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Thermal Tests for CubeSat in Brazil: lessons learned and the challenges for the future

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Abstract

All materials and equipment used in space systems and satellites need to undergo thermal tests to check their performance and anticipate possible failures or abnormalities. The CubeSats also undergo these thermal tests in order to qualify their operation, when they are exposed to a vacuum environment and temperature variation imposed by the space environment, and also with the purpose of reducing the outgassing rate of the components to acceptable levels, due to the fact that these satellites have been frequently manufactured with components not 100% qualified for these purposes. The cost of thermal testing is high because of the sophisticated equipment (thermal vacuum chambers, pressure and temperature control systems, cryogenics systems), the required components and the highly skilled workforce of technicians who prepare all systems for those tests (e.g. control instrumentation, power supply), as well as all necessary support areas for their achievement. The Integration and Testing Laboratory - LIT, at the National Institute for Space Research - INPE, in São José dos Campos - SP, Brazil, recognized for its expertise in assembly, integration and tests for satellites and space components, provides their technicians, their infrastructure and knowledge in conducting space simulation tests on satellites and applies and assists the instrumentation and execution of CubeSat tests. This article is intended to discuss the proposals and the economically viable methodologies developed, the lessons learned and the challenges for the future, applied to space systems testing.

Keywords: CubeSat, space simulation test, thermal vacuum test, outgassing, acceptance level

1. Introduction

The small satellites were the first artificial satellites built and launched [1]. Since then, they have gotten bigger and more complex. The complicated design, project, construction and the space environment operation, mainly, directed the research and development of scientific payloads, telecommunication and military applications, almost exclusively, to institutions and governments capable of producing a lot of knowledge and having money to invest [2].

Over 50 years from the launch of the first satellite, all the attention has turned again to the small satellite category and now it figures as an important dissemination of knowledge and a practical learning tool. The short time in development, the small size, and the lower costs, if compared with big satellites, allow universities around the world to design, build, test, and find a capable company able to launch their own satellites at a relatively lower cost. They may also be launched in the ride of a larger satellite and that also optimizes launches. Also, governments and research institutions are developing their own CubeSats because of those advantages [3].

The CubeSat concept began in 1999 when professors Bob Twiggs, at Stanford University, and Jordi Puig-Suari, at California Polytechnic State University developed the CubeSat concept with the intention of making it possible to use its idea for the development of university students [4]. Later the CubeSats were standardized in one "unit" (1U) a cube with 10 cm x 10cm x 10 cm and mass close to one kilogram. It can also be set with two units (2U) and three units (3U). With this standardization, it was possible to develop specific deployers that can be used in conventional launchers or in the ISS - International Space Station.

The CubeSats, as well as any other materials or equipment used in spatial systems and spacecrafts, need to undergo many tests with the intention to ascertain their performance and to anticipate possible failures that could compromise their lifespan and/or mission. Among the recommended tests are the thermal tests [4].

The thermal tests are fundamental to validate and qualify the Cubesat performance when it is exposed to temperature variations and vacuum pressures imposed by the space environment and also to reduce the degassing rates of the components to acceptable levels,

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due to the fact that these satellites have been frequently manufactured with components not 100% qualified for these purposes. In Brazil, the thermal tests are performed in the LIT – Integration and Tests Laboratory.

The LIT (Figure 1) is one of the laboratories of INPE – National Institute for Space Research, inaugurated in December 1987. It is specialized in all assemblies, integration, and test cycles for spatial components and systems [5]. In all its history, the LIT has supplied many of the necessities of the spatial programs. Since the beginning of the Brazilian Space Program, the LIT has performed many thermal tests in satellites such as Data Collector Satellite - SCD-1 [6], 2 e 2A, China-Brazil Earth Resources Satellite - CBERS-1, 2 [7,8] e 2B, Humidity Sounder for Brazil - HSB [9] (meteorological payload developed to equip Aqua Satellite - NASA), Technological Satellite - SATEC [10], the thermal model test [11] and all the Brazilian equipment and subsystems of CBERS 3-4, and the space simulation test of Scientific Application Satellites-D - SAC-D/Aquarius flight model [12] (NASA / CONAE).

