Revision Strategy of Lean Satellite Testing Standard ISO-19683

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ISO-19683, "Space systems – Design qualification and acceptance tests of small spacecraft and units" was published in July 2017. It was the product of an international joint endeavor by the lean satellite (a.k.a. small satellite) community since 2011. The standard describes the minimum test requirements and test methods for lean satellite and their units. According to ISO rule, ISO-19683 has to go through a systematic review process in summer 2022. The standard has served as a guideline for lean satellite testing for the past five years. The document, however, was made based on the state-of-art knowledge in early 2010s. In the past 10 years, much wider and deeper knowledge regarding the lean satellite testing has been gained. Also, in early 2010s, most of lean satellites was still one of a kind, dealing with a single satellite only. But, nowadays, we see many constellation programs especially in the area of CubeSats. As a standard should be a living document, the testing standard has to be revised to reflect those changes surrounding lean satellites. In June 2022, Kyushu Institute of Technology launched a new project to revise the standard. In the revision, we consider the two points; (1) reflecting the state-of-art knowledge based on the experience of the past 10 years, (2) adding a chapter regarding testing of constellation satellite programs. For the second points, we do basic researches on how to improve the efficiency of testing multiple satellites simultaneously and how to formulate a logic of skipping some tests for satellites of identical design.

Key Words: lean satellite, testing, constellation, standard, reliability

1. Introduction

Lean satellite is a satellite that utilizes non-traditional, risk-taking development and management approaches – with the aim to provide the satellite value to the customer and/or the stakeholder at low-cost and without taking much time to realize the satellite mission[1]

An activity to make an international standard of lean satellites that of course included CubeSats started in year 2011. The standard aimed at answering several needs. The first and biggest one was to improve reliability of lean satellites. It was clear that verification and testing processes needed improvements. There were already several testing standards available, such as ECSS-E-ST-10-03C[10], NASA-STD-7002A[11], GSFC-STD-7000[12]. Even an ISO standard of satellite system and unit testing existed as ISO-15864[13]. But applying those standards to lean satellites was not a solution because of the increased cost and time necessary. In 2011, it was very chaotic about what tests were needed, if needed what test levels were appropriate, and what tests were not needed. There was a need of written guidelines about testing lean satellites to improve their reliability while keeping the nature of low-cost and fast-delivery.

The second need was related to trading of lean satellite components. In 2011, lean satellite components were already widely traded on Internet. To many lean satellite developers, the components looked attractive in terms of price and the time to be saved by using the commercial product instead of building the components from scratch. There was little guarantee, however, to those products. The test history was not transparent to the buyers. Flight heritage did not guarantee that the products were made of the same parts. The standards aimed at giving the minimum assurance that the products went through the known environment tests whose test conditions were well documented.

In May 2011, an idea of the new standard was presented at ISO/TC20/SC14 that handled all spacecraft hardware related standards. The first reaction of the committee was "CubeSats are students' toy. They are polluting orbits with debris. Do something". There was a need to form a group to support the initiative. Thanks to the Japanese government's funding support, a workshop was hosted every year to discuss the testing standard. Later this group grew to discuss wider aspects of small satellites and led to IAA (International Academy of Astronautics) study of "Definition and Requirements of Small Satellites Seeking Low-Cost and Fast-Delivery", which proposed a concept of "lean satellite" in its final report published in 2017 [1]. The testing standard was finally published as ISO-19683 "Space systems - Design Qualification and Acceptance Tests of Small Spacecraft and Units" in July 2017.

The scope of ISO-19683 is written as "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." The word of "small spacecraft" is used in the standard as a result of compromise made to have the consensus among the ISO member countries. In Introduction, the document defines "small spacecraft" as "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." Figure 1 shows the target of ISO-19683.

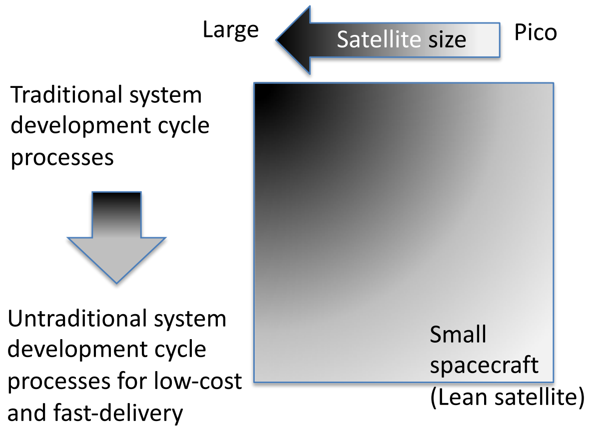

Fig. 1. Applicability of ISO-19683

Although the scope says "commercial small spacecraft", the document can be used for any kind of satellites such as academia, civil, and others. The word of "commercial" was placed because ISO standards aim at promoting worldwide trade of goods and services where the commercial satellites would receive the most benefit. The standard can be used as a guideline for the newcomers to the space sector, as a common document in an international satellite project, or for other purposes.

