Development Prospective for a Picosatellites Laboratory

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Abstract-In this article the features and technical conditions for developing picosatellites are shown, the analysis and results for the Colombia 1 picosatellite are presented, this work has been developed in the framework of the CubeSat-UD project at the Distrital University Francisco José de Caldas. Finally exposed the laboratory tests to be performed according to the manufacturers and recommendations of and based on them are shows the prospective establishment of a laboratory that would be required to perform such tests and ensure the flight to launch conditions.

Keyword: CubeSat, Picosatélite, Laboratory tests.

1. INTRODUCCIÓN

The CubeSat Project started in 1999 in a cooperation of the Stanford University with the California Polytechnic State University, commonly known as Cal Poly, the main idea of the project was to create a development standard that allows to reduce largely the time and cost of the implementation of a picosatellite, in this conditions it is easier to develop this kind of projects in high level universities and colleges[1],[2],[3].

A CubeSat is a cubic form picosatellite that can be observed in Figure 1 which dimension is in general 10x10x10 and its weight is around 1,33 kg[4]. Thanks to this CubeSat Project the problem of finding a proper launching vehicle is mostly solved since the program includes the development of a deployment standard system for CubeSat called P-POD (Poly picosat Orbital Deployer) that will be in charge of carrying the CubeSat in the launching vehicle, regularly the Cal Poly is an intermediary between the developers and the launching company[5].

Figure 1. CubeSat Structure.
Source:[6]

The basic functions from the P-POD are to protect the launching interface and the payload[7]. Normally, the low cost missions imply a low risk that is why the P-POD must guarantee the integrity of its own structure as much as the one from the CubeSats[8].

Figure 2. Poly Picosatélite Orbital Deployer (P-POD)
Source:[9]

The general characteristics to make the design of a CubeSat are [7]: All the parts must stay connected to the CubeSat during the launching, no Fireworks nor explosive elements are allowed, any propulsion system will be designed, integrated and proved according to the AFSPCMAN 91-710 Volume 3, the propulsion system must have at least three ways to be deactivated, the total of energy stored will not be over 100 watts-hour, the dangerous material of the CubeSat will be set depending on the AFSPCMAN 91-710, Volume 3, the strong magnets can interfere with the separation between the CubeSat and the P-POD. As a general guideline, it is recommended to delimit the magnetic field out of the surround static CubeSat at 0,5 Gauss over the magnetic field of the Earth[10].

2. ANALYSIS AND OBSERVATION OF RESULTS OF THE DESIGN OF THE CUBESAT-UD COLOMBIA 1

Below are described the characteristics of the different modules of the CubeSat picosatellite, and the results of research for the modules of the picosatellite Colombia 1 Universidad Distrital.

2.1 Structural Module

The Structural module of a CubeSat is a standardized design, you can take the dimensions of 1U, 1.5U, 2U, 3U or 6U, and which shall conform to the requirements of the P-POD[11]. The structure in the majority of cases is constructed by the developer themselve, universities in the majority of cases. Nonetheless, there are also CubeSat component suppliers that can provide such structure[12].

The structure of the CubeSat should be sufficiently strong to survive the requirements of proof and the cumulative load of all tests and launches required. The rails should be smooth and the edges must be rounded to a minimum radius of 1 mm. It is recommendable the use of 7075 aluminum or 6061-T6 to the main structure. If other materials are used, the thermal expansion must be similar to the aluminum 7075-T73 (material P-POD) and approved by the launch of Cal Poly staff [9],[13].

2.2.Main subsystem OBC (On Board Computer)

This subsystem is responsible for processing data from the mission and control signals within the Pico-Satellite CubeSat-UD via I2C, SPI or UART[14]; Data from the mission will be the interface between the OBC and the communications module of the Pico-Satellite receiving telemetry signals, on the other hand the control signals are the communication interface among the microcontroller and the data of the subsystems of power, communications and sensors of temperature and attitude Control.

