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Space systems — Design qualification and acceptance tests of small spacecraft and units

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National foreword

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Space systems — Design qualification and acceptance tests of small spacecraft and units

Systèmes spatiaux — Qualification de la conception et essais de réception des petits véhicules spatiaux

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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This document was prepared by Technical Committee ISO/TC 20, *Aircraft and space vehicles*, Subcommittee SC 14, *Space systems and operations*.

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Introduction

There is an increasing demand for small/micro/nano/pico satellite development and utilization worldwide; yet, there is no clear and globally accepted definition of what is considered “small”, “micro”, “nano” or “pico” satellites. These satellites are often built with emphasis on low cost and fast delivery. They are characterized by extensive use of non-space-qualified commercial-off-the-shelf (COTS) units. For the sake of convenience, the term “small spacecraft” is used throughout this document as a generic term to refer to these satellites.

A small spacecraft is a satellite that utilizes non-traditional risk-taking development and management approaches to achieve low cost and fast delivery with a small number of team. To achieve these two points, low cost and fast delivery, satellite design relies on the use of non-space-qualified commercial-off-the-shelf (COTS) units, making satellite size inherently smaller. The design accepts a certain level of risk associated with the use of COTS.

A certain set of tests is necessary to ensure the mission success of small spacecraft. Applying the same test requirements and methods as those applied to traditional large/medium satellites, however, will nullify the low-cost and fast-delivery advantages possessed by small spacecraft.

This document is meant to improve the reliability of small spacecraft, especially those with commercial purpose, while maintaining the low-cost and fast-delivery nature of small spacecraft. This document intends to promote worldwide trade of small spacecraft products by providing a minimum level of assurance that a product made of non-space-qualified commercial-off-the-shelf parts and units can work in space. This document also aims to serve as a testing guideline for those who intend to enter satellite manufacturing through development of small spacecraft products.

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Space systems — Design qualification and acceptance tests of small spacecraft and units

1 Scope

This document provides test methods and test requirements for design qualification and/or acceptance of small spacecraft or units. It provides the minimum test requirements and test methods to qualify the design and manufacturing methods of commercial small spacecraft and their units and to accept the final products.

This document places emphasis on achieving reliability against infant mortality after satellite launch to orbit while maintaining low cost and fast delivery.

This document is applied to satellites whose development methods are different from the ones used for traditional satellites that have little room for risk tolerance, as shown in Figure 1. The scope of this document encompasses different categories of small spacecraft, so-called mini-, micro, nano-, pico- and femto-, as well as CubeSat, spacecraft. Therefore, for the sake of convenience, the term "small spacecraft" is used throughout this document as a generic term.

This document includes CubeSat, as long as it is developed with the untraditional processes.

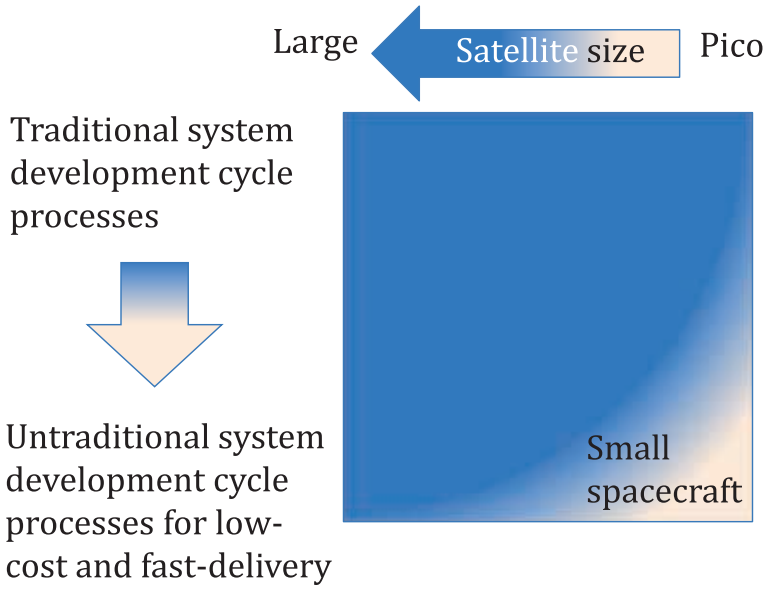

Figure 1 — Applicability of this document

This document does not cover satellite deployment mechanisms, such as POD, as the verification requirements are defined in the Interface Control Document (ICD) with the launcher, such as ISO 26869.

This document does not cover software testing, although some tests such as functional test, mission test and end-to-end test are inherently used to test the software installed in the hardware being tested. General requirements and processes of satellite software testing can be found in various references, such as ECSS-E-ST40.

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This document does not cover requirements regarding safety nor debris mitigation. Appropriate documents such as ISO 14620–1 or ISO 24113 can be referred to. Other common requirements for small spacecraft can be found in Reference [14].

