Technology Updates

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Topics

- Uniformity of TRL assessments
- STMD updates
- Increasing cadence by reducing cost - Nathan Strange
- Uranus Technology study status:
  - TPS development - Parul Agrawal
  - Science - Mark Marley
- A Low-Cost Small RPS Enabled Mission Concept - Jackie Green

TECHNOLOGY READINESS LEVEL

Task: *How to provide a uniform TRL assessment for PSD across NASA and the broader community*

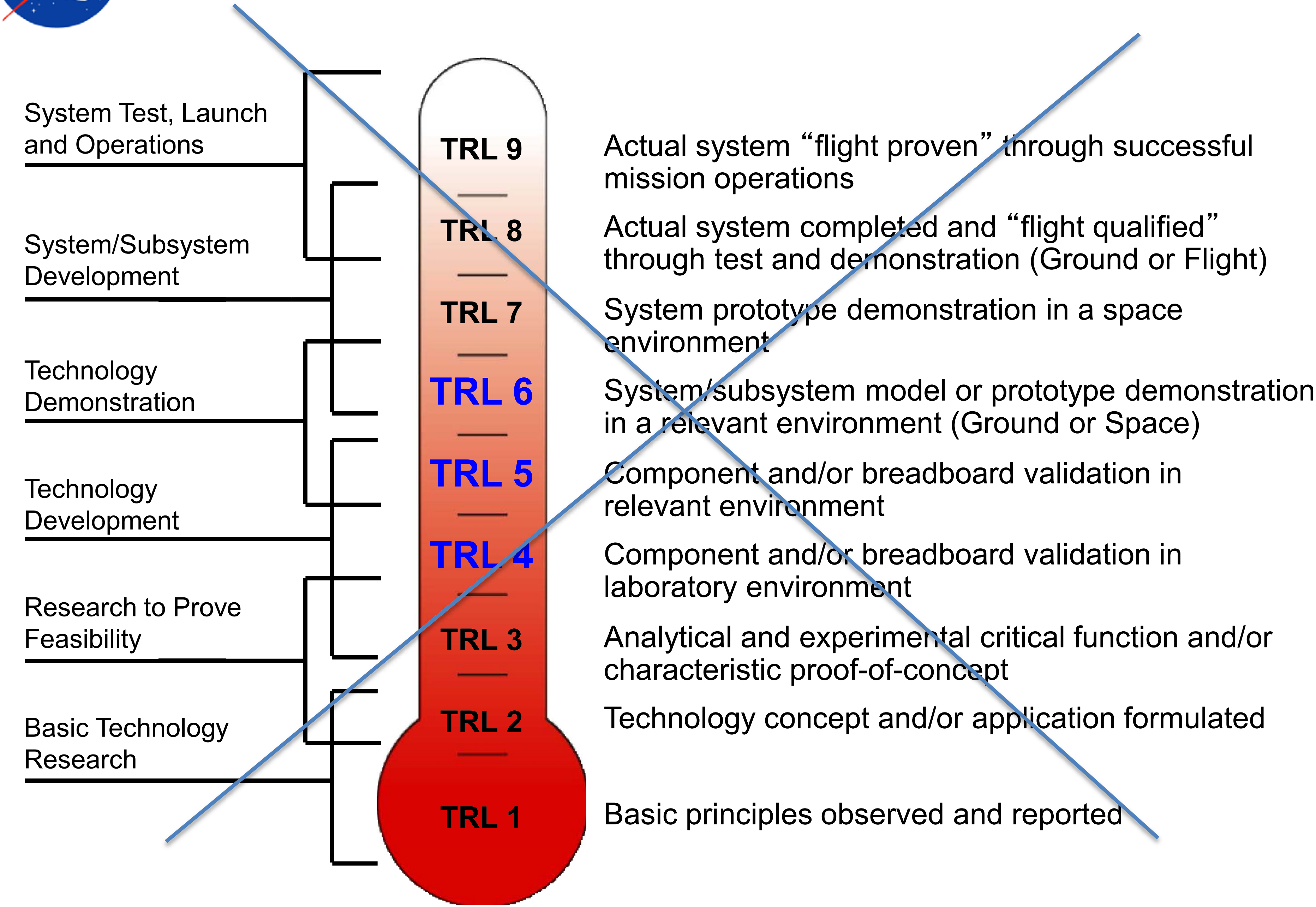
QUIZ

What document do you think describes the TRL scale adopted by NASA?

A) NPR 7120.8
B) Thermometer Chart
C) NPR 7123.1
D) NPR 7120.5
E) I thought TRLs were just guidelines. Why does NASA adopt a TRL scale?

What most people think the NASA TRL Scale is

Technology Readiness Levels (TRLs)



Answer

7123.1B Appendix E

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

7123.1B Appendix E

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 (R&D) 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.

