



BSI Standards Publication

Space engineering - Testing guidelines

National foreword

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Space engineering - Testing guidelines

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European Foreword

This document (CEN/CLC/TR 17603-10-03:2022) has been prepared by Technical Committee CEN/CLC/JTC 5 "Space", the secretariat of which is held by DIN.

It is highlighted that this technical report does not contain any requirement but only collection of data or descriptions and guidelines about how to organize and perform the work in support of EN 16603-10-03.

This Technical report (TR 17603-10-03:2022) originates from ECSS-E-HB-10-03A.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. CEN [and/or CENELEC] shall not be held responsible for identifying any or all such patent rights.

This document has been prepared under a mandate given to CEN by the European Commission and the European Free Trade Association.

This document has been developed to cover specifically space systems and has therefore precedence over any TR covering the same scope but with a wider domain of applicability (e.g.: aerospace).

Introduction

Testing is an important part of a Space Project, because of its impact on cost and because is the most effective way to demonstrate a product functionalities and performances.

As such, this Handbook is of outmost importance in defining how the requirements can be implemented into the verification approach and in providing “real life” experience and examples in order to have an effective application into the test execution.

In order to meet this objective, the WG have tried, in preparing this Handbook, to be as exhaustive as possible in providing methods and techniques, as well as examples, in a punctual one-to-one requirement versus guideline approach.

The WG also recognized that this approach, even if punctually exhaustive, provided in most cases an unstructured definition of the tests as a whole giving a leopard spots information which may not be useful in preparing and conducting a test.

As a consequence, the WG have decided to complement the main body of the Handbook with Annexes where a structured and comprehensive test organization has been defined and described.

In those cases, testing people can find how a test is prepared, applied and executed in terms, for example, of test setup, test configuration, used instrumentation and test facilities/equipment, test preparation suggestions, safety rules to be considered, data acquisition and reporting content, together with pictures, tables and sketches of real cases,

This approach has allowed, in particular for Mechanical, Microvibration and Integrity Tests as well as for Alignment and PIM tests, to have in one shot a complete and structured set of guidelines easing the implementation of the requirements of such tests.

It is to be underlined that some of this material comes from the ECSS-E-HB-32-26 “Spacecraft mechanical load analysis handbook”, which contained a lot of information about mechanical testing.

It is worthy to pay attention that the Annexes of this Testing Guidelines do not correspond to the Annexes of the Testing Standard.

Moreover, this handbook only applies for the Revised version of the ECSS-E-ST-10-03 Standard (ECSS-E-ST-10-03C Rev.1, 31 May 2022).

1

Scope

This handbook provides additional information for the application of the testing standard ECSS-E-ST-10-03 to a space system product.

This handbook does not contain requirements and therefore cannot be made applicable. In case of conflict between the standard and this handbook, the standard prevails.

This handbook is relevant for both the customer and the supplier of the product during all project phases.

To facilitate the cross-reference, this handbook follows as much as practical, the structure of the standard even if, as written in the Introduction, some tests are described in the Annexes to allow a better comprehensive view.

Where test material is already covered in other ECSS handbook, this document refers to them instead of duplicating the information, this is the case of ECSS-E-HB-32-25 "Mechanical shock design and verification handbook" and the various parts of ECSS-E-HB-31-01 "Thermal design handbook".

As the Standard applies to different products at different product levels of the space segment, the space segment equipment and the space segment elements. In the testing standard the requirements applicable to each level are addressed in different chapters clearly identified. The standard clearly states that it is not applicable to other segment (launch and ground) as well as software; as a consequence, no pre-tailoring matrix is needed.

Moreover, as per testing standard, this handbook does not contain guidelines for constellation programmes.

Testing aspects are derived from the verification approach covered in the ECSS-E-ST-10-02 and in its corresponding handbook ECSS-E-HB-10-02.

The application of the requirements of the standard to a particular project is intended to result in effective product verification and consequently to a high confidence in achieving successful product operations for the intended use, in this respect this handbook has the goal to help reaching these objectives.

References

EN Reference	Reference in text	Title
EN 16601-00-01	ECSS-S-ST-00-01	ECSS – Glossary of terms
EN 16603-10-02	ECSS-E-ST-10-02	Space engineering - Verification
EN 16603-10-03	ECSS-E-ST-10-03	Space engineering - Testing
EN 16603-31	ECSS-E-ST-31	Space engineering - Thermal control general requirements
EN 16603-31-02	ECSS-E-ST-31-02	Space engineering – Two-phase heat transport equipment
EN 16603-32-02	ECSS-E-ST-32-02	Space engineering – Structural design and verification of pressurized hardware
EN 16603-33-11	ECSS-E-ST-33-11	Space engineering - Explosive subsystems and devices
EN 16603-35-02	ECSS-E-ST-35-02	Space engineering - Solid propulsion for spacecrafts and launchers
EN 16603-ST-40	ECSS-E-ST-40	Space engineering - Software
TR 17603-10-02	ECSS-E-HB-10-02	Space engineering - Verification guidelines
TR 17603-20-01	ECSS-E-HB-20-01	Space engineering - Multipactor handbook
TR 17603-20-07	ECSS-E-HB-20-07	Space engineering - Electromagnetic compatibility handbook
TR 17603-31-01 to TR 17603-31-16	ECSS-E-HB-31-01 (all parts)	Space engineering – Thermal design handbook
TR 17603-32-25	ECSS-E-HB-32-25	Space engineering - Mechanical shock design and verification handbook
TR 17603-32-26	ECSS-E-HB-32-26	Space engineering - Spacecraft mechanical loads analysis handbook
EN 16602-10-09	ECSS-Q-ST-10-09	Space product assurance – Nonconformance control system
EN 16602-70-01	ECSS-Q-ST-70-01	Space product assurance – Cleanliness and contamination control
EN 16602-70-05	ECSS-Q-ST-70-05	Space product assurance – Non-destructive testing
EN 16602-80	ECSS-Q-ST-80	Space product assurance – Software product assurance
	NASA-STD-7012	Leak test requirement
	ATS paper_MATED Improvement (October 2018)	MATED (Model And Test Effectiveness Database) Improvement and Added Value on Industry

	MTF.AIDT.TN.2168, Issue 1, Rev.1 (3 March 2020)	Dynamited Final Report
	ECSSMET 2016 (article)	DYNAMIC TESTS, WHAT'S BEHIND THE CURVES ?
	MSG-NNT-SE-TN-0742 (28 October 1996)	Notching guidelines for mechanical test
	TASI-ASE-ORP- 0006_Iss.01 (20 October 2014)	Analysis of Spacecraft qualification Sequence & Environmental Testing (ASSET)
	TASI-ASE-ORP-0009_01 (3 October 2016)	Analysis of Spacecraft qualification Sequence & Environmental Testing (ASSET+)

Terms, definitions and abbreviated terms

3.1 Terms from other documents

- a. For the purpose of this document, the terms and definitions from ECSS-S-ST-00-01 apply, in particular for the following terms:
 - 1. **space segment element**
 - 2. **space segment equipment**
 - 3. **thermal balance test**
- b. For the purpose of this document, the following terms and definitions from ECSS-E-ST-10-03 apply:
 - 1. **dwelling time**
 - 2. **temperature cycle**
- c. For the purpose of this document, the following terms and definitions from ECSS-E-ST-31 apply:
 - 1. **acceptance temperature range**
 - 2. **design temperature range**
 - 3. **minimum switch-on temperature**
 - 4. **predicted temperature range**
 - 5. **qualification temperature range**
 - 6. **radiative sink temperature**
 - 7. **temperature reference point (TRP)**

3.2 Terms specific to the present document

3.2.1 dummy

simplified physical representation of an item.

NOTE Level of representativeness of a dummy is to be defined case by case taking into account the objectives of the tests which it will be used for. Particular points which are to be assessed could be interfaces, volume, physical properties (Mass, COG, MOI), thermal, electrical, functional and dynamic behaviour, materials....

3.3 Abbreviated terms

For the purpose of this document, the abbreviated terms from ECSS-S-ST-00-01 and the following apply:

Abbreviation	Meaning
AC	actuator control
AFT	allowable flight temperature or abbreviated functional test
AIM	active inter modulation
AIT	assembly, integration and test
AIV	assembly, integration and verification
AOCS	attitude and orbit control subsystem
AOCS SW	attitude and orbit control subsystem software
ARF	alignment reference system
AVB	avionics verification bench
CATR	compact antenna test range
C&C	characterization and calibration
CCR	corner cube reflector
CCS	central checkout system
CDR	critical design review
C&CCP	cleanliness and contamination control plan
CFD	(attitude and orbit control subsystem) closed loop functional test - design
CLT	closed loop test
CoG	centre of gravity
CP	common (reference) point
CSW	central software
DC	direct current
DHS	data handling system
DRD	document requirements definition
DM	development model
DML	declared material list
DMS	data management system
DUT	device under test
EED	electro explosive devise
EEE	electrical and electronic equipment
EFM	electrical functional model
EFT	electrical functional test
EGSE	electrical ground support equipment
EIRP	equivalent isotropic radiated power

