First Steps to Establish a Small Satellite Program in Peru

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Abstract—In the past years a couple of universities in developing countries did manage to establish and develop small satellite programs in their countries. They were using the so-called Cubesat technology. Now it is the time for Perú in South America to do the same. The aim of this paper is to inform the space community on the first steps and achievements carried out by some Peruvian institutions to create an aerospace program starting with a small satellite project. This challenging project will be carried out with the involvement of governmental and educational institutions in Peru as well as abroad.[12]

The small satellite program will be conducted by the Center for Technological Information and Communications (CTIC) at the National University of Engineering (UNI) in Lima, Peru. CTIC has the goal of developing a Pico-satellite, using the technology of and having the size of a CubeSat, and to launch it in the next 3 years, demonstrating that in Peru such a space program is feasible. Since last year, the efforts of Peruvian students, young engineers, academic personal and consultants have been centralized in the definition of the mission design. They have already mastered to identify and select which subsystems the satellite will carry into space. The Peruvian government is also interested in and currently is working on the development of the aerospace area in the country. The National Commission of Investigation and Aerospace Development of Peru (CONIDA) and the Department of Defense are supporting such challenging and promising program. A first step has been achieved establishing the National Committee for Operations of Satellite Images (CNOIS). The objective and purposes of CNOIS is to promote the technological and scientific development of the country in the remote sensing area.

This paper will describe the, until now, selected subsystems and the possible payload to be used during the operational mission live of the first Peruvian satellite.

The progress of our society and country can be ensured by developing this kind of technology. It will give us a great opportunity to perform space science and exploration.

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1. INTRODUCTION

At the end of the last decade, professor Robert Twiggs from Stanford University proposed the concept of a cubic Pico satellite bus, which was named CubeSat [1]. It defines a 10x10x10cm cube with a mass of maximal 1kg. In the past years a couple of universities in developing countries did manage to establish and develop small satellite programs in their countries. They were using the so called Cubesat technology. Now it is the time for Perú in South America to do the same.

The aim of this paper is to inform the space community on the first steps and achievements carried out by some Peruvian educational institutions to create an aerospace program starting with a small satellite project. This challenging project will be carried out with the involvement of governmental and educational institutions from Peru as well as abroad. This challenging small satellite program will be conducted by the Center for Technological Information and Communications (CTIC) at the National University of Engineering (UNI – for its initials in Spanish) in Lima.

The CTIC was constructed in 2006 with the support and financed by the government of South Korea. CTIC has the goal to develop the Pico-satellite CHASQUI-I[3], using the technology of and having the size of a Cubesat and to

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[2] IEEEAC paper #1671, Version 1, Updated December 21, 200

[3] CHASQUI is a Quechua word used for "messenger". The Chasquis were agile and highly-trained runners that delivered messages, royal delicacies and other objects throughout the Inca Empire.

launch it in the next 3 years, demonstrating that in Peru such a space program is as well doable.

The initial idea to build a student satellite at the National University of Engineering was conceived by the Peruvian engineers Hector Bedon and Jaime Estela supported by Juan Martín Canales Romero. The project cemented its basis in October 2008, when they met at the German Space Operations Center in Munich. Currently Mr. Bedon is team lead of the CHASQUI project. Mr. Canales and Mr. Estela work for the German Aerospace Center (DLR) in Germany and are project's technical and management advisers.

The motivation for the project development is primarily educational; it is to educate Peruvian students in space technologies and space system engineering with the further goal to develop in a near future a national program on small satellites. Since end of 2008, the efforts of Peruvian students, young engineers, academic personal and advisers have been centralized in the definition of the mission design. They have already mastered to identify and select which subsystems the satellite will carry into space.

This paper summarizes the work performed and the results achieved during the project's Phases A and B.

2. CHASQUI - I: THE PROJECT

The work has been carried out in the Center for Technological Information and Communications (CTIC) by Peruvian professors, engineers and students of several faculties with the support of technical advisors and consultants.

Mission Objectives

The main goal of the overall CHASQUI project is to let Peruvian students and engineers design, build and launch a CubeSat with the purpose to provide "hands-on" education and gain experience with Pico-satellite technology. This objective assumes the development of both ground and space systems in order to achieve the reception of data from the satellite, its payload and subsystems, and confirm operations. The mission duration shall be at least 6 months however we envisage building the satellite to have an orbital life longer then half a year.

The key elements of the project are:

- Educate Peruvian students and engineers in space technologies
- Technological demonstration in the area of solar cells and embedded software
- Cooperation with national and international partners, like universities and space related institutions

The need for a better organization to accomplish such a complex enterprise led to the distribution of the work into teams or modules, each one with a certain task and function. Thus, it has been established that CHASQUI-I program will be divided into 7 modules, which are: Power and Thermal Control (PCT), Communication System (SICOM), Images Capture (SIMA), Attitude Determination and Control System (UDCA), Central Control and Information Management (CCMI), Mechanical Structure (EMEC), and Ground Stations (ESTER). Each of these groups represents a satellite subsystem except the last one, which deals with the task to permit the communications between the Pico-satellite and the control center. An engineering team and technical consultants manage the whole project.

CHASQUI-I will have the following characteristics:

(1) Dimensions: 10 x 10 x 10 cm^3
(2) Mass: 1 Kg
(3) Orbit: Sun-synchronous polar at altitude about 450-850 km (LEO)
(4) Lifetime: 6 - 8 months
(5) Payload: VGA camera and NIR camera
(6) Communications: UHF downlink/VHF uplink
(7) Key components: Digipeater (digital repeater)

Table 1 lists the CHASQUI-I modules and provides a short description of their tasks.

Table 1. CHASQUI-I Modules and their Tasks

Subsystems	**Description**
Central Control and Information Management (CCMI)	controls and manages the subsystems' information - low power consumption
System for Image Acquisition (SIMA)	obtains Earth pictures
Power and Thermal Control (PCT)	controls the power and thermal states of the different components
Communication System (SICOM),	sends/receives data to/from ground
Attitude Determination and Control System (UDCA)	controls the orientation of the spacecraft
Mechanical Structure (EMEC)	design of the satellite structure
Ground Stations (ESTER)	builds the ground segment

3. CHASQUI - I SUBSYSTEMS

3.1. Central Control and Information Management System (CCMI)

This section documents the definition activities leading a sophisticated system for the CHASQUI-I spacecraft, i.e. the Central Control and Information Management system. At the beginning, this module's, as well as all the CHASQUI-I team's, main task was the study of other similar projects. For this a lot of related documentation, like CubeSat standards and specifications, publications made by universities worldwide were revised, and we managed to get in touch with specialists and students from other universities and institutes with experience in subjects related to ours.