7123.1B Appendix E

TRL	Definition	Hardware Description	Software Description	Exit Criteria
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.

2nd Part of the Problem (sanitized from a Proposal Evaluation)

MAJOR WEAKNESSES

- **The proposal fails to meet Announcement of Opportunity (AO) requirements to provide rationale supporting claimed technology readiness at each level of assembly, does not demonstrate the adequacy of prior ground and airborne heritage to this space-borne instrument, and does not sufficiently demonstrate the adequacy of ongoing breadboard development testing**.

For example, the electronics subsystem is characterized in Table J.9.2-1 as having no prior design heritage because of major modifications, operation in a significantly different environment, and lack of ground testing. Table E.1.6-1 contradicts this by claiming that the electronics subsystem (excluding its field programmable gate array [FPGA] component) is Technology Readiness Level (TRL) 7-9, without providing sufficient rationale for such a claim.

In addition, the proposal provides inadequate rationale for how the TRL of components are combined into a subsystem TRL assessment, and how the TRL of subsystems are combined into an instrument system level TRL assessment. Such descriptions are required by the AO.

Background

- In 2011 the Planetary Science Technology Review Panel found that inconsistent and inaccurate TRL and heritage assessments were performed and recommended that PSD develop a more consistent and accurate TRL assessment process
- NASA has implemented a new TRL scale in 7123.1B, Appendix E, which over-rides 7120.8 (and the thermometer chart!)
- PSD relies heavily on TRL assessments for ROSES, missions and instrument AO's, but these are often inconsistent and not uniformly applied by the various proposers, NASA Centers and SOMA. PSD has to mediate the debate.
- PSD would also like to enhance its interactions with STMD to better communicate technologies worthy of investment, effectively advocate their selection and agree on terminology when transitioning technology to PSD.

Scope of task

- The scope of this effort is limited to planetary science/ technology community (though there is potential applicability to the larger SMD community)
- Sources of input to this study include the NASA PSD, Center Chief Technologists and Engineers, SOMA, Center proposal managers and external proposers and STMD managers, planetary science and technology community
- All spacecraft and instrument technology developments are considered
- Output will be a report with findings and recommendations for PSD to better categorize the technology readiness of components and systems.

Outside the scope of this study:

- Redefinition of TRL levels
- Organizational relationships between PSD and STMD, SOMA or proposers.

Approach

- Agree on the set of task outputs with PSD
- Collect inputs and recommendations from PSD PE's, PS's and PM's on TRL-related issues
- Extend scope of TRL stakeholders interviewed, including SOMA and CCT's, to ascertain their TRL usage and views on how TRLs are generated and used
- Generate interim preliminary findings and communicate them to the PSD ← We are here
- Interview other stakeholders (STMD, CCE's, proposers, science and technology community etc) and iterate solutions
- Generate revised findings and present recommendations to PSD management
- Initiate selected follow-on tasks based on PSD decisions

Some Initial Findings from Interviews

- **Inconsistencies in TRL Determination**
  - Community lacks understanding of TRL and a common, accepted process to evaluate and assess the TRL of components and systems
  - Technology centers and mission centers evaluate TRLs differently
  - Tool for low-TRL estimation does not exist
- **Education and Training**
  - There are no TRL training materials for stakeholders (technology proposers, reviewers, mission developers)
  - No training sessions available to the community (e.g., at AGs, conferences, proposer workshop)
  - No established process to make knowledge more widely available

Some Initial Findings from Interviews (cont’d)

- **TRL Assessment Needs**
  - Proposers need to do a better job of defining plans to get to TRL 6 by PDR
    - Identify performance levels needed and cost to accomplish
- **SOMA Perspective**
  - SOMA is primarily focused on having proposers:
    - Show a defensible plan for getting to TRL 6 by PDR
    - Show a backup plan if TRL 6 is not achieved by PDR
  - For TRL 6, the key is the relevant environment. Proposers stumble over environment

Initial Findings from Interviews (cont'd)

- **Instrument TRL Issues**
  - Need to use simplified science traceability matrix at an early stage of development
  - Planetary Protection and Contamination control need to be incorporated early in instrument designs. Need to be called out early.
- **Integration to System Level**
  - TRL integration to system level is not performed in a consistent manner
  - Components vs. system level TRL is an issue for most people
- **Testing to achieve TRL 6**
  - Must be in a relevant environment
  - Define standard environments (e.g. Europa, Titan etc.)
  - Should be a checklist of tests for sub-system and system testing to establish TRL 6

Initial Findings from Interviews (cont'd)

- **Heritage**
  - The value of heritage is often over-stated and often leads to false claims
  - Many arguments regarding heritage and cost savings
    - A preferred approach is to identify technologies and develop a technology plan leading to flight on a specific mission.
  - Heritage can go to zero when you rearrange boxes or have a different environment
- **PSD Programmatic Relationships with STMD**
  - Need agreement between PSD & STMD on planetary technologies selected. When do they transition to PSD? How do they transition?
  - STMD needs mission infusion paths identified
  - Need agreement on how to perceive the TRL, or more appropriately, the work plan required to fly the technology on a specific mission or set of missions.

