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Science Office for Mission Assessments

SOMA

Assessment of TRL in AO-Based Evaluations and Common Causes of Major TRL Weaknesses

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Outline

- Background
- Technology Readiness Level and AOs
- Common TRL Major Weaknesses
  - The TRL of the system (WBS Level 3) is either not provided or is inadequately supported.
  - The Plan to establish TRL 6 at the system level is inadequate.
  - Significant number of elements require technology maturation.
  - Software development is not addressed and only hardware is considered in the TRL assessment.
  - Heritage is claimed to elements designed and built by institutions not included on the proposing team.
  - Statement that institutional evaluation determined TRL 6 without explanation.
- Expected Compliance with AO
  - TRL assessment is performed at the systems level (WBS Level 3).
  - Technology maturation plan is defined and resources are scoped.
- Backup Slides

Technology Readiness Level and the AO

- TRL levels and criteria are defined in NPR 7123.1B Appendix E and the NASA Systems Engineering Handbook NASA/SP-2016-6105 Rev 2.
- The SALMON-3 AO and the 2018 HPSMO PEA M TRL requirements are derived from and are consistent with these definitions.
- TMC evaluation is consistent with the relevant AO and these definitions.
  - Per the AO, TRL is assessed at the "system level" defined as WBS Level 3, i.e., individual instrument and spacecraft subsystem level.
  - Weaknesses are assessed if the requirements of the AO or PEA are not met.

Common TRL Major Weaknesses 1

- The TRL of the system (WBS Level 3) is either not provided or is inadequately supported. The rationale for establishing TRL 6 is not provided. For example,
  - Only component level TRL assessment is performed and component TRL is either explicitly equated with system level TRL or system level TRL assessment is omitted. No rationale is provided why component level establishes the system level TRL.
    - The current state of integration and/or the complexity of integrating new components is not addressed.
    - TRL 6 elements are used in a new way that lowers the TRL which is not accounted for in the rationale.
    - Integration of lower TRL level components into a new or existing design is not addressed.
  - TRL of the systems cannot be higher than lowest component TRL. Integration complexity can lower the system level TRL below that of the lowest component.
  - Component TRL is inadequately supported. For example,
    - The assumed relevant environment is not explicitly stated or is incorrectly stated.
    - The relevant environment is stated too broadly or the TRL assessment does not adequately take into account the as-proposed mission unique design configuration or environment, which changes the heritage TRL values.
  - Claimed testing to establish TRL 6 is inadequately described.
    - Test results are not shown demonstrating performance agreement with analytical predictions even though testing is claimed.
    - Test configuration is inadequately described to establish that the unit tested meets the definition of prototype and is sufficiently similar to the proposed unit.

Common TRL Major Weaknesses 2

- The plan to establish TRL 6 at the system level is inadequate and does not meet the AO requirements. For example,
  - The plan only addresses maturation of individual components. Integration into the system is not planned and the rationale for omitting an integrated test is not provided.
  - Testing described does not include sufficient parameters to demonstrate adequate performance for the mission. Scaling is not adequately justified.
  - Description of the intended test setup and/or included hardware/software for the testing is not provided.
  - Differing definitions of development units, e.g., breadboard, brassboard, prototype, engineering model, leads to uncertainty if the test unit is insufficiently described.
    - Descriptions should be provided consistent with NPR 7123.1B.
  - TRL 6 exit criteria is not provided, i.e., what performance is sufficient.
  - The “relevant” environment is not defined. Environmental testing is inadequately described and is not linked to the mission environments.
  - No estimate of the resources (staffing, cost, and schedule) required to complete the technology development is provided.
    - Or, the resources described are assessed as insufficient and the proposal lacks justification.

Common TRL Major Weaknesses 3

- Significant number of elements require technology maturation. The AO specifies "Proposals with a limited number of less mature technologies and/or advanced engineering developments when proposed are permitted”.
  - Too many elements requiring technology maturation spread the team too thin and cannot be accomplished within limited time and budget prior to PDR.
  - The technology maturation plan does not demonstrate how the multiple elements will be managed, staffed, and funded within limited resources.
- Software development is not addressed and only hardware is considered in the TRL assessment
  - NPR 7123.1B includes both hardware and software TRL definitions.
  - New and/or unique approaches that are implemented in software must also be demonstrated to TRL 6.
- Heritage is claimed to elements designed and built by other institutions not included on the proposing team.
  - Recreating someone else’s design lowers the TRL for this application.
  - Since the design will not be the same, heritage to external elements only demonstrates that such technology is feasible but not that this design is at TRL 6.
- Statements that institutional evaluation establishes TRL 6 without further explanation
  - The supporting rationale and assessment criteria are not provided. The basis for the institutional evaluation is not provided.