Abbreviation	Meaning
ELI	electrical integration test
EMC	electromagnetic compatibility
EPT	equipment polarity test
E2EPT	end-to-end polarity test
EQM	engineering qualification model
ESD	electrostatic discharge
ETB	engineering test bench
FDIR	failure detection isolation and recovery
FFT	full functional test
FFT-A	full functional test - acceptance
FFT-D	full functional test - design
FFT-Q	full functional test - qualification
FFT-W	full functional test - workmanship
FGSE	fluid ground support equipment
FM	flight model
FMD	force measurement device
FT	functional test
FVB	functional validation bench
GPS	global positioning system
GSE	ground support equipment
HFE	human factor engineering
HSVF	hardware software verification facility
HVAC	high vacuum
ICD	interface control document
I/F	interface
IPA	isopropyl alcohol
IR	infrared
IS	interface simulator
ISST	integrated subsystem test
IST	integrated system test
ITP	interface temperature point
IUT	item under test
LEO	low Earth orbit
LNA	low noise amplifier
LVDT	linear variable displacement transducer
MDP	maximum design pressure

Abbreviation	Meaning
MFT	mechanical functional test
MFW	mechanical functional test- workmanship
MGSE	mechanical ground support equipment
MLI	multi-layer insulation
MoI	moment of inertia
MOS	margin of safety
MRC	master reference cube
MRF	mechanical reference system
MT	mission test
NCR	nonconformance report
NDI	non-destructive inspection
NEA	non-explosive actuator
NRB	nonconformance review board
NSVB	numerical software validation facility
OBC	on board computer
OGSE	optical ground support equipment
PCB	printed circuit board
PFM	protoflight model
PISA	payload interface simulator assembly
PDR	preliminary design review
P/F	platform
PIM	passive intermodulation
PIMP	passive intermodulation product
P/L	payload
ppm	parts per million (10^{-6})
P/N	part number
PSD	power spectral density
PT	performance test
PTR	post test review
QA	quality assurance
QM	qualification model
QS	quasi static
RE	radiated emission
RF	radio frequency
RFD	request for deviation
RFT	reduced functional test

Abbreviation	Meaning
RIU	remote interface unit
rpm	round per minute
RTB	real time testbed
RTS	real time simulator
Rx	receiver
SAR	synthetic aperture radar
scc	standard cubic centimeter
SDE	software development environment
SFT	system functional test
SMC	space and missile systems center
SP	sensor processing
STM	structural thermal model
RMS	root mean square
S/C	spacecraft
SCOE	special check out equipment
SDE	software development environment
SHF	super high frequency
SMP	simulation model portability
SPL	sound pressure level
RMS	root mean square
S/N	serial number
SRDB	system, spacecraft or satellite reference data base
SVF	software validation (verification) facility
SVFDEV	software validation (verification) facility development
SysTF	system test facility
S/W	software
TCS	thermal control subsystem
TH	theodolite
ThM	thermal model
TM/TC	telemetry/telecommand
TRB	test review board
TRF	theodolite reference system
TPRO	test procedure
TRP	temperature reference point
TRPT	test report
TRR	test readiness review

Abbreviation	Meaning
TSPE	test specification
TT&C	telemetry, tracking and command
TVTB	thermal vacuum thermal balance
Tx	transmitter
UHF	ultra high frequency
VCD	verification control document
VM	virtual model
VP	verification plan

General requirements

4.1 Test programme

4.1.1 Test programme basics

The text in this clause 4.1.1 covers requirements 4.1a to 4.1e in ECSS-E-ST-10-03.

The set-up of an appropriate test programme for a space mission is a crucial element for the whole project. With a baseline test programme, as usually established during the Phase B of a project, some cornerstones are set, which do have a major impact on costs, schedule and risk. The testing starts on parts level (which is not addressed herein; see ECSS Q-60 and Q-70 branches), is continued at space segment equipment level and finalized at space segment element level with some extensions to space system level (which is not addressed herein). The challenge for the correct establishment of a test programme along the verification plan is to find the right combination of:

- **Completeness:** no test repetitions if not intended, but no forgotten test aspects. Remark: The VCD is treated to give the baseline number of tests only. Other tests can be necessary for validation purpose.
- **Simplicity:** do not intend to perform complicated tests, where simple methods provide adequate results.
- **Timing:** a test can be worthless or increase programmatic risks, even if performed correctly, but at the wrong time in the sequence of tests.
- **Meaningfulness:** always put in question if the test is meaningful in the way and at the time it is planned.
- **Representativeness:** Test like you fly serves as a general rule for this.
- **Innovation:** especially unique designs and instruments require innovative concepts for tests.

The goal in establishing a test plan, developed on the basis of the verification plan (including model philosophy and what tests are planned on which model), is to reach a complete test programme, optimized with respect to cost, planning and risk. In particular, the test plan mitigates the risk of late problems discovery and the risk of in-orbit failures especially during the infant mortality period. Often, there is no perfect solution, hence a compromise is necessary, keeping this approach in mind. The test plan at equipment level usually is straightforward. At space segment element level, the test plan is generally more complex. In particular, at space segment element level major issues to be clarified are typically:

- Is the test programme appropriate to verify compliance to the requirements?
- What is the most appropriate approach (how to inject failures/failure simulations) to test FDIR issues?
- Is the baseline environmental sequence of tests the best compromise for the specific project?
- Are there any tests missing to become confident with the product apart from requirements closure?
- Does the test programme fit to cost and schedule?

- Has the programme been checked for possible overtesting issues?
- How robust is test programme towards late deliveries of items (e.g. instruments, equipment)?
- Retesting or delta-testing: has an approach been defined to deal with these issues in case of failures, sequence changes or redesign/rework/retro-fits?
- Do we need to identify Regression testing?

These questions are addressed during PDR (draft test plan available) and properly answered before CDR (agreed test plan).

The verification plan, establishes a general approach on the verification (not only by test), which puts some boundaries to the development of the test plan. The test plan defines the implementation and the details of the “how-to” (see ECSS-E-ST-10-02 “Verification” and ECSS-E-HB-10-02 “Verification guidelines”).

As said above, establishing an appropriate test programme at space segment element level deals with complex interactions between the different equipment and subsystems. Examples for these interactions, which are taken into consideration when setting up the test programme, are:

- Availability of the “right” software at the time of the test: for schedule reasons, software coding is a parallel process to system integration and testing. The sequence of tests takes into account the capability of the software version at the point in time for a specific test, so an alignment between the sequence of tests and the software development schedule is mandatory.
- FDIR is probably the most complex test issue to deal with. The FDIR concept is implemented in software and hardware. The response to each failure taken into account in the FDIR concept is verified. Therefore, you find a way for simulating these failures (different and probably innovative means need to be found!) and you assure that even if the FDIR reaction is either not correctly implemented or if there is a mistake in the concept, that flight hardware is not damaged in any case.
- Dealing with deviations from the baseline: During the testing phase, adaptations and modifications of the baseline test flow becomes necessary for various reasons, like, for example, late deliveries, unavailability of facilities, failures, and NCR’s with impact on the flow. Often it is decided if a test can take place even if the test setup is not as complete as expected before. An agreement between customer and contractor is found, and this is easier if two precautions have been taken: a clear retesting strategy is agreed, and a delta-testing strategy is in place. See also Test Management in clause 4.3.
- The AIT plan is usually produced by the AIT team taking into account several inputs:
 - Type of test required by the verification plan for the various hardware model,
 - Facilities intended to be used,
 - GSE to be used.
- In general, the test specification is produced by the engineering team taking into account higher level specifications (i.e. launcher requirements, environment specification) and detailed technical analysis of the item under test.
- The AIT team derives the test procedure from the test specification in close contact with the engineering team that produces the test specification.
- In some cases, the engineering team defines test requirements and the AIT team generates a detailed test specification to be reviewed by engineering.
- The test preparation and execution do take into account safety aspect as defined in the project safety plan to ensure protection of the personnel, facility and flight hardware.

- Some tests, especially the Reduced Functional Test (RFT), are performed several times during the AIT in particular before, during and after environmental tests or transportation. The objectives of these tests are to check the IUT is working well and also to detect any variation (drift) of a parameter/result/measurement. Relevant parameters are to be identified such which are to be followed during the AIT timeline as a sign of evolution and possibly degradation (e.g. RW friction torque).

4.1.2 Specific tests

Some tests are specific for the mission. Depending on the payload and the mission, and especially applicable for scientific missions, test methods are developed to verify the function and performance of the spacecraft. Examples for such tests are Thermal Balance tests with sun simulation of several solar constants for mercury or solar missions (Bepi Colombo, Solar Orbiter), specific deployment tests (James Webb Space Telescope), planetary environment tests for probes sent to a planetary or Moon surface, optical instruments with high temperature stability and high dimensional stability, landing tests... Common for all these tests are a high grade of innovation, usually high effort in preparation and high costs, and they are often a crucial element in the verification process. In the beginning of a project these tests are hard to calculate in terms of hours and costs. Therefore, a special focus is put on the identification and the proper preparation of such tests early in the project.

Identification: In fact, such tests are identified during a phase B of a project and treated in sufficient detail during the proposal preparation for the phases C and D. Sufficient detail means to establish a baseline for the “how to”, to identify the test facilities (and needed upgrades, if applicable), the test duration and therefore a good estimation for expected costs. Otherwise, such tests can run out of control during the project execution. Preparation: achievement of early agreements with the test facility, supervision of the test in the project risk register, early identification of long lead items and time estimations for facility upgrades and developments, and a proper milestone planning are mandatory. However, once these tests are performed, they are usually followed by a big audience and treated as a cornerstone of the project.

4.1.3 Risks during testing

Even for tests meant as non-destructive, each test is putting a risk on the item under test. Therefore, tests without gaining more confidence are avoided. If the test article does not pass the test or, in extreme, is damaged as a result of a non-compliance to the requirements, then the test has fulfilled its objective.

