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Overview of Nano-satellite Environmental Tests Standardization Project: Test Campaign and Standard Draft

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ABSTRACT

To improve the reliability of nano-satellites while keeping their advantages, low-cost and fast-delivery, a new way of thinking about environment test is necessary. In the present paper, the word of “nano-satellite” means a satellite whose weight and size is, but not limited to, typically less than 50kg and 50cm, respectively. The nano-satellites intend to achieve the low-cost and fast-delivery by extensive use of non-space-qualified commercial-off-the-shelf (COTS) parts and components. Currently there is confusion among developers and customers about how the environment tests should be done for nano-satellites. A new government funded project started whose objective is to establish international standards of environment tests of nano-satellite system and components. The project aims to establish an international standard for testing of nano-satellite system and components. In the project, we will tailor the existing testing standards for traditional large/medium-class satellites with clear rationales supported by basic researches and the outcomes of past nano-satellite projects. Currently, testing campaign is underway to gather basic data such as temperature and acceleration distributions within a satellite under thermal-vacuum or vibration environments during the laboratory tests using dummy satellites. The first workshop was already held in December 2011. The present paper briefly introduces the project’s current status..

1. INTRODUCTION

Reliability vs low-cost and fast-delivery

There is increasing demand of nano-satellite development worldwide among newcomers to space. In the present paper, the word of “nano-satellite” means a satellite whose weight and size is, but not limited to, typically less than 50kg and 50cm, respectively. The newcomers are mostly small business, universities and developing countries. They were outside the established space community made of space agencies and large prime contractors and their subsidiaries that were often dependent on government (civil and military) spending on space. To join the space community, the new comers were required to demonstrate their products satisfy the high reliability required by the customers. The requirements originated from the inherent high price of the space assets. The high hurdle against entering the space community made the industrial base of space sector stagnate or even deteriorate. Nano-satellite has a possibility of expanding the space industrial base and opening a new market of space applications, leading to a new way of thinking about how to run the space activities.

The advantages of nano-satellite are low-cost and fast-delivery. These advantages are gained by the extensive use of COTS (commercial-off-the-shelf) components and parts, and subcontracting to non-space small business manufacturers. COTS components are not meant for use in space. Therefore, the advantages are gained by sacrificing reliability against low-cost and fast-delivery. In fact, several statistics show the poor success rate of nano-satellites. Bouwmeester et al,(1) showed that only 48% of nano-satellite (defined by a weight of less than 10kg) succeeded in mission after the successful launch. Saito(2) showed that the success rate dropped significantly if the weight of satellite made by universities or non-space manufacturers exceeded 10kg. Satellite failure in general is dominated by infant mortality(3,4,5). Smaller satellites tends to fail more in the early stage of operation in orbit(6).

The low success rate of nano-satellite is acceptable to a certain degree as long as the purpose is educational or technology demonstration. If the satellites are launched for commercial purpose, however, the failure is not really an option, considering the fact that the price per satellite still exceeds a million dollar.

Failure of one satellite among one hundred of satellites forming a constellation will be acceptable in future. But we are not in that stage yet. Nano-satellites are still being commercially utilized as a single or a formation flight of at most three or four. If they keep failing in orbit at the present rate, the reputation of nano-satellite will never reach the stage to invite serious investment from outside the space community. Then, nano-satellites remain only as the platform of education or technology demonstration. No serious investment will be made to utilize a nano-satellite constellation for revolutionary space application. The space community will lose a chance to revitalize itself. Therefore, improving the reliability of nano-satellite is an urgent problem to be solved. It is a difficult problem though, as we have to find the optimum balance between the reliability and low-cost/fast-delivery.

NETS project

To improve the reliability, we propose standardization of nano-satellite environmental testing. Since September 2011, a new project, "Nano-satellite Environment Test Standardization" (NETS) project, has started under the support of Japanese government funding. The project will be promoted by four organizations, Kyushu Institute of Technology (KIT), International Standard Innovation Technology Research Association (INOTEK), The Society of Japanese Aerospace Industries (SJAC) and Astrex with participation of domestic and international stakeholders. The goal of the project is to establish an ISO standard including the following points;

(1) Environment Tests of Nano-satellite System,

(2) Documentation of Nano-satellite Environment Tests,

(3) Environment Tests of Nano-satellite Components.

