload Dimensions**

**Data Format & Storage**

The TIGRE SAT payload plans to use the serial telemetry downlink which is at a baud rate of 1200 for the data. The total bytes required for the flight is determined by the quantity of the sensors and the total bytes of the measurement of the sensor times the hours the payload may remain in flight.

The system will have six sensors; three axis magnetometer, three axis gyroscope, three axis accelerometer, an internal temperature sensor, GPS and six Sun sensors. Each sensor with three axes will have a total of six bytes (2 bytes per axis) and the internal temperature sensor will have a total of two bytes. The time stamp consists of four bytes, one byte for the hours, one byte for the minutes, one byte for the seconds, and one byte for the date. The GPS will consist of 91 bytes depending of the National Marine Electronics Association (NMEA-GGA) string selected. In total we have 129bytes without the CMOS camera, the camera will consume 307.2 Kbytes and it will be store once a min. The sample rate will be of approximately 1 second. Each Sun sensor takes 2 bytes of data. The total byte required for the system in a 20hr flight is approximately 377Mega bytes. For telemetry we only desire to downlink the data from the sensors and encoder.

## Testing and Integration Procedures

## Testing at Inter American University of Puerto Rico Bayamon Campus

The TIGRESAT payload will require environmental testing for both instrument calibration and flight system validation. This project will perform environmental extreme temperature to ensure that the payload will perform successfully by using data provided by the HASP Call for Proposals document. A physical prototype of the experiment will be develop to test within 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. By do this we will be reading to pass and complete the integration process as efficient as possible.

Project Manager: Javier I Espinosa Student Project Manager
(787) 420 3877
Dr. Vo Hien Faculty Adviso, PI
(787) 241 8046

The administrative planning, organizing, directing, coordinating, analyzing, controlling, and approval processes used to accomplish overall project objectives, which are not associated with specific hardware or software elements. This element includes project reviews and documentation, and non-project owned facilities. It excludes technical planning, management, and delivering specific engineering, hardware and software products.

Systems Engineering: Tania Rosario
TaniaR13@gmail.com

The technical and management efforts of directing and controlling an integrated engineering effort for the project. This element includes the efforts to define the project flight instrument and ground system, conducting trade studies, the planning and control of the technical project efforts of design engineering, software engineering, integrated test planning, system requirements writing, configuration control, technical oversight, control and monitoring of the technical project, and risk management activities. Documentation products include requirements documents, interface control documents, and master verification and validation plan.

## Management

This project will operate under the supervision of Dr. Vo, Hien as shown in **Figure 12** at the Inter American University of Puerto Rico. Professor of different discipline are working in this experiment to supervise the student groups. The focus of the Aerospace Research and Innovative Experience for Students is to allow students to participate and be become part of a real real-world space-systems project. To better prepare the student for careers in space science and engineering. A additional motivation is to create an environment where creativity and independence is encouraged, thus allowing to apply the theory from the class room to real hands on work.