But putting a risk on the test specimen means that there is a probability to damage it by not performing the test in the right way. The risks are of different nature:

- If the test is putting stress on the specimen beyond the required limits, it can be physically damaged (e.g. vibration test, thermal test).
- If the specimen is not commanded in the right way, the commands can cause a damage.
- If the specimen is handled with MGSE, there is a risk of damage by handling (lifting devices, deployment support MGSE...).

Before performing a test, the risks are clearly identified and proper mitigation actions are implemented. These mitigation actions are:

For a): Ensure that the stress put on the specimen is the lowest possible without putting the verification into question (e.g. vibration levels and notching criteria carefully derived). In no case any qualification levels of units may be exceeded, including test tolerances. Automatic test aborts on facility level are implemented (prepared and rehearsed), if sensors indicate in-situ level exceeding (specifically vibration

testing). A manual test abort is possible in cases where damage to the item under test can occur. To ensure the above, the whole control and data acquisition chain is verified by dedicated tests (i.e. dry runs, pre-tests for vibration tests). The overall test approach is validated by predictions derived from analysis.

For b): Pre-testing of scripts on non-flight hardware (e.g. engineering model) is applied wherever possible. Commands known as potentially risky (e.g. check of pyro ignition lines, release mechanisms) require special treatment, attention and a design with proper safe and arm functions embedded in both flight hardware and test equipment.

For c): Assure proper training of the crew. Assure that the MGSE acceptance is done according to applicable standards, e.g. proof load tests. Set up handling procedures, involve experts for specific handling activities where own experience is missing.

These risks during testing can and are minimized. However, they cannot be reduced to zero. Therefore, the whole test program is set up as stringent and short as possible – in line with the verification plan as given above.

4.1.4 Overtesting

There can be different definitions for overtesting, according to the aspect that is emphasized:

1. unnecessary amount of tests w.r.t. what a correct establishment of a test programme requires

NOTE This definition is related to risk mitigation, since test by definition is a risk per se, while the results of the test aim at increasing the confidence about the behaviour of the item. Ideally, a correct test programme maximizes the confidence while minimizing the amount of tests needed.
2. definition of test specifications that are too conservative w.r.t. what is necessary to achieve an acceptable degree of confidence of the behaviour of the item

NOTE W.r.t. definition 1, this definition emphasizes the importance of specifying adequate requirements (in terms of pass/fail, algorithms, sequences, set-up...).
3. unintended testing of an item beyond the limits given inside the test specification

NOTE These limits can be related to the duration of activation and the level of the stimulus applied (for example, vibration levels, temperature levels, electrical levels like supply voltage).

In the rest of this clause, only definition 3 is taken into account and the consequences are explained.

Following definition 3, overtesting does not necessarily mean that the test item has been damaged. It means that limits which have been set for the test (usually for a good reason) and which have been considered for the verification programme, were exceeded. Therefore, a careful evaluation treated within an NCR process is carried out once overtesting occurred, following the process stated inside ECSS-Q-ST-10-09.

Overtesting effects can be:

- Damage of the test item: repair or exchange to follow, use-as-is is no option practically in all cases.
- Pre-damage of the test item. Example: due to unexpected high mechanical stress (e.g. by wrongly applied notching or shaker malfunction) the crack growth calculation can be outdated and is updated to check whether the item is still flight worthy or if it can fail during the next stress event (launch).

- Wear higher than calculated. Example: during the test programme, an item which is subject to wear (pump, mechanism, slip ring...) has been used for 300h instead of planned 200h. Depending on the whole lifetime and margins, this can cause degradation of the mission lifetime.
- Loss of qualification status: If out-of-qualification stresses (temperatures, mechanical stresses...) have been applied, the qualification status is lost. Using a qualification model undergoing the extended qualification range is a possibility to retrieve the qualification status.

Once overtesting occurred, the evaluation process of how to proceed is started. This is handled on a case-by-case basis. The countermeasures can be:

- replacement of the item affected,
- repair if damaged,
- refurbishment,
- use-as-is after check.

None of these countermeasures are applied without a specific analysis of the event and its impact. A simple re-check of function and performance is not a viable solution because of the possibility of undetected degradation.

4.1.5 Test effectiveness

The above-mentioned optimization of a test programme with respect to cost, schedule, and risk requires a good understanding of the test effectiveness. The better the understanding of the test effectiveness is, the more efficient the set-up of the test programme is. In particular, the defects detection efficiency by monitoring and the precipitation efficiency of latent infant mortality defects participate to the global test effectiveness. Investigations on test effectiveness have been made and are ongoing, in case the available and up to date information can be checked (e.g. Model and Test Effectiveness Database (MATeD), Analysis of Spacecraft qualification Sequence and environmental Testing (ASSET) study).

References:

- MATeD: ATS paper_MATED Improvement
- ASSET: <https://exchange.esa.int/asset/> TASI-ASE-ORP-0009_01
- ASSET +: <https://indico.esa.int/event/151/> TASI-ASE-ORP-0006_Iss.01

NOTE *Links to download the referenced documents from the ECSS.NL website are given in Annex G.*

4.2 Development test prior to qualification

The text in this clause 4.2 covers requirements 4.2a to 4.2c in ECSS-E-ST-10-03.

The definition of development model can be found in the clause 5.2.5 of ECSS-E-HB-10-02 "Verification guidelines".

It is necessary to clearly distinguish between development and qualification. Development and development tests offer the possibility of design changes, depending on the outcome of the tests. Contrary to this, a qualification test campaign is performed on hardware whose design is not expected to change. Therefore, generally a qualification test campaign only starts after the related development tests have been finished.

However, due to schedule constraints, there is always pressure to start with qualification as early as possible. It is a matter of a risk assessment for the specific case to decide whether the qualification is

started even if there are open points out of the development tests. Usually the first step is the decision to build (and how to build) a qualification model. For this, results of the development tests are available which allow having a certain design status “most probably” not subject to change any more. The more the overlap between development and qualification is, the higher the risk – a schedule vs. risk trade needs to be performed before a decision.

Development tests are not formally limited to any operational conditions. They can be used to check for margins and limits, and also to set proper qualification limits (as far as not already given by requirements).

During development tests one can be interested in checking for the real limits of operation, for example, during thermal testing, cooling down to the point where failures occur. This is allowed and can help in an operational failure case to evaluate recovery strategies.

A development model or even parts of it cannot be used for qualification purposes afterwards, because the documentation associated with such model does not allow to properly identify the complete history of the model or the part and, more severe, the stresses put on the item under test during the development tests can have an impact on the results of the qualification tests.

Starting from a reproducible and “clean” status is therefore fundamental not to mix development model parts with a qualification model and, of course, not with a flight model.

Development tests by nature do not have stringent documentation requirements as tests on qualification or flight hardware. Test procedures can be modified during test execution if the item under test does not behave as expected. Or it can be the other way around: running the tests gives insight about how the test procedures can be tuned.

No formal NCR and waiver process is carried out as part of the development process. However, as a minimum, the detailed test configurations, a record of test steps which have been performed and the test results need to be stored to highlight progress in the development process and to allow to conclude on the success of the development or to identify lesson learnt and recommendation of design improvement, if necessary. This documentation also is of aid for investigation in case of need later on.

4.3 Test management

4.3.1 General

The text in this clause 4.3.1 covers requirements 4.3.1a and 4.3.1b in ECSS-E-ST-10-03.

Unclear assignment of responsibilities can cause major problems during different phases of the test programme. Non-optimal responsibility assignment causes a lot of trouble especially when deviations to the test procedure occur and the responsibilities to deal with them are proved to be unclear.

Some element level tests being particularly complex to organise (thermal vacuum test, static test), it is recommended to organise the test preparation as a project in itself, with specific milestones.

Test definition and specification phase:

The responsibility for the verification concept, the identification of needed tests for verification, and the test specifications are on system engineering side. The AIT responsibility during this phase is to answer to these requests by setting up a test plan, preparing to select the test facilities, and to check the suitability of the test means with regard to the test requirements. Responsibility does not mean that it is done by this party all alone, but the book captainship is on this side. In fact, engineering and AIT work in close cooperation and complement each other to be able to define and run the test programme – see also test specification and test procedure below.

Test preparation phase:

In this phase AIT prepares the test procedures in close collaboration with the engineering team. One of the main aspects is to define the role and responsibilities (according to DRD TPRO Annex C of ECSS-E-ST-10-03) during the test. In particular, the process and the responsible that authorize procedure variations are identified.

Test execution:

Test is executed upon approval at TRR in accordance with the procedure. Procedure variation if needed follows the agreed process and responsibility. The post test review decides on the end of the test execution and the release of the item under test and test facility for further activity.

4.3.2 Test reviews

4.3.2.1 Test programme

The text in this clause 4.3.2.1 covers requirements 4.3.2.1a and 4.3.2.1b in ECSS-E-ST-10-03.

The text in clause 4.3.2.2 to 4.3.2.4 covers requirement 4.3.2.1c in ECSS-E-ST-10-03.

Test blocks are useful to release a certain amount of test activities at a time. A full test programme can usually not be released in just one meeting (TRR), as the programme covers a large amount of tests, which cannot be prepared up to the very last detail at the beginning. On the other hand, releasing each and every single test procedure by means of a TRR would require a high number of such meetings including the effort of their organization and preparation. Therefore, an appropriate set of blocks is defined, each of which are released by separate TRR. For each test block, all documentation is prepared and all other preconditions (GSE ready, all open points discussed, availability and role of personnel clarified, facility ready...) are fulfilled to have a successful TRR for this test block.

It is to be underlined that the review and agreement of the test specification prior TRR, e.g., by a dedicated, informal Test Specification Review meeting has proven being efficient. This is to agree with the customer as early as possible on the scope and the content of the test, which simplifies also the execution of the TRR.