Satellites dealt in the standard are mainly made of non-space-qualified commercial-off-the-shelf components to achieve low-cost and fast-delivery. Their weight and size is, but not limited to, typically less than 50kg and 50cm, respectively. The purpose of the present paper is to introduce the project with emphasis on background and purpose and provide recent updates.

The standards can satisfy the needs from the several sectors. First, they can satisfy the needs of nano-satellite developers. Currently, if one wants to build a satellite quickly and cheaply, the easiest way is to buy components/units from the market. Unlike the traditional satellites, there is no time or money to visit the supplier before the developer makes decision. There are already Internet shops that advertise products for nano-satellites. There is little guarantee, however, to those products. The test history is not transparent to the buyers. Even flight heritage does not guarantee that the products are made of the same parts. Therefore, if we want to make sure that the products we are buying can work in space, we tend to buy space-qualified components manufactured by well-known space manufacturer. The standards can give the minimum assurance that the products sold in the market have gone through the known environment tests.

The standards can satisfy contractual needs of satellite purchase. In the contract of large/medium class satellite, the buyer and seller both understand to what degree the tests should be done based on the experience gained through over 50 years of space activities. The nano-satellites are new to the market and buyers can be also new to the space market. There may be a gap between the buyer, those who want to do business using nanosatellites, and the seller, those who want to build satellites, about to what degree the tests should be done. The buyers may want thoroughness similar to the traditional satellites and yet much cheaper price. The seller may want to relax some of the test requirements. At this moment, there are no agreed-upon criteria about the test and verification of nano-satellites. As the time goes on, such criteria will be formed eventually. But there is a need to accelerate the formation of criteria to accommodate the rapid pace of nano-satellite development.

Needs of environment test standards

The standards can satisfy the needs of new comers to space that has little knowledge about the environment tests by providing a guideline of test and verification that is affordable for their purpose. It will help small business, universities and developing countries to enter the space sector through nano-satellite development. The standard will help improving the reliability of nano-satellite made by the new comers.

2. PROJECT APPROACH

Figure 1 depicts the approach we take in the NETS project. There are already various environment test standards both domestic and international. Those standards were based on 50 years' experience. They are meant for very expensive satellites. But at the same time, they are meant to be highly reliable. Therefore, we take advantage of the existing standards by tailoring the requirement written there. To do tailoring, we need a certain rationale based on scientific knowledge. To obtain the rationale, in this project we carry out basic researches. The basic research will also produce new inventions that are suitable for the nano-satellite environment.

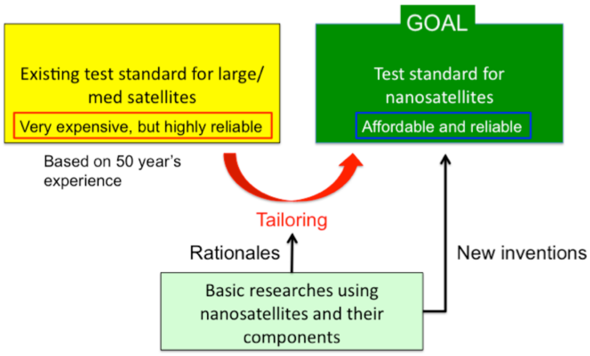

Figure 1: Approach of NETS project

In NETS projects, we first plant to study the existing test standards. In 2011, we compared ISO-15864, JERG-2-002, NASA-STD-7002A, GSFC-STD-7000, ECSS-E-ST-10-03C and SMC-S-016. Tables 1 and 2 list the tests requirement specified by those standards for the system level test and the unit level test for electrical and electronic units. Some tests listed in one standard are not necessarily mentioned in other standards. The test requirement differs for each standard, reflecting the test philosophy of each country or organization. We have compiled a complete set of tables to compare the test conditions among the standards. This document research forms the basis of tailoring the existing standards to the nano-satellite test standard.

We carried out extensive interview with 15 nano-satellite developers in Japan who have experience of developing nano-satellites. The 15 developers were made of one space agency, 5 private companies or associations of private companies, and 9 universities. The interview was made about 18 satellites developed or being developed by the 15 developers. The satellite size ranged from 1U cubesat to 100kg micro satellites (5 Cubesat-class, 4 10kg-class, 1 30kg-class, 7 50kg-class, 1 100kg-class).