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 11221:2011, *Space systems — Space solar panels — Spacecraft charging induced electrostatic discharge test methods*

ISO 14302, *Space systems — Electromagnetic compatibility requirements*

ISO 15864:2004, *Space systems — General test methods for space craft, subsystems and units*

ISO 17566:2011, *Space systems — General test documentation*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— IEC Electropedia: available at http://www.electropedia.org/

— ISO Online browsing platform: available at http://www.iso.org/obp

3.1
flat-sat
table-sat
configuration where only *units* (3.4), sometimes bare circuit boards only, are laid out in atmosphere on a table while not being mounted to the satellite structure

3.2
flight model
satellite or unit model dedicated to launch and operate in orbit and subjected to acceptance testing

3.3
test article
satellite or *unit* (3.4) on which a test is conducted

3.4
unit
lowest level of hardware assembly for which acceptance and qualification tests are required

3.5
POD
box housing *CubeSats* (3.6) during launch

3.6
CubeSat
box-shaped satellite whose volume is composed of “N” 10 cm × 10 cm × 10 cm sub-volumes

EXAMPLE 1U = 10 cm × 10 cm × 10 cm, 2U = 20 cm × 10 cm × 10 cm, and 3U = 30 cm × 10 cm × 10 cm.

Note 1 to entry: See ISO 17770 for further definition.

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4 Abbreviated terms

AT	Acceptance test
COTS	Commercial-off-the-self
CVCM	Collected volatile condensable materials
EMC	Electromagnetic compatibility
ESD	Electrostatic discharge
ESS	Environment stress screening
EED	Electroexplosive devices
EM	Engineering model
EMC	Electromagnetic compatibility
FM	Flight model
FMEA	Failure Mode and Effects Analysis
FMECA	Failure Mode, Effects, and Criticality Analysis
IC	Integrated circuit
ICD	Interface control document
LEO	Low Earth Orbit
MEMS	Micro Electro Mechanical Systems
MMA	Moving mechanical assembly
PFT	Proto-flight test
PFM	Proto-flight model
QM	Qualification model
QT	Qualification test
QCM	Quartz Crystal Microbalance
RF	Radio frequency
PSD	Power spectral density
SAA	South Atlantic Anomaly
SE	Single event
SEE	Single event effect
SRS	Shock response spectrum

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STM Structural thermal model

TID Total ionization dose

TML Total mass loss

5 General requirements

5.1 Tailoring

Specifications described in this document are tailorable upon agreement between the customer, the manufacturer and the launch provider. Annex A provides tailoring and waiver guides of test requirements.

5.2 Qualification test

For satellite system level qualification tests, there is little difference between small spacecraft and traditional satellite qualification tests in terms of objectives and requirements. Qualification tests demonstrate that items meet design requirements and include proper margin. Qualification tests can serve as good practice for personnel who are inexperienced in testing toward acceptance tests to be carried out later. If the same design is used for many satellites, such as satellites of a constellation program, the qualification tests are not necessary except for the first satellite. ISO 15864:2004, 4.4 provides additional requirements for system qualification test.

Unit level qualification tests dealt in this document is different from those done for traditional satellites. The unit QT in this document provides a minimum guarantee that a given unit sold as “a satellite unit” has a certain level of tolerance against the space environment. Therefore, the unit QT in this document does not include proper margin against the maximum predicted environment stress, which depends on each satellite. This document provides numeric values for the test level and duration of unit QTs as much as possible with their rationale given in Annex B. The satellite developers who purchase the COTS-unit tested according to this document shall make consistent decisions about how to obtain the margin. The satellite developers may purchase a dedicated test model in addition to the flight model and carry out another QT with the margin. They may carry out PFT using a flight model or only AT taking the risk of little margin. The satellite developer shall provide the test levels and duration of the additional QT, AT or PFT. See C.1 for additional note.

5.3 Acceptance test

There is little difference in terms of objectives and requirements of acceptance tests between small spacecraft and traditional satellites. ISO 15864:2004, 4.5 provides requirements for acceptance test.

5.4 Proto-flight test

There is little difference in terms of objectives and requirements of proto-flight tests between small spacecraft and traditional satellites. ISO 15864:2004, 4.6 provides requirements for proto-flight test.

5.5 Retest

Situations that may require retest are described in ISO 15864:2004, 4.8.

5.6 Test documentation

In order to minimize program cost, the amount of paper work should be reduced as much as possible. The documents used inside the developing organization can only be simplified considering the small size of the team. At the same time, however, the test documentation shall be detailed enough to ensure

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traceability from the later stages of satellite development or operation. The importance of the test procedure document should not be underestimated, as well-prepared tests will eventually save both time and money.

For the unit QT, the test documentation shall provide the important information necessary to prove that the COTS-based units have adequate durability against the space environment. See C.1 for additional notes.

5.6.1 Test plan, specification and procedure

The simplicity of a small spacecraft allows the combination of the test plan, specification and procedure documents for the system test or unit test into one document as recommended by ISO 17566. In the following cases, it is recommended to separate the test plan/specification and the test procedure into two separate documents.

a) The test is fairly complex and requires many discussions and iterations within the development team to define the test specification.

b) The test is carried out at a location outside the developing organization and requires consultation with the test institution well before the test.

c) The test has to be approved by the customer. The test plan/specification may be used as the document for approval.

d) Others.

The contents of the test plan, specification and procedure shall be based on ISO 17566:2011, Table 2 or Table 3. Some of the content in the specification, such as test facility requirements and procedural test requirements, may be moved to the test procedure document. The documents may be revised as test preparation progresses. It is important to keep track of the version number, the revision points and the revision dates.