For Colombia-1 a microcontroller MSP430F1612 is used and it is implemented in Pumpkin card with the following characteristics: 5 v single power, 3.3V I/O Texas Instruments microcontroller in 16-bit MSP430 ultra low power consumption. With 50-60 KB Flash, 2-10 KB RAM, 48-pin I/O, 2 USART, SPI 2 1 I2C, ADC-12-bit, 12-bit DAC, 3 DMA, multiple timers, on-board temperature sensor, and multiple clock sources, slot for SD cards for mass storage of 2 Gb capacity, USB 2.0 device for pre-launch communications interface, load and battery power, direct wiring of Remove-Before-Flight and release Switch (LSW), 10 A, energy consumption can be controlled externally, fingerprint PC/104 + 5 v and GND connectors J1/J2 of Bus PC/104, compatible with except of PUMPKIN, RTOS, and EFFS-THIN FAT file system SD card file system for ease in programming[15].

It currently has two OBC acquired from the company Pumpkin and three developed by the research group, Like the one shown in the figure 3.

Figure 3. OBC developed at GITEM.
Fuente: [16]

2.3 Communications module

The communications module in addition to being one of the most important subsystems that compose the CubeSat, has a number of conditions and limitations as for example the size of the module, it normally requires that the operation of the Picosatellite is on amateur radio frequencies typically 144 Mhz, uplink and 440 Mhz for downlink with use of modulations as the AM, FM, FSK, GFSK[17],[18].

Table 1. Communications module features

Name	Communications module
Size	10 cm x 10 cm
Mass	52 g
Sources	3,3 V ; 5 V
Modulation Schemes	Beacon – OOK
	Data – FSK
Data Rate	1200 bps - 9600 bps
Frequencies	Transmission:

	386 MHz - 440 MHz
	Reception: 129 MHz -145 MHz
Connectors	Transmission: SMA - 50Ω
	Reception: SMA - 50Ω
Temperature	-40°C a 125°C

Fuente:[16]

The figure 4, describes the functions of the communications module:

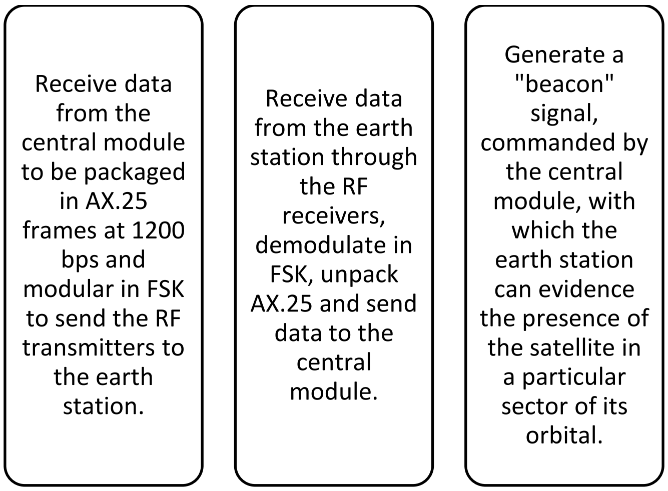

Figure 4. Communications module features.
Source: Own elaboration

In general the communications module consists of three essential parts: AX.25 which is a standard protocol used by amateur radio operators worldwide and other projects of picosatellite, in order to be able to establish radio-link with ground stations[19]. The Beacon module has as main function generate in transmission CW (continuous wave carrier), a signal radio beacon type coded in Morse to allow tracking of the satellite and provide also basic telemetry data[20]. The transceiver is a device that has a transmitter and a receiver that allows the satellite to send and receive RF signals in order to establish communication links[21].

For Colombia 1, an AX.25 protocol analyzer software was developed, this software consists of 4 modules which allow the user an easy interaction and analysis of AX.25 frames from the acquisition card [22]. The initial menu with 4 different modules of use that the user has as shown in the Figure 5.

Figure 5. AX.25 Protocol Analyzer
Source: [22]

The second submodule de Colombia 1, is the Beacon, seeks to fulfill three purposes: the first is to give telemetry of all sorts of variables of interest of the state of the satellite, the second is to generate the "BEACON" signal so the ground stations can detect it and make the link and the last is to fulfill its mission which is guided to telemedicine and is to allow transmission of ECG(Electrocardiogram) signals [23]. The Figure 6. Corresponds to the block diagram of the beacon submodule of Colombia 1.