Owing to the fact that the CCMI module depends on the other modules' requirements, support from PAET students (PAET means in Spanish: Programa de Alta Especialización Técnica; High Technical Specialization Program) has been requested by CTIC. These students have as main task to be always in contact with each module and inform the CCMI responsible about the progress in the project every week. The members of the CCMI module should master the design of printed circuit boards (PCBs), microcontrollers programming, embedded systems design; as well as the module's simulation and testing.

General Objective

- To develop the CHASQUI-I CCMI module's electronic card with the required features to accomplish the mission.

Specific Objectives

- To determine the communication features with other modules,
- To determine the control functions with the other subsystems,
- To establish the operation modes and manage these modes,
- To determine the electronics and components for a good functioning of the module and the whole satellite,
- To study and program the microcontroller,
- To perform simulations and tests of the central module with three types of microcontrollers.

The central module is implemented as an electronic card with a low-power-consumption microcontroller (uC). The type of communication chosen is I2C, because it has a synchronous bus which allows communicating the uC and peripherals with two lines. We will also use the SPI standard for storing the captured images in an SD card. There will just be a test to be performed, because we will also work with an IC FLASH memory in order to bring down the power consumption of the module. An UART bus for the camera control is also needed, since it contains a microcontroller that uses that bus for its control. The central module will also digitalize the analog signals from the voltage, current and temperature sensors.

As described before, it has been decided to work with an ultra-low-power consumption microcontroller and with the communication peripherals I2C, SPI, UART and ADC, as shown in Figure 1.

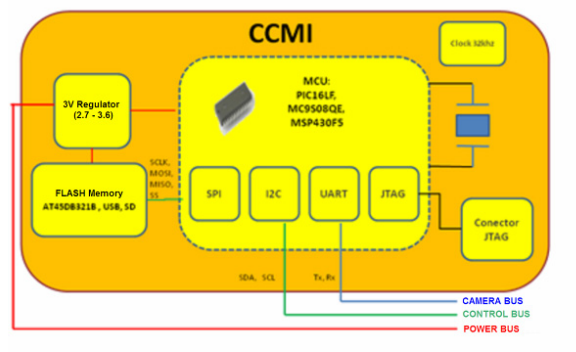


Figure 1 – CCMI Module General Diagram

So when revising different manufacturers' datasheets, three feasible options were taken into account: a Microchip PIC16LF, due to its simplicity in programming and experience developed with this microcontroller; a Freescale Semiconductors MC9S08QE, due to the experience and test boards we have; and a third option the Texas Instruments MSP430F5 since it was used by other Pico satellites and it is characterized by its low-power-consumption. Currently, parallel work with the three microcontrollers is being performed. Table 2 provides an overview of the CCMI module's main characteristics.

Table 2. Technical Characteristics of the CCMI Module

Measures:	95 x 84 mm
Weight:	100 gr
Material:	Fiber glass FR4
Microprocessor:	16 bits, low-power (In evaluation and tests)
Voltage:	3.3 V
Frequency:	4 MHz
Power	< 60mW

Figure 2 shows a representation of the CCMI diagram connected to the other satellite subsystems.

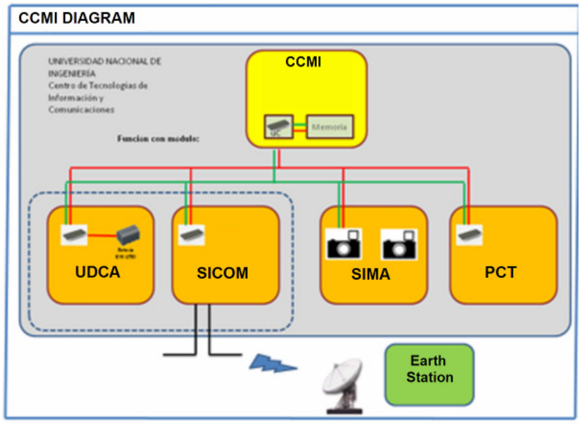


Figure 2 – CCMI Connections Diagram

The communication characteristics between the central module CCMI and the other subsystems are described below:

- **CCMI → PCT**

The PCT module function is to control the power and temperature conditions of the Pico-satellite; it shall also advice the central module in case the CHASQUI-I might enter in emergency mode.

Table 3. PCT Module Communication Features

Supply	
+3,3V; Ground	PCT
Binary Inputs (BIT)	
(2) bits of availability	CCMI
Analog inputs	
(of each sensor)	
Digital outputs	
(2) bits of availability	CCMI
(3) pins of 1-bit output	Actuators
Sensors	
(2) thermal sensors LM95075 (batteries)	
(5) thermal sensors (solar cells)	
(1) voltage sensor for the batteries	
(1) current sensor for the batteries	
Communicates with	
CCMI (I2C)	
Actuator	
(2) thermal heaters for the batteries	
Bus	
I2C	CCMI

Currently, there is an analysis of two possible options in order to determine which of the microcontrollers, the one of the CCMI module or the PCT, should digitize the signals from the temperature, voltage and current sensors. In the first case (Fig. 3a) the CCMI module should tell the PCT module the values of the sensors readings or the operation modes of the system. In the second option (Fig. 3b) the uC of the PCT module determines the operation mode based on the reading information of its sensors, it will also be able to tell the central module that lecture using the I2C bus.

First Option

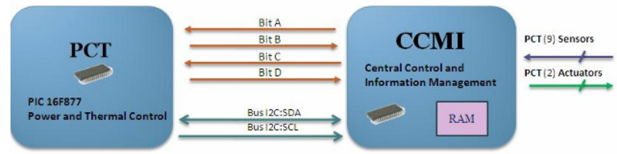
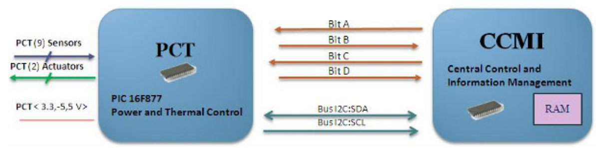


Figure 3a – Sensors to the uC from the CCMI Module

Second Option



Bit A: Sensors Data Request
Bit B: Sensors Data Send
Bit C: Operation Bit Send
Bit D: Emergency Mode

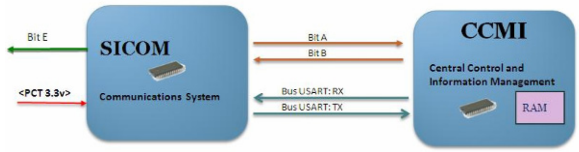
Figure 3b – Sensors to the uC from the PCT Module

- **CCMI → SICOM**

The central module manages the communication with the ground station (ESTER) through the SICOM module; which sends/receives the data and commands between the satellite and the ground station.