5.6.2 Test report

The test report content shall be based on ISO 17566:2011, Annex D. Any anomaly during the test and its disposition shall be reported in the test report. The test report shall clearly describe the following information or refer to the test documents that contain the information.

a) Temperature measurement points and the measured temperature profile in the case of thermal tests, e.g. thermal cycle, thermal vacuum, thermal balance, etc.

b) Acceleration measurement points in the case of mechanical tests, e.g. vibration, shock, etc.

c) The points of reference (thermo-couples or accelerometers) used to control the test levels, e.g. temperature, vibration, acoustic, etc.

d) The measured pressure profile during the test in the case of tests conducted in a vacuum, e.g. thermal vacuum, vacuum functioning, multipaction, etc.

e) The power spectrum density waveform of the acceleration measured at the reference points in the case of random vibration test or modal survey.

f) The shock response spectrum calculated from the acceleration measured at the reference points in the case of shock test.

g) The source of radiation particles, their energy and the total fluence in the case of SEE test.

h) The radiation source and energy, total dose and shielding effects considered to derive the total dose, dose rate and temperature during testing in the case of TID test.

i) The result of functional performance measurements before, during and after the environment test.

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If the test results in failure, the test report shall be precise enough to assist with the root cause analysis or other investigation. See Reference [22] for root cause analysis.

5.6.3 Datasheet for unit test results

The following information shall be included in the datasheet for unit test results.

a) Random vibration spectrum in power spectral density, root-mean-square value of acceleration and duration for each axis if random vibration test was carried out.

b) Vibration level, sweep rate and frequency range for each axis if sinusoidal vibration test was carried out.

c) Radiation and conduction emission spectrum if EMC test was carried out.

d) Temperature profile, number of cycles, hot and cold soak temperatures and their duration, temperature ramp rate (up/down) and gas environment if thermal cycle test in atmospheric pressure was carried out.

e) Temperature profile, number of cycles, hot and cold soak temperatures and their duration, temperature ramp rate (up/down) and pressure profile if thermal vacuum cycle test was carried out.

f) Shock response spectrum for each axis and the method of applying the shock acceleration if shock test was carried out.

j) The source of radiation particles, their energy and the total fluence if SEE test was carried out.

k) The radiation source and energy, total dose, shielding effects considered to derive the total dose, dose rate and temperature during testing if TID test was carried out.

l) The power spectral density of the measured force for various rotational speeds if microvibration acceptance test was carried out.

5.7 Test conditions, tolerances and accuracies

The requirements in ISO 15864:2004, 4.10 shall apply.

5.8 Functional test

Complete functional tests shall be performed at the beginning and end of the test sequence. Partial functional tests shall be conducted before and after each environmental exposure.

5.9 Design, verification and testing philosophy

Annex C describes the difference of small spacecrafts from traditional satellites in terms of design, verification and testing philosophy. Tables C.1 and C.2 summarize the characteristics inherently associated with the satellite program/design and the corresponding verification strategy when low cost and fast delivery are the primary drivers.

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6 Satellite system tests

6.1 Test items

The satellite system test items are listed in Table 1. Annex D provides test selection logic flows.

Table 1 — System test items

Test items	QT	AT	PFT
Electrical interface	R	R	R
Functional test	R	R	R
Mission test	R	R	R
Total Ionization Dose (TID) test	O[a]	—	O[a,b]
Single Event Effects (SEE) test	O[a]	—	O[a,b]
Spacecraft Charging Induced Electrostatic Discharge (ESD) test	To be done in the unit level.		
Electromagnetic Compatibility (EMC) test	R	O[c]	R
Deployment test	R	R	R
Magnetic field test	O[d]	O[d]	O[d]
Antenna pattern test	To be done in the unit level.		
Alignment measurement	O[e]	O[e]	O[e]
Physical property measurement	R	R	R
Launcher/Spacecraft interface test	R	R	R
Quasi-static load test	O[f]	O[f]	O[f]
Modal survey	O[g]	—	O[g]
Sinusoidal vibration test	O[h]	O[h]	O[h]
Random vibration test	R[i]	R[i]	R[i]
Acoustic test	O[i]	O[i]	O[i]
Shock test	O[j]	O[j]	O[j]
Thermal balance test	O[k]	—	O[k]
Thermal vacuum test	R[l]	O[m]	R[l]
Functional test in vacuum		—	
Thermal cycle functional test		O[n]	
Cold/hot start test	O[o]	O[o]	O[o]
Thermal cycle endurance test	To be done in the unit level.		
Pressure test	O[p]	O[p]	O[p]
Leakage test	O[p]	O[p]	O[p]
Microvibration test	To be done in the unit level.		
Burn-in and wear-in test	To be done in the unit level.		

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Table 1 *(continued)*

Test items	QT	AT	PFT
End-to-end mission simulation	—	R	R
Bake out and outgas	—	O[q]	O[q]

R Required; O Optional

[a] To be done in the flat-sat configuration without satellite structure. See Figure D.1.

[b] Use of dedicated test model.

[c] To be done in anechoic chamber if radio licence is not obtained yet. See Figure D.2.

[d] Required when a magnetic sensor is on-board the satellite.

[e] Required for an observation (earth or astronomy) satellite.

[f] Required if launcher ICD requires or if structural analysis cannot replace testing. See Figure D.3.

[g] Required if very high accuracy of the structural analysis is necessary. See 8.15.

[h] Required if Launcher ICD requires. See Figure D.4.

[i] When acoustic test is also required by launcher ICD, either random vibration or acoustic test is recommended, whichever is more appropriate, with the other discretionary. See Figure D.5 for the selection logic of acoustic test.

[j] Required if launcher ICD requires. See Figure D.6.

