National Aeronautics and
Space Administration

# Planetary Science Technology Review Panel

**Final Report**
**July 29, 2011**

This page intentionally left blank.

***Planetary Science Technology Review Panel***

# Signature Page

**Panel Members**

Tibor Kremic, Chair — Date: 7/29/2011
NASA Glenn Research Center

Peter M. Hughes — Date: 7/29/2011
NASA Goddard Space Center

Raleigh B. Perry — Date: 7/27/11
NASA Langley Research Center

James T. Singleton — Date: 26 Jul 11
Edwards Air Force Base

**Advisors**

Patricia M. Beauchamp — Date: 7-27-2011
Jet Propulsion Laboratory

______________________________ 7/28/11
John T. Clarke
Boston University
Date

______________________________ 7/27/11
Ralph D. Lorenz
Applied Physics Laboratory, Johns Hopkins University
Date


This page intentionally left blank.

# PLANETARY SCIENCE TECHNOLOGY REVIEW PANEL

TIBOR KREMIC, NASA Glenn Research Center, *Chair*
PETER M. HUGHES, NASA Goddard Space Center
RALEIGH B. PERRY, NASA Langley Research Center
JAMES SINGLETON, AFRL, Edwards Air Force Base

**Advisors**

PATRICIA M. BEAUCHAMP, Jet Propulsion Laboratory
JOHN CLARKE, Boston University
RALPH LORENZ, Applied Physics Laboratory, Johns Hopkins University

**Technical Support**

WALDO J. RODRIGUEZ, NASA Langley Research Center
LINDA L. NERO, SGT Inc., NASA Glenn Research Center

**NASA Headquarters' Point of Contact**

GORDON JOHNSTON, NASA Headquarters

# Acknowledgments

The Planetary Science Technology Review panel would like to acknowledge the many contributions that were provided during the course of this study. All of the presenters at the panel's face-to-face meetings and during the assessment teleconferences provided valuable inputs. We also acknowledge the inputs we received during presentations at several conference venues and assessment group meetings. The support we received to raise awareness of this effort and to provide a mechanism by which to communicate to the science, technology, and mission communities is greatly appreciated. We also wish to thank all those that provided ideas and input through emails, inputs into the survey, or ideas and suggestions by word of mouth to a team member. We could not have achieved our objectives without your contributions.

Finally, we would like to acknowledge the staff and leadership of the Planetary Science Division (PSD) at NASA headquarters, particularly Dr. James Green. It was their foresight and desire to bring about positive change that began this process. And it will be their tireless efforts that make the eventual improvements that will provide better science through increased technology resource efficacy.

# Contents

# Executive Summary

The Director of the NASA's Planetary Science Division, Dr. James Green, chartered the Planetary Science Technology Review (PSTR) panel to provide the Planetary Science Division (PSD) at NASA Headquarters (HQ) with a set of recommendations on how to achieve more technology, and thereby more science, with its technology resources. The focus of the PSTR panel was on "how" to better implement technology development, i.e., how can technology efforts be better managed, planned, infused, implemented, and documented/communicated so that mission costs and risk are minimized and new science is enabled or enhanced? Concurrent with the PSTR review, the National Research Council (NRC) implemented a Planetary Decadal Survey, which answered, among other things, the question of "what" technologies PSD should develop. A third review was implemented by the Planetary Science Subcommittee (PSS) of the NASA Advisory Council (NAC). That review assessed and made recommendations regarding the efficacy of PSD Science, Research, and Technology (SR&T) resources. SR&T resources fund science, research, and limited technology efforts. Through discussions with the chair of the PSS, it was agreed that PSTR would address whatever technology content exists in the SR&T programs. All three review efforts were intended to complement each other.

The PSTR objectives were achieved through a three-phase implementation plan that included assessment, formulation, and communicating/reporting.

The purpose of the assessment phase was to inform the review team about the content and scope of PSD technology development efforts, identify problems, barriers, or issues that may impact efficacy, and evaluate examples of successful technology efforts that may have application in the PSD. During the formulation phase, potential solutions were generated that were designed to address the issues identified during the assessment phase and specific objectives identified in the review Charter. The communicating and reporting phase was conducted throughout the entire task. Communication with the science, technology, and mission (STM) communities first focused on identifying and corroborating issues and then shifted to vetting solution options to provide the best possible input to the PSD.

Over 40 briefings were conducted during the assessment phase. These briefings sought representatives from known stakeholders in the planetary science technology community. During the process, several observations and issues were consistently reported. These issues were considered the major findings and were broken into four categories as listed in TABLE ES.1. The issues are discussed in detail in the body of the report.

TABLE ES.1 Major Observations/Issues

| Issue Number | Observation/Issue |
|---|---|
| **Strategy** | |
| S-1 | No overall strategy or accountable manager |
| S-2 | No clear path for technology maturation from TRL 0 to 9 |
| S-3 | Limited engagement of other NASA OCT, ESMD, and ESD technologists |
| S-4 | Technology should be perceived as more than just hardware development |
| S-5 | Efforts by external stakeholders are not worked into PSD strategy |
| **Process/Structure** | |
| P-1 | Programs are not consistent and do not have clearly defined processes |
| P-2 | Technology managers are overloaded and often oversee flight projects |
| P-3 | Inconsistent and inaccurate TRL and heritage assessments |
| P-4 | Limited processes that encourage interaction between stakeholders |
| **Resources** | |
| R-1 | Technology budgets are unpredictable |
| R-2 | Technology budgets are insufficient |
| R-3 | Inadequate leveraging of others' investments |
| **Culture/Communication** | |
| C-1 | Technology investments have not yielded all the benefits they could have |
| C-2 | Inadequate communication (in & out) |
| C-3 | Projects are too risk averse to new technology |
| C-4 | Tenuous commitment by top management |
| C-5 | Need to better sustain capabilities |

The next phase of the review generated potential solutions to these findings and issues and to the challenges identified in the Charter. Suggestions were collected from a number of sources. These included technology, science, and mission conferences like the Division of Planetary Science (DPS) of the American Astronomical Society and the Institute for Electrical and Electronics Engineers (IEEE) Aerospace conferences, through the various planetary assessment group meetings like the Outer Planets Assessment Group (OPAG) meetings, and through a simple open-ended Web survey. These suggestions, and the inputs from the PSTR team, were used by the civil servant members of the panel to generate draft recommendations. The draft recommendations were sent back out to the full PSTR team and the science, technology, and mission communities for additional feedback. The civil servants then generated the final recommendations. The result of the process is a set of eleven major recommendations grouped into the same categories as the issues, with an added category for management. Although the categories are similar and all the issues are addressed with recommendations, there is not a one-to-one paring of issue to recommendation because several recommendations address multiple issues. The major recommendations are listed in TABLE ES.2.

TABLE ES.2 Summary of Major Recommendations

| **Major Recommendation** |
|---|
| **Management** |
| MR-1) Establish a dedicated Director position with overall responsibility for PSD technology |
| MR-2) Establish a small supporting program office |
| **Strategy** |
| MR-3) Develop a comprehensive strategy for PSD technology |
| MR-4) Strategically allocate resources (guidelines are provided by PSTR) |
| MR-5) Actively pursue a strategy of leveraging opportunities within and outside NASA |
| **Process** |
| MR-6) Develop a more consistent and accurate TRL assessment process |
| MR-7) Develop clear, transparent, and consistent decision and review processes |
| MR-8) Develop a more structured and rigorous process to create interactions between technologists, scientists, and missions |
| **Culture and Communication** |
| MR-9) Develop an overall communication plan and technology database |
| MR-10) Foster a culture that advocates for and defends technology |
| **Resources** |
| MR-11) Dedicate stable funding at the higher end of the decadal suggested range - 8% |

There are four recommendations that are expected to provide the greatest improvement impact. These include MR-1) establishing a technology director position with responsibility for the overall technology strategy having the authority to carry out such a strategy, MR-2) establishing a supporting program office to help implement the strategy and the other recommendations, MR-3) developing a strategy that encompasses the whole of PSD technologies, from early concept to flight, and encompasses space craft, instrument, and mission support technologies, and MR-6) improving the Technology Readiness Level (TRL) accuracy and consistency.

The PSTRs' work included recommending high-level metrics by which to assess overall technology program success. The team developed high-level metrics for technology maturation and infusion, leveraging investments by other stakeholders, communication, and program implementation elements. Examples of some of high-level metrics include ensuring that 10 to 30% of TRL 1-2 technologies achieve TRL 3 within a specified period, ensuring that each technology development effort has maturation milestones and that progress be reviewed annually, attracting external investments for technology developments needed by PSD (measured as a percentage of PSD technology investments), and implementing an annual PSD technology workshop. Several metrics are suggested that focus on assessing PSD implementation of PSTR recommendations. The complete set of metrics is discussed in Chapter 5.

Implementing the recommendations and the measurement principles provided in this report will improve the efficacy of the technology resources, help technology development efforts be more efficient, achieve better mission infusion, and ultimately provide better science for lower cost.

# 1

# Introduction

## Purpose and Goals

The purpose of this review is to provide the Planetary Science Division (PSD) at NASA Headquarters (HQ) with a set of recommendations on how to efficiently and effectively develop new technologies that can lead to increased scientific discoveries, lower mission costs, or both. The emphasis of the PSTR panel is on "how" to implement technology development programs more effectively in PSD.

Concurrent with the PSTR review, the National Research Council (NRC) was tasked with completing the 2013–2023 Planetary Decadal Survey. The Decadal Survey was expected to comment and make recommendations on future missions and what technologies will be needed while the PSTR panel recommends how to implement the technologies desired. Given this complementary nature of roles, the PSTR panel did not conclude its work until after the Decadal Survey report was released, and the PSTR panel had time to review the report and tailor final recommendations in light of the Decadal Survey content. A third review was being implemented by the Planetary Science Subcommittee (PSS) of the NASA Advisory Council (NAC). That review assessed and made recommendations regarding the efficacy of PSD Science, Research and Technology (SR&T) resources. SR&T can fund science, research, and technology efforts but most focus on science and research activities. Through discussions with the chair of the PSS, it was agreed that PSTR would address whatever technology content exists in the SR&T programs. All three review efforts were intended to complement each other.

The complete set of PSTR objectives for this review is provided in the review Charter located in Appendix G. The objectives and purpose are achieved through a three-phase implementation plan illustrated in the summary schedule found in Appendix F. The three phases include assessment, formulation, and communicating and documenting findings and products.

The purpose of the assessment phase was to inform the review team on the content and scope of PSD technology efforts, to recognize problems, barriers, or issues that may affect the efficacy of these efforts, and to identify examples of successful technology efforts that may be applicable to PSD.

The formulation phase captured the generation of potential solutions to issues identified during the assessment phase and also solutions options for the known problems identified in the review Charter.

The communication and documentation phase has been an ongoing activity throughout the entire effort. Communication with the science, technology, and mission (STM) communities helped to identify and corroborate issues and then to vet solution options so that the best possible input can be provided to the PSD.

Each phase is discussed in more detail in subsequent sections of this chapter.

## DEFINITION OF TECHNOLOGY AND USE OF TECHNOLOGY RESOURCES

Technology, as adopted by the PSTR panel, is the application of knowledge to create or use a technical capability to enhance or enable future planetary missions in a significant way, in other words, creating or applying technical knowledge to what we do. It should be noted that technology is not relegated to tangible products or even software, but includes technology support facilities, software tools, processes (e.g., in planetary protection), as well as hardware systems and instruments. Purchases of products that require only standard integration activities and do not involve maturation efforts are not considered technology developments. Likewise engineering efforts that do not significantly increase capability or do not require novel knowledge are also not considered technology developments.

A couple of examples are provided to help reduce any ambiguity in this definition. Maturing a remote sensing capability from component to system-level operations is considered development, as is development of cryogenic sample handling techniques. A unique facility that maintains a critical PSD technical capability would be considered technology and examples include the facility required to qualify thermal protection materials for planetary missions or a unique extreme environments facility for Venus surface science and testing. On the contrary, the procurement of Pu-238 to supply radioisotope power for planetary missions should not be considered technology and it should not be funded with technology resources.

The PSTR panel recommends that the maturation of a technology should continue to be funded by technology resources until the point the technology is baselined on a funded mission that has adequate resources allocated to complete the maturation and integration process. On a case-by-case basis, agreements between mission and technology programs may be generated to share resources and better enable the infusion process. This recommendation implies that PSD technology programs have responsibility for requirements and maturation until these roles are assumed by a mission that has adequate means to complete the process. This does not imply that the technology programs should not seek frequent inputs from potential missions when levying requirements on technology projects. Technologies that have flown on a mission may become technology development efforts once again if the application, environment, or production capability has changed. The findings and recommendations found in this report assume this definition of technology and technology/mission funding boundary.

## ASSESSMENT PHASE

The assessment phase of the review was intended to accomplish a number of important functions. The primary function was to inform the panel and advisors of the content of the existing technology activities within the PSD and of the management approaches and practices used in implementing the various efforts. To make meaningful recommendations on how to improve processes and policies one must first understand what those processes and policies are and how they impact the effectiveness of the technology efforts and their application. The other critical component of the assessment process was to evaluate what is working and what is not. This is a subjective matter, so the evaluation considered the views of the various stakeholders and therefore the evaluation needs to query members from the impacted communities. For planetary science technology development, the stakeholder communities include 1) Headquarters Program Executives and Officers, 2) planetary scientists, 3) technologists and technology programs, and 4) flight missions where technologies are applied.

NASA Headquarters Program Executives and Officers manage the overall activities and provide the high-level requirements and guidance. They establish the management and review processes for the technology developments. The planetary scientists are the ultimate customer and user and directly, or indirectly, define future technology needs. The scientists are also pivotal in determining if a technology is adopted for use. The technologists are the providers and must abide by the PSD processes and policies. Their ability to efficiently and effectively deliver the needed technologies is significantly influenced by the processes and policies being assessed in this review. Finally, the flight missions have the responsibility for implementing the technologies into flight systems that function together for a given purpose. They operate the technologies and must react to anomalies. The ease with which a new technology is adopted and operates is of great concern to the flight missions and to PSD.

The assessment phase also examined if needed technology content was missing from the current PSD technology portfolio. Some of the missing content had been noted in NRC reports, NAC, or community assessment groups like the Outer Planets Assessment Group (OPAG). In addition, the assessment phase considered other strategies, processes and policies used by NASA, other Government agencies, or industry, and how those practices may be applicable to a PSD technology program.

The PSTR panel interactions with the various stakeholders began to raise awareness of the review and began preparing the stakeholder communities to provide ideas and feedback on potential recommendations for any issues or concerns identified.

There were three main goals for the assessment phase of the review. The first was to identify the top issues that the PSD should address. The second was to collect and organize the data to be able to substantiate any assertions made. Lastly, the third was to provide a foundation upon which to make informed recommendations.

## ASSESSMENT APPROACH AND METHODOLOGY

The general approach taken by the panel was to engage members of the stakeholder communities through face-to-face meetings or more often via teleconference presentations that were conducted on a weekly or sometimes biweekly cadence. The first round of meetings focused on the Headquarters Program Executives and Officers. This provided knowledge of the scope and content and the existing processes and management practices used to guide the technology efforts. The meetings were held at NASA Headquarters and covered all technology elements within PSD as well as some technology efforts from other divisions within NASA. Armed with a data of existing activities, the panel embarked on a campaign to engage the other stakeholders to either learn of new issues, look deeper into a potential issue, or to corroborate information. Over 40 interviews were conducted. A comprehensive list of assessment interviews is provided in Appendix E. After most interviews, the panel and advisors discussed the lessons taken and what follow-ups were needed. Particular care was taken to ensure that several interviews were held with people representing each of the major stakeholder communities. A second round of face-to-face meetings was held toward the end of the assessment phase to wrap up missing elements and to recap or update information on the recent changes within NASA such as new technology planning by NASA's Office of Chief Technologist and the Exploration Systems Mission Directorate.

A written record of each meeting and teleconference was distributed to the panelists and advisors. An online collaboration tool was used to ensure access to the latest data available. Presentations were made available to the panel and advisors and, when possible, also made available on the panel's public Web site.

## Formulation Phase

The purpose of the formulation phase was to provide a set of recommendations that address the observations/issues identified in the assessment phase as well as those specifically listed in the Charter or other documents referenced in the Charter.

The nature of some observations/issues is such that potential recommendations are self-evident. For example, that fact that there is no overall coordinated strategy for the various technology efforts implies that a solution is to create a coordinated strategy for technology, and indeed a recommendation to do so is offered. Even though some of these recommendations seem obvious, they are not offered without considerable discussion within the PSTR team and vetting among the STM communities. In other words, even for seemingly obvious recommendations, considerable thought went into the specific recommendation(s), who should be responsible for implementing the recommendation, and what metrics could be used to demonstrate results of the implementation.

Recommendations are grouped into the categories used for observations/issues (with the exception of the added category for management). Although the categories match between recommendations and observations/issues, one will not find a direct pairing of recommendation to observation. The reason is that a single recommendation may be designed to simultaneously address a number of issues. The top three recommendations address a majority of the 17 issues identified.

Because of the complementary nature of the PSTR task to the Planetary Decadal Survey, all PSTR recommendations remained in draft mode until after the release of the Decadal Survey. Final recommendations were generated only after discussions with the chair of the Decadal Survey and members of the committee responsible for the technology chapter in their report.

## Recommendation Generation Approach and Methodology

The general approach taken by the PSTR team to generate recommendations can be described by a "propose-vet-refine" process. In reviewing observations and issues, the team (panel and advisors) offered ways to address the weaknesses and this led to discussions and sharing of opinions. Discussions were captured via written record and at the end of the sessions the civil servant panel met and documented resulting draft recommendations. The draft recommendations then went through a sharing and vetting process. This process included sharing the draft recommendations with the larger team. The draft recommendations were then presented to the PSD leadership and staff to understand any unforeseen impacts, discuss concepts and reasoning, and clarify wording. The draft recommendations were then shared publically on the PSTR Web site and presented at planetary assessment and analysis group meetings and conferences. Comments and inputs were solicited from the audiences at these meetings and conferences and captured into a database. A survey asking for potential ideas for solutions to the observations/issues was sent to the science communities through Planetary Exploration Newsletter (PEN), the weekly planetary science newsletter, and through the assessment and analysis group leaders. Those inputs were also captured in a database and forwarded to the entire PSTR team for review. The wording and scope for draft recommendations were continually refined during the entire process and, final recommendations were generated by the civil servant panel after the PSTR team had time to review the Planetary Decadal survey report.

## EXPECTATIONS FOR RECOMMENDATIONS

The PSTR team believes a comment is warranted about expectations for the recommendations provided. It must be realized by the STM communities that PSTR recommendations are just that: recommendations. The PSD is expected to consider all recommendations coming from this review, but the actions taken or changes implemented may divert from the recommendations provided. The review panel and advisors understand that programmatic, political, or other factors may come into play when taking forward steps. The ultimate actions and responsibility for said actions rests solely with PSD.

