NASA Procedural Requirements

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Appendix E. Technology Readiness Levels

TRL	Definition	Hardware Description	Software Description	Exit Criteria
1	**Technology Research** - Basic principles observed and reported	Lowest level of technology readiness. Scientific research begins to be envisioned as applied research and development. Examples might include paper studies of a technology's basic properties.	Scientific knowledge generated underpinning basic properties of software architecture and mathematical formulation.	Peer reviewed publication of research underlying the proposed concept/application.
2	**Technology concept** - Concept and/or application formulated	Invention begins. Once basic principles are observed, practical applications can be invented. The application is speculative, and there is no proof or detailed analysis to support the assumption. Examples are still limited to paper studies.	Practical application is identified but is speculative; no experimental proof or detailed analysis is available to support the conjecture. Basic properties of algorithms, representations, and concepts defined. Basic principles coded. Experiments performed with synthetic data.	Documented description of the application/concept that addresses feasibility and benefit.

3	**Proof-of-Concept** - Analytical and experimental critical function and/or characteristic proof-of-concept	At this step in the maturation process, active research and development (RandD) is initiated. This must include both analytical studies to set the technology into an appropriate context and laboratory-based studies to physically validate that the analytical predictions are correct. These studies and experiments should constitute "proof-of-concept" validation of the applications/concepts formulated at TRL 2.	Development of limited functionality to validate critical properties and predictions using non-integrated software components.	Documented analytical/experimental results validating predictions of key parameters.
4	**Technology Demonstration** - Generic design demonstrating concept-enabling performance consistent with potential applications - Low-fidelity validation of critical functions using breadboards/brassboards with non-flight-like parts and packaging in a laboratory environment at room temperature or environment required for functional validation	Following successful "proof-of-concept" work, a single technological element is integrated to establish that the pieces will work together to achieve concept-enabling levels of performance for a component and/or breadboard/brassboard. This validation must be devised to support the concept that was formulated earlier and should also be consistent with the requirements of potential system applications. The validation is relatively "low fidelity" compared to the eventual system.	Key, functionality critical software components are integrated and functionally validated to establish interoperability and begin architecture development. Relevant environments defined and performance in the environment predicted.	Documented test performance demonstrating agreement with analytical predictions. Documented definition of relevant environment.
5	Conceptual Design and Prototype Demonstration - Flight performance requirements, definition of critical environments, preliminary interfaces, and conceptual design complete - Components characterized - Performance, lifetime, and "robustness" in critical environments	The fidelity of the component and/or subassembly being tested has to increase significantly. The basic technological elements must be integrated with reasonably realistic supporting elements so that the total applications (component-level, subsystem-level, or system-level) can be	End-to-end software elements implemented and interfaced with existing systems/simulations conforming to target environment. End-to-end software system tested in relevant environment, meeting predicted	Documented test performance demonstrating agreement with analytical predictions. Documented definition of scaling requirements.

	validated by analysis - Components and subassemblies with new technology or moderate to significant engineering development validated in newly developed areas using stand-alone subassembly-level prototypes of approximate size, mass, and power and built with anticipated "flight-like" parts and materials tested in a laboratory environment at extremes of temperature and radiation (if relevant)	tested in a "simulated" or somewhat realistic environment.	performance. Operational environment performance predicted. Prototype implementations developed.	
6	Preliminary Design and Prototype Validation - Preliminary assembly, subsystem, and system hardware and software design complete - Multiple assemblies or subassemblies incorporating new technology or moderate to significant engineering development validated in newly developed areas using engineering models (integrated form, fit, function prototypes) of the correct size, mass, and power, built with flight-like parts, materials, and processing and packaging, tested in a flight-like environment over the range of critical flight-like conditions	A major step in the level of fidelity of the technology demonstration follows the completion of TRL 5. At TRL 6, a representative engineering model or prototype system or system, which would go well beyond ad hoc, "patch-cord," or discrete component level breadboarding, would be tested in a relevant environment. At this level, if the only relevant environment is the environment of space, then the model or prototype must be demonstrated in space-like environments.	Prototype implementations of the software demonstrated on full-scale, realistic problems. Partially integrated with existing hardware/software systems. Limited documentation available. Engineering feasibility fully demonstrated.	Documented test performance demonstrating agreement with analytical predictions.
7	Detailed Design and Assembly Level Build - Final assembly, subsystem, and system hardware and software design, interfaces, performance, and constraints documented -Production capability and/or parts availability, discrepancy paper, drawings, CAD/CAM files, and vendor's current capability validated -Near flight-like assemblies pass stress and life tests that demonstrate significant margins operating at extremes of input and output over a range of driving environments -Flight-like assemblies or subsystems successfully pass function/performance validation tests	Assemblies near or at planned operational system. TRL 7 is a significant step beyond TRL 6, requiring an actual prototype demonstration in a space environment. The prototype should be near or at the scale of the planned operational system, and the demonstration must take place in space environments. Examples include testing the near flight-like assemblies in an environmentally realistic test bed.	Prototype software exists having all key functionality available for demonstration and test. Well integrated with operational hardware/software systems demonstrating operational feasibility. Most software bugs removed. Limited documentation available.	Documented test performance demonstrating agreement with analytical predictions.

8	Subsystem Build and Test - Flight assemblies fabricated, integrated, and functionally tested - Build and test procedures qualified in subsystem assembly facility - Flight subsystems built and functionally tested - Identical/actual flight subsystem environmentally tested	Technology has been proven to work in its final form and under expected conditions. In almost all cases, this level is the end of true system development for most technology elements. This might include integration of new technology into an existing system.	All software has been thoroughly debugged and fully integrated with all operational hardware and software systems. All user documentation, training documentation, and maintenance documentation completed. All functionality successfully demonstrated in simulated operational scenarios. Verification and validation completed.	Documented test performance verifying analytical predictions.
9	System Operational - Flight system build and test procedures qualified in flight system integration facility - Flight system integrated and functionally tested against requirements and operating scenarios - Flight system environmentally tested	Actual application of the technology in its final form and under mission conditions, such as those encountered in operational test and evaluation. In almost all cases, this is the end of the last "bug fixing" aspects of true system development. This TRL does not include planned product improvement of ongoing or reusable systems.	All software has been thoroughly debugged and fully integrated with all operational hardware and software systems. All documentation has been completed. Sustaining software support is in place. System has been successfully operated in the operational environment.	Documented mission operational results.

Note: In cases of conflict between NASA directives concerning TRL definitions, NPR 7123.1 will take precedence.

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