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Space systems — Verification programme and management process

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Foreword

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

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

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

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

This verification programme document provides top-tier and overarching requirements in space programmes. Implementation will ensure thoroughly verified space systems in a timely and cost-effective manner for verification distributed among all participating organizations (see AIAA S-117).

Many space programmes are very complex systems consisting of numerous elements (such as spacecraft, launch and ground segments, systems, subsystems, units, interfaces). It is common for these elements to be distributed across many international/domestic contractors, subcontractors, and suppliers with little room for failure/mistakes in any part of a space system. This is what is meant as a distributed program in the context of this document. A critical function of any distributed verification programme is to ensure that a thorough and solid specification is established for each level of a system being developed. This is accomplished if the system developer for each level contractually takes responsibility/ownership of developing their specifications in coordination with their systems engineering organization. This approach ensures that requirements establishment and associated verification activities are well integrated. Additionally, cost constraints often require avoidance of additional verification due to late changes. Lack of detailed descriptions in specifications can cause costly late changes and/or post-launch failures. Mission success does not allow unrecoverable post-launch failures; as such, verification of space systems requires technical communication of verification means, data and data aggregation among all involved (system contractors, subcontractors and vendors).

This document ensures that requirements associated with space system missions, concept of operation (mission operation concept), contractual agreed normative references as well as each contractor's command media are thoroughly verified with the use of a distributed verification programme. It defines a standardized set of verification management processes for each element of a space system from the earliest to the latest phase and from the lowest to the highest level of their developments in order to acquire/deliver thoroughly verified systems.

The need for a distributed verification programme was identified based on the evaluation of over 130 space systems failures associated with international, commercial, and government space programmes (see INCOSE Journal).

Every element of a space system can be verified and tracked by each work breakdown structure based working group (WBS-WG; see ISO 21349) utilizing standardized verification management (VM) processes as follows:

a) VM process 1: requirements flow-down and establishment of specification;

b) VM process 2: verification cross-reference matrix (VCRM);

c) VM process 3: integration and test (I&T);

d) VM process 4: use of a specification verification ledger (SVL);

e) VM process 5: acceptance/delivery reviews

f) VM process 6: verification-related risk and issue/watch list management

This document also helps each space programme to integrate any heritage/commercial systems to new programmes by examining whether the applicability of these systems has been thoroughly verified. Appropriate modifications of any heritage/commercial systems for new/modified systems are systematically identified and verification accomplished by applying these uniform six verification management processes.

Space systems — Verification programme and management process

1 Scope

This document establishes a set of requirements for planning and executing verification programmes for commercial/non-commercial manned and unmanned space systems.

This document defines a distributed verification programme for each contractor that engages in the development of any element of a space system, starting from the lowest level (i.e. unit/piece part level) and the earliest phase (i.e. requirement phase) to the acceptance and the delivery review of a system's development as well as the launch site activities.

This document primarily addresses verification associated with space, launch, and ground segment acquisitions. Space support segments including range safety, ground support equipment, and launch operation facilities, which are not otherwise addressed in this document, can also benefit from the described verification programme and management processes.

2 Normative references

There are no normative references in this document.

3 Terms and definitions and abbreviated terms

3.1 Terms and definitions

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

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

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

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

3.1.1
heritage system
system/item with from the original supplier that has maintained the great majority of the original service, design, performance and manufacturing and has already flown in space

3.1.2
late change
change to the space, launch, ground segments, or their interfaces, procedures or processes, which compromise or potentially invalidate previously executed verification approved at each system level preliminary design review (PDR) and/or critical design review (CDR)

3.1.3
mission critical failure
condition that meets one or more of the following criteria:

a) failure leading to inability to meet/achieve mission objective (e.g. payload or spacecraft bus is no longer capable of supporting the mission objectives);

b) inability to meet minimum performance specifications for primary mission;

c) degrading condition whose trend indicates a loss of mission before mean mission duration or design life;

d) repetitive transient condition(s) that, uncorrected, would lead to an unacceptable loss of mission performance, data or services (e.g. satellite with processor susceptibility to single event upsets in orbit with mean time to upset much less than mean time to recovery from upset*)*

3.1.4
operational test and evaluation
test and evaluation that represents the mission in terms of phase, transitions, environments, personnel and events in an end-to-end system configuration (i.e. combination of hardware/software and data when functioning as an integrated system), accepting mission inputs, executing mission functions and producing mission outputs according to the typical operational rhythm, timelines, and sequences resulting in end-user goals (products, services, and timeliness)

3.1.5
specification verification ledger
digital database for verification information of the space system specification

3.1.6
subject matter expert
person with substantial knowledge of, and experience with, the topic at hand, including terms, technology and methods

3.1.7
verification cross-reference matrix
matrix, usually electronic database of some type, maintained to correlate all verification needs within an assigned portion of a program, up to and including a complete program matrix

Note 1 to entry: The matrix does not replace other verification plans or requirements, but is a summary of them.

