Workbook Instructions

This workbook is a tool to aid in calculating Technology Readiness Levels for advanced information (or informatics) systems research and development programs funded by the NASA Earth Science Technology Office. This document is a required input for the annual research review. TRLs should be assessed annually, reported during the annual presentation and uploaded to e-Books.

The workbook consists of six worksheets. Each worksheet is straightforward and is designed to help the project manager consider all elements bearing on the proper assessment of technology readiness.

1. Workbook Instructions – This page
2. TRL Definitions – The traditional definitions for hardware and software TRLs.
3. TRL Worksheet – This is the primary worksheet where the components and subsystems are defined for each system
4. Component Analysis – A series of question is provided for assessment of TRL 3, 4, and 5.
5. Subsystem Analysis – A series of questions is provided for assessment of TRL 3, 4, 5, 6, and 7.
6. System Analysis – A series of questions is provided for assessment of TRL 3, 4, 5, 6, and 7.

The questions posed are designed to guide the user through the process so that a reasonable and defensible estimate of TRL is assigned to the technology being developed.

The following steps should be followed for assessing technologies involving software or software/hardware technologies:

1. The product being analyzed is described in a hierarchical fashion, with four levels (product / subsystem / component).
2. For each item above, at the lowest level, key technology risk items are defined.
3. The TRL assessment is performed on each component by addressing a series of questions and providing a justification for a selected TRL.
4. The TRL of the parent assembly is assessed in a similar way, but may not be higher than the lowest TRL of constituent components.
5. The TRL of the parent subsystem is then assessed and may not be higher than the lowest TRL of its constituent components.
6. Finally, the TRL of the entire product is assessed, again noting that the product TRL may not be higher than the lowest TRL of its constituent subsystems.

The final report consists of the entire map of TRLs (steps 1-6) on Worksheet #3, with justifications.

Technology Readiness Level (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 or application formulated	Invention begins, practical application 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 & concepts defined. Basic principles coded. Experiments performed with synthetic data.	Documented description of the application/concept that addresses feasibility and benefit
3	Analytical and/or experimental critical function 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 predicitions of key parameters
4	COMPONENT or breadboard validation in laboratory	A low fidelity system/component breadboard is built and operated to demonstrate basic functionality and critical test environments and associated performance predicitions are defined relative to the final operating environment.	Key, functionally critical, software components are integrated, and functionally validated, to establish interoperability and begin architecture development. Relevant Environments defined and performance in this environment predicted.	Documented test performance demonstrating agreement with analytical predictions. Documented definition of relevant environment.
5	COMPONENT or breadboard validation in a relevant environment	A mid-level fidelity system/component brassboard is built and operated to demonstrate overall performance in a simulated operational environment with realistic support elements that demonstrates 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/ SUBSYSTEM 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 integrate 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 space	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 environment and platform (ground, airborne or space).	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. V&V completed..	Documented test performance verifying analytical predictions
9	Actual system flight proven through successful mission operations	The final product is successfully operated in an actual mission.	All software has been thoroughly debugged and fully integrated with all operational hardware/software systems. All documentation has been completed. Sustaining software engineering support is in place. System has been successfully operated in the operational environment.	Documented mission operational results

Other Definitions

Breadboard: A low fidelity unit that demonstrates function only, without respect to form or fit in the case of hardware, or platform in the case of software. It often uses commercial and/or ad hoc components and is not intended to provide definitive information regarding operational performance.

Brassboard: A medium fidelity functional unit that typically tries to make use of as much operational hardware/software as possible and begins to address scaling issues associated with the operational system. It does not have the engineering pedigree in all aspects, but is structured to be able to operate in simulated operational environments in order to assess performance of critical functions.

Prototype Unit: The prototype unit demonstrates form, fit, and function at a scale deemed to be representative of the final product operating in its operational environment. A subscale test article provides fidelity sufficient to permit validation of analytical models capable of predicting the behavior of full-scale systems in an operational environment

Engineering Unit/Model: A high fidelity unit that demonstrates critical aspects of the engineering processes involved in the development of the operational unit. Engineering test units are intended to closely resemble the final product (hardware/software) to the maximum extent possible and are built and tested so as to establish confidence that the design will function in the expected environments. In some cases, the engineering unit will become the final product, assuming proper traceability has been exercised over the components and hardware handling.