NOTE According to ECSS-E-ST-10-03C Rev.1 requirement 4.3.2.1b NOTE 2, Integration is listed as a typical test block. This block is normally authorized by an Integration Readiness Review (IRR). An IRR is held for each integration block, which can cover a series of follow-on test blocks. The IRR verifies the following status:

- Hardware incoming inspection performed
- All hardware available as needed for the integration phase
- Documentation is ready (specifically Integration Procedures)
- NCR/RFD/RFW status evaluated and not blocking for the integration
- Staff to perform the work is identified, trained and available
- All necessary tools and GSE are available and calibrated
- Shelf-life materials (e.g., glues) are checked to be inside expiration date
- Material and Process issues are either closed or no blocking points
- No open RFA or qualification
- AIT and safety constraints are defined and special precautions are in place
- The facility is ready and cleanliness requirements are met
- No open work other than as identified and considered non-blocking during the IRR

4.3.2.2 Test readiness review (TRR)

The text in this clause 4.3.2.2 covers requirements 4.3.2.2a to 4.3.2.2d in ECSS-E-ST-10-03.

As given in the standard, the most important part of the TRR is to run through a checklist to verify that all preconditions for the execution of the test are fulfilled. In fact, the TRR is a question-and-answer meeting between the project PA, the test responsible. Good preparation for the meeting is mandatory – the checklist is confirmed point by point. To allow for such a smooth meeting, the documentation is reviewed and agreed in advance, not to have major issues unexpected at the TRR. Therefore, if there are open technical issues, they are identified before the TRR and the preparatory technical work takes place in advance in order to reach an agreement during the TRR. It is better to avoid any discussion of the content of documents within the TRR, especially discussions on the test procedure content. Test content as defined by the test specification is agreed with the customer in advance, starting with the development of the verification content and proceeding step by step to test specification release.

The TRR ends with the conclusion whether the test (block) is properly prepared or not, and, in case it is, it releases the start. Open topics can be handled by a delta TRR or can be considered as normal work not blocking the test release. In any case they need to be tracked and closed.

It is strongly recommended:

- to check the readiness of the test hardware by physically inspecting the test HW and the facility as part of the TRR.
- that TRR takes place at the test facility.
- to review the Success Criteria applicable for the PTR (or intermediate PTR if any).

4.3.2.3 Post test review (PTR)

The text in this clause 4.3.2.3 covers requirements 4.3.2.3a to 4.3.2.3c in ECSS-E-ST-10-03.

The focus of the PTR is to come to a quick formal agreement on breaking the test setup to allow AIT to go on with the planned activities. As long as this agreement is missing, all further AIT activities are stopped. Therefore, within the PTR, the detailed results of the test are not checked and handled. Deviations from the procedure and failures are addressed and discussed as well as preliminary data assessment to exclude the need of any direct retesting in the current setup. The PTR is scheduled right after test finalization.

The Criteria for a successful PTR as defined/reminded during the TRR will be assessed.

4.3.2.4 Test review board (TRB)

The text in this clause 4.3.2.4 covers requirements 4.3.2.4a to 4.3.2.4c in ECSS-E-ST-10-03.

Differently from a PTR, the TRB needs a not negligible time for preparation after the test is finished. The test report is prepared. Any open point, including NCRs resulting from the test execution, is addressed. The TRB is the final acceptance board for the test.

During the TRB the major stakeholders are the engineering team supported by the AIT team.

4.3.3 Test documentation

4.3.3.1 General

It is highly recommended to establish a first issue of the AIT Plan even if the System Engineering Plan and the Verification Plan are not available in the final form. The AIT Plan is derived from these documents, but only partly. Identification of facilities and the organization and management of AIT are mostly independent of the engineering input. Also, major parts of the GSE (MGSE as well as EGSE and, if applicable, OGSE and FGSE) can already be defined in an early state.

4.3.3.2 Assembly, integration and test plan

4.3.3.2.1 Overview

The text in this clause 4.3.3.2 covers requirements 4.3.3.2a to 4.3.3.2c in ECSS-E-ST-10-03.

During the project the AIT Plan undergoes an evolution process. The level of detail increases from early phases to PDR and CDR. PDR and CDR are usually defined milestones for an updated document delivery. The CDR version is very close to the final issue, where only late modifications are implemented.

The AIT Plan available at the first TRR for a given model test programme is the final issue concerning this model.

Apart from other sections to be addressed in the AIT Plan (see according DRD ECSS-E-ST-10-03, Annex A), the AIT Plan serves as a roadmap for all AIT activities. All information necessary to properly run the AIT activities are found in this document, in particular the integration and sequence of tests as well as the prerequisites for any activities (e.g. identification of the facilities, necessary GSE, general test setup, AIT organization and staffing). The AIT Plan is an applicable document for all AIT documents giving more detailed information: AIT flows, document lists, GSE specifications, test procedures...

In the following, as this document is a testing handbook, we concentrate on the test related issues for the AIT Plan. Concerning testing, the AIT Plan is the answer to the Verification Plan (VP, as per DRD Annex A of ECSS-E-ST-10-02). Generally speaking, the Verification Control Document (or Verification Control Matrix at the beginning) identifies which requirements are verified by test and the AIT Plan states how it is going to be tested. Therefore, the following topics related to the “how” are addressed:

- content of the tests,
- splitting and sequencing of tests,
- necessary GSEs,
- necessary facilities,
- organization and management of the tests.

4.3.3.2.2 Content, splitting and sequence of tests

The Verification Plan defines all the requirements that are verified fully or partially by test. In addition, some interdependencies and the associated verification sequences are detailed. The AIT Plan takes the Verification Plan as a basis to develop the whole and detailed test programme (including test matrix and sequence of tests). In an iterative and communicative way, the test specifications are developed by the engineering staff (again what testing required in a specific test), followed by the test procedures by the AIT team (how this required testing is performed). A good interaction between engineering and AIT is essential for a good result concerning test contents and sequence of tests.

As an illustration, the basic logic of a typical S/C integration and sequence of tests is as follows:

- building the “functional core” of the system by integrating the on-board computer including command ability (direct access) and power supply. Interface and basic functional tests are performed.
- adding the platform subsystems one after another: power subsystem, partly represented by simulators (see clause 4.3.3.2.3 “EGSE”, batteries and solar arrays to be integrated in a later stage), TT&C system to allow flight like (at least similar) commanding, followed by AOCS units. Each integration step needs to be followed by the corresponding interface and basic functional tests.
- subsystem and platform level tests are to follow to check functions and performances within the platform level, e.g. open and closed loop tests for the AOCS, tests of mechanisms in the platform level test environment, in-depth on-board data handling testing.
- integration and interface as well as functional tests of the payload.
- system level testing like Polarity Test, Mission Simulation Tests and FDIR.
- finalization of the spacecraft with appendices and MLI, preparation for environmental tests, global leak test.
- environmental tests in a sequence appropriate for the specific mission – no “golden rule”, but always an evaluation of pros and cons for a specific sequence of tests.
After environmental tests, the Final functional tests need to be performed again (before the launch campaign)
- transport to the launch site and launch campaign (to be set up in close cooperation with the launch authority).

During Launch Campaign, at least a RFT need to be performed

4.3.3.2.3 EGSEs

The AIT Plan identifies all necessary EGSEs. However, not covered are specific simulators used for on-board S/W validation and verification before implementation of the S/W on the target system.

NOTE S/W validation and verification requirements are covered by ECSS-E-ST-40 and ECSS-Q-ST-80.

The needed EGSEs for a typical spacecraft system level test usually consist of:

- a central checkout system (CCS) as a “backbone” of all EGSE major parts to be connected to the spacecraft, also including data management (AIV/AIT database, SRDB).
- an on-board data handling EGSE, including bus Analyser and data loader.
- a power EGSE, consisting of Solar Array Simulator, Battery Simulator, Battery Management Unit and others, usually several racks.
- an AOCS EGSE, used to simulate and stimulate AOCS sensors and to provide an environment of simulated mission scenarios concerning attitude and orbit control.
- a TT&C EGSE including TM/TC front end to allow communication with the spacecraft, consisting of various ways to do so: via direct data bus connection; hardwired, but with modulation/demodulation; end-to-end version using test caps including damping devices to establish a radio frequency link.
- a payload EGSE, which is mission specific.
- other EGSEs like RF suitcase and umbilical EGSE, TCS simulation, propulsion GSEs.

A typical setup is shown in Figure 4-1.