## COMMUNICATION/REPORTING PHASE

The communication phase of the task went on continuously for the entire duration of the effort. It started with a short presentation to the Planetary Science Subcommittee (PSS) of the NAC's Science Committee in December of 2009. The presentation discussed the concept and intent for the PSTR panel. With support from the PSS the task was initiated. A communication plan was developed early in the task to ensure that the relevant audiences were reached. In compliance with the plan and PSTR objectives, communication of status and solicitation of input was conducted at regular intervals during the assessment and formulation phases. A public Web site was created with an open portal for inputs. The request for ongoing inputs and the Web site address were provided to audiences at all presentations and in all briefing packages. The communication plan was periodically updated as new opportunities arose or content changed. Communication with the STM communities will continue through summary presentations at planetary venues beyond release of this final report. A communication summary matrix is provided in Appendix B.

The reporting phase entails the interim report and this formal report as final documentation of all phases of the task. The interim report was submitted to PSD in PowerPoint presentation format in September 2010. Contents included a summary of purpose, assessment approaches and methodology, and major findings. The major findings are the compilation of all noted observations and issues into 17 major items.

# 2

# Assessment Findings

The assessment comprised numerous face-to-face and teleconference presentations or interviews. There were over 40 such events over the course of 8 months. These, along with inputs collected during communication events, yielded over 300 notes by the PSTR team of observations and issues related to PSD technology efforts. After much discussion and deliberation these notes were consolidated to 17 major observations/issues and placed into four categories. The four categories include strategic, process/structure, resources, and culture/communication. These observations/issues are presented as findings of the assessment phase of this review.

TABLE 2.1 lists the issues by category. The issues are listed in priority order by category. The priorities were generated by the panel considering the opinions and discussions that occurred within the larger PSTR team. No attempt was made to prioritize one category above another.

There was one notable overall issue that is not captured in the summary but is important to recognize and address. This issue is the lack of a clear understanding within PSD and its technology stakeholders of what the definition of "technology" is and what should be funded by technology resources. A related question is "When does a technology development cease to be that and become just another mission element whose implementation is funded by the mission?" The PSTR recommended definition for technology development, as described in Chapter 1, is the application of knowledge to create or use a technical capability to enhance or enable future planetary missions in a significant way.

Finally, best practices or lessons learned from other programs have been incorporated into the recommendations and not elaborated upon separately in the assessment summary chapter.

TABLE 2.1 Major Technology Development Observations/Issues

| Issue Number | Technology Development Observation/Issue |
|---|---|
| **Strategy** | |
| S-1 | No overall strategy or accountable manager |
| S-2 | No clear path for technology maturation from TRL 0-9 |
| S-3 | Limited engagement of other NASA OCT, ESMD, and ESD technologists |
| S-4 | Technology should be perceived as more than just hardware development |
| S-5 | Efforts by external stakeholders are not worked into PSD strategy |
| **Process/Structure** | |
| P-1 | Programs are not consistent and do not have clearly defined processes |
| P-2 | Technology managers are overloaded and often oversee flight projects |
| P-3 | Inconsistent and inaccurate TRL and heritage assessments |
| P-4 | Limited processes that encourage interaction between stakeholders |
| **Resources** | |
| R-1 | Technology budgets are unpredictable |
| R-2 | Technology budgets are insufficient |
| R-3 | Inadequate leveraging of other's investments |
| **Culture/Communication** | |
| C-1 | Technology investments have not yielded all the benefits they could have |
| C-2 | Inadequate communication (in & out) |
| C-3 | Projects are too risk averse to new technology |
| C-4 | Tenuous commitment by top management |
| C-5 | Need to better sustain capabilities |

A detailed description and discussion of each major observation and/or issue is provided in Chapter 3.

# 3

# Discussion of Major Observations/Issues

## Strategic

Strategic issues relate to an overall planetary technology strategy.

### *S-1 Accountable manager responsible for an overall strategy*

*PSD does not have an accountable owner or a comprehensive technology development strategy that establishes priorities and improves performance and coordination*

During the initial round of presentations with the cognizant PSD technology program officers, it became quickly apparent that the various technology efforts were not coordinated or driven by an overarching strategy or an accountable manager. Technology programs and projects in PSD operate independently with little emphasis placed on coordination among the technologies. Program officers establish priorities within the specific project or program, but it was unclear how priorities were established between projects and what guided that decision. A weakness of such a system is that priorities can become misaligned with PSD strategic needs resulting in some needed technologies not getting the needed resources. Not funding or underfunding certain strategic technologies is one criticism of the NRC's mid-decade report.[1] This is further evidence that not having an overall strategy and an accountable owner of that strategy is an issue. Additional evidence exists in the form of findings by assessment groups such as the OPAG, who have repeatedly included technology needs in their finding letters.

An overall strategy would consider early technology concepts and innovations and have a

[1] National Research Council, *Grading NASA's Solar System Exploration Program: A Midterm Review*, The National Academies Press, Washington, DC, 2008

mechanism to evaluate those in light of mission priorities. An approach would be available to bring that technology to maturity and eventual application. There was no evidence that this presently exists with PSD technology efforts.

Leveraging technology investments by other Divisions and Directorates within NASA, other Government agencies, universities, or industry would be beneficial in times of limited or deflating technology budgets, yet little effort or attention seems to be directed to this element of strategy. This further underscores the impact of not having an overall technology strategy and accountable owner.

Some other specific comments or notes captured during the assessment phase that related to this issue include

1) There appears to be a lack of consistency in technology development and communication within the PSD.
2) No integrated prioritization plan appears to be in place.
3) In addition to funding instrument development, other systems such as navigation, communications, and planetary protection also need to be developed, but are not funded at appreciable levels.
4) Defendable roadmaps are critical in securing and sustaining funding—not all technologies presently have one.
5) University technology development is critical to training the next generation of scientists and engineers, but there is no comprehensive strategy within PSD promoting university involvement.

The top issue in the strategy category is not having a comprehensive and coordinated technology strategy and an accountable owner.

### *S-2 Clear Path for Technology Maturation*

*There is no clear path to mature and infuse technologies through the existing programs from TRL-0 to TRL-9. There is limited funding at mid-TRLs (often referred to as the valley of death) and there are inadequate mechanisms within PSD for suborbital test flights or technology demonstration missions.*

The technology programs within PSD often operate independently. This and the lack of an overall strategy have resulted in gaps between technology programs. These gaps prevent clear maturation paths for a technology. They may cause barriers to maturing a technology to the next TRL or cause technologies to be abandoned. To continue maturation, technology products may have to jump between programs, find funding outside NASA, or find other means to cover the gaps.

With a few exceptions there is little evidence for “on ramps” for new technologies at low TRL levels. There is a general absence of attention to the development of new game-changing technologies for future instruments and missions. Much of the existing technology portfolios cover the TRL 2–4 range. There is also a void of funding at the upper end of the TRL spectrum. For example, there are no regular technology demonstration missions or suborbital flights planned. The lack of suborbital opportunities, in particular, may impact future scientists and engineers. Students and early career hires do not receive adequate hands-on experience with new technology, due to insufficient opportunities and resources. Suborbital programs would be a good way to offer these opportunities at low cost and on rapid time scales.

In addition to voids at the two TRL ends, the problem also exists that there are very few options for technologies trying to bridge the TRL "valley of death."

Further complicating the matter is that programs or tasks are not consistently supported. A technology may go unfunded for some program cycles resulting in poor progress in efficiency and maturation.

The recent approach taken by PSD to study and incentivize technology inclusion on missions is seen as an excellent step to begin addressing technology maturation challenges for high TRL technology products. This solicitation for Discovery mission concepts included the option of an advanced radioisotope power system with an incentive to include that technology. This approach shared the intent to mature and fly the advanced technology and it supported the mission planning community by providing an opportunity to prepare and vet ideas that can later be proposed for a mission. The cost sharing incentive used for other NASA-developed technologies like the NEXT electric propulsion systems and the high-performing AMBR chemical rocket is also encouraging.

### *S-3 Engaging other technology groups within NASA*

*PSD should be proactive and engage other NASA organizations such as the OCT, ESMD, and ESD as appropriate to ensure coordination and effective leveraging of plans and activities.*

NASA has become more technology friendly, and several technology investment initiatives have been started. From a strategic perspective, PSD needs to be proactive in engaging these groups, particularly the Office of Chief Technologist (OCT) and the technology planners in the Exploration Systems Mission Directorate (ESMD). The observation is that these groups have begun making plans and examining investment options, yet the PSD may not be in a position to forward their needs or are not given adequate opportunity to do so.

Another part of the issue is that where there has been long standing programs, like the Earth Science Division's (ESD) technology program, there is no evidence of attempts to leverage overlapping needs. Although the environments in low-Earth or geosynchronous orbits can be vastly different from planetary environments, it is expected that some synergy and common developments, particularly at the lower TRLs could be identified. The lack of interactions result in gaps in technologies, with each group thinking the other will handle it; solar power technology is one example. Opportunities to cost share are missed, and technology resources do not go as far as they could.

### *S-4 Technology is Not Just the Hardware*

*Technologies that address integration, ease of use, and system level issues are not adequately considered. Technology is more than just hardware and a qualified system is more than a set of qualified components.*

PSD technology programs appear to be too focused on the hardware aspects of technology development. Furthermore, even for hardware developments, the resources and programs focus primarily on component or subsystem-level developments, and few resources are available for system level development and testing.

The PSD technology portfolio reveals little investment in integration technologies, processes and tools for system level integration or testing, making technology products user friendly—such as developing user manuals, as well as other possible investments. Other examples of possible "technologies" are specialized facilities and astrodynamics' tools.

This is considered a strategic issue because the ultimate goal is more scientific knowledge, and technology is a tool to achieve that. If only hardware technologies are considered, a whole range of science targets will remain unreachable. Consider, for example, the Dawn mission. Without the low-thrust trajectory analysis tools, mission planners would never have considered going to two asteroids. The possibility became reality when hardware advances in the form of electric propulsion were coupled with advances in astrodynamics software tools. It is imperative to encompass all technology needs when strategically planning a technology portfolio.

### *S-5 Efforts by external stakeholders not worked into PSD strategy*

*Universities and other external organizations are not adequately and consistently engaged and supported in technology development.*

Technology developments do not leverage external interactions and capabilities sufficiently, leading to increased challenges in moving new technologies forward. There is little evidence to suggest that external partners are thought of as potential assets to leverage. University efforts, in particular, need to be better infused into the PSD technology strategy. PSD may be missing the benefits of university investments in technology. Future skills and talent are impacted when students do not get training on technologies required by NASA. Given the tight budgets and technical hurdles any successful leveraging that could be achieved would improve PSD technology readiness.

In addition to simply wanting more NASA technology opportunities, the university presenters were critical of NASA technology programs for changing or eliminating projects on short notice and for inconsistent funding. This has made it difficult for them to teach and graduate students in the technology fields. Inconsistent support impacts the future technologist base as students and professors find other areas to pursue where projects are more stable. University technology development is critical to training the next generation of scientists and engineers.

## PROCESS/STRUCTURE

Process and structure issues relate to technology program processes and supporting institutional structures.

### *P-1 Inconsistent Processes*

*Technology-related decision making, planning, implementing, and review processes are not well defined and are often inconsistent across programs.*

The fact that the various technology developments efforts are managed independently has resulted in inconsistent processes across the various technology programs. The methods for planning, the reporting requirements, and review processes vary from program to program. This makes it challenging for technologists to plan and estimate schedules and resources. It also makes it difficult when a technology principal investigator must propose to different programs as the technology matures. These inconsistencies result in lower efficiency, miscommunication, and missed opportunities and frustration both for NASA and the proposers.

There is little evidence that many of the technology development efforts are seeking to comply with higher level NASA technology management processes as identified in NASA Procedural Requirements NPR 7120.8. There is evidence that the larger technology programs being implemented at centers, for example the Radioisotope Power Systems (RPS) program, are complying with the high-level NASA processes, but many of the technology projects in PSD do not have a supporting program office. In those cases, it is unclear if NASA processes are being strictly followed.

### *P-2 Overloaded and Scattered Technology Management*

*Technology management is scattered across busy program executives, and officers at NASA Headquarters that have other competing responsibilities.*

It was very clear during the NASA Headquarters Program Officer presentations that they were very capable and dedicated professionals. It was very clear that each person had many other duties and responsibilities as well. Often those duties were supporting missions in development or operations, or in a science or mission solicitation, evaluation, or selection processes. Each of these efforts involves larger budgets than the typical technology program, each generally has tighter schedule requirements, and each generally has more visibility. This tends to result in the program officer's time and attention being directed to the other duties besides the technology efforts. This does not imply neglect or incorrect time management, but is rather a management structure issue.

The current technology management structure makes it difficult to focus time and attention on the planning and implementation of the divisions' technology efforts.

### *P-3 Inconsistent and Inaccurate TRL Assessment Process*

*The heritage and TRL assessment processes are not accurate and consistent.*

A common theme during the assessment briefings was inaccurate TRL claims and inconsistent interpretations of TRL. Because TRL assessment has become a measure to indicate when a technology can be proposed and the perceived risk it brings to missions, it has become increasingly important to accurately assess technologies. However, for any given technology, stakeholders will have different perspectives and will often assess different levels of readiness to a technology. A technologist may perceive the technology to be at TRL of 5 or 6 whereas the mission perspective may be a TRL 4. Even from one technologist to another, differences in opinion on readiness will be found.

There is ambiguity when it comes to what constitutes "the system" for a technology and also what is a relevant environment. In a technology development effort, that system may be the interconnected components and subsystems that work together demonstrating that the technology interacts and controls the elements in a known and predictable manner. The system for a mission will contain a much broader set of elements, some of which the technologist may not even be aware of. The relevant environment question is particularly vexing for PSD. Unlike Earth focused missions, planetary missions vary widely in the expected operating environment depending both on the final destination and trajectory. Some environments are extremely cold, others extremely hot; some destinations have high radiation. Sample-handling technologies may face regolith, rock, ice, rubble, gas, or liquid. Coupled with the diverse destinations is the fact that mission details are often unknown when technologies are being developed. Much of the PSD mission set is selected competitively and therefore, it is difficult for technologists to anticipate environment and assess TRL.

The inability to consistently assess TRL contributes to other issues as well, such as the risk aversion of NASA missions. The importance and complexity of this problem warranted a sub study of this issue by the PSTR team and the findings of that work are discussed in a Chapter 4.

### *P-4 No Process to Enforce Interaction of Scientists and Technologists*

*There is no clear structure that links technologists to missions and promotes early interaction with scientists.*

It is commonly understood and several of the interviews reinforced the notion that the sooner and more effectively the technologists communicate with the mission engineers, the easier the infusion will be. With early interactions, the technologists can highlight the features, plan the testing, and enable better future integration. Technologists need to have access to the mission details. Likewise, mission engineers can plan the infusion better and avoid the pitfalls of misapplying a technology if they better understand capabilities and constraints.

It appears that the issue is deeper than just more communication, although that is a problem that will be discussed later. This issue appears to be a structural one. The NASA technology and mission implementation processes are not ensuring that adequate interfacing occurs. As an example, NASA realized that safety and mission assurance functions were critical to mission success. The functions and people with those skills were embedded into the project structure and processes so that it became a day-to-day operation to include safety in decision making. Similarly, and more recently the same issue occurred with the chief/systems engineering functions. These too have been embedded in the daily processes. This is not yet the case for technologists, mission engineers, and scientists on robotic science missions.

This interfacing issue occurs for various reasons. Technologists and mission management are often at different institutions. This increases communication challenges and mission requirements and needs may not get adequately conveyed. Another factor is that missions are often competed and there is pressure to keep the project teams small. This may hamper the mission team’s ability to gather all the technology information they should. Mission engineers are very capable people and they may believe integration and infusion can be handled internally without the burden and cost of pulling in technologists from outside. There appears to be a negative connotation to soliciting outside support for technology infusion. Often, the result is inadequate interfacing and that allows technology-related issues to plague the missions.

The basic issue is that the processes and structure do not force timely and sufficient interaction between technologist, mission engineer, and scientist so that more technology products are successfully infused.

## RESOURCES

These are issues that relate to resources made available for technology development activities.

### *R-1 Unpredictable Technology Budgets*

*Technology budgets are unstable and unpredictable. This makes technology maturation, as well as sustaining skills and capabilities, challenging and adds risk to overall mission success.*

Budgets for technology development programs are unstable and unpredictable causing perturbations in technological development cycles. These perturbations lead to poor technology maturity progress and difficulty in sustaining technology skills, and add risk to overall mission success. Without stable funding, the technologies under development cannot be fully qualified and are usually left at mid-TRL. When a directed mission finally needs a specific technology, funding is reallocated to address the need, but this is very inefficient. In addition, the funding to cover the current need is generally gathered from other technology development efforts planned for later missions, leading to a cyclical spiraling problem caused by the perceived expendability of future technology development.

This problem boils down to a question of priorities and reserve management. If a mission in development, where hundreds of millions of dollars have been invested, runs into cost overruns it is unlikely it will be cancelled. Resources from technology programs are often reprogrammed to address these overruns. Priorities are generally given to missions and launch dates and technology efforts have inherently lower priorities.

Another factor that contributes to this issue is the constant pressure to do more with budgets that are not increased to accommodate the increased scope. Holding reserves has not proven to be a reliable solution because reserves in one program are also targets when problems arise elsewhere in the Agency. Recently NASA has instituted a policy to fund projects at the 70 percent confidence level. This was done to get actual mission costs closer to estimated costs and to better manage reserves and reduce the need to raid other projects when there are overruns. Although this policy is presently being implemented on missions, there is no plan to do this for technology projects even though technology issues are often blamed for mission overruns. If technology is where many of the unknowns and risks are, why not better fund those programs and hold healthier reserves for technology projects?

There are several consequences for using technology resources as “go-to” sources when nearer term projects get in trouble. Without a commitment to sustain funding to technology programs, PSD cannot leverage past efforts or interagency cooperation. For example, academia may not consider NASA to be a good partner because rapid changes in research priorities prove to be deadly for academic programs. On competitive programs, sustained funding is needed partly because, during lapses of funding, both selected and nonselected bidders become critics of NASA. In addition, mission teams and scientists become skeptics of technology developments in general. Examples of underfunded efforts create poor technology readiness track records and call into question future readiness claims. Valuable team members may leave when the funding is not consistent.

NASA has been increasing mission complexity and decreasing upfront planning resources. The lack of funding to higher TRL technology development efforts has increased the burden on the adopting missions. The effect is more work to be done with less resources, a shifting of work to later in mission phases, and increasing costs and risk.

### *R-2 Insufficient Budget for Critical Technologies*

*Previously identified technology priorities have not been adequately funded to make progress. The list includes the gap to infusion, extreme environments, planetary protection sample return, and other technologies listed in the 2008 CASSE report (solar system decadal mid-term).*

Current funding rates are seen as insufficient to accomplish the developments expected. Budgets have been cut in many areas. At the same time, technology programs continue to set optimistic goals to fit within budget guidelines and progress expectations. These optimistic goals may differ from actual flight requirements because technology budgets are not adequate. Many technology development programs have changed from planning flight validation to settling on ground validation. The current funding in PSD technology budget lines is roughly 6 percent of total budget, and there is widespread evidence that this level is insufficient to meet all the needs.