Table 4. SICOM Module Communication Features

Supply
+3,3V, Ground
Binary inputs (BIT)
(1) Emergency Information Bit (PCT)
Analog inputs
Vcc (3,3V)
ESTER (Ground Station) Radio Waves
Digital inputs
Data from CCMI (UART)
Digital outputs
Data to CCMI (instructions in-hexadecimal)
Send of a Beacon frame for external synchronisation
Communicates with
CCMI, PCT, ESTER
Bus
UART



Bit A: Beacon Send Confirmation
Bit B: Beacon Send Order
UART: ESTER Data and Orders

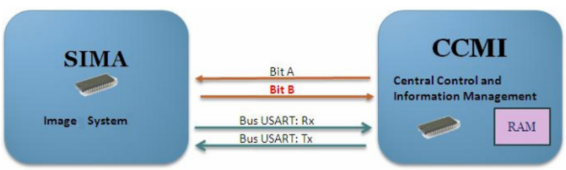
Figure 4 – SICOM-CCMI Communications

- **CCMI → SIMA**

The central module function in this case is to order the microcontroller to capture the satellite images and its storage in a memory.

Table 5. SIMA Module Communication Features

Supply	
+3,3V; Ground	PCT
Binary Inputs (BIT)	
(2) bit of availability	CCMI
Communicates with	
CCMI (UART)	



Bit A: Camera selector
Bit B: Luminosity Sensor (optional)

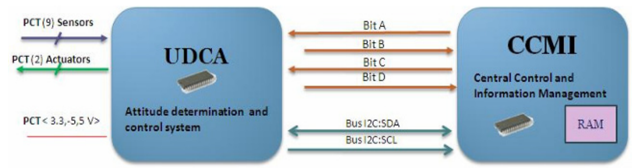
Figure 5 – SIMA - CCMI Communications

- **CCMI→UDCA**

In this case, the central module arranges and confirms the request of stabilization and orientation of the satellite.

Table 6. UDCA Module Communication Features

Supply	
+3,3V; 5V;-5V; Ground	PCT
Binary Inputs (BIT)	
(2) bits of availability	CCMI
Analog inputs	
(of each sensor)	
Digital outputs	
(2) bits of availability	CCMI
(3) PWM	Actuators
Sensors	
S65S60 solar sensors	
Gyroscope 1 axis MLX90609	
Magnetometers 3-axis HCM5843	
Communicates with	
CCMI (I2C)	
Actuator	
Permanent magnet	
Torque coils	
Bus	
I2C (2)	CCMI



Bit A: Orientation request
Bit B: Orientation acknowledgement
Bit C: Self-orientation request
Bit D: Self-orientation acknowledgement

Figure 6 – UDCA - CCMI Communications

CHASQUI-I Operation Modes

The operation modes are the states in which the CHASQUI-I will be operating in space. After its launch and by reaching its final orbit the Pico satellite will be in the **waiting mode** state until the ground station signal is found. In this very moment, the satellite will reach the **normal mode**. In case there is not communications with Earth yet, the system will have return to the **waiting mode**. If any issue in the **normal mode** or in the **waiting mode** occurs, the system will enter the **emergency mode**, from which will go out when the problem is solved. Figure 7 shows graphically the satellite states sequence or operations modes.

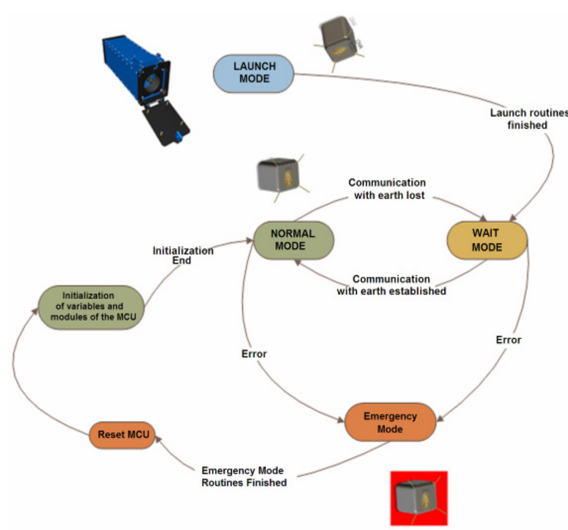


Figure 7 – CHASQUI-I Operation Modes

Conclusions

- The data to be handled are camera data, maintenance data and commands.
- The bus for communication with PCT and UDCA modules are I2C, and two UART buses for the SIMA and SICOM modules. In addition, there will be telemetry indicating the states of each module.
- The images (which are captured by the SIMA module) will be stored in an SD card, but because of the use of the camera compressor, the system will use an IC Flash for this objective.

3.2. System for Image Acquisition (SIMA)

Two VGA cameras and control electronics compose the SIMA module. This ensemble will enable the Central Processor Module to obtain Earth pictures, depending on the satellite attitude, position and light intensity. These cameras have different spectral sensitivity thus one of them will take pictures in the visible range while the other will take pictures in the Near Infrared region of the spectrum. The use of NIR pictures will enable us to observe fluorescence phenomena, incrementing the white-black contrast between forest-desert regions. This characteristic is well known in remote sensing and it was observed in previous tests performed on Earth by our team using CMOS sensors. We consider if the satellite attitude as well as illumination and position are proper set, a good contrast between forest-desert regions should be observed.

So far no previous academic Pico satellite mission has taken pictures within the NIR region. This will make CHASQUI-I the first Pico satellite in its kind to perform this task. Several considerations have been taken in to account in order to select the SIMA components. Among them are: power budget, picture size, speed of transmission between the satellite and the ground station, fast programming and implementation, white balance and gain control, easy communication with the Central Processor Module, working temperature, lightning and weigh conditions. Since the transmission speed Satellite-Earth is 1200 baud, a resolution of 640x480 pixels has been chosen. The OV7640 CMOS VGA camera chip from Omnivision accomplished with the requirements of resolution, power budget, lightning and temperature. It has also automatic white balance (AWB) and automatic gain control (AGC). We consider the use if these controls will solve contrast problems presented in other previous mission where the camera has neither AWB nor AGC.