This article is intended to describe and compare the CubeSats' thermal tests performed at LIT. For this, a Cubesat's project overview, the LIT's testing facilities, the thermal test specifications and procedures, its particularities and results will be shown. In addition, we will make a comparison between the specifications of the thermal tests performed at LIT and other test specifications found in the bibliography, and at the end a general conclusion of this analysis will be presented.

Figure 1: LIT's Test hall and TVCs.

2. CubeSat Programs

Five CubeSats programs were tested at LIT. In this chapter, each project, mission, payloads overview, the launching information and its results will be shown.

2.1 NANOSATC-BR1

NANOSATC-BR1 was the first Brazilian CubeSat, manufactured from a platafom 1U (10cm x 10cm x 11.3cm) and mass close to one kilogram (Figure 2), from ISIS (Innovative Solutions In Space, Netherlands). Its payload was composed of, among other technological and scientific experiments, a magnetometer to study magnetosphere`s disturbances, focused on SAA - South Atlantic Anomalies and the Brazilian sector of EEJ - Equatorial Electrojet [13].

The CubeSat was developed in a partnership among the Southern Regional Space Research Center (CRS/CCR/INPE-MCT) of INPE, UFSM – Federal University of Santa Maria, UFRGS – Federal University of Rio Grande do Sul, AEB – Brazilian Space Agency, among other institutions of education and development. During its research and development phase, were involved several students, professors, technicians and engineers. Were published more than fifty documents, including speeches, technical articles and reports [14].

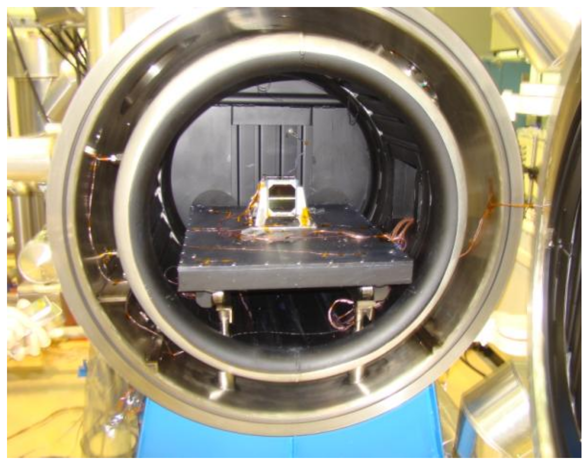

Figure 2: NANOSATC-BR1 inside the thermal vacuum chamber.

On the occasion of its launch, on July 19th 2014, by the launcher RS-20, Dnepr Launch Vehicle, from Yasny Launch Base, in Russia, with other 33 satellites, it beat the record for the number of payloads placed in orbit in the same mission [15].

In operation for over two years, CubeSat NANOSATC-BR1 has succeeded in data acquiring able to prove the prediction of theoretical values of the intensity of Earth's Magnetic Field, as predicted by the model of IGGF - International Geomagnetic Reference Field, from IAGA - International Association of Geomagnetism and Aeronomy and the IUGG - International Union of Geodesy and Geophysics [16].

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2.2 AESP-14

AESP-14 was the second Brazilian CubeSat, and the first 100% made and developed in Brazil. Assembled in a platform 1U (10cm x 10cm x 10cm), with mass close to 760 grams and projected mission life of about three months, AESP-14's main objective was students' technical training, encompassing all spatial project/product life stages, since the mission definition, structural development and manufacturing, hardware and software design, assembly, integration, life tests, launch and operation [17, 18, 19, 20].

Its scientific mission was composed of a miniaturized Langmuir Probe, developed by the Atmospheric Science Department of INPE. Its intention was to investigate the mechanisms of equatorial plasma bubbles, providing in situ data about atmospheric/ionospheric phenomena to Brazilian researchers [17, 18]. It was developed in a partnership between ITA – Technological Institute of Aeronautics and INPE. During all the developing stages the project was supported by a group of undergraduate and post graduate students, professors, technicians and engineers [17].