ISO-19683 can be regarded as a tailoring guide of ISO-15864, "Space systems - General test methods for space craft, subsystems and units". ISO-15864 is intended for traditional satellite whose size can be as big as possible. Many of test requirements are the same between CubeSats and the traditional satellites. Therefore, ISO-19683 simply refers ISO-15864 whenever possible to avoid duplication. Table 1 lists the table of contents of ISO-19683.

Table 1. ISO-19683 Table of contents.

1	Scope
2	Normative references
3	Terms and definitions
4	Symbols (and abbreviated terms)
5	General Requirements
5.1	Tailoring
5.2	Qualification test
5.3	Acceptance test
5.4	Proto-flight test
5.5	Retest
5.6	Test documentation
5.7	Test conditions, tolerances and accuracies
5.8	Functional test
5.9	Design, verification and testing philosophy
6	Satellite System Tests
6.1	Test items
6.2	Test level and duration
7	Unit Tests
7.1	Test items
7.2	Test levels and duration
8	Test Requirements
8.1	Electrical Interface
8.2	Functional test
8.3	Mission test
8.4	Total Ionization Dose (TID) Test
8.5	Single Event Effect (SEE) Test
8.6	Spacecraft Charging Induced Electrostatic Discharge (ESD)
8.7	Electromagnetic Compatibility (EMC) Test
8.8	Deployment
8.9	Magnetic Field Test
8.10	Antenna Pattern Test
8.11	Alignment Measurement
8.12	Physical Property Measurement
8.13	Launcher/Spacecraft interface test
8.14	Quasi-Static Load Test
8.15	Modal Survey
8.16	Sinusoidal Vibration Test
8.17	Random Vibration Test
8.18	Shock Test
8.19	Thermal Balance Test
8.20	Thermal Vacuum Test
8.21	Functional test in vacuum
8.22	Cold/Hot start
8.23	Thermal Cycle Functional Test
8.24	Thermal Cycle Endurance Test
8.25	Pressure Test
8.26	Leakage Test
8.27	Micro-vibration Test
8.28	Burn-In and Wear-In Test
8.29	End-to-End Mission Simulation
8.30	Bake Out and Outgas
8.31	Tailoring and waivers Guide
Annex A	Design, Verification and Testing Philosophy of Small Spacecraft
Annex B	Test Selection Logic Flow
Annex C	Environment stress screening and Burn-in
Annex D	Tailoring and waivers guide
Annex E	Basis of Test Levels and Duration
Annex F	Thermal vacuum or thermal cycle?

ISO-19683 describes the requirements for qualification test (QT), acceptance test (AT) and proto-flight test (PFT) at unit (component) level and system level. For system level test, the meaning of QT, AT and PFT are the same as the ones for traditional satellites, which is defined in ISO-15864. For unit level test, the meaning of AT and PFT are the same as the ones for traditional satellites, which is defined in ISO-15864.

The unit level QT described in ISO-19683, however, is different from those described in ISO-15864. The unit QT in ISO-19683 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 ISO-19683 does not include proper margin against the maximum predicted environment stress, which depends on each satellite. ISO-19683 provides quantitative requirements for the test level and duration of unit QTs. The unit QT levels and durations specified in ISO-19683 is the minimum level to be satisfied as long as they are sold as a commercial product for space. In another word, if the product fails the unit QT in ISO-19683, it shouldn't be sold as "a satellite unit". Annex-E of ISO-19683 gives rationales for the unit QT test levels and durations.

According to ISO rule, every international standard has to go through the systematic review (SR) process once every five years. Therefore, ISO-19683 has to go through SR in summer 2022. The standard has served as a guideline for lean satellite testing for the past five years. The document, however, was made based on the state-of-art knowledge in early 2010s. In the past 10 years, much wider and deeper knowledge regarding the satellite testing has been gained. In those days, many commercial components still had little flight heritage. But nowadays, many components have cumulated flight heritage in various missions and CubeSat platforms are being sold offering the flight proven satellite bus to those who want to fly their mission payloads quickly. Also, in early 2010s, most of lean satellites was still one of a kind, dealing with a single satellite only. But, nowadays, we see many constellation programs especially in the area of CubeSats. Figure 2 shows the launch trend of 1-10kg satellites which are mostly categorized as lean satellites, especially CubeSats. In 2013, we started seeing the rise of CubeSat constellations, especially Planet Lab. But the majority was still single satellite program.