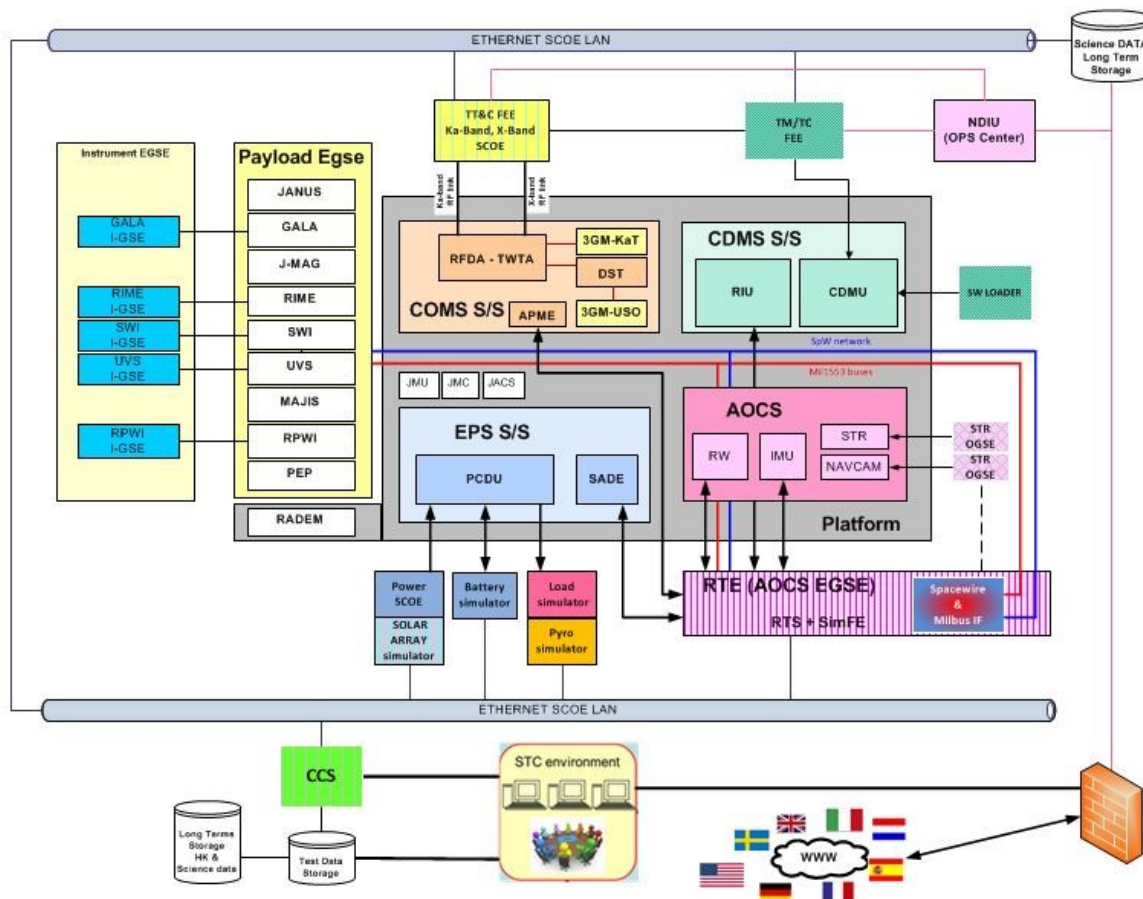


Figure 4-1: Testing at S/C level and example of typical EGSE setup for JUICE S/C (courtesy Airbus Defence and Space)

Apart from the EGSEs needed to run spacecraft tests, other EGSEs are identified and procured or made available in time. This includes facility EGSEs or facility equipment to be procured or rented for the specific project:

- general purpose test equipment like break-out-boxes, multimeters, oscilloscopes, probes, measurement equipment in general: these are either available from a central AIT pool or procured in time.
- small “stand-alone” EGSEs for specific tasks or special tests, e.g. read-out equipment and data storage for thermal test data and sensors, illumination devices for solar array checks, specific measurement equipment for pyro resistance checks...
- facility related EGSEs to support, for example, vibration, thermal vacuum, acoustic noise, shock, EMC and CATR testing, GPS clock reference.

It is important that the EGSE is validated and calibrated before starting the test activities.

The calibration is maintained throughout the ground test activities.

Finally, it is worthy to be mentioned that EGSE and SCOE are highly project dependent, e.g. "COTE" is even not a name known in some Industries.

Anyway, for sake of clarification, a list of typical EGSE/SCOE and main purpose description is added here below in Table 4-1.

Table 4-1: Typical EGSE/SCOE list

No	EGSE/SCOE	Main use case	Secondary Use Case	Comment
1	Power SCOE	Power Supply		
2	Umbilical SCOE	Power Supply		
3	Launch SCOE	Power Supply	TM/TC Connection (Bypass)	can include TM/TC SCOE, TM/TC FE "anti" seismic rack to withstand launch loads in bunker
4	Launch Power Supply	Power Supply	TM/TC Connection (Bypass)	can include TM/TC SCOE, TM/TC FE "anti" seismic rack to withstand launch loads in bunker
5	COTE	Power Supply	TM/TC Connection (Bypass)	Check-out Terminal Equipment
6	Main Bus Power Supply	Power Supply		
7	Battery Power Supply	Power Supply		
8	TM/TC SCOE	TM/TC Connection (Bypass)		
9	TM/TC Front-End	TM/TC Connection (Bypass)		
10	TT&C SCOE	RF connection (Telemetry, Tracking and Command)		can include TM/TC SCOE, TM/TC FE
11	TTC FF	RF connection (Telemetry, Tracking and Command)		can include TM/TC SCOE, TM/TC FE
12	TT&C SCOE	RF connection		can include TM/TC SCOE, TM/TC FE
13	RF SCOE	RF connection		can include TM/TC SCOE, TM/TC FE
14	S-BAND SCOE	RF connection		can include TM/TC SCOE, TM/TC FE
15	X-BAND SCOE	RF connection		can include TM/TC SCOE, TM/TC FE
16	Ka-BAND SCOE	RF connection		can include TM/TC SCOE, TM/TC FE

4.3.3.2.4 MGSEs

It is important to identify the MGSEs needed for the integration and test activities. Therefore, it is recommended to go through the whole AIT sequence and to identify, for each step, which kind of MGSE is needed to perform the task. At least MGSE, which is not available off the shelf or not trivial to manufacture, needs to be identified, specified and procured well in advance. Typical "big blocks" of

MGSE are transport containers, lifting devices, integration stands and trolleys, module integration aids, test adapters, test and handling clamp band (see hereunder pictures). However, there are also some delicate items to be considered like zero-g devices or deployment rigs. All of these need a procurement process similar to an equipment procurement: issue a specification, select a supplier, agree on milestones like reviews, monitor the detailed development and manufacturing process, witness the acceptance tests (like proof load test, drop test for damper systems, Non-Destructive Inspection tests).

Possible problems during the integration process are anticipated to be prepared with the right MGSE. Also, some flexibility in the concept is anticipated to adapt for late design changes of the spacecraft or its modules.

It is good practice to perform dry runs to become familiar with the MGSEs handling. This is considered in the scheduling.

Small MGSEs are items like diving boards, special tools, scaffolds, fixations, brackets, safety covers and so on.

It is highly recommended to establish a complete list of all MGSEs needed for the project, including small items, but except standard tools, and to track the need date as well as the estimated date of availability.



Figure 4-2: GOCE spacecraft Container



Figure 4-3: Exomars Schiaparelli Descent Module Container



Figure 4-4: AEOLUS multipurpose trolley



Figure 4-5: Lifting device for Exomars Schiaparelli Descent module

4.3.3.2.5 Other GSEs

Apart from EGSEs and MGSEs, project specific and subsystem specific GSEs are identified. This covers fuelling GSEs, optical GSEs, cooling GSEs (fans or liquid cooling) and more, as applicable.

4.3.3.2.6 Facility infrastructures

The handling of flight items during their lifetime on earth usually requires specific attention with regard to the environment provided by the facilities. To avoid contamination by particles usually a cleanroom ISO class 8 is used for integration purposes. In addition, temperature and humidity are controlled and recorded within limits as given in ECSS-Q-ST-70-01 (RH (55 ±10) %, T (22 ±3) °C in standard cases).

Depending on specific mission requirements other environmental conditions can become applicable. For missions to planets of the solar system the planetary protection rules apply, (see Committee on Space Research – COSPAR PLANETARY PROTECTION POLICY), resulting in more stringent requirements especially on biological contamination. For flight hardware with delicate optics usually higher clean room classes are required (typically ISO class 5).

There are more requirements on the facilities than just the environment (for example, special security requirements can apply). The infrastructure is appropriate for the tasks to be performed: the suitability of the infrastructure is checked against the requirements, for example:

- Fixed facility infrastructure:
 - Crane(s) with necessary load capacity and clearance (lifting height),
 - Facility grounding concept,
 - ESD flooring as applicable,
 - Electrical infrastructure (e.g. power up to three-phase current 330 V / 63 amps),

- Safety measures for dangerous operations like pressure tests (bunker), if applicable,
 - Illumination according to the needs and legal constraints (brightness, specific working area illumination),
 - Size of access and integration area (see example of floor planning below).
- Moveable facility infrastructure:
 - Cherry pickers,
 - Fork lifts,
 - Lockers / storage means,
 - Clean benches with filters for e.g. gluing activities.
- See also for Safety issues 4.4.1e.

4.3.3.2.7 Integration area planning

Note that apart from the area needed for the spacecraft itself working areas, EGSE, MGSE need to be considered in detail. The working area comprises scaffolds, desks to place tools, desks and chairs for QA and documentation, access areas for alignment activities and more. All floor planning takes into account specific activities, which lead to an increased area need for a limited time: module mating activities, transport preparation involving transport containers and logistics, deliveries of large components.

4.3.3.2.8 Storage area planning

A dedicated non-working area (mainly for GSE) is very often necessary to temporarily store containers, crates etc. that are not continuously used for integration and test activities. Storage conditions need to be identified and taken into account as part of the logistics.

4.3.3.2.9 AIT facilities

Some tests require specialized facilities providing the means to perform vibration and acoustic noise tests, thermal tests, EMC tests, and RF tests. Or facility equipped with adequate test feature for physical properties (Mass, CoG, MoI) determination, appendages deployment, and propulsion test.

For other tests especially for planetary environments, facilities have either to be set up or identified according to the very unique needs of such missions.

To ensure the suitability of the environmental test facilities, the technical data with regard to the applicable requirements are checked first.

