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Space systems — Definition of the Technology Readiness Levels (TRLs) and their criteria of assessment

Systèmes spatiaux — Definition des Niveaux de Maturité de la Technologie (NMT) et de leurs critères d'évaluation

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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. www.iso.org/directives

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The committee responsible for this document is ISO/TC 20, *Aircraft and space vehicles*, Subcommittee SC 14, *Space systems and operations*.

Introduction

Technology Readiness Levels (TRLs) are used to quantify the technology maturity status of an element intended to be used in a mission. Mature technology corresponds to the highest TRL, namely TRL 9, or flight proven elements.

The TRL scale can be useful in many areas including, but not limited to the following examples:

a) For early monitoring of basic or specific technology developments serving a given future mission or a family of future missions;

b) For providing a status on the technical readiness of a future project, as input to the project implementation decision process;

c) In some cases, for monitoring the technology progress throughout development.

The TRL descriptions are provided in Clause 3 of this International Standard. The achievements that are requested for enabling the TRL assessment at each level are identified in the summary table in Clause 4. The detailed procedure for the TRL assessment is to be defined by the relevant organization or institute in charge of the activity.

This International Standard was produced by taking due consideration of previous available documents on the subject, in particular including those from the National Aeronautics Space Administration (NASA), the US Department of Defence (DoD) and European space institutions (DLR, CNES and ESA).

Space systems — Definition of the Technology Readiness Levels (TRLs) and their criteria of assessment

1 Scope

This International Standard defines Technology Readiness Levels (TRLs). It is applicable primarily to space system hardware, although the definitions could be used in a wider domain in many cases.

The definition of the TRLs provides the conditions to be met at each level, enabling accurate TRL assessment.

2 Terms and definitions

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

2.1
breadboard
physical *model* (2.10) designed to test functionality and tailored to the demonstration need

2.2
critical function of an element
mandatory function which requires specific *technology* (2.19) verification

Note 1 to entry: This situation occurs when either the element or components of the element are new and cannot be assessed by relying on previous realizations, or when the element is used in a new domain, such as new environmental conditions or a new specific use not previously demonstrated.

Note 2 to entry: Wherever used in this International Standard, "critical function" always refers to "technology critical function" and should not be confused with "safety critical function".

Note 3 to entry: Wherever used in this International Standard, "critical function" always refers to "critical function of an element".

2.3
critical part of an element
element (2.4) part associated to a critical function

Note 1 to entry: The critical part of an element can represent a subset of the element and the technology verification for the critical function may be achievable through dedicated tests achieved on the critical part only.

Note 2 to entry: Wherever used in this International Standard, "critical part" always refers to "technology critical part".

Note 3 to entry: Wherever used in this International Standard, "critical part" always refers to "critical part of an element".

2.4
element
item or object under consideration for the technology readiness assessment

Note 1 to entry: The element can be a component, a piece of equipment, a subsystem or a system.

2.5
element function
intended effect of the *element* (2.4)

2.6
functional performance requirements
subset of the *performance requirements* (2.14) of an *element* (2.4) specifying the *element functions* (2.5)

Note 1 to entry: The functional performance requirements do not necessarily include requirements resulting from the *operational environment* (2.11).

2.7
laboratory environment
controlled environment needed for demonstrating the underlying principles and functional performance

Note 1 to entry: The laboratory environment does not necessarily address the *operational environment* (2.11).

2.8
mature technology
technology defined by a set of *reproducible processes* (2.17) for the design, manufacture, test and operation of an *element* (2.4) for meeting a set of *performance requirements* (2.14) in the actual *operational environment* (2.11)

2.9
mission operations
sequence of events that are defined for accomplishing the mission

2.10
model
physical or abstract representation of relevant aspects of an *element* (2.4) that is put forward as a basis for calculations, predictions, tests or further assessment

Note 1 to entry: The term "model" can also be used to identify particular instances of the element, e.g. flight model.

Note 2 to entry: Adapted from ISO 10795, definition 1.141.