In the interview, we asked the following questions;

- What standards they used
- What tests did they do? What test did they skip and why?
- What are the anomalies found during the tests and in orbit?
- How was the documentation made?

Because all the satellites were or will be launched as auxiliary payloads, all the satellites went through extensive mechanical tests specified in the user manual of the launchers. The vibration tests were effective to detect the defects in the design as well as the workmanship. All the developers except two performed shock test as well. Thermal vacuum tests were often skipped for Cubesat-class satellites due to several reasons; a) there was not enough schedule for the test (Cubesats were all developed as university student satellites), b) there was no test facility available, c)the test was judged unnecessary. For 50kg-class or larger micro-satellites, all of the satellites did or plan to do thermal vacuum. Only three developers, private companies and agency, did the single event test. On the other hand, eight developers performed total dose test, reflecting the fact that the total dose is relatively easier than the single event test.

Among the 18 satellites, 11 satellites have been launched already. 5 satellites (2 Cubesat-class, 1 10kg-class, 1 50kg class, 1 100kg-class) had full mission success, 4 satellites (2 Cubesat-class, 1 10kg-class, 1 50kg-class) had a partial success, 1 satellite (30kg-class) had a total loss, and 1 satellite had a launch failure. The other 6 satellites are waiting for launch. All of the 5 satellites that couldn't achieve the mission success suffered infant mortality. 4 satellites out of the 5 satellites had deployable mechanisms that had more or less the serious effects on the mission failure.

Regarding the use of the documents, most of the university developers referred only to the user manual of the launchers. The private companies referred to JERG-2-002, GSFC-STD-7000, ECSS-E-ST-10-03C and others. But they did not exactly follow the traditional standards. During the interview, many developers, especially universities, commented about the importance of not binding the educational satellites, especially Cubesat-class by the testing standards. It is important that the test standard will not interfere with the free and innovative satellite development in universities. At the same time, developers of relatively large-class satellites welcomed the idea of standard and expressed the needs of standard that helps the procurement of the satellite units. They wanted more clear data of temperature range and mechanical properties for the satellite units sold in the market.

For the basic researches, we prepare multiple test samples of RF transmitter (X-band solid-state amplifier with 3 W output power, 16V～36V input voltage, 153mm(W)×94mm(D)x34mm(H)) and power control unit (PCU, maximum solar array input power 200W with MPPT control, 28 V/3A output, 5 output channels, 196mm(W)×200mm(D)×56.5mm(H)) as shown in Fig.2. We will test those samples until their performance output deviate from the nominal values beyond pre-determined limits. The tests to be carried out are thermal vacuum, thermal cycle, radiation, vibration, shock and others. Currently, in all of the environment test standards, thermal vacuum test is required for the electric and electronic components such as RF or PCU unless comprehensive analysis proves that the thermal vacuum can be replaced by thermal cycle (see Table 2). We will do thermal vacuum, thermal cycle and vacuum tests and study whether we can have the same result by a combination of thermal cycle and vacuum (room temperature) alone, leading to considerable saving in the test cost.

In Figure 3, we show an example of the temperature profile used in the thermal test of PCU. The temperature range is between -24^{o}C and 61^{o}C and the number of cycles is 14 (actually Fig.3 shows 13.5 cycles if we disregard the initial baking). These numbers are taken from the acceptance test levels of thermal cycle test of electrical and electronic units of SMC-S-016. The temperature is changed at +5oC/min and -3^{o}C/min, which were chosen from the capability of the test facility. The temperature is monitored at two holes to be used to mount the units to a satellite. The initial hot temperature soak at +80^{o}C for 2 hours is for the baking purpose. Then the temperature is reduced to -40^{o}C. At -40^{o}C, the unit is turned on to see whether the unit can be turned on and initiate the starting sequence following separation from a launcher. The cold start test does not intend to verify the steady operation at -40^{o}C as the units will soon reach the minimum predicted operational temperature due to the heat generated internally and the external heat input. The cold start test was inserted because a micro/nano satellite often launched as an auxiliary payload may be placed in the shadow of other satellites for a significantly long time before the separation. After the cold start test, the temperature is raised to -24^{o}C and the cycles between -24^{o}C and +61^{o}C are started. At each of cold and hot soak (2 hours each), the unit performance test is carried out to see whether any deviation from the nominal operational performance occurs or not.