4.3.3.2.10 Test Article Instrumentation process

The Design Authority, in agreement with the test conductor or technician (from AIT), approves in a technical meeting on the instrumentation to be utilized to monitor the test performances.

As cooperation activity (co-engineering) before issuing the instrumentation plan, the following main topics are discussed and agreed in detail:

- Instrumentation location to check the accessibility and removability or passivation.
- Instrumentation installation, when and at what time need to be included in the scheduled sequence of tests.
- Instrumentation range and measurement uncertainty in order to use proper standard instrumentation or if strictly needed procure a new instrument.
- Installation procedures (draft) to avoid incorrect installation, Test Article damaging and failure.

- Instrumentation harness routing not to influence the instrumentation readings and test article behaviour (e.g. thermal leaks through harnesses, or issues with deployment/motion).
- Verify that test instrumentation can withstand another environment (vibration sensor compatible of Thermal Vacuum) if instrumentation not installed just before the test, and removed just after the test.

After the definition of the test instrumentation plan, the whole instrumentation is calibrated checking that the duration of calibration covers all instrumentation activities with also the test execution, with margins.

Dedicated paragraphs of a dedicated instrumentation procedure, or inside the test set-up preparation procedure, describes the instrumentation operations and sequences with also the tables of the main parameters, i.e.:

- instrument type,
- P/N & S/N (if not available in advance a blank range to be filled),
- position/location (with annexed figures),
- directions and axis (for accelerometers, displacement transducers, alignment mirror targets...),
- range,
- measurement uncertainty/sensitivity,
- calibration due date,
- pictures of the installed instrumentation,
- and operator signature and installation date.

Functional check steps are planned, at the end and during the instrumentation process, before and in some case after test execution, in the dedicated installation procedure and they are performed accordingly.

The procedure contains also removal procedures steps.

The instrumentation that is not removed for flight is identified and conditioned as required. An analysis has confirmed that there is no detrimental impact (e.g. contamination, short circuit, mechanical behaviour).

In addition, it is necessary to ensure that the test facility includes proper controls in the final checks with the Data Acquisition system.

After installation of the instrumentation, deviations with respect to the agreed instrumentation plan are clearly identified, e.g. sensors not located or oriented as expected due to unforeseen constraints. It is important to capture the “as instrumented” configuration.

4.3.3.3 Test specification (TSPE)

The text in this clause 4.3.3.3 covers requirements 4.3.3.3a to 4.3.3.3c in ECSS-E-ST-10-03.

Test specifications at equipment level and at element level are generally under the responsibility of engineering, not of AIT. Usually, only the developers have a detailed inside view of the equipment which allows defining a proper test specification. However, involvement of AIT in the TSPE preparation is crucial to avoid unfeasible requirements. Early discussions between both parties help to streamline test setups, as AIT is experienced in turning specifications into real test steps.

The DRD for the Test specification is in Annex B of ECSS-E-ST-10-03. It includes the description of the expected and needed content, which are therefore not repeated here, but commented in the following text. The test specification introduction emphasizes two aspects of paramount importance:

- Test purpose (= achievement of test objectives).
- Test limitations (= any open issue, assumption and constraint that does not allow the full achievement of the test objectives).

The Test specification is used as a basis to write the test procedure with all step-by-step activities.

The complexity of a TSPE is directly linked to the complexity of the test.

For a “simple test”, which means, for example, without specific means to develop, and no contribution of many disciplines or sub-contractors, only the TPRO is issued, based on engineering inputs, and it covers the purpose of the TSPE. This is for example the case for physical properties (Mass, CoG, MoI) measurements at equipment level, or derived from a test performed in other projects. For this kind of simple tests, it is acceptable to start directly with the test procedure.

If the test is complex or long to prepare, for example a S/C level EMC test or a S/C level thermal test, at least two issues of TSPE are necessary. A preliminary one is needed to allow for identification of long lead items, booking of the facility, iteration with involved disciplines and similar issues requiring anticipation. A final one captures all requirements to finalize the test procedure.

It is recommended to establish a table containing the requirement identification from the VCD, the requirements text, the verification methods for the requirement as per VCD, and a reference to the point in the test sequence for the planned verification. Discuss the requirements as addressed before as well as the proposed test approach to give rationale for the validity of the requirement verification, if not obvious.

The test description addresses the following topics:

- Test item configuration: required as-built status of the item including S/W version, if applicable.
- Test and operation means: e.g. shaker, vacuum chamber, anechoic chamber, also including description of GSE measurement equipment.
- Test setup including boundary conditions: adapters, interfaces, mounting conditions.
- Ground Support Equipment: mechanical as well as electrical or other GSE necessary to run the test, including test tools.
- Test conditions: specific environmental conditions (temperatures, vacuum, cleanliness...) or other conditions to be fulfilled before running the test.

Requirements on the test facility, either internal or external, need to be addressed. Specifically, for environmental test campaigns, the test facility requirements become part of the contractual documentation with the test house. For environmental tests, usually the following test facility requirements are treated in the TSPE:

- Interface requirements (mounting interfaces, crane interfaces, infrastructure interfaces...).
- Safety requirements (apply for pressure tests, toxic fluids, crane and lifting devices margins).
- Measurement equipment requirements: number of channels, measurement uncertainties, sample frequencies...
- Precise location of sensors, type of sensors selected, measuring range, measurement uncertainty, acquisition frequency, number of sensors. In some cases, this information is captured in instrumentation plans, which can be referenced in the TSPE. Note: some of the instrumentation does not fall under the facility responsibility.
- Facility capability requirements like mass and load requirements or automatic abort capability for vibration, temperature range for thermal testing, frequency capabilities for RF testing.
- Required support means (transport, lifting, nitrogen supply...).

Concerning the test sequence, the TSPE gives a planned test sequence as a frame to establish a TPRO later on. Requirements addressed and verified during specific parts of the sequence are assigned to these parts. The flow of activities is chosen in a way to minimize testing effort without compromising the verification process, i.e. any necessary reconfiguration activities are optimized. The presentation of the flow in the TSPE is limited to the different configurations and major test activities to allow getting an overview of the whole test sequence, but include all necessary information to deduct the step-by-step TPRO later on.

Logical Test sequence: In case of logical constraints to the test sequence (e.g. a measurement value of an activity is needed as input to perform a test step of another activity), these logical constraints need to be identified and described in the TSPE to avoid reshuffling of the sequence during the TPRO preparation.

Pass/fail criteria are defined to allow clear check points between tests steps to decide whether the test is to be continued or stopped.

Test conditions are part of the specification so they are not pass/fail criteria.

Defining the appropriate input pass/fail criteria takes into account the test tolerance bands. Also output pass/fail criteria include test uncertainties to allow for a decision if the test item is reacting or performing as expected.

Responsibilities are essential for successful test performance. Therefore, the roles and responsibilities of e.g. the lead test engineer, the AIT test lead, the project manager and maybe the customer as well are clarified early to avoid discussions about decisions when they are needed urgently.

4.3.3.4 Test procedure (TPRO)

The text in this clause 4.3.3.4 covers requirements 4.3.3.4a to 4.3.3.4c in ECSS-E-ST-10-03.

Turning the specification into a step-by-step procedure is a task of AIT. However, as now the developer view is often missing, it is recommended to support the test procedure generation from the engineering side. To make background information available during procedure generation involvement of engineering is necessary. A company structure which allows for some flexibility concerning cooperation of engineering and AIT is beneficial for this. As a general guideline, unproven test procedures are run and checked on engineering models or on a simulator before execution on flight hardware. The step-by-step description needs to exclude any unambiguity. The level of detail is adjusted to the experience and education of the personnel which runs the procedure. This can vary with different company organizations.

The DRD for Test procedure is in Annex C of ECSS-E-ST-10-03. It includes a proper description of the expected and needed contents, which are therefore not repeated here.

4.3.3.5 Test report (TRPT)

The text in this clause 4.3.3.5 covers requirements 4.3.3.5a to 4.3.3.5b in ECSS-E-ST-10-03.

Depending on the test purpose (interface test, functional test, performance test...) the test report is issued by AIT or engineering. For interface and functional tests, the focus is mostly on simple pass/fail criteria, verification of requirements in this stage of testing is very limited. Therefore, the test report often consists of a summary of the results, with the as-run test procedure as annex. As long as no deviations occur, no engineering judgment is necessary. Once the phase of performance or environmental testing is reached, engineering produces a test report. In this case, it is often referred to as a test evaluation report. The test results often need a careful evaluation with regard to requirements verification.

Due to the nature of tests, there can be several test reports, for example for thermal tests there are a test facilities report, containing raw data from facilities, an AIT test report, including the operational results of the thermal test activities, and a test evaluation report, issued by the engineering team.

To conclude successfully a TRB, the test report is accepted or accepted with updates by all involved parties, as defined in in clause 4.3.3.4c of ECSS-E-ST-10-03. It derives that an issued version of the test report is available before the TRB which is subject of review and acceptance as described above, at the TRB.

The DRD for Test Report is in Annex C of ECSS-E-ST-10-02.

4.3.4 Anomaly or failure during testing

The text in this clause 4.3.4 covers requirements 4.3.4a to 4.3.4c in ECSS-E-ST-10-03.

Deviations from expected measurement values or unexpected behaviour of the item under test need to be evaluated. To allow for this, recording of the test steps is a necessary precondition for post-test evaluations. Recording is not limited to the failure or anomaly itself, but also clearly describe the test status and conditions. For functional tests, replay of the test steps to verify that either the anomaly or failure has been a single event or is repeatable is often needed to identify the root cause. But this can be done only if it is demonstrated that a replay will not damage anything.

