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Space engineering — Verification guidelines

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National foreword

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The UK participation in its preparation was entrusted to Technical Committee ACE/68, Space systems and operations.

A list of organizations represented on this committee can be obtained on request to its committee manager.

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European Foreword

This document (CEN/CLC/TR 17603-10-02:2021) 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 16603-10-02.

This Technical report CEN/CLC/(TR 17603-10-02:2021) originates from ECSS-E-HB-10-02A.

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).

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1 Scope

This handbook provides additional information for the application of the verification standard EN 16603-10-02 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 is practical, the structure of the standard and quotes the requirements, to make it self standing and easier to read (*the text from the standard is in italic*).

As the Standard applies to different products at different product levels from single equipment to the overall system (including space segment hardware and software, launchers and Transportation Systems, ground segment, Verification tools, and GSE) several examples of tailoring, to match the specificity of each application, are proposed in Annex B.

Specific discipline related verification aspects are covered in other dedicated standards and handbooks. In particular the detailed aspects for Testing are covered in the EN 16603-10-03 and in its corresponding handbook TR 17603-10-03.

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.

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2 References

This document is the handbook corresponding to the Verification standard ECSS-E-ST-10-02C.

The following documents are referenced in this text or provide additional information useful for the reader.

EN Reference	Reference in text	Title
EN 16601-00-01	ECSS-S-ST-00-01	ECSS system - Glossary of terms
EN 16603-10	ECSS-E-ST-10	Space engineering - System engineering general requirements
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 16603-40	ECSS-E-ST-40	Space engineering - Software
EN 16603-50	ECSS-E-ST-50	Space engineering - Communications
EN 16603-70	ECSS-E-ST-70	Space engineering - Ground systems and operations
TR 16703-10-03	ECSS-E-HB-10-03	Space engineering - Testing guidelines
-	ECSS-E-TM-10-21	Space engineering - System modelling and simulation
EN 16601-10	ECSS-M-ST-10	Space project management - Project planning and implementation.
EN 16602-10-09	ECSS-Q-ST-10-09	Space product assurance - Nonconformance control system.
EN 16602-20	ECSS-Q-ST-20	Space product assurance - Quality assurance.
EN 16602-20-07	ECSS-Q-20-07	Space product assurance - Quality assurance for test centres.
EN 16602-40	ECSS-Q-ST-40	Space product assurance - Safety.
EN 16602-60	ECSS-Q-ST-60	Space product assurance - Electrical, electronic and electromechanical (EEE) components.
EN 16602-70	ECSS-Q-ST-70	Space product assurance - Materials, mechanical parts and processes.

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3 Terms, definitions and abbreviated terms

3.1 Terms from other documents

For the purpose of this document, the terms and definitions from ECSS-ST-00-01 apply, in particular for the following terms:

validation

verification

3.2 Terms specific to the present handbook

3.2.1 acceptance stage

verification stage with the objective of demonstrating that the product is free of workmanship defects, is in accordance with the qualified design and is ready for its intended use

3.2.2 analysis

verification method performing a theoretical or empirical evaluation using techniques agreed with the customer

NOTE The selected techniques can typically include statistics, qualitative design analysis, modelling and computer simulation.

3.2.3 commissioning

verification and validation activities conducted after the launch and before the entry in operational service either on the space elements only or on the overall system (including the ground elements)

3.2.4 in-orbit stage

verification stage valid for projects for which in-orbit verification is performed, including the commissioning and verification activities which are delayed because the activation of a space element is performed later during the mission (e.g. for Interplanetary mission, lander).

3.2.5 inspection

verification method by visual determination of physical characteristics

NOTE 1 Product characteristics include constructional features, hardware conformance to document drawing or workmanship requirements, physical conditions, software source code conformance with coding standards

NOTE 2 See also ECSS-ST-00-01.

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3.2.6 model philosophy

definition of the optimum number and the characteristics of physical models required to achieve confidence in the product verification with the shortest planning and a suitable weighing of costs and risks

3.2.7 post-landing stage

verification stage valid for projects for which post-landing verification is performed (e.g. for Multimission projects)

3.2.8 pre-launch stage

verification stage with the objective to verify that the flight article is properly configured for launch and capable of functioning as planned for launch

3.2.9 qualification stage

verification stage with the objective to demonstrate that the design fulfils the applicable requirements including proper margins

3.2.10 review-of-design

verification method using approved records or evidence that unambiguously show that the requirement is met (e.g. using design documents, design reports, technical descriptions, engineering drawings)

3.2.11 test

verification method by measurement of product performance and functions under representative simulated environments

NOTE See also ECSS-ST-00-01.

3.2.12 Verification Control Board (VCB)

a board composed of customer and supplier representatives that monitors the verification process and formally assesses the requirements verification close-out.