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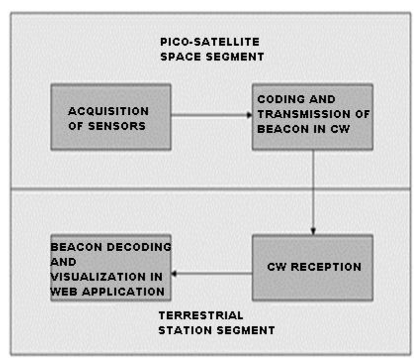
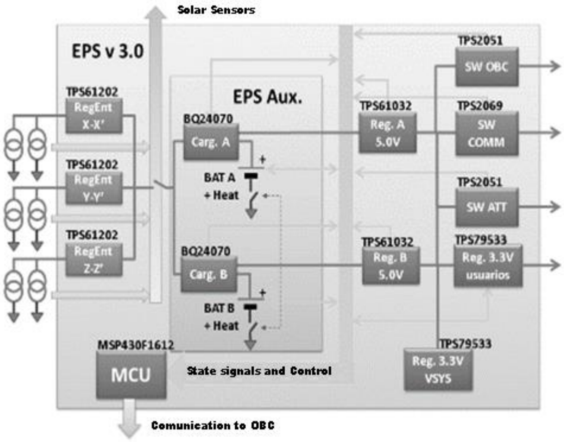


Figure 6. Block of the Submodule Beacon system.
Fuente:[23]

2.4 Power Module

EPS (Electric Power System), or energy module has two configurations: the first one is the use of "non-rechargeable batteries to supply power to the satellite only after the deployment and until the solar cells begin to provide energy, and the second one which uses rechargeable batteries that provide power to the satellite on many occasions throughout its useful life"[24] and the second corresponds to a set of solar cells. Figure 7. It shows the stages of Colombia 1's power module. The final version of the module is divided into two cards, the main EPS and the auxiliary EPS, in the latter are the batteries heaters control circuits, battery chargers and there will be connected the battery Set. Three pairs of connectors of TFM and SFM references are implemented to connect these two cards each other [25].

Figure 7. Stages of the power module 3.



Fuente:[16]

2.5 Module of Attitude Control

This module is the responsible of controlling the position of the CubeSat depending on what it is going to do, we there it is to guide the solar panels to a better position or to give the right target of the antennas to the earth station; the attitude depends on the solar sensors and the magnetic field measurer. [26],[27]. On the other hand, for the attitude control, magnetometers and torque coil are used [28].

2.6 Earth Station

Any satellite communication system is composed by an Earth Station and an orbit station, in this case the CubeSat. The architecture of the communication system is similar to the two stations (Earth-CubeSat station), however the main differences are the size, weight and temperature[29].

The Earth Station for the CubeSat Colombia 1 in orbit LEO (Low Earth Orbit), is composed by a directional antenna for each band, a checking system, an informative system to predict the orbit, a transceiver equipment, a TNC (Terminal Node Controller) and an informative system of data bases, which are the minimum elements that a Earth Station must have [30].

3. CONDITIONS FOR A PICOSATELLITE LABORATORY

The picosatellite laboratory is a fundamental part in the design and development of a CubeSat, is the stage where the tests that will allow each of the modules will be developed to comply with the criteria of evaluation. The laboratory should standardize their processes based on quality standards in this case the NTC-ISO/IEC17025 standard or national or regional equivalent this contains 25 sections of requirements to meet in order to obtain the accreditation: Sections relating to the management: Organization, system management, control of documents, review of orders and contracts, sub-contracting of tests and calibrations, procurement of services and supplies, services to customer complaints, works of tests or calibrations non-compliant control, improvement, corrective action, preventive action, control registers, internal audits, reviews by the address[31].