AIT and QA check whether a non-conformance is resulting out of the anomaly or failure and in case start the NCR process on the issue. According to the non-conformance processing flow of ECSS-Q-ST-10-09, disposition on corrective and preventive measures including retest activities is given.

4.3.5 Test data

The text in this clause 4.3.5 covers requirements 4.3.5a to 4.3.5c in ECSS-E-ST-10-03.

To record test data together with environmental conditions and test setup details (specifically software versions) is mandatory to later on analyse the test results. Missing information, detected during test evaluation, leads to the necessity of test repetition.

Parameters, which are going to be measured several times during the overall test campaign, and which can vary within a certain range, are identified. For these parameters, a specific analysis is performed, aiming on the identification on trends in the measurement results. This allows for a prediction of probably out of range results after a certain lifetime. Typical tests related to the identification of trends is the reduced functional tests execute before and after transportation and before, during and after environmental tests.

Test data is available in electronic form as far as possible, to streamline processing.

For example, in case of vibration testing, all time histories are recorded for further analysis in case of issue. The availability of the time history is checked with the test facilities.

4.4 Test conditions, input tolerances, and measurement uncertainties

4.4.1 Test conditions

- a. The test levels and the test durations that a TSPE require are the main test conditions for the fulfilment of the test objectives.

If using predicted environmental and interface conditions, the environment specifications or documents managing interfaces between products usually provide the TSPE input information:

- An environment specification describes the different life phases environmental conditions (ground, launch, in-service and withdrawal from service).
- Generally, the prediction of an environmental or interface test condition uses in-service data of previous missions, relevant ground or launcher environments, analytical predictions including calculation uncertainties, relevant previous test results including test uncertainties, or a combination thereof. Such test conditions can cover one or more missions.

As an example, if using predicted reliability performances for electronic equipment, the Arrhenius law drives the temperature levels that the TSPE requires. In that case, these temperature levels do not come from TCS (Thermal Control Subsystem) performances predictions.

The predicted environmental conditions can cover either only one mission, for example on a unique LEO orbit, or a set of missions, for example including LEO and non-LEO orbits with interplanetary trajectories.

As an example, in the functional domain, worst case conditions, coming from the specific mission, are taken into account for certain verification activities like test of power profile. This corresponds to the "test like you fly".

For the mechanical domain see ECSS-E-HB-32-26 "Spacecraft mechanical loads analysis handbook".

- b. Deleted requirement.
- c. Examples of effects that might induce differences in behaviour due to the testing environment:
- Effects of appendages flexibility during attitude control tests.
 - 1g effects or atmosphere effects on mechanisms torque capability or stiffness.
 - As indicated in the note in the standard, a typical difference between room pressure and vacuum is the absence of convection for the heat transfer and the effect on temperature differences. Note that in some cases, conduction through the gas has significant effects. For example, in cases where there is a thin layer of gas (e.g. gas gap) is present, convection does not happen in this thin layer, but gas conduction changes the heat transfer. This is the case for Multi-Layer Insulation.
 - If gas in movement is present around for example a space segment element, effects of heat transfer by free or forced convection on temperature differences between different points of this space segment element.
- d. No specific guidelines for this requirement.
- e. Safety aspects can be critical, e.g. during pressure tests, static tests, vibrations, tests with batteries, hazardous materials (e.g. Beryllium), pyro devices. Potential hazards are identified and registered and protection means provided (safe unloading during static test, ear protection for vibrations).

Examples for Static tests see A.3, for centrifuge see A.5, for vibration see A.7 and for Pressure tests see B.3.

NOTE Test facilities typically have safety procedures to be followed and for which personnel are trained. However, for ad hoc type of tests (e.g. pressure tests, static tests, landing tests), those safety aspects are addressed.

- f. Test facilities and GSEs are not the weak part (i.e. do not impact on test performances). GSEs have sufficient margins (in terms of performance and reliability) and redundancy features not to affect the test. MGSE is typically tested before use. Strength tests are performed on a regular basis for items that are re-used (e.g. slings), according to national safety rules. For example, a test heater is sized with derating rules at least as severe as flight ones. It has happened that a thermal test had to be aborted because a test heater started to burn. Similarly, to reduce the risk of a clamp band failure during vibrations or static test, more robust clamp bands can be used, which do not only rely on friction but can also include a mechanical stop on the rear frame of the launcher interface. These topics are addressed early when procuring the GSE and verified at TRR.
- g. These topics are addressed early during test preparation and verified at the TRR.
- h. It is very important to perform test predictions or test simulations (including as much as possible the effects of the test facility. Example: virtual testing) before the test starts. In case of vibration testing, it is important to begin the test with dry runs and low levels. In some cases, coupled prediction analysis are performed considering simulation models of the facility and of the test article. These topics are addressed early during test preparation and verified at the TRR.

4.4.2 Test input tolerances

- a. No specific guidelines for this requirement.
- b. This handbook, as the testing standard, does not cover metrology uncertainty budgets and test uncertainty budgets. The guides (JCGM 100 series, EA-4/02 and EA-4/16), in the bibliography of the standard, are the international state of the art in terms of uncertainty of measurement and in terms of uncertainty in quantitative testing. EA-4/02 and EA-4/16 are European guides that apply the JCGM 100 series. A general knowledge of the practice of this terminology and of these fundamental basics is of great help in formulating explicit requirements about these uncertainty budgets in each test specification.

See additional guidelines in the guidelines to the requirement 4.4.3b.

- c. No specific guidelines for this requirement.
- d. No specific guidelines for this requirement.
- e. No specific guidelines for this requirement.

4.4.3 Measurement uncertainties

- a. See guidelines to the requirement 4.4.3b.
- b. See first considerations in the guidelines to the requirement 4.4.2b.

Metrology and test equipment calibrations are crucial

To support efficiently each test objective and knowing that the engineering team takes care of the accuracy of each test implementation, metrology and test equipment calibrations ensure an accurate value of each test input and output measured parameter.

Repeated calibrations based on approved calibration procedures, with traceability to international standards for metrology and to test standards for test equipment, are the fundamental and primary activity:

- For each test input parameter associated with a test input tolerance, each measured value can vary within the allowable tolerance band. And to do this, the specified allowable uncertainty width (with typically a 95% confidence level), associated to all measurement instruments and test equipment used to control and monitor this test parameter, is a little fraction of the tolerance band width. For this purpose, most of the space programmes international standards require or preconize this width better than one third of the test tolerance band width. Figure 4-6 illustrates the decision rule associated to test input tolerance assessment, as per ISO/IEC 17025:2017, entitled "*General requirements for the competence of testing and calibration laboratories*".
- For a test input or output measured parameter, the test implementation uncertainty is test dependent and can be much bigger than the metrology and test equipment calibrations uncertainty. Generally speaking, a global measurement uncertainty includes the measurement implementation contribution and the contribution of the calibrations of the complete metrological chain. As an example, for sensors as thermocouples, the uncertainty coming from even good thermal contacts, between a surface near the temperature intended to be measured and the thermocouple (sensor head and wires), makes negligible the metrological chain calibration contribution to the global uncertainty. For vibrations, the orientation and exact location of the accelerometers are sources of uncertainty. For a static test, orientation and location of strain gauges are sources of uncertainty. For acoustic test, location of the microphones influences the measured sound pressure level, which is never fully homogeneous in the test volume. This is particularly true for direct field acoustic test. For static tests, mounting of the LVDTs might lead to significant uncertainty.

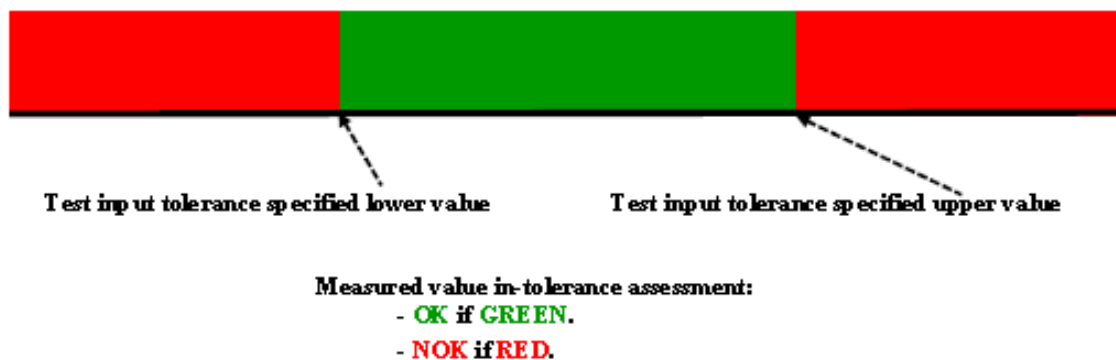


Figure 4-6: Test input in-tolerance or out-of-tolerance assessment (decision rule)

Test results conformity assessment is performance dependent

For test output measured parameters participating to the space product verification, the approach of the conformity assessment differs according to two main categories of space product performances:

- For a performance verified by a quasi-direct measurement, Figure 4-7, inspired by the Figure 10 of the JCGM 106:2012 guide, entitled "*Evaluation of measurement data -- The role of measurement uncertainty in conformity assessment*", illustrates the approach. This figure illustrates the decision rule, as per ISO/IEC 17025:2017, associated to conformity assessment with the guard band approach.

In case of two (lower and upper) bounds for the specified allowable values, this figure visualizes a range of allowable values (orange and green zones) from lower to upper specified limits and two guard bands (orange zones) defined as the $2\text{-}\sigma$ confidence interval (95% confidence level) of the global measurement uncertainty.

