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

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

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

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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.

2.7
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 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 coupled to the detector increases the temperature of the superconducting material, pushing it further into the non-superconducting state and thereby increasing its electrical resistance. This increase in resistance can be used to detect very small changes in temperature, and hence in energy.

b) The concept of using the photoelectric effect for building solar cell power generators is formulated.

3.4 TRL 3 — Analytical and experimental critical function and/or characteristic proof-of-concept

3.4.1 Description

The proof of the element function or characteristic is done by analysis, including modelling and simulation, and by experimentation. The proof must include both analytical studies to set the technology into an appropriate context and laboratory-based experiments or measurements to physically support the analytical predictions and models.

At TRL 3, the element performance requirements are general, broadly defined and can be preliminary. They are consistent with any formulated concept or application. The element functional performance requirements are established and the objectives are defined in relation to the current state of the art.

3.4.2 Examples

The following are examples of TRL 3:

a) High efficiency Gallium Arsenide solar panels for space application are conceived for a use over a wide temperature range. The concept critically relies on an improved welding technology for the cell assembly. Samples of solar cell assemblies are manufactured and submitted to a preliminary thermal environment test at ambient pressure for demonstrating the concept viability.

b) A fibre optic laser gyroscope is elaborated using optical fibres for the light propagation and Sagnac effect. The overall concept is modelled including the laser source, the optical fibre loop and the phase shift measurement. The laser injection in the optical fibre and the detection principles are supported by dedicated experiments.

c) A chemical propulsion engine for a rocket is elaborated using oxygen and hydrogen propellants stored in liquid form. The injection system principle using liquid oxygen and hydrogen is demonstrated with a dedicated test bench.

3.5 TRL 4 — Component and/or breadboard functional verification in laboratory environment

3.5.1 Description

A laboratory breadboard model of the element is integrated to establish that the “pieces” will work together to demonstrate the basic functional performance of the element. The verification is “low fidelity” compared to the eventual system, and is limited to laboratory environment.

At TRL 4, as for TRL 3, the element performance requirements are general and broadly defined. They are consistent with any potential system applications. The element functional performance requirements are established and the objectives are defined in relation to the current state of the art.

3.5.2 Examples

The following are examples of TRL 4 (with reference to the examples given for TRL 3):

a) Gallium Arsenide solar panel: Solar panel breadboards are manufactured using the solar cells assembly technology and the selected interconnectors. The breadboards are submitted to a reduced thermal environment test and to a functional performance assessment.

b) Fibre optic laser gyroscope: A breadboard model is built including the proposed laser diode, optical fibre and detection system. The angular velocity measurement performance is demonstrated in the laboratory for one axis rotation.

c) Bi-liquid chemical propulsion engine: A breadboard of the engine is built and thrust performance is demonstrated at ambient pressure.

3.6 TRL 5 — Component and/or breadboard critical function verification in a relevant environment

3.6.1 Description

TRL 5 is reached when the critical functions of the element are demonstrated in the relevant environment using appropriate breadboards, which are generally not full scale or full function. The test performance is in agreement with analytical predictions.

At TRL 5, the mission objectives and operational environment are preliminary but sufficiently understood for enabling a preliminary definition of: the element performance requirements, the associated relevant environment, and the preliminary design of the element. Missing or incomplete requirements are acceptable at this stage as far as they do not affect the identification of the element critical functions and the associated verification plan.

For reaching TRL 5, the critical functions of the element are identified, requiring specific verification, and the corresponding relevant environment is defined. In relation with the critical functions identification, scaling requirements are defined and a verification plan is established and the breadboard tests successfully executed for securing the element performance and removing the unknowns.

The breadboards can be tailored to the critical function verification needs but shall be representative of the element, as necessary for unambiguously removing the unknowns and demonstrating the element performance.

It is worth noting that some of the critical function unknowns can be related to the performance requirements themselves. For example, a performance or design parameter can be unknown or inaccurately specified, although clearly associated to a critical function and to well-defined mission performance requirements. For this specific case, the breadboard demonstration should mitigate the uncertainty on this parameter, with potential feedback on the element design.

When TRL 5 is reached, the element feasibility can be considered as demonstrated, subject to scaling effects, since the critical functions performance is verified through breadboard testing in the relevant environment. The element performance requirements are often consolidated at this stage, taking into account the breadboard verification tests. However, the element development is not fully secured because of uncertainty resulting from scaling effects. There are also remaining risks associated with a failure in the identification of critical functions, a lack of completeness in the associated verification plan, and/or an underestimation of coupling effects between the element parts that make the model(s) inappropriate for removing the unknowns.