In order to reduce the size of the image file and the Central Processor Module calculations, the OV528 serial bridge controller will be used. This chip takes directly the 8-bits YCbCr 4:2:2 progressive video data from the CMOS VGA camera chip and performs the JPEG image compression. As result, the image file size is around 27KB at 640x480pix resolution. The OV528 chip is connected directly to the Central Processor Module and the communication is done using serial transmission (UART). The OV528 chip enables the Central Processor Module to configure and command the camera. The Central Processor Module sets these commands and their values are stored in the 24LC64 EEPROM, which is wired to the OV528 through I2C. Taking the last description into account each of the VGA cameras is composed by the OV7640 CMOS VGA camera chip, a OV528 serial bridge controller and a 24LC64 I2C serial EEPROM. The power supply for the ensemble is 3.3V and requires 60mA when takes pictures.

In order to obtain both visible and NIR pictures one of the cameras uses an IR-cut filter while the other uses an IR-pass filter (>700nm). Both cameras and a control-multiplexing circuit are set on a printed circuit board. The two camera lenses are lined in the middle of the satellite face.

Depending on the satellite operation modes, the SIMA performs its own operations. During launch, the Emergency and the Waiting Modes the SIMA module is switched off. When the satellite enters to the Normal Mode, and after the attitude and the position are proper set, the SIMA module is turned on. Only one camera is used at a time, and each taken picture is stored in the memory of the Central Processor Module. Each time the CHASQUI-I has an active link with the ground station, the Central Processor Module sends the pictures. The SIMA module diagram is depicted in Figure 8.

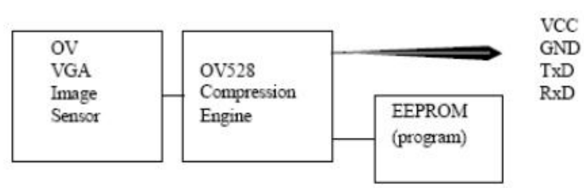


Figure 8 – SIMA Module Diagram

3.3. Power and Thermal Control (PCT)

Power System

The power system is responsible for generating, storing and distributing electrical power to the Pico-satellite subsystems. The parts of this system are:

- Solar cells, which receive and convert solar energy into electrical energy
- Rechargeable batteries, which store energy supplied by the solar cells
- Power board, which contains the electronics necessary to control these processes above

Solar Cells—Triple-junction photovoltaic cells have been selected. They absorb more solar spectral energy and generate high efficiency electricity. The solar cells will be placed on the outer surface of the satellite; two solar cells per side, making a total of 12. On each site the solar cells are connected in series to increase the supplied voltage to charge the batteries. The solar cells were donated by EADS Astrium GmbH, with the help of Mr. Reinhard Doffin, Product Line Manager Solar Arrays, Ottobrunn-Munich, Germany.

Rechargeable Batteries—Lithium-polymer batteries will be used, because these have a high density of stored energy and a higher voltage relative to other battery types. The role of the batteries is to store energy during the sun phase; this is the period in which the solar rays reach the satellite. In the eclipse phase the satellite will use this stored energy from the batteries because in this phase the satellite will not receive sunlight. A battery discharges 30% of its maximum capacity in order to increase their lifetime, which is approximately six months. Inside the satellite the three batteries will be connected in parallel. The batteries were donated by VARTA Germany.

Power Board—It contains the following components and electronic circuits:
Microcontroller—it processes and sends data and commands to other components of the power system and also to other satellite systems.
Voltage regulators and converters—these components receive power directly from the battery and deliver the adequate energy to the satellite subsystems. The different subsystems use 3.3V and 5V.
Charge Control Circuit—this circuit receives commands from the microcontroller and has three functions:

- Set the solar cells to the maximum point of energy generation
- Provide the adequate charge for the batteries
- Control the loading and unloading cycles of the batteries to protect them from over-load or over-discharge

Emergency mode switch—when the satellite needs to go to the emergency mode, which occurs when the energy level in the batteries is very low, the microcontroller switch off the dispensable systems via the Emergency Mode Switch. The microcontroller will switch on the disconnected systems when the batteries store again enough energy.
Sensors: the power board has also voltage and current sensors for the batteries, which collect information about the energy level of the batteries and sent it to the microcontroller.
Heater Control Unit—in the power board is also located a circuit that controls the electrical heaters located inside the battery box, the function of these is to prevent the temperature of the batteries fall below its operating range, and the microcontroller will set these heaters accordingly.

The illustrations in Figures 9a and 9b display the Power subsystem and the PS controller.

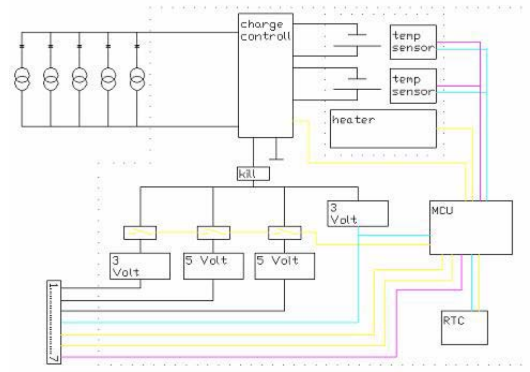


Figure 9a – Power Subsystem (PS)

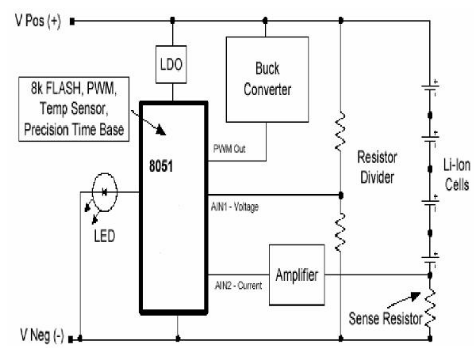


Figure 9b – Power Subsystem Controller

Thermal Control System

The thermal control system is responsible for controlling the temperature of the CHASQUI-I. This system is autonomous and has as main objective to maintain the temperature of all subsystems and payload within their operating ranges, so that they can operate and live on orbit successfully. This system consists of two subsystems; one for active control and one for passive control.

- The passive thermal control subsystem regulates the temperature by heat insulation, to prevent power consumption when it is not necessary. This system works usually with insulation, coatings, radiators, etc.
- The active thermal control subsystem is responsible to keep the temperature of the devices within the operating range, using heaters that operate during the eclipse phase, where due the absence of sunlight, will be necessary to raise the temperature of the devices.