Preliminary Recommendations

- Education and training
- Socialize TRL's and the importance of their role within PSD to the broader scientific and technology community
- NASA Centers need to communicate with each other often to agree on TRL
- PSD needs to evaluate the role of TRLs in their process

Inputs and solutions welcome

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Chester.S.Borden@jpl.nasa.gov

We are happy to set up interviews and discuss issues and solutions

Back–up Charts

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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.

7123.1B Appendix E

TRL	Definition	Hardware Description	Software Description	Exit Criteria
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 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)	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 tested in a "simulated" or somewhat realistic environment.	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.

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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.

7123.1B Appendix E

TRL	Definition	Hardware Description	Software Description	Exit Criteria
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.

CHANGES IN STMD TECHNOLOGIES

Technology Demonstrators Category 1

Autonomous Landing and Hazard Avoidance Technology (ALHAT, JSC)

No longer STMD but now AES and combined with Morpheus

Description

The Autonomous Landing and Hazard Avoidance Technology (ALHAT) project is developing advanced technologies vital to achieving this real-time capability. These technologies include surface-tracking sensors which very precisely measure spacecraft altitude and velocity relative to the planetary surface and actively measure the topography or roughness of the landing area.

High-speed, high-volume processors combine ALHAT algorithms with this sensor data to navigate to what's known as the "pre-mission landing aim point," where the technology will determine safe landing areas close to this point.

The spacecraft is then navigated to a safe area close to the landing aim point for touchdown. This entire process is done autonomously with automated guidance, navigation and control software onboard the spacecraft.

Application to Planetary Science

This technology is important for future planetary missions including landed missions to Mars & Europa. For Mars Sample Return it could enable precise targeting to a cached sample site for retrieval of a sample or for landing in science rich targets with very hazardous terrain such as the base of a steep cliff. For a Europa lander it could enable sampling of highly localized areas of high science value.

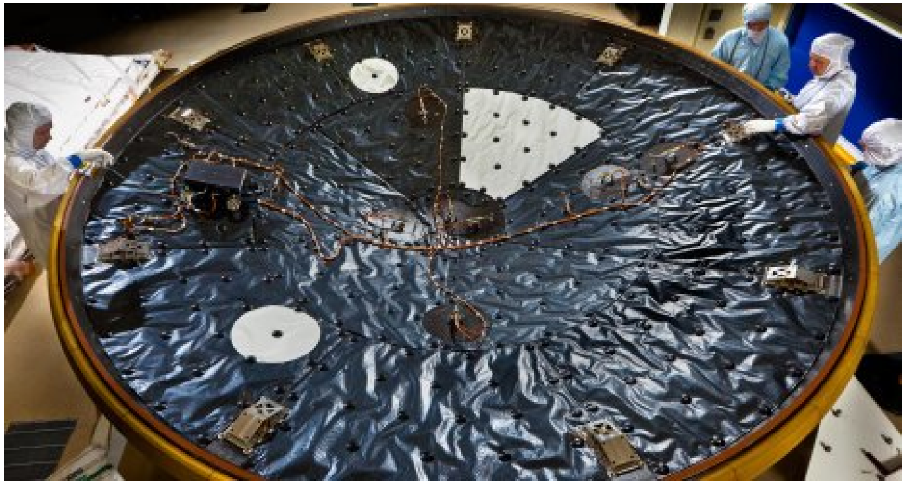
Technology Demonstrators – Cat 1

Completed. No longer STMD

MEDLI (MSL Entry Descent and Landing Investigation, LaRC)

Description

The MSL Entry, Descent, & Landing Instrument Suite is a first-of-its-kind instrumentation system on the Mars Science Laboratory.



MEDLI measured the temperature and pressure within the spacecraft heatshield as it flew through the Martian atmosphere, delivering unprecedented environmental data that will help NASA build more efficient robotic and crewed Mars landers in the future.

About a tenth of MEDLI's data was transmitted during entry and descent; the rest was stored on the Curiosity rover, and communicated a few days after landing.

MEDLI data helped generate the "tones" that tell the operations team on Earth how the spacecraft is progressing through the Mars atmosphere, delivering heat shield temperature data and other information.