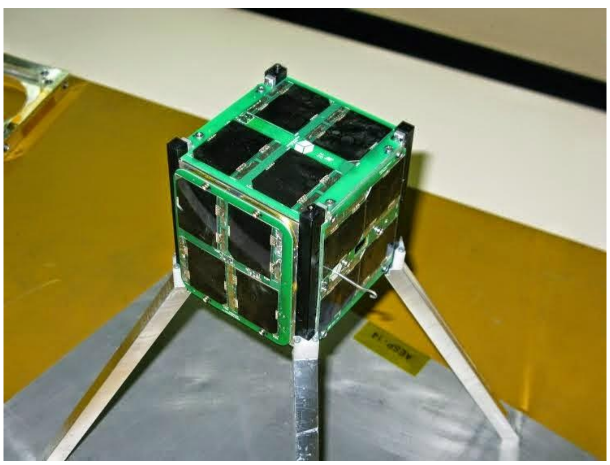

Figure 3: CubeSat AESP-14.

AESP-14 (Figure 3) was successfully launched into space on January 10th, 2015, by the launch vehicle Falcon-9 V1.1 [18], SpaceX (Space Exploration Technologies Corp.), from Cape Canaveral Air Force Station, Florida – USA, together with Dragon CR-5 spacecraft, which carried supplies to the ISS – International Space Station [19]. On February 05th, 2015, it was released into space from the ISS (Figure 10). However, unfortunately, no signal from the satellite was received [20].

The CubeSat should open its antenna thirty minutes after the space deployment, a functional procedure to send data to Earth. After several unsuccessful attempts, the satellite was declared inoperative [21]. Nevertheless, the project was considered fulfilled because the technical training mission was completed with success.

2.3 SERPENS

CubeSat SERPENS (Sistema Espacial para Realização de Pesquisas e Experimentos com Nanosatélites) (Figure 4) was another Brazilian CubeSat which was successfully developed and made in Brazil. It was built in a platform 3U (10cm x 10cm x 30cm) with mass close to three kilograms and mission life designed for about six months [22].

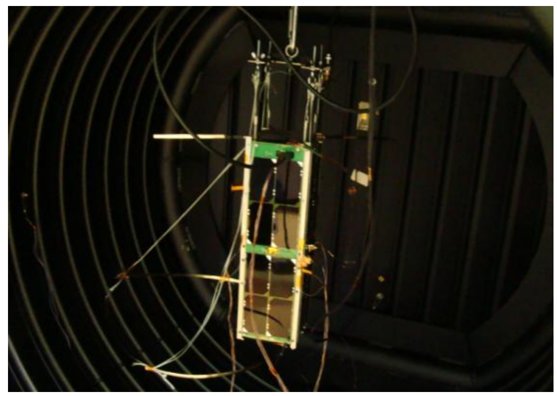

Figure 4: CubeSat SERPENS before thermal vacuum test.

Developed by a consortium of Brazilian and international universities, among them the UnB – Brasília University, the UFSC – Federal University of Santa Catarina, the UFABC – Federal University of ABC, the UFMG – Federal University of Minas Gerais, the University of Vigo (Spain), California Polytechnic State University (USA), Morehead State University (USA) and the Sapienza University of Rome (Italy). Its main mission was the execution of the full spatial mission, using CubeSats, involving spatial engineering students from the vehicle design up to its orbital operation. The students received assistance from a team of professors, technicians and engineers [23,24].

For its mission, CubeSat SERPENS was built in two sectors: sector A, responsible for VHF communication and sector B, responsible for UHF communication [25]. Both sectors, on orbit, will receive data from several data collection platforms installed in the Brazilian territory. That information will be available for to be relayed to receiving stations on Earth [23]. Sector B was a project which was part of Humsat Constelation. The main objective of Humsat Constelation is to allow data collection from ground sensors, worldwide, principally in regions without telecommunication infrastructure, basically consisting of a system of collection and storage data for subsequent transmission [26,27].

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SERPEENS was launched to the ISS – International Space Station, on August 19th, 2015, by the Japanese launch vehicle H-IIB, inside the pressurized cargo supply HTV-5 "Kounotori 5", from Tanegashima Space Center, Japan. On September 17th, 2015, using the deployer system J-SSOD - JEM Small Satellite Orbital Deployer, it was released into space from the ISS.