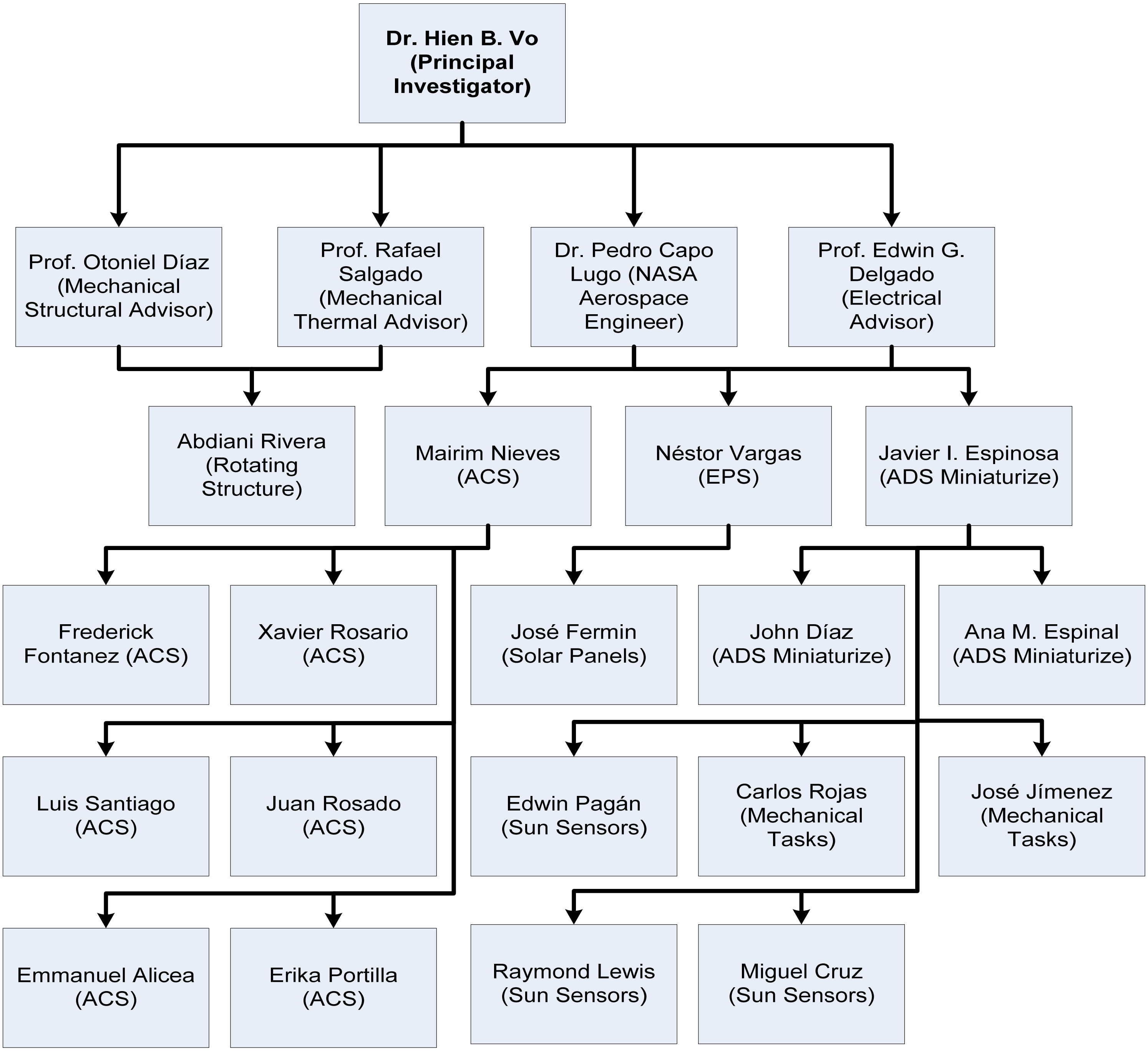

**Figure 11 ADCS Project Organization**

# Project Time Line

| Name | Begin date | End date |
|---|---|---|
| Improvements & Incorporation on the Following Sections | 11/1/10 | 11/5/10 |
| Science & Technical Objectives and Requirements Selection | 11/2/10 | 11/3/10 |
| Science & Technical Background | 11/3/10 | 11/5/10 |
| Scientific & Technical Reseach Mission | 11/1/10 | 11/2/10 |
| System Design | 11/1/10 | 11/11/10 |
| Electrical Design | 11/1/10 | 11/30/10 |
| Mechanical Design | 11/1/10 | 12/22/10 |
| Teleconference Q & A | 11/11/11 | 11/12/11 |
| Software Design | 11/22/10 | 12/16/10 |
| Preliminary Design Review (PDR) Document Revision | 12/14/10 | 12/15/10 |
| Preliminary Design Review (PDR) Document Deadline | 12/16/10 | 12/17/10 |
| Announce student payload selection | 1/14/11 | 1/15/11 |
| Monthly status reports and teleconferences | 1/1/10 | 4/30/10 |
| Fabrication | 2/1/11 | 3/25/11 |
| Preliminary PSIP document due | 4/21/11 | 4/22/11 |
| Preliminary HASP thermal/vacuum testing | 5/23/11 | 5/27/11 |
| Final PSIP document due | 5/31/11 | 6/1/11 |
| Monthly status reports and teleconferences | 5/2/11 | 8/31/11 |
| Final FLOP document due | 7/29/11 | 7/30/11 |
| Student payload integration at CSBF | 8/1/11 | 8/5/11 |
| HASP flight preparation | 8/29/11 | 9/1/11 |
| Target flight ready | 9/1/11 | 9/2/11 |
| Target launch date and flight operations | 9/5/11 | 9/6/11 |
| Recovery, packing and return shipping | 9/7/11 | 9/10/11 |
| Monthly status reports and teleconferences | 9/1/11 | 11/30/11 |
| Final Flight/ Science Report due | 12/15/11 | 12/16/11 |
| TIGRE SAT Project | 11/1/10 | 12/16/11 |