2.11
operational environment
set of natural and induced conditions that constrain the *element* (2.4) from its design definition to its operation

EXAMPLE 1 Natural conditions: weather, climate, ocean conditions, terrain, vegetation, dust, light, radiation, etc.

EXAMPLE 2 Induced conditions: electromagnetic interference, heat, vibration, pollution, contamination, etc.

2.12
operational performance requirements
subset of the *performance requirements* (2.14) of an *element* (2.4) specifying the *element functions* (2.5) in its *operational environment* (2.11)

Note 1 to entry: The operational performance requirements are expressed through technical specifications covering all engineering domains. They are validated through successful in orbit operation and can be verified through a collection of element verifications on the ground which comprehensively cover the operational case.

Note 2 to entry: The full set of performance requirements of an element consists of the operational performance requirements and the performance requirements for the use of the element on ground.

2.13
performance
aspects of an *element* (2.4) observed or measured from its operation or function

Note 1 to entry: These aspects are generally quantified.

Note 2 to entry: Adapted from ISO 10795, definition 1.155.

2.14
performance requirements
set of parameters that are intended to be satisfied by the *element* (2.4)

Note 1 to entry: The complete set of performance requirements inevitably include the environment conditions in which the element is used and operated and are therefore linked to the mission(s) under consideration and also to the environment of the system in which it is incorporated.

2.15
process
set of interrelated or interacting activities which transform inputs into outputs

Note 1 to entry: Inputs to a process are generally outputs of other processes.

Note 2 to entry: Processes in an organization are generally planned and carried out under controlled conditions to add value.

Note 3 to entry: A process where the conformity of the resulting product cannot be readily economically verified is frequently referred to as a “special process”.

[SOURCE: ISO 10795, definition 1.160]

2.16
relevant environment
minimum subset of the *operational environment* (2.11) that is required to demonstrate *critical functions of the element* (2.2) performance in its *operational environment* (2.11)

2.17
reproducible process
process (2.15) that can be repeated in time

Note 1 to entry: It is fundamental in the definition of “mature technology” and is intimately linked to realization capability and to verifiability.

Note 2 to entry: An element developed “by chance”, even if meeting the requirements, can obviously not be declared as relying on a *mature technology* if there is little possibility of reproducing the element on a reliable schedule. Conversely, reproducibility implicitly introduces the notion of time in the mature technology definition. A technology can be declared mature at a given time, and degraded later at a lower readiness level because of the obsolescence of its components or because the processes involve a specific organization with unique skills that has closed.

2.18
requirement
need or expectation that is stated and to be complied with

Note 1 to entry: Adapted from ISO 10795, definition 1.190.

2.19
technology
application of scientific knowledge, tools, techniques, crafts, systems or methods of organization in order to solve a problem or achieve an objective

2.20
validation
confirmation, through objective evidence, that the *requirements* (2.18) for a specific intended use or application have been fulfilled

Note 1 to entry: The term “validated” is used to designate the corresponding status.

Note 2 to entry: The use conditions for validation can be real or simulated.

Note 3 to entry: May be determined by a combination of test, analysis, demonstration, and inspection.

Note 4 to entry: When the element is validated it is confirmed that it is able to accomplish its intended use in the intended *operational environment* (2.11).

Note 5 to entry: Adapted from ISO 10795, definition 1.228.

2.21
verification
confirmation through the provision of objective evidence that specified *requirements* (2.18) have been fulfilled

Note 1 to entry: The term "verified" is used to designate the corresponding status.

Note 2 to entry: Confirmation can be comprised of activities such as: performing alternative calculations, comparing a new design specification with a similar proven design specification, undertaking tests and demonstrations, and reviewing documents prior to issue.

Note 3 to entry: Verification may be determined by a combination of test, analysis, demonstration, and inspection.

Note 4 to entry: When an element is verified, it is confirmed that it meets the design specifications.