On March 27th, 2016, as scheduled, CubeSat SERPENS reentered the Earth's atmosphere achieving its developing and workmanship training, spatial projects integration with international institutions, and the reception, storage and dispatch environmental data mission with full success [28].

2.4 UBATUBASAT

Picosatellite Tancredo – I is the first UBATUBASAT's satellite project, from public School "Presidente Tancredo de Almeida Neves", in the city of Ubatuba – SP, Brazil, with technical support from the Space Engineering and Technology area, at INPE. It was assembled from a tubesat kit, bought from Interorbital Systems. Its mass is less than 750 grams and has 90 days of expected life [29].

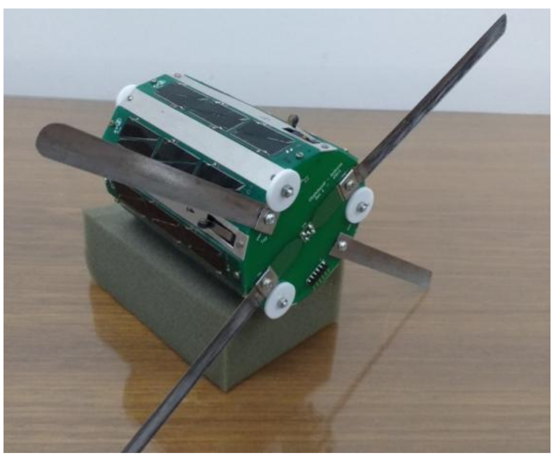

Figure 5: UBATUBASAT.

CubeSat UBATUBASAT (Figure 5) is a multidisciplinary school project to develop the interest of a group of 6th grade students and further on the interests of all students in the school in science and technology. Under Interorbital Systems' recommendation, an agreement was made between the school and INPE for technical advisory because of the latter's experience in satellites' projects, assembling, integration and tests. All training courses were given to the students in the LIT's laboratories [30,31].

Its payload is composed of a simple voice recorder, developed by the students, and a miniaturized Langmuir Probe, developed by the Aeronomy Department, at INPE. The voice recorder is, basically, dedicated to audio chip recording and to playing a message and the Langmuir Probe intends to gather data to help in the investigation of the mechanisms of plasma bubbles, electrons density and the spectral distribution of plasma irregularities [32].

The estimated date for the launch is the first semester of 2017, by launcher H-IIB, of JAXA - Japan Aerospace Exploration Agency, with the cooperation of GAUSS Srl - Group of Astrodynamics for the Use of Space Systems and Morehead State University – USA, responsible for the TuPOD - TubeSat Picosat Orbit Deployer development [33].

2.5 SUCHAI

SUCHAI (Satellite of the University of Chile for Aerospace Investigation) is the first Chilean CubeSat project. Built in a 1U platform, and mass close to one kilogram and developed by undergraduate students, engineers and professors of the Electrical Engineering, Physics and Mechanical Engineering Departments of the Faculty of Physical and Mathematical Sciences (FCFM) at Universidad de Chile [34]. The mission life is one year.

SUCHAI's main educational purpose was to teach the whole process that involves designing, building, integrating, testing, launching and operating a CubeSat [35]. It was the first step for the University of Chile's CubeSat program. This program intends to apply all the knowledge learned in the SUCHAI's development into two 3U CubeSats (SUCHAI2 and SUCHAI3) that are currently in the designing phase in the SPEL – Space and Planetary Exploration Laboratory (a research group that includes laboratories and personnel from the University of Chile and the University of Santiago, Chile) [34,36].

Figure 6: SUCHAI.

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The scientific payload is (1) a Langmuir Probe to study the ionosphere in synchronization , (2) an experiment to study the out of equilibrium fluctuations in a hostile environment, (3) an experiment that proposes studying the heat dissipation in electronic components in vacuum, (4) a digital camera, and (5) a battery health management experiment [35,37].

CubeSat SUCHAI (Figure 6), is available to fly and will be launched in 2016 in a SpaceX Falcon-9 rocket and will have a polar elliptical orbit 700Km (LEO).