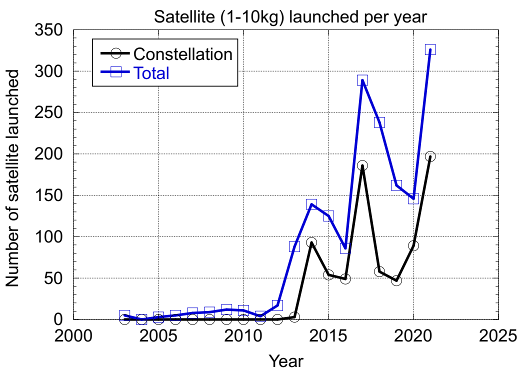

Fig. 2. Lean satellite launch trend

As a standard should be a living document, the testing standard has to be revised to reflect those changes surrounding lean satellites. In June 2022, Kyushu Institute of Technology (Kyutech) launched a new project to revise the standard. In the revision, we consider the two points; (1) reflecting the state-of-art knowledge based on the experience of the past 10 years, (2) adding a chapter regarding testing of constellation satellite programs. For the second points, we do basic researches on how to improve the efficiency of testing multiple satellites simultaneously and how to formulate a logic of skipping some tests for satellites of identical design. The purpose of the present paper is to give the overview of the new project.

2. Revision strategy

In the revision, we plan to add a new chapter 7, "Constellation program test" or "Multiple satellites program test". The chapter is not limited to constellations with tens, hundreds, or thousands satellites in multiple orbital planes to provide frequent coverage. It also targets a program that uses multiple satellites of identical design, such as formation flights.

Many cases in those programs do a pathfinder mission in orbit before flying many more satellites. The pathfinder mission is to check the overall satellite design, AIT (assembly, integration and testing) procedure, operability, and others in the real flight environment. The pathfinder mission is done because jumping to the full operation without it poses the unacceptable risks of losing multiple satellites during the full operation. The pathfinder mission may be divided into further multiple stages. The first satellite is designed and built by the satellite designers themselves those who know the satellite very well requiring little documentation to do AIT. In orbit demonstration of the first satellite validates whether the satellite system meets the customer requirements. The second satellite is built by the AIT technicians following the AIT procedure written by the satellite designers or the AIT engineers based on the experience of the first satellite. In orbit demonstration of the second satellite validates the AIT procedure. Then from the third satellites, multiple satellites can be built by the AIT technicians following the flight proven AIT procedure.

In the first path-finder missions, a full set of testing will be done before the launch to make sure that the satellite works in orbit. Based on the flight result, the second path-finder mission, if any, may skip some of the testing items or may modify the test levels and conditions. In the later generations where the identical satellites are produced in series, some test items may be skipped, or only a limited number of satellite may be tested as samples, or the test levels and conditions may be relaxed further. In the current version of ISO-19683, a table shown in Fig.3 are included as the system test requirement. We will add a table similar to this for each of pathfinder, second pathfinder, operational generations, instead of QT, AT, and PFT. We will also add unit AT requirements for the case where multiple units of the identical design are delivered for a constellation program.

In the current version of ISO-19683, Chapter 5 "General Requirements" assumes a satellite program made of single satellite. In this chapter we will add the constellation test strategy. Chapter 8 "Test Requirements" also assumes a single satellite. We will add constellation specific test requirements if any, e.g. testing multiple satellites together. In addition, we will revise the overall standard based on the knowledge cumulated over the past 10 years.

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.		

Fig. 3. System test requirements listed in ISO-19683.

3. Research Items

While we worked on ISO-19683 before, we did research on lean satellite testing. Especially, to derive the rationales used to define the unit QT levels and durations listed in Chapter 7.2 and the test requirements in Chapter 8. Those rationales are written in Annex E and F.

When we revise ISO-19683, we will do some researches. The purpose of the research is to reduce the time and cost to build lean satellite constellation. We reflect the research results to the standard revision. The following two items will be studied.

1. How to test multiple lean satellites and/or units effectively
2. How to judge whether we can waive or relax the test conditions when we test multiple satellites and/or units of the same design.

We will investigate how much time is spent in each test, such as vibration, shock, thermal vacuum, communication, etc., and which process of the tests is consuming the time. We will identify the test items to be done to all the satellites even if they use the identical design and study how to carry out the tests efficiently. Regarding the test items that can be skipped, we collect the evidence data to support the logic of skipping the test.

Table 2 lists the satellites Kyutech recently developed. Since 2012, we have put 21 satellites made of 11 projects into orbit. Especially BIRDS satellite projects release multiple satellites of identical designs into ISS orbit. BIRD satellites are student educational satellites. Therefore, although the design is inherited from the earlier generations, every time we build EM and repeat the test as training. KITSUNE is a technology demonstration satellite and involves three dedicated research staffs. Most of the members have experience of at least one satellite project. Although the delivery times except BIRDS-3 is nearly 2 years, actual satellite development was 20 months for BIRDS-4 and KITSUNE. The delivery was delayed because the frequency license was delayed. BIRDS-5 took nearly two years because the satellite development was done during the pandemic.