Technical Sections: Staff, facilities and environmental conditions, methods of test and calibration and validation of methods, equipment and traceability of measurements, sampling and handling of items of test or calibration, quality assurance of the results of test and calibration, the performance report[32].

Another important aspect to consider in a laboratory of Picosatellites is the evaluation, to ensure that the levels of security of the CubeSats and the P-POD in relation to the launch vehicle, also need to verify the resistance of this satellite to environments similar to the launch and once in orbit. Usually the tests are done by the company which will launch the satellite but otherwise the "CubeSat Design Specifications" document. Another important aspect to consider is the fulfillment of requirements for the P-POD that must be evaluated to ensure its proper functioning and compliance of their objectives [33].

The following is a description of each of the tests established in the Goddard criteria because these were the first to be implemented within the projects CubeSat checks. Both the criteria for LSP-REQ-317.01 as the MIL-STD-1540 were added in the latest version of the "CubeSat Design Specifications" of the 2013.

Technical requirements: They correspond to the fulfillment of the characteristics of a Cubesat.

Electrical Requirements: Any electronic system must be active during the launch, the CubeSat must include at least one deployment to the rail (standoff) appointed to completely turn off the power source of the satellite once it acts, the Cubesat must include a pin "RBF" (remove before flight) by its acronym in English or be launched with completely discharged batteries. The RBF pin must be removed from the Cubesat after integration into the P-POD[16].

Operational Requirements: The requirements must be met in relation to the integration and operation, legal obligations, additionally the security of other CubeSats must be ensured.

3.1 Labs tests

Once all the requirements are met according to what the law sets, a series of laboratory tests can begin based on the following phases of design and development. Table 2. It contains a synthesis of the compulsory compliance testing.

Table 2. Labs tests for a CubeSat

Parameter	Objective	Methodology
Temperature	Determine the behavior of the equipment when it is subjected to a temperature extreme.	The CubeSat is subjected to a maximum temperature of 80° C for a period of 30 minutes, then it is made to descend the temperature up to - 20° C for 30 minutes and repeats the operation 4 times. Then it is expected to take the room temperature for 15 minutes and proceed to verify the behavior of the system. Length: An hour and a half.
Vibration	Determine the behavior of the equipment when it is subjected to maximum stress-induced vibration in one of the three axes (X, Y, Z) to a level of vibration of 150kN.	The CubeSat is subjected to a vibration of 150kN for a period of time of 15 minutes, then it is removed and proceeded to verify the behavior of the system. Length: Half an hour
Vacuum	Determine the behavior of the team when it is subjected to stress by vacuum.	The CubeSat is subjected to a pressure mbar for a period of four hours, then removed and proceeded to verify the behavior of the system. Length: Half an hour
Mass	Determine if the computer meets the specifications	The CubeSat is weighed on a digital scale and the results are recorded. Once it is verified, the measurement should be performed three times more, in order to determine if it is acceptable to the result of acceptance.

		Length: Half an hour

Fuente:[34]

Temperature testing and vacuum for CubeSat-UD Colombia 1, are intended to demonstrate that the picosatellite model has the ability to survive to the thermal conditions and experienced pressure during the entire process of launching and deployment, in addition to reducing the gases emitted by the components in these situations to an acceptable level. The most critical component with respect to temperature are the batteries, for this reason, these should be widely tested (- 30 to + 85 ° C) before the integration of the subsystems [16].

3.2 Levels of evaluation

For the evaluation of the CubeSat, there are two levels of test before being considered for launch, these levels are certification and acceptance.

Certification: It ensures that the design of the satellite is acceptable and that it will operate within the expected environments. Certification begins when the process of elaboration of the satellite finishes and ends when the satellite is ready for acceptance testing. It consists of a series of tests where the satellite is exposed and subjected to conditions as the expected during and after the launch. The requirements and demands of the certification tests depend on several factors such as mission-specific characteristics, the CubeSat standard requirements and requirements that set the pitcher company."[35]. The certification can be performed to a prototype model or a model of flight. The first occurs when there are two identical elements to be tested. Certification to a flight model, is that component which, once it is designed and built, is evaluated, certified and sent into space. In the CubeSat projects exist, basically, only the flight model. [36].