Active Thermal Control—The active thermal control subsystem consists of heaters which protect the batteries from extreme cold temperatures. The heaters are based on a Nichrome wire with a diameter of 0.5 mm and a length of approximately 24 cm. The heater control is doing by a micro controller, which turn on the heater when the temperature of the battery is out of its minimum operating range and turn off when it reaches the average operating temperature. The batteries will be installed inside an aluminum box with temperature sensors.

Passive Thermal Control—The thermal properties of the mechanical structure, in this case 6061-T6 Aluminum has to be considered; its properties are relatively constant and vary depending on the temperature. For the package of the batteries two insulators will be used. These insulators are Kapton.

During the thermal analysis and due to the temperature changes, it was identified that the most sensible parts are: the batteries, the cameras, the solar cells and some electronic devices. The operating temperature of each electronic device was defined as per their technical specifications. To have the values of the internal temperature in the satellite the thermal resistances of the devices were used in the thermal simulation.

3.4. Attitude Determination and Control System (UDCA)

The CHASQUI-I must be equipped with an attitude determination and control subsystem (ADCS) in order to be able to perform its objectives of taking Earth pictures and to aim the antenna towards the ground station. The ADCS is not only used to orient gradually the satellite in the desired direction despite its attitude in space, but it is also used to reduce the satellite rotational kinetic energy after deployment or when necessary. Gentle rotation allows for moderate energy consumption while achieving the desired pointing accuracy. High angular velocities are undesired; they limit the use of the on-board electronics. A total rotation rate is therefore assumed to have to stay between 0.2 and 10 degrees per second. The ADCS configuration is presented below in Figure 10. Sensors for the attitude determination subsystem (ADS) are mini-GPS, magnetometers, photodiodes and gyrometers, all of them connected and housed on the ADCS board. Data are collected by a microcontroller which executes both the attitude determination and the stabilization/orientation algorithms, and also sends data to the ground station. Corrections to the attitude are sent to the coil actuators. For orienting the satellite, the attitude control subsystem (ACS) will use a combination of magnetorquers, and permanent magnets on one or two perpendicular axes to dissipate angular velocities. The most stringent design constraints are mass, volume and power, thus ADCS is limited to 15% of the total satellite mass and volume, and its maximum allocated power is 1W. An additional demand of low costs is present since CHASQUI-I is an university project. Considering these constraints, the ADS is being constructed using a combined sensor system. The final sensor system is being evaluated on its capability to get an accurate attitude to meet the mission objective. Attitude determination algorithms such as QUEST (Quaternion Estimation) and EKF (Extended Kalman Filter) are being implemented on the ADCS software to improve the accuracy of the attitude determination. The use of a high-performance microcontroller enables a real-time attitude determination using these advanced algorithms. One of the microcontrollers being evaluated is the digital signal controller (DSC) MC568013 from Freescale. The programming of the DSC is based on the modes of operation. Figure 11 shows the DSC communication with the sensors through SPI and I2C protocols. The I2C protocol is also used for communication with the CCMI when ADCS data uplink or downlink is required. Elemental communication with the CCMI is performed using 4 bits. Attitude estimation will also be performed on the control center by recalculations based on the sensor data received from the satellite.

The ACS will take advantage of a passive magnetic control by positioning a permanent magnet aligned to the payload board. The control authority left will be taken by the

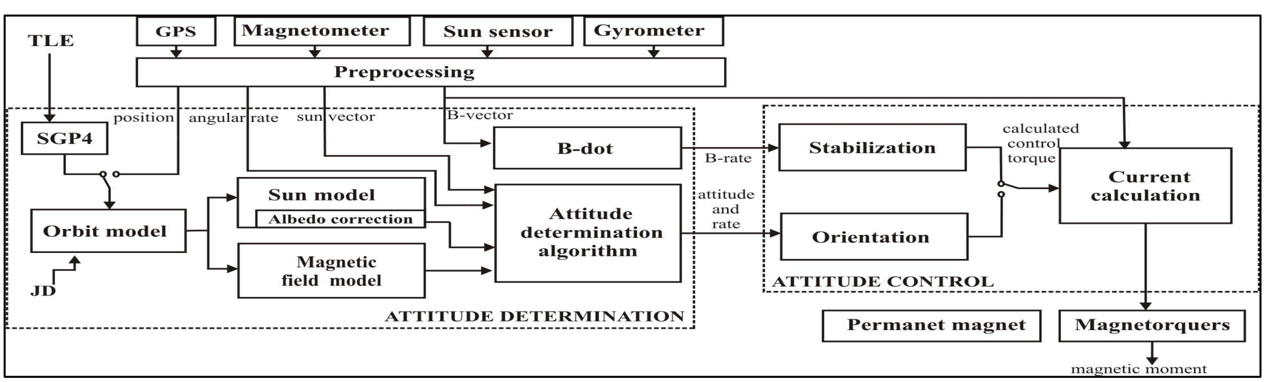


Figure 10 – The ADCS configuration

magnetorquers. Detailed analysis is being performed in order to get an optimal design for the coils and permanent magnets. The optimality criteria are small power consumption and reduced mass, thus making our ACS attractive considering the design constraints. Figure 11 also shows the power bus from the PCT. The DSC has PWM channels to drive the magnetorquers. For detumbling purposes, a B-dot control will be implemented as part of the ADCS software. For tight control of the satellite angular momentum, the ADCS must be able to overcome the disturbance torques experienced in space. Worst-case disturbance torques have been calculated for CHASQUI-I, as shown in Figure 12.

The decision on the orientation control law for the ADCS software still needs to be made. Types of control laws being considered are optimal control and nonlinear control. Even though there is enough theory to reliably scale permanent magnets and magnetorquers; test and verification of the control system is desired. A Simulink model of the satellite and its space environment is being developed to permit an initial evaluation of the control system. Additional considerations on how to make the ADCS fault tolerant, redundant and autonomous still have to be analyzed.