In the briefings with other mission directorates and industry where figures were made available, a 6 percent technology budget was generally considered appropriate. There are two problems for PSD, however, that drive up the ratio they need to invest relative to what others' invest. First, PSD demands technologies that must function in environments that are both unique to PSD and extreme. This means that materials, methods of operation, and test programs all have to be different from everyone else, thereby raising the cost for PSD above what others typically pay. The second factor is that there is less leveraging that PSD can do with others investing in similar technologies.

Consider, for example, an electric propulsion subsystem. There are numerous spacecraft with electric propulsion flying around Earth for civil as well as military applications. However, because PSD missions travel throughout the solar system the subsystem requirements are very different. PSD is forced to develop its own version of electric propulsion that is more complicated and costly. This is also true for advanced communications and avionics technology. Compounding this problem is the fact that they are the only potential user, therefore, increasing their investment share. PSD may need to sustain the industry capability for critical technologies. These factors imply that PSD investment in its technology should be a higher percentage than what others invest.

Another result of inadequate funding is the inefficiency in maturing technology in current programs. For example, Mars has an instrument development program, but it is currently not funded. Overhead and processes exist but are not used to generate progress. Other solar system destinations do not have their own programs, but are captured under one program, PIDDP, which is oversubscribed, causing another set of issues.

There is a list of technologies that the NRC and assessment groups have recommended but are not being funded adequately. Examples are planetary protection technologies, extreme environment instruments and mechanisms, and sample handling technologies, to name just a few.

All these factors support the assertion that a 6 percent investment in technology development may not be adequate for PSD.

### *R-3 Leveraging Technology Investments by Others*

*Technology investments made by other agencies and the SBIR/STTR processes are not adequately leveraged.*

To capitalize on others investments and to improve efficiency of the overall technology development system, early phase technology development efforts such as SBIRs, STTRs, and other external investments need to be viewed as resources to be leveraged by PSD. This should occur for strategic reasons as discussed above but especially for resource leveraging. It is recognized that synergies between PSD technologies and others may not be easily identified because of unique PSD requirements; however, some leveraging can be achieved, especially in the early phases of a technology as might be found in SBIR projects. The challenge is that these programs are not tightly focused to specific PSD objectives, and there is little organized drive to transition the results to specific applications. Currently, PSD does not appear to be looking at these programs for leverage. There is little evidence that SBIR or other technology programs are leveraged in a significant way. Many SBIR initiated technologies have achieved application for other users, and this should encourage PSD to more aggressively pursue leveraging SBIR investments. Likewise, there are many successful cost-sharing partnerships, and PSD should be more aggressive in pursuing these as well.

## Culture and Communication

Culture and communication issues speak to the culture and communication among and between space projects teams, the supporting technologists, their respective institutions, within NASA, and external stakeholders.

### *C-1 Investments Not Yielding the Expected Benefits*

*Technology investments do not always realize the possible benefits. Better documentation and accessibility to technology is critical to ensure broader use and to maximize investment potential. There is no easy way to comprehensively search and learn about technologies NASA is developing or has made available.*

In recent years, the PSD has been showing nearly $100 million per year on its technology budget lines. It is expected that products from these investments will become available to future scientists, missions planners, and proposers. This is not always the case because of a lack of awareness of available technologies. There is no easy way to collect, track, and summarize PSD technology developments, and there is no evidence that NASA or the PSD are maintaining a repository, database, or other tools where technology information is stored and made available to interested parties. PSD does not provide funds to keep documents on the history of a given technology. Different programs and projects may maintain some elements of a repository like the Earth Science Technology Office (ESTO) program or the SBIR program, but these tools are often geared to the implementers of the tasks more so than to scientists or future users. Getting an awareness of a technology or the capability it affords is not as easy as it should be. Recently the NASA OCT has indicated its intention to develop a technology database, but the scope and intended audience is currently unclear.

Awareness of technology developments becomes an even bigger issue when interfacing outside of NASA. There is little evidence of NASA using deliberate and routine mechanisms to stay aware of or influence technology work by other agencies, academia, and industry.

NASA does not effectively document technology for the next user. There is evidence from the Dawn mission that because of funding constraints, adequate development and test data and documentation was not generated during the development of the electric propulsion system on the New Millennium DS-1 technology demonstration mission. This resulted in costly changes and schedule slips and a nearly cancelled mission. There is evidence, the Mars Science Laboratory (MSL) Entry Descent and Landing Instrument (MEDLI) suite being one case, that when science missions fly new technologies there is resistance to allocate resources toward collecting the data needed to validate and monitor the performance of the technology at a level that could then help improve a future generation of that technology.

A barrier to broader use of NASA-developed technologies may stem from institutions seeing the technology or the expertise they have developed as a competitive advantage for future competed work. A new technology may offer an edge and enable a better proposal with better science. Often items developed in industry with Government funds get advertised, but not shared. This, however, is counter to the intent of Government-funded development. NASA benefits most when a wide audience has full and open access to developed technologies. The technology has the best chance of infusion when it is considered and proposed by the broadest set of users. Even when there is no deliberate decision to take institutional advantage of what should be a NASA-wide capability, there may still be a "not invented here" barrier. The best technologies may not be considered because the institution may have to depend on outside collaborators for expertise. This is particularly true for competed missions.

### *C-2 Not Enough Communication*

*Communication and exposure among all stakeholders (scientists, technologists, mission teams, centers, etc.) is inadequate to ensure effective technology planning, development, and infusion.*

One of the major cultural challenges that technology developments and infusion of technologies into missions face is that there is an overwhelming amount of information to be communicated between people at all levels of widely diverse organizations within and external to NASA. For example, scientists, technologists, and mission managers have differing interests, expectations, and methods of working and interacting. These differences result in one or more of the technology stakeholders not having the right information at the right time.

Contributing to the problem is NASA's culture of separating technologists from scientists and mission teams. Without adequate exposure to the flight team culture and their needs, technologists will not understand their "customer." Likewise, without adequate exposure to the technologists a flight team will not understand the product they are "purchasing." The NASA center structure, where there are flight centers, research centers, and operations centers, adds to the difficulty in effective technologist-to-mission-to-scientist communication.

The result of untimely or inadequate communication is often a mismatch between a new technology and its application. Evidence of this issue was identified in discussions with the Program Offices for Mars Technology and New Millennium. There is additional evidence of the absence of technologists on science and mission review panels and the absence of scientists and individuals involved in missions on technology review panels. The industry stakeholders note the importance of early interactions among technologists and the rest of the stakeholders.

There also appears to be a lack of communication between NASA and other agencies thereby creating insular NASA programs. Various interviewees mentioned that NASA did not appear to coordinate technologies with other agencies, and we heard that technology communication within and external to NASA is, with a few exceptions, primarily ad hoc.

A related observation was that NASA-funded technologies are not readily available to the broader community, and there is no clearinghouse where technology can be made accessible to others. Unless external organizations have a specific contact within a NASA center, it is extremely difficult to ascertain where new technologies exist that might be of interest. One noted exception is the SBIR program and database that, at least to one interviewee, is perceived to be excellent at interfacing with centers because there are technical monitors at the centers that have a vested interest in the technologies' outcome. This results in better communication during development.

Communication during the review process should be improved. There is no uniform review process in place for technology programs. For example, not all technology programs have external reviewers who offer knowledge to advance the technologies or infuse it more rapidly. In addition, often the ROSES peer reviewers have little flight experience, so during the proposal review process there is a gap in understanding what NASA really requires to fly a new instrument or other technology. Similarly, technologists are typically not on standing review boards for flight missions, which may limit ability of the board to detect problems before they occur and to review the technology's implications on the flight system.

### *C-3 Projects are too Risk Averse to New Technology*

*Projects are too risk averse to new technologies.*

Reluctance to accept new technologies onto science missions is both a cultural and process issue. The growing NASA conservatism toward technology risk is a risk in and of itself for technology development. This NASA conservatism has been adopted by flight projects that tend to avoid anything that may be considered new technology. Projects are conceived and sold on the basis of existing capabilities. Effort and resources are required by the project to manage the technology risk. The additional effort starts with the proposal where projects must justify the use and readiness of a new technology. The NASA competitive process for mission selection (Announcement of Opportunity (AO)-driven) demands additional explanation or justification for new technology and creates a disincentive for adopting new technologies. A project team will expect more scrutiny of the proposal and will devote more time and space to discussing the need for the technology and how it will be managed. This leaves less space for emphasizing the mission benefits. There is also a fear that reviewers may not be familiar with a new technology, which would make selection less likely. This notion of additional effort required by the project would follow throughout the life cycle with every review and decision gate.

Small and mid-sized missions are particularly apprehensive to include technology risk because of the cost cap, schedule, and the nature of competition. On a competed planetary mission, there is little time to mature technology once the mission is selected for flight. An example of what may happen in a risk-averse environment is seen with the New Horizons micro digital sun sensor. The sensor was identified as a low-mass, low-power new technology in New Horizons Step 1, but it was descoped and exchanged for a poorer performing (higher power demand) off-the-shelf sensor because of perceived risk at Preliminary Design Review (PDR). The same fate befell new sun sensors advocated for MSL, where new sensors would have led to a mass saving, but were not adopted because of perceived risk.

Risk aversion by projects tends to limit new technology development for flight to those cases where a new technology solves a key problem that cannot otherwise be overcome, i.e., the technology is mission-enabling.

The final cause for project risk aversion is due to prior performance by technologists and mission integrators. Faced with the infusion challenges, technologists provided overly optimistic assessments of readiness and underestimated the time and resources required to mature and infuse a technology. Communication issues described above have resulted in missions not getting the expected benefits.

An interesting note from the assessments was that oftentimes when technology issues plagued a project the culprits were not the new "riskier" items that many initially worried about. The new riskier technologies received a healthy amount of resources and attention. All the stakeholders were engaged early and often. The problems often arose with technology efforts that were not perceived to be new technology. Teams thought they understood the issues or capability limits but did not.

### *C-4 Tenuous Commitment*

*Tenuous top-level sustained commitment for technology.*

In the past several years, support for technology efforts from senior NASA leaders has been weak. The direct results of this were deep cuts in technology budgets across NASA. Although the situation is improving and new technology development efforts have begun, there is still a concern that the support is tenuous. A long-term cultural change is needed where NASA leadership recognizes the critical role technology has in sustaining the future and the importance it must carry in current resource decisions.

The support for PSD technology must start in PSD. The PSD director is commended for initiating a review and seeking ways to improve technology development. The commitment must continue to address critical issues such as a lack of an overall strategy, unstable and unpredictable resources, and the need for a technology manager to oversee all of the technology programs. PSD management must influence the SMD and Agency management in advocating the importance of technology for future science and NASA missions.

Tenuous top management support for technology is also reflected in the inconsistent NASA support for students in the technology fields. NASA was criticized in discussions with academics for cutting funding on development projects and on other support for students on short notice and unpredictable schedules. This practice reinforces the culture that technology is not as important and valuable as other fields, causing students to pursue other careers. Students take approximately four to five years to graduate with Ph.Ds, and inconsistent funding is too disruptive for the academic environment. If this issue is not addressed sufficiently it will negatively impact NASA's ability to train students in new technologies, which will impact its future achievements.

Technology development is not well-served by starting and stopping over decades. The assessment revealed that inconsistent support is, in some ways, worse than limited but consistent support.

The review panel recognizes that there are recent changes at the NASA Agency level that may make this less of a problem, but steps need to be taken so that the recent technology emphasis is not temporary, and technology leadership remains consistent in the future.

### *C-5 Need to Better Sustain Technology Capability and Heritage*

*Technology capability and heritage is lost during gaps in flights or technology programs.*

When a program gets cut or ends, the technology capability declines and is eventually lost. People are extremely important in capturing and then reusing technology advances and maintaining the knowledge gained in a field. A technology does not survive unless teams continue development and maintain the tacit knowledge. Lack of sustained support risks the loss of heritage and expertise because the development teams are drawn to funded projects.

Gaps in funding not only affect people but they could impact availability of parts as well. Suppliers may not continue to offer the products and material sources may disappear. The time lapse may result in technology companies going out of business or being bought out by others, two typical problems with technology companies that affect system heritage. An example of supplier issues occurred recently on the MSL mission. The microvalves used on the Sample Analysis at Mars (SAM), a gas chromatography mass spectrometer instrument, were manufactured by a small company that did not have sufficient business from NASA to maintain their staff. Consequently when SAM needed the microvalves, the company had to restaff and recreate the know-how to build the flight-qualified valves costing valuable time and extra resources.

Beyond tacit knowledge, explicit knowledge capture is also important. There is direct impact to heritage and sustaining capability when adequate attention and resources are not applied to documenting developments for later reuse. PSD technology programs must improve identifying the technology knowledge to capture and documenting that knowledge.

# 4

# Recommendations

The PSTR panel generated 11 major recommendations following the process described in Section 1, Introduction. These recommendations are described as major because the panel believes that these will have the greatest impact in addressing the issues uncovered. All 11 major recommendations were presented to the science and technology communities in draft form at numerous forums as described earlier. They were also presented to the PSD leadership and program officers. Upon release of the Planetary Decadal Survey in March 2011, the panel and advisors convened to consider the Survey report and compare it to the issues and draft recommendations identified by the PSTR team. It was found that the PSTR draft recommendations were consistent with the technology-related content of the Decadal Survey. The PSTR panel had avoided drafting any recommendations that specified technology resources or the distribution of those resources to the various technology areas. With the release of the Survey report however, the panel formulated its resource recommendations and refined the other draft recommendations. The results of those efforts are found in TABLE 4.1, Summary of Major Recommendations. In addition to the 11 major recommendations, there are numerous other recommendations that either address a specific issue or support another recommendation.

TABLE 4.1 Summary of Major Recommendations

| Major Recommendation |
|---|
| **Management** |
| MR-1) Establish a dedicated Director position with overall responsibility for PSD technology |
| MR-2) Establish a small supporting program office |
| **Strategy** |
| MR-3) Develop a comprehensive strategy for PSD technology |
| MR-4) Strategically allocate resources (guidelines are provided by PSTR) |
| MR-5) Actively pursue a strategy of leveraging opportunities within and outside NASA |
| **Process** |
| MR-6) Develop a more consistent and accurate TRL assessment process |
| MR-7) Develop clear, transparent, and consistent decision and review processes |
| MR-8) Develop a more structured and rigorous process to create interactions between technologists, scientists and missions |
| **Culture and Communication** |
| MR-9) Develop an overall communication plan and technology database |
| MR-10) Foster a culture that advocates for and defends technology |
| **Resources** |
| MR-11) Dedicate stable funding at the higher end of the decadal suggested range - 8% |

A detailed description and discussion of each major and supporting recommendation is provided in the subsequent paragraphs.

## Recommendations regarding technology Management

Recommendations in the Management category relate to the structure and approach to managing PSD technology developments.

### *Recommendation MR-1: Establish a dedicated program Director position with accountability and responsibility for PSD technology efforts.*

Establishing a Technology Program Director (TPD) in PSD is one of the most important steps to improving the efficacy of PSD technology efforts. As described in Chapter 3, current efforts lack overall coordination, vision, and accountability. Although current program and program officers have plans and processes, there is no one person accountable for providing the coordinating function. Further, no person has responsibility for generating and maintaining a strategy, providing guidance and support in balancing resources, setting priorities, and enforcing implementation and review consistency. The TPD is envisioned to provide these types of functions. The person selected for this role should be a strong leader and experienced in managing technology development efforts. The panel stresses that *technology* management is not the same as *project* management; therefore, skills in technology management as applied to science missions are required. The other skills required are evident in the duties described below.

Proposed responsibilities for the TPD can be collected into two groups: strategy/leadership and implementation.

In strategy and leadership areas, the TPD would be responsible for generating and maintaining an overall technology strategy that sets clear technology priorities traceable to science and mission priorities. These priorities are defined by the scientific community through the Planetary Decadal Survey and national interests established by Federal Executive and Legislative branches of Government.

The application of an effective strategy would influence the budget formulation and planning process. The TPD should be given responsibility to formulate technology budgets that support the overall strategy and to plan the allocation of those resources to balance needs, address shortfalls, and in general keep current with mission and science needs.

There are numerous technology-related interfaces to other NASA organizations and to entities outside of NASA. The TPD is expected to act as point of contact (POC) for all PSD technologies. An effective strategy also includes a communications plan that provides guidance on the desired level of interactions with stakeholders. The TPD would be responsible for establishing that plan and would take a lead role in its implementation.

Given the breadth and scope of missions and required technologies, it is expected that roadmaps for key individual technologies will need to be generated. These roadmaps will identify major milestones and capture the development paths for individual technology efforts. The TPD will be responsible for those roadmaps and for coordinating the roadmaps with budget constraints and changing mission needs. The TPD will also coordinate these roadmaps with the agency level technologies roadmaps being developed under the guidance of the OCT. The OCT roadmaps are not expected to address the unique PSD technology needs or go to the level of detail required by PSD.

Recommendation MR-2 discusses a supporting program office. The TPD would act as the program director for the supporting office.

Other TPD responsibilities address implementation. A primary implementation function of the TPD would be responsibility for establishing and overseeing the decision processes for priority setting, gate keeping, and the reviews of technology development efforts. Consistent with NASA Headquarters functions, the TPD would also be responsible for ensuring the integrity of technology-related selection processes for technologies in opportunity announcements.

Another role of the TPD is to ensure that a technology is (1) maturing, (2) getting infused, or (3) terminated. This policy, coupled with the tight focus on mission needs, should address the "sandbox" problem and ensure that all resources dedicated to technology efforts are utilized in the best possible way.

One of the major technology development issues is accessibility of technology data. The TPD would be responsible for ensuring that the products and data from PSD technology development efforts are readily available to as broad an audience as possible, yet safeguarding proprietary and export controlled information as appropriate. A key to successfully sharing technology data is to ensure that the right data is available at the right level of detail for the interested stakeholder at the right time. Accomplishing this will not be a trivial matter, and this is viewed as another significant responsibility of the TPD.

The TPD would be responsible for ensuring that leveraging efforts are effective and that all the appropriate stakeholders are engaged. As the PSD begins to better leverage other technology efforts within and outside NASA, guidance, processes, and policies will need to be established to govern those interactions. This will also be the responsibility of the TPD.

As mentioned earlier, the TPD would be responsible for the overall strategy, which requires technology efforts be driven by science and mission priorities. The TPD would have the additional implementation duty of ensuring that technology efforts are consistent with the needs of the entire PSD. These needs are that technologies make timely progress toward maturity, the environments and uses are understood, and, when development efforts are complete, that the product will be at the expected level of maturity for infusion. Technology programs are often criticized for becoming "sandboxed" where technologists enter unending cycles of improvement and refinement and never actually generating a usable product. TABLE 4.2 summarizes the Strategy/Leadership and Implementation duties for the TPD.