[k] Required if design is new and thermal accuracy does not have enough accuracy. See Figure D.7.

[l] Either thermal vacuum or a combination of thermal cycle function and functional test in vacuum is required. See Figure D.7.

[m] Required if temperature distribution is large. See Figure D.7.

[n] Required if thermal vacuum test is not done. See Figure D.7.

[o] Required if separation temperature after cold launch is much higher or lower than the max/min temperature. See Figure D.8.

[p] Required if pressure vessel is on-board the satellite.

[q] Required if launcher ICD requires or if a payload sensitive to contamination is on-board the satellite.

6.2 Test level and duration

The test level and duration of system tests shall be specific to each satellite, depending on the environments to be encountered and the mission objectives. In the mechanical and thermal tests, the test level of AT shall cover the maximum temperature range and acceleration predicted. For the mechanical and thermal QT or PFT, appropriate margin shall be added.

7 Unit tests

7.1 Test items

The unit test items are listed in Tables 2, 3 and 4. Annex D provides test selection logic flows.

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Table 2 — Unit test items (QT)

Test items	Electrical and electronic	Antenna	MMA	Solar array	Battery	Valve	Pressure vessel	Thruster	Optical	Structural
Electrical interface test	To be done at the assembly and integration to the system level.									
Functional test	R	R	R	R	R	R	R	R	R	—
Mission test	To be done in the system level.									
Total Ionization Dose (TID) test	O[a]	—	—	—	—	—	—	—	—	—
Single Event Effects (SEE) test	O[a]									
Spacecraft Charging Induced Electrostatic Discharge (ESD) test	O[b]	—	—	O[b]	—	—	—	—	—	—
Electromagnetic Compatibility (EMC) test	R	O[c]	O[c]	—	—	—	—	—	—	—
Deployment test	—	O[d]	O[d]	O[d]	—	—	—	—	O[d]	O[d]
Magnetic field test	—	—	O[e]	—	—	O[e]	O[e]	O[e]	O[e]	—
Antenna pattern test	—	R	—	—	—	—	—	—	—	—
Alignment measurement	To be done in the system level.									
Physical property measurement	R	R	R	R	R	R	R	R	R	R
Launcher/Spacecraft interface test	To be done in the system level.									
Quasi-static load test	To be done in the system level.									
Modal survey	O[f]	O[f]	O[f]	O[f]	O[f]	O[f]	O[f]	O[f]	O[f]	O[f]
Sinusoidal vibration test	—	O[g]	—	O[g]	—	—	—	—	O[g]	O[g]
Random vibration test	R	R	R	R	R	R	R	R	R	R
Acoustic test	—	—	—	—	—	—	—	—	—	—
Shock test	O[h]	O[h]	O[h]	O[h]	O[h]	O[h]	—	O[h]	O[h]	O[h]
Thermal balance test	—	O[i]	O[i]	O[i]	—	—	—	—	O[i]	O[i]
Thermal vacuum test	O[j]	O[l]	O[j]	O[l]	O[l]	O[l]	O[l]	O[j]	O[j]	—
Functional test in vacuum	O[k]	O[l]	O[k]	O[l]	O[l]	O[l]	O[l]	O[k]	O[k]	—
Cold/hot start test	O[m]	—	O[m]	—	—	O[m]	—	—	—	—
Thermal cycle functional test	O[k]	O[l]	O[k]	O[l]	O[l]	O[l]	O[l]	O[k]	O[k]	—
Thermal cycle endurance test	R	O[n]	O[n]	O[n]	—	—	—	—	O[n]	O[n]
Pressure test	—	—	O[o]	—	—	R	R	R	—	—
Leakage test	—	—	O[o]		R	R	R	O[o]	—	—
Microvibration test	—	—	O[p]	—	—	—	—	—	—	—

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Table 2 *(continued)*

Test items	Electrical and electronic	Antenna	MMA	Solar array	Battery	Valve	Pressure vessel	Thruster	Optical	Structural
Burn-in and wear-in test	—	—	O[q]	—	—	—	—	—	—	—
End-to-end mission simulation	To be done in the system level.									
Bake out and outgas test	To be done in the system level.									

R Required; O Optional

[a] May be done when a manufacturer wants to demonstrate radiation tolerance. See Figure D.9.

[b] Required if a unit is exposed to outer space and high voltage is used. See Figure D.10.

[c] Required when unit is equipped with electrical and electronic circuits.

[d] Required for deployable units.

[e] Required when units use magnet.

[f] Required if very high accuracy of the structural analysis is necessary. See 8.15.

[g] Required if fundamental frequency is below 200 Hz. See Figure D.11

[h] Required if sensitive material or parts to high frequency acceleration are used. See Figure D.11.

[i] May be done at unit level if a test facility cannot house the entire system. See 8.20.2.

[j] Required if temperature distribution is large. See Figure D.12.

[k] Required if thermal vacuum test is not done. See Figure D.12.

[l] Either thermal vacuum or thermal cycle plus functional test in vacuum is required (see Figure D.12) if electronics or moving parts are involved.

[m] Required if unit is turned on immediately after separation.

[n] Unit exposed to outer space only.

[o] Required when unit is sealed or pressurized.

[p] Required when need is identified by analysis.

[q] Required when unit is not a one-shot device.