3.2.13 verification level

product architectural level at which the relevant verification is performed

3.3 Abbreviated terms

The following abbreviated terms are used within this document:

Abbreviation	Meaning
AIT	assembly, integration and test
AITP	assembly, integration and test plan
AIV	assembly, integration and verification
AIVP	assembly, integration and verification plan
AOCS	attitude and orbit control system

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Abbreviation	Meaning
AR	acceptance review
ARPT	analysis report
BB	Breadboard
CDR	critical design review
CRR	commissioning result review
CP	commissioning plan
DM	development model
DRD	document requirements definition
ECSS	European Cooperation for Space Standardization
EEE	electronic electrical and electromechanical
EIDP	end item data package
ELR	End of Life Review
EM	engineering model
EMC	electromagnetic compatibility
EOL	end-of-life
EQM	engineering qualification model
FM	flight model
FMECA	failure mode effects and criticality analysis
FRR	flight readiness review
FS	flight spare
GPS	global positioning system
GSE	ground support equipment
H/W	Hardware
HFE	human factors engineering
I/F	Interface
IM	integration model
IRPT	inspection report
ISO	International Organisation for Standardisation
LRR	launch readiness review
LTM	Life Test Model
MU	mock-up
NCR	Non conformance report
NRB	Non conformance review board
OBDH	on-board data handling

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Abbreviation	Meaning
ORR	Operations Readiness Review
P/L	Payload
PDR	preliminary design review
PFM	protoflight model
PRR	preliminary requirement review
PTR	post test review
QA	quality assurance
QM	qualification model
QR	qualification review
RCS	reaction control system
RF	radio frequency
RFW	request for waiver
ROD	review of design
RRPT	review of design report
S/C	spacecraft
S/W	software
SM	structural model
SRR	system requirements review
SS	subsystem
STM	structural-thermal model
SVF	software validation facility
TCL	test configuration list
ThM	thermal model
TPRO	Test Procedure
TRR	test readiness review
TRPT	test report
TSPE	Test Specification
TT&C	telemetry, tracking and command
VCB	verification control board
VCD	verification control document
VP	verification plan
VRPT	verification report

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4 Verification principles

4.1 Introduction

ECSS-E-ST-10 states that verification demonstrates, through a dedicated process, that the deliverable system meets the specified requirements and is capable of sustaining its operational role during the project life cycle.

ECSS-E-ST-10-02 establishes the requirements for the verification of a space system product. It specifies the fundamental concepts of the verification process, the criteria for defining the verification strategy and the requirements for the implementation of the verification programme. It is intended to apply to different products at different levels, from single equipment to the overall system (including space segment hardware and software, ground segment, launchers and transportation systems, Verification tools and GSE).

Concerning the scope of the standard, it is useful to address at this point some frequently asked questions posed by users, in order to emphasize certain concepts and definitions imposed by higher level standards and by the accepted European practices enshrined within the standard.

4.2 Verification versus Validation

A question often posed is why, within European space projects, we mandate a "verification" programme as opposed to a "verification and validation" programme, as practiced in other engineering disciplines (e.g. software, ground segment).

In general terms verification addresses whether a product satisfies the requirements placed upon it, whilst validation addresses whether a product will satisfy the needs of its users, or as is often more simply said,

Verification proves the product is right.

Validation proves it is the right product.

The Verification Standard does not mandate the need for a separate programme of validation of space products, since product verification is performed against a set of requirements that also address the suitability of the product to fulfil the needs of its intended use. However, the standard does not prevent the execution of a separate validation activity if this is considered appropriate, as is practiced for example, in the operation or ground segment domains. Essentially the process to be followed is the same, although it addresses mainly the use of the product.

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4.3 Applicability to all engineering domains

The verification standard is applicable to all engineering domains where space products are developed and as such it is viewed as an "umbrella" under which all domains are covered.

In order to use the standard in a specific engineering domain it is necessary to tailor the standard for that domain and where necessary, to make applicable the standards that define the verification requirements of that domain. A clear example is the verification of the ground segment and operations, whereby its verification is addressed specifically in ECSS-E-ST-70 (Ground systems and operations), by mandating specific verification (and validation) requirements and processes for the ground segment. The fact that ECSS-E-ST-10-02C addresses in detail the space segment does not preclude the use of the standard in other domains, subject to correct tailoring.

4.4 Development

The ECSS glossary defines development as the process by which the capability to adequately implement a technology or design is established before manufacture and that this process can include the building of various partial or complete models of the products in order to assess amongst other things, their performance.

Whilst it is obvious that testing and analysis activities occur during the product development process, they are not addressed by the standard because they are not formal requirement verification activities in the sense of the customer-supplier relationship and consequently do not fall within the mandate of ECSS verification standard.

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5 Verification guidelines

5.1 Verification process

ECSS-E-ST-10-02C clause 5.1 specifies that:

a. The verification process shall demonstrate that the deliverable product meets the specified customer requirements and is capable of sustaining its operational role through:

1. Verification planning;

2. Verification execution and reporting;

3. Verification control and close-out.

The detailed objectives of the Verification process are as follows:

a. to demonstrate the qualification of design and performance, as meeting the specified requirements at the specified levels;

b. to ensure that the product is in agreement with the qualified design, is free from workmanship defects and acceptable for use;

c. to confirm product integrity and performance at particular steps of the project life cycle (e.g. launch, commissioning, mission events and landing).

While this process looks sequential in nature, it is in fact more complex because the verification process of a multi level product is conducted in a top down approach for the planning, while the execution and reporting is conducted bottom up. In addition, the verification control and close-out is conducted in parallel to the entire process.

The verification process activities are incrementally performed at various levels and in different stages, and utilizing a combination of the different verification methods as described in the following clause 5.2.