TABLE 4.2 Summary of Technology Program Director Responsibilities

| **Responsibilities of the Technology Program Director** |
|---|
| **Strategy /Leadership** |
| Develop and maintain an overall PSD technology strategy with clear priorities |
| Formulate technology budgets and plans |
| Develop a strategic technology communication plan and act as POC for PSD technologies |
| Integrate PSD technology needs and efforts into a coordinated roadmap |
| Serve as the Program Executive of the supporting program office |
| Advocate for technology needs and communicate accomplishments and highlights |
| **Implementation** |
| Develop and oversee decision processes for priority setting, gate keeping, and program reviews |
| Ensure the integrity of the selection processes |
| Ensure all technologies are either making steady progress toward maturation, being infused, or getting terminated |
| Ensure that the proper technology-related data and status is easily available to the right person, at the right time, at the level of detail needed |
| Oversee the processes that leverage and/or influence stakeholders within or outside NASA |
| Ensure all PSD technology efforts are traceable to PSD science goals |

Currently there are several program officers and program executives that lead various technology efforts in PSD. Along with establishing the dedicated TPD position, the panel recommends the consolidation of management responsibilities to as few program officers and/or program executives as practically possible. This will help ensure coordination, integration, and consistency, as well as assist in maintaining balance in resource allocation, visibility, and other areas. When technology management responsibilities are consolidated under a dedicated TPD, it is expected that timeliness and attention to technology-related issues will improve. Although the ideal is to consolidate all technology management efforts under the TPD, it is recognized that there are special cases where such a change may not be practical or desired. The nature of nuclear materials, the national policies governing their management and handling, and the existence of a recently established Agency-level program indicates that the Radioisotope Power Systems (RPS) leadership structure remain intact. However, the overall strategy, communication plan, processes, and reviews established by the TPD could be applicable to and utilized by the RPS program.

The PSTR panel debated extensively on the suggested authority level of the TPD. Because of the need to address numerous long-standing weaknesses in technology-related areas, the classic stature of technology when compared to missions or other areas, and strong technology supporting comments in the Decadal Survey and science community, the panel feels that the TPD should be considered a senior person within PSD reporting directly to the Division Director. The person needs the authority to compete on equal footing with the planetary or Mars program directors and the Research and Analysis (R&A) lead. Furthermore, a Director title will support the concept of building a technology-fostering culture.

### ***Recommendation MR-2: Establish a small program office to support the Technology Program Director.***

Considering the improvements that could be made and the list of responsibilities for the TPD, it is clear that even a dedicated person will not be able to implement the needed activities without assistance. The PSTR panel recommends assistance in the form of a small supporting program office. The duties of the program office would be typical for an office that support Headquarters-led division-wide efforts such as the Discovery, Lunar Quest, ESTO, or other program offices with the exception that the office would be smaller than the examples provided. It would be focused exclusively on supporting the TPD in managing a well orchestrated and implemented PSD technology program.

The actual duties will need to be negotiated between the TPD, PSD, and the program manager, but some of the potential duties could be

- assist in developing and implementing the overall strategy
- generate and maintain technology roadmaps
- modify existing or generate new tools to capture and communicate technology information
- create and maintain technology databases and Web sites
- seek out opportunities and assist with technology infusion
- implement workshops and reviews
- produce reports and implement actions

The PSTR panel reviewed the current and expected future content of PSD technologies, compared that to the Decadal Survey report, and formulated a recommended structure that will be appropriate for managing PSD technology efforts. PSD technology content can be effectively grouped into four main areas: Instruments, Spacecraft Systems, Mission Support, and Planning/Communicating/Documenting (see FIGURE 4.1). Depending on NASA Headquarters and TPD needs, a business support function may also be requested, but that is not deemed as essential for improving PSD technology efficacy from a technical perspective.

Grouping technology management support into the areas shown will help assure that the right skill set can be found and applied to PSD technology management needs. The Instrument category would be led by an individual with experience and insight into instrument-related challenges, and who understands many of the mission needs and opportunities. This person would have extensive contacts in the science community and be able to relate science requirements to instrument requirements. Similarly, the spacecraft systems lead would be expected to have experience developing technologies that would integrate and function with the spacecraft bus and payload systems. The mission support lead may be a more diverse function, but experience in software development, mission design, and unique ground systems supporting deep space missions would be valuable. Technologies such as spacecraft cleaning for planetary protection are also in this category. A critical role for all three positions will be to maintain a network of contacts in their respective communities and actively seek out and assist in the infusion of technologies onto missions. These positions can, in some sense, consider themselves “shepherds” of technologies in their areas, and their job is to graduate the successful technologies onto a mission.

The systems engineering component will be a critical function. The primary purpose will be to ensure that technology developments are planned and implemented in a manner that considers systems level issues and mission needs. The program systems engineer will be engaged early in technology development planning and testing to provide timely input and guidance. The system engineer will need a strong background in technology integration as well experience in mission and spacecraft development. Although several technology projects employ systems engineering talent, this role helps provide additional insight, offers an unbiased input, and provides insight in light of the overall program goals and needs.

The planning, communicating, and documenting category would focus on the systems and tools that ensure that the technologies are developed and the knowledge is captured, appropriately maintained, and easily accessible. Developing creative ways to maintain knowledge on NASA’s and other's technology developments will be challenging. It may be possible to consolidate this function into the other areas after the initial tools and processes are developed and working efficiently. Initially, it is expected that this function will require full-time attention.

The last component is business support. The business support scope and deliverables will be defined by HQ and program needs and the resources are envisioned to be matrixed into the program from the PM Center’s business office.

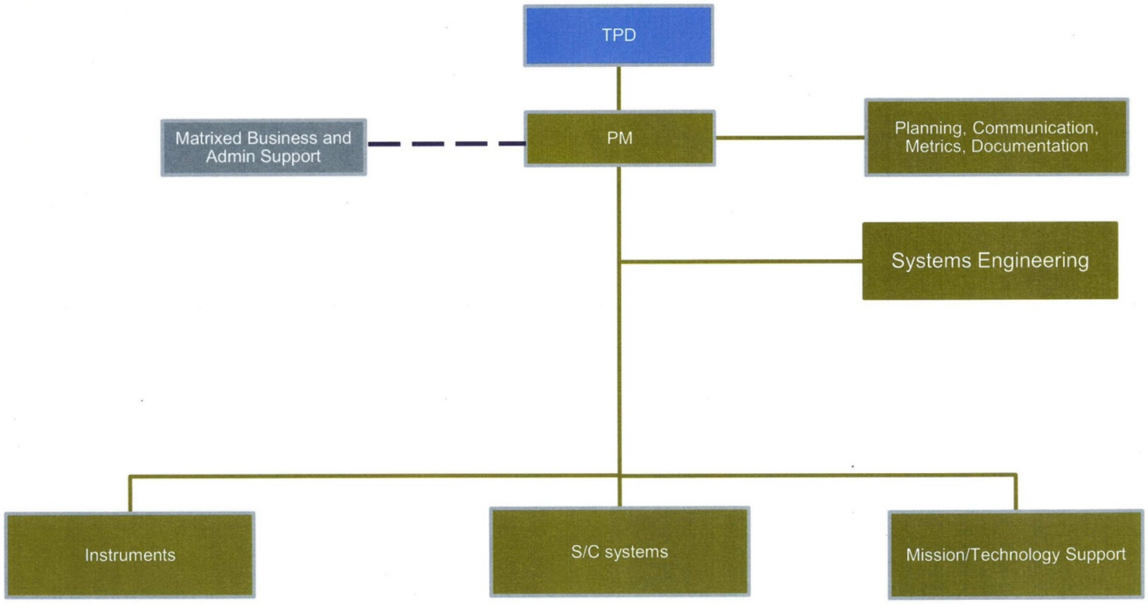



FIGURE 4.1 Notional Technology Program Structure

It is recognized that there are costs to be incurred in establishing and maintaining even a small program office. A detailed estimate has not been conducted, but the panel believes that the efficiencies to be gained, the technology investment resources saved, and the increased science that will result will far outweigh the roughly $2 million cost to operate an office of this size. Management costs of $2 million per year would be roughly 2 to 3 percent of total investment costs so even minimal efficiency gains could easily be recovered. However, much greater gains in efficiency are expected. The panel felt that a dedicated permanent office was preferable over other possible options such as getting contracted help, detailees, or other similar support mechanisms. Although it will certainly be better to have some support rather than no support, the major issue remains that an overall coordinated plan and smooth implementation needs to developed and implemented. The more institutional boundaries, varying agendas, and competing interests that exist, the more difficult it will become to create a cohesive team and orchestrated program. The panel believes that despite the startup and assignment challenges and costs, a supporting program, focused on PSD interests, is worth the cost and effort.

## Recommendations Regarding technology development strategy

Recommendations in the Strategy category relate to recommendations about high-level technology development strategies and philosophies.

### *Recommendation MR-3: Develop a comprehensive strategy*

Recommendation MR-1 advocates that the TPD is responsible for developing and implementing an overall strategy. The PSTR panel feels that the TPD and PSD leadership needs to be intimately involved in the contents of an overall technology strategy. Numerous details need to be considered (some of which the panel is not privy to) and developing a comprehensive and cohesive plan may take much longer than the panel is expected to be in service. The approach taken, therefore, is to provide a framework or structure upon which the TPD and PSD can build. The recommended structure attempts to capture the elements that need to be considered in a comprehensive strategy. The structure provided offers recommendations on balancing priorities along several dimensions: resources, technology areas, technology maturity levels, and sustaining of capabilities.

The guidance provided here was assessed against the recommendations of the Planetary Decadal Survey report and found to be consistent. This was completed by reviewing the specific technology investments and investment levels found mainly in Chapter 11 of the Survey report and mapping that information into the categories in the PSTR strategy. The PSTR panel feels that the categories presented in this strategy are the appropriate ones when the purpose is to manage a comprehensive and cohesive program. The structure presented in the PSTR strategy, and duplicated in the structure of the support program office (see MR-2), is designed to enable effective management of PSD technology efforts.

A simple tool, shown in FIGURE 4.2, was developed to help portray the necessary contents of an overall strategy. There are several options one may consider for the units/contents of the empty cells in the figure. For example, the cells may contain percentage of technology resources, in which case the tool would be useful for a strategic resource balancing discussion. The cells could also indicate underlying projects or programs that would be useful to assess program coverage and technology development gaps.

| Technology Area | Critical Capabilities/ Facilities, etc | TRL 0-1 | TRL 2-3 | TRL 4-6 | TRL 7+ | Recommended Total Percent |
|---|---|---|---|---|---|---|
| Instruments | | | | | | |
| Spacecraft Systems | | | | | | |
| | | System Level Maturity<br>Low High | | | | |
| Mission Support | | | | | | |
| Planning/ Documentation/ Communication | | | | | | |

FIGURE 4.2 Strategy Scoping and Balancing Tool

The significance of this tool is that it captures the major factors to consider in developing a technology strategy, namely a path for maturation to mission infusion, awareness of critical long-term technology needs, capturing all technology development needs, and the interactions and impacts of balancing all these factors in fixed budget environment.

The columns in the strategy tool (FIGURE 4.2) represent the maturation of the technology. A well-known issue of technology development has been an inability to support the whole of the maturation process. The TRL 4-6 “valley of death” is the prime example, but depending on the technology and the respective programs, there are gaps throughout the maturation processes. For example, with the possible exception of some RPS efforts, there are no programs in PSD to support low TRL spacecraft systems development. There are also no mechanisms to mature technologies beyond TRL 6 for those technologies that may require a demo flight to achieve mission infusion, e.g., aerocapture.

The question asked is, "Why should PSD invest in technology at these maturity levels?" With the creation of the Office of Chief Technologist, NASA is developing a process to generate new and innovative low-TRL technologies, and this opportunity should be leveraged by PSD. However, OCT will only invest in technologies that promise cross-cutting applicability, and many needed PSD technologies may not fit within this criterion. Some examples are high-radiation tolerant instruments and other extreme environment instruments and mechanisms, very long-life power and propulsion systems, high levels of automation, and others that may have little or no interest outside PSD. Another possible source of low-TRL technologies is the SBIR program. This program also needs to be better leveraged, but there are challenges with this source as well because PSD has unique applications. Businesses desire to focus on products that have applicability to as many customers as possible. The very long lead times and specific PSD needs make it difficult to attract this talent. The intent for the strategy is not that PSD blindly devote a blanket amount of resources to low-TRL development in all technology areas. The intent is to force awareness in the decision processes that low-TRL technologies are needed for PSD. Deliberate steps should be taken to identify the likely needs based on future mission concepts and ensure that innovative solutions and technologies are being developed either within PSD or in other groups, such as OCT, SBIR, the defense world, or elsewhere.

There is a PSD void at the other end of the maturity spectrum. Perhaps this is due to the perception that if a technology is at TRL 6, it will be either developed by a mission or it does not have enough relevance to deserve further funding. In theory, this view is credible, but there are current characteristics of the infusion processes that reduce the applicability of this theory in practice. The first issue is the risk-averse nature of NASA and the mission selection process. Without outside stimulus, missions do not propose new technologies unless absolutely required. The safer more evolutionary missions and instruments are proposed that do not purport to require advanced technologies. The risk-adverse nature of the NASA's selection process requires some technologies to be developed or proven beyond more than simply a relevant environment. A second issue is that proposal review processes strongly favors missions that do not include new technologies. The limited flight opportunities may impact technology infusion simply by timing. The capability to implement a technology can be lost while waiting for the next announcement or directed mission. Some technologies can become outdated as NASA's or PSD's focus swings over time. The result can be very useful technologies that never fly. Mechanisms or stimuli like the recent Discovery program incentive need to exist to ensure the critical technologies are infused despite weakness in the infusion processes. The communities will need to know that opportunities will exist before the AO is released.

The proper balancing of resources and the incentives to propose new technologies will address the "valley of death" at the mid TRL levels as well. It is understood that as TRL levels increase the costs to move up another level increase rapidly. This fact is simply further reason to adopt the proposed strategy of considering the whole scope of technology together with sensitivity to resource balancing and impacts to future capability.

The remaining column in the strategy tool (FIGURE 4.2) focuses on critical capabilities and infrastructure. The case has been made for the unique technology needs of PSD. These needs not only drive specific technology developments but will, in some cases, require maintaining a capability for future missions. The arc jet facility for planetary probes is one example and a future Venus or Titan surface simulator is an example of a possible future need.

The rows in the strategy tool represent the technology areas relevant to PSD. The planetary Decadal Survey report grouped technologies as found in Appendix D. The PSTR panel felt that grouping technologies into instruments, spacecraft systems, and mission support allowed for better management by combining technologies that follow similar development processes and challenges. All technologies in the decadal report logically fit into one of the recommended PSTR categories.

PSTR also recommends a technology category for planning, documenting, and communicating. This type of technology need did not come out strongly in the decadal report but, given the issues identified during the assessment, it is expected to make significant improvements in overall technology maturation, infusion, and use. As tools and systems are developed, it is expected that resource needs will be reduced in this area and applied to the other three categories.

The real value of this recommendation is to force a decision and balancing process to be undertaken by the TPD and PSD leadership and less in the absolute values that may be invested in a particular cell in FIGURE 4.2. Budgets will vary and mission priorities may change, and this will result in a different set of technology areas and maturity levels to emphasize. The most important strategic action will be to assess all the pieces of the technology portfolio and to make deliberate adjustments understanding how those adjustments impact the whole of the strategy and what the effects on future technology readiness and mission capabilities will be.

In addition to the elements of the structure, other strategy considerations can include items such as training future engineers and technologists. For example, The PSD technology strategy should also include a plan to fund students needed to develop and support the needed future technologies. The TPD and supporting program are responsible for identifying and documenting this and other similar strategy elements.

### ***MR-4: Strategically allocate resources. The PSTR guidelines***

Once a strategy was in place to consider all the elements and scope of PSD technologies the PSTR panel deliberated on what would be a workable balance, and indirectly, what should be emphasized. The results of that deliberation are shown in FIGURE 4.3.

| **Technology Area** | **Critical Capabilities, Facilities, etc.** | **TRL 0-1** | **TRL 2-3** | **TRL 4-6** | **TRL 7+** | **Recommended Total Percent** |
|---|---|---|---|---|---|---|
| Instruments | ----- | 7 | 8 | 12 | 8 | 35 |
| Spacecraft Systems | ----- | 5 | 10 | 12 | 8 | 35 |
| | | System Level Maturity<br>Low High | | | | |
| Mission Support | 5 | 2 | 5 | 8 | NA | 20 |
| Planning/Documentation/Communication | ----- | 2 | 2 | 3 | 3 | 10 |

FIGURE 4.3 Recommended Resource Balancing as a Percentage of Total PSD Technology Resources

PSTR generated this balance independent of the decadal report inputs; however, mapping the Decadal Survey's investment recommendations into the PSTR defined categories yields very similar results. PSTR recommendations are consistent with those of the decadal report to a great extent. The differences that do exist are relatively minor and they involve technology areas where the PSTR panel is placing more emphasis than what was apparent in the Decadal Survey report. One of these is the mission support. The PSTR panel, through community interactions and the interview process, came to the conclusion that PSD needs to expand its common perception of the definition of technology development. The general perception is that technology is associated with a piece of hardware. Testing and integrating technologies, tools for exploring astrodynamics and mission planning, and unique test capabilities should also be considered for technology development and resource allocation. In addition, the PSTR panel believes that insufficient emphasis was placed on mission support technologies.

A second area where the PSTR panel places increased emphasis is in mission studies and their importance to planning a viable technology program. The need for mission studies was mentioned in the Survey report, and the PSTR panel agrees with and supports the report contents. We emphasize that mission studies are needed to determine technology development requirements, and therefore, become a basis for assessing TRL and consequently whether or not a technology is ready for adoption onto a mission. Also, mission studies are needed to identify PSD needs in coming years so that the TPD can effectively set technology goals based directly on PSD's upcoming needs.

### ***MR-5: Actively pursue a strategy of leveraging***

For any given set of needed technologies, the greater the cost pressures, the more important it will be to effectively leverage others' technology investments. In the near term, the technology resources available to PSD are expected to be relatively limited. The panel strongly encourages developing a strategy of identifying and leveraging technology development efforts. The panel deliberated on leveraging with three major partner classes, universities, other NASA organizations, and industry/other Government agencies.

The greatest cost-to-benefit ratio may come from leveraging university efforts. Not only do universities offer access to low-cost student labor, but also they are an ideal partner because they need real world design and test efforts to draw students to their programs. The students benefit from having substantive work upon which to plan a degree. To foster leveraging opportunities, the panel recommends implementing workshops focused on future needed technologies. These workshops should encourage student participation and be structured such that NASA needs are shared with the academic community, including offering the academic community clear paths and opportunities for engagement.