Expected Compliance with AO

- TRL assessment is performed at the system level (WBS Level 3: individual instrument or spacecraft subsystem).
  - Component TRLs are provided and substantiated.
  - Rationale for combining component TRLs, including integration complexity, to establish system TRL is provided.
  - Relevant environment(s) is clearly established and reflects proposed mission. Planned testing and/or analysis sufficiently represents the environment.

- Technology maturation plan is defined and resources are scoped.
  - The plan clearly defines the approach including scaling, performance, analysis, and testing. Test configurations, testing to be performed, and success criteria are described.
  - Analysis tools are defined. Integration of analysis and test are described.
  - Resources are clearly identified and quantified with detailed schedule and cost provided. Durations are supported.

BACKUP SLIDES

SALMON-3 AO HPSMO PEA M

- Section 5.3.4 Science Investigations
  - New Technologies/Advanced Engineering Developments are described in Section 5.3.5 of the SALMON-3 AO. This PEA solicits science PMO, NMES, and SCM investigations with associated TRL 6 by PDR requirements; it does not solicit technology or advanced engineering development projects.
  - Note that Section 5.3.5 of the SALMON-3 AO references NASA/SP-2007-6105 Rev 1, *NASA Systems Engineering Handbook.* The latest version of this document, NASA/SP-2016-6105 Rev 2, should be used instead, and is available in the Program Library.

SALMON-3 AO

Appendix B, F.4 New Technologies/Advanced Engineering Developments

- PEAs issued by NASA STMD, including those that solicit a technology demonstration investigation as opposed to a science or exploration investigation, will require technologies to be matured to TRL-5, not TRL-6, no later than PDR and therefore Requirement B-46 applies for TRL-5 by PDR. If Requirement B-46 is not applicable, it will be replaced by requirements in the applicable PEA.

Requirement B-46. This section shall describe any proposed new technologies and/or advanced engineering developments and the approaches that will be taken to reduce associated risks. Descriptions shall address, at a minimum, the following topics:

- Identification and justification of the TRL for each proposed system (level 3 WBS payload developments and level 3 WBS spacecraft elements) incorporating new technology and/or advanced engineering development at the time the proposal is submitted (for *TRL definitions*, see NPR 7123.1B, *NASA Systems Engineering Processes and Requirements*, Appendix E, in the PEA-specific Library);
- Rationale for combining the TRL values of components and subsystems to derive each full system TRL as proposed, appropriately considering TRL states of integration (see NASA/SP-2007-6105 Rev 1, *NASA Systems Engineering Handbook*);
- Rationale for the stated TRL value of an element that is an adaptation of an existing element of known TRL;
- The approach for maturing each of the proposed systems to a minimum of TRL-6 (or TRL-5) by PDR:
  - Demonstration (testing) in a relevant environment can be accomplished at the system level or at lower level(s);
  - If applicable, justify what demonstration(s) in a relevant environment at lower level(s) (subsystem and/or subsystem-to-subsystem) would be sufficient to meet system level TRL-6 (or TRL-5), considering (i) where any new technology is to be inserted, (ii) the magnitude of engineering development to integrate elements, (iii) any inherent interdependencies between elements (e.g., critical alignments), and/or (iv) the complexity of interfaces – see the PEA-specific Library for examples;
  - Include discussion of simulations, prototyping, demonstration in a relevant environment, life testing, etc., as appropriate;
- An estimate of the resources (staffing, cost, and schedule) required to complete the technology and/or advanced engineering development; and
- Approaches to fallbacks/alternatives that exist and are planned, a description of the cost, decision date(s) for fallbacks/alternatives, relevant development schedules, and performance liens they impose on the baseline design, and the decision milestones for their implementation.

If no new technologies or advanced engineering development is required, system TRL-6 (or TRL-5) or above at the time of proposal submission shall be clearly demonstrated.

NPR 7123.1B Appendix E

TRL	Definition	Hardware Description	Software Description	Exit Critieria
5	Component and/or breadboard validation in relevant environment.	A medium fidelity system/component brassboard is built and operated to demonstrate overall performance in a simulated operational environment with realistic support elements that demonstrate overall performance in critical areas. Performance predictions are made for subsequent development phases.	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 performance. Operational environment performance predicted. Prototype implementations developed.	Documented test performance demonstrating agreement with analytical predictions. Documented definition of scaling requirements.