3.6.2 Examples

The following are examples of TRL 5:

a) A 3,5 m two-mirror space telescope is proposed for far infrared astronomy and is operated at 70 K. The primary mirror is parabolic and is made of 12 silicon carbide petals assembled with a high-temperature brazing process. The optical performance in cold environment is identified as a critical function and the 3,5 m primary mirror as a critical part. A 1,3 m spherical mirror breadboard is manufactured and measured at 70 K for demonstrating the optical performance in cold environment. The breadboard is made of nine brazed petals using the same manufacturing processes that are foreseen for the flight full scale model. The expected performance of the 3,5 m telescope is extrapolated from the breadboard test results using mathematical models.

b) A 6, m deployable space telescope comprised of multiple petals is proposed for near infrared astronomy operating at 30 K. The optical performance of the individual petals in cold environment is identified as a critical function and is driven by the material selection. A series of 1 m mirrors (corresponding to a single petal) were fabricated from different materials and tested at 30 K to evaluate performance and select the final material for the telescope. Performance was extrapolated to the full sized mirror.

c) For a launch vehicle, TRL 5 is the level demonstrating the availability of the technology at subscale level. For instance, the fuel management is a critical function for a reignitable upperstage. The demonstration of the management of the propellant is achieved on ground and at subscale level since a full scale demonstration can hardly be achieved at this stage.

3.7 TRL 6 — Model demonstrating the critical functions of the element in a relevant environment

3.7.1 Description

TRL 6 is reached when the critical functions of the element are verified in the relevant environment. For that purpose, a representative model(s) in terms of form, fit and function is used for demonstrating the critical functions and unambiguously demonstrating the element performance. The test performance is in agreement with analytical predictions.

At TRL 6, as for higher TRLs, the mission objectives, operational environment and the operational performance requirements are established and agreed upon by the stakeholders, taking into account the element integration in the final system.

The element's overall performance is in principle demonstrated. In particular, it should be possible at this stage to establish a development schedule for the element. There are remaining development risks regarding performance which can include: a failure in the identification of critical functions, a lack of completeness in the associated verification plan, and/or an underestimation of coupling effects between the element parts that make the model(s) inappropriate for removing the unknowns.

3.7.2 Examples

The following are examples of TRL 6:

a) A Doppler lidar is proposed for wind speed measurement from space. It features a high power laser, a telescope for the laser pulse emission, a large two-mirror receiving telescope for the signal collection, a receiver assembly and an electronics control unit. The instrument lifetime is identified as being a critical function because of the uncertain lifetime of the laser due to the use of high energy laser pulses. The laser system is the corresponding critical part of the lidar. A full scale model of the laser source assembly is manufactured and tested in the relevant environment (e.g. operation in vacuum and high energy pulse mode) for demonstrating the laser lifetime.

b) A remote sensing camera includes a large 3-mirror telescope, a detection assembly, a cooling chain for the detector cooling and an electronics control unit. All elements have been demonstrated at TRL 6 except for the mirror assembly and its optical performance in orbit, which is driven by the distance between the primary and secondary mirrors needing to be stable within a fraction of a micrometre. The corresponding critical part includes the two mirrors and their supporting structure. A full scale breadboard consisting of the two mirrors and the supporting structure is built and tested in the relevant environment (e.g. including thermo-elastic distortions and launch vibrations) for demonstrating the required stability can effectively be met with the proposed design.

c) For a launch vehicle, the propellant management or the reignitable upper-stage in a 'zero gravity' environment is identified as a critical function. For that purpose, a full scale demonstration of the reignitable upper-stage is done with testing of critical parts in the 0-g relevant environment using parabolic flights and sounding rockets.

3.8 TRL 7 — Model demonstrating the element performance for the operational environment

3.8.1 Description

TRL 7 requires the validation of the element performance through testing to demonstrate performance in the operational environment.

At TRL 7, the mission objectives, operational environment and the operational performance requirements are established and agreed upon by the stakeholders, taking into account the element integration in the final system.

For reaching TRL 7, a representative model, fully reflecting all aspects of the flight model design, is operated in an environment which replicates all of the necessary conditions of the actual operational environment to demonstrate that it will perform in that actual operational environment.

When the model demonstration is achieved on the ground, the element model is submitted to a series of tests which are conceived for representing the expected operational environment with adequate margins. Therefore, the model is not intended to be used for flight, since it is generally over-tested. However, in some cases the testing processes and margins are adapted for the model to be flown.

When operational environment is mandatory for the performance demonstration, the model is the first representation of the element that is flown.

3.8.2 Examples

The following are examples of TRL 7:

a) Spacecraft units or equipment are generally requested to reach this level on ground prior to the integration of the flight units on the spacecraft, by submitting the hardware to a dedicated test programme. Examples of units are the star tracker, multi-layer thermal insulation, power control and distribution electronic unit, on-board computer, etc. The tests at unit level are conceived to cover the effective environment that is expected to be experienced by the unit inside the spacecraft and in the operational environment.

b) In some cases, the element is such that its performance demonstration cannot be achieved through ground testing only and requires full operational testing. This situation occurs for a launch vehicle, where only the first flight can be viewed as a performance demonstration in the operational environment. This situation can also occur for some specific instruments for which performance demonstration in Earth gravity environment is considered as hardly possible.

c) Equipment can reach TRL 7 either in the context of a spacecraft development for a given mission, or independently through dedicated investments. However, when the equipment is foreseen to be used for another mission at a later stage, its TRL may need to be reassessed, as mentioned in Clause 4. Any evolution in the equipment hardware and/or in the performance requirements may require complementary demonstration tests for confirming TRL 7.