Another recommendation is to initiate academic teams tasked with overcoming known technology challenges. Part of the strategy should be to target universities and students in the engineering and technology fields. NASA SMD has several opportunities for science graduates to expand their experience and contribute to their fields. We recommend extending that philosophy to the engineering and technology fields. Consider the issue of cryogenic sample collecting and storing. An approach may be to competitively select a lead academic institution where their role would be to leverage students and researcher efforts, both internally and across other universities, to achieve a coordinated set of efforts to address the problem. Consortia, or possibly even institutes, can be created if the challenges are large enough. In all cases, the leveraging results in energetic and creative people working on a focused problem that benefits not only PSD but also the university and students.

Leveraging the investments of other divisions and directorates in NASA is recommended. Because PSD missions face unique and extreme environments, the panel believes that particularly at lower TRL levels, there are synergies that can be exploited between technology developments of instruments, spacecraft subsystems, and mission support technologies with organizations such as those in the Earth Science division. The OCT, in particular the SBIR and STTR programs is another key partner to be considered. The recent effort to focus SBIR content to more closely address NASA programmatic needs should be continued. PSD should not only proactively share requirements with the SBIR/STTR programs, but remain engaged in awards, as appropriate, to ensure that long-term, low-TRL technologies are fostered and matured.

Given that many budget and procurement timelines will be common with the other NASA organizations, another potential goal is to meet with the other organizations on a periodic basis, especially prior to PPBE and major procurement efforts. These meetings should review technology needs and priorities and status of current efforts with the intent of leveraging the upcoming event for mutual benefit. The panel recommends that the leveraging efforts described here be the responsibility of the dedicated TPD. NASA structure and the respective responsibilities will continue to change over time so proactive posture of PSD will be critical to maintain a strategy of leveraging.

It will be important to leverage the investments of other Government organizations, international stakeholders, and industry. The panel realizes that many needs of PSD will be unique so leveraging efforts will be limited, but there are areas where synergies are expected. It is important for PSD to share needs with industry often in an attempt to provide input early in the industry’s development cycle. For example, radiation-hardened devices can be accommodated much easier if the need is known early in the devices’ planning stages. It is expected that successful leveraging of industry and other Government agencies will be challenging. These organizations are less likely to share technology investments because of security or competitive interests. However, if NASA can demonstrate they will share only public info and protect all other details, this will help address their concerns. PSD may need to identify and communicate incentives for industry and Government to volunteer the desired information. The challenge in working with international partners is the International Traffic in Arms Regulations (ITAR) controls. Although ITAR is a challenge, it is not an absolute barrier, and technologies at lower TRLs are candidates for leveraging. Those incentives need to be determined on a case-by-case basis for each partner. Given the limited field, it is not unreasonable to expect that several key partners can be identified in this category.

### ***Other Strategy Recommendations***

The panel and many of the inputs received support the technology incentive approach utilized by PSD in the recent New Frontiers and Discovery calls. PSD should continue and strengthen the incentives for strategically relevant technologies. A mission-concept study phase exploring the use of a key technology is advisable prior to the actual mission for high-value strategic technologies. This approach was used by PSD in studying potential mission concepts if ASRG technologies were available.

The panel suggests that PSD clearly communicates to the proposing and reviewing communities the related risk it is expecting for a technology for a given call. For example, if PSD would consider a new instrument or spacecraft system included in mission proposals, that position should be communicated in the call. The message could be communicated at the pre-proposal conferences as well as to the NASA proposal reviewing office.

In a strategic perspective, PSD should look closer at the potential of suborbital testing to raise instrument and spacecraft technology maturity. Such testing will allow achieving higher maturity for some technologies, and it could provide systems engineering experience for students or younger engineers. NASA often has excess capacity in its balloon launches so launch and balloon costs are funded by others.

## RECOMMENDATIONS REGARDING TECHNOLOGY DEVELOPMENT PROCESSES

Recommendations in the Process category relate to recommendations about processes and procedures for technology development.

### *MR-6: Develop a more consistent and accurate TRL assessment process*

PSD technology development can greatly benefit from improving the accuracy and consistency of TRL assessments and identifying the maturation steps necessary to fly on a specific mission or in a specific environment. Better TRL assessment will enable technology programs to enhance infusion efficacy, reduce risk and cost, lower risk aversion, and foster a pro-technology culture. The panel's assessment indicates that the current TRL issue is rooted in several areas including lack of an authoritative body that can determine a technology's TRL, ambiguity in the definition of maturity levels, perspectives and motives of stakeholders, and uncertainty in the physical environment for the technologies ultimate application.

The first recommendation is to establish an authority within PSD to determine a TRL for a technology relative to PSD missions and needs. The PSD should create a process that results in a "TRL certification" from PSD that would carry weight with mission and review teams when they assess technology maturity. PSD, and in particular the TPD, should establish a clear process that evaluates technologies and assigns an objective TRL. The process would determine the future validation/verification requirements, including test levels. Scientists, missions, and technologists would all understand the technology performance in a given environment. To implement this recommendation, it is envisioned that a TRL assessment tool be developed or adopted that can be completed by the technologists and the program. The tool would be used interactively and would serve to make routine assertions on maturity progress and TRL assessments for low-TRL and relatively low-cost investments. For high-value, strategic, or high-TRL technologies, it is expected that a team of experts would be convened with expertise in systems engineering and the respective technical field. They would provide a more detailed review of maturity for an intended or assumed environment. The basis for this two-step approach is that routine assessments for low TRL do not warrant the high cost and time investment of a detailed review by an expert team. Discussions between the technologist and program with input from a mission or system specialist are sufficient. As investments grow and maturity increases to the TRL 4 to 5 range, a detailed summary of work to date and plan of future development and testing should be available. The level of effort and investment would now warrant a team to review that information and provide feedback and TRL assessment to the technologist and the other stakeholders. Care should be taken so that the process does not become so onerous that it ceases to be a tool for assessment and becomes barrier to infusion.

Implementing this recommendation provides an unbiased TRL assessment that is valid and can be used in PSD reviews and proposals. The more detailed assessment would reduce the ambiguity in maturity definitions because there will be a clear path that defines the tests and test levels to implement to claim a given TRL. Ambiguity is removed and replaced by specific test plans. This approach is very similar to the method used by the New Millennium Program (NMP) when assessing technologies to fly on the dedicated mission proposals. For example, NMP conducted a thorough review of the solar sail technology development. They carefully considered the mission environment and developed a detailed plan with the technology project team, indicating the developments, tests, and test levels to be completed to move from a TRL 4 to 5 to 6. This development and test plan was available to the mission proposal team, and everyone understood the technology status and plans.

A PSD-owned assessment process would minimize the bias and perspective issues when reviewing a technology for a PSD application. As described above, all stakeholders would understand the assessment process, and specific tests and TRLs would be available to provide a basis for evaluating a technology's impact and risk to a mission's proposal. This information, provided by an unbiased yet knowledgeable source, would reduce risk and smooth infusion.

The last issue is the uncertainty of the environment. PSD missions target diverse destinations, and consequently, diverse environments. PSD competes Discovery and New Frontiers missions and does not know a priori the missions or all the technologies that will be needed, and the unique and unusual environmental exposure to the technologies. To address this challenge, the panel recommends that PSD, through the technology program office and TPD, determine a set of reference mission concepts that envelop most of the environments that may be seen by proposed missions. This mission set would be selected with community input through the assessments groups, PSS, and/or other bodies to ensure no one concept is promoted and others are not intentionally omitted. It is expected that this process may suggest one-half dozen or so studies to undertake, with many of them possibly already worked in the recent Decadal Survey effort. These studies and the resulting environments can be posted on a PSD technology Web site (discussed in later sections), the TMCO Web site, and other public locations. Upon completion and posting, the science, mission and technology communities would have a set of published environments that technology developers can work toward. Mission teams would also have a clear picture of the envelope that technologies would be qualified to and can plan in any delta tests if their specific mission concept exceeds the environmental envelopes.

During the assessment of this issue, the PSTR panel learned of efforts in the Agency to improve TRL definition with the possibility of developing an internationally accepted definition. The panel recommends that PSD work in concert with these efforts, and that they should adopt the TRL definitions used by the Agency. However, the process for assigning a TRL to a PSD-developed technology will remain the responsibility of PSD and the TPD, and it should be completed as described in this recommendation.

### *MR-7: Develop clear, transparent, and consistent decision and review processes*

In the assessment phase, it was apparent that PSD needs to provide more clarity to the technology community about the decision factors, implementation, and review processes. The variability in these processes will be addressed by creating the TPD position and restructuring the content as suggested earlier in this document. Consistent management and structure will facilitate addressing clarity and transparency. Consolidating management should address the consistency issues, and it is one of the reasons for the consolidation recommendation. The supporting program, which would follow NASA program and project management processes such as NPR 7120.8, would clarify decision processes and key decision points. It would show the links to science objectives. The supporting office should develop a program plan that would be available to interested parties that clarifies roles and processes. Variability in clarity, transparency, and consistency enters the processes when technology developments are directed as opposed to competed through ROSES calls. However, these sources of variability should be addressed by recommendations MR-1 and MR-2 and to some degree MR-3.

Successful program management requires regular performance evaluations and objective feedback. The panel recommends that the programs and supporting program office be reviewed by an independent body as described by NASA program/project management procedures and as chartered by the TPD. Current program implementation reviews (PIRs) are required every two years. For the first few years, annual reviews should be conducted to ensure the program initiation and newly established tools and processes are functioning effectively, as a two-year cadence may not be adequate while initiating a new effort of this scope.

Review panels should be staffed by a consistent set of panel members similar to the Standing Review Boards (SRBs) used by many NASA missions and programs. Augmentation should be provided with expertise reflective of the specific technology content of the program at the time of the review. The review panel should have representation in areas of systems engineering, technology development management, scientists, technical experts as described above, and mission development. The primary purpose of the reviews will be to assess performance of the program in developing the technologies and provide comparative assessments with SOA technology program development practices. The reviews are not anticipated to focus on which specific technologies should be developed because those are defined by the Decadal Survey and the long-term strategic plan. This does not imply that independent review of technology content will not occur if a major resource or other significant change occurs that alters the overall strategy or decadal priorities.

The recommendation that addresses communication issues, MR-9, describes methods to share processes and appropriate data through Web sites and databases. These tools should be used to convey the relevant decision and review processes to stakeholders. There are several existing programs (e.g., ESTO) that have refined their systems and tools to communicate their processes. These programs may be considered as models to emulate as appropriate.

### *MR-8: Develop a structured and rigorous process to create interactions among technologists, scientists, and missions*

It is commonly accepted that early and frequent interaction between technologists, scientists, and mission planners improves technology infusion success. Unfortunately, the method needed to accomplish this goal is less obvious. Panel recommendations in this area focus on creating a "forcing" function and providing targeted resources.

Forcing is recommended through the addition of language to the program/project management documents and related SMD guidelines and the SMD handbook. The intent is to follow previous approaches used by NASA to ensure appropriate systems engineering and safety inputs to projects and programs. Although the panel recommends following this precedence, it does not imply that the interaction goal has the same importance as safety. Rather, the intent is to strongly encourage interaction though documents that are commonly used by NASA science mission teams.

Resource augmentation is recommended through several methods. Mission review boards should include experienced technologists and scientists. Another approach is to select young technologists, scientists, and engineers, through selective competitions, to work at other NASA centers for up to a year. They should be encouraged to work in several different parts of the host organization to get exposure to the various perspectives, cultures, and needs. These rotations may require temporary relocations, and resources should be made available to accommodate the rotations. Because these resources may be very limited, competitively selecting the intercenter details will allow the long-term value for enhancing interactions to be evaluated. Formal training is also suggested. This does not directly force an interaction, but providing science training for technologists and engineers and technology training for mission teams and scientists will allow them to be more comfortable in those environments and get a sense of the primary issues and considerations of their counterparts.

A final method of improving knowledge and interaction among these fields is to improve the communication methods and tools. Therefore, the recommendations described in MR-9 will also have benefit here.

## RECOMMENDATIONS REGARDING TECHNOLOGY DEVELOPMENT CULTURE AND COMMUNICATIONS

Recommendations in the culture/communications category relate to recommendations to improve overall technology-related communications and to foster a culture that better supports technology development efforts.

### *MR-9: Develop a technology communication plan and tools*

In any team environment, communication is a key factor to success. PSD develops a host of technologies across a number of disciplines. Numerous skills, institutions, and agendas are involved. Such an environment suggests that effective communication will occur only with careful thought, planning, and effective communication tools. The first recommendation from the panel is for TPD/PSD to develop a communication plan for its technology efforts. The plan should consider the audiences to be reached and the type of information to be disseminated. Carefully designed databases will be one of the tools important in tracking and communicating the needed information. Ideally, it can become a portfolio management tool for the TPD and the supporting program office. The ESTO program may be a benchmark for the types of tools and methods that may be used. Another important tool will be a PSD technology Web site providing public information on technology investments, contacts, structure, processes, and other information. The panel discussed what information may be useful to capture and the results of those discussions are captured in FIGURE 4.4.

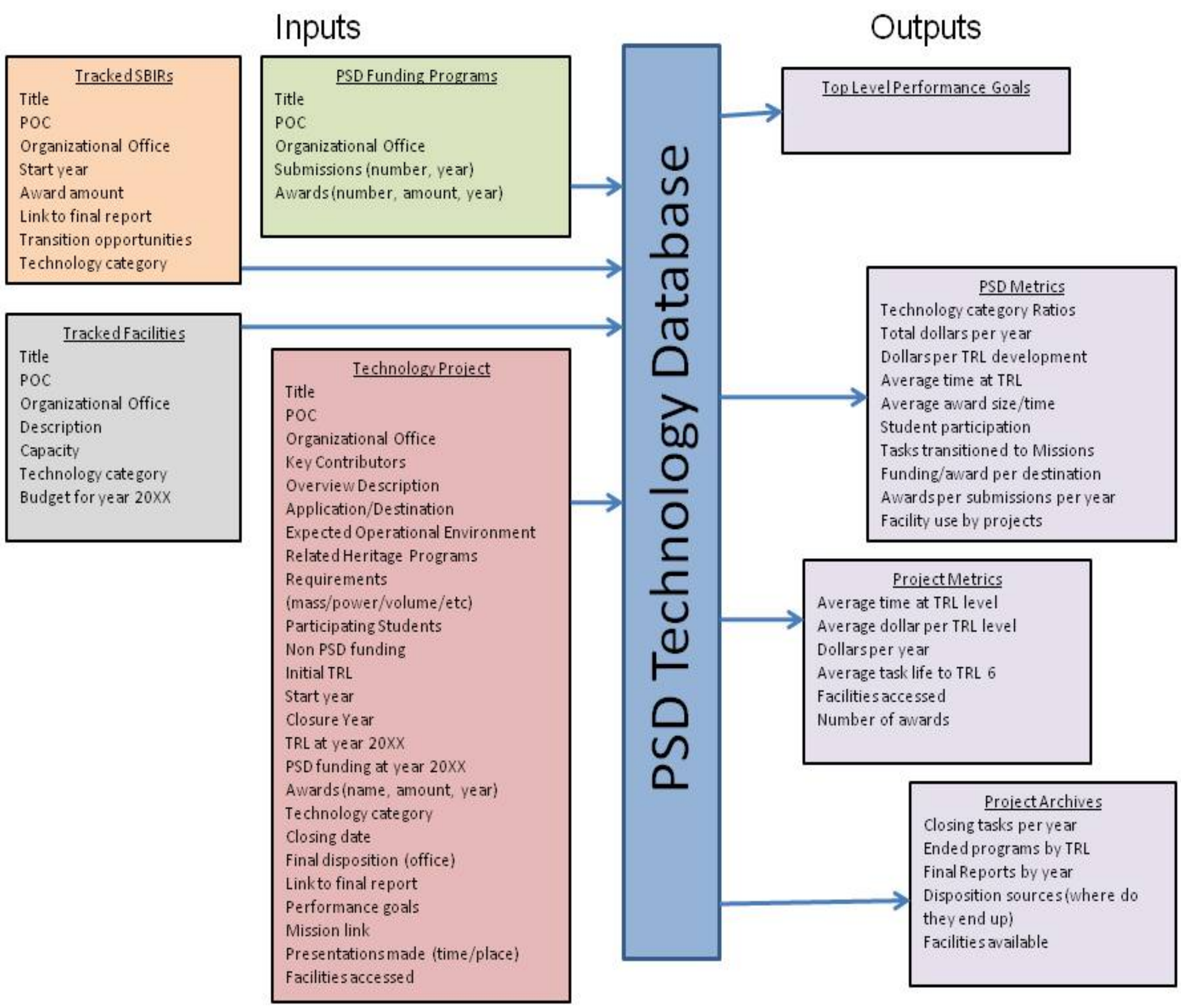



FIGURE 4.4    Possible Technology-Related Data to Capture

Every database requires constant updating, and one of the recognized challenges will be keeping the database populated with current information. One method used by technology programs in the past was to include requirements for publication and database population in project task agreements. A second method is to release the final 5 to 10 percent of funding when the required documentation (a comprehensive final report being one example) and communication requirements are completed. The third method to foster communicating and documenting technology work is by designing the tools with user interest in mind and ensuring that only data absolutely needed is requested. Careful consideration will be required for data access and protection. ITAR-controlled and proprietary information needs to be protected and used only by the appropriate people. The panel also envisions PSD capturing technology efforts in work by other Government agencies, industry, and NASA programs. This data should be used to plan leveraging strategies and implement partnerships.

The communication plan should consider the objectives, format, and content of workshops to host and conferences to attend. These can be important tools in leveraging, engaging students, and fostering scientist, technologist, and mission interaction. Workshops should have clear objectives, and effectiveness and impact should be assessed after each event.

The important point to reiterate is that the overall objective is to make the appropriate information accessible to the scientists and technologists at the level of detail they need. This will require careful structuring of the data and the reporting tools. One of the four positions recommended for the supporting program office was a lead for communication and documentation. The person would be responsible for ensuring that the right data is collected and the optimum tools are available to use that data.

### *MR-10: Foster a culture that advocates for and defends technology*

NASA has struggled with a consistent posture on technology development. The current administration is supportive of technology development investments, but this has not always been the case. Today, many individuals realize that to maintain a capability for robotic or human exploration a constant and consistent investment needs to be made in new technologies. This fact should be routinely communicated and deeply engrained at all levels of NASA. The panel recommends that specific steps be taken to strengthen this appreciation. One approach is to include technology goals as part of the performance evaluations for the TPD, any Program Officer with technology development responsibilities, and especially for the Division Director. The Division Director should have the additional responsibility of advocating for technology resources and highlighting technology accomplishments to SMD leadership. One of the key roles envisioned for the TPD is the advocacy of technology to the other members of PSD. The TPD should provide routine highlights, discuss advances, and periodically share technology capabilities. These can be done through a technology “corner” at staff meetings, monthly program reviews, brown-bag lunches, and with inputs to the SMD MSR. Reviewers selected to review mission proposals must be well versed, or be provided briefings, on the latest status of the state-of-art in relevant technologies. If reviewers are unfamiliar with a technology it may unfairly be labeled as risky, where in fact, it may simply be a lack of awareness by the reviewers. This erroneous message will get out to the mission teams who will avoid that technology and reinforce a technology-aversion culture.