3.1.8
verification method
method including test, analysis, demonstration, or inspection

Note 1 to entry: See ISO 9000.

3.1.9
verification record
record of requirement conformity or compliance based on the assigned *verification method(s)* (3.1.8)

3.2 Abbreviated terms

AIAA	American Institute of Aeronautics and Astronautics
CDR	critical design review
CDRL	contract data requirements list
COTS	commercial, off-the-shelf
CM	configuration management
DT&E	development test and evaluation
EM	engineering module
EMC	electro-magnetic compatibility
EMI	electro-magnetic interference

FCA	functional configuration audit
I&T	integration and test
IF	interface
LRR	launch readiness review
MRR	manufacturing readiness review
NRB	non-conformance review board
OT&E	operational test and evaluation
PCA	physical configuration audit
PDR	preliminary design review
PMPCB	parts, materials, and processes control board
QA	quality assurance
SC	spacecraft
SVL	specification verification ledger
SDR	system design review
SRR	system requirements review
TPRD	test parameters requirements document
TRR	test readiness review
VCRM	verification cross-reference matrix
VM	verification management
WC	worst-case
WBS	work breakdown structure
WBS-WG	WBS-based working group

4 Requirements for space system verification management processes

4.1 General

Each space system and lower-level systems developer shall implement the verification processes detailed in 4.2 through 4.7. To better support a specific programme or project, the processes defined in this document may be tailored to match the actual requirements or needs of the programme.

4.2 VM process 1: requirement flow-down and establishment of specification

4.2.1 General

The developers of each level of the system, in coordination with their systems engineering organizations, develop a system-level specification with both performance and verification requirements for their system. They capture the requirements that are flowed down from the top-level space system to WBS elements, external interface specifications, and concept of operations (CONOPS) of their system.

They capture all the derived and specific requirements including those of normative references that are necessary to design and develop their system. They also capture/modify all the heritage system requirements that are compatible with the top-level requirements determined by the requirements flow-up process.

Each specification shall include sections relating to:

a) the function, performance, constraints, and normative references for the product;

b) a detailed statement of how verification will be made for each separate requirement.

This includes verification methods and associated verification approaches.

NOTE 1 Specifications are defined in ISO 9000.

NOTE 2 See ISO/IEC/IEEE 15288 for flow-down and flow-up in the systems engineering "V".

NOTE 3 See ISO 16404 for general requirement management process including those associated with support to systems engineering activities such as those associated with verification and configuration management.

NOTE 4 See ISO 14711 for CONOPS-related documents.

4.2.2 Specification requirements and review

4.2.2.1 General

Specifications shall be delivered for review at each corresponding system level's review from the top system level to the lowest unit level specification [e.g. system requirements review (SRR), system design review (SDR), preliminary design review (PDR), critical design review (CDR)].

NOTE See ISO 14300-1 for project phasing and reviews.

4.2.2.2 Top-level requirements flowed-down/up documented traceability

Each of the top space system level requirements flowed down/up shall have documented traceability in the verification record to the lowest level of the work breakdown structure (WBS).

4.2.2.3 Verification of non-derived requirements specific to each system

Verification requirements shall capture all the non-derived requirements that are specific to each of the elements being developed.

NOTE Non-derived requirements are requirements which do not have a parent requirement in the next higher level, such as those that are needed to satisfy heritage systems.

4.2.2.4 Verification of compatibility of heritage systems requirements

When heritage systems are used, verification requirements shall ensure that each of the requirements in the heritage system specification is compatible with and supports the higher- and lower-level system requirements. If not, they need to modify any noncompliant requirements accordingly (see ISO 16290).

4.2.2.5 Requirement verifiability

Each of the requirements shall be verifiable by analysis, test, inspection or demonstration or a combination of them (see ISO 9000).

4.2.2.6 Normative references flow-down

Each of the normative references listed at any system level shall also be flowed down from the appropriate level specification to any of the applicable lower level specifications.

4.2.2.7 Configuration management (CM)

The system level requirements shall be under CM control upon completion of SRR.

Lower level requirements shall be under CM control upon completion of PDR.