Table 2. Recent Kyutech satellites

	BIRDS-3	BIRDS-4	KITSUNE	BIRDS-5
CubeSat size and number of satellites	1Ux3	1Ux3	6U	1Ux2, 2Ux1
Team size (person)	8	14	18	14
External Team collaborators			4	
Launch Method	ISS	ISS	ISS	ISS
Development Phase	BBM EM EM-2 FM	BBM EM FM	EM FM	BBM EM FM
Number of Missions	4	9	8	9
Testing time (person days)	208	285	609	852
From Kick-off to Delivery time (Month)	16.5	23	26.7	23
Success level (1-5)	5	4	Ongoing	Not launched yet

Table 3. Days spent in satellite system tests (EM(QT) and FM(AT))

	BIRDS-3	BIRDS-4	KITSUNE	BIRDS-5
Vibration	4	8	4	9
Thermal vacuum	8	15	11	18
Thermal cycle	N/A	N/A	N/A	N/A
Radio test in an anechoic chamber	21	30	16	12
Long-distance Communication	3	4	3	0
Functional test (mission simulation)	13	20	45	26
Antenna deployment	10	20	4	9
Attitude control hardware-in the-Loop	4	4	13	12
Long-duration operation	55	44	31	14
Others	2	6	36	12
Total (days)	120	151	163	112

Table 3 lists the number of days spent in systems tests (EM and FM, or QT and AT). From Table 3, we can see that a significant amount of time is spent in communication and functional test rather than environment test such as vibration and thermal vacuum. It was because the satellite bus design was already flight proven at least in ISS orbit. The longest operation time was more than 2 years. Based on our experience, we think the following tests are very important to assure the mission success when we already have certain flight heritage in the satellite bus.

- To check the items where individual difference among the satellite is important.
  - Radio test; because loss (e.g. cable, connector, etc.) and noise needed for link budget can be different for each satellite
  - Fit-check; especially for CubeSat as the slight

skewness of the satellite structure may prevent satellite from fitting into POD.
    - Calibration of attitude sensors; especially magneto-sensors where the effect of residual magnetic field matters significantly
- To check the items that may become a single point of failure
    - Solar panel output; Confirm satellite telemetry by illuminating the panel by sun-simulator after attached to the satellite
    - Antenna deployment; Confirm that the antenna can be deployed under the worst of the worst conditions

There are various test items that have to be done to all the satellites regardless its production numbers from the safety point of view. Currently, screening of all the flight batteries are required for the case of ISS launch. Vibration test is done to all the satellites. For those tests, finding an efficient method of testing multiple satellites is important. For the case of vibration test, the majority of the testing time is spent in preparation, such as preparing the documents (test plan, test procedure, test report) and attaching accelerometers. One point we should discuss is that whether we can suffice the purpose of workmanship check by simply measuring the natural frequency of each satellite by a method other than vibration shaker. Another point is that it would soon exceed the limit of human capability to check the test report one by one once the number of satellites becomes more than 10. A computer aided method such as machine learning may become necessary to detect the fault from numerous graphs of Power Spectrum Density (PSD).

There are many other research items. We will continue working and share the results within the lean satellite community.

4. Conclusion

ISO-19683, "Space systems – Design qualification and acceptance tests of small spacecraft and units" was published in July 2017. It was the product of an international joint endeavour by the lean satellite community since 2011. The standard describes the minimum test requirements and test methods for lean satellite and their units.

According to ISO rule, every international standard has to go through the systematic review (SR) process once every five years. Therefore, ISO-19683 has to go through SR in summer 2022. The document, however, was made based on the state-of-art knowledge in early 2010s. In the past 10 years, much wider and deeper knowledge regarding the satellite testing has been gained. Also, in early 2010s, most of lean satellites was still one of a kind, dealing with a single satellite only. But, nowadays, we see many constellation programs especially in the area of CubeSats.

In June 2022, Kyushu Institute of Technology launched a new project to revise the standard. In the revision, we consider the two points; (1) reflecting the state-of-art knowledge based on the experience of the past 10 years, (2) adding a chapter regarding testing of constellation satellite programs. For the second points, we do basic research on how to test multiple lean satellites and/or units effectively and on how to judge whether we can waive or relax the test conditions when we test multiple satellites and/or units of the same design. The research results will be shared and discussed in the lean satellite community.

Based on the new findings, ISO-19683 will be revised. The draft will be discussed widely in the lean satellite community. Currently, we plan to publish the revised standard by March 2026.

Acknowledgments

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