PSD should encourage technology-related inputs from the various assessment and analysis groups such as OPAG and MEPAG and also include technologists on the steering committees for these organizations. Technology-related findings should be encouraged, which become inputs to the PSS. This will not only serve to provide PSD specific inputs to plan technology strategy, but will help keep technology in the minds of senior leaders and foster a technology-friendly culture.

### *Other Recommendations Related to Culture and Communications*

It is the opinion of the panel and advisors that missions, in particular, and NASA, in general, have become too risk averse, and this has negatively impacted future capability and technology development. Although risk aversion by mission teams can be a useful posture to help provide missions the best chance of successful implementation, it can become an unnecessary barrier to technology infusion, especially on competed missions.

Part of the solution to this problem will be to improve the performance of technology development projects and their track records by delivering needed technology when promised. All the recommendations provided in this report are intended to improve the performance of technology development efforts, and it is expected that implementing these recommendations will lead to lower risk aversion. One particularly important recommendation to address the risk aversion issue is MR-6, the TRL assessment improvement. A clearer understanding by all parties of a technology's maturity will reduce uncertainty and risk. Over time, the mission teams and NASA, experiences with new technology, will shift to a more positive experience and eventually lower aversion to new technology adoption on missions.

Incentivizing technology infusion, providing Government-furnished technologies to be integrated by mission teams, and offering suborbital flights will provide more opportunities for technologists to fly hardware and more technology infusion experience for mission teams. More opportunities for technologists to infuse their products will give them a better basis for estimating future efforts and increasing infusion success rates. More flight opportunities will reduce the pressure to exaggerate readiness, which will lead to more successes and lower risk aversion.

Another method to improve technology infusion success and lower risk aversion is to increase the time and resources provided for mission concept development. More time and funds allowed in Phases A and B are expected to enable teams to better understand risks and the efforts needed to address them. A larger investment in concept and design phases has long been understood to improve cost performance and mission success in later phases (Phases C and D).

## RECOMMENDATIONS REGARDING TECHNOLOGY RESOURCES

Recommendations in the Resource category relate to recommendations about allocation and use of resources for technology development

### *MR-11: Dedicate stable funding at the higher end of the decadal report range, 8%*

The panel fully supports the 2013 planetary Decadal Survey report's comments regarding resources that should be devoted to PSD technology development efforts. The following quote, used in the Decadal Survey report, is particularly reflective of the PSTR panel recommendations:

"The committee unequivocally recommends that a substantial program of planetary exploration technology development should be reconstituted and carefully protected against all incursions that would deplete its resources. This program should be consistently funded at approximately 6-8 percent of the total PSD budget."

Additionally, as discussed in R-1 of the assessment section, the PSTR panel considers the inconsistency of funding to be the primary resource challenge. Protecting a stabile budget will provide the greatest resource-related benefit to technology development efforts. If managers and developers understand what resources will be available, they can plan accordingly and still deliver products. Inconsistent funding has a host of negative impacts beyond just poor maturity progress. Some of the other negative effects include reducing interest and capability in the field, impacting student's educations, and harming Government-partner relationships. Better technology advocacy, as recommended in MR-10, may help protect technology resources in tight budget environments and may help maintain greater consistency.

The other aspect of resources is the total amount allocated to technology efforts. PSTR discussions with industry and others involved in technology development have shown that for aerospace organizations, 6 to 8 percent investment in technology development is not uncommon, and this is consistent with the Decadal Survey report. There are several factors for PSD that have driven the PSTR panel to recommend investment at the higher end of this range.

The targets of PSD missions are scattered across the solar system. As discussed in other sections, this means that PSD technologies may be subjected a very wide range of environment and lifetime requirements, much larger than one would find in industry, defense, and even other NASA science divisions. Ultimately, it will take more resources from PSD to apply the same technical capability to its targets. This additional burden falls on PSD because they need to bear the full development burden. For example, instrument technologies flying in Earth orbit have the benefit of being able to tap into technology experience and efforts by many organizations and industries. On the contrary, few people are concerned with backward contamination issues from cryogenic samples, for example.

Even when there are similar interests in a given technology with other stakeholders, synergistic development may be limited. For example, both the military and commercial industry develop electric propulsion systems. Although these organizations and NASA communicate about the products they are developing and the issues they need to address, the goals diverge rather quickly when ascending the maturity ladder and synergies become harder to identify. Consider that military and commercial interests are Earth orbiting where solar power levels are constant and the mission lifetimes are on the order of a decade. Many PSD missions move around the solar system and need a completely different control and power processing architecture, one that accounts for varying power and thrust levels. PSD missions to the outer solar system will have very long cruise stages that increase life and testing requirements for spacecraft systems such as power.

Two factors have been discussed—greater environmental challenges and the limited partnering options that tend to increase the fraction of resources PSD—will need to invest in technology as compared to others. That is another reason that the PSTR panel recommends investment at the 8 percent level.

Two technology investment areas are emphasized by the PSTR panel that is not readily apparent in the Decadal Survey report; these are non-hardware-related technologies and low-TRL developments. The PSTR panel believes that there are significant gains to be made in overall science delivery with an increase in what are not traditionally considered technology areas within PSD. Software and aids like astrodynamics tools and optimizers have made tremendous impacts on mission capability. Investments in guidance, navigation and control, and the use of gravity assists have enabled numerous missions, and this capability would not exist without investments in non-hardware technologies. Test and integration technologies are two other examples that could greatly improve missions. These types of technologies can significantly improve mission success and capability, but resources for their development did not appear to be a part of the Decadal Survey's 6 to 8 percent. The other investment area not included by the Decadal Survey report is low TRL developments. The Decadal Survey assumed that low TRL developments will be addressed by the NASA's newly created OCT. It has been strongly encouraged that PSD adopt a strategy and take immediate steps to leverage OCT investments; however, OCT is requiring that technologies they invest in have cross-cutting applicability. PSD-required technologies will often diverge from the other interests within NASA and some needed PSD technologies will not receive OCT support. PSD therefore needs to plan for some amount of investment in selected technologies in the TRL 1 to 3 range. This again would increase the needed investment to the higher end of the suggested range.

### *Other Recommendations Related to Resources*

PSD needs to clearly specify what technology means to the division and track technology budgets according to that definition. This will help in understanding the performance of technology investments and clarifying the actual investments for stakeholders. A recommended definition is provided in the introduction to the findings chapter, and if that definition is adopted by the TPD and PSD, it would help draw clearer boundaries.

PSD should reevaluate its overall reserve strategy. A number of inputs to the panel indicate that PSD's reserves are the technology programs. As discussed in the previous paragraph, this is not an advisable posture, and PSD needs to find an alternative method to manage its reserves. This may require reducing the expectations for the number of missions that can be successfully implemented with a given overall PSD funding level.

Similarly, PSD should reevaluate its reserve strategy when it comes to the technology programs themselves. Technology projects are planned with little or no financial reserves. It is assumed that if one technology project overruns its budget, it is either delayed or another technology task is reduced. The current practice treats the whole of the PSD technology program more as a reserve fund rather than as a set of real programs and projects. The message from the NRC, assessment groups, and the Decadal Survey is to depart from that model and treat technology as other critical PSD efforts are treated. NASA has recently revised its mission funding strategy going to a 70 percent confidence funding level, and this was done to bring final missions costs in line with confirmed costs. Ironically, missions are required to carry reserves for technology efforts, yet higher TRL technology efforts, outside of missions, are not provided reserves even though one expects to have surprises during development activities. The same basic philosophy now being used to manage missions is recommended for managing higher TRL technology efforts in PSD. The panel does not advocate a 30 percent across the board reserve, but it does advocate that technology development efforts at TRL 5 and higher be provided reasonable reserve, with the amount of that reserve being dependent on several factors such as technology criticality to a specific mission, number of possible missions impacted, and relative size of the investment to complete.

A strategy used by missions to get back within cost constraints when issues arise is to have a set of a prior defined descope options. The panel recommends that a similar approach be used for technology efforts. The TPD, with support of the program office, should develop a descope plan that identifies the technology development tasks that will be reduced or eliminated if the available resources cannot sustain the entire planned program.

Another resource recommendation addresses the issue of funding graduate students. Funding for technology tasks should be granted for a 4 to 5 year range when those tasks support graduate students. Tasks and the students must demonstrate successful progress, but assuming that the expected progress is being made a priority needs to be assigned to those tasks that incorporate the student's efforts toward a degree.

### *Other Recommendations*

One recommendation spans a number of categories and does not clearly fall into predominately one category. This recommendation has to do with the sustaining of capabilities that are critical to future PSD missions. Capability sustainment finds little support in a project-oriented organization, as project-oriented organizations focus on clear requirements and reject unnecessary burdens. The issue is that projects have limited lifetimes and have no interest or requirement for future mission needs. Typically, capability is managed by the institutional departments of an organization, and institutional departments may not have the technical ability to predict the technology needs of PSD, nor will they have an incentive to keep that capability given limited applicability to other stakeholders. Therefore, PSD must identify their critical technologies and work to ensure that the appropriate resources are made available. Capabilities that could be candidates for sustainment are ones that have high barriers and large amounts of tacit knowledge. Entry, descent, and landing capability is an example that NASA has decided is a critical capability and sustains at the Agency level. Potential PSD needs may include nuclear and/or solar power systems, planetary protection technologies, extreme environment technologies, test facilities, and others.

Not all future technology needs require constant and consistent funding. Some technology developments can be cancelled for a period of time, but in those cases PSD will need to estimate both financial and schedule impacts to that cancellation and recognize that the longer the gap the greater the startup time and costs. Knowledge management literature offers some insight into how quickly capability is lost during investment gaps. When a technology effort is cancelled it is critical to adequately document the SOA at cancellation. A final report should be required to ensure that the progress made is not lost.

When considering sustainment costs, there are several approaches that may be used to minimize or possible share these costs. For example, PSD should work with the centers and identify ways to leverage resources. Centers may know of other stakeholders and can spread costs across more funders. Universities may be used as relatively inexpensive knowledge banks where minimal funding may sustain tacit knowledge for long gaps in between investments.

A final comment is that once a technology is flown on one mission, it may not mean its maturation is complete for another mission. The obvious difference may be the target operating environment, but other mission specifics such emissions requirements, different payloads and their sensitivities, and other mission nuances may require additional investments on the part of the technology program. These possibilities should be considered in the specific technology roadmap and infusion plan and included in the larger PSD technology program strategy.

# 5

# High-Level Metrics

The PSTR panel was chartered to provide recommendations on metrics that may be considered to measure technology program effectiveness. To implement this charge the panel first deliberated on the technology development data one may wish to collect. Results of that deliberation are reflected in FIGURE 4.4 found in Chapter 4. Assuming that the suggested data is available, the panel generated a handful of metrics to assess overall technology performance. The intent is not to provide an exhaustive set of goals for each piece of data being collected, but rather to provide PSD some high-level goals with which to assess overall technology program performance. The recommended metrics are summarized in TABLE 5.1 and discussed in subsequent paragraphs.

TABLE 5.1 Summary of Recommended Program Metrics

| Metric/Goal | Metric/Goal |
|---|---|
| **Technology Maturation and Infusion** | |
| G-1a | 10 to 30% of TRL 1–2 technologies make it to TRL 3 (adjust metrics over time) |
| G-1b | 40 to 60% TRL 3–4 technologies make it to TRL 6 (adjust over time) |
| G-1c | Infusion to flight for technologies that achieve TRL 6 should be > 80% |
| G-2 | Develop a maturation schedule for each technology and ensure the technology is making the progress it should. Review on an annual basis. |
| G-3 | Each technology should have specific technical requirements and maturation milestones to achieve. Review on an annual basis. |
| **Leveraging** | |
| G-4 | Attract leveraging support of technologies suitable to PSD and track it as a percentage of total PSD technology investment. Work towards developing a specific goal based on initial experiences. |
| **Communication** | |
| G-5 | Implement at least one PSD technology-focused workshop annually |
| G-6 | All technology development efforts are described in conference proceedings or peer reviewed publications and results are documented in a standard final report. |
| **Programmatic** | |
| G-7a | Establish a responsible technology program director (TPD) by end of FY12 and the supporting office/structure by end of FY13. |
| G-7b | Create, document, and communicate an overall technology strategy by middle of FY13. |
| G-7c | Establish a TRL assessment process for PSD technology developments and identify representative environments that can become pseudo requirements for technology development projects by middle of FY13. |
| G-7d | Roadmaps for all technology developments are developed and linked to the overall strategy, the Decadal Survey, and expected mission needs by end of FY13. |
| G-8 | Timely and adequate funds are provided in needed technology developments. The goal is to fund technology efforts at levels needed to achieve desired readiness as identified in the respective technology's roadmap. |

One clear objective for technology development efforts is to eventually fly the respective technologies. Fortunately, it is easy to determine if a technology is used on a flight mission. Surprisingly, this information is not readily available for many technologies. Stove-piped program structures, the long time periods between development and flight, and changes in teams and institutions are factors that contribute to the difficulty in answering this question today. Collecting the data suggested would allow this basic question to be answered. The next question, addressing what should be the infusion goal, is not as readily answerable. The expectation for infusion rate depends significantly on the maturity of a technology. One would not expect even a 10 percent infusion rate for a batch of technologies with the TRL in the 1 to 2 range. Many concepts simply do not turn out as hoped and eventually the idea is dropped. In contrast, if NASA has been evolving and refining a concept and a design, the expectations for eventual use are much higher. Following this logic the proposed goals are graduated based on TRL. The recommended goal is to achieve a TRL 3 for approximately one in four of the early technology concepts considered. Once a technology is at TRL 3 to 4 approximately one in two should reach TRL 6. Once NASA has invested in a technology to TRL 6, it is expected that clear applications are known and therefore at least four of five technologies should get infused at some future opportunity. The goals provided here are selected based on panel judgment and are expected to be adjusted based on actual development experience in the future.

Given that different technologies will require different levels of effort and time to mature, it is not practical to establish arbitrary schedule progress goals. Each technology will have a maturation and infusion roadmap, and it is recommended that the roadmap have a reasonable schedule that can be used as a measure of progress. Performance against the individualized schedule should be measured at least once per year. The roadmaps need to be linked to the overall PSD technology strategy and to the Decadal Survey. There are also technology development needs for competed missions. Roadmaps for these technologies will not tied to specific missions. Even though some technology development efforts will not have a specific mission links, there must still be clear future mission applications and these applications can be found in the Decadal Survey Report.

Different technologies will have different technical requirements. Once again the PSTR role is not to a priori identify what those requirements ought to be for the various technologies, but rather to recommend that specific technical requirements be in place. Technology efforts are often solicited via a NASA call or other mechanisms where many of the specific technical requirements are not flowed down, but proposed by the projects. This can make it difficult to ensure that the requirements are consistent with other development efforts and consistent with mission expectations and needs. PSD needs to ensure that each technology development effort has clear goals that are traceable back to the Decadal Survey and/or the overall technology strategy. This is the responsibility of the TPD as discussed in Chapter 4.

The PSD technology program needs to identify stakeholders that share technology interests with PSD and influence those stakeholders to share in at least some of the development costs. To measure progress on leveraging initiatives, the panel chose not to provide a specific goal, but recommends tracking the amount of resources that are leveraged and indentifying a specific goal after some experience is collected. The intent of this goal and the value it adds is to force a leverage-seeking culture and strategy and monitoring of performance.

In the communication area, an overall program goal is to share all the available and required PSD technology information and the PSD technology strategy with stakeholders. PSD should conduct at least one technology-focused workshop annually. Invited participants should include university representatives and students that have interest in technology-related fields. A workshop objective would be to encourage interchange between mission, science, and technology experts around technology-related topics. The annual ESTO workshop may be a model to use as a starting point, but the vision is to encourage greater interaction around technology users and potential providers.

The importance of capturing and making PSD technology information accessible has been discussed in prior chapters. A recommended goal is that all PSD funded technology development efforts are reported in conference proceedings or in peer reviewed journals. In addition, a comprehensive final report needs to be delivered to the TPD and supporting program office. The contents of the report would be determined by a standard template that is consistent with the data needs identified in FIGURE 4.4. This information should then be added to the technology database described earlier as appropriate given the particular proprietary or access factors.

The programmatic goals identified here do not include the typical cost, schedule, and technical types of goals. Instead, these goals focus on implementing the major improvements recommended by this review. To that end, the goals are to implement the three most critical major recommendations by end of FY12. These are 1) establishing a position within PSD with authority and responsibility for the overall technology strategy and implementation and establishing the beginnings of a supporting program, 2) developing and sharing the overall technology strategy, and 3) creating the PSD technology TRL assessment process. The TRL assessment process includes implementing the studies required to set environmental bounds, and provides guidance for technologists and a bar against which to measure readiness.

The final metric recommended is to ensure that adequate funding flows consistently, as defined by needs derived from technology roadmaps and overall strategy. If each technology has a roadmap and a maturation path, the phased resource needs can be identified. The overall PSD technology strategy will provide technology priorities. Armed with this information and the available technology budget, funding goals can be established and performance measured.

Developing meaningful metrics is a challenging endeavor. The PSTR panel offers these high-level metrics as a start to performance measurement and suggests that the best people to develop the majority of the detailed metrics will be the TPD and supporting program office. It is expected that additional metrics will be generated and existing metrics will be tuned by the TPD and implementing program office as processes start and mature.