3. Facilities and Methods

3.1 Test Facilities

For the thermal test achievements two TVC – Thermal Vacuum Chamber and one TCC – Thermal Climatic Chamber of Thermal Vacuum and Climatic Test Group were used, at LIT, Brazil. The TCC is 1,000mm x 1,000mm x 1,000mm and is able to perform in a -100°C to 180°C temperature range, having humidity and temperature gradient programmable. For spatial devices, a continuous purge of gaseous nitrogen is maintained inside the test chamber compartment in order to avoid water vapor condensation on specimen.

Thermal tests in vacuum environment were performed in two different chambers. TVC 250 liters, for the NANOSAT-BR1 and AESP-14 tests, and TVC 01x01meter, for SERPENS, UBATUBASAT e SUCHAI tests. Both chambers work with mechanical and cryogenic pumps capable of carrying the vacuum pressures until 1 x 10-6mBar. They are equipped with a shroud, projected to work with radiation as the only way to temperature changes. It is controlled by a thermal system that works with nitrogen and capable to perform a -180°C until 180°C range of temperature. Moreover, it is important to highlight that all temperature and pressure control systems are calibrated periodically, according to the legislation, the good quality practices and reliability.

3.2 Test Methods

All CubeSat programs described in chapter 2 underwent thermal-tests at LIT. Figure 07 lists each thermal test accomplished and shows the comparison among their models, temperature and all main specifications.

CubeSat	Model	Test Type	Pressure [mBar]	Maximum Temperature	Minimum Temperature	Cicles	Exposure Time	Termocouple Quantity	Prerequsite	Launcher
NANOSATC-BR1	QM [39]	TCT	Atm	50°C	-10°C	4	30 minutes	11	NANOSATC-BR1 Team Proto-Flight type ISILaunch07 [38]	RS-20 Dnepr
	FM [39,40]	Burn-In	$\leq 5x10^{-5}$	50°C	-	1	02 hours	11		
		TCT	$\leq 5x10^{-5}$	50°C	-10°C	2	0.5 hour			
AESP-14	QM [41]	TCT	Atm	70°C	-55°C	7	Hot: 01 hour Cold: 45 min	32	AESP-14 Team [20]	Falcon-9 v1.1.
	FM [42]	Burn-In	$\leq 5x10^{-5}$	60°C	-	1	02 hours	8		
		TCT	$\leq 5x10^{-5}$	60°C	-20°C	2	30 minutes			
SERPENS	EM [44,45]	Burn-In	$\leq 5x10^{-5}$	60°C	-	1	03 hours	2	SERPENS Team [43]	H-IIB and ISS
	FM [44,45]	TCT	$\leq 5x10^{-5}$	42°C	-15°C	3	1.5 hours	15		
UBATUBASAT	Batery [48,49]	TCT	$\leq 5x10^{-5}$	60°C	-20°C	4	30 minutes	3	UBATUBASAT Team [46,47]	H-IIB
	FM [48,49]	TCT	$\leq 5x10^{-5}$	60°C	-15°C	4	Hot: 30 min Cold: 20 min	8		
SUCHAI	QM	Bake-Out	≤ 5x10-5	70°C	25°C	2	01 hour	10	ISILaunch09 [50]	Waiting for Launch
	FM [51,52]	Bake-Out	$\leq 5x10^{-5}$	60°C	-	1	24 hours	5		
Table Acronyms:	FM - Flight Model TCT - Thermal Cycling Test			QM - Qualification Model Atm - Atmosphere			EM - Engineering Model Min - Minutes			

Figure 7: CubeSat's thermal test specification.

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4. Discussion and Results

NANOSATC-BR1's environment level requirements and procedures from the launch provider service and the specification of the thermal test are shown in the 7th chapter [38]. In this chapter ISL – Innovative Space Logistics BV stresses that although the thermal cycle test is not required, it is highly recommended for all levels: Qualification, Acceptance and Proto-Flight. However, a material characteristic list is required to ensure that no degassing of contaminating happens during launch or in orbit.