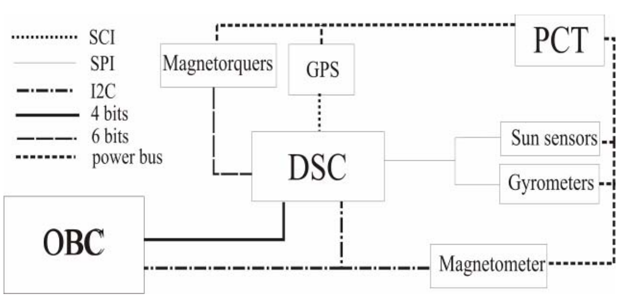


Figure 11 – ADCS communication and power buses

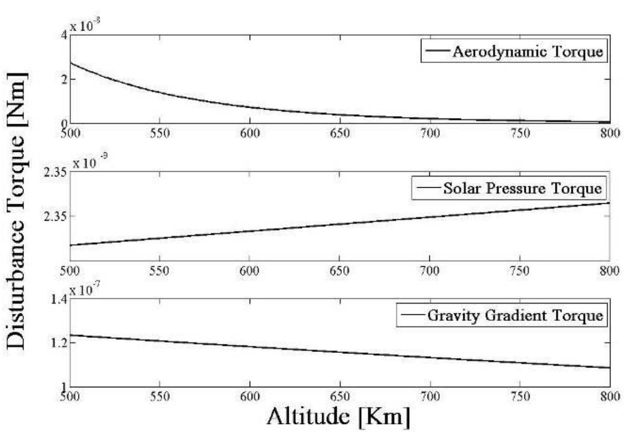


Figure 12 – Worst-case disturbance torques

3.5. *Communication System (SICOM)*

The SICOM subsystem has the task to send the generated on board data to the ground and to receive commands from the ground station. The characteristics of this subsystem are:

- Frequency band: UHF, 435...436 MHz
- Operation mode: Half duplex
- Transmit power: 0.5 W
- Modulation: FSK
- Downlink Baudrate: 1200 bits/s
- Uplink Baudrate: 1200 bits/s

The SICOM sends a Beacon with the most important parameters values of the satellite to indicate the good functionality of this. A micro controller will manage the SICOM module. The most important characteristics of this device are:

- Low power consumption: The necessary energy to operate this micro controller is 3.5 V and 400uA by 1MHz. In Standby modus it consumes 1.3uA
- RISC Architecture of 16 Bits
- A/D Converter of 12 Bits
- D/A Converter of 12 Bits
- UART communication interfaces

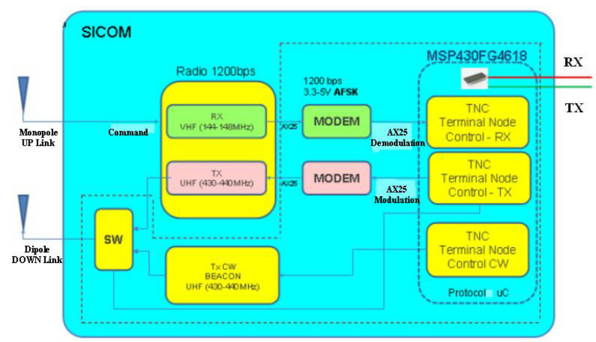


Figure 13 – SICOM block Diagram

The data to be sent to the ground will be packed using the AX.25 protocol, which is a data link layer protocol use by amateur radio operators. With this protocol there will be established a point-to-point link between radio stations without additional network layers. This simple protocol has a speed limitation. A typical data rate is 1200 bps and rarely higher than 9600 bps. The SICOM module can also perform the function of a Digipeater (Digital Repeater). Digipeaters receive and retransmit packets in the same frequency to cover a big area for communications purposes.

3.6. *Mechanical Structure (EMEC)*

As per CubeSat specifications these satellites are cube shaped with a nominal length of 100 mm per side. Taking into account this dimensional and mass requirement the present chapter deals with the evolution and the development of the CHASQUI-I mechanical structure which includes three phases: first phase is about the study of

CubeSat state-of-the-art; in the second phase a prototype, that is an own UNI design, has been developed and is compatible with the CubeSat technology. In phase three engineering models of the structure have been built. Here all the components will be assembled, to carry out a set of preliminary mechanical tests, before the accomplishment of standardized tests for its certification.

*Phase 1—*In this phase, the search of the state-of-the-art of Pico-satellites was realized, emphasizing that nowadays there are a lot of models, all of them measures 10x10x10 cm and aluminum 6061-T6 is used. Due to its specific weight, this material provides less weight and satisfies the mechanical exigencies for satellites of small size. This stage culminates with the elaboration of the carton model shown in Figure 14 and, with the knowledge that the used thickness of the plates/walls used to build the satellite structures is mainly 1 or 1.2 mm.

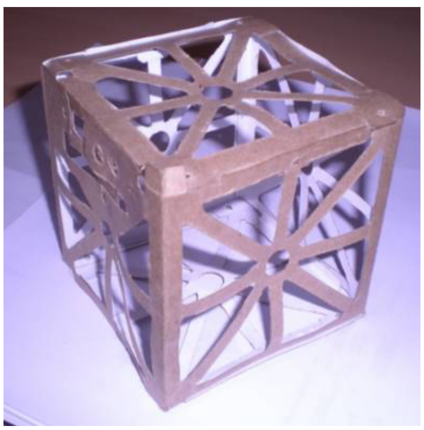


Figure 14 – Carton Model made in Phase 1

*Phase 2—*In this phase the viability of the diverse processes of manufacture is analyzed to elaborate the structure of CHASQUI-I, deciding to build a cube with holes and assembled as shown in the Figure 15

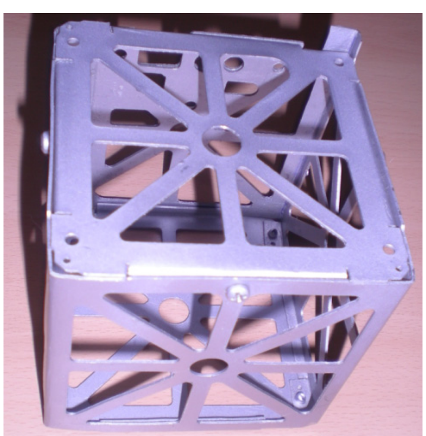


Figure 15 – Model made in Phase 2

*Phase 3—*In this phase several models were projected and built, considering continuous changes. The components were assembled within the structure to obtain the center of mass and to assure that the satellite does not exceed the weight of 1 kg.

The manufacture procedure to build the structure of CHASQUI-I went following process:

- Cut of a plate unfolded for five faces as shown in Figures 16 and 17,
- Cut of a plate unfolded for upper cover,
- Drilled of the holes, previous to assemble the structure,
- Cold welding folding,
- Riveting of the faces,
- Armed of the base of the bucket
- Integration of the modules in the interior of the structure.

Table 7 shows a manufacture procedure to obtain the engineering model of Figure 18.

Table 7. CHASQUI-I Manufacture process

Components	**Operation**	**Used machinery and/or tool**
Plates	Cutting	CNC Machine
Columns	Milling of faces and of ends, threaded rolling	Milling machine and conventional winch, diestock female
Nuts	Threaded rolling	Conventional winch, male diestock

Figure 16 shows the walls of the satellite's structure.