5.2 Verification planning

5.2.1 Verification approach

5.2.1.1 General

ECSS-E-ST-10-02C clause 5.2.1 specifies that:

a. The customer shall define the project requirements, verification objectives and constraints affecting the supplier verification process.

Note: For example, ground segment characteristics, launch service, envisaged end to end tests involving several suppliers. The usual general objectives are listed in clause 4.1.1 "Verification objectives".

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b. The requirements specified in 5.2.2.1a shall always include those of the technical specification

c. The supplier shall define the verification approach by conducting the following steps:

1. Identify and agree with the customer the set of requirements to be subject of the verification process;

2. Select the methods and levels of verification, associated model philosophy and verification tools;

3. Identify the stages and events in which the verification is implemented.

d. The verification approach shall be defined by the supplier in the Verification Plan (VP) for approval by the customer prior to implementation.

e. For each requirement to be verified, the verification strategy shall be defined in terms of the combination of the selected verification methods for the different verification levels at the applicable verification stages in the initial issue of the Verification Control Document (VCD also called verification matrix (see Annex B), for approval by the customer.

To reach the verification objectives a verification approach is defined in phases A and B of the project by analyzing the requirements to be verified, taking into account:

a. design peculiarities and constraints,

b. qualification status of candidate solutions (product category),

c. availability and maturity of verification tools,

d. verification (including test) methodologies,

e. programmatic constraints, and

f. cost and schedule.

The requirement criticality, in terms of technical and programmatic impacts on the verification implementation, should be assessed by the involvement of the verification team in the requirement definition process during phases A and B, since it drives the verification strategy.

The verification approach should allow:

a. To ensure the definition of correct verification criteria for each requirement by participating in the preparation of product specifications.

b. To assess the impact that verification has on the design (e.g. modularity, testability, and accessibility).

c. To ensure a coherent approach to verification implementation throughout the various levels avoiding duplication of activities.

d. To ensure early verification of critical items to reduce the risks of late failure identification.

e. To ensure the coverage of the interface verification.

f. To optimize the design and use of ground support equipment, simulators, test tools and test software (e.g. re-use between levels, stages and models).

g. To optimize the use of test facilities.

h. To plan for feedback to the verification activity from the commissioning results in case of multi-mission projects or recurring products.

i. To consider innovative solutions that can reduce overall verification costs.

j. To provide visibility and objective evidence of verifications performed.

The use of requirement categories and requirement traceability helps to ensure consistency between verification activities, and to avoid duplications or gaps in the entire verification.

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In generating the verification approach, the supplier conducts the following verification steps (see Figure 5-1) while ensuring coherency across all verification levels

a. Identify “What” are the products and requirements subject of the verification process;

b. Identify “How” to verify them by a selected method of verification at a certain level on the basis of a determined model philosophy during the project implementation phases;

c. Identify “When” to implement the verification steps through selected stages and events all along the project life cycle.

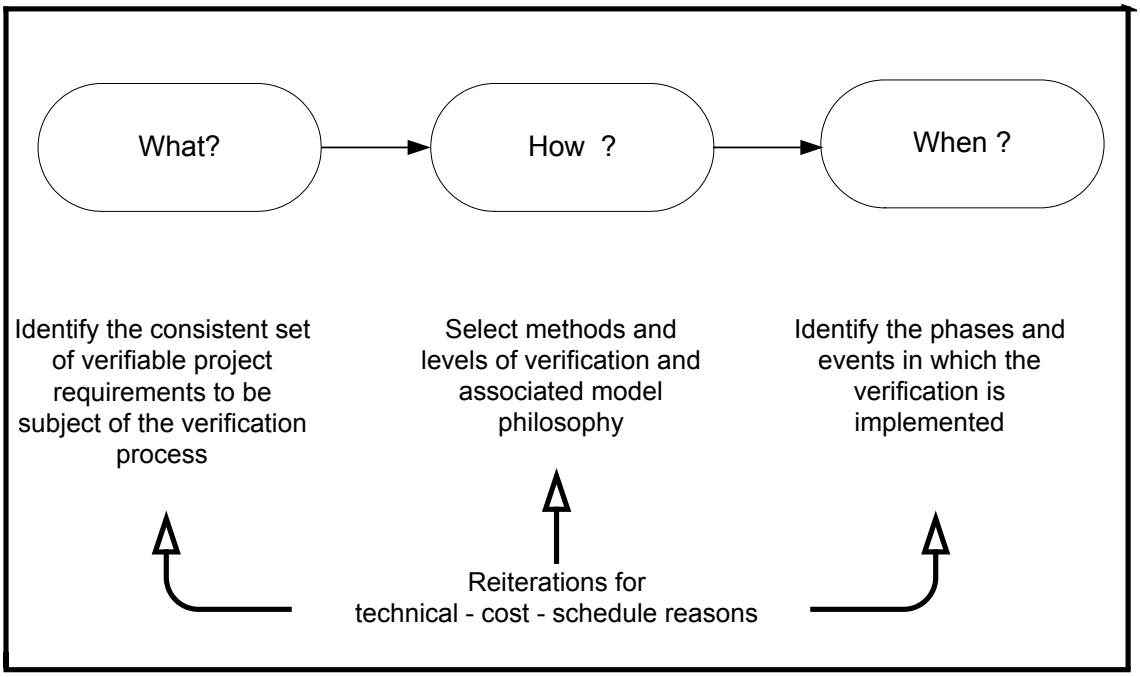

Figure 5-1: Basic verification approach

5.2.1.2 What

Requirements may be grouped in homogeneous category at this step if it facilitates subsequent work. The requirements applicable to a particular product are usually all contained in technical specifications (including interface requirements). A subset of some standards may be part of the set.