Following that recommendation, the NANOSATC-BR1 team specified two thermal tests. The FM was qualified by a thermal test, in atmospheric pressure. The FM was tested by a combined thermal vacuum test. In the beginning a two-hour Burn-In Test was performed and, immediately after that, the thermal cycling test in vacuum was performed. All tests were performed without any problems and the CubeSat's functional tests did not show any problems before, during or after the tests. The NANOSATC-BR1's thermal test campaign finished in March / April 2014 [39,40].

The CubeSat AESP-14 team tested two models: QM and FM. For QM, a thermal cycling test, in atmospheric pressure was performed with a severe temperature range and a longer exposure time. During the test a continuous purge of gaseous nitrogen was maintained inside the test chamber compartment to avoid water condensation. For the FM thermal vacuum test, ASEP-14 followed the same strategy applied to NANOSTC-BR1. In the beginning of the thermal test a Burn-In Test was performed, and following that, the thermal cycling test was executed, both in vacuum environment [20]. All functionalities were tested and the CubeSat worked well. The thermal tests campaign was finished in May / June 2014 [41,42].

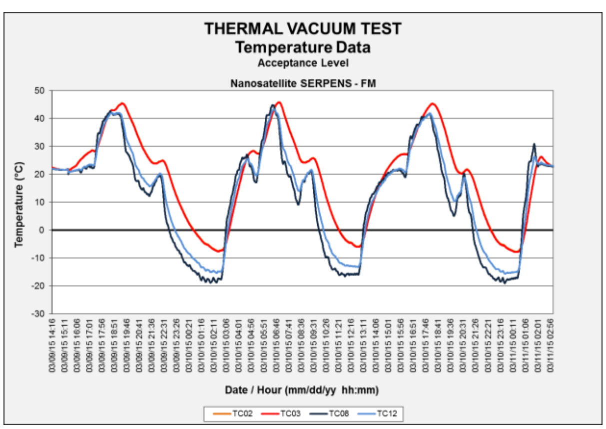

Figure 8: Temperature graphic SERPENS.

The SERPENS team brought two models to be tested: EM and FM. The top qualified EM model underwent a Burn-In Test. However, the EM's Burn-In test was carried out in vacuum environment with a little bit higher temperature than the one used for the FM model's test. FM's thermal cycling test in vacuum (Figure 8), if we compare with all other CubeSats tested, had the smallest temperature range. When comparing the SERPENS' TVT with two tests that happened before, we see that this model didn't have a Burn-In test combined with the TVT [43,44]. Anyway, all thermal tests were performed in accordance with their specifications and the CubeSat was approved in all. The test campaign ended in March / April 2015 [45].

In accordance with the origins of UBATUBASAT's project, its team had only one model to be tested. In addition, they had to test their battery, though [46]. In fact, before the battery's thermal test was performed, it was exposed to a two-hour in vacuum condition, ambient temperature, not only to avoid but also to reduce possible degassing contamination to the thermal vacuum chamber. Due to that, the battery was not qualified for use in vacuum environment [47]. The battery worked as expected during the TVT.

For the FM, the TVT was performed in vacuum with a temperature range close to the one used for the other CubeSats [48]. CubeSat UBATUBASAT worked in all functional tests and was approved to launch. The TVT finished in December 2015 shutting down the thermal test phase [49].

The SUCHAI team came to LIT in two different moments. In the first one, they brought a QM that underwent a Bake-Out test composed of two cycles. On this test, the maximum temperature was higher than the one used for the FM. The test was successfully completed and finished in May 2014.

Two years after, a Bake-Out test was performed on the FM and it was tested following the ISILaunch09 [50,51] procedure. In accordance with this document: "... the purpose of the bake-out test is to reduce to an acceptable level the outgassing rates of flight equipment associated with instrumentation that is sensitive to molecular contamination…". Following this recommendation, the TVT was performed exactly as it is required. The Bake-Out test finished in January 2016 [52] and the CubeSat presented perfect operation and was able to perform the last tests.

Comparing all test specifications in Figure 7 it is easy to see how alike they are, and this might happen because of many reasons. Many documents and books suggest the thermal profile test for satellites, spaceships, materials and CubeSats, mainly. With the current growing interest in this kind of project, not only by universities but also by governmental institutions, a large number of studies and analyses are being held. Those analyses ranging from the payload development to the dedicated thermal analysis and power generation, storage and administration for CubeSats, for example,

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are providing reliable material to assist researchers, students, professors and designers in decision-making. Equally important is the information from the electronic devices, payloads and other information that can limit the temperature range tolerance.