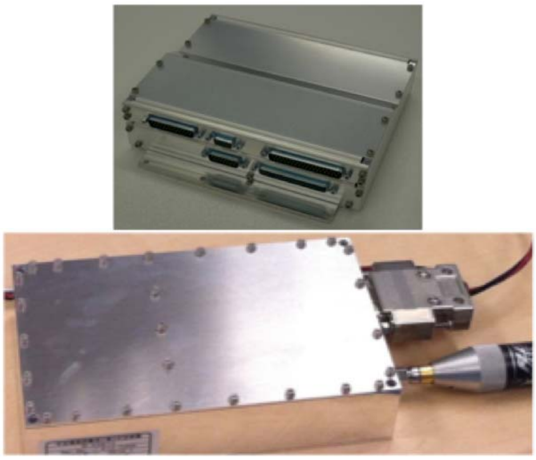

Figure 2: Test sample of PCU (left) and RF (right)

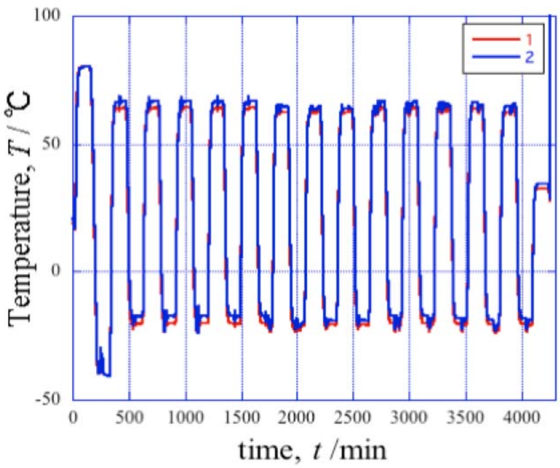

Figure 3: Temperature profile used in thermal cycle test. Temperatures measured at the two mounting holes are shown

As of now, we have finished the thermal cycle of PCU in nitrogen gas environment in atmospheric pressure and confirmed that the PCU made of COTS parts worked flawlessly. We are now carrying out the thermal vacuum test in pressure less than 1.3x10^{-3}Pa using a vacuum chamber equipped with liquid nitrogen shroud. We will compare not only the test results but also the test costs (personnel, time, money, etc) between the thermal cycles and the thermal vacuum.

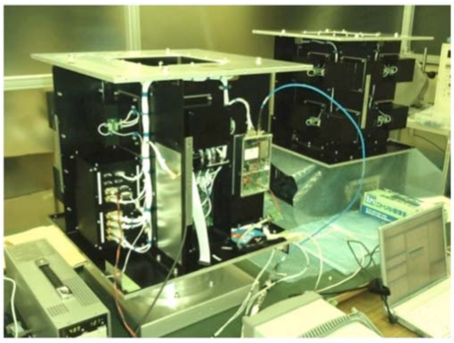

Figure 4: Dummy satellites to be tested

Figure 5: 1st International Workshop, December, 2011

We also prepare dummy satellites that are made of basic satellite functions such as RF transmitter, PCU, battery, computer. Although the other components are made by dummy mass with heater inside, the components mentioned above and the satellite structure are of flight quality. The dummy satellite is a copy of a 50kg-50cm nano-satellite that was previously developed for remote sensing purpose. We are carrying out thermal balance test where we simultaneously measure the temperature of 50 points inside the satellite. We are also carrying out a modal survey test where we measure the acceleration of 32 points in three directions inside the satellite. The base vibration levels are set to 0.3, 0.5 and 0.6G rms between 20 and 2000Hz. The linearity of the amplification of the acceleration at each point is checked to extrapolate the result to the higher level of acceleration. We will also perform a shock test to observe the distribution of high frequency acceleration inside the satellite. We prepare two dummy satellites as shown in Fig.4. One is tested in Japan. The other will be used for a round-robin test to be carried out at an international partner institution abroad.

The results of the basic researches as well as the document study and interviews are being examined in detail by domestic committees formed by nano-satellite developers, component providers, space agencies, government organizations, and academia. The committees also discuss the drafts of the standards before being presented to the international community.