In order to facilitate the verification implementation, the project requirement should be:

a. traceable,

b. unique and associated to a proper identifier (preferably a unique requirement ID, in its absence a document and sub clause number,

c. single and not a combination of several requirements,

d. verifiable using one or more approved verification methods,

e. unambiguous,

f. referenced as necessary to other requirements (with applicable document and sub clause identification),

Some requirements are obvious in their verification execution (example: requirements to issue test procedures/reports). To limit the documentation and tracking effort these requirements should be identified and in agreement with the customer marked as "not to be tracked" in the VCD. This means

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that these requirements are still applicable requirements but no formal verification report is issued and tracked in the VCD.

In other words a successful verification starts with a satisfactory set of requirements. Each requirement is seen as both the origin and the conclusion of the verification process, and treated as fundamental technical information rather than a constituent of a verbose text.

5.2.1.3 How

5.2.1.3.1 Overview

Then the supplier defines the verification approach in steps, generally conducted in an iterative process based on technical, cost and schedule considerations.

The verification planning activity should take into account the following elements:

a. the product and specification trees;

b. the applicable models;

c. the estimated duration of procurement, design and manufacturing of each model;

d. the utilization of models (in line with the model philosophy);

e. the estimated duration of the integration of models;

f. the selected test programme and sequences at different levels with estimated time and resources;

g. the analysis, review-of-design and inspection activities combined on the basis of the verification strategies and estimated time and resources;

h. the activities and time associated with the procurement of the verification tools to be used;

i. the project milestones and the verification output.

5.2.1.3.2 Step 1 – method, level, model philosophy and verification tool.

After identification of the requirements to be verified the potential verification methods and alternatives in each particular case are assessed in the context of the overall flow, the testing techniques, and the analytical tools available.

The verification levels are selected, taking into account as a minimum the programmatic aspects specified below:

a. standardized product levels (e.g. service modules);

b. make or buy decisions (e.g. off-the-shelf products);

c. reduction of overhead costs (e.g. deletion of subsystem level);

d. responsibility.

Additionally to the aspects associated with a specific requirement (category), the following rules apply to the selection of levels of verification:

a. In order to have an early feedback in the programme, verification of critical requirements (for instance related to new technologies) should be achieved at the lowest level of integration of the product to which the critical requirement applies.

b. All physical or functional requirements for a given product should be verified on that product level.

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c. Special attention should be given to the selection of levels of verification of external interfaces due to the potential impacts on the verification program.

d. In the case of verification by test, the use of actual interfaces is preferable to the use of simulators.

e. Duplication of verification activities on different levels should be avoided.

f. In addition to the combination of the verification activities between the different levels, the verification of complex functional chains (e.g. operational performances and mechanisms actuation) should include integrated end-to-end testing.

Models are selected by defining the optimum number and type of physical models to achieve a high confidence in the product verification, with the shortest schedule and a suitable balance of costs and risks. Model philosophy should be defined and frozen in project Phase A or B. Examples of model philosophies are prototype, protoflight or a mix of both, called hybrid model philosophy. This is further discussed in clause 5.2.5. The number of models is minimized and their reuse between different levels maximized to reduce costs. Parallel models are utilized in order to suitably separate the test activities from each other and consequently to reduce risks of schedule slippage.

The Design verification (qualification main objective) is carried out on the product which is representative of the end product configuration (e.g. prototype models, flight models in case of protoflight or hybrid approach).

The Workmanship verification (acceptance main objective) is carried out on the final products (e.g. flight models, and spares).

Customer approval is necessary when design parameters, are verified using development models.

5.2.1.3.3 Step 2 - facilities

Selection of the facilities according to their technical characteristics, location, availability and cost.

5.2.1.3.4 Step 3 - resources

Identification of the resources required.

5.2.1.4 When (stage and event)

The verification stages are selected taking into account:

a. the project characteristics,

b. the associated life cycle

c. the adopted model philosophy

Additionally to the aspects associated with a specific requirement (category), the following rules apply to the selection of stages of verification:

a. When due to the mission characteristics verification includes in-flight activities, the verification does not rely only on in-flight activities. Requirements are verified prior to the flight to the extent compatible with the acceptable risks and with the physical possibilities (e.g. microgravity).

b. All verifications associated with any stage should be completed prior to the start of the next stage. In particular, qualification is finished before the start of acceptance.

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5.2.2 Verification methods

5.2.2.1 General

ECSS-E-ST-10-02C clause 5.2.2.1 specifies that:

a. Verification shall be accomplished by one or more of the followings verification methods:
1. test (including demonstration);
2. analysis (including similarity);
3. review-of-design;
4. inspection.

b. All safety critical functions shall be verified by test.

c. Verification of software shall include testing in the target hardware environment.

d. For each requirement verified only by analysis or review-of-design, a risk assessment (part of the VP) shall be conducted to determine the level (major/minor) of the impact of this requirement on the mission.

e. If the impact of the requirement is major, a risk mitigation plan (part of the VP) shall be defined which includes a cross check based on two independent analyses (in terms of model used and suppliers).