The thermal tests are, in most cases, not only recommended but also required. Problems related to the thermal balance in satellites can affect their lifespan as well as cause damage to an important payload. What this affirmation proves is the large amount of required thermal testing for materials, components, devices, equipment, and spatial systems in all phases of their life, before the launch.

A very important additional reason for performing thermal tests in vacuum is that they cooperate with the acceleration of the contaminant outgassing rates. Those contaminants can damage sensible components during the launch or on its orbital life, based on the assumption that CubeSats are launched, usually, as a ride on bigger satellites or spacecraft.

For this reason, the attention of the space launch vehicle companies has apparently been growing up. An example that might be used as a comparison is the difference between FM's NANOSATC-BR1 and SUCHAI test specification: The "Environment Levels Auxiliary Payloads – ISILaunch07" in Issue 0.9, page 08, reference document for the NANOSATC-BR1's environmental tests, features the "Thermal Cycling" as highly recommended [38]. On the other hand, the document "Environment Level Auxiliary Payloads – ISILaunch09", in Issue 1.2, Page 11, classifies the thermal test (Bake-Out) as required and provides all the necessary information for its achievement [50]. All in all, both documents have the same source.

Another reason that can justify the difference between ISILaunch07 [38] and ISILaunch09 [50] is that different test specification were made for each launcher. In this case, the standardization occurs due to the launch vehicle that will be used. This way, the environmental test procedure ISILaunch07 is applied to programs that will use the launch vehicle "X" and, the environmental test procedure ISILaunch09 is for launcher "Y". It important to remember that we are focusing on the thermal tests only. The comparisons among other tests (vibration and sock, for example) are not being analyzed.

Figure 9 shows the comparison among the same procedures but different issues of the QB50 environmental test procedure [54,55,56,57], NASA's CubeSat test procedure [58] and a CubeSat's supplier and seller (EnduroSat) qualification procedure [59].

Document	Section/Type	Pressure [mBar]	Maximum Temperature	Minimum Temperature	Cicles	Exposure Time	Level	Observation
QB50 - Issue 4 [54]	2.6 - TCT	No (*)	No (*)	No (*)	No (*)	No (*)	QL and AC	(*) To be determined
	2.7 - TVT	No (*)	No (*)	No (*)	No (*)	No (*)	QL and AC	
QB50 - Issue 5 [55]	2.6 - TCT	No (*)	No (*)	No (*)	No (*)	No (*)	QL and AC	(*) To be determined
	2.7 - TVT	No (*)	No (*)	No (*)	No (*)	No (*)	QL and AC	
QB50 - Issue 6 [56]	2.6 - TVT	$\leq 5x10^{-5}$	50°C	-20°C	4	01 hour	QL and PFL	(**) After thermal stabilization.
	2.7 - Bake-Out	$\leq 5x10^{-5}$	50°C	-	1	03 hours (**)	AL and PFL	
QB50 - Issue 7 [57]	2.6 - TVT	$\leq 5x10^{-5}$	50°C	-20°C	4	01 hour	QL and PFL	(**) After thermal stabilization.
	2.7 - Bake-Out	$\leq 5x10^{-5}$	50°C	-	1	03 hours (**)	AL and PFL	
NASA LPS-REQ-317.01 Rev. B [58]	TVT Bake-Out	$\leq 5x10^{-5}$	70°C	-	1	03 hours (**)	AL and PFL	(**) After thermal stabilization.
EnduroSat [59]	TVT	$\leq 5x10^{-5}$	60°C	-20°C	4	02 hour	QL	
	Bake-Out	$\leq 5x10^{-5}$	40°C	-	1	02 hours		

Table Acronyms: TVT - Thermal Vacuum Test; TCT - Thermal Cycling Test; QL - Qualification Level; AL - Acceptance Level; PFL - Protoflight Level

Figure 9: Information about thermal test specifications.