The guarded approach avoids false conformities within the confidence level, but can lead to false rejections and, if the specified interval width is small, to conformities impossible to assess (no green zone). In order to mitigate these two risks, the only way is low global measurement uncertainties. For the second risk and in case of two (lower and upper) bounds for the specified allowable values, the conformity assessment is only possible if the global measurement uncertainty is significantly lower than the specified allowable interval. With a factor superior to two, a green zone appears. With a factor three, the green zone width equals the measurement uncertainty.

As an example, for a mass measurement with an upper specified limit, the absorbed humidity or another uncertain or unrepresentative test condition can be a mass measurement implementation contribution to the global mass measurement uncertainty much bigger than the calibrations contribution. It is particularly the case if the uncertain or unrepresentative test condition varies between different tests and if the analysis of its impact on the result is uncertain. So, the test specification requires similar conditions (pressure, temperature, humidity) between different mass measurements, in accordance with ECSS-Q-ST-70-01 clause 5.3.

- For a performance verified by a numerical model correlation activity, the TSPE requires each need in terms of uncertainty, including confidence level. Before that, the engineering team ensures the satisfaction of specific needs exceeding the performance of previously available measurement instruments and test equipment. The corresponding decision rule, as per ISO/IEC 17025:2017, is the assessment of the flight predictions results obtained with each validated numerical model.

Examples: higher than ever dimensional stability to avoid thermo-elastic displacements, lower than ever temperature difference, tighter than ever requirements on temperature stability or variation, or very small displacement to be measured for thermo-elastic stability.

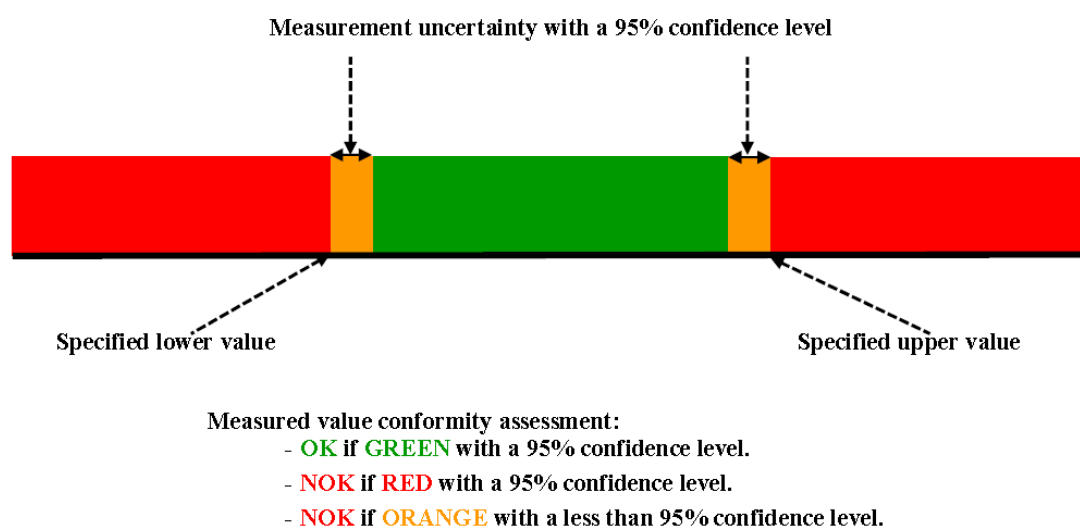


Figure 4-7: Conformity assessment with the guard bands approach (decision rule)

- c. No specific guidelines for this requirement.
- d. No specific guidelines for this requirement.
- e. Deleted requirement.

4.5 Test objectives

4.5.1 General requirements

- a. The test programme definition takes into account:
 - verification programme defined in ECSS-E-ST-10-02,
 - model philosophy defined in ECSS-E-ST-10-02,
 - requirements defined in ECSS-E-ST-10-03.
- b. No specific guidelines for this requirement.

4.5.2 Qualification testing

- a. For functional testing, margins are not systematically applied.
- b. The qualification at element level is often spread out over different models.
- c. Deleted requirement.
- d. Deleted requirement.
- e. No specific guidelines for this requirement.
- f. No specific guidelines for this requirement.

4.5.3 Acceptance testing

- a. For mechanical acceptance testing also makes sure that the flight model behaves as the model on which qualification testing is performed (e.g. dynamic signature). If not, then the qualification can be jeopardized.
- b. An important objective of acceptance testing at equipment level is to precipitate by environmental stress screening any latent defect in materials, parts, processes and workmanship that is susceptible to cause detrimental problems or failures during posterior AIV activities at element level and during the in-service infant mortality period. In particular, for temperature cycles, the precipitation efficiency of the thermo-mechanical stresses depends on the amplitudes of the temperature ranges and rates of change. A temperature range limited to the working operational temperature range is not sufficient. Other type of defects, as design defects that escape to qualification stage or as patent defects in materials, parts, processes and workmanship that escape quality control and previous environmental tests, can also cause detrimental problems or failures.
- c. Further information about acceptance can be found in ECSS-E-HB-10-02 section 5.2.4.3.
- d. No specific guidelines for this requirement.

4.5.4 Protoflight testing

4.5.4.1 Overview

Note that protoflight approach can be performed according to the type of environment. For example, a given project could have a protoflight approach for thermal and perform the mechanical qualification on a structural model (SM) and only mechanical acceptance on the flight model (FM).

4.5.4.2 Requirements

- a. See the guidelines for acceptance testing in 4.5.3b with the difference that the protoflight stage has also the objective of detecting design defects.
- b. No specific guidelines for this requirement.
- c. No specific guidelines for this requirement.

4.6 Retesting

4.6.1 Overview

No specific guidelines for this overview.

4.6.2 Implementation of a design modification after completion of qualification

- a. No specific guidelines for this requirement.

4.6.3 Storage after protoflight or acceptance testing

The text in this clause 4.6.3 covers requirements 4.6.3a to 4.6.3g in ECSS-E-ST-10-03.

If specific needs for testing during storage are foreseen, it is highly recommended to rehearse the procedures before the storage takes place.

4.6.4 Space segment element or equipment to be re-flown

- a. In the previous programs where re-flown was done (e.g., Spacelab, Spacehab, MPLM), tests were performed after landing and before the re-flown (mainly functional tests) to verify that the performance and capabilities were as required by mission and specifications. Analogous approaches are foreseen for possible future missions (e.g., Space Rider) where replacement of units after flight is also evaluated. Typically long duration tests in the C/D phases (e.g., vibration tests) are adopted to cover the item long duration exposure to the encountered flight environments (i.e., re-flights). In the following Note it is possible to find Wikipedia web information on those missions:

NOTE MPLM (Multi-Purpose Logistic Module) Leonardo, from:
[https://en.wikipedia.org/wiki/Leonardo_\(ISS_module\)](https://en.wikipedia.org/wiki/Leonardo_(ISS_module)), MPLM Raffaello,
 from:

- https://en.wikipedia.org/wiki/Raffaello_MPLM, SPACEHAB Logistics Double Module, from:
- https://www.nasa.gov/mission_pages/station/structure/elements/spacelab.html, SPACEHAB, <https://en.wikipedia.org/wiki/Spacelab>

b. See requirement 4.6.4a.

4.6.5 Flight use of qualification Space segment element or equipment

- a. No specific guidelines for this requirement.
- b. No specific guidelines for this requirement.
- c. No specific guidelines for this requirement.

Space segment equipment test requirements

5.1 General requirements

The space segment equipment testing is key for a comprehensive test and verification program of the whole space segment element. Ideally the same principles are applied on the equipment and space segment element verification levels. This is requested especially for the functional and performance testing described in the clauses below and in more detail in the foreword of equipment level section 5.5.1.1.

- a. No specific guidelines for this requirement.
- b. No specific guidelines for this requirement.
- c. An aspect to consider is the capability to detect defects produced by the other environments. For example, a structural failure due to thermo-elastic stresses during a thermal test can be detected during vibrations later on, while it can remain undetected if vibrations were performed before the thermal test. On the other hand, a defect produced in vibrations, e.g. on a connector, can be detected during a thermal test afterwards, while it can escape if vibrations are performed after the thermal test. Another consideration is that thermal tests include functional and performance tests and monitoring capability in between. This is very effective to highlight flaws and they offer very good perceptiveness because of this functional and performance verification and because of this monitoring (as opposed to vibrations for example). From a programmatic point of view, capability to detect defects as early as possible calls for early thermal tests (especially by temperature cycling for efficient thermo-elastic stress), while from a technical point of view, it can be considered better to perform them towards the end of the sequence of tests to capture any defect caused by the other environments or AIT activities. These guidelines deal with the screening efficiency objective of the testing sequence. Naturally, this global screening efficiency greatly depends on the screening efficiency of each test in the sequence. In particular, for thermo-mechanical latent defects, the precipitation efficiency of temperature cycling varies sharply with the number of cycles and with the amplitudes of the temperature ranges and rates of change. For example, a temperature range limited to the working operational temperature range is not sufficient to reveal during ground testing latent flaws that can appear later in flight after a certain amount of cumulative thermo-mechanical stress.
- d. Any critical parameter is identified and subjected to trend analysis (e.g. batteries voltage monitoring).
- e. No specific guidelines for this requirement.
- f. No specific guidelines for this requirement.
- g. No specific guidelines for this requirement.
- h. No specific guidelines for this requirement.
- i. No specific guidelines for this requirement.
- j. No specific guidelines for this requirement.