Test is the preferred verification method as it provides generally a higher confidence in the verification of a product's performance and design. If a representative test cannot be conducted, then an analysis substitutes or complements it.

In selecting the verification method/levels/stages the following guidelines are considered:

a. The selected method does not produce risks to personnel, flight hardware and facilities;

b. The selected method is feasible and the required facilities exist as far as possible.

c. The selection of the methods considers the level of confidence that can be achieved with a given fidelity, accuracy, and validity;

d. Analysis is used when flight conditions cannot be accurately simulated on the ground and/or when it is not economically feasible to test the entire spectrum of flight conditions. Analysis and test methods are very often complementary.

e. If several verification methods are possible with the same level of confidence on the verification results, the selection is oriented to minimize the required effort (impact on cost and schedule)

f. Verification of critical requirements (for instance related to new technologies) should be achieved as soon as possible (e.g. at the lowest suitable level) to have early feedback on the programme.

g. To bypass difficulties of testing (i.e. size of facilities, test representativeness) in presence of complex systems or to minimize expensive system testing a combined approach could be selected including test campaign at lower level and analysis at higher level.

h. In particular if environmental testing at higher level is impracticable or too costly, lower level testing should be carried out, completed by analysis, to demonstrate compliance with higher level requirements.

i. When mission characteristics require in-flight verification, the verification does not rely on on-orbit activities only; requirements are verified with proper methods prior to the first flight.

j. Internal and external interface verification is carried-out at the appropriate responsibility level. In case of testing the use of actual interfaces is preferable to the use of simulators.

k. The lower level verification should be completed prior to the associated higher level one.

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l. Duplication of verification activities on different levels should be avoided.

m. The verification in any stage should be completed prior of the start of the next stage, in particular qualification should be finished before acceptance start.

n. Final verification of software is performed by test in the target hardware environment.

o. the verification of complex functional chains (typically operational performances and mechanisms actuation) should plan for an integrated end-to-end testing, in addition to the verification activities performed at lower levels

p. All physical or functional requirements for a given product should be verified on that particular product level to the maximum extent feasible and reasonable.

q. Attention should be paid to avoid over-testing, since parts and equipment are being tested at parts, equipment, subsystem and system level.

r. Verification by similarity is an exceptional process, which can be applied only if all the conditions mentioned in Clause 5.2.2.3.b are met. It cannot be considered as a standard verification method.

The four verification methods are not necessarily applicable or efficient for all stages (and all the stages are not applicable to all the products). The following table provides a synthesis of the following requirements while adding some example.

Method	Test	Analysis	Review of Design	Inspection
Qualification stage	X	X	X	X
Acceptance stage	X			X
pre-launch stage	X			X
in-orbit stage (including commissioning)	X	X(1)	X(2)	X (3)
post-landing stage	X			X

(1) For example budgets (e.g. link, power, mass).

(2) In this case limited to the software change process for in-flight software or ground segment software.

(3) For manned spacecraft or for ground segment.

5.2.2.2 Test

ECSS-E-ST-10-02C clause 5.2.2.2 specifies that:

a. Verification by test shall consist of measuring product performance and functions under representative simulated environments.

b. The analysis of data derived from testing shall be an integral part of the test *and the results included in the test report*.

c. When the test *objectives* include the demonstration of qualitative operational performance, the execution shall be observed and results recorded.

d. A test programme shall be prepared for each product in compliance with test requirements specified in ECSS-E-ST-10-03.

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e. The test programme shall be coordinated with the integration flow.

f. Tests performed as part of the integration flow to check quality and status of the in-progress configuration (including interfaces), having a formal verification purpose, shall be included in the test programme.

g. The test programme shall *be defined in the Assembly, Integration and Test plan (AITP)).*

Although the detailed requirements concerning testing are captured in the test standard ECSS-E-ST-10-03, the verification standard provides high level requirements for all verification methods in order to have a coherent verification approach

In defining the test programme the following guidelines are considered:

a. Critical products and interfaces are tested early in phase C/D of the programme.

b. Test flow and sequence are based on the possibility to detect potential failures and defects early in the test programme.

c. The balance of costs and risks is taken into account.

d. Work around plans and contingencies are taken into account.

e. Re-integration testing (also called regression testing) should be avoided.

f. Test feasibility should be confirmed in phase A or B of the programme.

g. The reuse of models, simulators and support equipment should be considered.

Tests are selected based on their effectiveness in verifying the specified requirements considering lessons learned, statistical data from past projects and state of the art test methods. The lessons learned and the statistical data (combining information on ground testing failures and flight anomalies) are useful to determine test effectiveness. Failures not detected during ground testing can end up as early flight failures.

The impacts of the de-integration and re-integration tests (also called regression tests) on the verification program are assessed. De-integration and re-integration are performed for various reasons e.g. fault-findings, during post landing phase in the case of multimission or to carry-out modifications or repairs.

Starting from the initial VCD, test matrices are established showing the correlation of requirements (categories) with the test to be performed at the different levels in the various verification stages. They identify the test verification events to be used for planning purposes.

Test is further addressed in the Test handbook.

5.2.2.3 Analysis

ECSS-E-ST-10-02C clause 5.2.2.3 specifies that:

a. Verification by analysis shall consist of performing theoretical or empirical evaluation using techniques agreed with the Customer.