Table 3 — Unit test items (AT)

Test items	Electrical and electronic	Antenna	MMA	Solar array	Battery	Valve	Pressure vessel	Thruster	Optical	Structural
Electrical interface test	To be done at the assembly and integration to the system level.									
Functional test	R	R	R	R	R	R	R	R	R	—
Mission test	To be done in the system level.									
Total Ionization Dose (TID) test	—	—	—	—	—	—	—	—	—	—
Single Event Effects (SEE) test	—	—	—	—	—	—	—	—	—	—
Spacecraft Charging Induced Electrostatic Discharge (ESD) test	—	—	—	—	—	—	—	—	—	—
Electromagnetic Compatibility (EMC) test	—	—	—	—	—	—	—	—	—	—

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Table 3 *(continued)*

Test items	Electrical and electronic	Antenna	MMA	Solar array	Battery	Valve	Pressure vessel	Thruster	Optical	Structural
Deployment test	—	O[a]	O[a]	O[a]	—	—	—	—	O[a]	O[a]
Magnetic field test	—	—	—	—	—	—	—	—	—	—
Antenna pattern test	—	R	—	—	—	—	—	—	—	—
Alignment measurement	To be done in the system level.									
Physical property measurement	R	R	R	R	R	R	R	R	R	R
Launcher/Spacecraft interface test	To be done in the system level.									
Quasi-static load test	To be done in the system level.									
Modal survey	O[b]	O[b]	O[b]	O[b]	O[b]	O[b]	O[b]	O[b]	O[b]	O[b]
Sinusoidal vibration test	—	—	—	—	—	—	—	—	—	—
Random vibration test	R	R	R	R[c]	R	R	R	R	R	R
Acoustic test	—	—	—	O[c]	—	—	—	—	—	—
Shock test	—	—	—	—	—	—	—	—	—	—
Thermal balance test	—	—	—	—	—	—	—	—	—	—
Thermal vacuum test	O[d]	O[e]	O[d]	O[e]	O[e]	O[e]	O[e]	O[d]	O[d]	—
Functional test in vacuum	—	—	—	—	—	—	—	—	—	—
Cold/hot start test	O[f]	—	O[f]	—	—	O[f]	—	—	—	—
Thermal cycle functional test	O[g]	O[e]	O[g]	O[e]	O[e]	O[e]	O[e]	O[g]	O[g]	—
Thermal cycle endurance test	—	—	—	—	—	—	—	—	—	—
Pressure test	—	—	O[h]	—	—	R	R	R	—	—
Leakage test	—	—	O[h]		R	R	R	O[g]	—	—
Microvibration test	—	—	O[i]	—	—	—	—	—	—	—
Burn-in and wear-in test	R	—	O[j]	—	—	R	—	R	—	—

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Table 3 *(continued)*

Test items	Electrical and electronic	Antenna	MMA	Solar array	Battery	Valve	Pressure vessel	Thruster	Optical	Structural
End-to-end mission simulation	To be done in the system level.									
Bake out and outgas test	To be done in the system level.			R	To be done in the system level.					

R Required; O Optional

[a] Required for deployable units.

[b] Required if very high accuracy of the structural analysis is necessary. See 8.15.

[c] When acoustic test is also required by satellite system ICD, either random vibration or acoustic test is recommended, whichever is more appropriate, with the other discretionary. See Figure D.5 for the selection logic of acoustic test.

[d] Required when large temperature distribution exists inside the unit.

[e] Either thermal vacuum or thermal cycle is required if electronics or moving parts are involved.

[f] Required if unit is turned on immediately after separation and separation temperature after cold launch is much higher or lower than the max/min temperature. See Figure D.8. Can be combined with thermal vacuum test or thermal cycle functional test.

[g] Required when thermal vacuum test is not done.

[h] Required when unit is sealed or pressurized.

[i] Required when need is identified by analysis.

[j] Required when the total duration of the acceptance test sequence is insufficient.

Table 4 — Unit test items (PFT)

Test items	Electrical and electronic	Antenna	MMA	Solar array	Battery	Valve	Pressure vessel	Thruster	Optical	Structural
Electrical interface test	To be done at the assembly and integration to the system level.									
Functional test	R	R	R	R	R	R	R	R	R	—
Mission test	to be done in the system level									
Total Ionization Dose (TID) test	O[a,b]	—	—	—	—	—	—	—	—	—
Single Event Effects (SEE) test	O[a,b]									
Spacecraft Charging Induced Electrostatic Discharge (ESD) test	O[a,c]	—	—	O[a,c]	—	—	—	—	—	—
Electromagnetic Compatibility (EMC) test	R	O[d]	O[d]	—	—	—	—	—	—	—
Deployment test	—	O[e]	O[e]	O[e]	—	—	—	—	O[e]	O[e]
Magnetic field test	—	—	O[f]	—	—	O[f]	O[f]	O[f]	O[f]	—
Antenna pattern test	—	R	—	—	—	—	—	—	—	—
Alignment measurement	To be done in the system level.									
Physical property measurement	R	R	R	R	R	R	R	R	R	R
Launcher/Spacecraft interface test	To be done in the system level.									