3.9 TRL 8 — Actual system completed and accepted for flight (“flight qualified”)

3.9.1 Description

The qualified element is integrated into the final system ready to be flown.

At TRL 8, the mission objectives, operational environment and the performance requirements are established and agreed upon by the stakeholders, taking into account the element integration in the final system.

For reaching TRL 8, the system, including the element under consideration, has been accepted for flight. By definition, all technologies being applied in actual systems go through TRL 8.

3.9.2 Examples

This level is reached by all elements after spacecraft flight readiness acceptance.

3.10 TRL 9 — Actual system “flight proven” through successful mission operations

3.10.1 Description

The qualified element is integrated in the final system and in service for the assigned mission.

At TRL 9, the mission objectives, operational environment and the performance requirements are established and agreed upon by the stakeholders, taking into account the element integration in the final system.

TRL 9 is reached and the element is mature following successful operation and performance achievement in the actual operational environment.

3.10.2 Examples

This level is reached by all spacecraft after successful commissioning in operational service.

4 Summary table

Table 1 provides a summary of TRLs as resulting from their definition. The second column describes the milestone reached at each TRL, while the third column provides a description of the information to be documented for enabling a proper TRL assessment. The detailed procedure for the TRL assessment is to be defined by the relevant organization or institute in charge of the activity.

Table 1 — TRL summary: Milestones and work achievement

Technology Readiness Level	Milestone achieved for the element	Work achievement (documented)
TRL 1: Basic principles observed and reported	Potential applications are identified following basic observations but element concept not yet formulated.	Expression of the basic principles intended for use. Identification of potential applications.
TRL 2: Technology concept and/or application formulated	Formulation of potential applications and preliminary element concept. No proof of concept yet.	Formulation of potential applications. Preliminary conceptual design of the element, providing understanding of how the basic principles would be used.
TRL 3: Analytical and experimental critical function and/or characteristic proof-of-concept	Element concept is elaborated and expected performance is demonstrated through analytical models supported by experimental data/characteristics.	Preliminary performance requirements (can target several missions) including definition of functional performance requirements. Conceptual design of the element. Experimental data inputs, laboratory-based experiment definition and results. Element analytical models for the proof-of-concept.
TRL 4: Component and/or breadboard functional verification in laboratory environment	Element functional performance is demonstrated by breadboard testing in laboratory environment.	Preliminary performance requirements (can target several missions) with definition of functional performance requirements. Conceptual design of the element. Functional performance test plan. Breadboard definition for the functional performance verification. Breadboard test reports.

Table 1 *(continued)*

Technology Readiness Level	Milestone achieved for the element	Work achievement (documented)
TRL 5: Component and/or breadboard critical function verification in a relevant environment	Critical functions of the element are identified and the associated relevant environment is defined. Breadboards not full-scale are built for verifying the performance through testing in the relevant environment, subject to scaling effects.	Preliminary definition of performance requirements and of the relevant environment. Identification and analysis of the element critical functions. Preliminary design of the element, supported by appropriate models for the critical functions verification. Critical function test plan. Analysis of scaling effects. Breadboard definition for the critical function verification. Breadboard test reports.
TRL 6: Model demonstrating the critical functions of the element in a relevant environment	Critical functions of the element are verified, performance is demonstrated in the relevant environment and representative model(s) in form, fit and function.	Definition of performance requirements and of the relevant environment. Identification and analysis of the element critical functions. Design of the element, supported by appropriate models for the critical functions verification. Critical function test plan. Model definition for the critical function verifications. Model test reports.
TRL 7: Model demonstrating the element performance for the operational environment	Performance is demonstrated for the operational environment, on the ground or if necessary in space. A representative model, fully reflecting all aspects of the flight model design, is built and tested with adequate margins for demonstrating the performance in the operational environment.	Definition of performance requirements, including definition of the operational environment. Model definition and realization. Model test plan. Model test results.
TRL 8: Actual system completed and accepted for flight ("flight qualified")	Flight model is qualified and integrated in the final system ready for flight.	Flight model is built and integrated into the final system. Flight acceptance of the final system.
TRL 9: Actual system "flight proven" through successful mission operations	Technology is mature. The element is successfully in service for the assigned mission in the actual operational environment.	Commissioning in early operation phase. In-orbit operation report.

Bibliography

[1] ISO 10795, *Space systems — Programme management and quality — Vocabulary*

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