Note: Techniques comprise systematic, statistical and qualitative design analysis, modelling and computational simulation.

b. Verification by similarity shall be part of the verification by analysis.

c. Similarity analysis shall provide evidence that an already qualified product fulfils the following criteria:

1. The already qualified product was not qualified by similarity.

2. The product to be verified belongs to category A or to category B (defined in Table 5-1) but no testing is required to achieve qualification.

Note: Implicitly the product to be verified cannot belong to categories C and D equipment (defined in Table 5-1).

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d. Similarity analysis shall define any difference that can dictate complementary verification activities.

e. An analysis programme shall be defined in the Verification Plan (VP).

f. An analysis programme shall be applicable to qualification and in-orbit stages only.

An analysis programme compatible with the selected verification approach is defined on the basis of the verification strategies for the various requirements (categories). In defining the analysis programme the following guidelines are considered:

a. The analytical technique is validated. The verification by analysis is dependant on the quality of the analytical techniques and on the experience gained in using them.

b. Mathematical model used to perform the analysis should be verified, as far as possible, with laboratory data or in-flight data.

c. When analysis is supported by test data, testing is performed on a representative model.

d. The modelling system used is described, and its usage justified.

e. The product configuration, to which the analysis applies, is identified.

f. All boundary conditions are stated.

g. All assumptions used in the analysis are stated.

h. The field of investigation and the range of validity of the results are defined.

i. The analytical uncertainty is taken into account such that specified performance is demonstrated with a defined margin.

j. Analysis covers both the nominal and the worst case conditions.

k. Analysis for verification may use existing analysis prepared for other purposes (e.g. design or requirement allocation)-

l. Analysis can be used in support of test or vice versa.

m. Analysis may be used at all verification levels.

Starting from the initial VCD, analysis matrices are established showing the correlation of the requirements (categories) with the analyses to be performed at the different levels. These matrices identify the analysis verification events to be used for planning purposes.

Sometime the expressions “qualification by similarity”, or “verification by similarity” are used in an improper way. Verification by similarity is not an additional verification method on top of the 4 defined in the standard. A similarity analysis can be conducted on a product in order to provide evidence that it belongs to category A (as defined in Table 5-1). If it is achieved, then the new product is considered qualified (by similarity) as specified in clause 5.2.4.2. If the similarity analysis shows that the product belongs to category B, then the similarity analysis should provide sufficient information to allow determining the required delta qualification programme.

5.2.2.4 Review-of-design (ROD)

ECSS-E-ST-10-02C clause 5.2.2.4 specifies that:

a. Verification by Review-of design (ROD) shall consist of using approved records or evidence (e.g. design documents and reports, technical descriptions, engineering drawings) that unambiguously show that the requirement is met.

Note: Examples of such approved records are design documents and reports, technical descriptions, and engineering drawings

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b. A review-of-design programme shall be defined in the Verification Plan (VP).

c. A review-of-design programme shall only be applicable in the qualification stage or in the in-orbit stage

A review-of-design programme, compatible with the selected verification approach, is defined on the basis of the verification strategies for the different requirement (categories). In defining the review-of-design programme, the following guidelines are considered:

a. The activity should be carried out simultaneously with the product design reviews.

b. The activity may include the review of lower level records (e.g. requirement verified by test at a lower level).

Verification by review-of-design may be used at all verification levels.

Starting from the initial VCD, review-of-design matrices are established showing the correlation of the requirement categories with the review-of-design activities to be performed at the different levels. These matrices identify the review-of-design verification events to be used for planning purposes.

Review of design in the in-orbit stage is limited to the software change process See ECSS-E-ST-40 for more details.

5.2.2.5 Inspection

ECSS-E-ST-10-02C clause 5.2.2.5 specifies that:

a. Verification by inspection shall consist of visual determination of physical characteristics.

Note: Physical characteristics include constructional features, hardware conformance to document drawing or workmanship requirements, physical conditions, software source code conformance with coding standards.

b. An inspection programme shall be defined in the Verification Plan (VP).

Inspection can be complementary to review of design.

An inspection programme compatible with the selected verification approach and model philosophy is defined on the basis of the verification strategies for the different (categories of) requirement. In defining the inspection programme the following guidelines are considered:

a. The activity should be carried out together with quality assurance tasks during the manufacturing or integration process.

b. The activity may be performed by the crew during the in-orbit verification.

c. Inspection can be complementary to the review-of-design.

Verification by inspection may be used in all stages and all verification levels.

Starting from the initial VCD, inspection matrices are established showing the correlation of the requirement categories with the inspections to be performed at the different levels in the applicable verification stages. These matrices identify the inspection verification events to be used for planning purposes.

5.2.3 Verification levels

ECSS-E-ST-10-02C clause 5.2.3.1 specifies that:

a. Verification shall be accomplished through the selected verification levels.

Note: Usual levels are defined in 4.2.3

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b. When a requirement is fully verified at lower level, the traceability to lower level verification evidence shall be identified.

c. Formal close-out of qualification and acceptance at lower levels shall be performed prior to close-out at higher level.