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Table 4 *(continued)*

Test items	Electrical and electronic	Antenna	MMA	Solar array	Battery	Valve	Pressure vessel	Thruster	Optical	Structural
Quasi-static load test	To be done in the system level.									
Modal survey	O[g]	O[g]	O[g]	O[g]	O[g]	O[g]	O[g]	O[g]	O[g]	O[g]
Sinusoidal vibration test	—	O[h]	—	O[h]	—	—	—	—	O[h]	O[h]
Random vibration test	R	R	R	R[i]	R	R	R	R	R	R
Acoustic test	—	—	—	O[i]	—	—	—	—	—	—
Shock test	O[j]	O[j]	O[j]	O[j]	O[j]	O[j]	—	O[j]	O[j]	O[j]
Thermal balance test	—	O[k]	O[k]	O[k]	—	—	—	—	O[k]	O[k]
Thermal vacuum test	O[l]	O[n]	O[l]	O[n]	O[n]	O[n]	O[n]	O[l]	O[l]	—
Functional test in vacuum	O[m]	O[n]	O[m]	O[n]	O[n]	O[n]	O[n]	O[m]	O[m]	—
Cold/hot start test	O[o]	—	O[o]	—	—	O[o]	—	—	—	—
Thermal cycle functional test	O[m]	O[n]	O[m]	O[n]	O[n]	O[n]	O[n]	O[m]	O[m]	—
Thermal cycle endurance test	—	O[p]	O[p]	O[p]	—	—	—	—	O[p]	O[p]
Pressure test	—	—	O[q]	—	—	R	R	R	—	—
Leakage test	—	—	O[q]		R	R	R	O[p]	—	—
Microvibration test	—	—	O[r]	—	—	—	—	—	—	—
Burn-in and wear-in test	R	—	O[s]	—	—	R	—	R	—	—

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Table 4 *(continued)*

Test items	Electrical and electronic	Antenna	MMA	Solar array	Battery	Valve	Pressure vessel	Thruster	Optical	Structural
End-to-end mission simulation	To be done in the system level.									
Bake out and outgas test	To be done in the system level.			R	To be done in the system level.					

R Required; O Optional

[a] Use dedicated test model.

[b] May be done when a manufacturer wants to demonstrate radiation tolerance. See Figure D.9.

[c] Required if a unit is exposed to outer space and high voltage is used. See Figure D.10.

[d] Required when unit is equipped with electrical and electronic circuits.

[e] Required for deployable units.

[f] Required when units use magnet.

[g] Required if very high accuracy of the structural analysis is necessary. See 8.15.

[h] Required if fundamental frequency is below 200 Hz. See Figure D.11.

[i] When acoustic test is also required by satellite system ICD, either random vibration or acoustic test is recommended, whichever is more appropriate, with the other discretionary. See Figure D.5 for the selection logic of acoustic test.

[j] Required if sensitive material or parts to high frequency acceleration are used. See Figure D.11.

[k] May be done at unit level if a test facility cannot house the entire system. See 8.20.2.

[l] Required if temperature distribution is large. See Figure D.12.

[m] Required if thermal vacuum test is not done. See Figure D.12.

[n] Either thermal vacuum or thermal cycle plus functional test in vacuum is required (see Figure D.12) if electronics or moving parts are involved.

[o] Required if separation temperature after cold launch is much higher or lower than the max/min temperature. See Figure D.8. Can be combined with thermal vacuum test or thermal cycle functional test.

[p] Required when units are exposed to outer space. Determined after consultation with the satellite developer.

[q] Required when unit is sealed or pressurized.

[r] Required when need is identified by analysis.

[s] Required when unit is not a one-shot device.

7.2 Test levels and duration

Table 5 lists the test level and duration for unit QT. The test level and duration for unit AT or PFT shall be determined after consultation between the satellite developer and the unit manufacturer. See Annex E for AT or PFT of electrical and electronic units.

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Table 5 — Test level and duration of Unit QT

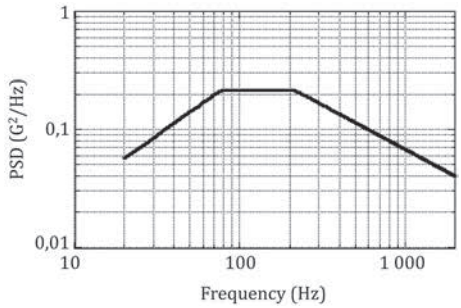
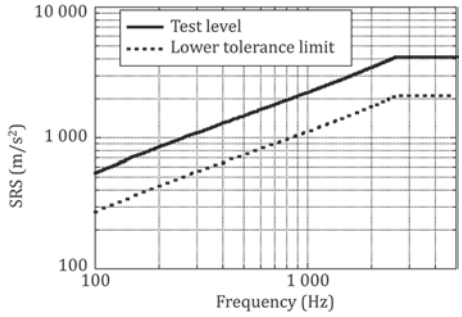
Test item	Test level and duration	Requirement	Note
Radiation (Total dose)	Total dose	10 kRad(= 100 Gy) or higher	The shielding effect due to the unit housing shall be taken into account.
	Dose rate	0,01 Gy/s or lower	
EMC	Power bus conducted interference, load induced, frequency domain	10 kHz to 10 MHz	Equivalent to MIL-STD.461 CE102[23].
	Radiated electric field emissions	10 kHz to 1 GHz or higher	Equivalent to MIL-STD.461 RE102[23].
Sinusoidal vibration	Vibration amplitude	8,4 $G_{0\text{-}p}$ or higher	
	Frequency	approximately 5 Hz to 100 Hz	
	Sweep rate	4 Oct/min up and down	
	Number of applications	Once in each axis	
Random vibration	Root mean square	13,3 Grms or higher	
	PSD		This PSD may be tailored according to the satellite mass for which the manufacturer expects to use the unit under test.
	Lower tolerance limit on PSD	0 dB	
	Duration	1 min for each orthogonal axis	
	Frequency	20 Hz to 2 000 Hz	
	Number of applications	Once in each axis	
Shock	SRS		
	Number of shocks	Once in each axis	
	Q factor	10	