In the NETS project, to form consensus among the experts of nano-satellite worldwide, we will have a series of workshops. The workshop will serve as an open forum for those who are interested in standardization of nano-satellite technologies. In the workshop, the results of the basic researches will be shared among the participants to make the scientific basis of discussion. The draft of the standards will be discussed in detail before being presented to ISO/TC20/SC14 for formal discussion. In December 2011, the First International Workshop on Standardization of Nanosatellite Technologies was held at Kitakyushu with participation of 90 experts including 36 from abroad (see Fig.5). In the workshop, the needs and merits of the test standardization were identified as following,

- Promote worldwide trade of nanosatellite products
- Improve the reliability of nanosatellites
- Making satellite development free of specific launchers
- Serves as a guideline of environment tests for newcomers to space

The standard will put an emphasis on preventing infant mortality in orbit rather than assuring long life in orbit. It is important to try not to prevent new inventions by imposing restrictions. The goal is to provide affordable and reliable test methods to the stakeholders such as nano-satellite developers, component manufacturers, launch providers, nano-satellite users, nano-satellite testers, space agencies, academia and others. The standard will focus on design qualification and acceptance of flight models and its target is a satellite built for commercial purpose not for education or technology demonstration purposes. The tasks and roadmap were laid out at the workshop. We aim to have an ISO standard by 2015. The workshop was closed by adopting the following resolution unanimously, *"Participants of 1st Workshop of International Standardization of Nanosatellite Technologies recognize that international standardization for nanosatellite testing has a great merit for the growth of worldwide nanosatellite activities and utilization and agree to cooperate as experts toward establishment of an ISO standard on nanosatellite testing"*.

3. MILESTONES AND ROADMAP

Under the current plan, the NETS project will be funded for three years until fiscal year of 2013. By the end of FY 2013 (March 2014), we anticipate the following milestones.

1. 1st international workshop, Dec. 14, 2011
2. Brief outline of the standards, March, 2012
3. Working draft ver.1, Fall, 2012
4. 2nd international workshop, December 10 to 14, 2012
5. Working draft ver.2, Spring, 2013
6. New work item proposal to ISO/TC20/SC14, Spring, 2013
7. 3rd International workshop, Summer, 2013
8. Committee draft ver.1, Fall, 2013
9. Registration of committee draft ver.2 for voting, Spring, 2014
10. After the end of government funding, we anticipate the following,
11. Voting of Committee Draft, Spring-Summer 2014
12. Voting of Draft International Standard Fall-Winter, 2014
13. Approval as Final Draft International Standard for editing, Spring 2015
14. Formal publication as ISO, Fall 2015

4. DRAFT OUTLINE

In May 2012, the outline of the standard draft has been released. Its title is "Space systems —Design Qualification and Acceptance Tests of Micro/Nano Satellite and Units". Its content is listed in Table 3.

Table 3: First Draft Outline

1	Scope
2	Normative references
3	Terms and definitions
4	Symbols (and abbreviated terms)
5	Design, Verification and Testing Philosophy of Mirco/nano Satellites
6	General Requirement
6.1	Tailoring
6.2	Qualification test
6.3	Acceptance test
6.4	Proto-flight test
6.5	Retest
6.6	Test documentations
6.6.1	Test plan (Test specification)
6.6.2	Test procedure
6.6.3	Test report
6.6.4	Reporting anomaly during test and its disposition
6.6.5	Data sheet for unit test results
6.7	Test conditions, tolerances and accuracies
7	Satellite System Tests
7.1	Test items
7.2	Test selection logic flow
7.3	Test levels and duration
8	Unit Tests
8.1	Test items
8.2	Test selection logic flow
8.3	Test levels and duration
9	Test Requirements
9.1	Electrical Interface
9.2	Comprehensive performance test
9.3	Limited Performance test
9.4	Fault-free
9.5	Cold start
9.6	Deployment
9.7	Attitude Control
9.8	Mechanical Function
9.9	Functional test in vacuum
9.10	End-to-End compatibility
9.11	End-to-End Mission Simulation
9.12	Burn-In and Wear-In Test
9.13	Alignment Measurement
9.14	Physical Property Measurement
9.15	Magnetic Field Test
9.16	Antenna Pattern Test
9.17	Modal Survey
9.18	Thermal Balance Test
9.19	Electromagnetic Compatibility (EMC) Test
9.20	Dynamic Balance
9.21	Launcher/Spacecraft interface test
9.22	Single Event
9.23	Burn-in and Wear-in Test
9.24	Multipaction Discharge
9.25	Electrostatic Discharge (ESD)
9.26	Corona and Arc Discharge
9.27	Static Load Test
9.28	Acceleration Test
9.29	Sinusoidal Vibration Test
9.30	Random Vibration Test
9.31	Acoustic Test
9.32	Shock Test
9.33	Thermal Vacuum Test
9.34	Thermal Cycle Test
9.35	Pressure Test
9.36	Leakage Test for Sealed Units
9.37	Bake Out and Outgas
Annex A (Informative) Basis of Test Levels and Duration	