Excerpts from NPR 7123.1B

- TRL definitions were last updated in this document in March 2014.
- 5.1.6 Accurate assessment of technology maturity is critical to technology advancement and its subsequent incorporation into operational products. The program/project ensures that Technology Readiness Levels (TRLs) and/or other measures of technology maturity are used to assess maturity throughout the life cycle of the project. When other measures of technology maturity are used, they should be mapped back to TRLs. The definition of the TRLs for hardware and software are defined in Appendix E. Moving to higher levels of maturity requires an assessment of a range of capabilities for design, analysis, manufacture, and test.

Appendix E: TRL

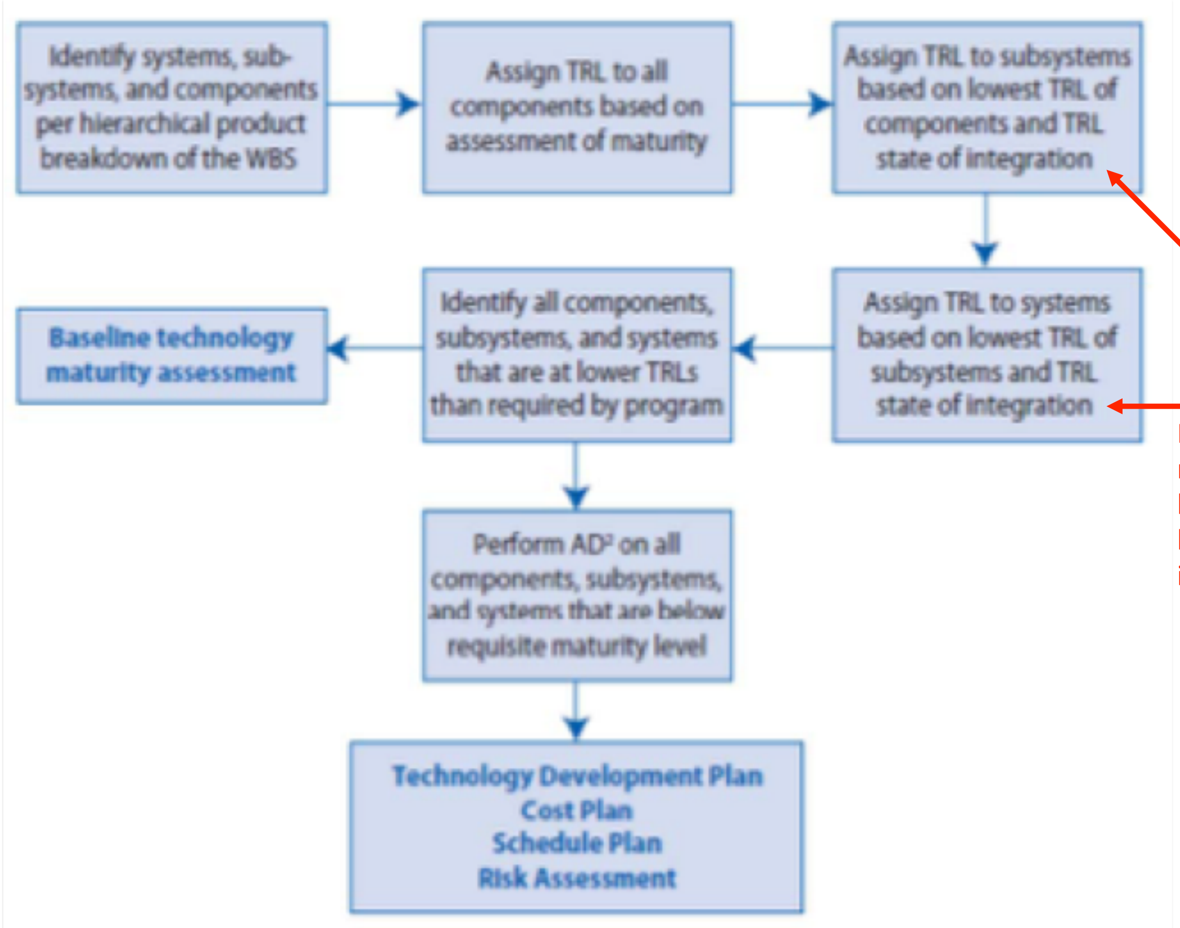
TRL	Definition	Hardware Description	Software Description	Exit Criteria
1	Basic principles observed and reported	Scientific knowledge generated underpinning hardware technology concepts/applications.	Scientific knowledge generated underpinning basic properties of software architecture and mathematical formulation.	Peer reviewed publication of research underlying the proposed concept/application.
2	Technology concept and/or application formulated	Invention begins, practical applications is identified but is speculative, no experimental proof or detailed analysis is available to support the conjecture.	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	-Analytical and experimental critical function and/or characteristic proof-of- concept	Analytical studies place the technology in an appropriate context and laboratory demonstrations, modeling and simulation validate analytical prediction.	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	Component and/or breadboard validation in laboratory environment.	A low fidelity system/component breadboard is built and operated to demonstrate basic functionality and critical test environments, and associated performance predictions are defined relative to final operating environment.	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.