Acceptance, is the last level that must pass a component that you want to send into space. After acceptance testing, developers can analyze their CubeSats through access panels and the evaluating staff of the P-POD will perform a visual inspection. The tests that are conducted at the levels described above follow the standard GEVS"[35], table 3 contains a list of tests according to the standard GEVS.

Table 3. Tests specified by the standard GEVS

Test	Protoflight certification	Acceptation
Structural Strength Time	1.25xThreshold load 30 seconds-5 cycles	Threshold load 30 seconds-5 cycles
Acoustic Time	Threshold level +3dB 1 minute	Threshold level 1 minute
Random Vibration Time	Threshold level +3dB 1 minute/axis	Threshold level 1 minute/axis
Sinusoidal Vibration Time	1.25xThreshold level 4 oct/min	Threshold level 4 oct/min
Mechanical Impact	2 impacts 1.4xThreshold level 1 for axis	1 impact Threshold level
Thermal Vacuum	Maximum temperature 10 º C Minimum temperature -10 º C	Maximum temperature 5 º C Minimum temperature -5C º C

Source:[10]

3.3 Tests according to Cubesat Design Specifications

In [10], Emphasis is placed on four tests: random vibration tests, of baking thermal vacuum, of mechanical impact and visual inspection. Below, we describe each of these tests:

Random Vibration: The launch phase different satellite loads are subjected to different vibration that's why preliminary evidence is necessary that can simulate the vibration conditions in which the satellites are exposed[37]. The random vibration test is performed on a vibrating table. This test subjects to the satellite to vibrations with frequencies ranging from the 20 to 2000 Hz. Amplitude levels are given in units of Grms2/Hz, where G is the constant of Universal gravitation expressed in rms(root mean square) [38],[39].

GEVS standard marks the following requirements, gathered in table 4, in terms of this test:

Table 4. Requirements given by GEVS for random vibration test

Frequency [Hz]	$[PSD[G^2/Hz]$	
	Approbation	Acceptation
20	0.026	0.013
20-50	6dB/oct	6dB/oct
50-800	0.16	0.08
800-2000	-6dB/oct	-6dB/oct
2000	0.026	0.013
Total	14.1 Grms	10 Grms

Source:[6]

Vacuum thermal baking: It is important that the satellite stays free of contamination since many of its components are sensitive to external changes. This procedure consists of raising such materials to the highest temperature in a clean room and it must be in vacuum, usually the test temperature is 10° C above the expected in the launch. During the test, the CubeSat is cleaned and placed in a vacuum chamber with an initial pressure of 10-4Torr[40]. The temperature is increased from 25° C to 70° C in steps of 5° C per minute. In this way the components of the CubeSat will release gases that retain and if this procedure does not proceed, the components will be taken apart sometime during the launch or the development of the mission, there could be two configurations with respect to this test. In the first one the CubeSat will be subjected to a temperature of 70° C for 3 hours inside the Chamber, the second one it will be exposed to a temperature of 60 ° C for 6 hours [41].

Mechanical Impact: The mechanical impact test consists of subjecting the CubeSat to different physical impacts that will receive during its launch, being in orbit and operation stage. There are two types of impacts: the self-induced and the external. The external impacts are those that can be caused by the interaction between the satellite and its surroundings, the CubeSat must be subjected to impacts in each of its three axes (X, and y Z, with reference to its geometric center) magnitude of up to 1.4 times the expected[33].

4. MAIN FEATURES A PICOSATELLITE LABORATORY

In a picosatellite laboratory it is necessary to ensure compliance with certain characteristics that ensure the welfare and proper functioning of the subsystems that make up the CubeSat, the main features are a clean lab and the steps to prevent the phenomenon of static that can damage important components of the CubeSat.

4.1 Clean room

The design of a clean room aims to get low levels of pollution, temperature and humidity-controlled, it is used in space projects or research, this type of room is to be used where the processes of design and engineering are conducted during the preparation of the model of picosatellite [42].