A.1 General
A.2 Temperature
A.3 Vibration
A.4 Shock
Annex B (Normative) Thermal vacuum or thermal cycle?
Annex C (Informative) Testing strategy

More detail is available at http://cent.ele.kyutech.ac.jp/nets_web.html.

The scope of the standard is written as the following;

"Test requirements and test methods to qualify the design and manufacturing method of micro/nano satellites and their components, and accept the final products. Satellites dealt in this standard are mainly made of non-space-qualified commercial-off-the-shelf components to achieve low-cost and fast-delivery. Their weight and size is, but not limited to, typically less than 50kg and 50cm, respectively. This standard put emphasis on achieving reliability against infant mortality after its launch to orbit while maintaining low-cost and fast-delivery."

5. CONCLUSION

As there is a growing interest in nano-satellite development and application outside the established space sector, there is an urgent need to improve the reliability of nano-satellites so that their business-use can attract serious investment. Application of nano-satellites as a constellation has a possibility of revolutionizing the way of thinking about how to run the space activities.

International standardization of nano-satellite environment testing has merits for nano-satellite developers, nano-satellite business providers and newcomers to space by providing reliable test standards while keeping the low-cost and fast -delivery nature of nano-satellites.

A new project, "Nano-satellite Environment Test Standardization" (NETS) project has started to lead the international endeavour. The project consists of basic researches to tailor the existing test standards based on scientific data and to add new inventions to the nano-satellite tests. The research findings will be shared through a series of international workshops and research community network to improve the nano-satellite reliability. The NETS project group is ready to serve the worldwide nano-satellite community by being the focal point of the new international endeavour. From January 2012, a mailing list has been started. Those who want to join the mailing list should send their intent to nets_office@langmuir.ele.kyutech.ac.jp. The project web page is now open at http://cent.ele.kyutech.ac.jp/nets_web.html, where various files can be downloaded.

The second workshop will be held from December 10 to 14, 2012, at Kitakyushu. The workshop is made of demonstration tests of the dummy satellites and discussion on the first version of the working draft.

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Table 1: Tests requirements listed in various standards