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Table 5 *(continued)*

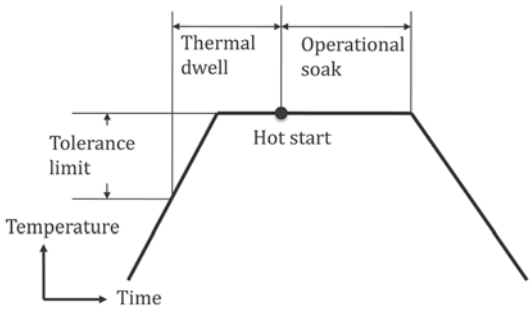
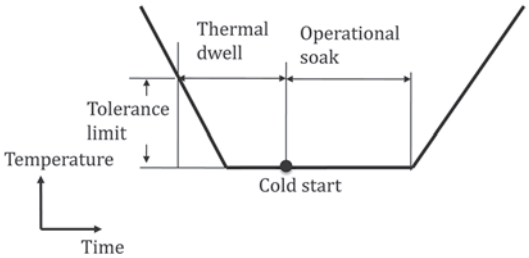
Test item	Test level and duration	Requirement	Note
Thermal vacuum (internal unit only)	Temperature range	−15 °C to +50 °C	Specify the measurement points in the datasheet.
	Number of cycles	2 or more	
	Operational soak duration	1 h or longer	
	Thermal dwell	1 h or longer	
	Tolerance limit	3 °C	
	Temperature ramp rate	+5 °C/min or slower −5 °C/min or slower	
	Chamber pressure	$1{,}0 \times 10^{-3}$ Pa or lower	
	Temperature profile at high temperature limit		
	Temperature profile at cold temperature limit		
Vacuum function	Elevated temperature	+50 °C or higher	
	Soak time at elevated temperature	60 min or longer	
Cold start	Starting temperature	−35 °C or lower	Not applicable to battery and reaction wheel.
Hot start	Starting temperature	+70 °C or higher	Not applicable to battery.

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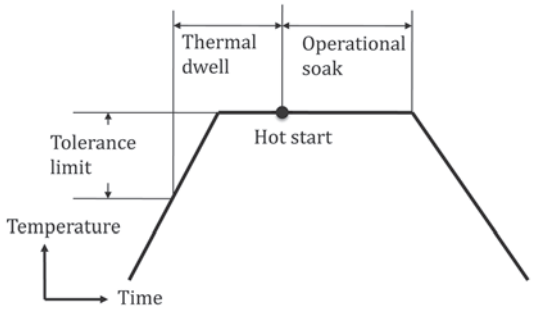
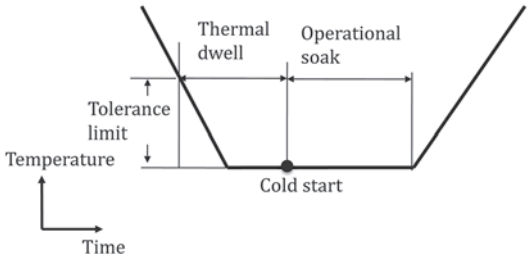
Table 5 *(continued)*

Test item	Test level and duration	Requirement	Note
Thermal cycle functional (internal unit only)	Temperature range	−15 °C to +50 °C	
	Number of cycles	2 or more	
	Operational soak duration	1 h or longer	
	Thermal dwell	1 h or longer	
	Tolerance limit	3 °C	
	Temperature ramp rate	+5 °C/min or slower −5 °C/min or slower	
	Temperature profile at high temperature limit		
	Temperature profile at high temperature limit		
Thermal cycle endurance	Temperature range	−70 °C (or lower) to +100 °C (or higher) for an external unit −25 °C (or lower) to +60 °C (or higher) for an internal unit	Not applicable to battery.
	Number of cycles	24 or more	
	Soak duration	5 min or longer	
	Ramp rate	2 °C/min or slower	
	Functional test	Only before the first cycle and after the last cycle	

8 Test requirements

8.1 Electrical interface

8.1.1 Purpose of test

The electrical interface test verifies that all interface signals are within acceptable limits of applicable performance specifications. The test is important to reduce the risk of schedule delay and cost increase due to defects found during/after integration.

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8.1.2 Test facilities and setup as basic requirements

There is no requirement.

8.1.3 Test article configuration

There is no requirement.

8.1.4 Monitoring during test

There is no requirement.

8.1.5 Test levels and duration

There is no requirement.

8.1.6 Test conditions and guidelines

The test shall be conducted before the integration of an assembly, unit, or subsystem into the next higher hardware assembly. Prior to mating with other hardware, electrical harnessing shall be tested to verify proper characteristics such as routing of electrical signals, impedance, isolation and overall workmanship.

8.2 Functional test

8.2.1 Purpose of test

The functional test verifies that the electrical and mechanical performance of the test article meet specification requirements.