For clean room design parameters are: number and size of particles in the air, dry temperature and its distribution, humid temperature and its distribution, air flow, speed and direction, as well as their distributions in the room, the internal pressure of the air and its distribution, geometry, and interior finishes, lighting, fire protection, electrostatic protection[43].

Clean rooms are defined by their class. The classification refers to the amount of particles of a size of 0,5 µm or greater in a cubic meter of air according to US Federal Standard 209E this type of clean rooms are occupied for the manufacture of circuits that require a very high purity, in comparison, the level of contamination within a modern hospital is 10,000 polluting particles per cubic meter [44]. Table 5 shows the simplified classification according to the US FEDERAL STANDARD 209E clean room class:

Table 5. Federal Standard 209 E class limits.

Type ISO	Maximum particle concentration (particle / m3)					
	0.1um	0.2um	0.3um	0.5um	1um	5um
ISO Type 1	3	2				
ISO Type 2	100	24	10	4		
ISO Type 3	1000	237	102	35	8	
ISO Type 4	10000	2370	1020	352	83	
ISO Type 5	100000	23700	102000	3520	832	29
ISO Type 6	1000000	237000		35200	8320	293
ISO Type 7				352000	83200	2930
ISO Type 8				3520000	832000	29300
ISO Type 9				35200000	8320000	293000

Source:[45]

4.2 Equipment and tools

According to the experience gained by the Group GITEM ++ in the design and construction of the subsystems of the CubeSat-UD, a series of elements that must have a laboratory of Picosatellites is required.

Anti-Static Elements: Firstly for the construction of electronic circuits it is necessary to have an anti-static equipment to avoid damaging sensitive devices like microcontroller; For the electrostatic discharge(ESD) is used carpet anti-static floor for vinyl cutting, cable for vinyl connection to ground, antistatic heel, antistatic bathrobe, non-conductive Nylon gloves, antistatic bracelets, table landed to Earth[46].

Measuring Elements: The main measuring elements in a laboratory are: Oscilloscope, Multimeter, signal generator, Analyzer of spectrum, power supplies[47].

Virtual Tools: In order to develop each subsystem of the CubeSat, it is always necessary the use of software, either of simulation to get a basic idea of behavior and characteristics that will have or to design the development cards and choice of components[48].

The basic components that the Earth station should have to have communication with the CubeSat are as follows: antenna Yagi, rotors for antenna (for modification of the orientation). Filter, recorder, transmitter, receiver with LNA (Low Noise Amplifier), modem TNC (analogue to digital conversion) antenna (Ax.25 protocol), RF scanner, computer (data-processing), and software to predict the orbital position of the satellite[49].

Verification and testing equipment: the equipment required for the testing of pre-launching validation and verification: Chamber anechoic, vibrating table, thermal vacuum chamber and testPOD[50].

5. CONCLUSIONS

In the frame of this investigation it was possible to do an analysis of the current state of the subsystems that compose CubeSat-UD Colombia1 obtaining this way a clear vision of the advances of the project in general, additionally based on this there were established the requests that must fulfill the subsystems in a laboratory of picosatellites as the rules and international standards.

At present the group Gitem has designed, implemented and put to the test the modules of central control, potency, communications, control of attitude and earth station; In the experience it was possible to have demonstrated that for an efficient development of a project of this magnitude it is indispensable to implement a normative structure as the norm ISO-NTC 17025:2005 establishes it and on having had fulfillment of the same one to obtain a certification at national and international, not alone level to have the success of the prototypes developed on the part of the entities pitchers if not to obtain credibility before the organizations.

As recommendation and according to the investigated in commercial modules of potency and others designed by universities, there is demonstrated a tendency to respect the distribution of the pins of potency; This is with the objective of prevent delays on the mission, if it fails the potency module could be replaced easily. Also the use of 4 printed layers on the development cards is recommended instead of two as it is commonly done, to have a major handling of dissipation, isolation of electromagnetic interferences, handling of signs of information and to diminish the tracings that in the end a reduction will allow in the size of the printed matter.

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