Documents	ISO-15864			NASA STD-7002A	JERG-2-002			SMC-S-016		ECSS-E-ST -10-03C			GSFC-STD-7000	
Tests	QT	PFT	AT	PFT	QT	PFT	AT	QT/ PFT	AT	QT	PFT	AT	QT/ PFT	AT
Alignment measurement	R	R	R	R	R	R	R			R	R	R		
Functional (Electrical)	R	R	R	R	R	R	R	R	R	R	R	R	R	R
Functional (Mechanical)	R	R	R	R	R	R	R	R	R	R	R	R	R	R
Performance	*1	*1	*1	R	*1	*1	*1	*22	*22	R	R	R	R	R
End-to-End Compatibility				R				R	R				R	R
End-to-End Mission Simulation				R				*22	*22	R	R	R	R	R
End-to-End Polarity (Sign)										R	R	R		
Launcher Interface										O*2	O*2	O*3		
Tracking and control compatibility test	R	R	R											
Failure-Free Performance				R									R	R
Inspection								R	R					
Physical Property	R	R	R	R*12	R	R	R			R*4	R*4	R*4	R	R
Dynamic Balance	O	O	O	R	O	O	O						R	R
Static Load	N	N	N							O*5	O*5	N		
Spin										O*6	O*6	O*6		
Transient										O	O	O		
Random Vibration	R*7	R*7	R*7	O*8 *13	R*7	R*7	R*7	R*7 *9	R*7 *9	O*7	O*7	O*7	R*10	R* 10
Acoustic	R*7	R*7	R*7	R	R*7	R*7	R*7	R*7 *9	R*7 *9	O*7	O*7	O*7	R	R
Sinusoidal Vibration	R	R	R	R	R	R	R			R*11	R*11	O	R	R
Shock	R	R	O	R	R	R	O	R	R	O	O	O	R	R
Micro-vibration susceptibility										O	O			
Modal Survey	O	O	O	R	R	R	O	R	O	O	O	N	O	O
Strength				R*12									O	O
Pressure Profile				O*13									N	N
Appendage Deployment				R										
Leak	R	R	R	N	R	R	R	R	R	O*14	O*14	O*14	R	R
Proof Pressure	R	R	R					R	R	O*14	O*14	O*14		
Pressure Cycling	R	R	R					N	N	O*15	O*15	N		
Burst pressure	R	R	R					N	N	O*14	O*14	N		
Thermal Vacuum	R	R	R	R*16	R	R	R	R	R	R	R	R	R	R
Thermal Cycle	O	O	O	N	N	N	N	N	N	O*17	O*17	O*17	O	O
Thermal Balance	R	R	O	R	R	R	O	R	R	R	R	O	R	R
EMC	R	R	O	R*18	R	R	O	R*19	R*20	R	R	R*21	R	R
Electromagnetic	O	O	O		O	O	O			O	O	O	R	R
Antenna Pattern	N	N	N		O	O	O							

R：Required O：Optional N：Non-necessary

*1 Carried out in electrical functional test

*2 Mandatory for satellite interfacing with launcher

*3 For satellite interfacing with launcher where launcher interface have being modified

*4 Spin balance tests shall be used for spin stabilized systems
*5 Mandatory if not performed at structure subsystem level
*6 Mandatory for spinning satellits with an acceleration greater than 2g or more to any part of the space segment element
*7 Either vibration or acoustic test is recommended, whichever is more appropriate, with the other discretionary.
*8 Required for a satellite less than 456kg
*9 Vibration can be used in lieu of acoustics for vehicles under 180 kg.
*10 Required for a satellite less than 456kg
*11 Sinusoidal vibration may be replaced by transient combined with modal survey
*12 May be accomplished by analysis
*13 Test if assessed to be sensitive to the environment
*14 Mandatory for space segment elements that include pressurized equipment.
*15 Mandatory for Pressurized space segment elements that will experience several re-entries.
*16 If operation required in vacuum
*17Applicable to space segment elements that operate under a non-vacuum environment during their entire lifetime
*18 Radiated emission and susceptibility required. Conducted emission and suceptibility tests are required for attached payloads or payloads that derive power from an off-board source
*19 EMC testing shall be conducted when there are radiated emission requirements below 10 dBuV/m or there is a requirement on passive intermodulation levels.
*20 EMC testing required when there is less than 12 dB margin
*21 Limited to Conducted emission and Grounding test as per E-ST-20-07 Clause 5.3.9
*22 Carried out in End-to-End Specification Performance Test

Table 2: Tests requirements for electrical and electronic units listed in various standards