Relevant Environment: Not all systems, subsystems, and/or components need to be operated in the operational environment in order to satisfactorily address performance margin requirements. Consequently, the relevant environment is the specific subset of the operational environment that is required to demonstrate critical "at risk" aspects of the final product performance in an operational environment. It is an environment that focuses specifically on "stressing" the technology advance in question.

Product breakdown			*Technology Level Assessment*			*Implementation Approach*	
System / Subsystem	**Assembly**	**Component**	**Key Technology Items***	**TRL**	**Justification**	**Implementation Method**	**Vendors (if applicable)**
Your System							
Your subsystem 1							
	Your assy 1						
		Your component 1					
		Your component 2					
		Your component 3					
		Your component 4					
		Your component 5					
	Your assy 2						
		Your component 1					
		Your component 2					
Your subsystem 2							
	Your assy 1						
	Your assy 2						
	Your assy 3						
	Your assy 4						
	Your assy 5						
	Your assy 6						
Your subsystem 3							
	Your assy 1						
	Your assy 2						
	Your assy 3						
	Your assy 4						
	Your assy 5						
	Your assy 6						
	Your assy 7						
Your subsystem 4							
	Your assy 1						
		Your component 1					
		Your component 2					
		Your component 3					
	Your assy 2						
		Your component 1					
		Your component 2					
		Your component 3					
Your subsystem 5							
	Your assy 1						
Your subsystem 6							
	Your assy 1						
	Your assy 2						

**** May have more than one technology item per component/ assembly***

Please use these questions to determine TRLs of components / assemblies.

(The justification column on the TRL Worksheet tab should summarize the rationale on which the TRL is based.)

		% Completed
TRL 3	Critical functions/components of the concept/application identified?	
	Preliminary performance metrics established for key parameters?	
	Component analytical predictions made?	
	Component performance assessed by Modeling and Simulation?	
	Component acquisition/coding completed?	
	Component V&V completed?	
	Analysis of test results completed establishing key performance metrics for components?	
	Lab test support equipment and computing environment completed for component/proof-of-concept testing?	
	Analytical verification of critical functions from proof-of-concept made?	
	Analytical and experimental proof-of-concept documented?	

TRL 4	**Have the criteria for TRL 3 above been satisfied?**	
	Concept/application translated into detailed component level software architecture design?	
	Preliminary definition of operational environment completed?	
	Key parameter performance metrics established for integrated component laboratory tests?	
	Component level coding completed?	
	Analysis of test results completed verifying performance relative to predictions?	
	Laboratory test support equipment and computing environment completed for integrated component testing?	

TRL 5	**Have the criteria for TRL 4 above been satisfied?**	
	Critical functions and associated components identified?	
	Modeling & Simlation pre-test performance predictions completed?	
	Scaling requirements defined & documented?	
	Critical component implementations identified and designed?	
	Component implementations completed?	

Please use these questions to determine TRLs of subsystems.

(The justification column on the TRL Worksheet tab should summarize the rationale on which the TRL is based.)