# Appendixes

# A

# Panel Face-to-Face Meeting Dates and Topics

| Meeting | Date | Location | Agenda |
|---|---|---|---|
| 1 | Jan. 26–27, 2010 | JPL Conference Center, Washington, DC | Program briefs from: ARMD, AMMOS, ESTO, Planetary Protection, AIST, ASTID/ASTED, ESMD, ISP, Mars, PIDDIP, Luna Lander, Outer Planets, RPS, Dawn mission |
| 2 | May 11–12, 2010 | JPL Conference Center, Washington, DC | Program briefs from: ESMD, Explorers and Helio, SOMD Communication, OCT, Technology Management, Decadal White papers, New Frontiers, Discovery, Lunar Quest, SBIR/STTR, Air Force Technology |
| 3 | Aug. 31–Sept. 1, 2010 | Madison Monona Conference Ctr., Madison WI | Panel: Assessment Review |
| 4 | Dec.7–8, 2010 | CAS Bldg., Boston Univ., Boston, MA | Panel: Review Suggestion Inputs, Draft Recommendations |
| 5 | March 14–15, 2011 | OAI, NASA GRC, Cleveland, OH | Panel: Decadal Survey Report Review, Review Recommendations, Metrics |

# B

# Communication Matrix

| Meeting | Date | Location | Purpose | Poster | Presentation/ Workshop | Members Attending: Pat (B) Beauchamp | John (C) Clarke | Peter (H) Hughes | Tibor (K) Kremic | Ralph (L) Lorenz | Brad (P) Perry | James (S) Singleton | Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| OPAG | February 8, 2010 | Washington, DC | Raise Awareness | | | | | | K | | | | |
| OCT | February 17, 2010 | Washington, DC | Share Status & Results | | | | | | K | | | | |
| PEs/J. Green/J. Adams | February 17, 2010 | Washington, DC | Share Status & Results | | | | | | K | | | | |
| Decadal Steering mtg | February 22, 2010 | Irvine, CA | Inform comm. of existence and purpose of panel and initiate discussion | | K | | | | K | | | | |
| LPSC | March 1, 2010 | Woodlands, TX | Raise Awareness | | | B | C | | | L | | | J. Green coment |
| IEEE Aerospace conf | March 6, 2010 | Big Sky, MT | Raise Awareness | | | B | | | | L | P | | |
| MEPAG | March 17, 2010 | Monrovia, Ca | Raise Awareness | | | | | | | | | | |
| PSS | April 8, 2010 | Washington, DC | Share Status & Results | | | | | | | | | | |
| ABSSciCon | April 26, 2010 | League City, TX | Raise Awareness | | | B | | | K | | | | |
| JANNAF | May 3, 2010 | Coloroado Springs, CO | Raise Awareness | | K | | | | K | | | S | |
| PEs/J. Green | May 26, 2010 | Washington, DC | Share Status & Results | | | | | | K | | | | |
| PSS | July 12, 2010 | Washington, DC | Inform and get concurrance of present status and coordinate results | | K | | | | K | | | | |
| SBAG | August 3. 2010 | Pasadena, CA | Raise Awareness | | | | | | K | | | | |
| VEXAG | September 2, 2010 | Madison, WI | Inform and collect input | | K | | | | K | L | | | |
| PEs/J. Green | September 14, 2010 | Washington, DC | Share Status & Results | | | | | | | | | | |
| OPAG | September 16, 2010 | Boulder, CO | Raise Awareness | | | B | | | | L | | | |
| DPS | October 3, 2010 | Pasadena, CA | Solicit recommendations | B, C | B, C, K, L, P | B | C | | K | L | P | | J. Green comment |
| AGU | December 13, 2010 | San Franacisco, CA | Raise Awareness | | | B | C | | | L | | | |
| J. Green/J. Adams | January 12, 2011 | Washington, DC | Share Status & Results | | | | | | K | | | | |
| PSS | January 17, 2011 | Wahington, DC | Share Status & Results | | | | | | K | | | | |
| SBAG | January 25, 2011 | Washington, DC | Raise Awareness | | | B | | | K | | | | |
| PM challenge | February 9, 2011 | Long Beach, CA | Paper and Presentation | | K, P | | | H | K | | P | | |
| OCT | February 18, 2011 | Wahington, DC | Share Status & Results | | | B | | H | K | | | S | |
| IEEE Aerospace conf | March 5, 2011 | Big Sky, MT | Panel, Paper and Presentation | | K, S | B | | | K | | | S | |
| LPSC | March 7, 2011 | Woodlands, TX | | | | | | | | | | | |
| CAPTEM | March 13, 2011 | Telcom | Summary Presentation | | | | | | K | | | | |
| J.Green | April 28, 2011 | Wahington, DC | Share Status & Results | | | B | C | H | K | L | P | S | |
| PEs/J. Adams | May 2, 2011 | Wahington, DC | Share Status & Results | | | B | C | H | K | L | P | S | |
| Lost Cost Mission | June 20, 2011 | Laurel, MD | Share Results | L | | B | | | K | L | | | |
| DPS | October 1, 2011 | Nantes, FR | Share Results | B, K | | | | | K | | | | |
| | | | | | | | | | | | | | |
| | | | | | | | | | | | | | |
| **Future Communication** | | | | | | | | | | | | | |
| Note: The Panel will present a summary of the results of the review in FY2012 in the same venues as visited during FY2010-11. | | | | | | | | | | L | | | |
| | | | | | | | | | | L | | | |
| **Legend:** | | | | | | | | | | | | | |
| | | | | | | | | | | | | | |
| **Pat Beauchamp** | B | | | | | | | | | | | | |
| **John Clarke** | C | | | | | | | | | | | | |
| **Peter Hughes** | H | | | | | | | | | | | | |
| **Tibor Kremic** | K | | | | | | | | | | | | |
| **Ralph Lorenz** | L | | | | | | | | | | | | |
| **Brad Perry** | P | | | | | | | | | | | | |
| **James Singleton** | S | | | | | | | | | | | | |

# C

# Issues and Recommendations Matrix

| | MR-1) | MR-2) | MR-3) | MR-4) | MR-5) | MR-6) | MR-7) | MR-8) | MR-9) | MR-10) | MR-11 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Issues, Needs** / **Recommendations** | **Establish a dedicated Director position with overall responsibility for PSD technology** | **Establish a small supporting program office** | **Develop a comprehensive strategy for PSD technology** | **The PSTR recommended resource allocation strategy** | **Actively pursue a strategy of leveraging opportunities within and outside NASA** | **Develop a more consistent and accurate TRL assessment process** | **Develop clear, transparent, and consistent decision and review processes** | **Develop a more structured and rigorous process to create interactions between technologists, scientists, and missions** | **Develop an overall communication plan and technology database** | **Foster a culture that advocates for and defends technology** | **Dedicate stable funding at the higher end of the decadal suggested range - 8%** |
| *S-1 No overall strategy or accountable manager* | D | D | D | D | | | | | I | | I |
| *S-2 No clear path for technology maturation from TRL 0-9* | D | D | D | D | | | | | | | I |
| *S-3 Limited engagement of other NASA OCT, ESMD and ESD technologists* | D | | D | | D | | | | I | | |
| *S-4 Technology should be perceived as more than just hardware development* | D | I | D | | | | | | I | | |
| *S-5 Efforts by external stakeholders are not worked into PSD strategy* | D | I | D | | | | | | D | | |
| *P-1 Programs are not consistent and do not have clearly defined processes* | D | D | | | | D | D | D | D | | |
| *P-2 Technology managers are overloaded and often oversee flight projects* | D | D | | | | | | | | D | I |
| *P-3 Inconsistent and inaccurate TRL and heritage assessments* | D | D | | | | D | D | | I | | |
| *P-4 Limited processes that encourage interaction between stakeholders* | D | D | D | | | | | D | D | I | |
| *R-1 Technology budgets unpredictable* | D | I | D | I | | | | | | | D |
| *R-2 Technology budgets are insufficient* | D | I | D | D | I | | | | | | D |
| *R-3 Inadequate leveraging of other's investments* | D | I | D | | D | | | I | D | | D |
| *C-1 Technology investments have not yielded all the benefits they could have* | D | D | D | | I | D | | I | D | I | |
| *C-2 Inadequate communication (in & out)* | D | D | | | I | D | | I | D | | |
| *C-3 Projects too risk averse to new technology* | I | I | | | | D | D | | D | D | D |
| *C-4 Tenuous commitment by top management* | D | | I | | | I | | | D | D | |
| *C-5 Need to better sustain capabilities* | D | I | D | D | I | | | | | D | |

# D

# Decadal Survey

Table D.1 Summary of Types of Missions That May Be Flown in the Years 2023–2033 and Their Potential Technology Requirements

| Objective: 2023-2032 | Mission Architecture | Key Capabilities |
|---|---|---|
| *Inner Planets* | | |
| Venus climate history | • Atmospheric platform<br>• Sample return | **• High-temperature survival<br>• Atmospheric mobility<br>• Advanced chemical propulsion<br>• Sample handling** |
| Venus/Mercury interior | Seismic networks | • Advanced chemical propulsion<br>• Long duration high-temperature subsystems |
| Lunar volatile inventory | Dark crater rover | • Autonomy and mobility<br>• Cryogenic sampling and instruments |
| *Mars* | | |
| Habitability, geochemistry, and geologic evolution | Sample return | • Ascent propulsion<br>• Autonomy, precision landing<br>• In situ instruments<br>• Planetary protection |
| *Giant Planets and their Satellites* | | |
| Titan chemistry and evolution | Coordinated platforms: orbiter, surface and/or lake landers, balloon | • Atmospheric mobility<br>• Remote sensing instruments<br>• In situ instruments-cryogenic<br>• Aerocapture |
| Uranus and Neptune/Triton | Orbiter, Probe | • Aerocapture<br>• Advanced power/propulsion<br>• High-performance telecom<br>• Thermal protection/entry |
| *Primitive Bodies* | | |
| Trojan and KBO composition | Rendezvous | Advanced power/propulsion |
| Comet/asteroid origin and evolution | • Sample return<br>• Cryogenic sample return | • Advanced thermal protection<br>• Sampling systems<br>• Verification of sample—ices, organics<br>• Cryogenic sample preservation<br>• Thermal Control during entry, descent, and landing |

# E

# List of Interviews

| | | | Flight Programs | | | | | Technology Management | | | | Technology Tasks/Projects | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Date | Topic | HQ PE/PO | Flagship | Discovery | New Frontiers | Mars | Other | Industry | NASA | Gov | University | Instruments | Bench Marking | Other | Comm / DSN | Notes & Comments |
| 1/26/2010 | ARMD | x | | | | | x | | x | | | | | | | |
| 1/26/2010 | AMMOS | x | | | | | | | | | | | | x | | |
| 1/26/2010 | ESTO | | | | | | | | x | | | x | x | x | | |
| 1/26/2010 | PSD Overview/Manangement | | | | | | | | x | | | | | | | |
| 1/26/2010 | Suborbital Investigations under Planetary Astronomy | x | | | | | x | | | | | x | | | | |
| 1/26/2010 | Planetary Protection | x | | | | | x | | | | | | | x | | |
| 1/26/2010 | AIST | x | | | | | | | x | | | x | x | x | | |
| 1/26/2010 | ASTID/ASTED | x | | | | | | | x | | | x | | x | | |
| 1/27/2010 | Technology Investments | | | | | | | | | | | | | | | Budget overview |
| 1/27/2010 | ESMD | | | | | | x | | x | | | | x | | | |
| 1/27/2010 | ISP/Mars | x | | | | | | | x | | | x | | x | | |
| 1/27/2010 | PIDDIP | x | | | | | | | | | | x | | | | |
| 1/27/2010 | Lunar Lander | x | | | | | x | | x | | | | | x | | |
| 1/27/2010 | Outer Planets | x | x | | | | | | | | | | | x | | |
| 1/27/2010 | Samples, Curation, Planetary Major Equip. | x | | | | | | | x | | | | | x | | Facility and ground systems |
| 1/27/2010 | RPS | x | | | | | | | x | | | | | x | | |
| 2/25/2010 | New Millennium Program | | | | | | x | | JPL | | | | x | x | | |
| 3/11/2010 | Aerocapture/EDL | | | | | | | | x | | | | | x | | Agency EDL activities |
| 4/8/2010 | Mars Technology Program | | | | | x | | | JPL | | | x | x | x | | Tech progrm with multi-mission view |
| 4/22/2010 | MSL | | x | | | x | | | JPL | | | x | | x | | |
| 4/15/2010 | Flight Missions | | | | | x | x | | JPL | | | | x | | | Broad expereince and lessons learned |
| 4/29/2010 | GSFC Instruments | | | | | | | | x | | | x | | | | Broad expereince and lessons learned |
| 5/6/2010 | SAM | | x | | | x | | | x | | | x | | | | |
| 5/6/2010 | MESSENGER | | | | x | | | | | | | x | | x | | |
| 5/11/2010 | Decadal white papers | | | | | | | x | x | | x | | | | | |
| 5/12/2010 | AFRL | | | | | | x | | | x | | | | | | |
| 5/11/2010 | Dawn | | | x | | | | | | | | | | | | |
| 5/11/2010 | ESMD technology update & gnrl lessons learned | | | | | | | | x | | | | x | | | Many new activities intitiated under ETDD |
| 5/11/2010 | Explorers & Helio Program Insights | | | | | | x | | | | | | | | | |
| 5/11/2010 | NASA SOMD communication plans and insight | x | | | | | | | x | | | | | | x | Similar issues as PSD technology development |
| 5/11/2010 | NASA Chief Technology Office gnrl lessons learned | | | | | | | | x | | | | | | | CTO impacts to technology development |
| 5/11/2010 | Technology management lessons learned | | | | | | | | x | | x | | x | | | |
| 5/12/2010 | New Frontiers/Discover/Lunar Quest Program Insights | | | x | x | | x | | x | | | | | x | | Lunar program has technology development. Other programs feel impacts |
| 5/12/2010 | SBIR/STTR process and options | x | | | | | | | x | | | | | | | Low TRL |
| 5/20/2010 | Technology development at APL | | | x | x | | | x | APL | | | | | | | |
| 5/20/2010 | Scientist view of NMP | | | | | | x | | | | x | | | | | |
| 5/20/2010 | SMD POC to OCT role | x | | | | | | | x | | | | | | | Interfaces to OCT |
| 5/27/2010 | LASP (Academic views / Suborbital roles) | | | x | x | x | x | | | | x | x | | x | | |
| 5/27/2010 | Academic views /Technology | | | | | | x | | | | x | | | x | | Spacecraft subsystem technologies |
| 6/10/2010 | Technology management | | | | | | x | x | | | | x | x | x | | |
| 6/10/2010 | New Horizons | | | | x | | | x | APL | | | x | | x | | |
| 6/17/2010 | Honeybee Robotics | | x | | | | x | x | | | | | | x | | Small business experiences |
| 6/17/2010 | Aerospace Corp | | | | | | x | x | | x | | | x | x | | |
| written input | UC Berkley | | | | | | | | | | x | x | | | | |
| | | | **Special Topics** | | | | | | | | | | | | | |
| 1/20/2011 | JPL/TRL | | | | | | | | JPL | | | | | x | | ESTO TRL tool |
| 1/27/2011 | JPL/Databases | | | | | | | | JPL | | | | | x | | Databases of the past |
| written input | TRL tool | | | | | | | | JPL | | | | | x | | NMP TRL 'handshake process |
| 3/15/2011 | Tech dev. /Decadal survery | | | | | | | | | | x | | | x | | Recomm/decadal survey |
| 6/16/2011 | System Engineering & Infusion | | | | | | | | JPL | | | | | x | | Recomm/decadal survey |

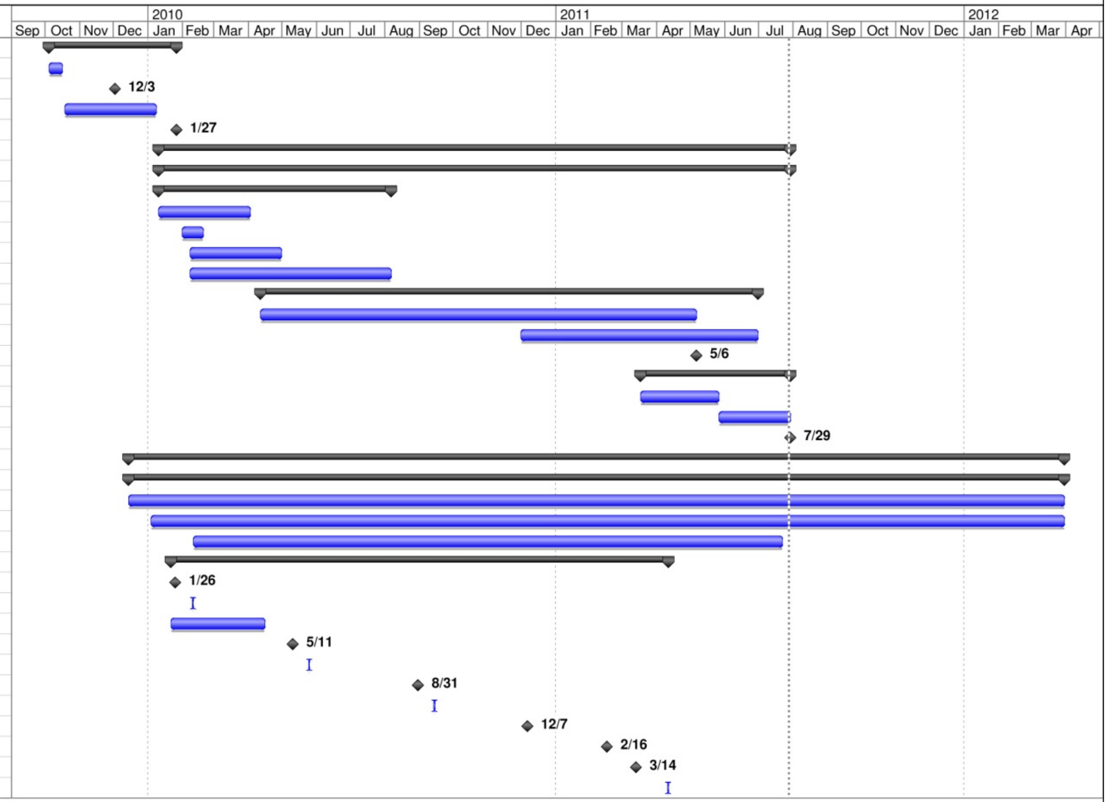
# F

# Schedule

## Planetary Science Technology Review

### Summary Schedule

| ID | Task Name |
|---|---|
| 1 | **Panel Formation** |
| 2 | Identify Panel Chair |
| 3 | Present idea and notional approach to PSS |
| 4 | Identify members |
| 5 | Finalize Charter and rough schedule |
| 6 | **Plan Development and Implementation** |
| 7 | **Research/develop approach/iterate with PSD and Community** |
| 8 | **(Phase 1- Assessment)** |
| 9 | Collect info and assess current PSD technology efforts |
| 10 | Establish website for panel use and communication with community |
| 11 | Assess and review NRC assessments of performance |
| 12 | Research best practices and generate ideas |
| 13 | **(Phase 2 - Plan Formulation)** |
| 14 | Formulate set of draft approaches to improve processes/policies |
| 15 | Formulate metrics and performance goals |
| 16 | Present preliminary options/recommendations to PSD leadership and staff |
| 17 | **(Phase 3 - Generate Products)** |
| 18 | Incorporate changes based on decadal survey |
| 19 | Generate final report |
| 20 | ***Submit Final Report*** |
| 21 | **Communication** |
| 22 | **Solicit science community input and provide status** |
| 23 | Present activity and status at AGU, LPSC, DPS, AbSciCon |
| 24 | website for comments/ideas |
| 25 | Conduct weekly telecons with panel and PSD (Thur at 2:00 EST) |
| 26 | **Meetings** |
| 27 | Panel kick-off intro-meeting and program briefings |
| 28 | Status meeting with sponsor |
| 29 | Technology program briefings and inputs |
| 30 | 2nd panel mtg |
| 31 | Status meeting with sponsor |
| 32 | 3rd panel mtg |
| 33 | Status meeting with sponsor |
| 34 | 4th panel mtg |
| 35 | Status meeting with Sponsor |
| 36 | 5th panel mtg |
| 37 | Status meeting with Sponsor |




Project: Planetary Technology Plan
Date: 7/28/11

| | | | |
|---|---|---|---|
| Task | Summary | Rolled Up Progress | Project Summary |
| Progress | Rolled Up Task | Split | Group By Summary |
| Milestone | Rolled Up Milestone | External Tasks | Deadline |

Page 1

# G

# Statement of Task

# Charter

## For the Planetary Science Technology Evaluation & Implementation Panel

The Planetary Science Division (PSD) within the Science Mission Directorate (SMD) at NASA HQ desires to review its existing instrument and technology programs with respect to their effectiveness in leading to flight systems and reducing mission implementation risk. To this end, the PSD is forming an internal panel of experts to assist in this process and provide PSD with recommendations that could be implemented within existing resources and in line with the Planetary Science Decadal. The panel will engage the science and technology community and seek inputs from industry, universities, and other organizations with a diverse set of backgrounds and perspectives. The panel also may seek opinions and analysis from consultants and contractors as needed to achieve its objectives.