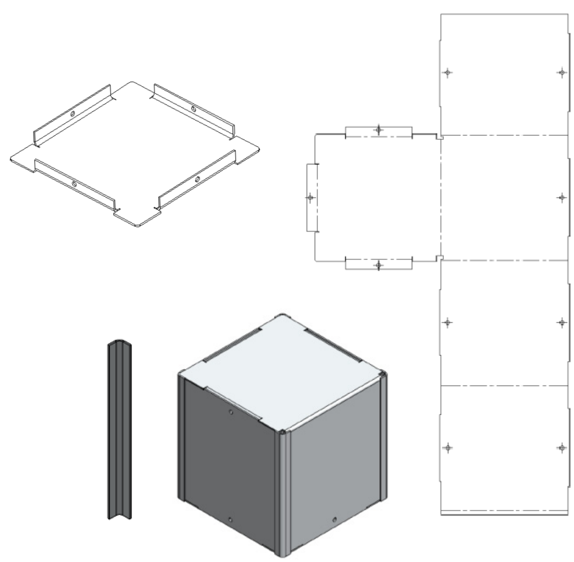


Figure 16 – Structure Components in Phase 2

Figure 17 – CHASQUI-I Model of faces without holes elaborated in Phase 2.

Figure 18 shows the improved structure version, i.e. the engineering model of the CHASQUI-I and its assembled components.

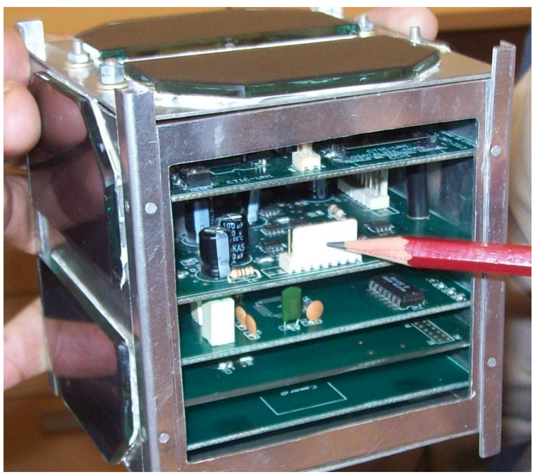


Figure 18 – CHASQUI-I and assembled Components

In order to simulate the structure of the satellite, it has been followed the methodology of the mechanical design and it was modeled using the commercial software of the Finite Element Method (FEM). The FEM modeling allows us to obtain results in the complete field of global conditions like stresses, deformations of each module components to guarantee the constructive form.

4. GROUND STATIONS

The group dedicated to design and define the ground station's characteristics and requirements is called ESTER, for the Spanish – EStación TERrena [2]. A ground station consists of a set of equipments, facilities and software for wireless communication between the ground and the satellite. The satellite can be our own CubeSat or any other satellite using one of the frequency bands supported by the equipment.

The main functions of a ground station are:

Tracking—to hear the satellite's beacon in order to know its position and identity.
Telemetry—to state variables acquisition (temperature, voltage, etc.) in order to monitoring the satellite and determine its operational parameters.
Command—to issue orders to the satellite, such as system reset, taking pictures, etc.

The core components of the Peruvian ground station are:

- Transceiver ICOM IC-910H (VHF and UHF)
- Power supply for the transceiver PS-125
- Two pre amplifiers (VHF, UHF)
- Antenna rotor YAESU G-5500
- ARS-El interface for the rotor
- A Power meter
- Two X-Quad antennas, one for VHF (2 m), other for UHF (70 cm)
- Two lightning arrestors
- Two phasing harnesses
- Cables and connectors
- Personal computers with network adapter.

Some additional equipment's are also considered like:

- Two LCD displays for orbit visualization
- Fast Ethernet Switches and Cat5e cables for network access
- UPS (Uninterruptible power supply)

A block diagram with the main components of the Ground Station is shown in Figure 19.

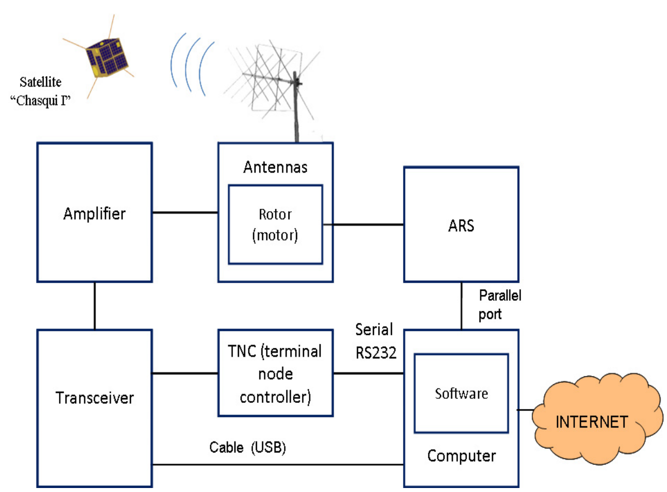


Figure 19 – Block Diagram of the Ground Station

The modulation method to transmit the digital information is the Frequency-shift keying (FSK). We assume that the satellite will be able to communicate when it is above 10 degrees of elevation. Table 8 provides the link budget calculations for downlink.

Table 8: Link Budget Calculations

Frequency	435 MHz
Wavelength	λ= 0.6892 m
Tx Antenna Gain	-10 to 10 dB
Equivalent isotropic Radiated power	EIRP=-5.04dBW
Max. propagation path length	1932.245 Km
Free Space Loss	150.931dB
Rx Antenna gain	12.8dBd = 14.95dBi
Data rate	1200 bps
Eff. noise temperature	266K
Carrier pow. /noise pow.	C/N=28.049 dB
Eb/No	19.0181 dB
Required Eb/No (FSK, BER=10^{-5})	13.8 dB

Software for the Ground Station:

The operations of the ground station will need not only hardware, but one or more software products with following characteristics:

- Direct human control for console or GUI.
- Remote control or Tele-Operation enabled.
- Advanced commands available
- Ability to receive files and format data.
- Ability to read telemetry data.
- Ability to configure and monitor the equipment (especially transceiver and rotor)
- Radio tuning, to correct Doppler Effect.
- If possible, some form of automatic control

In our case, for the software design, we are evaluating 3 options: the Mercury GS, the GENSO software, and our in-house software development. Mercury GS is Open Source and it has been used successfully, but it is old and it has to be adapted for modern version of Linux, Java, and other SW programs. GENSO S/W looks promising but, at the moment of writing this article, has not been released yet, and of course it has no previous history of success. In-house development provides more control on the functionalities, but it will take more time to develop this tool. For the first months, the first ground station (currently planned to be located in the Peruvian capital, Lima) will support and monitor CubeSats missions worldwide.