		% Completed
TRL 3	**Are all of the subsystem's components at TRL 3?**	
	Subsystem analytical predictions made?	
	Subsystem performance assessed by Modeling and Simulation?	
	Laboratory tests and test environments established?	
	Lab test support equipment & computing environment completed for component/proof-of-concept testing?	
	Analysis of test results completed establishing key performance metrics for subsystems?	
TRL 4	**Are all of the subsystem's components at TRL 4?**	
	Have the criteria for subsystem TRL 3 been satisfied?	
	Have the subsystem's critical functions and performance parameters been derived from science measurement requirements?	
	Have laboratory tests shown that the software meets the critical functional and performance parameters?	
	Definition of relevant operational environment documented	
	Laboratory tests and test environments defined for integrated component testing?	
	Pre-test predictions of integrated component performance in a lab environment assessed by Modeling & Simulation?	
	Key parameter performance metrics established for integrated component laboratory tests?	
	Laboratory test support equipment and computing environment completed for integrated component testing?	
	System/subsystem/component level coding completed?	
	Preliminary system requirements defined for end users' application?	
	Critical test environments and performance predictions defined relative to the preliminary operating environment?	
	Preliminary system requirements defined for end users' application?	
	Relevant test environment defined?	
TRL 5	**Are all of the subsystem'scomponents and assemblies at TRL 5?**	
	Have the criteria for subsystem TRL 4 been satisfied?	
	Has the softare's critical functions and performance parameters been validated in a relevant environment? List environmental tests completed.	
	Critical functions and associated subsystems identified?	
	Modeling & Simlation pre-test performance predictions completed?	
	Scaling requirements defined & documented?	
	Critical subsystems implementations identified and designed?	
	Subsystem/component integrations and implementations completed?	
	Subsystems/integrated components successfully demonstrated in a relevant environment?	
	Successful demonstration documented along with scaling requirements?	
TRL 6	**Are all of the subsystem's components and assemblies at TRL 6?**	
	Have the criteria for subsystem TRL 5 been satisfied?	
	Has a subsystem prototype demonstrated that it meets these requirements in a relevant environment? List the environmental test completed.	
	Subset of relevant environments identified that address key aspects of the final operating environment?	
	Modeling & simulation used to simulate subsystem engineering model/prototype performance in the relevant environment?	
	Hardware/software interfaces baselined?	
	Scaling requirements finalized?	
	Software model or prototype built that adequately addresses critical scaling issues?	
TRL 7	**Are all of the subsystem's components and assemblies at TRL 7?**	
	Have the criteria for subsystem TRL 6 been satisfied?	
	Hardware interfaces baselined?	
	Design addresses all critical scaling issues?	

Please use these questions to determine the TRL of the system.

(The justification column on the TRL Worksheet tab should summarize the rationale on which the TRL is based.)

		% Completed
TRL 3	**Are all of the system's components at TRL 3?**	

TRL 4	**Are all of the subsystems at TRL 4?**	
	Concept/application translated into detailed system/subsystem/component level software architecture design?	
	System/subsystem/component level coding completed?	
	Critical test environments and performance predictions defined relative to the preliminary definition of the operating environment?	
	Analysis of test results completed verifying performance relative to predictions?	

TRL 5	**Are all subsystems at TRL 5?**	
	Have all of the system's critical functional and performance requirements been derived from science measurement requirements?	
	Has a system brassboard demonstrated that it meets these requirements in a relevant environment? List environmental tests completed.	
	Relevant environments finalized?	
	Facilities, GSE, STE available to support testing in a relevant environment?	
	System level performance predictions made for subsequent development phases?	

TRL 6	**Are all subsystems at TRL 6?**	
	Have the criteria for system TRL 5 been satisfied?	
	Have all of the system's essential functional and performance requirements been derived from science measurement requirements?	
	Has a system prototype demonstrated that it meets these requirements in a relevant environment? List the environmental test completed.	
	System requirements finalized?	
	Operating environment definition finalized?	
	Modeling and simulation used to simulate system performance in an operational environment?	
	Modeling and simulation used to simulate system engineering model/prototype performance in the relevant environment?	
	Facilities, computing environment available to support software model testing in the relevant environment?	
	Software model or prototype built that adequately addresses critical scaling issues tested in the relevant environment?	
	Prototype implementation of the software demonstrated on full-scale realistic application?	
	Analysis of test results verify performance predictions for relevant environment?	
	Initial draft of required software documentation completed?	
	Test performance documented demonstrating agreement with performance predictions?	
	Engineering feasibility fully demonstrated and documented?	

TRL 7	**Have the criteria for system TRL 6 been satisfied?**	
	Have a complete set of functional and performance requirements for the instrument been derived from science measurement requirements?	
	Has an engineering model or flight model instrument demonstrated that it meets these requirements in the final intended operating environment?	
	Hardware interfaces baselined?	
	Design addresses all critical scaling issues?	
	Modeling and simulation used to predict performance in the operational environment?	
	Facilities, computing environment available to support prototype and qualification testing of operational software?	
	Fully integrated software model that adequately addresses all critical scaling issues and component and hardware interfaces?	
	Major software testing/V&V completed and results documented?	
	All performance specifications verified by test or analysis?	
	Fully integrated prototype software successfully demonstrated in operational environment?	
	All final acceptance testing plans/procedures/criteria have been baselined?	
	Intermediate draft of required software documentation completed?	
	Successful operational demonstration documented?	