The number and type of verification levels depends upon the complexity of the project and on its characteristics (levels are generally derived from product and specification trees). The usual verification levels for a space project are:

a. Equipment (e.g. valves, batteries and individual electronic boxes);

b. Subsystem (e.g. electrical power, attitude control, structure, thermal control and software);

c. Element (e.g. launcher, satellite, ground segment);

d. Overall system (e.g. combined space and ground segments, manned infrastructure system).

Below the equipment level there is the parts and materials level. The general requirements for the evaluation, approval and procurement of parts and materials are defined in ECSS-Q-ST-60 and ECSS-Q-ST-70.

The identification of the verification levels is driven by technical and programmatic considerations (e.g. functional architecture and overhead cost) having in mind that verification is carried out against the applicable requirements under the responsibility of the organization upon which the requirements are placed.

5.2.4 Verification stages

5.2.4.1 General

ECSS-E-ST-10-02C clause 5.2.4.1 specifies that:

a. Verification shall be accomplished through the selection of the appropriate stages on the basis of project specificity from the following:

1. qualification,

2. acceptance,

3. pre-launch,

4. in-orbit (including commissioning),

5. post-landing.

b. Qualification, acceptance and pre-launch stages shall be completed before launch.

c. When the verification programme includes an in-orbit stage, the verification shall not rely only on in-orbit activities.

d. When the verification programme includes a post landing stage, the verification shall not rely only on in-orbit activities or post landing activities.

Even if the verification programme includes an in-orbit stage or a post landing stage, the verification is conducted also before launch (this is shown with the entries in the Verification stages of the VCD relevant to pre-launch on-ground verification e.g. qualification, acceptance).

5.2.4.2 Qualification

ECSS-E-ST-10-02C clause 5.2.4.2 specifies that:

a. In the qualification stage the verification shall demonstrate that the design, including margins, meets the applicable requirements.

b. Qualification shall be carried-out on hardware and software which is representative of the product configuration in terms of design, materials, tooling and methods.

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c. The qualification programme shall be prepared considering the product category according to heritage as defined in Table 5-1.

Table 5-1: Product categories according to heritage

(Table 5-1 of ECSS-E-ST-10-02)

Category	*Description*	*Qualification programme*
A	*Off the shelf product without modifications and* • *subjected to a qualification test programme at least as severe as that imposed by the actual project specifications including environment and* • *produced by the same manufacturer or supplier and using the same tools and manufacturing processes and procedures*	*None*
B	*Off the shelf product without modifications. However:* • *It has been subjected to a qualification test programme less severe or different to that imposed by the actual project specifications (including environment).*	*Delta qualification programme, decided on a case by case basis.*
C	*Off the shelf product with design modifications* *Modification includes changes to design, parts, materials, tools, processes, procedures, supplier, or manufacturer*	*Delta or full qualification programme (including testing), decided on a case by case basis depending on the impact of the modification..*
D	*Newly designed and developed product.*	*Full qualification programme.*

During this stage, verification activities are executed with the objective to demonstrate that the design being qualified and therefore that the flight product will fulfil the requirements in the expected environment. To cover the uncertainties in measurement and environment, margins are applied. Discipline specific margins (e.g. power, frequency, data rate, processor loading) are defined in the discipline specific standards. Test margins and tolerances are defined in the testing standard ECSS-E-ST-10-03. These margins have also to cover the aspect that the flight product has to survive the flight levels/stresses as well as the acceptance tests.

The qualification programme for Cat B product has mainly to cover the differences in the requirements, including the environment.

In case of a different supplier, changed processes or different parts, it also demonstrates that the final product still fulfils the requirements. The delta qualification programme therefore concentrates on these aspects.

Cat C products have design modifications with respect to the originally qualified design. The delta qualification programme in this case concentrates on the impact of these changes on the qualification. In case of major modifications a full qualification programme is performed.

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5.2.4.3 Acceptance

ECSS-E-ST-10-02C clause 5.2.4.3.1 specifies that:

a. In the acceptance stage the verification shall demonstrate that the product is free of workmanship errors and is ready for subsequent operational use.

b. Acceptance shall be carried-out on the final hardware and software.

ECSS-E-ST-10-02C clause 5.2.4.3.2 specifies that:

a. The acceptance article shall be manufactured in agreement with the qualified design.

b. The acceptance article shall perform as the qualified product.

During this stage, verification activities are executed with the objective to demonstrate that the product under acceptance:

a. conforms to its relevant qualified design,

b. is not affected by defects that could be introduced during manufacturing or assembly, either by workmanship or by inadequate process,

c. is able to fully provide its required functions and performances, as specified for flight.

This verification process applies on hardware and software in their full flight configuration.

5.2.4.4 Pre-launch

ECSS-E-ST-10-02C clause 5.2.4.4 specifies that:

a. In the pre-launch stage the verification shall demonstrate that the product is properly configured for launch activities and early operations.

b. In the pre-launch stage the verification shall confirm that the product is capable of functioning as planned during launch and early operations.

A number of activities are usually accomplished during the pre-launch stage. These activities are needed to demonstrate that the transportation to the launch site or any storage condition have not damaged the product , to put the flight product in its specific launch configuration, and to integrate it with the launcher vehicle where applicable, depending on the product level.

Test and inspection techniques are applied at this stage. They complement the verification activities completed at acceptance, where the real flight products and interfaces now replace the use of the simulators.