In a small spacecraft project, environment tests are often done at a location outside the developer's institution and the test time is very limited. Anomalies found on-site are a major cause of schedule delay. Thorough testing at the developer's institution before moving to the test site will help identify whether any anomaly found on-site is due to system integration, a change of the testing place (from a laboratory to a vacuum chamber for example), or the actual environmental stress imposed to the test article. Troubleshooting on-site often takes an unexpectedly long time due to limitation of tools, personnel, etc. A thorough functional test after system integration at the developer's home institution will save the overall testing time and improve quality.

8.2.2 Test facilities and setup as basic requirements

The requirements in ISO 15864:2004, 7.2.2 shall apply.

8.2.3 Test article configuration

The test article shall be in the operational configuration corresponding to each function to be tested. For the system level test, all units or their simulated article shall be integrated in a flight-representative manner as much as possible. The simulated article may range from a mere mass dummy to an exact copy of flight hardware. The test may be conducted in atmosphere unless the functionality under test requires vacuum environment.

8.2.4 Monitoring during test

The requirements in ISO 15864:2004, 7.2.4 shall apply.

8.2.5 Test levels and duration

There is no requirement.

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8.2.6 Test conditions and guidelines

The requirements in ISO 15864:2004, 7.2.6 shall apply.

8.3 Mission test

8.3.1 Purpose of test

The mission test verifies that the integrated satellite can function in all the operational modes, including contingency to satisfy the specification requirements.

8.3.2 Test facilities and setup as basic requirements

Mission tests may be conducted in atmosphere. Operational modes that require vacuum environment, such as thruster firing, may be simulated by other means. Communication with the satellite may be done either through cables or RF airlink.

8.3.3 Test article configuration

The test article shall be in the operational configuration corresponding to each operational mode as much as possible.

8.3.4 Monitoring during test

The satellite conditions shall be monitored in as much detail as possible and compared with the telemetry data.

8.3.5 Test levels and duration

Nominal operational modes shall be tested long enough to detect any latent software error that manifests only after a certain run time. The duration shall be agreed upon with the customer.

8.3.6 Test conditions and guidelines

Mission tests shall include simulation of all operational modes in nominal situations, (e.g. separation, early orbital operations, mission operations and decommissioning) within the constraints of what can be simulated on the ground. The actual sequence from separation to early orbital operation shall be simulated in actual flight sequence. If hot-launch is anticipated, the modes during final countdown, launch and ascent shall be tested.

Mission tests shall also include simulation of contingency operations within the constraints of what can be simulated on the ground. The contingency operations, which are time critical, are for example those when the satellite is or could be in danger, to recover from a safe mode, to reconfigure the satellite after a major failure, etc.

8.4 Total Ionization Dose (TID) test

8.4.1 Purpose of test

TID test verifies that the test article can withstand the radiation environment imposed during the test article mission lifetime in orbit.

For system TID test, the purpose is to identify the system behaviour when the effect of radiation damage begins to appear and to derive and/or verify a possible mitigation scheme if the expected radiation damage during the mission life may exceed the design limit.

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8.4.2 Test facilities and setup as basic requirements

The test article shall be placed in a radiation test facility, such as Co^{60} (gamma ray).

8.4.3 Test article configuration

The entire test article shall be exposed to radiation such that the cumulative dose becomes as uniform as possible. The housing if any shall be removed and the circuit board shall be exposed.

For system TID test, the satellite structure and the unit housing shall be removed. The unit circuit boards shall be interconnected with each other, i.e. in the so-called flat-sat or table-sat condition and exposed to the radiation simultaneously. The units shall be made of electronics parts from flight spares. Although the boards shall be as flight representative as possible, the test article is not appropriate for flight due to cumulative damage by radiation and is regarded as a dedicated qualification test model. If some units are already proven to have enough radiation tolerance, they may be heavily shielded so that they can be used for flight. The test article may be operated by an external power supply. The power supply is controllable outside the radiation area so that the hardware can be reset by power cycling during the test without entering the radiation area.

8.4.4 Monitoring during test

The test article shall run continuously in the nominal orbit operational mode while it is being irradiated. Critical parameters to indicate are the health condition of the test article and the behaviour of the test article and these parameters shall be monitored continuously.

8.4.5 Test levels and duration

For the system TID test, the total dose during the test shall be equivalent to or greater than the expected total dose in orbit. Shielding effects due to the satellite structure shall be taken into account.

For the unit TID test, the total dose shall be at least 100 Gy. The dose rate shall be 0,01 Gy/s or less to avoid excessive positive charge build up during irradiation compared to the orbital environment where a typical dose rate is μGy/s or less. If the unit has housing, the test dose may be reduced from 100 Gy by taking into account of the shield effect.

8.4.6 Test conditions and guidelines

Before and after TID test, a complete set of functional tests shall be carried out to check the functionalities of the parts not used in nominal operation during irradiation.

8.5 Single Event Effect (SEE) test

8.5.1 Purpose of test

SEE test in this document is not intended to derive the cross-section of a single event per LET nor susceptibility of each electronic part to radiation particles. Its purpose is to understand the behaviour of the entire satellite system or an individual unit when a single event, especially single event latch-up, occurs in orbit and to verify that the designed recovery methods work as intended.

8.5.2 Test facilities and setup as basic requirements

The test article shall be placed in a radiation test facility, such as proton beam, heavy ion beam, Californium-252, etc.

8.5.3 Test article configuration

The test article shall be circuit boards and applicable flight software. The unit housing shall be removed. The satellite structure is not included. The boards shall be interconnected with each other, i.e. the so-

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