Note 5 to entry: Adapted from ISO 10795, definition 1.229

3 Technology Readiness Levels (TRLs)

3.1 General

A technology for an element intended for an application reaches the maturity level, corresponding to TRL 9, when it is well-defined by a set of reproducible processes for the design, manufacture, test and operation of the element and when, in addition, the element meets a set of performance requirements in the actual operational environment.

The element under consideration is assumed to be a physical part of a system. Systems are generally subdivided into sub-systems with potentially several sub-levels. The element can be any part of the system and is not necessarily a specific sub-system or at a specific sub-level.

A prerequisite for TRL assessment is the identification of the element that is subject to the assessment. Higher TRLs further require the definition of the performance requirements, and therefore require the knowledge of the mission and the system where the element is intended to be used and its operational environment. Performance requirements can be preliminary and targeting several missions at low TRLs, then progressively refined and verified at higher levels.

The entire TRL scale applies for a given element. Therefore, there is no gradation in the element complexity when moving from low to high TRLs.

Higher TRLs also imply that the element is in its final form and is being integrated into a system for validation or use. Therefore, the TRL of a given element may be downgraded if this same element is used in a different system, unless all environment and interface requirements for the element in the new system can be demonstrated to be equally or less demanding than for the original system.

A TRL assessment is valid for a given element and at a given point in time. It may evolve if the conditions that prevailed at the time of the assessment are no longer valid. Such a situation may lead to TRL reassessment and degradation, which can occur in particular when the re-build/re-use of an element is envisioned. Examples are when the obsolescence of the electronics requires modifications or when the production involves a specific knowledge that has been lost.

The time or effort to move from one TRL to another are technology dependent and are not linearly connected to the TRL scale. Experience shows that they can vary widely depending on the element and mission under consideration. Therefore, while the TRL scale is an appropriate tool for assessing the technology maturity status at a given point in time, it gives no indication of the effort and cost to be spent for reaching the next level.

While TRL 9 refers to mature technology, lower TRLs reflect the fact that one or more conditions for reaching a mature technology have not been met, such as:

a) The processes involved for the element manufacturing have not been fully defined,

b) The operational performance requirements have not yet been fully defined,

c) The element has not yet been fully defined,

d) The element has not yet been built,

e) The element performance requirements have not yet been demonstrated in its operational environment.

When the element is an integrated system or subsystem, it can consist of sub-elements, each involving some specific technology. In that case, the TRL of the element cannot be greater than that of the individual sub-elements.

For each TRL, the expected status of the element performance requirements is stated in the description.

3.2 TRL 1 — Basic principles observed and reported

3.2.1 Description

Scientific research exists related to the technology to be assessed and begins to be translated into applied research and development. Basic principles are observed and reported through academic-like research. Potential applications are identified but performance requirements are not yet specified.

At TRL1, no specific mission can be associated with the technology as concepts and/or applications are only formulated at TRL 2. Therefore, the performance requirements may not be defined at this stage.

3.2.2 Examples

The following are examples of TRL 1:

a) In 1895 German physicist William Conrad Roentgen discovered X-rays.

b) Superconductivity is discovered by H. Kamerlingh Onnes in 1911, showing abrupt disappearance of electrical resistance for certain materials below a characteristic temperature.

c) In October 2010 researchers announced the discovery of the world’s second giant virus, dubbed CroV. This virus, which infects single-cell marine creatures, is considered enormous due to the size of its genome – approximately 730 000 base pairs, or genetic building blocks, more than double the size of the largest known “normal” virus.

3.3 TRL 2 — Technology concept and/or application formulated

3.3.1 Description

Once basic principles are observed, practical applications can be invented. Applications are speculative and there may be no proof or detailed analysis to support the assumptions.

At TRL 2, the element performance requirements are general and broadly defined but consistent with any formulated concept or application.

3.3.2 Examples

The following are examples of TRL 2:

a) The use of a superconducting material, such as aluminium or titanium, around its superconducting transition edge temperature is envisioned for building high sensitive bolometric detectors. Energy