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

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Foreword

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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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For an explanation on the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see the following URL: www.iso.org/iso/foreword.html.

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

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.

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.

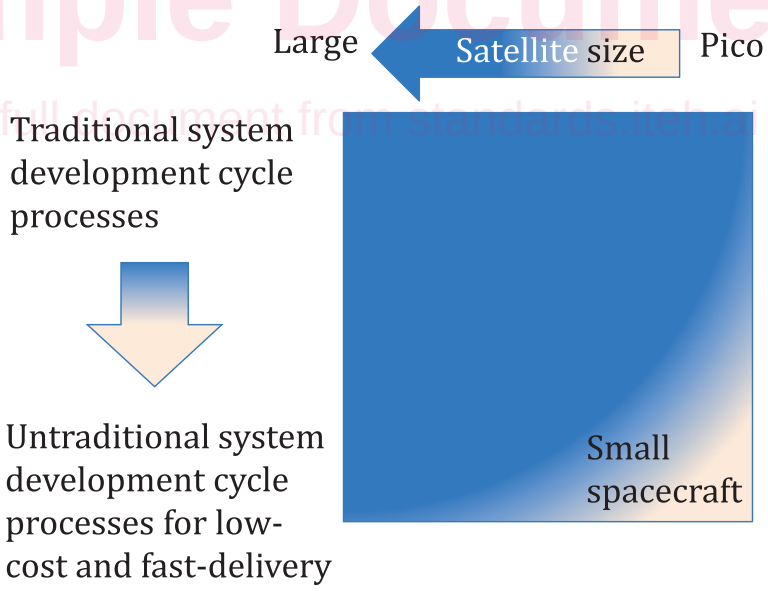

Figure 1 — Applicability of this document

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.

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.

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

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

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.

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.

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.		