### Objectives

**The primary objective of this panel is to assist PSD in developing a coordinated and integrated technology management plan that will better utilize technology resources.** There are also several specific supporting objectives to be addressed. These have been identified and phased below.

Phase 1 (Assessment)

1) Assess current and past PSD technology development programs, activities, and practices identifying what worked and didn't. Also review technology development efforts both internal to PSD as well as outside of PSD and NASA looking for other approaches and best practices.

2) Assess the current review/oversight processes used by the various PSD technology programs and provide suggestions to consider where modifications may be beneficial

3) Consider prior reviews of the PSD and other applicable technology development efforts, e.g NRC's Solar System Exploration Midterm Review in 2008, and ensure that recommendations address the weaknesses identified by this and other sanctioned community reports or reviews

Phase 2 (Formulation)

4) Engage the science and technology community in the panel's thinking and planning process and communicate to them the status and plans

5) Recommend an integrated and coordinated plan that addresses the whole of PSD technology development needs including but not limited to instrumentation and sensors, spacecraft systems (such as power, communication, and propulsion), planetary protection, sample curation, field testing, and flight demonstration missions as required. Recommend approaches to improve technology maturation through the higher Technology Readiness Levels (TRL's)

6) Align the PSD technology development plan to address the decadal technology recommendations. The panel should consider how to manage technology needs beyond the decadal horizon

7) Endow the recommended plan with flexibility to take advantage of domestic or foreign missions of opportunity (MOO's) or other partnering opportunities as applicable to technology development or maturation

8) Recommend modifications to current processes to assess performance in order to be transparent to PSD, the planetary science community, missions, and other stakeholders. Recommend technology development metrics for PSD to consider

Phase 3 (Documenting Findings and Products)

9) Generate a final report that outlines findings and a recommended plan. Also develop two notional technology development roadmaps grounded in current decadal recommendations, identifying key opportunities or needs and utilizing realistic costs for the technology developments. The two roadmaps should reflect two different funding levels, a) current PSD technology budget predictions and b) a budget that supports all the required technologies

## Duration of Activity

The effort will begin in early 2010 and is planned to take 12-15 months to complete although adjustments may be required based on decadal progress and information release.

## Deliverables

Deliverables include: a) final report describing findings and recommendations, factors considered, top risks and watch items, and a list of community town hall meetings conducted and the associated notes from those meetings, b) the notional roadmaps, and c) presentations at appropriate meetings such as the PSS, AGU, DPS, and LPSC and assessment groups to communicate status and plans

**Panel Chair**

Dr. Tibor Kremic has been selected as the chair

**Panel Membership**

Panel members will be Federal government civil servants and will be jointly selected by the panel chair and Dr. James Green, Director of NASA"s Planetary Science Division. This process will also be used to replace a member if, during the period of performance, it becomes necessary to do so for any reason.

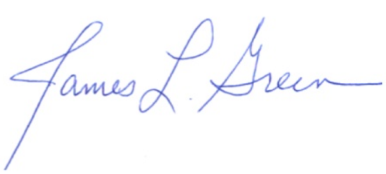
**Consultants, Advisors, and Contractor Support**

Integral to the objectives of the panel is engagement with and seeking input from the science and technical community. The panel may choose to engage the science community in a variety of ways, including seeking information through workshops that involve relevant industry representatives. The panel also may seek consultation, advice, studies, and reports from universities and contractors. The panel, however, will retain responsibilities for the forming recommendations. The role of any individuals or parties supporting this activity who are not Federal civil servant employees will be limited to providing individual input and may not participate in any consensus-building process that results in decisions or recommendations. Moreover, consultants and advisors who provide input or advice for consideration by the panel should be mindful about potential future organizational conflicts of interest and should promptly communicate the possibility to the panel so that appropriate action may be taken to prevent or mitigate such conflicts.

**Costs/Expenses**

The costs for panel members to support this activity will be paid by the Planetary Science Division. Costs may include travel expenses and the cost of contractor support.

Commissioned this day by Dr. James Green, Director Planetary Science Division, NASA HQ.



Date: ______2/25/2010_____

# H

# Biographical Sketches of Panel Members, Advisors, Technical Support, and Point of Contact within PSD

*Panel Members*

TIBOR KREMIC, *Chair,* has held various technical and management positions since joining NASA in 1990. He currently works in the Space Science Projects Office at NASA's Glenn Research Center managing their science-related activities. Prior experience includes a one-year detail serving as the Assistant Division Director for Planetary Science at NASA HQ. During this time he supported the Division Director and Deputy in the management of the Planetary Science Division's (PSD) numerous flight and technology development programs and projects. Prior to his time at NASA HQ, Dr. Kremic was the program manager for the In-Space Propulsion technology program. This program manages the Agency's investment in advanced propulsion system technology development for robotic space missions. During his tenure in this role, he oversaw development of various advanced propulsion system and subsystem technologies including advanced chemical propulsion, electric propulsion, aerocapture, and others. Prior NASA assignments included design and management of systems and projects of varying nature and scope. He also serves on several boards and committees such as JANNAF's (Joint Army, Navy, NASA, Air Force) subcommittee on spacecraft propulsion.

PETER M. HUGHES is the Chief Technologist for NASA's Goddard Space Flight Center. In this position, he serves as the Chair of the GSFC Technology Federation and is responsible for planning, coordination, execution and oversight of GSFC technology programs to meet Goddard's Science and Exploration Mission responsibilities. He manages GSFC's Internal

Research & Development program and helps manage the Center's Strategic Lines of Business. In his previous positions Mr. Hughes was the Assistant Chief for Technology in the Information Systems Division at GSFC, Technology Systems Engineer or Mission Technologist for the Extreme UltraViolet Explorer (EUVE), Hubble Space Telescope Ground System, and EOS-DIS. Mr. Hughes served as the Chief Architect and Project Manager of the GenSAA System and for which he holds NASA's first software patent. He also fully designed and implemented the CLEAR System, the first real-time expert system to monitor a low earth-orbit satellite and supported a number of other initiatives investigating advanced technologies in artificial intelligence, software engineering, and human factors research. Peter received his B.S. in Computer Science from the College of William and Mary and an M.S. in Computer Science from Johns Hopkins University. He received his M.S. in the Management of Technology at the University of Pennsylvania's Executive Masters for Technology Management (EMTM) program, a joint program sponsored by the Wharton Business School and the SEAS School of Engineering.

RALEIGH B. PERRY serves as the Director of the Science Office for Mission Assessments (SOMA) within the Science Mission Directorate (SMD) at NASA Headquarters and physically located at NASA Langley Research Center in Hampton, Virginia. SOMA assists SMD in preparing and implementing Announcements of Opportunity to solicit new Earth and Space Science exploration missions and instruments, and leads the technical, management, and cost evaluation of proposals and concept study reports. Mr. Perry previously served as the Acquisition Manager for New Frontiers, Discovery, Explorer, Near Infrared Camera for the James Webb Space Telescope, and the Pluto-Kuiper Belt Mission. He is a 1978 aerospace engineering graduate of the Georgia Institute of Technology and has accomplished graduate studies in astronomy at the University of Virginia. Mr. Perry has published over 30 peer reviewed astronomy journal papers and professional presentations on solar system objects, variable stars, novae, and supernovae. He is an Associate Fellow of the American Institute of Aeronautics and Astronautics, and also a member of the American Astronautical Society, the American Astronomical Society, and the American Geophysical Society.

JAMES SINGLETON is a AFRL program manager of flight demonstration missions for Propulsion directorate's Spacecraft Branch at Edwards Air Force Base, California. He has a master's degree in Physical Chemistry from the University of Southern California and has worked for AFRL for seven years. Before joining AFRL, he had a background in quality assurance and production management in industry. Recently James has run propulsion sensors on TacSat-2 in a successful one-year mission, has integrated payloads for Advanced EHF, DSX, and CHIRP, and is currently working to develop thrusters for an advanced nontoxic monopropellant. His projects are focused on answering integration questions spacecraft designers may have with new technology and enabling the final stages of technical transition through flight applications.

*Advisors*

PATRICIA M. BEAUCHAMP joined the Jet Propulsion Laboratory in Pasadena, California, in 1992 and is currently developing future Outer Planet Missions. She is also a Co-I and theme lead on a NASA Astrobiology Institute award entitled "Titan as a Prebiotic Chemical System." For a large portion of her career at JPL she has been developing planetary science instruments, most recently as Manager of the Planetary Instrument Development office (to 2009). Pat was the

Project Manager for the Miniature Integrated Camera Spectrometer, which flew on the New Millennium DS1 mission. Earlier, she held several technical and management positions in the Observational Instruments Division. In addition to developing and flying instruments, she spent five years leading the Center for In-Situ Exploration and Sample Return (CISSR), which enabled JPL to transition technically into the era of planetary in situ exploration. This encompassed identifying and implementing all aspects of technologies, processes, and institutional infra-structure. Prior to joining JPL, Dr. Beauchamp was manager of the Material Science Department at Aerojet Electro-Systems Division. She obtained her Ph.D in Chemistry in 1981, followed by post-doctoral research in Chemical Engineering, both at Caltech. She holds a B.S. in Chemistry and B.A. in Mathematics with honors. She has received a number of student and professional awards and is the author or co-author of over 40 scientific publications, a patent, and numerous Government technical reports.

JOHN CLARKE is Professor in the Department of Astronomy and center for Space Physics at Boston University. He received his Bachelor of Science in Physics from Denison University (1974), a Master of Arts in Physics from Johns Hopkins University (1978), and his Ph.D. in Physics from Johns Hopkins University in 1980. He started out as an assistant research physicist in the Space Sciences Laboratory at the University of California, Berkeley; worked on the Hubble Space Telescope Project as an advanced instruments scientist at NASA Goddard Space Flight Center, and a research scientist at the University of Michigan. He won the 2005 Alumni Merit Citation, Denison University; 1998 University of Michigan Research Achievement Award; 1996 NASA Group Achievement Award for Comet S/L-9 Jupiter Impact Observations Team; 1994 University of Michigan Research Excellence Award; 1994 NASA Group Achievement Awards (3) for WFPC 2: First Servicing Mission, WFPC 2 Science, WFPC 2 Calibration;1987 NASA Scientific Research Award;1980 Forbush Fellow, Department of Physics, Johns Hopkins U.; 1974 Sigma Pi Sigma, Physics Honorary–Denison. He is a member of the Professional American Astronomical Society Memberships: American Geophysical Union American Association for Advancement of Science International Astronomical Union. He is on the boards as: Consulting Editor—Icarus Steering Committee, Outer Planets Assessment Group, Solar System Decadal Survey Panel—Outer Planets Research Planetary atmospheres, UV astrophysics. Interests: FUV instruments for remote observations

RALPH LORENZ has a B.Eng. in Aerospace Systems Engineering from the University of Southampton in the UK and a Ph.D. in Physics in 1994 from the University of Kent at Canterbury. He worked from 1990 to 1991 for the European Space Agency on the design of the Huygens probe and during his PhD research designed and built its penetrometer instrument which, 12 years later, measured the mechanical properties of Titan's surface when Huygens landed in January 2005. From 1994 to 2006 he worked as a planetary scientist at the Lunar and Planetary Laboratory, University of Arizona, with particular interests in Titan, Mars, planetary climate, nonequilibrium thermodynamics, aerospace vehicles, and radar. He continues to work on those topics as Senior Professional Staff at the Johns Hopkins University Applied Physics Laboratory in Laurel, Maryland. He served on the science team of the New Millennium DS-2 Mars Microprobes, chaired the 2007 Titan Explorer Flagship Science Definition Team, and has participated in several New Frontiers and Discovery mission proposals. He served on the National Research Council's Committee on Space Science Missions Enabled by Nuclear Power and Propulsion, and on the Committee on the Origins and Evolution of Life. He is on the editorial board of the International Journal of Astrobiology and is author or co-author of several books including "Lifting Titan's Veil," "Spinning Flight," and "Space Systems Failures" as well as over 150 publications in refereed journals.

*Technical Support*

WALDO J. RODRIGUEZ is currently an Acquisition Manager at the NASA Science Office for Mission Assessments (SOMA) within the NASA Science Mission Directorate (SMD). SOMA works with SMD personnel in developing and implementing Announcement of Opportunities (AOs) to solicit Earth and Space Science missions, mission of opportunities, and instruments. SOMA acquisition managers lead the technical, management, and cost evaluation of proposals responding to these AOs and of concept study reports that are submitted for competitive Phase A downselects. When requested, SOMA acquisition managers lead technical reviews of SMD senior reviews, independent reviews, and special studies and assessments. Dr. Rodriguez served as acquisition manager for Earth System Science Pathfinder (ESSP), Explorers, and Radiation Belt Storm Probes (RBSP). Dr. Rodriguez also led the technical evaluation for the Earth Science Division senior review and independent reviews.

Dr. Rodríguez came to NASA from Norfolk State University (NSU) where he was an Associate Professor in Chemistry. At NSU he secured outside funding from Federal agencies and established a ground-based remote sensing laboratory and a fully equipped state of the art scientific visualization laboratory. Before joining NSU he was a National Research Council (NRC) Postdoctoral Fellow serving at NASA Langley Research Center where he performed laser research and development for lidar applications. At Calgon Carbon Corporation, he designed developed and implemented an instrument to determine the surface properties of one of the company's production materials. He earned his Ph.D. in Chemistry from Tulane University and his B.S. in Chemistry from Iowa State University. He has over 20 publications, over 50 presentations in science and technical conferences, and a patent disclosure. He has received various individual and group awards.

LINDA L. NERO is an Engineer Project Coordinator for the In-Space Propulsion Technology Program at SGT Inc., NASA Glenn Research Center in Cleveland, Ohio. She also supports the Radioisotope Power Systems Program and the ISS and Human Health Office at Glenn. She received her Bachelor of Arts degree in chemistry (1962) from Wittenberg University, Springfield, Ohio, a master of arts in chemistry (1966) from Bowling Green State University, and a bachelor of science in chemical engineering (1984) from Cleveland State University, Cleveland, Ohio. Prior to joining NASA, Linda was a process engineer for British Petroleum at their Research Center in Cleveland. She did research on the dehyrocyclization of alkylaromatics to indene, receiving two patents. In developmental engineering, she worked on the oxidation of butane to maleic anhydride using a proprietary vanadyl pyrophosphate fluid-bed catalyst and Sohio's acrylonitrile process. She holds two patents on the use of the Fourier Transform Infrared Spectrometer to identify the effluent stream from an ammoxidation fluid-bed reactor using the proprietary Sohio ammoxidation fluid-bed catalyst.

*NASA Headquarters' Point of Contact*

GORDON JOHNSTON is in the Planetary Science Division at NASA Headquarters. He is the Program Executive for two missions, OSIRIS-REx and LRO, and for In-Space Propulsion

Technology. He has B.A. and M.S. in Mathematics from CSUN, and a M.S. in Engineering and Management from MIT. He began his career at JPL in 1977, planning images for the *Viking* orbiter. On *Galileo* he led remote sensing science mission design and planning. In 1987 he moved to NASA headquarters and managed programs in systems analysis (to identify technology needs), university-based space technology research, advanced data systems technology, and instrument technology. In 1997 he joined the Office of Earth Science and helped plan its technology programs. He led several mission selection technical panels for Earth Science, including the first and second ESSP AOs, the Triana AO, and the LightSAR AO. In 1999 he was competitively selected for APPL PMDP-ALO through which he completed the System Design and Management program at MIT. Upon returning to NASA headquarters, he worked in space architecture, representing science in planning lunar exploration architectures, leading strategic road-mapping efforts, and interagency coordination of Earth observations. In 2008 he assumed his current Planetary Program Executive role.

# I

## Acronyms

| | |
|---|---|
| AFRL | Air Force Research Laboratory |
| AGU | American Geophysical Union |
| AIST | Advanced Information Systems Technology |
| AMMOS | Advanced MultiMission Operations System |
| AO | Announcement of Opportunity |
| APL | Applied Physics Laboratory |
| ARMD | Aeronautics Research Mission Directorate |
| ASRG | Advanced Stirling Radioisotope Generator |
| ASTED | Astrobiology Science and Technology for Exploring Planets |
| ASTID | Astrobiology Science & Technology for Instrument Development |
| DoD | Department of Defense |
| DPS | Division of Planetary Science of the American Astronomical Society |
| ESD | Earth Science Division |
| ESMD | Exploration Systems Mission Directorate |
| ESTO | Earth Science Technology Office |
| FPGA | Field-Programmable Gate Array |
| HQ | Headquarters |
| IEEE | Institute for Electrical and Electronics Engineers |
| ISP | In-Space Propulsion |
| ITAR | International Traffic in Arms Regulations |
| JPL | Jet Propulsion Laboratory |
| LPSC | Lunar and Planetary Science Conference |
| MEDLI | MSL Entry Descent and Landing Instrumentation |
| MESSENGER | MErcury Surface, Space ENvironment, GEochemistry and Ranging |
| MIDP | Mars Instrument Development Program |
| MOO | Missions of Opportunity |
| MSL | Mars Science Laboratory |
| NAC | NASA Advisory Council |
| NASA | National Aeronautics and Space Administration |
| NMP | New Millennium Program |
| NPR | NASA Procedural Requirements |

| | |
|---|---|
| NRA | NASA Research Announcement |
| NRC | National Research Council |
| OAI | Ohio Aerospace Institute |
| OCT | Office of Chief Technologist |
| OPAG | Outer Planets Assessment Group |
| PE | Program Executive |
| PEN | Planetary Exploration Newsletter |
| PI | Principal Investigator |
| PIDDP | Planetary Instrument Definition and Development |
| PIR | Program Implementation Review |
| POC | Point of contact |
| PSD | Planetary Science Division |
| PSS | Planetary Science Subcommittee |
| PSTR | Planetary Science Technology Review |
| R&A | Research and Analysis |
| ROSES | Research Opportunities in Space and Earth Sciences |
| RPS | Radioisotope Power Systems |
| SAM | Sample Analysis at Mars |
| SBIR | Small Business Innovation Research |
| SMD | Science Mission Directorate |
| SOA | State of the Art |
| SOMA | Science Office for Mission Assessments |
| SOMD | Space Operations Mission Directorate |
| SRB | Standing Review Board |
| SR&T | Science, Research, and Technology |
| STTR | Small Business Technology Transfer |
| TPD | Technology Program Director |
| TRL | Technology Readiness Level |