**Table 3: Work Breakdown Schedule**

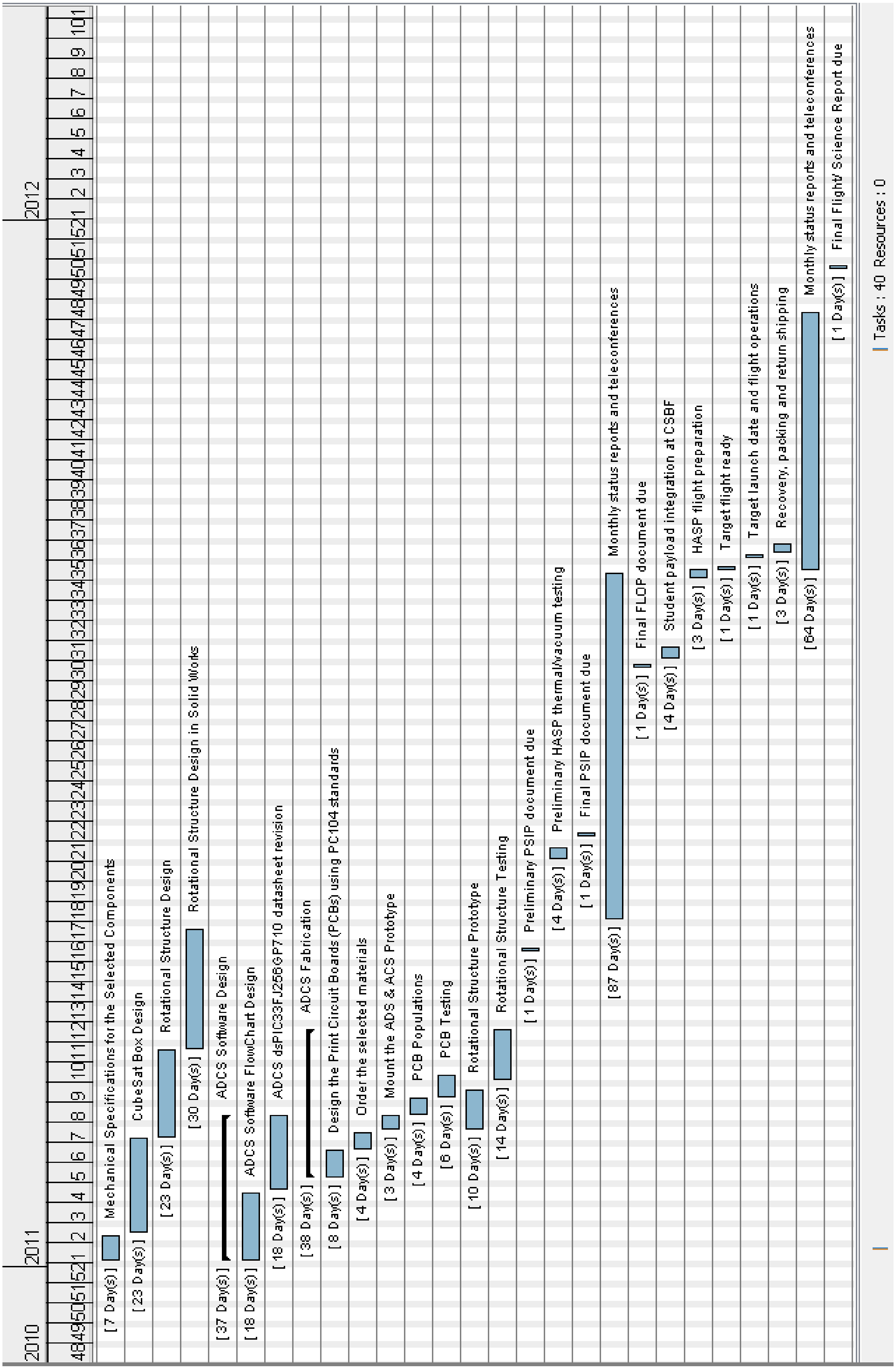

**Table 4: Gantt chart**