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The managers and designers of projects worldwide are showing the necessity of standardized testing procedures. This can be observed if we compare the same project procedure and different issues. QB50 is a mission that intends to demonstrate the possibility of launching a network of 50 CubeSats built by universities all over the world [53]. Until issue 5 the TCT and TVT were required, but the specification was not presented, only the information: "TBD – To Be Determined". However, starting in Issue 6, the thermal test qualifications were changed (TCT was replaced by Bake-Out) and the complete requirements are described. It is not possible to discuss the real reason why the specifications were standardized, but it makes things easier for the project´s participants and it could show a possible increased care for this subject.

In NASA's specification, there are two important observations, about the thermal tests: 1) "If the CubeSat cannot achieve these temperature levels, the CubeSat shall hold a minimum temperature of 60°C for a minimum of 6 hours." and 2) "CubeSat Thermal vacuum bakeout is required unless Launch Services Provider removes the requirement for individual CubeSats based on material selection, quantities and manifesting".

The standardized specification also serves as important data for other programs to specify tests, temperatures, exposure times, and other issues. Several materials are available nowadays. Another item that could be compared is the temperature range. Usually the variation between maximum temperatures and minimum temperatures is small. It is easy to analyze by only comparing the CubeSats' temperature range tested at LIT (Figure 7) with the specification that is shown in Figure 9.

4. Conclusions

With more than 25 years' experience in assembly, integration and tests of satellites and satellite components and equipment, the LIT offered its infrastructure and its experience to the CubeSats tested in its facilities.

Some additional remarks taken from those CubeSats' testing campaign are:

- To perform the thermal tests, the LIT made available its team of experienced and highly qualified technicians and engineers;

- All the students, professors and technicians involved with the CubeSats were able to experience all the test campaign routine, which was the same as the one applied in big satellite's testing program.

- In addition to the professionals directly involved in the tests, the LIT provided many other technicians from other support areas (data acquisition, contamination test analyses, electric/electronic area, for example).

- All infrastructure support and training was released to the test players.

- All security standards and procedures were adopted with CubeSats before, during and after their thermal tests (gloves, masks, anti-ESD protection systems).

- All quality warranty procedures in thermal tests were adopted.

- In order to perform the CubeSat's small tests test procedures and reports that prove and assure all test characteristics with international validity were made.

The LIT, committed with the CubeSat projects' nature offers an economically viable methodology, its experience, infrastructure, and high qualified team to carry out all qualification and acceptance tests and brings to the CubeSats' Teams the real experience in satellite tests program. And, with the success in the CubeSats' Thermal tests, the LIT stands as a valuable and experienced option to accomplish needed thermal tests for qualification and acceptance of CubeSats and its subsystems.

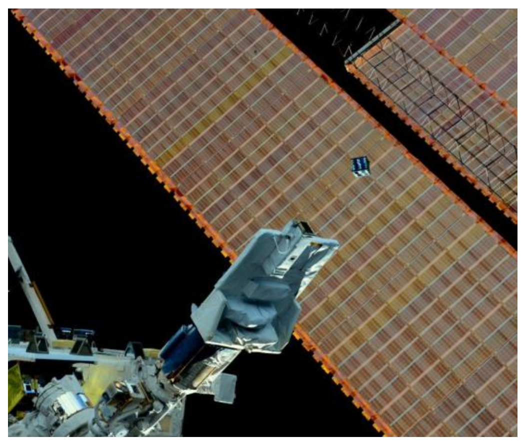

Figure 10: CubeSat AESP-14 deployed from ISS.

5. Lessons Learned

The mainly lessons learned by performing thermal vacuum tests in CubeSats are:

- It is important to underline that each project requires a dedicated thermal analysis, since there are risks in assuming any thermal test specification without a previous analysis.
- General procedures, usually, do not consider important differences as the heat distribution between a 1U and 3U CubeSats, payloads, batteries and other sensible components. These differences may make the thermal test poorly representative.
- It is fundamental perform thermal vacuum test in laboratories that have its chambers and equipments qualified for space devices tests.
- The costs for carrying out thermal tests, and all other tests, for qualification show up as a fundamental and

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important investment, because they can, mainly, anticipate and make evident any problem that could be fixed before the launch.

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