Documents	ISO-15864			NASA STD-7002A	JERG-2-002			SMC-S-016		ECSS-E-ST-10-03C			GSFC-STD-7000	
Tests	QT	PFT	AT	PFT	QT	PFT	AT	QT/ PFT	AT	QT	PFT	AT	QT/ PFT	AT
Functional (Electrical)	R	R	R	R	R	R	R	R	R	R	R	R	R	R
Functional (Mechanical)	R	R	R	R	R	R	R	R	R	R	R	R	N	N
Performance	*1	*1	*1	R	*1	*1	*1	*1	*1	*1	*1	*1	R	R
Humidity				O*3				O*4	N	O*4	O*4	N	O*4	O*4
Burn-in, Wear-in	N	R	R		N	R	R	N*6	R	O	O	O		
Life				R*7	*8	*8	*8	O*9	O*9	O*7	O*7	N		
Failure Free				R									O?	O?
Inspection								R	R					
Physical Property	R	R	R	R						R	R	R	O	O
Static Load	O	O	N		*8	*8	*8	O	N	R*11	N	N		
Spin										R*11	R*5	N		
Transient										R*11	R*5	N		
Random Vibration	R	R	R	R	R	R	R	R*12	R*12	R	R	R	R	R
Acoustic	O	O	O	O*2	O	O	O	R*12	R*12	N	N	N	R*13	R*13
Sinusoidal Vibration	O	O	O	R	O	O	O			R	R	N	R	R
Shock	R	O	O	R*15 *2	O*17	O*17	O*17	R	O	R	R	N	R*18	R*18
Micro-vibration generated environment										O*19	O*19	N		
Micro-vibration susceptibility										O*19	O*19	O*19		
Modal Survey	O	O	O	N	O	O	O						O	O
Strength				R*20									O	O
Pressure Profile				O*3									N	N
Acceleration	O	O	N		O	O	N	O	N	*21	*21	N		
Leak	O	O	O	R*22	R*22	R*22	R*22	O	O	O*23	O*23	O*23	R	R
Proof Pressure	N	N	N		N	N	N	O	O	O*23	O*23	N		
Pressure Cycling	N	N	N		N	N	N	O	N	O*23	N	N		
Burst pressure	N	N	N		N	N	N	N	N	O	N	N		
Burst										O	N	N		
Thermal Vacuum	R*24	R*24	R*24	R*25	R	R	R*26	R	R*27	R*25	R*25	R*25	R*34	R*34
Thermal Cycle	O*24	O*24	O*24	R*28	O	O	R*29	R	R	O*28	O*28	O*28	O*34	O*34
Thermal Balance	O	O	N	N	O	O	N						O*30	O*30
EMC（ESD、PIM、Multipaction included）	R	R	O	R	R	R	N	R	R	R*31	R*31	R*31 *32	R	R
Magnetic Field	O	O	N		O	O	N			O	O	O	R	R
Corona and Arc discharge	O	O	O							R	R	R		

*1 Performed with functional tests
*2 Test if assessed to be sensitive to the environment, but can be accomplished at a higher level of assembly

*3 Test if assessed to be sensitive to the environment
*4. Required if the unit is not fully environmentally protected on the ground (storage and transportation) and in flight
*5 One of the two types of test and not to be performed if covered by the sinusoidal vibration test.
*6 For acceptance and protoqualification testing, units shall be "burned in" beyond the durations prescribed for thermal cycle and thermal vacuum testing.
*7 This test is performed on life-limited space segment equipment or part of it.
*8 Carried out as development tests
*9 Applies to units that may have a wear-out, drift, or fatigue-type failure mode, or performance degradation, due to the operational environment.
*11 One of the three types of test and not to be performed if covered by the sinusoidal vibration test.
*12 Either vibration or acoustic required
*13 Test must be performed unless assessment justifies deletion.
*15 Required for Self-induced shock
*17 Required for units sensitive to shock and mounted close to the source of shock
*18 Test required for self-induced shocks, but may be performed at payload level of assembly for externally induced shocks.
*19 Test to be performed only if need is identified by analysis.
*20 May be accomplished by analysis
*21 Performed as either static load, spin or transient
*22 Required for sealed unites
*23 Leak and pressure tests may be combined. These tests are mandatory only on sealed or pressurized space segment equipment
*24 If the units are not sensitive to the vacuum environment, the test may be replaced with thermal cycle test at ambient pressure.
*25 If operation required in vacuum
*26 Required for non-shielded unit and high power RF units. Optional for other units
*27 Unnecessary if it can be shown that the design is insensitive to the vacuum environment
*28 Thermal ambient cycling test shall be selected only for space segment equipment that operate under a non-vacuum environment during their entire lifetime.
*29 Optional if thermal vacuum has been performed
*30 Test is not required at this level of assembly if analysis verification is established for non- tested elements.
*31Multipaction and PIM (Passive Intermodulation) are optional
*32 ESD is not necessary
*33 Required for sealed or pressurized unites
*34 Temperature cycling at ambient pressure may be substituted for thermal-vacuum temperature cycling if it can be shown by a comprehensive analysis to be acceptable. This analysis must show that temperature levels and gradients are as severe in air as in a vacuum.