5.2.4.5 In-orbit

ECSS-E-ST-10-02C clause 5.2.4.5 specifies that:

a. In the in-orbit stage the verification shall ensure no degradation occurred during the launch, early orbit phase, at periodical intervals and before specific operational use.

b. In the in-orbit stage the verification shall supplement/confirm ground verification by providing operating conditions which cannot be fully or cost effectively duplicated or simulated on ground.

c. In the in-orbit stage the verification shall characterize the system under operational conditions especially for the aspects that cannot be determined before the launch.

d. In the in-orbit stage the verification shall confirm that the space and ground elements are compatible with each other.

e. In the in-orbit stage the verification shall perform calibration and tuning activities specific to the mission payload.

Note: The working arrangement between the elements suppliers (e.g. satellite, ground segment) and the final customer defines the share of responsibilities

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for preparing, conducting and reporting the in orbit - commissioning activities. The completion of this stage allows declaring readiness for routine operations (Phase E2-exploitation).

The in-orbit stage is valid for projects where, due to their characteristics (e.g. mission or in-orbit operations), in-orbit verification is performed.
The space element supplier should update its analyses and mathematical models using in-orbit experience and the telemetry made available by the Customer (e.g. thermal, power, aero-thermal behaviour during re-entry, RF link budget).
Verification at periodical intervals concerns generally health check. The periodicity is mission dependent and agreed with the customer.
For GEO and LEO satellites, this verification during in-orbit stage is done during the commissioning shortly after the launch.
For other missions (e.g. moon, planets, comets, inter-planetary…), this verification may be delayed until reaching the targeted location(s) and environment(s).

5.2.4.6 Post-landing

ECSS-E-ST-10-02C clause 5.2.4.6 specifies that:

a. The verification in the post-landing stage shall address the product integrity and performance after the mission.

b. In case the product is intended to be re-launched the verification shall address:
   1. *health check, at periodical intervals agreed with the customer, during storage periods;*
   2. *the product performance after modification, repair or replacement;*
   3. *the readiness for reuse.*

The post-landing stage is valid for projects that, due to their characteristics (e.g. multi-mission projects), post-landing verification is performed.

Many projects are actually facing a return to earth or a multi-mission scenario (e.g. re-entry demonstrators, NASA STS, the Logistics Modules for the ISS) and in the next future, it is expected that the re-usable launchers or the advanced crew transportation systems, including associated re-entry demonstrators, will see similar perspectives.

In this context the classical verification stages, completed with the in-orbit activities, are complemented by additional post-landing verification. In the case of a simple re-entry, it covers at least the product integrity and performance after the mission.

In case of subsequent mission, it covers at least the health checks during storage, the product performance after modification, repair or replacement and the readiness for reuse. For products to be re-launched, the verification programme is updated taking into account the previous flight verification programme and in-orbit experience. This program is established by reviewing and assessing existing documentation, on the basis of the requirements for the new flight and by inspecting the hardware and software to be re-flown.

5.2.5 Models and Models Description

5.2.5.1 Introduction

ECSS-E-ST-10-02C clause 5.2.5 specifies that:

a. *The model philosophy shall be defined as part of the overall verification planning.*

During the development and verification process of a product various models are used. The model philosophy defines the optimum number and the characteristics of physical models required to

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achieve confidence in the product verification with the shortest planning and a suitable weighing of costs and risks.

The following guidelines, relevant mainly to flight elements, are intended to help the definition of the models involved in the verification process and the selection of the associated model philosophy. This section starts with a description of the models (build status and use) involved in the verification process, then criteria are established how to select a model philosophy and examples of typical model philosophies are provided.

Clause 5.2.5.2 describes the various models; the ECSS Glossary ECSS-ST-00-01C section 3.3 gives the definition of the main ones.

5.2.5.2 Models description

5.2.5.2.1 General

Various types of models can be employed according to verification requirements. These models can either be hardware models, virtual models (software simulators and analytical models) or a combination of both (hybrid models). A short description of the major models used is given. These models are maintained under configuration control (except models used for development purposes). The Table 5-2 provides a schematic summary of the models with related objectives, representativity and applicability. The representativity of the models depends from their intended use.

5.2.5.2.2 Mock-Up (MU)

Mock-Ups are used in support of design definition for overall architecture analyses, configuration design and assessment, interface control and definition, human factors and human computer interface (HCI) assessment, operational procedures evaluation and layout optimization.

According to their representativity, mock-ups are classified as:

a. Low fidelity: to be used in the initial verification phases (generally, mock-ups for human factors engineering requirement development activities or for validation of software HCI requirements).

b. High fidelity: under configuration control in all areas where interface control and flight hardware manufacturing support is provided (e.g. area of utility routing, connector brackets and attach points).

The Mock-Ups can be incremental tools, i.e. they are progressively upgraded to reflect a final configuration.

Mock-Ups intended for human factors evaluation are also used in test campaigns such as parabolic flights, buoyancy and swimming pool tests. Their representativity depends on the type of test to be performed.

5.2.5.2.3 Development Model (DM)

In general the Development Models are used in the development areas of new design or where substantial redesign is performed. They are applicable to every type of product (e.g. electronic box, mechanisms, structural parts and thermal equipment) and can be subjected to functional and/or environmental testing. Development Models of subsystems are also envisaged such as: thermal control active control loop breadboards, attitude & orbit control system and guidance & navigation control benches. The DM is sometimes also called Bread Board model (BB)

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