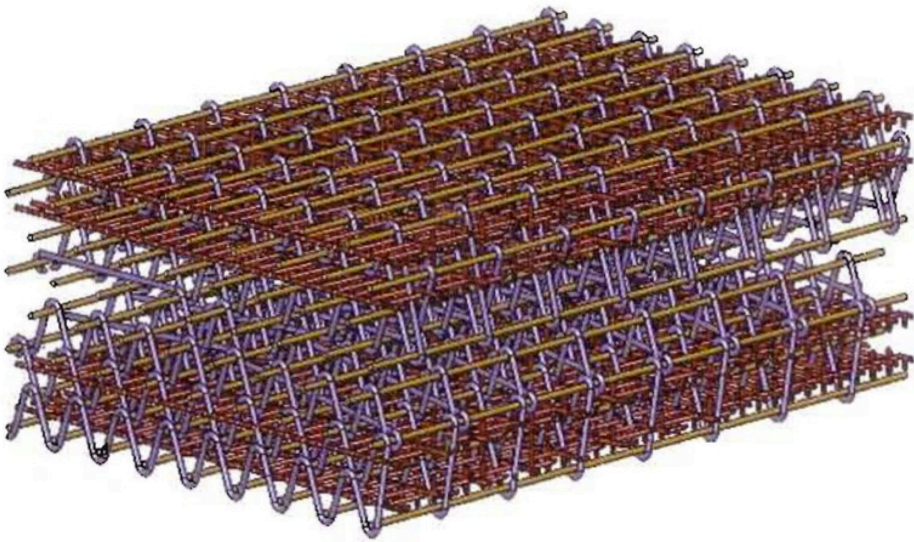
Application to Planetary Missions

- MEDLI data will help design the next generation of Mars heat shield with adequate but not excessive margins enabling high payload mass fractions for future Mars landed missions
- MEDLI can help establish the principle of conducting this type of monitoring in entry systems to ensure that all planetary entry systems will have adequate but not excessive margins

Game Changing Development - Cat 1
Woven Thermal Protection Materials (ARC)

Now called HEEET and moved from formulation to implementation. May be ready for New Frontiers AO.

- This project is employing an advanced, three-dimensional weaving approach in the design and manufacture of thermal protection systems.
- Woven TPS has the potential to significantly impact future NASA missions by changing heat shield development from a challenge to be overcome into a mission-enabling component.
- This technology will impact all future exploration missions, from the robotic science missions to Mars, Venus and Saturn to the next generation of human missions.



Application to Planetary Science

- Woven materials would be used to apply TPS materials to conventional rigid aeroshells as a replacement for tiles and other costly approaches
- The coating requirements for each technology will be dissimilar

GCD Projects Ranked "Very High" in PSD relevance

GCD Activities	Project Category	Org	Life Cycle Cost ($M)	Mars	Venus	Moon/ Mercury	Outer Planets	Small Bodies	Overall PSD Relevance
Deployable Aeroshell Concepts and Conformal TPS Project (DACC)	Implementation	ARC	$15.96	Very high	Very high	Not applicable	High	Not applicable	1 Very high
Heat Shield for Extreme Entry Environment Technology (HEEET)	Formulation	ARC	$1.06	Moderate	Very High	Not applicable	Very high	Moderate	1 Very high
Woven Thermal Protection System (WTPS)	Formulation	ARC	$1.85		Very high	Not applicable	Very high	Very high	1 Very high
In-Space Propulsion (ISP)	Implementation	GRC	$16.40	Very high	Very High	Very high	Very high	Very high	1 Very high
~~BARRIER INFRARED DETECTOR (BIRD)~~	~~Implementation~~	~~JPL~~	~~$1.00~~	~~High~~	~~High~~	~~High~~	~~High~~	~~High~~	~~1 Very high~~
Deep Space Optical Communication (DSOC)	Implementation	JPL	$9.52	Very high	Very high	Moderate	Very high	Moderate	1 Very high

Combined, moving to Implementation

Completed

Decadal Survey Key Capabilities Not Addressed

Recent Improvements made

Key Capabilities
~~Advanced Chemical Propulsion~~ — Closed GCD NRA for small Sat. Prop. including Chemical
Aerocapture
Cryogenic sample preservation
Cryogenic sampling and instruments
Impactor and penetrator systems
In situ sample analysis and age dating
innovative mission and trajectory design
Long durations high temperature subsystems
Planetary protection
~~Precision landing~~ — Closed GCD NRA for this topic
Radiation tolerance
~~Radiation tolerance (subsystem)~~ — GCD has a high performance space computing BAA with AFRL, which addresses radiation tolerant processors
~~Reduced spacecraft mass and power~~ — GCD has materials and structures for mass and power systems (batteries, fuel cells) for power
Sample verification -ices, organics
Survivability under high temperature and pressure
~~Survival and mobility in cryogenic conditions~~ — Human robotic systems project which is cross cutting with SMD needs

Key Message for PSD from OPAG

- Tasks where PSD co-funding is critical.
  - HEEET
  - Atomic Clock
  - Planetary Optical Communications