5. PERUVIAN SPACE PROGRAM

National Commission for Aerospace Research and Development (CONIDA)

The National Commission for Aerospace Research and Development (CONIDA) plays the role of an aerospace agency in Peru. Its mission of is to promote scientific research, develop space technology for national interests, and create services for driving the national aerospace development. The major tasks of CONIDA are:

(a) Promote in Peru the development and peaceful research in the space field.
(b) Organize studies, theoretical and practical research about space topics with national and foreign entities.
(c) Conclude cooperation agreements with similar national and international institutions.
(d) Encourage the exchange of technology and plan the training of national specialists. Propose the national law applicable to space.
(e) Support national space projects.

Bellow are listed the current and most important activities performed by CONIDA.

Geomatics—It is the research section, which has among its main objectives, to promote the use of geospace through application, development and transfer of these technologies to all sectors in the country in order to use natural resources efficiently and for improving socio-economic activities in the country.

Scientific Instrumentation: This is the unit in charge to develop a System of Data Acquisition and storage of scientific and technical parameters during a sounding rocket flight.

Sounding Rocket Program—The development of such activities is seeking ways to access space with their own technological solutions. There are close collaboration with local industry and universities, for achieving progress in the areas of chemical propellants, elastomers, composites, ablative and adhesives, forming, welding and heat treatment of high strength metals.

Astrophysics—The astrophysics section is dedicated to research and develop scientific projects and educational programs (basic and advanced levels) in the areas of solar physics, planetary systems and minor bodies, Sun-Earth Connection (forecasts of climate and space environment, solar activity , etc), Stellar and Galactic Astrophysic, Cosmic Rays, Space Radio-astrophysics and Geophysics. CONIDA operates the Solar Radio Observatory at the Base

Punta Lobos (South of Lima) and worked on the implementation of an astronomical observatory in the city of Moquegua, south of Peru at an altitude of 4600 meters above sea level. Since 2007 CONIDA participates in the international project for observation of the high energy solar flares through a Latin American network of antennas in the VLF band. This project is called SAVNET (South America VLF Network).

*Educational activities—*CONIDA coordinate programs on scientific Education and pre-professional training for university students interested in astronomy and astrophysics. Other educational programs support the definition of research theses for undergraduate and graduate students to obtain master and doctorate degrees. Within it objectives in astronomy CONIDA offers courses and workshops on astronomy and astrophysics for primary and secondary levels and even university levels.

*CONIDASAT—*One major milestone in CONIDA space program was achieved at the beginning of this decade. The project CONIDASAT, a satellite project for remote sensing, began in 2002 but was cancelled due to insufficient budget. In this project CONIDA engineers built different parts of the satellite, gaining this way experience in building satellites. The CONIDASAT project was proposed to develop the national technology capability, in particular, in the areas of remote sensing and Micro-satellites design. The main goal was to obtain complementary information along the Peruvian territory. Budget and creativity was part of the philosophy of the engineers responsible for the project. They tried to avoid extra costs and did manufacture their self equipment and instruments which, under other conditions, would represent a high investment for the project. We can mention that gyroscopes, reaction wheels and the onboard computer were developed in-house. Others parts were also built in Peru like the magnetic coils, honeycomb (structure), and a high resolution camera (resolution 2m). We wish to continue the path done in space engineering and follow the footsteps of our forerunner.

National Center for Satellite Imagery Operations (CNOIS)

The CNOIS is a technical project and its objective is to provide the different national public institutions with satellite information. This in order to make available the tools required for agriculture, mining, disaster prevention, defense and national security, environmental protection and rational use of natural resources, human resource training, increasing scientific activities and technology.

The CNOIS manages their actions through strategies and implements specific programs. The CNOIS project is multisectoral and works in coordination with the Presidency of the Council of Ministers (PCM) and in particular with its technical body, the National Office of Electronics and Informatics (ONGEI), which is responsible for implementing the infrastructure and database of satellite imagery (IDEP - Infraestructura de Datos Espaciales del Perú).

The CNOIS basic components are:

- Satellite mission control center
- Remote Sensing
- Training Center
- Communications system for distributing satellite information
- System access to historical Database of IDEP.
- Access to space policies and standards?

The CNOIS operation depends on CONIDA, which works closely with the ONGEI and PCM. CNOIS will be the prime provider of satellite information for all members of the IDEP. However it is noted that there are users who have high demand for information and that the nature of its activities, must be considered, such as Ministry of Defense and the Ministry of Environment.

6. Conclusions

The realization and development of a satellite project in Peru, like as the Pico satellite CHASQUI-I, is nowadays possible. For the first time, a spacecraft – primarily designed and built by Peruvian professionals, engineers and students is being developed and will be launched.

Peruvian engineers have been working on a plan to kick-off Peru's space adventure. If we are successful in our plans, in less than 3 years we will have significant progress in the space area and at least one satellite orbiting the Earth. After that, we will have lifted the lid on limited belief towards what we can achieve in Peru. We think this could be a first and crucial step towards changing attitudes and expectations in the space area. A combination of Peru's historically innovative nature and the confidence that everything can be achieved is an exciting prospect for our developing country.

Acknowlegments

This first paper about the Project CHASQUI-I is dedicated to the memory of our team member Ronald Arias, who passed away last July at an age of 21 years. His contribution and achievements within the project were a great support for the team.

The project engineering team would like to take this opportunity to thank all students who participate, Professors and advisors involved and the project partners, the Technical University of Aachen and Berlin in Germany, and the University Cheng Kung in Taiwan, who are making this whole project possible. We do warmly thank our sponsors: EADS Astrium for the donation of the solar cells.

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BIOGRAPHY

J. Martín Canales R. *received a Master degree in aeronautical engineering from the Institute of Aviation in Riga, Latvia (former USSR). He is also an aerospace engineer graduated at the Technical University of Munich, Germany. He previously served as scientist researcher at the Division of Astronautics of the University of Munich. Currently he works as Payload Operations Coordinator at the Columbus Control Center as member of the ESA Flight Control team at the German Space Operations Center (GSOC/DLR) in Germany. Mr. Canales Romero is technical consultant in mission design to the Peruvian National University of Engineering, in Lima.*

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