The requirements flow-down and flow-up efforts should be accomplished by utilizing data management software in order to effectively manage any part of system level requirements flowed down/up to/from any other system levels.

Validation of the developed specification may be considered as completed after independent subject matter experts from external organizations have reviewed the specification and their comments are incorporated into the specification.

4.2.3 Data supporting verification method and approach

Each specification verification implementation shall include data and processed data (information) which establishes the satisfaction of the requirement as well as the associated upper level requirements. This includes a synopsis and rationale for the actual implementation approach for each requirement.

4.3 VM process 2: verification cross-reference matrix (VCRM)

4.3.1 Cross-reference of specification requirements and verification method

The VCRM shall cross-reference specification requirements, their verification methods, verification level and milestones.

4.3.2 VCRM for the space system and lower level systems

Verification plans for the space system and all the lower-level systems, including external and internal IFs, are delivered at major reviews (See Clause 5). These plans shall include the VCRM for each level.

4.3.3 Verification by analysis

a) Design and analysis documents shall be developed for each level of the system being developed (system, subsystem, unit, etc.) and ensure that all the “verify by analysis” requirements in the corresponding specification are documented and satisfied.

   NOTE A list of analyses along with the approaches and methods, and a set of design reference cases that defines reasonable worst-case conditions and other conditions for each analysis used for “verification by analysis” are identified and documented.

b) Design analyses sometimes require the support from test results. In these cases, a list of “verify by test” requirements that require development test to support the design analysis shall also be included in the design and analysis list.

c) When a space safety-critical design or function is only satisfied by “verify by analysis” requirements in the corresponding specification and determined as one of the pass/failure criteria for the associated PDR and CDR, then a risk assessment shall be conducted and included of the contribution to residual risk on people, the space environment, and the mission, because of the space safety-critical design or function in question.

4.3.4 Verification by test

“Verification by test” is accomplished using such tests as development test, prototype test, life test, pre-flight brass board/engineering modules tests, actual flight system integration and acceptance/qualification test, and operational test depending on the nature of the requirements being verified.

A list of tests, approaches (such as with the use of flight units, engineering units, breadboard, coupons, software/hardware-in-the-loop test), and test conditions for “verification by test” shall be included in the VCRM and reviewed at the corresponding system’s PDR, CDR and TRR.

a) “Verification by test" based on development hardware/software or breadboard testing may be required to substantiate related analyses or vice versa. These development test lists, approaches, conditions and results are normally reviewed along with the associated analyses.

b) “Verification by test" requirements under the acceptance/qualification tests, shall be listed in a test parameters requirement document (TPRD) and incorporated into the corresponding test plan that is developed based on VM process 3, explained in 4.4.

4.3.5 Verification by inspection and demonstration

A list of and detailed approaches for “verification by inspection” and “verify by demonstration” requirements shall be developed for each of the applicable space system and lower level system specifications.

4.4 VM process 3: integration and test (I&T) process

4.4.1 General

In preparation for the I&T life cycle phase, system I&T plans shall be developed for the space system and each of the lower-level systems to ensure that the “as built” system is rigorously tested for acceptance tests,qualification tests or tests related to the mitigation of potential mission critical failures.

NOTE See ISO 17566, ISO 17401, ISO 14303, and ISO 15864 which define test documentation, spacecraft interface requirements document, launch-vehicle-to-spacecraft interfaces, and general test methods respectively.

4.4.2 Review of I&T plans for the space system and lower level systems

I&T plans for each of the spacecraft, launch vehicle, ground system and each of the internal and external interfaces including those developed by subcontractors and vendors shall be delivered for review and approval at each corresponding PDR, CDR, and TRR.

4.4.3 Space system and lower-level I&T sequence and test environments

A test sequence, environment types/levels, duration, and test monitoring approaches/methods, with documented rationales for selecting the acceptance, proto-qualification, or qualification test programme shall be established and documented for each of the space system and lower-level systems including those developed by subcontractors and vendors.

4.4.4 Operational tests for space system

An operational test plan shall be developed and executed prior to launch/operations to verify critical mission characteristics including the planned mission sequences, events, transitions, timelines, processes, configurations, command operations, data/telemetry downlinks and processing, and deployment functions.

NOTE An operational test is based on effectiveness (can the system perform the mission) and suitability (can the system perform the mission in a manner that is affordable and sustainable) without artificial constraints to the fullest extent possible.

4.4.5 Test readiness review (TRR) and entry/exit criteria

TRR shall be conducted prior to each of the space system and lower level systems I&T based on the entry and exit criteria that are reviewed and approved at PDR, CDR, and/or pre-TRR.