TRL	Definition	Hardware Description	Software Description	Exit Criteria
5	Component and/or breadboard validation in relevant environment.	A medium fidelity system/component brassboard is built and operated to demonstrate overall performance in a simulated operational environment with realistic support elements that demonstrate overall performance in critical areas. Performance predictions are made for subsequent development phases.	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 performance. Operational environment performance predicted. Prototype implementations developed.	Documented test performance demonstrating agreement with analytical predictions. Documented definition of scaling requirements.
6	System/sub-system model or prototype demonstration in a relevant environment.	A high fidelity system/component prototype that adequately addresses all critical scaling issues is built and operated in a relevant environment to demonstrate operations under critical environmental conditions.	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	System prototype demonstration in an operational environment.	A high fidelity engineering unit that adequately addresses all critical scaling issues is built and operated in a relevant environment to demonstrate performance in the actual operational environment and platform (ground, airborne, or space).	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	Actual system completed and "flight qualified" through test and demonstration.	The final product in its final configuration is successfully demonstrated through test and analysis for its intended operational	All software has been thoroughly debugged and fully integrated with all operational hardware and software	Documented test performance verifying analytical predictions.

Excerpts from NASA Systems Engineering Handbook (NASA/SP-2016-6105 Rev 2)

- In 2014, the HQ Office of Chief Engineer and Office of Chief Technologist conducted an Agency wide study on Technical Readiness Level (TRL) usage and Technology Readiness Assessment (TRA) implementation. Numerous findings, observations, and recommendations were identified, as was a wealth of new guidance, best practices, and clarifications on how to interpret TRL and perform TRAs.
- …that a dominant factor in the degree of uncertainty is the lack of understanding of the maturity of the technology required to bring the project to fruition and a concomitant lack of understanding of the cost and schedule reserves required to advance the technology from its present state to a point where it can be qualified and successfully infused with a high degree of confidence.
- Establishing the TRL is a vital first step on the way to a successful program.
- If the architecture and the environment have changed, then the TRL drops to TRL 5—at least initially. Additional testing may need to be done for heritage systems for the new use or new environment. If in subsequent analysis the new environment is sufficiently close to the old environment or the new architecture sufficiently close to the old architecture, then the resulting evaluation could be TRL 6 or 7,..

Excerpts from NASA Systems Engineering Handbook (NASA/SP-2016-6105 Rev 2)



Note that the level is not just the TRL of the lowest component but also the integration

Figure G.3-1 Technology Assessment Process

Excerpts from NASA Systems Engineering Handbook (NASA/SP-2016-6105 Rev 2)

- Note that the issue of integration affects the TRL of every system, subsystem, and component. All of the elements can be at a higher TRL, but if they have never been integrated as a unit, the TRL will be lower for the unit. How much lower depends on the complexity of the integration. The assessed complexity depends upon the combined judgment of the engineers.

Excerpts from NASA Systems Engineering Handbook (NASA/SP-2016-6105 Rev 2)

TRL ASSESSMENT

Red	Red = Below TRL 3
Yellow	Yellow = TRL 3,4 & 5
Green	Green = TRL 6 and above
White	White = Unknown
X	Exists

		Demonstration Units					Environment				Unit Description				
	Concept	Breadboard	Brassboard	Developmental Model	Prototype	Flight Qualified	Laboratory Environment	Relevant Environment	Space Environment	Space/Launch Operation	Form	Fit	Function	Appropriate Scale	Overall TRL
1.0 System															
1.1 Subsystem X															Red
1.1.1 Mechanical Components															
1.1.2 Mechanical Systems															
1.1.3 Electrical Components					X				X		X	X	X		Green
1.1.4 Electrical Systems															
1.1.5 Control Systems															
1.1.6 Thermal Systems							X				X	X			Yellow
1.1.7 Fluid Systems		X													Red
1.1.8 Optical Systems															
1.1.9 Electro-Optical Systems															
1.1.10 Software Systems															
1.1.11 Mechanisms	X														Red
1.1.12 Integration															
1.2 Subsystem Y															Yellow
1.2.1 Mechanical Components															

Figure G.4-3 TRL Assessment Matrix